CLIMATE CHANGE

25/2022

Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2022

National Inventory Report for the German Greenhouse Gas Inventory 1990 – 2020

German Environment Agency

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Imprint

Publisher
Umweltbundesamt
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Internet: www.umweltbundesamt.de

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/umweltbundesamt

Report completed in:
April 2022

Edited by:
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Publication as pdf:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4359

Dessau-Roßlau, May 2022

In remembrance of:

Michael Strogies

(1956 -2022)

Founding father of the German Emission Reporting System

Head of department, colleague and good friend

Contact

This report was produced in the framework of work of the National Co-ordination Agency (Single Entity) for the *National System of Emissions Inventories* (Nationales System Emissionsinventare; NaSE), sited within the Federal Environment Agency (UBA). Contributions for the chapters on agriculture, and on land use, land-use changes and forestry, were prepared by the Thünen Institute (TI).

The electronic version of this report, along with the pertinent emissions data in the Common Reporting Format (CRF) (Version 0.93, based on the CSE database, and with trend tables last revised as of 12 January 2022), is available on the website of the Federal Environment Agency:
http://www.umweltbundesamt.de/themen/klima-energie/treibhausgas-emissionen

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AbfAblV	Ordinance on Environmentally Compatible Storage of Waste from Human Settlements and on Biological Waste-Treatment Facilities (Abfallablagerungsverordnung)
ABL	Old German Länder
AGEB	Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen)
AGEE-Stat	Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien-Statistik)
AK	Working group (Arbeitskreis)
ALH	All other deciduous/broadleaf trees with high life expectancies (BWI tree-species group)
ALN	All other deciduous/broadleaf trees with low life expectancies (BWI tree-species group)
ANCAT	Abatement of Nuisances from Civil Air Transport
AR	Activity data (=AD)
ARD	Afforestation, reforestation, deforestation
ATKIS	Official topographic-cartographic information system (Amtliches Topographisch-Kartographisches Informationssystem)
AWMS	Animal Waste Management System
BAFA	Federal Office of Economics and Export Control
BAT	Best Available Technique
BDSI	Association of the German Confectionery Industry (Bundesverband der Deutschen Süßwarenindustrie e.V.)
BDZ	Federal Association of the German Cement Industry (Bundesverband der Deutschen Zementindustrie)
BEF	Biomass-expansion factor
BEU	Balance of emissions sources for stationary and mobile combustion processes (Bilanz der Emissionsursachen für stationäre und mobile Verbrennungsprozesse)
BGR	Federal Institute for Geosciences and Raw Materials (Bundesanstalt für Geowissenschaften und Rohstoffe)
BGS	Fuel, gas and electricity industries of blast furnaces, steelworks and rolling mills; and forging plants, press works and hammer mills, including the various other plants (without their own coking plants) publicly connected to such operations
BGW	Federal Association of the German Gas and Water Industry (Bundesverband der deutschen Gas- und Wasserwirtschaft)
BHD	Diameter at breast height (= DBH; tree-trunk diameter at a height of 1.30 m above the ground)
BHKW	Combined heat and power (CHP) unit (Blockheizkraftwerk)
BKG	Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie)
BImSchV	Statutory Ordinance under the Federal Immission Control Act
BML	cf. BMEL
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMUB	cf. BMU
BMEL	Federal Ministry of Food and Agriculture
BMELV	cf. BMEL
BMVEL	cf. BMEL

BMVG	Federal Ministry of Defence
BMWA	cf. BMWi
BMWi	Federal Ministry for Economic Affairs and Energy
BoHE	Main survey on soil use (Bodennutzungshaupterhebung)
BREF	BAT (Best Available Technique) Reference Documents
BSB	Biological oxygen demand (= BOD; Biologischer Sauerstoffbedarf)
BSB_5	Biological oxygen demand within 5 days (BOD_5)
BV Kalk	German Lime Association (Bundesverband der Deutschen Kalkindustrie)
BÜK	Soil-overview map (Bodenübersichtskarte)
BWI	National Forest Inventory (Bundeswaldinventur)
BWP	Association of the German heat-pump industry (Bundesverband Wärmepumpe e.V.)
BZE	Forest Soil Inventory (Bodenzustandserhebung im Wald)
CAPIEL	Coordinating Committee for the Associations of Manufacturers of Industrial Electrical Switchgear and Controlgear in the European Union
CEFIC	European Chemical Industry Council (French name: Conseil Européen des Fédérations de l'Industrie Chimique)
CFC	Chlorofluorocarbons (= Fluorchlorkohlenwasserstoffe (FCKW))
CFI	Continuous Forest Inventory
CH_4	Methane
C_{org}	Organic carbon stored in the soil
CO	Carbon monoxide
CO_2	Carbon dioxide
CORINAIR	Coordination of Information on the Environment, sub-project: Air
CORINE	Coordinated Information on the Environment
CRF	Common Reporting Format
CSB	Chemical oxygen demand (COD)
CVD	Chemical vapour deposition
D	Germany (Deutschland)
DBFZ	Deutsches Biomasseforschungszentrum (German centre for biomass research)
DEHSt	German Emissions Trading Authority (Deutsche Emissionshandelsstelle)
DESTATIS	Federal Statistical Office (official abbreviation: StBA)
DFIU	Franco-German Institute for Environmental Research, at the University of Karlsruhe (Deutsch-Französisches Institut für Umweltforschung an der Universität Karlsruhe)
DG	Landfill gas (Deponiegas)
DGMK	German Association of Oil, Natural Gas and Coal Science (Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle eV.)
DIN	DIN standard (Deutsche Industrienorm)
DIW	German Institute for Economic Research (Deutsches Institut für Wirtschaftsforschung)
DLR	German Aerospace Center (Deutsches Zentrum für Luft- and Raumfahrt)
DME	Dimethyl ether
DMKW	Diesel-engine power stations (Dieselmotorkraftwerke)
D_N	Nitrogen in wastewater
DOC	Degradable organic carbon Degradable organic carbon)
DOC_F	Fraction of DOC dissimilated (converted into landfill gas) Fraction of DOC dissimilated)
DSWF	"Forest Fund Database" for the former GDR (Datenspeicher Waldfonds)
DTKW	Steam-turbine power stations (Dampfturbinenkraftwerke)

DVGW	German Association of the Gas and Water Industry (Deutsche Vereinigung des Gas- und Wasserfachs eV.)
D7	Tree-trunk diameter at a height of 7 m above the ground
EBZ	Energy Balance line in the BEU (Energiebilanzzeile)
EEA	European Environment Agency
EECA	European Electronic Component Manufacturers Association
EEG	Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz); promulgated in Federal Law Gazette Part I No. 40 of 31 July 2004, p. 1918 ff.)
EF	Emission factor
EI	Emission index = emission factor
E_{KA}	Inhabitant connected to wastewater-treatment system (Einwohner mit Kläranlagenanschluss)
EL	Fuel oil EL (EL = easily liquid)
EM	Emission
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe
EMEV	Emissions-relevant energy consumption (Emissionsrelevanter Energieverbrauch)
ERT	Expert Review Team
ESIA	European Semiconductor Industry Association
ETS	EU Emissions Trading Scheme
EU	European Union
EU-EH	ETS (Europäischer Emissionshandel)
EUROCONTROL	European Organisation for the Safety of Air Navigation
EUROSTAT	Statistical Office of the European Communities
EW	Population (Einwohnerzahl)
EXIBA	European Extruded Polystyrene Insulation Board Association
FA	Combustion systems (Feuerungsanlagen)
FAP	Specialised contact person in the NaSe (Fachlicher Ansprechpartner)
FAL	Federal Agricultural Research Institute (as of 2008: cf. TI)
FAO	United Nations Food and Agriculture Organisation of the United Nations
CFC	Chlorofluorocarbons Chlorofluorocarbons, CFC)
F gases	Fluorinated greenhouse gases
FHW	District heating stations (Fernheizwerke)
FKW	Perfluorocarbons Perfluorocarbons, PFC)
FKZ	Research project number (Forschungskennzahl)
FNN	Forum Network Technology / Network Operation in the VDE
FPX	Professional polystyrene association (Fachverband Polystyrol-Extruderschaumstoff e.V.)
FV	Responsible expert (Fachverantwortlicher) in the NaSE
FWL	Thermal output from combustion (Feuerungswärmeleistung)
GEREF	GERman Emission Factor Database
GFA	Large combustion systems (Großfeuerungsanlagen)
GG	Total weight (Gesamtgewicht)
GIS	Gas-insulated switching systems
GMBL	Joint Ministerial Gazette (Gemeinsames Ministerialblatt)
GMES	Global Monitoring for Environment and Security
GMKW	Gas-engine power stations (Gasmotorkraftwerke)
GPG	Good Practice Guidance

GSE FM-INT	GMES Services Elements Forest Monitoring: Inputs for national greenhouse-gas reporting
GT	Gas turbines
GTKW	Gas-turbine power stations (Gasturbinenkraftwerke)
GuD	Gas and steam turbine power stations (Gas- und Dampfturbinenkraftwerke)
GWP	Global Warming Potential
HFC	Hydrofluorocarbons (= HFKW)
HCFC	Hydrochlorofluorocarbons (= HFCKW)
HFE	Hydrofluoroethers Hydrofluoroethers)
HFC	Hydrofluorocarbons Hydrofluorocarbons, HFC)
Hi	Net calorific value (Heizwert)
HK	Key category (Hauptkategorie); is applied to both emissions sources and sinks
HS	High voltage (Hochspannung)
HS-GIS	High-voltage gas-insulated switching systems
IAI	International Aluminium Institute
ICE	Intercity Express
IE	Included elsewhere
IEA	International Energy Agency
IEC	International Electrotechnical Commission International Electrotechnical Commission)
IEF	Implied emission factor
IfE	Institute for Energy and Environment (Institut für Energetik und Umwelt)
IFEU	Institute for Energy and Environmental Research (Institut für Energie- und Umweltforschung)
IKW	Industrial power stations (Industriekraftwerke)
IMA	Interministerial Working Group (Interministerielle Arbeitsgruppe)
IPCC	Intergovernmental Panel On Climate Change
IS08	Inventory Study 2008 (Inventurstudie 2008)
IVPU	German industry association for rigid polyurethane foam (Industrieverband Polyurethan-Hartschaum)
K	Fuel input for power generation (direct drive)
k.A.	No entry (keine Angabe)
KCA	Key category analysis
KP	Kyoto Protocol
KS	Sewage sludge (Klärschlamm)
KTBL	Association for Technology and Structures in Agriculture (Kuratorium für Technik und Bauwesen in der Landwirtschaft)
l	Level (= Level assessment pursuant to IPCC Good Practice Guidance)
LF	Agriculturally used land (landwirtschaftlich genutzte Flächen)
LKW	Truck (Lastkraftwagen)
LTO	Landing/take-off cycle
LUCF	Land Use Change and Forestry
LULUCF	Land Use, Land Use Change and Forestry
MBA	Mechanical-biological waste treatment (MBT; Mechanisch-Biologische Abfallbehandlung)
MCF	Methane Conversion Factor
MDI	Metered dose inhaler
MS	Medium voltage (Mittelspannung)
MSW	Municipal solid waste
MVA	Waste incineration plant (Müllverbrennungsanlage)

MW	Megawatt
N	Nitrogen
N_2O	Nitrous oxide (laughing gas)
NA	Not applicable
NASA	National Aeronautics and Space Administration
NaSE	German National System of Emissions Inventories (Nationales System Emissionsinventare)
NBL	New German Länder (neue Bundesländer)
NE	Not estimated
NEAT	Non-energy Emission Accounting Tables
NEC	Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain air pollutants National Emission Ceilings).
NEV	Non-energy-related consumption (nichtenergetischer Verbrauch)
NF_3	Nitrogen trifluoride
NFR	New Format on Reporting, Nomenclature for Reporting to the UN ECE Reporting to the UN ECE
NFZ	Utility vehicles (Nutzfahrzeuge)
NH_3	Ammonia
NIR	National Inventory Report
NMVOC	Non-Methane Volatile Organic Compounds
NO	Not occurring
NO	Nitrogen monoxide
NSCR	Non-selective catalytic reduction
OCF	One-component foam (installation foam)
ODS	Ozone depleting substances
ORC	Organic Rankine Cycle
OX	Oxidation factor
PAH	Polycyclic aromatic hydrocarbons (= PAK)
PAK	Polycyclic aromatic hydrocarbons (Polycyclische aromatische Kohlenwasserstoffe; = PAH)
PARTEMIS	Measurement and prediction of emissions of aerosols and gaseous precursors from gas turbine engines
PCDD/F	Polychlorinated dibenzo-dioxins/- furans
PF	Process combustion (Prozessfeuerungen)
PFC	Perfluorocarbons (= FKW)
PFPE	Perfluoropolyethers Perfluoropolyether)
PFPMIE	Perfluoropolymethyl isopropyl ether
PKW	Automobile (Personenkraftwagen)
PU	Polyurethane
Py-GAS-EM	Python-based GASeous EMissions (programme for calculation of agricultural emissions)
QK	Quality control (QC; Qualitätskontrolle)
QS	Quality assurance (QA; Qualitätssicherung)
QSE	Quality System for Emissions Inventories
REA	Flue-gas desulphurising plant (Rauchgasentschwefelungsanlage)
ROE	Oil equivalent (OE; Rohöleinheit)
RSt	Raw steel
RWI	Rheinisch-Westfälisches Institut für Wirtschaftsforschung
S	Fuel input for power generation

S	Heating oil, heavy (high viscosity; "Heizöl S")
S&A Report	Synthesis and Assessment Report
SA	Heating oil, heavy (high viscosity; low sulphur content; "Heizöl SA")
SE	Sampling error
SF_6	Sulphur hexafluoride
SKE	Hard-coal units (Steinkohleneinheiten)
SNAP	Selected Nomenclature for Air Pollution
SO_2	Sulphur dioxide
StBA	Federal Statistical Office (Statistisches Bundesamt Deutschland)
STEAG	STEAG Aktiengesellschaft (a large power producer in Germany)
T	Trend (= trend assessment pursuant to IPCC Good Practice Guidance, in the category overview tables)
TA Luft	Technical directive on air quality control; First General Administrative Provision on the Federal Immission Control Act (Clean Air Directive; Technische Anleitung zur Reinhaltung der Luft)
TAN	Total Ammoniacal Nitrogen
TFT	Thin-film transistor
THG	Greenhouse gases (GHG; Treibhausgase)
TI	Johann Heinrich von Thünen Institute
TI-AK	Johann Heinrich von Thünen Institute, Institute of Climate-Smart Agriculture (Institut für Agrarklimaschutz)
TI-WO	Johann Heinrich von Thünen Institute, Institute of Forest Ecosystems (Institute für Waldökosysteme)
TM	Dry matter (Trockenmasse)
TOC	Total Organic Carbon
TREMOD	Traffic Emission Estimation Model
TS	Siccative (Trockenstoff)
TÜV	Technischer Überwachungsverein (Certifying body for technical and product safety)
TVF	Tonne of utilisable production (Tonne verwertbare Förderung)
UBA	Federal Environment Agency (Umweltbundesamt)
UN ECE	United Nations Economic Commission for Europe
UN FCCC	United Nations Framework Convention on Climate Change
UN	United Nations
UStatG	Environmental Statistics Act (Umweltstatistikgesetz)
VDA	German Association of the Automotive Industry (Verband der Automobilindustrie e.V.)
VDE	Association for Electrical, Electronic & Information Technologies (Verband der Elektrotechnik Elektronik Informationstechnik e.V.)
VDEh	German Iron and Steel Institute (Verein Deutscher Eisenhüttenleute; in 2003, renamed "Stahlinstitut VDEh")
VDEW	Electricity Industry Association (Verband der Elektrizitätswirtschaft e.V.)
VDI	Association of German Engineers (Verein Deutscher Ingenieure e.V.)
VDKL	German cold-storage and logistics association (Verband Deutscher Kühlhäuser und Kühllogistikunternehmen e.V.)
VDMA	German Engineering Federation (Verband Deutscher Maschinen- und Anlagenbau e.V.)
VDN	Association of German network operators (Verband der Netzbetreiber e.V.)
VDZ	German Cement Works Association (Verein Deutscher Zementwerke e.V.)

VGB	Technical association of operators of large power stations (Technische Vereinigung der Großkraftwerksbetreiber e.V.)
VIK	Association of the energy and power industry (Verband der Industriellen Energie- and Kraftwirtschaft e.V.)
VOC	Volatile Organic Compounds
VRF	Variable refrigerant flow
VS	Volatile Solids
W	Fuel input for heat generation
WS	Portion of a specific wastewater treatment system (e.g. aerobic, anaerobic)
WZ	Economic activity listed in the National Classification of Economic Activities (NACE; Wirtschaftszweig)
XPS	Extruded polystyrene
ZSE	Central System of Emissions (CSE)
ZVEI	German Electrical and Electronic Manufacturers' Association (Zentralverband Elektrotechnik und Elektronikindustrie e.V.)

Units and sizes

Multiplication factors, abbreviations, prefixes and symbols

		Prefix/symbol	
Multiplication factor	Abbreviation	Name	Symbol
1.000.000.000.000.000	10^{15}	peta	P
1.000.000.000.000	10^{12}	tera	T
1.000.000.000	10^{9}	giga	G
1.000.000	10^{6}	mega	M
1.000	10^{3}	kilo	k
100	10^{2}	hecto	h
0.1	10^{-1}	deci	d
0.01	10^{-2}	centi	c
0.001	10^{-3}	milli	m
0.000001	10^{-6}	micro	µ

Units and abbreviations

Abbreviation	Units
°C	degrees Celsius
a	Year
cal	calorie
g	gram
h	hour
ha	hectare
J	joule
m^3	cubic metre
ppm	parts per million
ppb	parts per billion
t	tonne
W	watt

Standard conversions

Units			is equivalent to		
1	tonne (t)		1	megagram	(Mg)
1	kilotonne / thousand tonnes	(kt)	1	gigagram	(Gg)
1	megatonne / million tonnes	(Mt)	1	teragram	(Tg)

Reading the introductory information tables

The introductory information tables appear at the beginning of each source category chapter. Each such table provides an overview of the relevant source category's importance and of the methods used in connection with it.

KC	Category	Activity	EM of	1.990 (kt CO_2-eq.)	(fraction)	2.018 (kt CO_2-eq.)	(fraction)	Trend 1990-2018
L/T	**1A1c Manufacture of Solid Fuels and Other Energy Industries**	**All fuels**	**CO_2**	**65.289.06**	**(5.20)**	**9.700.88**	**(1.13)**	**-85.14%**
-/-	1A1c Manufacture of Solid Fuels and Other Energy Industries	All fuels	N_2O	659.23	(0.05)	150.93	(0.02)	-77.10%
-/-	1A1c Manufacture of Solid Fuels and Other Energy Industries	All fuels	CH_4	91.98	(0.01)	161.36	(0.02)	75.42%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	Tier 2	NS	CS
N2O	Tier 2	NS	CS
NOX, CO, NMVOC, SO2			CS

Key category

The upper section of the table shows the key-category-analysis lines that are relevant for the source category in question; the emissions, as an absolute figure (kt CO_2 equivalent) and as a percentage of total emissions in 1990 and in the last reported year; and the pertinent emissions trend between the base year (1990 or 1995 for the F gases) and the last reported year. In the German-language version of the NIR, the term "Hauptkategorie" is used synonymously with the term "key category".

L = Key category in terms of emissions level
T = Key category in terms of emissions trend
2 = Key category solely pursuant to Approach-2 analysis (including uncertainties)

Gas

The lower section of the table provides information about the methods used, the source for the activity data and the emission factors (EF) used.

Method used

D = IPCC default
RA = Reference Approach
Tier 1 = IPCC tier 1
Tier 2 = IPCC tier 2
Tier 3 = IPCC tier 3
C = CORINAIR
CS = Country-specific
M = Model

Source for the activity data

M = Model
Q = Questionnaires, surveys
PS = Plant-specific data
AS = Associations, business organizations
RS = Regional statistics
NS = National statistics
IS = International statistics

Emission factor (EF)

D = IPCC default
C = CORINAIR
CS = Country-specific
PS = Plant-specific
M = Model

0 Summary (ES)

As a Party to the United Nations Framework on Climate Change (UNFCCC), since 1994 Germany has been obliged to prepare, publish and regularly update national emission inventories of greenhouse gases. In February 2005, the Kyoto Protocol entered into force. As a result, the international community of nations is required to implement binding action objectives and instruments for global climate protection. This leads to very extensive and detailed obligations vis-à-vis the preparation, reporting and review of emissions inventories. In keeping with Article 3 of the Kyoto Protocol, the EU countries have been making use of the option of jointly fulfilling obligations under the Kyoto Protocol and the UN Framework Convention on Climate Change. They have been doing so via European regulations, most recently EU Regulation 525/2013[1] and its Implementing Regulation 749/2014[2]. Current European implementation of the Kyoto Protocol, via regulations, has made the Protocol's provisions legally binding for Germany.

Pursuant to Decision 24/CP.19, all Parties listed in ANNEX I of the UNFCCC are required to prepare and submit annual National Inventory Reports (NIRs) containing detailed and complete information on the entire process of preparation of such greenhouse-gas inventories. The purpose of such reports is to ensure the transparency, consistency and comparability of inventories and support the independent review process.

Pursuant to to decision 15/CMP.1, as of 2010 all of the countries listed in ANNEX I of the UN Framework Convention on Climate Change that are also parties to the Kyoto Protocol must submit annual inventories in order to be able to make use of flexible mechanisms pursuant to Articles 6, 12 and 17 of the Kyoto Protocol.

Together with the inventory tables in the Common Reporting Format (CRF), Germany submits a National Inventory Report (NIR), which refers to the period covered by the inventory tables and describes the methods and data sources on which the pertinent calculations are based. The report and the inventory tables have been prepared pursuant to the UNFCCC guidelines on annual inventories (FCCC/CP/2013/10/Add.3) and in conformance with the 2006 IPCC Guidelines for national Greenhouse Gas Inventories (IPCC Guidelines, 2006) and the IPCC Good Practice Guidance (IPCC-GPG, 2000). The NIR contains a Part II, along with additional sub-chapters, that fulfill the expanded requirements under the Kyoto Protocol and the relevant obligations at the European level.

Part I of the NIR comprising Chapters 1 to 10, contains all the information relevant to the annual greenhouse-gas inventory.

Chapter 1 provides background information about climate change and about greenhouse-gas inventories, as well as further information relative to the Kyoto Protocol. This section describes the National System pursuant to Article 5.1 of the Kyoto Protocol, which system is designed to aid and assure compliance with all reporting obligations with respect to atmospheric emissions and removals in sinks. In addition, this chapter describes the basic principles and methods with which the emissions and sinks of the IPCC categories are calculated, presents a short summary of key-category assessment and describes the Quality System for Emissions Inventories (QSE). The chapter concludes with sections on uncertainties analysis and completeness analysis.

[1] REGULATION (EU) No 525/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC

[2] COMMISSION IMPLEMENTING REGULATION (EU) No 749/2014 of 30 June 2014 on structure, format, submission processes and review of information reported by Member States pursuant to Regulation (EU) No 525/2013 of the European Parliament and of the Council

Chapter 2 provides a general overview of development of emissions of direct and indirect greenhouse gases and of removals of carbon dioxide in sinks.

Chapters 3 through 9 present information about the individual source and sink groups. Along with general descriptions and information relative to the methods used, sub-chapters in this section also include information about pertinent uncertainties, quality assurance and quality control, recalculations carried out and planned improvements for relevant source and sink categories.

The inventories, the National System and the Quality System for Emissions Inventories have all been further improved in keeping with the results of the reviews that have taken place in recent years. More-detailed information about recalculations, and information relative to the improvements and changes made with regard to the last greenhouse-gas inventory, is presented in **Chapter 10** .

Part II of the NIR, comprising **Chapters 11 to 16**, presents the so-called "Kyoto-NIR", in fulfillment of the expanded requirements for Kyoto reporting, and in keeping with the required organisation (annotated NIR).

Chapter 11 contains all information relative to Kyoto reporting in the areas of land use, land-use changes and forestry (LULUCF), especially the definition of "forest" chosen, details on the land-classification technique used and all information relative to selected activities pursuant to Arts. 3.3 and 3.4 of the Kyoto Protocol.

Chapter 12 is devoted completely to accounting for Kyoto units, a process for which, in Germany, the German Emissions Trading Authority (DEHSt) is responsible.

Chapters 13 and 14 provide an overview of changes made in the National System, and at the German Emissions Trading Authority, with the aim of ruling out the possibility of any undue influences on Kyoto reporting.

Chapter 15 lists all the measures that Germany is taking to minimise negative impacts pursuant to Article 3 (14).

Chapter 16 presents any required further information relative to Kyoto reporting.

Annexes 1 through 7, comprising **Chapters 17-23**, contain more-detailed descriptions of key categories, of individual categories, of the CO_2-reference procedure, of completeness issues, of the National System and the Quality System, of the CSE emissions database and of uncertainties.

More-detailed information about specific relevant issues is presented in the literature listed in **Chapter 24**.

The Federal Environment Agency makes all calculations for the greenhouse-gas inventory and carries out all relevant compilation. Data on emissions and sinks in the land use, land-use changes and forestry sector have been provided by the Johann Heinrich von Thünen Institute (TI). The reporting is coordinated by the Federal Environment Agency (UBA).

0.1 Background information on greenhouse-gas inventories and climate change (ES.1)

0.1.1 Background information about climate change (ES.1.1)

Ever since the start of industrialisation, significant trans-regional and global changes in the substance balance of the atmosphere have been observed as a consequence of human activities. Worldwide, concentrations of carbon dioxide (CO_2) have risen by approximately 43 % compared to their levels in pre-industrial times, whilst those of methane (CH_4) have increased by 150 %

and those of nitrous oxide (N_2O) have risen by 20 %. Furthermore, a number of brand-new substances – i.e. substances that for all intents and purposes do not occur in nature and are produced almost exclusively by humans – such as chlorofluorocarbons (CFCs), halons, perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) have entered the atmosphere. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)[3] highlights the ways in which humans are affecting the earth's climate.

0.1.2 Background information about greenhouse-gas inventories (ES.1.2)

In February 2005, the Kyoto Protocol entered into force. As a result, the international community of nations is required to implement binding action objectives and instruments for global climate protection. In the first commitment period, which lasted from 2008 through 2012, the European Community (at the time, with 15 Member States) committed itself to reducing its greenhouse-gas emissions by 8 % with respect to the base year (1990 and 1995[4]). This commitment has been divided and fulfilled within the EU in the framework of a burden-sharing agreement between the participating Member States[5]. In that agreement, Germany agreed to reduce its emissions by 21 % in comparison to the base year and thus agreed to make a substantial contribution to fulfillment of the EU's commitment. With a reduction of over 26 % by 2012, Germany exceeded that goal.

In the framework of the second commitment period of the Kyoto Protocol, the European countries have committed themselves to reducing their greenhouse-gas emissions by 20 % by 2020. At the same time, they have announced that, under certain conditions, this European contribution could be increased to a 30 %[6] reduction with respect to 1990.

0.1.3 Background information relative to supplementary information as required pursuant to Article 7 (1) of the Kyoto Protocol (ES.1.3)

The present report, in keeping with decision 15/CMP.1, presents, for the first time, supplementary information pursuant to Article 7 (1) of the Kyoto Protocol, for support of the review process under the Kyoto Protocol. This information includes:

- General information on inventory preparation in connection with reporting pursuant to Article 3 (3) Kyoto Protocol and for the selected additional activities pursuant to Article 3 (4) Kyoto Protocol; (cf. Chapter 11)
- Information regarding the certificates under the Kyoto Protocol in connection with decisions 13/CMP.1 and 5/CMP.1; (cf. Chapter 11)
- Information regarding changes in the National System of emissions reporting pursuant to Article 5 (1) of the Kyoto Protocol; (cf. Chapter 13)
- Information regarding changes in the National Registry; (cf. Chapter 13)
- Information regarding minimisation of negative impacts pursuant to Article 3 (14) of the Kyoto Protocol; (cf. Chapter 13)

[3] IPCC Fifth Assessment Report: Climate Change 2007, available in the Internet at: http://www.ipcc.ch/ipccreports/assessments-reports.htm

[4] For HFC, PFC and SF_6

[5] Burden-sharing agreement, adopted with Council Decision 2002/358/EC of 25 April 2002 concerning the approval, on behalf of the European Community, of the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the joint fulfilment of commitments thereunder [OJ L 130 of 15 May 2002]

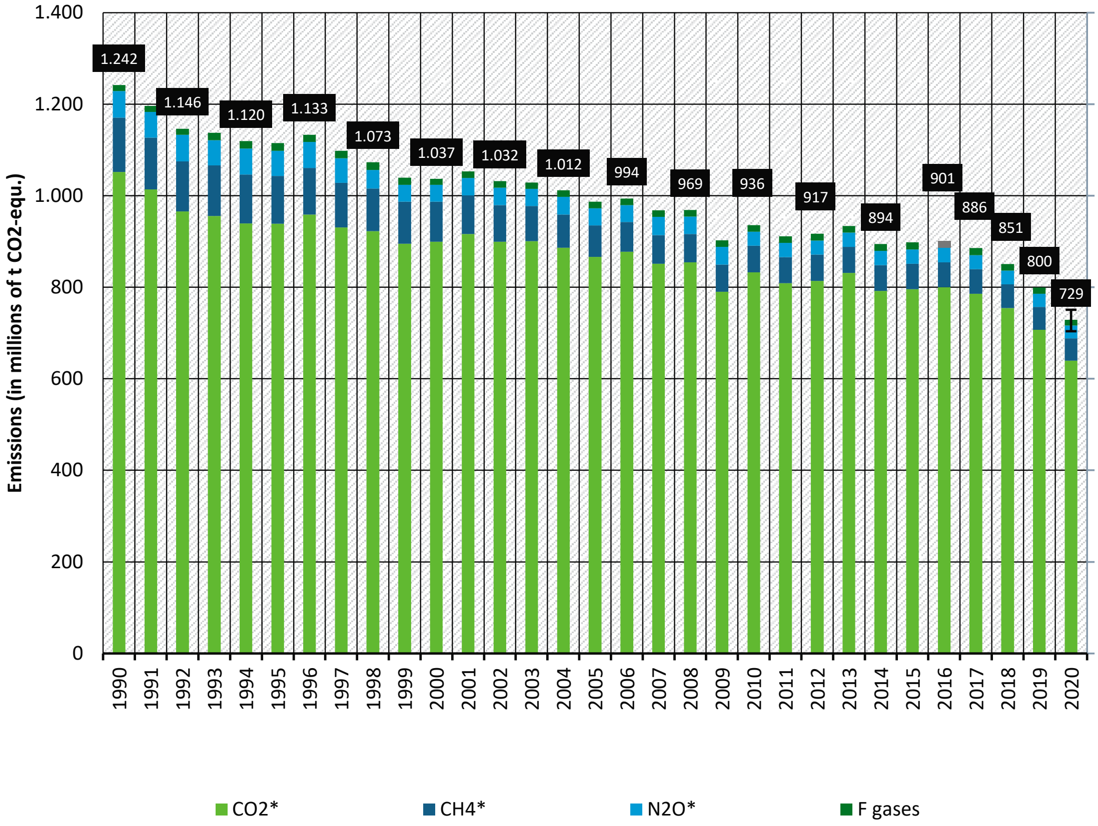
[6] Information on the quantified emission limitation or reduction objectives (QELROs) for the second commitment period under the Kyoto Protocol; SUBMISSION BY DENMARK AND THE EUROPEAN COMMISSION ON BEHALF OF THE EUROPEAN UNION AND ITS MEMBER STATES, Copenhagen, 19 April 2012

0.2 Combined greenhouse-gas emissions, their removals in sinks, and emissions and removals from KP-LULUCF activities (ES.2)

0.2.1 Greenhouse-gas inventory (ES.2.1)

In the relevant interval, 2008 through 2012, Germany completely fulfilled its obligations within the framework of the aforementioned European obligation, with regard to the base-year emissions determined in 2007[7]. It did this by achieving a reduction of 1,232,429.543 Gg (CO_2 equivalents). In the following year, 2013, emissions increased considerably over their levels in 2012. Cold winter weather in 2013 was the primary factor for this increase. In the following years, emissions were again considerably lower than their level in 2013, and they largely stayed in step with economic trends and weather patterns. Since 2017, emissions have fallen markedly every year (cf. Chapter 2.1).

Figure 1: Development of greenhouse gases in Germany since 1990, by greenhouse gases [8],



* not including LULUCF; error indicator, 2020: Tier-2 uncertainties

The individual greenhouse gases contributed to this development to varying degrees (cf. Table 1). This is hardly surprising given that, in any given year the various greenhouse gases account for varying proportions of total emissions (cf. Table 2). Detailed tables are provided in Annex Chapter 22.3.

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[7] The reference figures for determining achievement of reduction obligations under the Kyoto Protocol have been defined in keeping with results of the review, carried out in 2007, of the initial report and of reporting for 2006 pursuant to Article 8 of the Kyoto Protocol. Pursuant to its obligations under the Kyoto Protocol and EU burden sharing (Council Decision 2002/358/EC), Germany's reduction obligations amount to 21 %.

[8] * Not including CO_2 emissions and removals from Land Use, Land Use Changes and Forestry (LULUCF).

In 2020, with an 87.7 % share, carbon dioxide emissions again accounted for the largest share of greenhouse-gas emissions. Most of the carbon dioxide is released via stationary and mobile combustion of fossil fuels. As a result of a disproportionately large reduction of other greenhouse-gas emissions, CO_2 emissions' share of total emissions has increased by about 3 percentage points since 1990. Methane (CH_4) emissions, caused predominantly by animal husbandry, fuel distribution and landfills, accounted for a 6.7 % share. Emissions of nitrous oxide (N_2O), caused primarily by agriculture, industrial processes and burning of fossil fuels, contributed 3.9 % of greenhouse-gas releases. Fluorinated greenhouse gases ("F gases") contributed about 1.7 % to total emissions. The greenhouse gas NF_3, which is now also being reported, is of negligible importance. Furthermore, the low emissions of that substance are confidential in part, meaning that part of the emissions have to be reported elsewhere. The distribution of greenhouse-gas emissions in Germany is typical for a highly developed and industrialised country.

Information about the relevant trends is provided in Chapter 1, while all detailed tables relative to discussion of trends are provided in Annex Chapter 22.3.

Table 1: Emissions trends in Germany, by greenhouse gas and category

Emissions Trends	1.990	1.995	2.000	2.005	2.010	2.011	2.012	2.013	2.014	2.015	2.016	2.017	2.018	2.019	2.020
						(kt)									
CO_2 emissions (without LULUCF)	**1.051.979**	**938.614**	**899.352**	**866.303**	**832.541**	**808.912**	**813.693**	**831.208**	**792.255**	**795.557**	**800.340**	**785.616**	**754.408**	**707.150**	**639.381**
Net CO_2 emissions/removals	1.076.570	911.628	887.392	867.709	814.811	789.854	784.512	804.688	766.386	771.823	774.608	760.212	730.929	688.886	624.731
CH_4 (without LULUCF)	**118.555**	**104.350**	**87.798**	**68.701**	**58.140**	**57.051**	**57.597**	**56.966**	**55.847**	**55.627**	**54.366**	**53.798**	**52.007**	**49.944**	**49.015**
CH_4 (including LULUCF)	119.996	105.785	89.232	70.292	59.867	58.792	59.355	58.741	57.639	57.438	56.186	55.629	53.953	51.814	50.889
N_2O (without LULUCF)	**57.989**	**55.250**	**36.483**	**37.522**	**30.841**	**30.855**	**31.001**	**31.172**	**31.705**	**31.655**	**31.521**	**31.028**	**29.716**	**28.948**	**28.182**
N_2O (including LULUCF)	58.960	56.211	37.419	38.873	32.150	32.195	32.376	32.582	33.152	33.142	32.967	32.489	31.199	30.450	29.694
F gases, sum (CO_2 equi.) 1995 base year	**13.395**	**17.092**	**13.293**	**14.184**	**14.246**	**14.426**	**14.609**	**14.642**	**14.657**	**15.116**	**15.215**	**15.288**	**14.411**	**13.692**	**12.159**
Total Emissions without LULUCF (CO_2 equi.)	**1.241.919**	**1.115.305**	**1.036.926**	**986.709**	**935.768**	**911.244**	**916.901**	**933.987**	**894.465**	**897.954**	**901.442**	**885.729**	**850.542**	**799.734**	**728.738**
Total Emissions/Removals with LULUCF (CO_2 equi.)	1.268.922	1.090.716	1.027.337	991.058	921.074	895.267	890.853	910.653	871.834	877.519	878.975	863.618	830.492	784.842	717.473
Emission source and sink categories	**1.990**	**1.995**	**2.000**	**2.005**	**2.010**	**2.011**	**2.012**	**2.013**	**2.014**	**2.015**	**2.016**	**2.017**	**2.018**	**2.018**	**2.020**
						(kt)									
1. Energy	**1.036.444**	**917.379**	**869.647**	**831.839**	**800.987**	**777.237**	**783.914**	**801.247**	**761.165**	**766.393**	**768.977**	**750.503**	**720.389**	**673.836**	**608.399**
2. Industry	**96.891**	**98.600**	**77.895**	**75.602**	**62.559**	**62.485**	**61.569**	**61.319**	**61.194**	**60.229**	**62.076**	**65.933**	**62.967**	**59.790**	**55.473**
3. Agriculture	**70.581**	**61.252**	**60.997**	**58.081**	**57.761**	**57.844**	**58.511**	**59.271**	**60.547**	**60.388**	**59.993**	**59.311**	**57.634**	**56.912**	**56.095**
4. Land-Use Change and Forestry	**27.003**	**-24.590**	**-9.589**	**4.348**	**-14.694**	**-15.976**	**-26.048**	**-23.334**	**-22.631**	**-20.435**	**-22.467**	**-22.111**	**-20.050**	**-14.892**	**-11.265**
CO_2 (net emissions)	24.591	-26.986	-11.959	1.406	-17.730	-19.058	-29.181	-26.520	-25.870	-23.733	-25.732	-25.404	-23.479	-18.264	-14.650
N_2O + CH_4	2.412	2.396	2.370	2.942	3.036	3.081	3.133	3.185	3.239	3.298	3.266	3.293	3.430	3.372	3.385
5. Waste	**38.003**	**38.074**	**28.388**	**21.188**	**14.461**	**13.677**	**12.907**	**12.150**	**11.558**	**10.943**	**10.396**	**9.982**	**9.552**	**9.196**	**8.770**

Table 2: Contributions to emissions trends in Germany, by greenhouse gas and category

GHG Emission Fractions	1.990	1.995	2.000	2.005	2.010	2.011	2.012	2.013	2.014	2.015	2.016	2.017	2.018	2.019	2.020
							(%)								
CO_2 emissions (without LULUCF)	84.71	84.16	86.73	87.80	88.97	88.77	88.74	89.00	88.57	88.60	88.78	88.70	88.70	88.42	87.74
CH_4 (without LULUCF)	9.55	9.36	8.47	6.96	6.21	6.26	6.28	6.10	6.24	6.19	6.03	6.07	6.11	6.25	6.73
N_2O (without LULUCF)	4.67	4.95	3.52	3.80	3.30	3.39	3.38	3.34	3.54	3.53	3.50	3.50	3.49	3.62	3.87
F gases, sum	1.08	1.53	1.28	1.44	1.52	1.58	1.59	1.57	1.64	1.68	1.69	1.73	1.69	1.71	1.67
GHG Emission Fractions for Categories (without LULUCF)	**1.990**	**1.995**	**2.000**	**2.005**	**2.010**	**2.011**	**2.012**	**2.013**	**2.014**	**2.015**	**2.016**	**2.017**	**2.018**		**2.020**
							(%)								
1. Energy	83.46	82.25	83.87	84.30	85.60	85.29	85.50	85.79	85.10	85.35	85.31	84.73	84.70	84.26	83.49
2. Industry	7.80	8.84	7.51	7.66	6.69	6.86	6.71	6.57	6.84	6.71	6.89	7.44	7.40	7.48	7.61
3. Agriculture	5.68	5.49	5.88	5.89	6.17	6.35	6.38	6.35	6.77	6.73	6.66	6.70	6.78	7.12	7.70
5. Waste	3.06	3.41	2.74	2.15	1.55	1.50	1.41	1.30	1.29	1.22	1.15	1.13	1.12	1.15	1.20

* Information on the structure of the Common Reporting Format (CRF): http://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1ri.pdf

0.2.2 KP-LULUCF activities (ES.2.2)

Under Article 3.3, it is accounting GHG emissions of about 549 kt CO_2 equivalents for the year 2020.

Activities in the areas of Forest Management, Cropland Management and Grazing Land Management are reported under Article 3.4. The removals for the year 2020 amount to about -17,081 kt CO_2 equivalents.

0.3 Combined emissions estimates, and trends for source and sink groups, including KP-LULUCF activities (ES.3)

0.3.1 Greenhouse-gas inventory (ES.3.1)

Figure 2 shows the contributions of the individual categories to total greenhouse-gas emissions. It highlights the considerable constancy of the relative shares of the various categories and the absolute predominance of energy-related emissions. On the other hand, absolute energy-related emissions have continuously decreased over time. The variations that are superimposed over this trend are largely temperature-related. Because temperatures – especially in winter – affect heating patterns, they also affect energy consumption for heating, and thus they have major impacts on annual trends in energy-related CO_2 emissions.

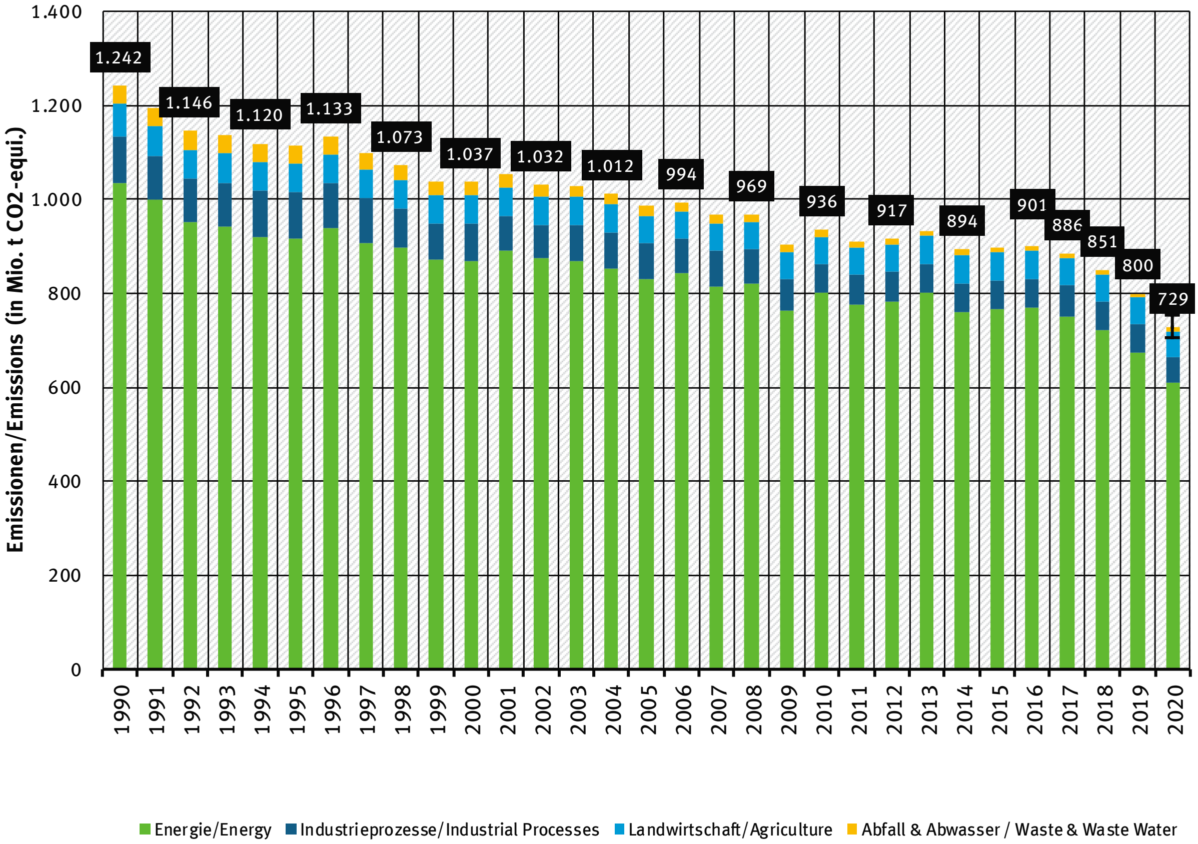
On the whole, greenhouse-gas emissions decreased by 41.3 % in 2020[9]. Considerations of the various components involved confirm this trend, to varying degrees. The relevant emissions changes for the most important greenhouse gases in terms of quantity were as follows: - 39.2 % for carbon dioxide (CO_2), - 58.7 % for methane (CH_4) and - 51.4 % for nitrous oxide (N_2O). The corresponding trends for the so-called "F" gases, which contribute about 1.7 % of greenhouse-gas emissions overall, have not been as clearly similar to each other, however. In keeping with the introduction of new technologies, and with use of these substances as substitutes, since base year 1995 SF_6 and PFC emissions have decreased, while HFC emissions increased. In total, emissions of F gases have decreased by 28.9 % since 1995, however.

With respect to the previous year, 2019, total emissions decreased by 8.9 %. That reduction was the largest seen since 1990, the year of German reunification. For the most part, the reduction seen is due to structural changes in the energy industry, as well as to pricing factors such as low gas prices, and high prices for CO_2 certificates within European emissions trading.

In addition, CO_2 emissions from electricity generation decreased again in 2020. Use of hard coal and lignite also decreased again. In recent years, coal has been increasingly supplanted by natural gas, which has lower specific CO_2 emissions, in electricity generation. Furthermore, renewable energies' share of electricity generation has increased considerably.

[9] All figures do not include emissions from the category of Land Use, Land-Use Change & Forestry (LULUCF).

Figure 2: Emissions trends in Germany since 1990, by categories[10,]

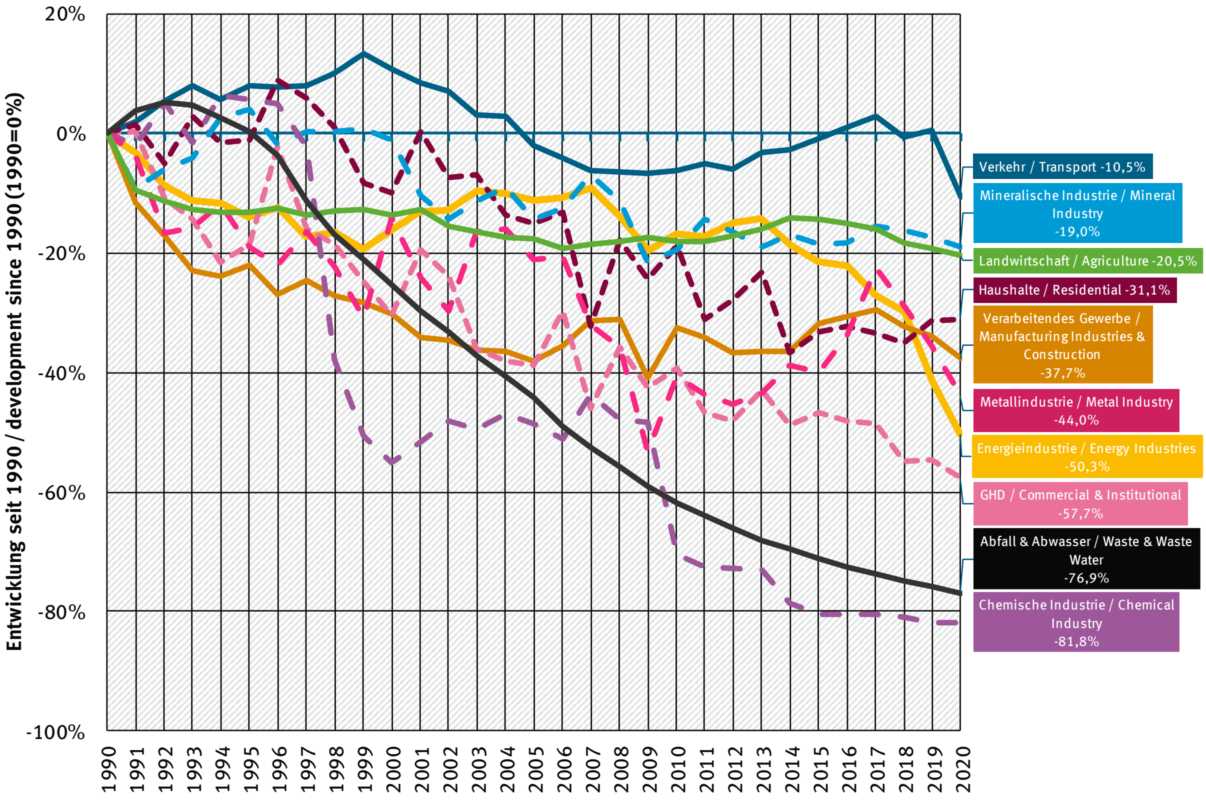


not including LULUCF; error indicator, 2020: Tier 2 uncertainties

Figure 3 shows the relative developments of emissions from categories since 1990. The most pronounced reductions occurred in the chemical industry sector and in waste-related emissions. Chemical industry emissions were affected especially by emissions reductions in the area of adipic acid production, tied to measures carried out in 1997 and in 2009, and by emissions reductions in solvent and product use, tied primarily to decreases in use of N_2O in anaesthesia. In the waste sector, increased recycling of recyclable materials (driven by the Packaging Ordinance), and reuse of materials as compost (driven by the Biowaste Ordinance), have led to a sharp reduction in the quantity of waste that is landfilled and, thereby, to continuous reductions in landfill emissions. The energy industry's emissions have also been decreasing considerably in recent years. In the sectors households and commerce/trade/services, emissions have been decreasing overall since the mid-1990s, with sharp fluctuations due to weather effects. A detailed discussion of emissions trends is presented in Chapter 1, Trends in Greenhouse Gas Emissions.

[10] * Not including CO_2 emissions from Land Use, Land Use Changes and Forestry (LULUCF).

Figure 3: Relative development of greenhouse-gas emissions since 1990, by categories[11,]



0.3.2 KP-LULUCF activities (ES.3.2)

Under KP-LULUCF, Germany reports the activities "afforestation" and "deforestation" pursuant to Article 3 (3) of the Kyoto Protocol. Pursuant to Article 3 (4), it reports the activities "forest management, cropland management, and grazing land management." Emissions of the greenhouse gases carbon dioxide, methane and nitrous oxide are reported.

Under Article 3.3, it is reporting GHG emissions of 549 kt CO_2 equivalents for the year 2020. That figure represents the sum of removals via the activity "afforestation and reforestation," amounting to -725.09 kt CO_2 equivalents, and emissions from "deforestation," amounting to 1,274.14 kt CO_2 equivalents. The emissions under "afforestation and deforestation" consist of 420.85 kt CO_2, 60.74 kt CO_2 equivalents of methane and 67.46 kt CO_2 equivalents of nitrous oxide. In the present submission, emissions pursuant to Article 3.3 of the Kyoto Protocol are listed as a source. This is the result of a methodological correction that has led to more-precise emission factors for forest biomass.

For the year 2020, the GHG emissions pursuant to Article 3.4 amount to -17,081 kt CO_2 equivalents. They consist of emissions of -54,098 kt CO_2-eq. from forest management, of 16,552 kt CO_2-eq. from cropland management and of 20,466 kt CO_2-eq. from grazing land management. Broken down by gases, the emissions are as follows: for carbon dioxide, -19,466 kt CO_2; for methane, 1,222 kt CO_2-eq.; and for nitrous oxide, 1,163 kt CO_2-eq.

[11] Emissions from Land Use, Land Use Changes and Forestry are reported in detail in the relevant chapter.

1 Introduction

1.1 Background information regarding greenhouse-gas inventories and climate change, and supplementary information as required pursuant to Article 7 (1) of the Kyoto Protocol

1.1.1 Background information about climate change

Climate change consists of changes in average weather conditions, and in extreme events, over an extended period of time. It can be either local or global.

Climate change may be attributable to the following causes:

- Changes in so-called "geo-astrophysical parameters" such as the solar constant, elements of the earth's orbit, etc.
- Changes in the earth's surface
- Changes in the energy balance in the "earth's surface and atmosphere" system
- Changes in the substance balance in the atmosphere (such as changes in the concentration of greenhouse gases).

Greenhouse gases, among which are carbon dioxide, nitrous oxide (laughing gas), methane, ozone and other gases (especially water vapour, the most important natural greenhouse gas), have a particular property: They allow the energy-rich radiation falling onto the earth from the sun (primarily in the visible, short-wave range) to pass almost unhindered, yet partially absorb the long-wave radiation emitted by the heated earth. This places them in an energetically excited state for a brief time, after which they return to their original basic state whilst emitting infrared radiation. Heat radiation occurs equally in all spatial directions – in other words, a substantial portion of this is returned to the earth's surface (”*thermal back radiation*”). So that this additional quantity of energy may nevertheless be irradiated (this must occur due to the dynamic, energetic equilibrium, at whose centre are the earth and the atmosphere), the earth must have a correspondingly higher temperature. This is a simplified description of the greenhouse effect.

Without the greenhouse gases occurring naturally, life on our planet would not be possible. Instead of having an average global temperature of approximately 15°C, the earth would have an average temperature of approximately –18°C. In other words, the natural greenhouse effect protects our life on earth.

Since the beginning of the industrial era, mankind has brought about marked changes in the atmosphere's substance cycles, however. These changes have been caused by humans' energy-intensive lifestyles and related emissions of greenhouse gases. From 1750 to 2021, the worldwide concentrations of carbon dioxide (CO_2) increased by about 49 %. As in previous years, the current CO_2 concentration in the atmosphere is the highest to have occurred over the past 800,000 years , and it now stands at about 415 ppm (Global Carbon Project, 2021). In the same period, the concentration of methane (CH_4) in the atmosphere increased by a factor of 2.5, to 1886 ppb, and the concentration of nitrous oxide (N_2O) increased by about 23 %, to 334 ppb (Dlugokencky, 2021). Furthermore, a number of brand-new substances – i.e. substances that for all intents and purposes do not occur in nature and are produced almost exclusively by humans – such as chlorofluorocarbons (CFCs), halons, perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3), have entered the atmosphere.

In spite of being "trace gases", greenhouse gases have considerable impacts. Their increasing concentrations have led to the anthropogenic (human-caused) greenhouse effect, which supplements the natural greenhouse effect.

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2015) has clearly confirmed that the earth's climate is currently changing: A wide range of changes have occurred throughout the entire climate system since the middle of the last century. The temperature of the lower atmosphere is rising, the oceans are warming, glaciers are melting, permafrost soils are thawing, icecaps are losing mass and sea levels are continuing to rise.

Extensive observations, expanded models and profound insights into the pertinent interrelationships indicate, with great reliability, that human activities are the main cause of the climate change currently taking place.

Significant examples of observed climate changes include the following:

- By 2019, and with respect to the base period 1850-1990, the average global surface temperature increased by 1.1 °C (World Meteorological Organization, 2020). Each of the past three decades has been warmer than all the previous decades since 1850. In the northern hemisphere, the last 30-year period (from 1983 to 2012) was the warmest such period in the past 1,400 years.
- The year 2016 was the warmest to date since the beginning of record-keeping in the second half of the 19th century. 2017 and 2015 were the next-warmest, and almost as warm. Nine of the ten warmest years observed to date occurred after 2005, and the five warmest years occurred after 2010 (World Meteorological Organization, 2018).
- In the period 1971 to 2010, the oceans have stored more than 90 % of the additional energy fed into the climate system. The **upper water layers** in the world's oceans (0 to 700 meters) warmed considerably in the period from 1971 to 2010. From 1971 to 2010, the temperature in the oceans' upper 75 meters rose by an average of 0.11°C per decade. In addition, data gained during the observation period 1957 through 2009 suggest a likelihood that the oceans have also warmed at **water depths between 700 and 2,000 meters**. Adequate measurement data for greater water depths are available only for the period 1992 through 2005. For depths below 3,000 meters, they show warming that is most pronounced in the southern oceans. Glaciers around the world have continued to retreat, apart from just a few exceptions, and the earth's polar icecaps have lost mass. In the entirely of the period 1971 through 2009, the average annual mass loss of **glaciers** (not including glaciers at the periphery of the large ice caps) worldwide amounted to about 226 gigatonnes per year. In a recent fraction of that period (1993 through 2009), the loss rate had increased to about 275 gigatonnes per year, however.
- Over the period 1979 through 2012, the area covered by **Arctic sea ice** decreased at a rate of 3.5 to 4.1 percent per decade. During the summer minimum (September), the decrease reached rates of 9.4 to 13.6 percent per decade. During the same period, the duration of the melting period increased by about 5.7 days per decade, and the thickness of the winter pack ice in the Northern Arctic Ocean decreased by about 1.3 to 2.3 meters.
- The spring **snow cover** in the Northern Hemisphere has been decreasing since the middle of the 20th century. From 1967 through 2012, snow cover during the months of March and April decreased by an average of 1.6 percent per decade, while the June snow cover decreased by 11.7 percent per decade.

- As a result of continuing melting of glaciers and icecaps, and of warming-related ocean-water expansion, the global mean sea level rose by about 19 cm from 1901 to 2010. **The average rise during that period amounted to about 1.7 millimeters per year. Over the last 20 years, the average rise, at about 3.2 millimeters per year, was nearly twice as large, however.**

The climate change will have extensive impacts on ecological and societal systems, with potentially serious consequences.

In 2015, the international community adopted the Paris Agreement, which aims to prevent dangerous climate-change impacts by limiting global warming to considerably less than 2 °C – and to 1.5 °C if possible – with respect to the pre-industrial temperature level (1.1°C of warming has already occurred ((World Meteorological Organization, 2020))). Successful limiting of warming to considerably less than 2 °C can be expected only in a scenario with highly ambitious climate policies.

The latest research findings indicate that greenhouse-gas emissions must reach their final maximum no later than 2020 and that a trend reversal must then begin taking place. In subsequent years, global emissions then urgently need to be reduced by at least 50 % by the year 2050, with respect to the emission level of the year 2000 .

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1.1.2 Background information about greenhouse-gas inventories

The world's nations were quick to recognize that the expected temperature changes would pose threats to ecosystems and to human civilisation, because the changes would take place relatively quickly, and existing systems would not be able to adapt to the new climate conditions without suffering damage.

The Framework Convention on Climate Change was adopted in 1992, in Rio de Janeiro, by nearly all nations of the world. Since 1994, the countries listed in ANNEX I of the Framework Convention on Climate are required to submit annual inventories of greenhouse gases, as of 15 April of each year, to the Secretariat of the Framework Convention. Such inventories must include data on emissions and sinks for the base year (1990 for CO_2, N_2O, CH_4; 1995 for HFCs, PFCs, SF_6 and NF_3) and for all years until two years prior to the year of the relevant report (UNFCCC, 2013b)).

At the third Conference of the Parties to the UN Framework Convention on Climate Change, held in Kyoto, legally binding obligations on emissions limitations and reductions were defined, for the first time, for the countries listed in ANNEX I. In the first commitment period under the Kyoto Protocol, industrialised nations were required to reduce their emissions of the six greenhouse gases carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) by an average of 5.2 percent in the period 2008 through 2012[12]. In the second commitment period of the Kyoto Protocol, the list of relevant gases was expanded to include nitrogen trifluoride (NF_3) and six hydrofluorocarbons

[12] The average reduction, 5.2 %, was calculated from the emissions limitations and reductions that the various parties to the Kyoto Protocol entered in the Protocol's Annex B.

(HFC-152, HFC-161, HFC-236cb, HFC-236ea, HFC-245fa, HFC-365mfc) and two perfluorocarbons (c-C_3F_6, $C_{10}F_{18}$).

For the first commitment period, the European Union adopted an obligation to reduce emissions by 8 %, with respect to the base year. For the second commitment period in the framework of the Kyoto Protocol, the European Union has adopted an obligation to reduce its GHG emissions by 20 %, with respect to the base year, by 2020. Via the European Effort Sharing Decision[13], that obligation has been divided among the 28 Member States and the European Union. While emissions reductions in those areas of inventories that are subject to emissions trading are implemented at the European level, the Member States are responsible at the national level for emissions reductions in inventory areas not subject to emissions trading. Germany is obligated to reduce its emissions to 451.33 million tonnes of CO_2-equivalents.

In the second commitment period of the Kyoto Protocol – as in the first – the effectiveness and success of the Kyoto Protocol vis-à-vis reduction of global greenhouse gas emissions depend on two key factors: Whether its Parties abide by the rules of the Protocol and meet their obligations, and whether the emissions data used for controlling compliance are reliable. As such, national reporting and the subsequent international review of emissions inventories play a key role.

1.1.3 Background information relative to supplementary information, as required pursuant to Article 7 (1) of the Kyoto Protocol (KP NIR 1.1.3.)

Pursuant to decision 15/CMP.1 of the 1st COP of the Kyoto Protocol, as of 2010 all of the countries listed in ANNEX I of the UN Framework Convention on Climate Change that are also parties to the Kyoto Protocol must submit annual inventories in order to be able to make use of flexible mechanisms pursuant to Articles 6, 12 and 17 of the Kyoto Protocol.

In 2008 (with the NIR 2008), Germany began early, on a voluntary basis, to fulfill these reporting obligations. In the process, over the past two years it has begun preparing intensively for the binding reporting required pursuant to Art. 7 of the Kyoto Protocol.

The first binding report, that for 2010 (NIR 2010), was reviewed in detail in September 2010 in the framework of an In-Country Review. The recommendations made in the 2010 In Country Review were implemented in a resubmission of November 2010, and in subsequent reports in the period 2011 through 2014.

The first report within the second commitment period of the Kyoto Protocol (NIR 2016) was also reviewed in the framework of an In Country Review. Its recommendations were implemented via a resubmission in November 2016 and the following reports.

In submitting its nineteenth National Inventory Report (NIR 2021), Germany also submits its thirteenth inventory report pursuant to the Kyoto Protocol (its sixth report within the second commitment period), with all the information called for in Art. 7.

Information relative to Arts. 3.3 and 3.4 of the Kyoto Protocol (UNFCCC, 1998b) is provided in Chapter 11. Information on accounting of Kyoto units for the second commitment period is provided in Chapter 11. The relevant changes in the National System are described in Chapter 13, and the changes in the National Registers are described in Chapter 13. Information on minimisation of negative influences pursuant to Art. 3 (14) of the Kyoto Protocol is presented in Chapter 13.

[13] Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009

1.2 Description of institutionalisation of inventory preparation, including the legal and procedural definitions relative to the planning, preparation and management of the inventory

Decision 24/CP.19 calls on all Annex I states to establish and describe national institutions for preparation of greenhouse-gas inventories. In addition, Article 5.1 of the *Kyoto Protocol* calls on the parties to the Kyoto Protocol to establish National Systems for preparation of GHG inventories. The requirements pertaining to such systems are set forth in the *Guidelines for National Systems* (UNFCCC Decision 19/CMP.1). The National System for Germany fulfills the requirements, as set forth by both decisions and by the European Regulation on a mechanism for monitoring and reporting greenhouse gas emissions in the European Union and its Member States.[14]

The National System provides for the preparation of inventories conforming to the principles of transparency, consistency, comparability, completeness and accuracy. Such conformance is achieved through use of the methodological regulations from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, through ongoing quality management and through continuous inventory improvement.

The National System has been institutionalised in a process lasting from 2007 to 2011, and on the basis of a 2007 agreement between state secretaries of the involved ministries. Initially, this occurred via the establishment of a National Co-ordinating Committee and of pertinent in-house regulations for the Federal Environment Agency (UBA). Later, institutionalisation was completed primarily via signing of relevant agreements with other federal institutions, with industrial associations and with individual business enterprises. In 2013 and 2014, the National System was adapted to the requirements applying under the second commitment period of the Kyoto Protocol and expanded.

The requirements-conformal institutionalisation and function of the National System has been confirmed by all international reviews carried out to date, including the 2010 and 2016 In Country Reviews.

1.2.1 Overview of the institutional, legal and procedural definitions relative to preparation of greenhouse-gas inventories and of supplementary information as required pursuant to Article 7 (1) of the Kyoto Protocol

At the ministerial level, the National System has been established under the leadership of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), via an agreement 5 June 2007 signed by state secretaries of the participating ministries that serves as a pertinent policy paper and is entitled "National Emissions Reporting System" ("Nationales System zur Emissionsberichterstattung"). With the inclusion of the Federal Ministry of Food and Agriculture (BMEL), the Federal Ministry for Economic Affairs and Energy (BMWi), the Federal Ministry of Transport and Digital Infrastructure (BMVI), the Federal Ministry of the Interior, Building and Community (BMI), the Federal Ministry of Finance (BMF) and the Federal Ministry of Defence (BMVg), all key institutions and organisations are now involved in preparing emissions inventories that are in a position to provide high-quality specialised contributions (cf. Chapter 1.2.1.4). The policy paper on emissions reporting defines the relevant responsibilities of the various participating federal ministries, and it mandates that the National System is to be built on the basis of existing data streams. Where the data streams are incomplete, the pertinent

[14] Regulation (EU) No 525/2013 of the European Parliament and of the Council of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change

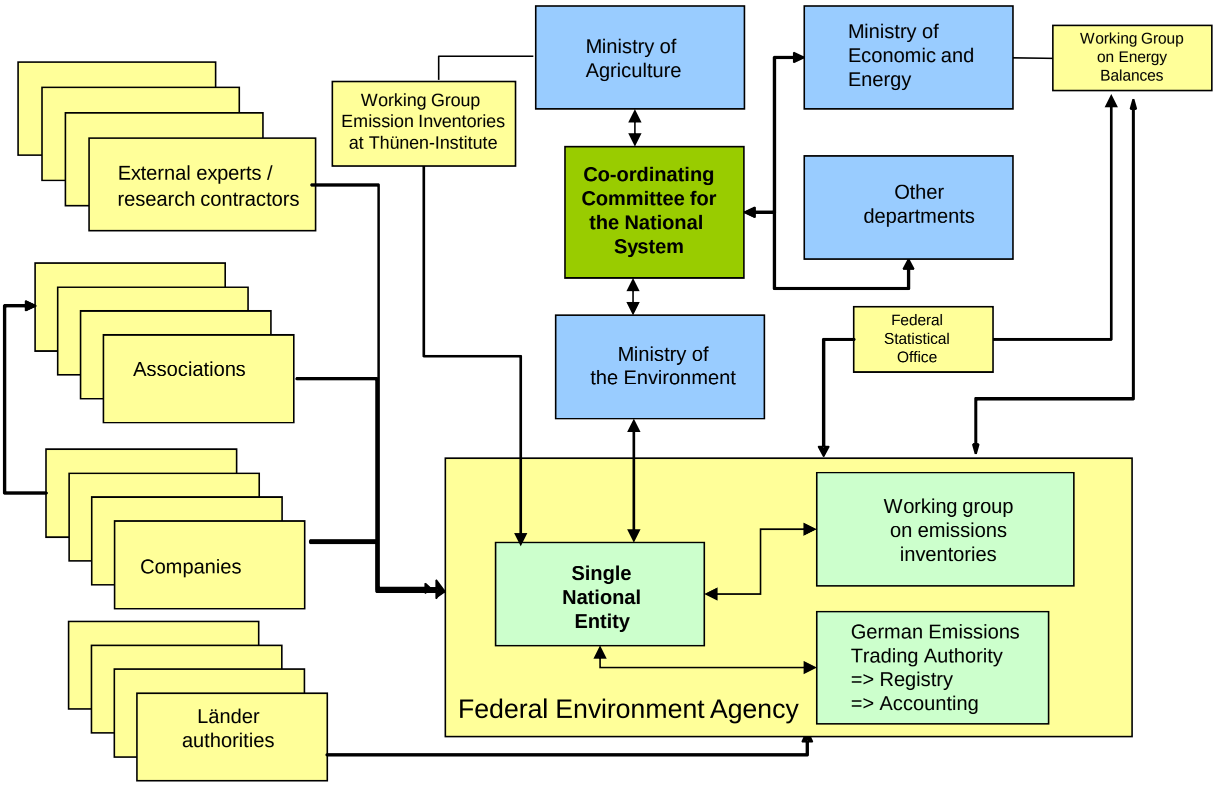
gaps are to be closed by the responsible ministries, via suitable activities. In support of the reporting process, the participating ministries established a co-ordinating committee (cf. Chapter 1.2.1.1).

The "National Emissions Reporting System" policy paper also assigns the Federal Environment Agency the task of serving as the Single National Entity for Germany. Within the Federal Environment Agency, the Emissions Situation section has been entrusted with this task (cf. Chapter 1.2.1.2). At the level of the Federal Environment Agency, the Single National Entity integrates other specialised agencies within the National System and coordinates the contributions of the other institutions and organisations involved in emissions reporting. For co-ordination of pertinent work within the Federal Environment Agency, a working group on emissions inventories was established (cf. Chapter 1.2.1.3). For implementation, within the Federal Environment Agency, of the IPCC guidelines for quality control and assurance, a Quality System of Emissions was established in 2005, via an in-house directive (cf. Chapter 1.3.3.1.1).

The following Figure 4 provides an overview of the structure of the National System in Germany.

The "National Emissions Reporting System" policy paper of 5 June 2007 is presented in Annex Chapter 22.1.1.

Figure 4: Structure of the National System of Emissions (NaSE)



1.2.1.1 The National Co-ordinating Committee

In its Sec. 2, the state secretaries' resolution of 5 June 2007 provides for the establishment of a National Co-ordinating Committee that is to be headed by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and to include representatives of all federal ministries that participate in emissions reporting.

The National Co-ordinating Committee has the tasks of supporting the emissions-reporting process and clarifying open issues pertaining to the National System. In particular, the

Committee carries out consultations with regard to gaps in data streams and settles issues pertaining to assigned responsibilities.

In addition, the National Co-ordinating Committee is responsible for approving inventories and the reports required pursuant to Arts. 5, 7 and 8 of the Kyoto Protocol.

The National Co-ordinating Committee met for the first time on 21 December 2007. It meets at least once per year, at the invitation of the BMU. Between meetings, the participating federal ministries carry out co-ordination via electronic communication.

In the second commitment period, the National Co-ordinating Committee continues to be an important, established component of the National System.

1.2.1.2 Single National Entity (co-ordination agency) for the National System

The state secretaries' policy paper of 5 June 2007 appointed the Federal Environment Agency (UBA) to carry out tasks of the **Single National Entity** for emissions reporting (**national co-ordination agency**). The Federal Environment Agency's in-house directive (Hausanordnung) 11/2005 gave its "Emissions Situation" Section responsibility for carrying out that function.

The Single National Entity's tasks include planning, preparing and archiving of inventories, describing inventories in the inventory reports and carrying out quality control and assurance for all important process steps. The Single National Entity serves as a central point of contact, and it co-ordinates and informs all participants in the National System. During the period 2003 to 2007, the Single National Entity has given priority to developing new data sources. Since 2008, its focus has been especially on a) improving existing data sources and safeguarding their availability for the long term, and b) maintaining the **institutionalisation of the National System**. Furthermore, institutions and organisations that need to be integrated within the *National System* have been identified and are now being successively integrated (cf. Chapter 1.2.1.4). In the years 2014 – 2016, its work focused especially on implementation of provisions under the second commitment periodof the Kyoto Protocol, and of the Revised UNFCCC Reporting Guidelines, in reporting and in the National System. Other important work has had to do with implementing the Quality System for Emissions Inventories (cf. Chapter 1.2.2).

The Single National Entity has developed two key **instruments** for carrying out those tasks:

The Federal Environment Agency's *Central System on Emissions* (CSE) database is the national, central database for emissions calculation and reporting. It is used for central storage of all information required for emissions calculation (methods, activity data, emission factors). The CSE is the main instrument for documentation and quality assurance at the data level.

Both within and outside of the Federal Environment Agency, the Quality System for Emissions Inventories (QSE) provides the necessary framework for good inventory practice and for routine quality assurance. Established within the Federal Environment Agency in 2005 via in-house directive 11/2005, it comprises the processes necessary for continually improving the quality of greenhouse-gas-emissions inventories. The framework it provides includes defined responsibilities and quality objectives relative to methods selection, data collection, calculation of emissions and relevant uncertainties and recording of completed quality checks and their results (confirmation that objectives were reached, or, where objectives were not reached, listing of the measures planned for future improvement). Ongoing quality improvement in the framework of the QSE is supported by a database that serves as the repository for all tabular documents emerging from the national QC/QA process (QC/QA plan, checklists, lists of responsibilities, etc.).

The quality control procedures have been developed with the help of external experts, taking special account of the Federal Environment Agency's work structures, general guidelines for quality assurance and the *IPCC Good Practice Guidance*. For the second commitment period, the quality control procedures have been brought into line with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Since 2008, the QSE has been expanded to cover the entire National System. This has occurred via integration of additional authorities, institutions and inventory experts in the quality-management process – via specification of minimum requirements for data documentation, QC/QA and archiving. In addition, the procedure is designed to enable other organisations to develop their own internal quality assurance systems on the basis of their existing structures. The QSE is described in detail in Chapter 1.3.3.

1.2.1.3 Working Group on Emissions Inventories, in the Federal Environment Agency

In its inventory work, and especially in work relative to emission factors, the Single National Entity receives significant support from other working units of the Federal Environment Agency, as well as from the Thünen institutes involved in preparation of the inventory. In addition, associations, companies and other independent organisations are integrated within the National System, for purposes of data provision, primarily via the Federal Environment Agency's specialised units that are responsible for the specific issues involved in each case.

In 2003, a *Working Group on Emissions Inventories* was set up to co-ordinate relevant work within the Federal Environment Agency; since then, it has liaised with all of the experts who are involved in inventory preparation.

The Single National Entity convenes meetings of the working group at least once a year. In addition, relevant members of the working group meet as necessary to discuss specific issues and to make any necessary in-house arrangements.

As necessary, information is provided via events of the working group, via the intranet of the Single National Entity for emissions reporting and via newsletters produced by the Single National Entity on the National System and on the Central System on Emissions (CSE) database (i.e. one for the National System and one for the database).

1.2.1.4 Co-operation by the Single National Entity with other federal institutions and with non-governmental organisations, in the framework of the National System

Via the "National Emissions Reporting System" policy paper of 05 June 2007, the involved ministries defined their responsibilities, relative to the various relevant source and sink categories, for the first commitment period of the Kyoto Protocol.

Furthermore, the relevant resolution sets forth that involved federal ministries are to undertake suitable activities to close data gaps that fall within their areas of responsibility. As necessary, data gaps are to be closed via provision of pertinent data, or via relevant calculations. In some cases, required data may be provided by reliable third parties.

The relevant arrangements are remaining in place during the second commitment period.

For some of the data streams moving to the Single National Entity from other federal institutions, special agreements have been concluded between a) the relevant institution in the case in question and b) the Single National Entity.

With regard to **data provision by the *Federal Statistical Office***, relative to emissions reporting, a legal arrangement was made in 2009, in the framework of an omnibus act (3rd SME Relief Act (MEG 3)), with application (inter alia) to the Energy Statistics Act (EnStatG). Following the amendment of the EnStatG in 2017, it was integrated within Sec. 13 (2) of that act. The MEG 3 makes possible the provision of data, for purposes of emissions reporting, from energy, environmental and production statistics that are subject to statistical confidentiality. On that basis, on 13 January 2010 an administrative agreement between the Federal Environment Agency and the *Federal Statistical Office* came into force that specifies data deliveries for emissions-reporting purposes. The agreement provides for annual reviews of the Federal Environment Agency's data requirements. In addition, a process of close direct exchanges between the Single National Entity and the Federal Statistical Office, regarding issues of emissions reporting, has been institutionalised.

The "National Emissions Reporting System" policy paper assigns responsibility for the areas of agriculture and LULUCF to the Federal Ministry of Food and Agriculture (BMEL). The BMEL has commissioned its subordinate departments to carry out the tasks necessary for emissions reporting. That commissioning took place via a directive of 29 July 2007 to the (then) Federal Agricultural Research Centre (FAL). As a result of a restructuring of the FAL as of 1 July 2008, the tasks are now carried out by the **Thünen Institute (TI)**. The relevant work includes all tasks in the agriculture and forestry sectors that are necessary for the preparation of the annual emissions inventories, including the writing of the relevant reports. The TI sends the pertinent data and report to the Single National Entity. With a concept (BMELV, 2016) that names and specifies all pertinent processes and actors, and the actors' roles, the BMEL and TI codified the procedures for preparation of emissions and carbon inventories for source and sink categories 3 and 4 (agriculture and forestry), and for KP-LULUCF (Art. 3.3. and 3.4 KP), and including a quality assurance concept.

In addition, on 13 February 2008, the TI concluded an agreement with the Federal Statistical Office on provision of emissions data on the basis of agricultural statistics. A research and development agreement between the TI and the *Association for Technology and Structures in Agriculture* (KTBL) has been in place since 7 July 2009. That agreement specifies the supporting work that the KTBL is to carry out for emissions reporting.

Furthermore, a working group on emissions reporting has been established within the TI, to serve as liaison to the Single National Entity within the Federal Environment Agency. That working group also has responsibility for planning and QC/QA for categories CRF 3 and CRF 4.

Responsibility for co-ordination of the Working Group on Emissions Reporting lies with the TI's Institute of Climate-Smart Agriculture (AK). Responsibility for reporting on agriculture and LULUC lies with the same institute, while responsibility for reporting on forests pursuant to the Convention and Kyoto Protocol Arts. 3.3 and 3.4 lies with the TI's Institute of Forest Ecosystems. As of the second commitment period of the Kyoto Protocol, the Thünen Institute of Wood Research (TI-HF) has responsibility for reporting on emissions from harvested wood products (HWP).

The working group on emissions reporting at the TI is integrated within the National System via direct (inter-departmental) participation within the Single National Entity's communications structures. The working group at the TI is also part of the working group ist on emissions inventories (Arbeitskreis Emissionsinventare – AKEI) within the Federal Environment Agency, and it is fully integrated within the Single National Entity's Quality System for Emission Inventories (QSE).

At least twice per year, additional co-ordinating meetings take place between the working group at the TI and the Single National Entity, for purposes of co-ordination and information provision – for example, with regard to inventory improvements and research projects.

Involvement of economic associations, companies and other independent organisations is achieved primarily via those departments of Federal Environment Agency divisions I, III and V that are responsible for pertinent concrete issues. The *Single National Entity* supports the departments in discussion of reporting requirements and in determination of requirements for data-sharing by associations. The data flows are continually reviewed by the Single National Entity and, where necessary, are updated and safeguarded by suitable agreements between the Single National Entity and associations / business enterprises.

The **Working Group on Energy Balances** (AGEB) is contractually obligated, via the Federal Ministry for Economic Affairs and Energy (BMWi), to provide Energy Balances. Use of a co-ordinated schedule ensures that a provisional Energy Balance for the last reported year is prepared on time, and is transmitted to the Federal Environment Agency, by 31 July of each year, for purposes of inventory preparation. An effort is made to transmit the final Energy Balance by 28 February of year x+2. The current agreement will end in 2022, with the preparation of the final Energy Balance for 2020. In 2019, and beginning with the 2018 provisional Energy Balance, responsibility for provision of data on renewable energies passed over to the Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat).

In 2008, a sample agreement was prepared for **inclusion of non-governmental agencies within the National System**. That agreement is used to involve stakeholders, under binding terms, within preparation of inventories. The sample agreement is adapted to the various data suppliers' own requirements and needs as is necessary. In July 2009, the Federal Ministry for Economic Affairs and Energy (BMWi) and the Federal Environment Agency concluded an agreement, with the German Chemical Industry Association (VCI) and German producers, on data provision in the categories Ammonia (2.B.1) and Nitric acid (2.B.2). In early summer 2014, that agreement was adapted to the requirements applying under the Revised UNFCCC Reporting Guidelines and the 2006 IPCC Guidelines. In addition, in 2009 agreements on data provision were reached with producers of adipic acid (2.B.3) located in Germany. Furthermore, an association agreement was concluded with the VDD industry association for bitumen paper and bitumen roof sheeting relative to the category Bitumen for roof sheeting (2.D.3.c). Since 2009, data for the aforementioned categories for emissions reporting have been provided on the basis of these agreements. In June 2011, the Single National Entity, acting with the support of the responsible ministry, the Federal Ministry for Economic Affairs and Energy (BMWi), entered into a cooperation agreement with the Wirtschaftsvereinigung Stahl German steel industry association. That agreement had become necessary because the Federal Statistical Office had discontinued its data collection and publication activities for Fachserie 4 Reihe 8.1 (iron and steel statistics) as of 31 December 2009, due to the expiration of the pertinent legal basis (Raw-materials-statistics act (Gesetz zur Neuordnung der Statistiken der Rohstoff- und Produktionswirtschaft einzelner Wirtschaftszweige (Rohstoffstatistikgesetz – RohstoffStatG; Act for reordering of the statistics on raw materials and production in individual economic sectors)). That move had considerably reduced the availability of the bases for calculations in that area, and it created a significant gap in the pertinent data streams. The new cooperation agreement closed that gap. The agreement assures data provision by both member companies of the assocation and by non-member companies.

A relevant voluntary commitment of semiconductor manufacturers with production sites in Germany, a commitment that served as the basis for data provision for category 2.F.6, expired on 31 December 2010. In August 2012, the Single National Entity acted to close the resulting potential data gap by entering into a cooperation agreement, with the Electronic Components and Systems (ECS) division of the German Electrical and Electronic Manufacturers' Association (ZVEI), that is designed to assure long-term provision of data to the Federal Environment Agency for category 2.E.1.

These agreements provide a reliable long-term framework for data provision, and they have had the effect of considerably improving data quality in the relevant categories.

1.2.1.5 Binding schedule in the framework of the National System

The binding schedule for preparation of emissions inventories and of the NIR is announced to all relevant internal and external stakeholders via the Federal Environment Agency's intranet site and via publication within the NIR itself. The following dates can vary by 1-2 days, in keeping with annual calendar varations:

15 May	The Federal Environment Agency's national co-ordinating agency (Single National Entity) requests responsible experts to submit data and report texts
31 July	Delivery of energy data of the Working Group on Energy Balances (AGEB), of statistical data of the Federal Statistical Office and of data provided under agreements with associations and companies, where such data serve as the basis for further calculations
by 1 September	Deliveries of ready-to-use inventory data from the Federal Environment Agency and from external institutions of the NaSE
as of 2 September	Validation / discussion of deliveries by responsible experts and quality managers, taking account of review results
by 1 October	Initial emissions calculations, and preparation of national trend tables; final editing by the Single National Entity within the Federal Environment Agency
6 November	In-house consultations at the Federal Environment Agency
as of 17 November	Final quality assurance by the QSE/CSE/NIR co-ordinator
25 November	Report of the Single National Entity to the BMU, for commencement of inter-ministerial co-ordination relative to the emissions data and the National Inventory Report
by 20 December	Approval via departmental co-ordination (initiated by the BMU)
as of 2 January	Final editing by the Federal Environment Agency's national co-ordinating agency (Single National Entity)
15 January	Report (CRF and certain parts of the NIR) goes to the European Commission (in the framework of the CO_2 Monitoring Mechanism) and to the European Environment Agency
15 March	Report (corrected CRF and complete NIR) goes to the European Commission (in the framework of the CO_2 Monitoring Mechanism) and to the European Environment Agency
15 April	Report goes to the FCCC Secretariat
May	Initial check by the FCCC Secretariat
June	Synthesis and assessment report I (by the UN FCCC Secretariat)
August	Synthesis and assessment report II (country-specific; by the UN FCCC Secretariat)
September - October	Inventory review by the UN FCCC Secretariat

1.2.2 Overview of inventory planning

Inventory preparation draws on the expertise of *research institutions*, via execution of research projects in the ReFoPlan (departmental research plan) framework. This takes place via consideration of specific questions and via overarching projects. In each of the research plans throughout the 2002-2009 period, the Single National Entity had a global project on *updating emissions-calculation methods*, a framework for initiating measures for continuous inventory improvement. In 2010 and 2011, measures for continuous inventory improvement were financed completely via the budget title for expert services. The Federal Environment Agency had agreed to provide the Single National Entity with funding, from the budget title for expert services (Title 526 02, Chapter 1605), for short-term contracts for purposes of inventory improvement under the responsibility of the Agency. The funding, provided as of 2005, in the interest of emissions reporting, came in addition to the research funding available from the ReFoPlan. Since 2012, the Single National Entity has again been able to finance research, in the framework of emissions reporting, via the ReFoPlan departmental research plan. In addition, the budget title for expert services remains available for such financing.

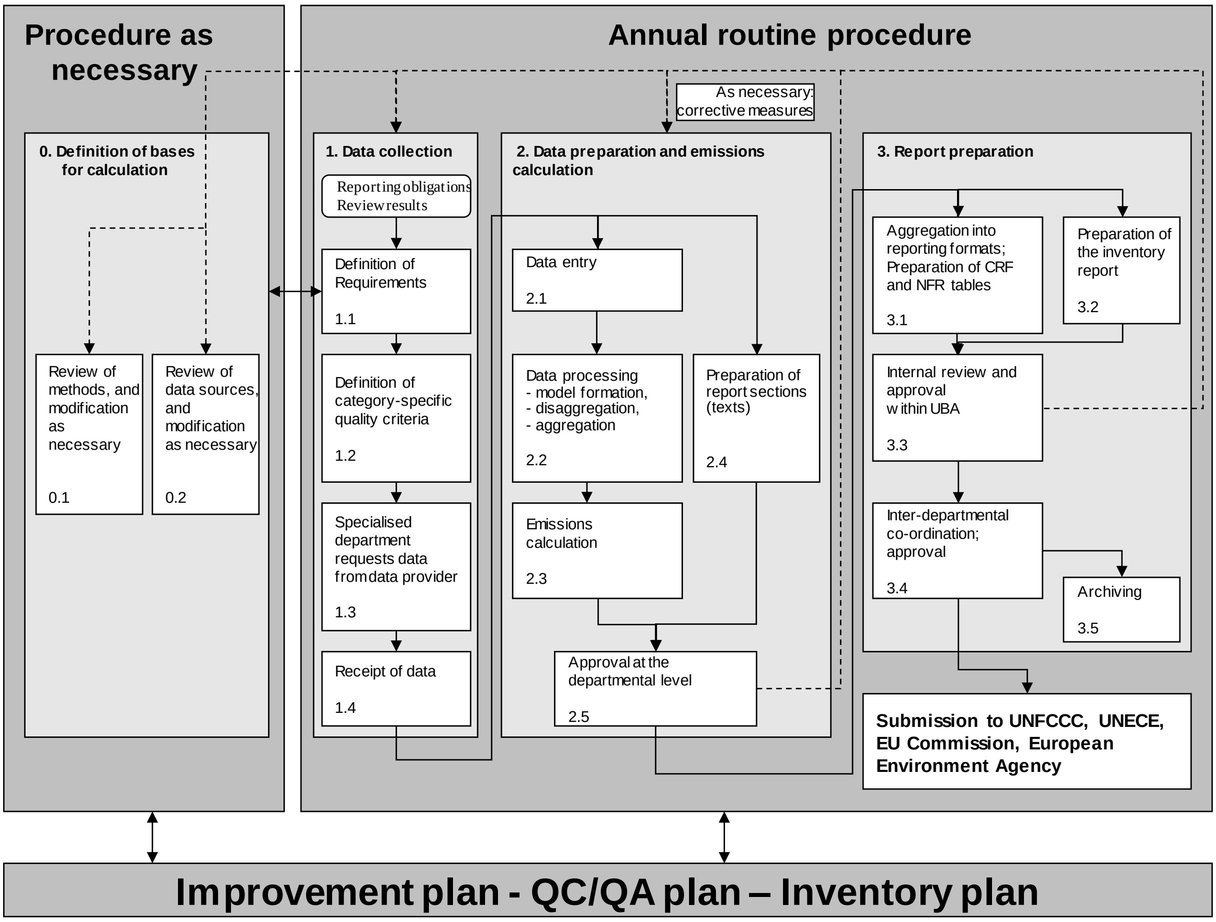
1.2.3 Overview of inventory preparation and management, including overview of supplementary information as required pursuant to Article 7 (1) of the Kyoto Protocol

The emissions-reporting process is a regular, annual process. Since it is a decentralised process, carried out by a range of different persons, it can differ for different parts of the inventory. Prior to the introduction of the QSE (in 2005), this process was intensively studied and analysed. As a result of that work, within the overall emissions-reporting process, the QSE differentiates the following main processes, which are described in detail in Chapter 1.3.2:

- Definition of the bases for calculation,
- Data collection,
- Data processing and emissions calculation, and
- Report preparation.

These main processes are broken down into sub-processes (cf. Figure 5).

Figure 5: Overview of the emissions-reporting process



It has proven to be the case that the workflow sequence chosen for inventory planning and preparation can influence the quality of the inventories. In other words, the sequence in which procedures are carried out is not irrelevant with regard to inventory quality. That is one of the reasons why the inventory-preparation process is closely tied to quality assurance and control measures. Suitable QC/QA measures have thus been assigned to each sub-process, to ensure that quality assurance not only safeguards the quality of inventory data in its final form, but also safeguards such quality on the pathways leading to that final form. This, in turn, makes it possible to carry out periodical internal evaluations of the inventory-preparation process pursuant to paragraph 26 of the *Reporting Guidelines* (24/CP.19).

The process, including QC/QA measures, fulfills the requirements of paragraph 21 (b) of the *Reporting* Guidelines (24/CP.19) with regard to inventory preparation.

The workflow for inventory preparation is described in detail in Chapter 1.3.

1.3 Inventory preparation

As the overview in Chapter 1.2.3 shows, inventory preparation functions in accordance with a regular, annual scheme. The processes for preparation of greenhouse-gas inventories, KP-LULUCF inventories and National Inventory Reports, and for execution of quality control and quality assurance measures, are very closely linked.

At the same time, the upstream processes for inventory preparation (cf. Chapter 1.3.1.1), including definition of bases for calculation (cf. Chapter 1.3.2.1), and data collection, processing and storage (cf. Chapter 1.3.2), remain distinct from those for quality control and quality assurance (cf. Chapter 1.3.3).

1.3.1 Greenhouse-gas and KP-LULUCF inventories

The upstream processes of inventory preparation and definition of the bases for calculation are identical for greenhouse-gas inventories and for KP-LULUCF inventories.

1.3.1.1 Preliminary/upstream processes

Apart from the sub-processes for emissions reporting, as outlined in Figure 5, certain upstream (preliminary) processes are carried out – in each case, between a pair of emissions-reporting cycles.

The following sub-processes are considered preliminary/upstream processes:

- Continuous review and assurance of data streams from data suppliers to the Federal Environment Agency, via improvement of institutionalisation of the National System;
- Implementation of improvements in inventory planning and inventory preparation;
- Identification of key categories (using Approach 1 pursuant to Chapter 4.3.1, Vol. 1 of the IPCC GL 2006);
- Calculation and aggregation of uncertainties relative to emissions, using Monte Carlo simulation (pursuant to Approach 1 or Approach 2, in keeping with the *IPCC Good Practice Guidance*);
- Expanded identification of key categories, via Monte Carlo simulation (using Approach 2 pursuant to Chapter 4.3.2, Vol. 1 of the IPCC GL 2006).

1.3.1.1.1 Improvement of the National System

The National System builds on existing data streams, and it provides for suitable measures to assure long-term data provision where such assurance is lacking (cf. Chapter 1.2.1.2). Consequently, data streams continually have to be reviewed between pairs of reporting cycles.

Where voluntary commitments expire, discussions have to be carried out with the relevant data suppliers in order to secure the commitments' renewal or their conversion into cooperation agreements. Where continued data provision is not assured, relevant commitments or co-operation agreements have to be obtained. In cases of any doubt, relevant legal provisions relative to data provision have to be reviewed and implemented.

Existing agreements have to be adapted as necessary to new circumstances and reporting requirements (for example, to changes in reporting procedures). Such efforts help assure the consistent high quality of the National System and the inventory preparation process.

Changes and improvements in the National System, during the current reporting cycle, are described in Chapter 13.

1.3.1.1.2 Implementation of improvements in inventory planning and inventory preparation

The quality system helps to assure the high quality of the inventory, and it supports the continual improvement of the inventory and of inventory planning.

In each case, and as possible, the following are implemented in the next reporting cycle: a) improvement requirements that have emerged from past quality control and quality assurance; b) results of past reviews; and c) planned improvements listed in the NIR.

A detailed description of the quality control and quality assurance procedures is provided in Chapter 1.6. The improvements achieved for the present report are described in the relevant category chapters.

1.3.1.1.3 Determination of key categories (pursuant to Tier 1)

In order to be able to focus the many and detailed activities and capacities required for inventory preparation and improvement on the principal categories of the inventory, the IPCC has introduced the definition of a "key category". Key categories are source/sink categories that play an especially prominent role in the national inventory because their emissions/removals have a significant influence on the total emissions of direct greenhouse gases – because of their absolute quantities, because of their contribution to the emissions trend over time, because of their uncertainties, or because they have been assessed by an expert as an important category.

The Single National Entity identifies key categories once per year, prior to the emissions-reporting process. Whereas in the reporting framework results are reported for year x, they cannot be taken specifically into account until inventory preparation for the year x+1. A category's designation as a key category helps decide what calculation method (Tier approach) must be used for the category and, as a result, how detailed emissions modelling for the category must be. In addition, the key-category selection process is used to identify any categories to which priority must be given in inventory improvement.

The *2000 IPCC Good Practice Guidance* (Vol. 1, Chapter 4) specifies the methods – "Approaches" – to be applied in identifying key categories. These methods identify the relevant key categories with the help of analysis of the inventory for one year with regard to emissions levels for individual categories (Tier 1 level assessment), time-series analysis of inventory data (Tier 1 trend assessment) and detailed analysis of inventory data with error evaluation (Tier 2 level and trend assessment with consideration of uncertainties).

The key categories have been defined by applying the two Approach 1 procedures, Level (for the base year and for the last year reported) and Trend (for the last year reported, as compared to the base year), to German greenhouse-gas emissions. In keeping with IPCC provisions, analyses have taken account of both emissions from sources and removals of greenhouse gases in sinks.

1.3.1.1.4 Calculation and aggregation of uncertainties relative to emissions

Uncertainties are a basic component of emissions inventories; an emissions inventory's uncertainties are determined in order to quantitatively assess the inventory's accuracy. While uncertainties are determined in connection with data gathering, and thus are part of the "data collection" section of the emissions-reporting process, they can be aggregated only after an inventory – or the pertinent emissions-reporting cycle – has been completed.

In calculation and aggregation of uncertainties, uncertainties for activity data and emission factors, which are normally estimated by experts at the lowest category level of the CSE, are converted into uncertainties for emissions and then aggregated. Uncertainties are aggregated once per year, at the end of the report-preparation cycle for the current report year.

For uncertainties determination, the individual uncertainties have been estimated, wherever possible to date, by data-supplying experts of the relevant Federal Environment Agency specialised sections and by external institutions.

1.3.1.1.5 Expanded determination of key categories

Aggregated uncertainties serve as a basis for expanded identification of key categories (Tier 2 key-categories determination).

1.3.2 Data collection, processing and storage, including data for KP-LULUCF inventories

1.3.2.1 Definition of bases for calculation

Selection and review of, and (where necessary) changes in, the calculation methods used to determine emissions affect the entire emissions-reporting process. For this reason, the main process "determination of the bases for calculation" must begin with review of the suitability of the methods to be used. The *2006 IPCC Guidelines* specify, via use of decision trees, what methods are to be used for the various categories. In each case, such methods selection also depends on whether the group in question is a key category or not. Any use of different – country-specific – methods, instead of the prescribed methods, must be justified in the NIR. In each case, an outline of why the method in question is of equivalent or higher value is to be provided, along with clear documentation.

Another factor that is critical to the success of the overall process is **selection and review of, and (where necessary) changes in, data sources**, since the quality of results of all downstream processes (data preparation, calculation, reporting) cannot be better than that of the primary data used. Data sources may be oriented to the activity data, emission factors or emissions for/of a specific category. In many cases, the data sources used have been relied on for a number of years. It can become necessary to select new data sources – for example, as a result of required changes in methods, of the elimination of an existing data source, of a need for additional data or of findings from quality checks of previously used data sources.

The suitability of a given data source depends on various criteria. These include:

- Long-term availability,
- Institutionalisation of data provision,
- Good documentation,
- Execution of quality assurance and control measures, by the persons/organisations providing data,
- Identification of uncertainties,
- Representative nature of the data in question, and
- Completeness of the expected data.

In each case, it is vital that the reasons for choosing a particular data source be documented and, where the data source has significant deficits, that suitable measures for improving the data be planned.

Efforts are made to give requirements relative to quality control, quality assurance and documentation to providers of data; where research projects are commissioned, such efforts are particularly relevant, since they support the ability of the Federal Environment Agency, as the customer for such services, to exert considerable influence on contractors.

1.3.2.2 Data collection

Data collection and documentation take place under the responsibility of the relevant experts. One way of collecting data is to evaluate official statistics, association statistics, studies, periodicals and research projects. Research projects can include research projects carried out by the Agency itself; third-party research projects; data collection via use of personal information; and data collection via Federal Government / Länder data exchanges. In sum, work results obtained by other means are often reused for the purposes of emissions reporting.

Data collection comprises the following steps:

- Definition of requirements,
- Determination of the category-specific quality criteria for the data,

- Requesting of data from data providers (carried out by the relevant experts' group), and
- Receipt of data.

Requests for inventory input are sent, via the National Single Entity (national co-ordinating agency), to the responsible experts. In each instance of a request, the relevant specialised subject-area supervisor is notified about the request. A master file, specifying the structure for such input, is provided for NIR preparation. The requirements for later data input are provided by the relevant CSE (ZSE) specifications (direct entry or fill-in of the import format). Reporting requirements (including pertinent QC/QA measures), along with the results of all inventory reviews, the databases for the various specific categories and the current results of key-category identification, are all communicated to the responsible experts via informational events held by the *Federal Environment Agency's Working Group on Emissions Inventories*, via the Federal Environment Agency's intranet and share-point sites for emissions reporting and via an electronic inventory description (cf. Chapter 1.3.3.1.5). On this basis, responsible experts **define requirements** relative to data sources and to calculation methods.

Such requirements influence the upstream process of defining the bases for calculation (review and selection of methods and data sources) – a process which always takes place when requirements have not yet been fulfilled or have changed.

Before any third parties begin with data collection – after the requirements pertaining to data sources and methods have been defined – the **category-specific quality criteria for such third-party data should be defined**, in order to support the QC process on the data level. At present, this step is optional, since in most categories the available data offer little opportunity for selection and differentiation, because not enough data sources are available.

When a responsible expert **requests data** from a third party able to supply data, the expert is expected to accompany his or her request with a description of the amount of data expected from the prospective data supplier, of the relevant data-quality requirements and of the relevant data-documentation requirements. Upon **receipt of data**, the data are checked for completeness, compliance with quality criteria and currentness. Data validation is carried out by the relevant expert.

1.3.2.3 Data preparation and emissions calculation

The process of data preparation and emissions calculation comprises the following steps:

- Data entry,
- Data preparation (model formation, disaggregation, aggregation)
- Calculation of emissions,
- Preparation of report sections (texts), and
- Approval by the relevant experts.

Large shares of **data entry and processing** (processing of data, and emissions calculation) take place in the CSE. This considerably enhances transparency and consistency, and it opens up the possibility of automating general data-level quality-control measures in the CSE (such as checking of orders of magnitude and of completeness, etc.). In cases that lend themselves to such automation, the automation serves as a useful complement to the execution of certain QC measures. The plausibility of results of calculations with complex models should be checked via cross-checks, with simplified assumptions, carried out outside of the CSE.

After all checks have been carried out, and the relevant parties have been consulted where necessary, the **emissions are calculated** in the CSE by means of an automated procedure, based on the following principle:

activity data * emission factor = emission

Once upstream calculation pathways are set up within the CSE, the relevant calculations can be initiated automatically. Their results then enter into the emission calculation per se.

Once the time series for activity data, emission factors, uncertainties and emissions have been completed, the pertinent report sections are prepared. As a result, the term "data" is understood in a broad sense. In addition to number data, time series, etc., it also includes contextual information such as the sources for time series, and descriptions of calculation methods, and it also refers to **preparation of report sections** for the NIR and documentation of recalculations.

In each case, the relevant expert responsible for QC also has responsibility for **issuing expert-level approvals**, for written texts and for calculation results, prior to any further use of such texts and results by the Single National Entity. Such issuance normally takes place in connection with transmission to the Single National Entity, and it is carried out via approval of completed QC/QA checklists.

1.3.2.4 Report preparation

Report preparation includes the following steps:

- Aggregation of emissions data for the report formats: This includes export, from the CSE, of XML files for the CRF Reporter; preparation of data tables for the NFR; and aggregation of emissions data for preparation of the national trend tables,
- Compilation of submitted report texts to form a report draft (NIR), and editing of the complete NIR,
- Internal review of the draft (national trend tables and NIR) by the Federal Environment Agency, followed by approval as appropriate,
- Handover to the BMU, for interdepartmental co-ordination, leading to approval by the co-ordinating committee, followed by the final steps of
- Handover to the UNFCCC Secretariat, the EU Commission and the UNECE Secretariat, and
- Subsequent archiving.

Following complete preparation of data, report sections and QC/QA checklists by the responsible experts, and transmission of those materials to the Single National Entity, the materials are reviewed by category-specific, specialised contact persons at the Single National Entity, on the basis of a QC checklist. The results of this review are then provided to the relevant responsible experts, to enable these experts to revise their contributions (if necessary, following suitable consultation) accordingly.

Before emissions data can be transferred into the report formats for the Framework Convention on Climate Change (CRF = Common Reporting Format), the Kyoto Protocol and the UN ECE Geneva Convention on Long-range Transboundary Air Pollution (NFR = New Format on Reporting), emissions data from CSE time series (in the data-collection format) **must be aggregated** into the CRF/NFR category **report formats**. This is accomplished via hierarchical allocation within the CSE, a process that, in Annex 3, is described in detail for the various key categories. Where no changes with respect to the previous year have occurred, the aggregations are carried out automatically.

Following calculatory aggregation, activity data and emissions are read, via export in XML-file form, into the CRF reporter, which automatically prepares the IPCC CRF reporting tables. Nonetheless, quality control still has to be carried out to ensure that the emissions inventory and the CRF-Reporter tables agree with respect to relevant values and to the implied emission factors calculated by the CRF Reporter. Furthermore, suitable explanatory remarks have to be provided for any recalculations and notation keys.

Calculation of greenhouse gases in CO_2 equivalents is carried out in keeping with Art. 2 of Decision 24/CP.19 and of Art. 31 of the Revised UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add. 3), on the basis of the relevant global warming potentials (GWP), as published in the *Fourth Assessment Report*. The GWP, which are oriented to greenhouse gases' impacts within a 100-year time frame, are listed in the following table.

Table 3: Global Warming Potential (GWP) of greenhouse gases

Greenhouse gas	Chemical formula	IPCC AR4 GWP
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
Hydrofluorocarbons (HFC)		
HFC-23	CHF_3	14800
HFC-32	CH_2F_2	675
HFC-41	CH_3F	92
HFC-43-10mee	$CF_3CF_2CHFCHFCF_3$	1640
HFC-125	CHF_2CF_3	3500
HFC-134	CHF_2CHF_2	1100
HFC-134a	CH_2FCF_3	1430
HFC-143	CHF_2CH_2F	353
HFC-143a	CF_3CH_3	4470
HFC-152	CH_2FCH_2F	53
HFC-152a	CH_3CHF_2	124
HFC-161	CH_3CH_2F	12
HFC-227ea	CF_3CHFCF_3	3220
HFC-236cb	$CH_2FCF_2CF_3$	1340
HFC-236ea	CHF_2CHFCF_3	1370
HFC-236fa	$CF_3CH_2CF_3$	9810
HFC-245ca	$CHF_2CF_2CH_2F$	693
HFC-245fa	$CHF_2CH_2CF_3$	1030
HFC-365mfc	$CH_3CF_2CH_2CF_3$	794
Perfluorocarbons (PFC)		
Perfluoromethane	CF_4	7390
Perfluoroethane	C_2F_6	12200
Perfluoropropane	C_3F_8	8830
Perfluorocyclopropane	c-C_3F_6	17340
Perfluorobutane	C_4F_{10}	8860
Perfluorocyclobutane	c-C_4F_8	10300
Perfluoropentane	C_5F_{12}	9160
Perfluorohexane	C_6F_{14}	9300
Perfluorodecalin	$C_{10}F_{18}$	7500
Sulphur hexafluoride		
Sulphur hexafluoride	SF_6	22800
Nitrogen trifluoride		
Nitrogen trifluoride	NF_3	17200
Fluorinated ethers		
HFE-125	CHF_2OCF_3	*14900*
HFE-134	CHF_2OCHF_2	*6320*
HFE-143a	CH_3OCF_3	*756*
HFE-227ea	$CF_3CHFOCF_3$	*1540*
HCFE-235da2	$CHF_2OCHClCF_3$	*350*
HFE-236ca12	$CHF_2OCF_2OCHF_2$	*2800*
HFE-236ea2	$CHF_2OCHFCF_3$	*989*

Greenhouse gas	Chemical formula	IPCC AR4 GWP
HFE-236fa	*$CF_3CH_2OCF_3$*	*487*
HFE-245cb2	*$CH_3OCF_2CF_3$*	*708*
HFE-245fa1	*$CHF_2CH_2OCF_3$*	*286*
HFE-245fa2	*$CHF_2OCH_2CF_3$*	*659*
HFE-254cb2	*$CH_3OCF_2CHF_2$*	*359*
HFE-263fb2	*$CF_3CH_2OCH_3$*	*11*
HFE-329mcc2	*$CHF_2CF_2OCF_2CF_3$*	*919*
HFE-338mcf2	*$CF_3CH_2OCF_2CF_3$*	*552*
HFE-338mmz1	*$(CF_3)_2CHOCHF_2$*	*380*
HFE-338pcc13	*$CHF_2OCF_2CF_2OCHF_2$*	*1500*
HFE-347mcc3	*$CH_3OCF_2CF_2CF_3$*	*575*
HFE-347mcf2	*$CHF_2CH_2OCF_2CF_3$*	*374*
HFE-347mmy1	*$(CF_3)_2CFOCH_3$*	*343*
HFE-347pcf2	*$CHF_2CF_2OCH_2CF_3$*	*580*
HFE-356mec3	*$CH_3OCF_2CHFCF_3$*	*101*
HFE-356mmz1	*$(CF_3)_2CHOCH_3$*	*27*
HFE-356pcc3	*$CH_3OCF_2CF_2CHF_2$*	*110*
HFE-356pcf2	*$CHF_2CH_2OCF_2CHF_2$*	*265*
HFE-356pcf3	*$CHF_2OCH_2CF_2CHF_2$*	*502*
HFE-365mcf3	*$CF_3CF_2CH_2OCH_3$*	*11*
HFE-374pc2	*$CHF_2CF_2OCH_2CH_3$*	*557*
HFE-449sl	*$C_4F_9OCH_3$*	*297*
HFE-569sf2	*$C_4F_9OC_2H_5$*	*59*
HFE-43-10pccc124	*$CHF_2OCF_2OC_2F_4OCHF_2$*	*1870*
	$CF_3CF_2CH_2OH$	*42*
	$(CF_3)_2CHOH$	*195*
	$-(CF_2)_4CH(OH)-$	*73*
Perfluoropolyethers		
PFPMIE	*$CF_3OCF(CF_3)CF_2OCF_2OCF_3$*	*10300*

Source: FCCC/CP/2013/10/Add. 3, p.24

At the same time, the report co-ordinator **compiles the checked report texts to produce the draft** of the NIR.

Review and approval, **within the Federal Environment Agency**, of the completed report tables and the NIR, and of the inventory plan to be included in future, are certified via co-signing in the framework of the Federal Environment Agency's **internal co-ordination process**. Then, the materials are **forwarded** to the BMU, for the second approval phase within the framework of **interdepartmental co-ordination**. In a concluding step, the co-ordinating committee approves the report tables and the NIR for submission to the UNFCCC Secretariat. The ministry arranges for translation of the NIR and for its **submission to the UNFCCC Secretariat**.

The data tables and the pertinent NIR are archived in secure form in the inventory description (cf. also Chapter 1.3.3.1.5). The content of the CSE database used for calculation purposes is also archived.

1.3.3 Procedures for quality assurance and quality control (QA/QC), and detailed review of greenhouse-gas and KP-LULUCF inventories

1.3.3.1 The Quality System for Emissions Inventories

The QSE takes account of provisions of the *2006 IPCC Guidelines (Vol. 1, Chapter 6)*, of national circumstances in Germany and of the internal structures and procedures of the Federal Environment Agency (UBA), the reporting institution. The QSE's procedures are flexible enough to be able to routinely incorporate future changes in requirements. The QSE's scope of application comprises the entire emissions-reporting process.

The QSE covers all participants of the NaSE. Within the Federal Environment Agency, the QSE has been made binding via the agency's in-house directive (UBA-Hausanordnung) 11/2005. Details regarding assurance of the QSE's binding nature for other NaSE participants are provided in Annex 22.1.1.

1.3.3.1.1 Directive 11/2005 of the Federal Environment Agency

In 2005, via its *in-house directive (Hausanordnung) 11/2005*, the Federal Environment Agency established a *Quality System for Emissions Inventories* (QSE), within the Agency. The QSE provides the necessary framework for compliance with good inventory practice and for execution of routine quality assurance. The QSE conforms to the provisions of the *2006 IPCC Guidelines (Vol. 1, Chapter 6)*, and it has been adapted to the national circumstances prevailing in Germany and to the internal structures and procedures of the Federal Environment Agency (UBA), the reporting institution. The in-house directive (Hausanordnung 11/2005) issues binding provisions on relevant competencies within the Agency, lists deadlines for the various inventory-preparation steps and describes the necessary relevant review actions for purposes of quality control / quality assurance.

The directive has fulfilled requirements, pursuant to Paragraph 20 of the *Reporting Guidelines* (24/CP.19), for specification of relevant procedures and, pursuant to Paragraph 23 (a), for definition of specific responsibilities at the Agency level.

1.3.3.1.2 Minimum requirements pertaining to a system for quality control and assurance

The requirements pertaining to the system for quality control and quality assurance (QC/QA system) and to measures for quality control and quality assurance are defined primarily by Chapter 6 of the *2006 IPCC Guidelines (Vol. 1)*.

In 2007, the Federal Environment Agency derived General minimum requirements pertaining to a quality control and quality assurance system for GHG-emissions reporting" ("Allgemeine Mindestanforderungen an die Qualitätskontrolle und Qualitätssicherung bei der Treibhausgasemissionsberichterstattung") from the previously applicable Good Practice Guidance (Chapter 8) (cf. Chapter 22.1.2.1). External National System participants then adopted the minimum requirements after representatives of the participating federal ministries approved them in the framework of the National Co-ordinating Committee for the National System of Emissions Inventories (cf. Annex Chapter 22.1.1).

Further information regarding the Federal Environment Agency's necessary organisational measures for implementing these requirements is provided in the following chapters and in a complementary section in the Annex, 22.1.2.1.11.

1.3.3.1.3 Start-up organisation for establishing the Quality System for Emissions Inventories

Within the QSE framework, a concept for a start-up organisation was developed that defines binding responsibilities, for the Federal Environment Agency, for implementation of the necessary QC and QA measures. The defined roles and responsibilities have the purpose of facilitating effective information exchange and directive-conformal execution of QC and QA (cf. Table 4).

Table 4: QSE – Roles and responsibilities

Role	Task	Responsible
Responsible expert at the operational level (FV)	Preparation of parts of the National Inventory Report (NIR) Data collection and data entry in the CSE, and calculation in keeping with the selected//prescribed methods Execution of systematic QC measures in the NIR, CSE and inventory description Execution of verification measures Archiving of all category-specific inventory information (inventory description and decentralised documentation) If necessary (for category-specific QC): Definition of category-specific quality targets and of the criteria for their achievement, in consultation with the QC section representative, the specialised contact person and the QC/QA co-ordinator (QSEK). Review, processing and answering of review results Active participation in review processes. This includes giving presentations, providing explanations and being available for questions (before and during the process, and in any follow-up). Initiating and developing (preparing specifications) R&D projects, and providing specialised support	All staff appointed by the head (FGL), on a category-specific basis
QC/QA section representative (QKV)	Execution of systematic measures for assuring the quality of the data and report sections delivered to the Single National Entity Checking and approving data and report sections Ensuring that the necessary inventory work, quality controls, documentation and archiving are carried out Defining responsibilities relative to emissions reporting in specialised fields, and provision of the necessary time resources Providing support for review processes, and participating in them	All responsible heads (Federal Government and the Länder)

Specialised contact person (category-specific) in the SNE (FAP)	Category-specific support for responsible experts (FV) and QC/QA section representatives (QKV); support/guidance of FV/QKV in:
	• Implementation of international requirements
	• Supporting work involving data and report texts
	• Quality control / quality assurance
	  ○ Preparation of lacking parts of the National Inventory Report (NIR)
	  ○ Collection of any data lacking in the CSE, entry of such data into the CSE and carrying out of calculations in keeping with the selected/prescribed methods
	  ○ Ensuring that the necessary inventory work, quality controls, documentation and archiving are carried out
	  ○ Execution of systematic QC/QA measures in the NIR, CSE and inventory description
	  ○ Archiving of any lacking category-specific inventory information (inventory description and decentralised documentation)
	Initiating and supporting R&D projects
	Execution of all work using the CRF reporter, and execution of quality control
	Assumption of tasks of unavailable responsible experts (FV) and of positions that have not been filled
	Review, processing and answering (as necessary) of review results
	Support, participation in and execution of (as necessary) FV tasks in connection with review processes
	Execution of overarching work (affecting more than one category)
	If necessary (for category-specific QC): Definition of category-specific quality objectives and of the criteria for their achievement, in consultation with the QC section representative, the specialised contact person (FAP) and the QC/QA co-ordinator (QSEK).
		Staff of the Single National Entity (SNE) that are appointed on a category-specific basis

Role	Task	Responsible
Report co-ordinator (NIRK)	Coordination of text contributions Compilation of the NIR, from the various contributions Overarching QC and QA for the NIR, and some cross-checking with the CRF	An appointed staff member of the Single National Entity (SNE)
CSE co-ordinator (ZSEK)	Overarching QC and QA in connection data entry and calculations for the inventory (data) Assuring the integrity of databases and report tables (Common Reporting Format (CRF)) Emissions reporting and data aggregation into report formats Supporting specialised departments in connection with questions relating to the Central System of Emissions (CSE) and to the report tables Determination of uncertainties (with Approach 2), using Monte Carlo simulation	An appointed staff member of the Single National Entity (SNE)
QSE coordinator (QSEK)	Overarching QC and QA throughout the entire reporting process Maintenance and further development of the QSE Management and updating of the QC and QA plans, QC checklists and QSE manual Management for the administration and updating of the inventory plan and of the improvement plan If necessary (for category-specific QC): Definition of category-specific quality objectives and of the criteria for their achievement, in consultation with the responsible expert at the operational level (FV), the QC section representative and the specialised contact person (FAP)	An appointed staff member of the Single National Entity (SNE)
NaSE co-ordinator (NaSEK)	Ensuring of on-time, requirements-conformal reporting Initiation of overarching measures from the inventory plan Selection of institutions and collection of relevant informational materials and legal agreements Organisation of expert-peer reviews – for example, in the framework of NaSE workshops Ensuring that all relevant inventory information in addition to that archived in the inventory description is centrally archived Preparation of execution and post-processing of inventory reviews	An appointed staff member of the Single National Entity (SNE)

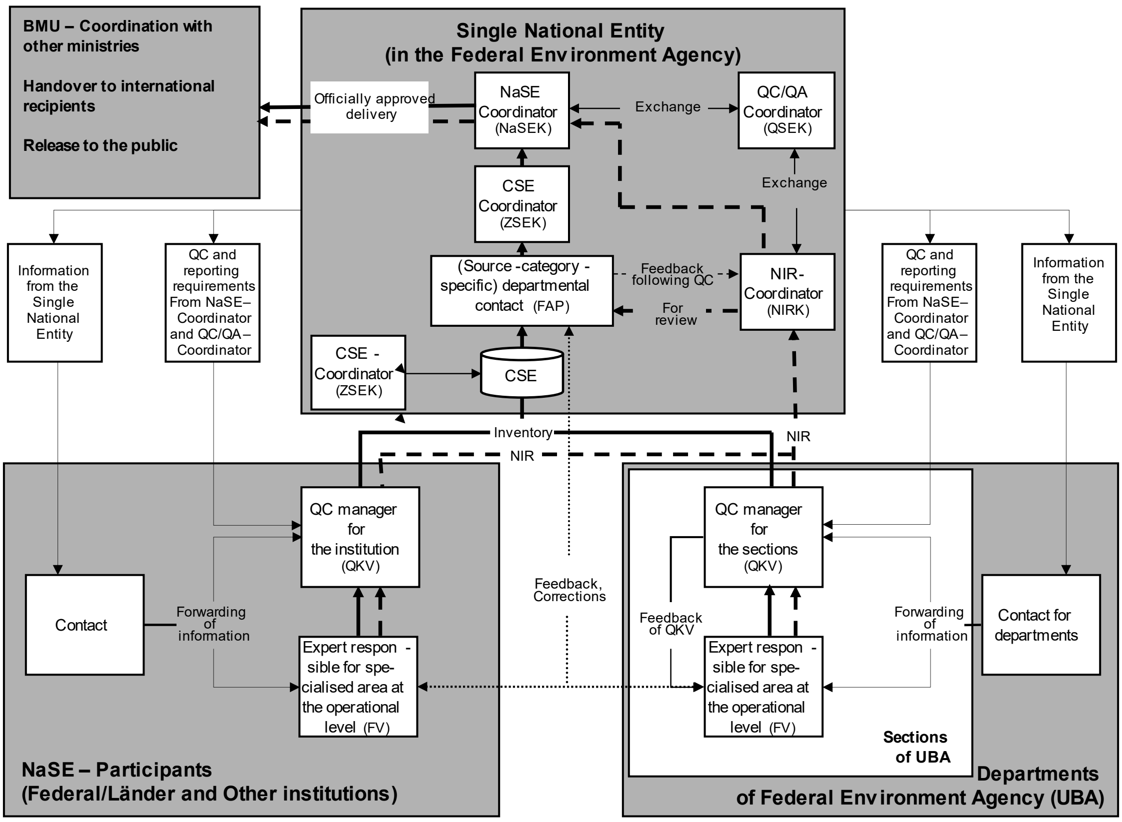
In very rare exceptional cases, the Federal Environment Agency (UBA) is unable to fill the position of the responsible expert at the operational level (FV) for a particular category. In such cases, the Single National Entity assumes complete responsibility for the QSE role system, by itself filling the roles of the responsible expert (FV), specialised contact person (FAP) and QC/QA section representative (QKV) – with a different person for each role.

This role concept is simplified, for reasons of capacity limitations, only in cases in which categories are of exceptionally low importance in terms of their contribution to total emissions. In such cases, the Single National Entity fills the roles of the FV and the QKV. In compensation, external quality assurance is then carried out, at regular intervals, for the relevant source categories. Currently, the situation and procedure described apply only for CRF 1.B.1.

1.3.3.1.4 The process organisation of the Quality System for Emissions Inventories

Procedures for QC/QA measures in the QSE are oriented to the emissions-reporting process described in Chapter 1.2.3. At the same time, quality management is directly linked with the various steps in the inventory process. Suitable QC measures, assigned to the various process players, have been allocated to each step of the inventory-preparation process (cf. Figure 6).

Figure 6: QSE – Roles, responsibilities and workflow

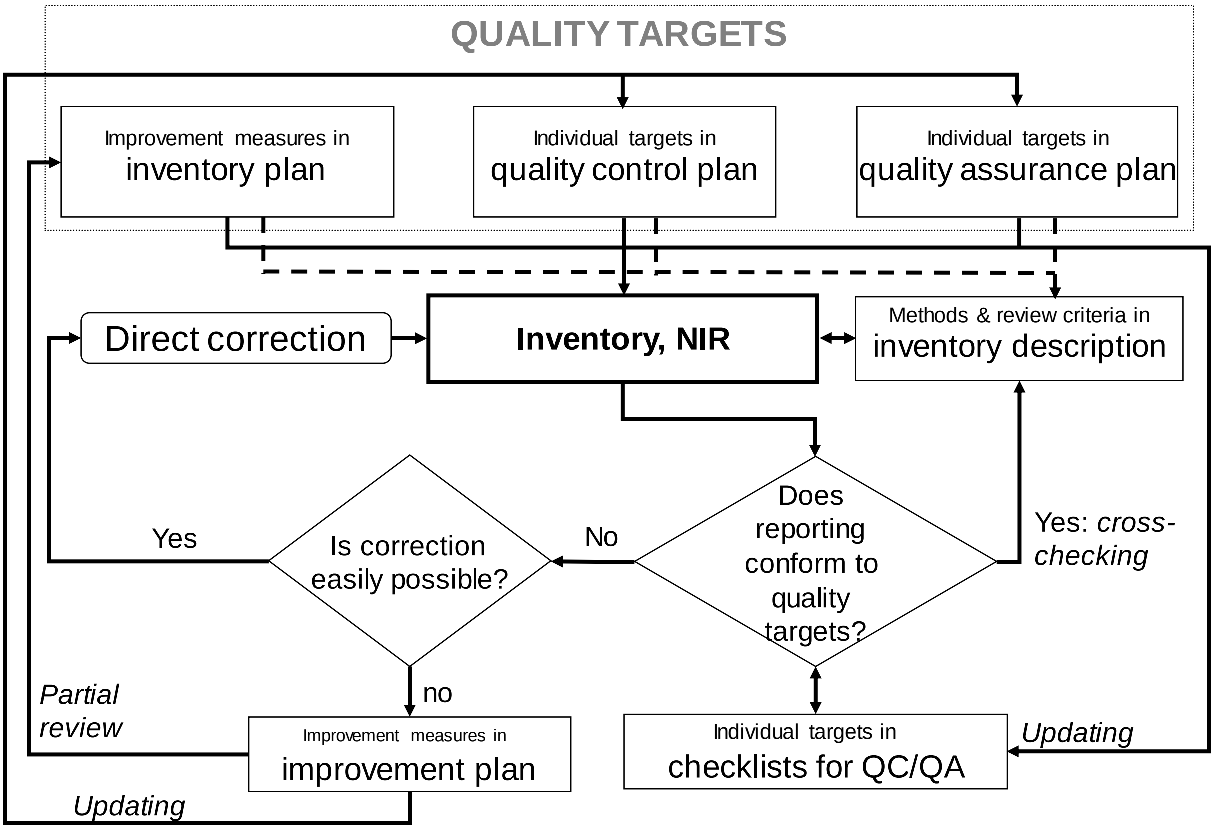


The required quality reviews pursuant to Paragraph 25 (f) of the *Reporting* Guidelines (24/CP.19) are provided, in the form of quality checklists and along with data requirements, to the FV, QKV, FAP and NIRK (cf. Table 4). They are completed in the course of the relevant supporting work.

1.3.3.1.5 Execution of QC/QA measures, and control and documentation of such measures within the Quality System for Emissions Inventories

The requirements pertaining to the execution, description and documentation of QC/QA measures, as formulated in connection with the minimum requirements for a QC/QA system (cf. Chapter 22.1.2.1), are largely fulfilled in conjunction with production of the pertinent inventory contributions. For the QSE, a concept was developed that represents all such measures and related actions in an integrated form tailoured to the specific parties and tasks concerned. The individual components are shown in Figure 7 (in simplified form with respect to the inventory plan and the quality control plan; cf. also in this regard Chapter 1.6.1.1).

Figure 7: Control and documentation of QC/QA measures



A general description of the **quality targets** is provided in the QSE handbook; the description is derived from the *2006 IPCC Guidelines (Vol. 1, Chapter 6)*. In addition, individual operational objectives, relative to quality control and quality assurance, have to be derived for the various categories from comparison of the requirements from the *2006 IPCC Guidelines*, the results of independent inventory review, the improvements required in the NIR framework and assessment of inventory realities.

Pursuant to the *2006 IPCC Guidelines (Vol. 1, Chapter 6)* and Paragraph 19 of the *Reporting* Guidelines (24/CP.19), the necessary QC/QA measures for emissions reporting should be summarised in a QC/QA plan. Such a QC/QA plan is to serve the primary purpose of organising, planning and monitoring such QC/QA measures. To permit transparent, effective control of execution and monitoring of measures for achieving these objectives, the measures are set forth in a **quality control plan (QC plan)** and a **quality assurance plan (QA plan)** with respect to specific roles and specific categories. Quality targets may be focused on the inventory, the reporting process or the QSE itself. In the framework of the quality assurance plan, scheduling of quality-assurance measures is also carried out. Such measures are executed partly by internal staff and mostly by independent, third parties (external). Both plans may be understood as sets of specifications.

As to their structure, the QC and QS plans are combined with the **checklists for quality control and quality assurance**, which are used to review and document successful execution of QC/QA. In this context, quality checks are actually defined not as checks but as quality objectives (data quality objectives pursuant to 2006 IPCC GL, Vol. 1, Chapter 6.5); in each case, either compliance with the objectives must be confirmed or non-compliance must be justified. The QC/QA checklists have to be completed by the participants in the NaSE[15] in parallel with the inventory preparation process. They facilitate immediate improvements. Where improvements cannot be carried out immediately, they are still useful in providing important information about the quality of the inventory's underlying data, methods and texts. The first time the Federal Environment Agency carried out systematic QC/QA, in the form of checklists, and in co-operation with the NaSE participants, was for the 2006 report. Since then, the checklists for general quality control are filled out every report year, and for all reported categories – i.e. both for key categories and for categories that are not key categories. Since the 2007 report, the checklists have been used in electronic form. Also as of the 2007 report, the general QC checks (formerly, Tier 1 checks) have been expanded to include a number of category-specific QC checks (formerly, Tier 2 checks), for key categories. For the 2008, 2009 and 2010 reports, the checklists for the experts involved in the various specialised areas, and for specialised contact persons, were comprehensively revised. Such revision has been aimed at further enhancing the clarity, practical usefulness and logical structure of the checklists. To ensure the success of the pertinent improvements, a number of persons from the affected group of persons were selected for inclusion in the revision process. No content-oriented requirements have been modifed as a result. Since then, the checklists have been reviewed annually for any need for updating, and revised or expanded as necessary. Like the checklists, the QC and QA plan is continually refined. As of the 2013 report, the checklists of the QC/QA section representatives (QKV), which were formerly category-specific, have been consolidated into single overarching checklists for each QKV (i.e. one checklist per QKV). This has been done in order to make the QC/QA process clearer for management personnel and to enhance resource efficiency.

As of the 2015 report, is has been assured that the general checklists meet the revised requirements applying under the 2006 *IPCC Guidelines (Vol.1, Kapitel 6)*. Lacking requirements have been added as necessary.

The two plans and the QC/QA checklists are instruments for reviewing fulfillment of the applicable international requirements, and they make it possible to control inventory quality via initiation of quality assurance measures pursuant to Paragraph 13 of the *Guidelines for National Systems*.

In the **improvement plan**, all identified possibilities for improvement (as identified in checklists, NIR information on planned improvements, audit results (if applicable) and other required improvements), and any issues brought up by independent inventory reviews, are collected and assigned possible corrective measures. The Single National Entity categorises the corrective measures, prioritises them and then, as a rule and via consultations with the relevant responsible experts, integrates them completely within the **inventory plan**. There, they are linked with deadlines and responsibilities. As an annex to the NIR, the inventory plan undergoes a co-ordination and release process. It is thus a binding set of specifications for improvements to be carried out in the coming reporting year.

The Single National Entity also maintains an **inventory description**, a central document record for the various categories. The description covers all key aspects of inventory preparation. It includes descriptions of all work that pertains to specific categories and that is relevant to preparation of category-specific inventories. The inventory description consists of a server-based folder (directory) system that is available both on mobile devices and on the desktops of the persons working in the framework of emissions reporting. The obligation to prepare defined documentation was introduced in the Federal Environment Agency via an in-house directive (cf.

[15] These include responsible experts (FV), specialised contact persons (Fachliche Ansprechpartner – FAP), QC/QA section representatives (QKV – quality control managers) and the coordinator for the national inventory report (Koordinator für den Nationalen Inventar Report – NIRK).

Chapter 1.3.3.1.1). It provides the key basis for archiving inventory information pursuant to the provisions of Paragraph 27 (a) of the *Reporting* Guidelines (24/CP.19).

- For a range of different reasons, the documentation concept calls for an archive that is predominantly, but not exclusively, centralised. The key reasons for this decision included the fact that the body of data that provides the basis for calculating the German inventory is extensive, and non-centralised.
- In addition, external parties hold some of the responsibility for the data,
- and confidentiality criteria preclude, for legal reasons, provision of certain data items, for archiving purposes, to a central agency.

The inventory description contains information as to the locations of documents that are not centrally stored.

1.3.3.1.6 The QSE handbook

The international requirements for quality assurance and quality control measures in emissions reporting have been set forth, for the National System of Emissions Inventories (NaSE) in Germany, in the "Handbook for quality control and quality assurance in preparation of emissions inventories and reporting under the UN Framework Convention on Climate and EU Decision 525/2013/EC" ("Handbuch zur Qualitätskontrolle und Qualitätssicherung bei der Erstellung von Emissionsinventaren und der Berichterstattung unter der Klimarahmenkonvention der Vereinten Nationen sowie der EU Entscheidung 280/2004/EG". That document, which is binding for the Federal Environment Agency, describes the Quality System for Emissions Inventories (QSE).

The QSE handbook has entered into force via an in-house directive of the Federal Environment Agency (cf. Chapter 1.3.3.1.1). It has been published, along with pertinent, co-applicable documents, in the Federal Environment Agency's intranet.

1.3.3.1.7 Support for the UNFCCC review

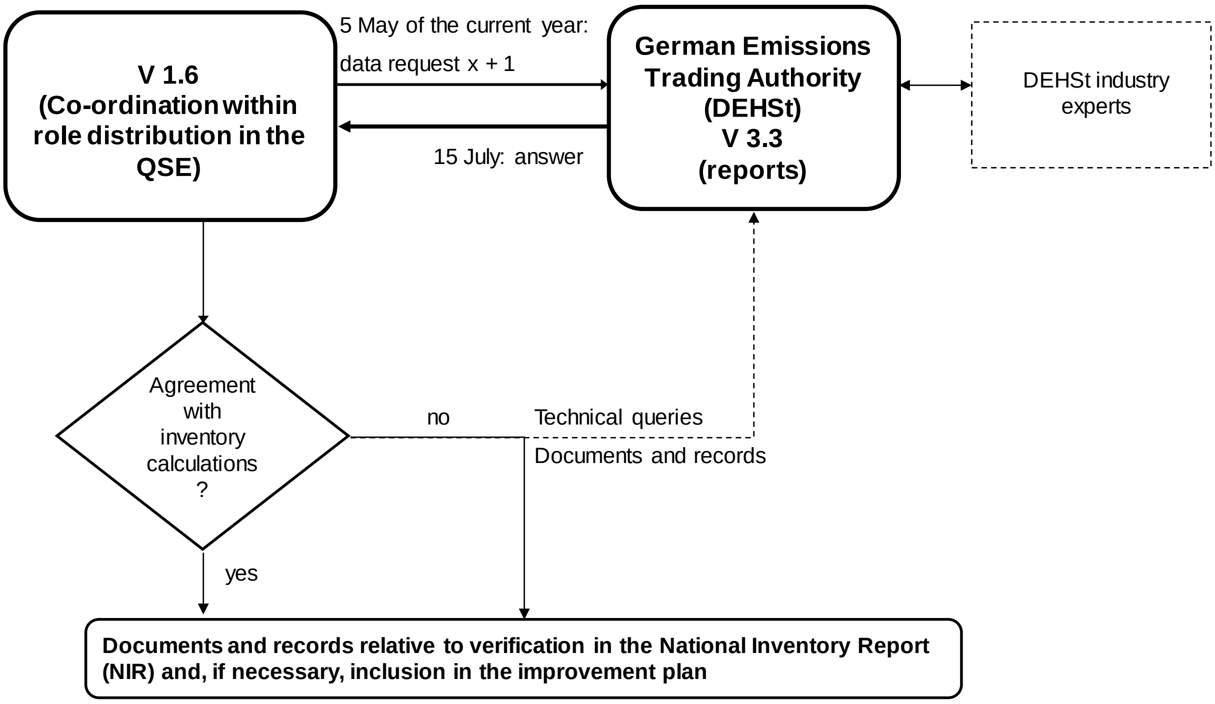
In addition to the Federal Environment Agency's own quality control and assurance measures, the UNFCCC review provides important impetus for inventory improvement. Consequently, it is in the Single National Entity’s own interest to fulfill the requirements for provision of archived inventory information for the review process (pursuant to Paragraph 27 (b) of the *Reporting* Guidelines (24/CP.19)) and to answer questions raised by expert review teams (pursuant to Paragraph 27 (c) der *Reporting* Guidelines (24/CP.19)). This relationship has been given priority in the design of the QSE.

1.3.3.1.8 Use of EU ETS monitoring data for improvement of GHG-emissions inventories

Monitoring data from European emissions trading will be used to improve the quality of annual national emissions inventories with respect to categories that include installations subject to reporting obligations under the CO_2 Emissions Trading Scheme (ETS).

The comparisons have confirmed, in principle, the usefulness of such comparisons for verifying individual categories and identifying data gaps. A formalised procedure, with defined deadlines and workflow, has been agreed for their regular use and for the relevant annual required data exchanges.

Figure 8: Procedural flow for annual inventory verification using ETS monitoring data



Regarding the details of data use in QC/QA, cf. also Chapter 1.6.2.1 Verification in selected categories.

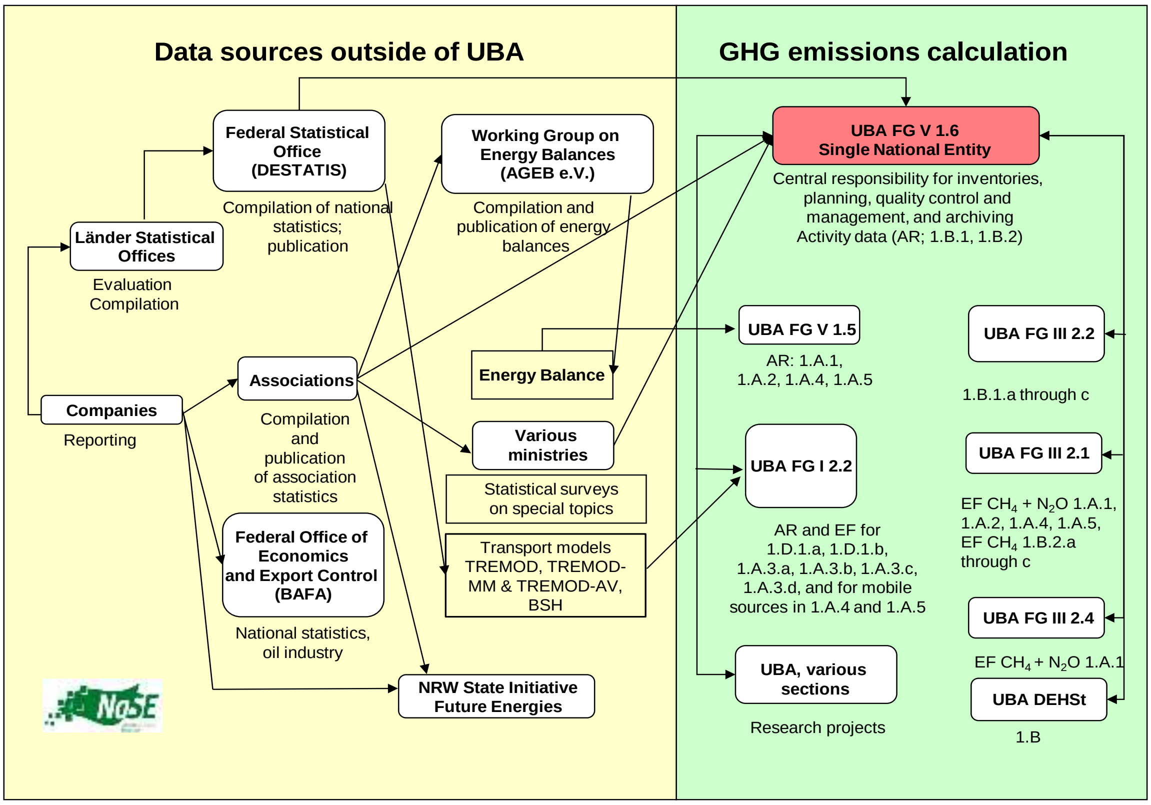
1.4 Short, general description of the methods and data sources used

1.4.1 Greenhouse-gas inventory

1.4.1.1 Data sources

1.4.1.1.1 Energy

Figure 9: Responsibilities and data flows for calculation of greenhouse-gas emissions in the energy sector



The central data sources for determination of activity data for category 1.A are the *"Energy Balances of the Federal Republic of Germany"* ("Energiebilanzen der Bundesrepublik Deutschland"; hereinafter referred to as: Energy Balances), which are published by the Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen – AGEB) and are based primarily official statistics of the Federal Statistical Office. The AGEB receives data on renewable energies, for the Energy Balance, from AGEE-Stat. An Energy Balance provides an overview of the links within Germany's energy sector, and it supports breakdowns in accordance with fuels and categories.

To date, the Federal Ministry for Economic Affairs and Energy (BMWi) has commissioned the AGEB for preparation of Energy Balances throughout the period 2007 – 2020. Under the pertinent three orders issued to date, the AGEB has been contractually required to meet the National System's minimum requirements for quality assurance. Since 2012, the AGEB has prepared a joint quality report for the Energy Balance (cf. Chapter 18.4.1), and an "energy data action plan for inventory improvement" (Aktionsplan Energiedaten Inventarverbesserung; cf. Chapter 18.4.1.1.1) that sets forth strategies for addressing issues raised in the inventory review process. This action plan fulfills the action-plan requirement set forth in Paragraph 39 of the 2011 review report (FCCC/ARR/2011/DEU).

The *Federal Statistical Office (Statistisches Bundesamt) is the most important data source for determination of activity data and for the preparation of Energy Balances. The resources of that office that are used in inventory preparation include* the *Fachserien 4 (technical series 4) Reihe (sub-series) 4.1.1, Reihe 6.4,* and, for waste data, Fachserie 19. These data are published relatively promptly after collection (about one year), and they are broken down finely in accordance with various areas of the manufacturing sector. To support further data differentiation, and clarification of details, the Federal Statistical Office provides special evaluations.

For the iron and steel sector, as of the 2012 report, data of the Wirtschaftsvereinigung Stahl German steel industry association are being used. Inter alia, these data replace the so-called "BGS form" (Fuel, gas and electricity industries of blast furnaces, steelworks and rolling mills; and forging plants, press works and hammer mills, including the various other plants (without their own coking plants) locally connected to such operations), a section of the "Fachserie 4, Reihe 8.1", publication of which was discontinued as of 31 December 2009.

The series *Statistik der Kohlenwirtschaft* ("Coal industry statistics"), especially its annual publication "*Der Kohlenbergbau in der Energiewirtschaft der Bundesrepublik Deutschland*" ("Coal mining in the energy sector of the Federal Republic of Germany"), is used as an additional data source. In addition, the special evaluations provided by the Bundesverband Braunkohle (DEBRIV; federal German association of lignite-producing companies and their affiliated organisations) are used for differentiation of the different types of raw lignite coal that are burned. Furthermore, DEBRIV provides the necessary data for calculation of fuel inputs for lignite drying.

Another data source consists of the *"Petroleum Data" of the Association of the German Petroleum Industry (MWV)*, which include data on petroleum production and consumption in Germany, broken down by various production, transformation and utilisation sectors. These statistical data, which are a key basis for the National Energy Balance, are published within just a few months after the relevant survey and are thus a relatively current source.

The quantities of secondary fuels used for energy generation (listed under CRF 1.A.2) are taken from the annual report of the German Pulp and Paper Association (Verband der Papierindustrie) and from reports of the German Cement Works Association (Verband der Zementindustrie – VDZ).

Another important data source is the Emissions Trading System (ETS). It keeps highly detailed, plant-specific data that are also used for the inventory. Emissions trading data is used especially in areas that are not covered by national statistics:

- fuel-related CO_2 emission factors for stationary combustion systems,
- fuel inputs for natural gas compressors,
- emissions from coke burn-off in catalyst regeneration, and in calcining, in refineries, and
- fugitive emissions in coking plants.

For collection of transport emissions data (1.A.3), *Official Mineral-oil Data* (amtliche Mineralöldaten) of the *Federal Office of Economics and Export Control (BAFA)* and *Petroleum Data* (Mineralöl-Zahlen) of the *Mineralölwirtschaftsverband e.V. Association of the German Petroleum Industry (MWV)* e.V. are used, in addition to Energy Balance data.

For air transports, in addition to the aforementioned sources, the following sources for consumption data are used: The fuel consumption and emissions are broken down in accordance with national and international flights, on the basis of data on real aircraft movements. Those data are collected and made available by the Federal Statistical Office, and then they are processed in the TREMOD AV model, a separate module of the TREMOD ("Transport Emission

Estimation Model") database. Fuel consumption and emissions are also broken down in accordance with the flight phases LTO cycle (Landing and Take Off; movements below an elevation of 3,000 feet) and cruise (movements above 3,000 feet); this is also done on the basis of the aircraft-movement data collected by the Federal Statistical Office.

Country-specific consumption and emissions data provided by Eurocontrol are used solely for verification purposes.

Road-transport emissions are calculated primarily with the TREMOD model. For calculations carried out in TREMOD, extensive basic data from generally accessible statistics and special surveys are used, co-ordinated, and supplemented. A precise description of the data sources for emission factors is provided by the "Handbook of road-traffic emission factors" ("Handbuch Emissionsfaktoren des Straßenverkehrs") (HBEFA, Version 4.1).

TREMOD is also used for modelling emissions from fuel combustion in railway vehicles and inland waterway vessels. The emissions caused by historic steam railways, via combustion of coal and coke, are calculated outside of TREMOD, on the basis of operator information.

The specific consumption and emissions of ship transports departing from German seaports are calculated within a model developed by the Federal Maritime and Hydrographic Agency (BSH). For this area, the breakdown of fuel consumption and emissions in accordance with domestic and international transports is based on data derived, inter alia, from the ships' AIS messages.

Data on emissions of other mobile sources (in 1.A.4 and 1.A.5.b) are also collected from figures of the Working Group on Energy Balances (AGEB), of the Federal Office of Economics and Export Control (BAFA) and of the Association of the German Petroleum Industry (MWV). Military transports (1.A.5.b) have a special status in this regard; the consumption data for such transports, which as of 1995 are no longer listed in the Energy Balances, are obtained directly from BAFA statistics.

Due to a lack of reliable figures on consumption of biofuels by mobile sources in the construction, agricultural and forestry sectors, and by the residential and military sectors, the relevant annual quantities are calculated on the basis of the official admixture quotas.

Data for categories of category 1.B.1 are taken from publications of Statistik der Kohlenwirtschaft e.V. (coal-industry statistics), the Federal Ministry for Economic Affairs and Energy (BMWi), the DEBRIV Federal German association of lignite-producing companies and their affiliated organisations, Deutsche Montan Technologie GmbH (DMT), the German Society for Petroleum and Coal Science and Technology (DGMK) and Interessenverband Grubengas e.V. (IVG; association for the mine-gas sector).

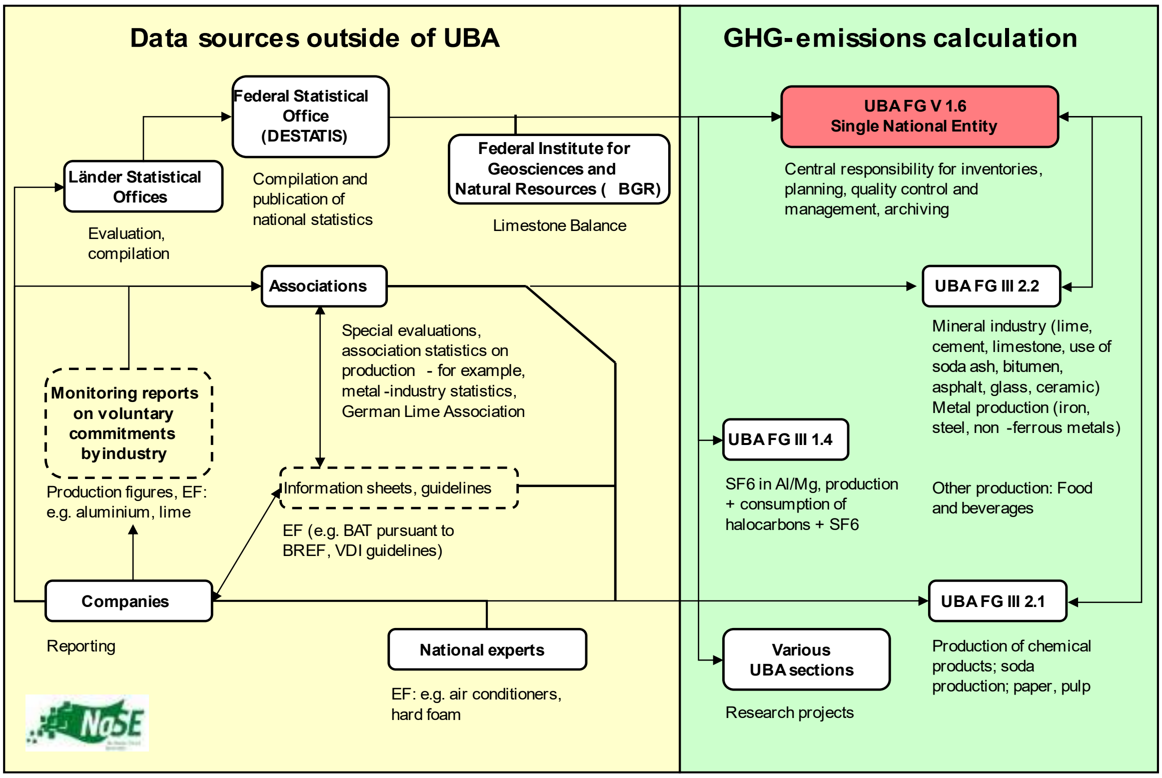
Data for categories in category 1.B.2 are taken from publications of the *Federal Statistical Office*, the Association of the German Petroleum Industry (MWV), the German Society for Petroleum and Coal Science and Technology (DGMK), the Federal association of the natural gas, oil and geothermal energy industry (BVEG), the German Technical and Scientific Association for Gas and Water (DVGW), the Federal association of the German gas and water industry (Bundesverband der deutschen Gas- und Wasserwirtschaft – BDEW; gas statistics) and the German Emissions Trading Authority (DEHSt).

1.4.1.1.2 Industrial processes

Activity data for the mineral industry are obtained primarily from association statistics. The data for the cement industry (2.A.1) were provided by the German Cement Works Association (Verband der Zementindustrie – VDZ), especially by that association's research institute, as well as by the Federal association of the German cement industry (Bundesverband der Deutschen

Zementindustrie e.V. – BDZ). For the most part, the data in question consist of data published in the framework of CO_2 monitoring under the industry's voluntary climate-protection commitment. The figures for lime and dolomite-lime production (2.A.2) are collected by the German Lime Association (BVK) on a per-plant basis and then provided annually in aggregated form. Glass-production figures (2.A.3) are taken from the regularly published annual reports of the Federal glass industry association (Bundesverband Glasindustrie), although relevant orientational figures on glass recycling are taken from other statistics. Production trends in the ceramics industry (2.A.4.a) are determined via official statistics and via conversion factors provided by experts, in the framework of a project. Figures for soda ash use (2.A.4.b) are obtained via expert assessment carried out by the Federal Environment Agency.

Figure 10: Responsibilities and data flows for calculation of greenhouse-gas emissions in the area of industrial processes



A range of different sources are used to determine emission factors for the mineral industry. The emission factor used for calculation of emissions from cement-clinker production (2.A.1) is based on a calculation of the German Cement Works Association (VDZ) carried out by aggregating plant-specific data. CO_2 emissions from lime production (2.A.2) and from soda-ash use (2.A.4.b) are calculated with the help of stoichiometric factors. The CO_2-emission factors for various types of glass (2.A.3) have been derived, by responsible experts, from glass-composition data, while CO_2-emission factors for the ceramics industry (2.A.4.a) have been derived, by Federal Environment Agency experts, from analyses of ETS data.

The activity data for category 2.B Chemical industry are determined from data of the *Federal Statistical Office (Statistisches Bundesamt, FS 4, R 3.1)* and directly from figures of industry associations and producers. Some of these data are confidential. The relevant emission factors have been determined by experts in the Federal Environment Agency, via research projects or by the pertinent producers. Until 2008, activity data for 2.B.1 Ammonia production and 2.B.2 Nitric acid production were collected by the *Federal Statistical Office*. Since 2009, data for ammonia and nitric-acid production have been collected by producers themselves – plant-specifically, on the basis of an agreement with the chemical industry and for the entire time series as of 1990. These data are forwarded to the association, which aggregates them and forwards them, in anonymised form, to the Federal Environment Agency. For this purpose, in addition to determining the applicable activity data, the producers also determine the applicable emissions for 2.B.1 and the applicable emission factors for 2.B.2. Until the mid-1990s, plant-by-plant activity data were supplied for 2.B.3 Adipic acid production. The default emission factor for N_2O was applied to that data. Now, plant operators are supplying emissions data directly to the Federal Environment Agency, on a confidential basis. For the area of adipic-acid production, data delivery has also been assured for the long term, via an agreement from 2009. In 2.B.4, only N_2O emissions from caprolactam production play a significant role. Those emissions are below the applicable threshold value, however, and thus are not reported. Since there is only one calcium carbide (2.B.4) producer in Germany, the relevant data are confidential. The Federal Environment Agency obtains these data directly from the producer. The CO_2 emissions from titanium dioxide production are not reported, because they lie below the applicable threshold (2.B.6). The *Federal Statistical Office* determines the total amounts of soda ash (2.B.7) produced in Germany. The pertinent emission factors are derived from the ETS monitoring data of the German Emissions Trading Authority (DEHSt). The activity data for production of the products listed under 2.B.8 Petrochemicals and carbon black production are obtained from statistics of the *Federal Statistical Office*. Some of the data are subject to confidentiality. The emission factors have been obtained from experts' assessments, research projects and default figures in the IPCC Guidelines. The activity data for carbon-black production are extrapolated backward, with the help of the default EF, from the CO_2 emissions reported in the context of the EU Emissions Trading System (ETS). In the area of production of halocarbons and SF_6 (2.B.9), data are obtained from *producers' figures and surveys of producers*. For the most part, activity data are researched in the framework of research projects, directly in accordance with the inventory's requirements. In some cases, producers supply only emissions data. Only small numbers of companies are involved in the various sub- source categories, and thus data in these areas are confidential. Under 2.B.10 Other, emissions of precursor substances from production of sulphuric acid and fertilisers are reported. The activity data are obtained from information provided by producers and from data of the Federal Statistical Office. The emission factors are obtained from experts' estimates and research projects.

The activity data for the metal industry (2.C) are provided by the *Federal Statistical Office,* by the relevant associations (Steel Institute VDEh, Wirtschaftsvereinigung Metalle (metals industry association) and Gesamtverband der Aluminiumindustrie (aluminium industry association) and by sellers of industrial gases. The emission factors for the metals industry (2.C) are normally calculated by experts in the Federal Environment Agency; in some cases, emission factors are provided by industrial associations or IPCC default values are used.

One exception in this regard is the category Ferroalloys; for it, activity data from statistics of the UK Geological Survey are used, while the relevant emission factors are taken from the results of a research project (in some cases, IPCC default values are also used).

In category 2.D Non-energy-related products from fuels and solvents, the activity data have been taken from published surveys of the Federal Statistical Office and of other federal authorities (for production and foreign-trade statistics, and for petroleum statistics) and of relevant associations (the VDD industry association for bitumen paper and bitumen roof sheeting; the German asphalt industry association (Deutscher Asphaltverband – DAV)). The activity data are supplemented with industry statistics and information supplied by experts.

The emission factors are obtained from various sources. The emission factors for paraffin wax use (2.D.2), for example, are calculated with the help of IPCC default values. The emission factors for lubricant use (2.D.1) have been determined via a research project (pursuant to the 2006 IPCC Guidelines, NMVOC emissions are to be given only as CO_2 equivalents). The emission factors for production and laying of bitumen paper and bitumen roof sheeting (2.D.3), and for production of asphalt for road paving (2.D.3), refer only to NMVOC, and they have been taken from research reports.

Emission factors, along with other parameters that enter into calculation of emissions from solvent use, are taken from national studies, experts' opinions and research projects directly commissioned by the Federal Environment Agency; in some cases, they are also based on information provided by experts in the context of dialogues with industry.

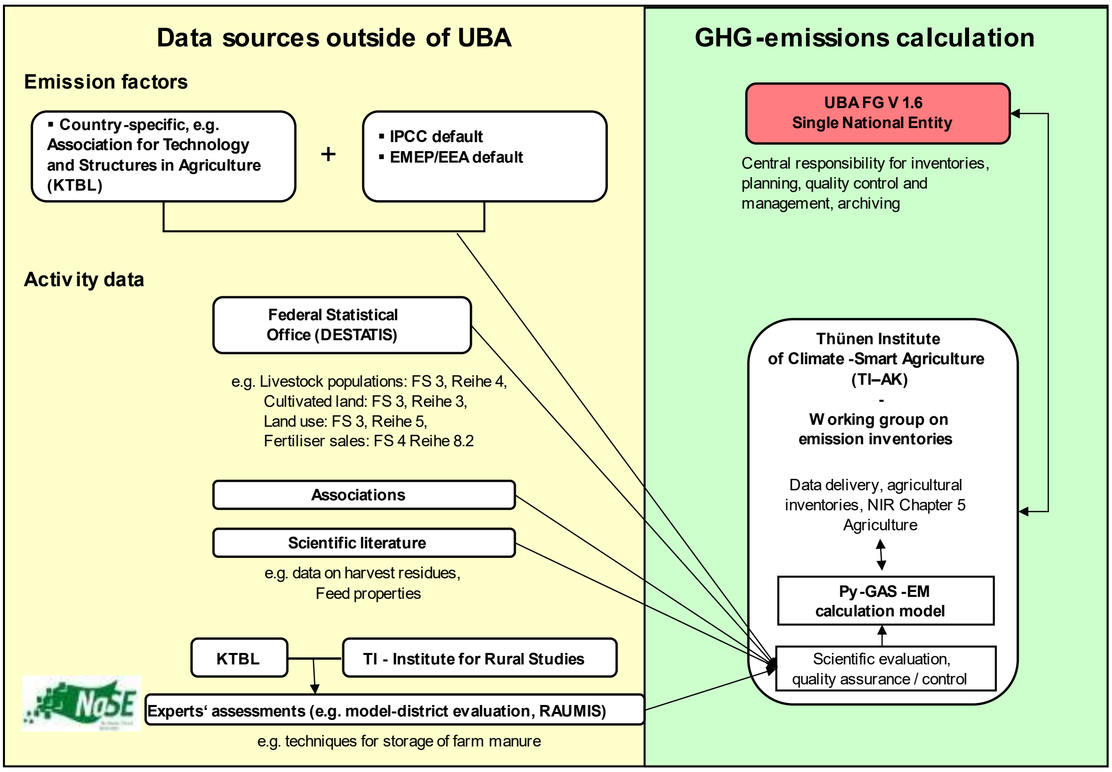
More-detailed pertinent information regarding emission factors is presented in the descriptions of methods for the various categories. The activity data for the electronics industry (2.E), for product use as substitutes for ODS (2.F) and for other product production and use (2.G), have been determined from information provided by producers and associations, from surveys of the Federal Statistical Office and of other federal authorities and with the help of calculation models. In individual cases, producers provide emissions data directly. The data are classified into several subcategories. Product use as ODS substitutes is also subdivided into production, use and disposal emissions. In these categories as well, the data in some areas are subject to confidentiality requirements.

Emission factors for fluorinated greenhouse gases are obtained in part from national and international fact sheets and directives or via surveys of experts; where necessary, IPCC default values are used.

In the area of 2.H.1 Other production: Pulp and paper production, data from the production report of the German Pulp and Paper Association (Verband Deutscher Papierfabriken – VDP) are used. In the area of 2.H.2 Other production: Food and beverages, data of the Federal Food Industry Association (Bundesvereinigung der Deutschen Ernährungsindustrie; BVE), of the Federal Statistical Office (Statistisches Bundesamt) and of the Federal Ministry of Food and Agriculture (BMEL) are used. The emission factors have been obtained from a research project that was completed in 2008.

1.4.1.1.3 Agriculture

Figure 11: Responsibilities and data flows for calculation of greenhouse-gas emissions in the area of agriculture



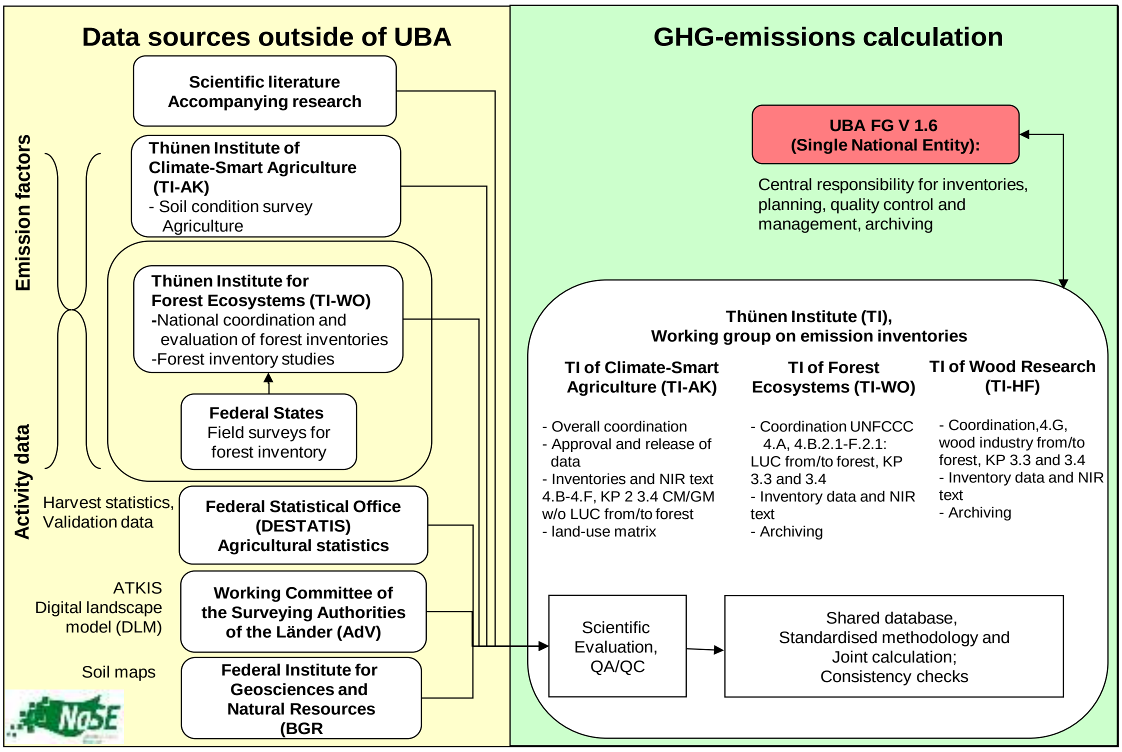
Emissions calculations for category 3 (Agriculture) are carried out by the Thünen Institute (TI). The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and the Federal Ministry of Food and Agriculture (BMEL) initiated a project for calculation of agricultural emissions in Germany. In it, the former Federal Agricultural Research Institute (FAL) developed a modular model for relevant spread-sheet calculation (GASeous Emissions (GAS-EM) (Dämmgen et al., 2002; Vos et al., 2022)). Now, for purposes of the 2022 submission, that model has been implemented in the python programming language (Py-GAS-EM).

Agricultural statistics of the Federal Statistical Office are another important data source for calculation of agricultural emissions. Animal statistics have been obtained from Fachserie 3, Reihe 4 of the Federal Statistical Office *(STATISTISCHES BUNDESAMT, FS 3, R 4)*; other Fachserien (technical series) provide data on amounts of fertilizer sold and agricultural land under cultivation. In some areas, such data are supplemented by figures from the pertinent literature (for example, crop residues and fertilizer data). Additional data are available from experts' assessments (for example, an evaluation of model districts with regard to techniques for storing farm fertilisers).

In many areas, calculations for the agriculture sector are based on highly differentiated activity data obtained via national data sources. The activity data are combined, depending on the emission sources involved, either with national emission factors or with the standard emission factors of the 2006 IPCC Guidelines and of the EMEP/EEA guidebook of the United Nations Economic Commission for Europe (UNECE).

1.4.1.1.4 Land-use changes and forestry

Figure 12: Data flows for calculation of greenhouse-gas emissions from the areas of land-use changes and forestry (LULUCF) and KP-LULUCF



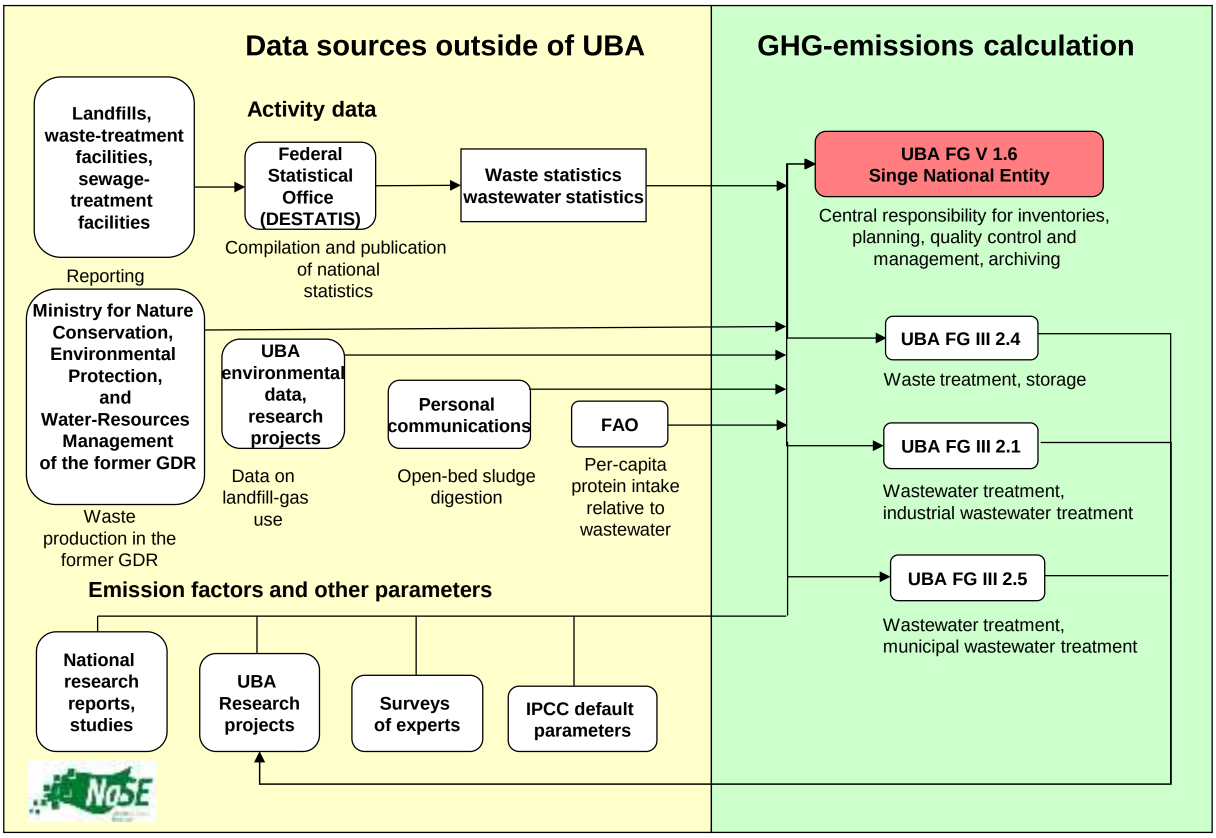
In the 2012 Submission, a consistent, unified method was introduced for taking account of land-use changes in the LULUC sector and the forestry sector. The method expands the existing sample-based system for determining forest-land areas, and land-use changes to and from forest land, for all land-use categories and change types. In the current submission, the method for preparation of the land-use matrix has been adjusted and expanded, and the practice of emission calculation at sample points has been introduced.

Soil carbon stocks are estimated with the help of soil maps and soil-profile data (both differentiated to show usages), and of data from Forest Soil Inventories and Agricultural Soil Inventories (BZE), while use-change-related changes in these stocks are estimated on the basis of changes in the mean stocks per land-use category.

Changes in biomass carbon stocks are estimated on the basis of harvest statistics, the main survey on soil use (Bodennutzungshaupterhebung), the National Forest Inventory (NFI) and specific factors that are given in the pertinent scientific literature and used in conjunction with area data.

1.4.1.1.5 Waste and wastewater

Figure 13: Data flows for calculation of greenhouse-gas emissions from the area of waste and wastewater



Federal Environment Agency Section FG III 2.4 *Waste technology, waste technology transfer* is responsible for selecting the methods, parameters and data for calculating emissions from the waste sector.

Activity data in the waste sector are drawn mainly from published data of the Federal Statistical Office, which provides detailed, disaggregated time series. The section on waste provides precise information as to what statistical series and sources were used. The Federal Statistical Office has not published any data on amounts of waste produced in the former GDR. In this area, an official source of the former GDR's ministry for nature conservation, environmental protection and water-resources management was used. The calculations relative to landfill-gas use are based on data from the Energy Balances and from Fachserie 19 of the Federal Statistical Office. The database for landfill-gas use was updated in the framework of the 2010 In-Country Review. Statistical data on gas collection at landfills in the follow-on care phase have been collected since 2012.

The emission factors and other parameters that enter into calculation of emissions from waste landfilling, from mechanical-biological waste treatment and from composting were taken from national studies and research reports conducted/prepared in research projects commissioned directly by the Federal Environment Agency. IPCC default parameters were also used for this purpose. Selected experts were also consulted regarding a few of the relevant parameters (for example, half-life selection). The relevant chapter presents the sources for the various parameters, in detail.

The Federal Environment Agency's Section for *General Aspects, Chemical Industry, Combustion Plants* (III 2.1) is responsible for selecting the methods, parameters and data for calculating emissions from the industrial wastewater / sewage sludge handling sector (5.D.2). The Federal Environment Agency's Section III 2.5 *Monitoring Methods, Waste Water Management* is responsible for selecting the methods, parameters and data for calculating emissions from the municipal wastewater handling sector (wastewater and sewage sludge) (5.D.1).

Activity data in the wastewater sector are drawn mainly from published data of the Federal Statistical Office, which provides detailed, disaggregated time series. The section on wastewater provides precise information as to what technical series and sources were used. The data on per-capita protein intake are taken from FAO data.

The emission factors and other parameters that enter into calculation of emissions from wastewater treatment were taken from national studies and research projects commissioned directly by the Federal Environment Agency. IPCC default parameters are also used. Various experts were consulted directly regarding a few parameters and methodological issues (for example, production of CH_4 emissions in aerobic wastewater-treatment processes).

1.4.1.2 Methods

The methods used for the individual categories are outlined in the overview tables for the various categories and in summary tables 3s1 and 3s2 of the CRF reporting tables. In addition, detailed descriptions are provided in the relevant category chapters.

A distinction is made between calculations made with country-specific ("CS") methods and calculations made, in the various categories, with IPCC calculation methods of varying degrees of detail (of varying "Tiers")[16]. The manner in which a calculation is assigned to the various IPCC methods depends on the pertinent category's share (expressed as equivalent emissions) of total emissions. Such assignment is carried out via an instrument known as "key-category analysis" (cf. Chapter 1.5 in this regard).

NMVOC emissions from solvent use, converted into indirect CO_2, are calculated on the basis of a product-consumption approach pursuant to the 2006 IPCC Guidelines. A similar procedure is used in the area of lubricant use.

1.4.2 KP LULUCF activities

The data sources and methods used for KP reporting do not differ from the data sources and methods used for reporting for categories within the CRF categories 4.A, 4.B, 4.C and 4.G in the UNFCCC framework. There are thus no differences with regard to the present purpose. Cf. also Chapter 1.4.1.1.4 and Chapter 6.1.

1.5 Brief description of key categories

1.5.1 Greenhouse-gas inventory (with and without LULUCF)

The key categories were identified by applying two Approach 1 procedures, Level (for the base year, 1990, and for the most current year) and Trend (for the most current year, as compared to the base year), to German greenhouse-gas emissions. In addition, the Approach 2 procedure was used. In keeping with the pertinent IPCC specifications for the Approach 1 procedure, analysis focussed both on emissions from sources and on removals of greenhouse gases in sinks. The analyses are first carried out solely for emissions from the sources listed in Annex 1 of the UN Framework Convention on Climate Change and, then, in a second step, for storage of greenhouse gases in sinks. All specified key categories result either from level analysis, or from trend

16 Tier 1 refers to the simpler calculation methods that may be used with fewer input data, whereas Tier 2 and Tier 3 require more differentiated input data and hence generally lead to more accurate results.

assessment, or from Approach-2 key-category analysis on the basis of current uncertainties determination. No new key categories have been added as a result of assessment of qualitative aspects (explanations regarding this aspect are provided in Annex Chapter 17.1.2).

For the current report, the Approach 1 procedure identified 48 categories, out of a total of 172 source and sink categories studied, as key categories. 34 of these were identified, by both trend and level analysis, as key categories. In addition, 11 categories were identified as key categories solely by trend analysis, and 3 categories were so identified solely by level analysis. Via the Approach 2 procedure, 9 additional key categories were identified (cf. Table 8).

Ultimately, 51 key categories were defined as a result. These are summarised in Table 5.

Table 5: Number of categories and key categories

Category	171		
			Key categories
by Level	Level & Trend	Trend	
3	34	11	**48 (Approach 1)** **+9 (Approach 2)** **57 (total)**

Table 6 provides an overview of the results of the key-category analysis based on Approach 1. Table 8 shows the additional key categories identified via Approach 2 analysis. Annex 1 (Chapter 17) of this report presents detailed explanations of the key-category analysis carried out.

Only few changes have occurred with respect to the results obtained in the previous year. The number of key categories pursuant to Approach 1 analysis, at 48, has decreased by three.

No new key categories have been added.

Three key categories have been eliminated.

- C_2O Emissions from Transport – Civil aviation (1.A.3.a)
- CH_4 Emissions from Households (1.A.4.b)
- CO_2 Emissions from Settlements (4.E)

Germany uses all recommended procedures for identifying and evaluating categories. The 2006 IPCC-Guidelines (IPCC (2006a): Vol. 1, Chapter 4.3) mandate that 95% of emissions from sources / removals in sinks be classified in key categories. The key categories that Germany has identified comprise emission-causing activities that account for about 98 % of the total inventory. This high percentage results from Germany's practice of identifying key categories by combining the results of all analysis procedures and evaluations. A comparison of the key-category analysis carried out within the CRF Reporter and Germany's key-category analysis has found that the two analyses differ only slightly. Small differences of approach are apparent; for example, Germany divides the energy sector into sub-categories, while the CRF Reporter differentiates it in accordance with fuel types. The resulting number of key categories is virtually the same in both analyses, however.

1.5.2 Inventory with KP-LULUCF reporting

As described in the previous chapter, the analysis of the UNFCCC inventory has shown that CO_2 emissions / removals in the categories *Forest Land* (4.A), *Cropland* (4.B), *Grassland* (4.C), Wetlands (4.D) and *Settlements* (4.E) suffice to make the categories key categories. For these categories, additional detailed analyses were carried out, in keeping with the methodological recommendations in Chapter "2.3.6 Choice of method" of the 2013 Revised Supplementary Methods and with the Good Practice Guidance Arising from the Kyoto Protocol. As a result, the sub-categories listed in Table 7 were identified as key categories for the KP-LULUCF inventory pursuant to Article 3.3. The key factors in such selections were the relevant emissions-contribution levels and emissions trends. With the help of Table 2.1.1, the activities selected in accordance with Article 3.4 were then correlated with these categories. Under this article of the Kyoto Protocol, Germany has selected the categories forest management, cropland management and grazing land management. These results, as well as the criteria used for the selection, are presented in CRF Table NIR.3 (Table 529 in Chapter 17.1.4)).

Table 6: Key categories for Germany pursuant to the Approach 1 method

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2020	Level 2020 + LULUCF	Trend 2020	Trend 2020 + LULUCF	KCA decision
1 A 1 a, Public Electricity and Heat Production	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 1 a, Public Electricity and Heat Production		CH_4	-	-	-	-	●	●	●	●	L/T
1 A 1 b, Petroleum Refining	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 1 c, Manufacture of Solid Fuels and Other Energy	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 2 a, Iron and steel	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 2 e, Food Processing, Beverages and Tobacco	fossil fuels	CO_2	-	-	-	-	-	-	●	●	-/T
1 A 2 f, Non-Metallic Minerals	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 2 g, Other	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 3 b, Road Transport	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 3 b, Road Transport		CH_4	-	-	-	-	-	-	●	-	-/T
1 A 3 b, Road Transport		N_2O	-	-	-	-	-	-	●	●	-/T
1 A 3 c, Railways	fossil fuels	CO_2	●	●	●	●	-	-	●	●	L/T
1 A 3 d, Domestic Navigation	fossil fuels	CO_2	-	●	-	●	-	-	-	-	L/-
1 A 4 a, Commercial/Institutional	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 4 a, Commercial/Institutional		CH_4	-	-	-	-	-	-	●	●	-/T
1 A 4 b, Residential	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 4 c, Agriculture/Forestry/Fishing	fossil fuels	CO_2	●	●	●	●	●	●	-	-	L/-
1 A 5, Other: Military	fossil fuels	CO_2	●	●	●	●	-	-	●	●	L/T
1 B 1, Solid Fuels		CH_4	●	●	●	●	-	-	●	●	L/T
1 B 2 b, Natural Gas		CH_4	●	●	●	●	●	●	-	-	L/-
2 A 1, Cement Production		CO_2	●	●	●	●	●	●	●	●	L/T
2 A 2, Lime Production		CO_2	●	●	●	●	●	●	-	●	L/T
2 B 1, Ammonia Production		CO_2	●	●	●	●	●	●	-	●	L/T
2 B 2, Nitric Acid Production		N_2O	●	●	●	●	-	-	●	●	L/T
2 B 3, Adipic Acid Production		N_2O	●	●	●	●	-	-	●	●	L/T
2 B 9 a, By-product Emissions		HFC-23	●	●	●	●	-	-	●	●	L/T
2 C 1, Iron and Steel Production		CO_2	●	●	●	●	●	●	●	●	L/T
2 C 3, Aluminium Production		CF_4	-	-	-	-	-	-	●	●	-/T
2 F, Product Uses as Substitutes for ODS		HFC-125	-	-	-	-	●	●	●	●	L/T
2 F, Product Uses as Substitutes for ODS		HFC-134a	-	-	-	-	●	●	●	●	L/T
2 F, Product Uses as Substitutes for ODS		HFC-143a	-	-	-	-	-	-	●	●	-/T
2 G, Other Product Manufacture and Use		N_2O	-	-	-	-	-	-	●	●	-/T
2 G, Other Product Manufacture and Use		SF_6	●	●	●	●	●	●	●	●	L/T

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2020	Level 2020 + LULUCF	Trend 2020	Trend 2020 + LULUCF	KCA decision
3 A, Enteric Fermentation	Dairy cows	CH_4	●	●	●	●	●	●	●	●	L/T
3 A, Enteric Fermentation	non-dairy cattle	CH_4	●	●	●	●	●	●	●	●	L/T
3 B, Manure Management	Dairy cows	CH_4	-	-	-	-	●	●	●	●	L/T
3 B, Manure Management	swine	CH_4	●	●	●	●	●	●	●	●	L/T
3 D, Agricultural Soils		N_2O	●	●	●	●	●	●	●	●	L/T
3 G, Liming		CO_2	-	-	-	-	-	-	-	●	-/T
3 J, Other		CH_4	-	-	-	-	-	-	●	●	-/T
4 A , Forest Land		CO_2		●		●		●		●	L/T
4 B, Cropland		CO_2		●		●		●		●	L/T
4 C, Grassland		CO_2		●		●		●		●	L/T
4 D, Wetlands		CO_2		●		●		●		●	L/T
4 G, Harvested Wood Products		CO_2		-		-		●		●	L/T
5 A, Solid Waste Disposal		CH_4	●	●	●	●	●	●	●	●	L/T
5 B, Biological Treatment of Solid Waste		CH_4	-	-	-	-	-	-	●	-	-/T
5 D 1, Domestic Wastewater		CH_4	-	-	-	-	-	-	●	●	-/T

Table 7: Results of KP-LULUCF key-category assessment

Category	Selected KP activities (cf. KP supplement, Table 2.1.1)	matter	1990	2020	1990	2020
4.A.1 Forest Land remaining Forest Land	FM	CO2	19,851.2	46,350.7	●	●
4.A.1 Forest Land remaining Forest Land	FM	CH_4	1.5	1.3	-	-
4.A.1 Forest Land remaining Forest Land	FM	N2O	1.1	1.1	-	-
4.A.2 Land converted to Forest Land	AD	CO2	144.1	98.8	●	●
4.A.2 Land converted to Forest Land	AD	CH_4	0.0	0.1	-	-
4.A.2 Land converted to Forest Land	AD	N2O	0.4	0.1	-	-
4.B.1 Cropland remaining Cropland	CM	CO2	10,699.7	7,611.3	●	●
4.B.1 Cropland remaining Cropland	CM	CH_4	5.4	2.8	-	-
4.B.2 Land converted to Cropland	D, CM	CO_2	3,062.7	9,044.7	●	●
4.B.2 Land converted to Cropland	D, CM	CH_4	0.5	2.2	-	-
4.B.2 Land converted to Cropland	D, CM	N_2O	0.8	2.2	-	-
4.C.1 Grassland remaining Grassland	GM	CO2	26,792.6	23,067.6	●	●
4.C.1 Grassland remaining Grassland	GM	CH_4	32.8	34.2	-	-
4.C.1 Grassland remaining Grassland	GM	N2O	0.2	0.4	-	-
4.C.2 Land converted to Grassland	D, CM, GM	CO_2	409.1	4,998.9	●	●
4.C.2 Land converted to Grassland	D, CM, GM	CH_4	2.1	4.3	-	-
4.C.2 Land converted to Grassland	D, CM, GM	N_2O	0.0	0.0	-	-
4.D.1 Wetlands remaining Wetlands	-	CO_2	3,597.6	3,593.3	●	●
4.D.1 Wetlands remaining Wetlands	-	CH_4	12.6	12.7	-	-
4.D.1 Wetlands remaining Wetlands	-	N_2O	0.1	0.1	-	-
4.D.2 Land converted to Wetlands	D, CM, GM	CO_2	108.1	858.9	●	●
4.D.2 Land converted to Wetlands	D, CM, GM	CH_4	0.8	14.7	-	-
4.D.2 Land converted to Wetlands	D, CM, GM	N_2O	0.0	0.0	-	-
4.E.1 Settlements remaining Settlements	-	CO_2	2,057.5	1,581.4	●	●
4.E.1 Settlements remaining Settlements	-	CH_4	1.8	1.6	-	-
4.E.1 Settlements remaining Settlements	-	N_2O	0.5	0.4	-	-
4.E.2 Land converted to Settlements	D, CM, GM	CO_2	280.9	505.6	●	●
4.E.2 Land converted to Settlements	D, CM, GM	CH_4	0.1	1.0	-	-
4.E.2 Land converted to Settlements	D, CM, GM	N_2O	0.1	0.7	-	-
4.F.1 Other Land remaining Other Land		CO_2	0.0	0.0	-	0.0
4.F.2 Land converted to Other Land	D, CM, GM	CO_2	0.0	0.0	-	0.0

Category	Selected KP activities (cf. KP supplement, Table 2.1.1)	matter	1990	2020	1990	2020
4.G Harvested wood products	FM	CO2	1,330.4	8,651.3	●	●

Table 8: Key categories for Germany identified solely via the Approach 2 method

IPCC Source Categories	Activity	Emissions of
1 A 4 b, Residential		CH_4
3 B, Manure Management	Dairy cows	N_2O
3 B, Manure Management	deposition	N_2O
4 B, Cropland		N_2O
4 C, Grassland		CH_4
4 D, Wetlands		CH_4
4 E, Settlements		N_2O
5 B, Biological Treatment of Solid Waste		N_2O
5 D 1, Domestic Wastewater		N_2O

1.6 Information regarding the quality assurance and quality control plan, the inventory plan (including verification) and management of confidential information

1.6.1 Quality assurance and quality control procedures

1.6.1.1 QC/QA plan

Pursuant to the 2006 IPCC Guidelines, the necessary QC/QA and verification measures for emissions reporting should be summarised in a QC/QA plan. Such a QC/QA plan is to serve the primary purpose of organising, planning and assuring the proper execution of such QC/QA measures.

The fundamental aim of the **QC plan**, and of the National System, is to subject the entire inventory, every year, to a complete QC process in keeping with the Guidelines – to a QC process that covers all categories, regardless of whether they are key categories. Therefore, the QC plan consists of the QC/QA checklists (cf. Chapter 1.6.1.2) and the inventory plan (cf. Chapter 1.6.1.3). A nearly identical approach is used with the QA section of the plan. This means that quality checks are carried out each year, as required by the Guidelines. At the same time, the required "peer reviews" are carried out periodically (see also below).

The **QA plan** thus consists of the QC/QA checklists (cf. Chapter 1.6.1.2) and of the schedule for emissions reporting (cf. Chapter 1.2.1.5), including the tasks that schedule specifies. Those checklists and the schedule, along with the approval processes specified by the QSE, ensure that inventories annually undergo numerous checks, including internal checks and (especially) checks carried out by external checking authorities focussed on quality assurance. The external checks also include the "basic expert peer reviews" that are carried out annually by the participating ministries. The results of those reviews, including any required corrections, enter into inventories prior to completion of the reporting process, and in the framework of the established routines. These quality assurance activities are complemented and reinforced by periodic peer reviews (cf. Chapter 1.6.1.4).

Regular adaptation and revision of the aforementioned instruments, also taking country-specific requirements into account, ensure that the requirements of the 2006 Guidelines are met also in terms of proper consideration of specific national circumstances.

A general description of the manner in which the quality assurance and control process is organised – with regard to both establishment and workflow – is provided in Chapter 1.3.3.1. That section also describes the principles by which QC/QA measures are controlled and documented.

The requirements for quality assurance and quality control measures in emissions reporting are described in detail in the "Handbook for quality control and quality assurance in preparation of emissions inventories and reporting under the UN Framework Convention on Climate and EU Decision 525/2013/EC" ("Handbuch zur Qualitätskontrolle und Qualitätssicherung bei der Erstellung von Emissionsinventaren und der Berichterstattung unter der Klimarahmenkonvention der Vereinten Nationen sowie der EU Entscheidung 280/2004/EG" (Federal Environment Agency, 2016, unpublished). The most important specifications set forth in the handbook consist of quality reviews carried out primarily prior to the conclusion of inventory preparation.

1.6.1.2 QC/QA checklists

The quality checks are carried out with the help of checklists (for the relevant content, cf. Chapters 1.3.3.1.5 and 22.1.2.1.11). These lists currently comprise some 85 role-specific individual targets and some 50 optional targets.

Currently, some 50 Federal Environment Agency and external staff, in various functional roles, and in four layered, cumulative QC/QA review levels, are involved in emissions reporting. The review levels are represented, in each case, by the relevant expert (Fachverantwortlicher – FV); his superior, the QC/QA section representative (QKV); a specialised contact person, within the Single National Entity, for the relevant category (Fachlicher Ansprechpartner – FAP); and, finally, the co-ordinators responsible for achieving a consistent overall result comprising the NIR, the inventory, the QSE and uncertainties estimates.

In inventory preparation, role-specific QC/QA reviews are linked with general quality targets (cf. Chapter 22.1.2.1.10.3) and individual process steps (cf. Chapter 1.2.3), so that final evaluation can also take account of such targets and steps whenever that is necessary. As a whole, the reviews cover the entire inventory-preparation process.

Subsequent evaluation of the checklists reveals, for specific categories, aspects that need to be reviewed – and, possibly, revised – with regard to fulfillment of specific inventory requirements. Such fulfillment is achieved via addition of pertinent further information. The great majority of all identified review requirements are added to the binding inventory plan. The inventory plan undergoes internal and interdepartmental approval processes and is then published in aggregated form.

1.6.1.3 Inventory plan

For the annual preparation of the inventory plan, the results of the QC/QA checklists for all categories are evaluated, and targets that have not been achieved are assigned improvement measures as necessary, as well as deadlines for their implementation (follow-up procedure). Those measures are then complemented by the improvement activities mentioned in the NIR (cf. Chapter 10.4.1), by the results of the various review procedures of the UNFCCC and the EU Commission, by audit results (cf. 1.6.1.4) and by any listings of further required improvements. The inventory plan comprises a range of individual measures that are to be implemented by the various roles within the QSE (cf. the role concept within QSE, Chapter 1.3.3.1.3) and by the Federal German ministries involved in emissions reporting (cf. Chapter 1.3.3.1.3), along with their subordinate authorities. The included measures have to be completed within the time periods defined within the inventory plan, although it must be noted that the relevant responsible NaSE participants have to provide the necessary personnel and financial resources for the measures.

During the preparation for each current IP, the QSE coordinator reviews whether the required actions defined in previous years have been completed. The IP is then updated with the information that results from such review. Required actions that could not be completed by the defined deadlines are flagged with an "overdue" status and given higher priority (in the "follow-follow-up procedure").

Because the individual measures included within the inventory plan are so numerous – they are too many to be listed here – they have been combined into overarching measures, as shown in Table 9. The inventory plan is updated at least once a year, via an ongoing process.

As measures within the inventory plan are implemented, large numbers of the included individual measures are processed to the point where they can be removed from the list. This occurs on a regular basis.

Table 9: Inventory plan – areas in which action is required

Main Category	Category (CRF-Code)	Data quality objective	Source	Source-Reference-Year of Reporting
Energy	1.A.3.d	Check whether requirements of IPCC-Guidelines pertaining to selection of calculation method and to procedures for applicable methods changes are fulfilled or if it´s necessary to adjust already existing calculation methods/modells.	NIR	2017
Industrial Processes	2.A.4.b.		Sonstige	2020
LULUCF	4, 4(V) , 4.B-E, KP		ARR, NIR	2020, 2022
Energy	1.A.4.	Check whether there are any gaps in time series.	CHKL	2020
Energy	1. fossil fractions of biofuels	Check whether the source category is completely covered by the relevant data source and whether the defined data sets for EF and AR are consistently delimited.	NIR	2020
Industrial Processes	2.C.2, 2.C.3.a		Audit	2016
LULUCF	4		ARR	2020
Energy	1.A.3.b+c, 1.A.4.c.ii+iii, 1.A.5.b.(iii)	Check whether uncertainties have been determined, are complete and up to date.	Audit, CHKL	2012, 2015+16, 2020, 2022
Industrial Processes	2.B.7, 2.B.10.(i), 2.C.3.a., 2.D.3.(b)		Audit, CHKL	2012, 2016, 2018, 2021+22
Waste	5.A.1, 5.B, 5.D.1+2		Audit, CHKL,Sonstige	2016, 2019+20
General	0.	Check whether obligations pertaining to keeping of records and documentation are fulfilled and whether the relevant documents are complete, meaningful and up to date.	Audit, CHKL	2015+16, 2018
Energy	1.A, 1.A.2.e, 1.A.2.g.vii., 1.A.3.a-c+d.(a+b)+e., 1.A.4.a.ii+b.ii+c.ii+iii,, 1.A.5.b (i+ii+iii)		ARR, CHKL	2013, 2017-22
Industrial Processes	2.A.1+3+4a, 2.B.3+8, 2.C.3.a., 2.D.1.(b), 2.D.3.(a,d,e,f,g,h,i)+j		Audit, CHKL	2016, 2018-21
LULUCF	4.A, KP		ARR	2020
Waste	5.A.1, 5.B.1+2, 5.D.1+2, 5.E.1.(a)		Audit, CHKL	2016, 2019-22
General	0.	Check whether data suppliers and contracted supporting entities are carrying out suitable routine quality controls, and whether the emissions-reporting requirements defined by the Single National Entity have been provided to such suppliers and entities and are being fulfilled.	Audit, Sonstige	2014, 2016
Energy	1.A.3.a-c+d (a+b), 1.A.4.c.iii, 1.A.5, 1.A.5.b		Audit, CHKL	2012, 2015+16, 2019, 2021+22
Industrial Processes	2.B.8.a., 2.C.2		Audit, CHKL	2012, 2016+17
Waste	5.B.1+2, 5.D.1		Audit, CHKL	2016, 2018
General	0.	Check whether requirements for cross-checking and verification of data and their underlying assumptions have been fulfilled.	ARR, CHKL, Sonstige	2015+16, 2018
Energy	1.A.1, 1.A.2f, 1.A.3.d.+(a), 1.A.4.c.iii., 1.A.5.b.(iii), 1.D.1.a.		ARR, Audit, CHKL, Sonstige	2015+16, 2022
Industrial Processes	2.B.7, 2.B.10.(i), 2.C.2+5+6		Audit, CHKL	2015+16, 2019-22
Waste	5.A.1, 5.B.1+2, 5.D.1+2, 5.E.1.(a)		CHKL, Sonstige	2018-20, 2022

General	-	Check whether it was possible to take pointers from inventory reviews and inventory plan into account.	ARR	2010
Energy	1.A.3.d(b), 1.B.2.b.iv-vi		CHKL	2019, 2022
Industrial Processes	2.B.10.(i)		CHKL	2022
Energy	1.A.2.g.vii., 1.A.3.a-c+d(a+b)+e., 1.A.4.a.ii.+b.ii+c.ii+iii, 1.A.5.b, 1.AD, 1.B.2.c-Flaring	Check whether data-consistency requirements are fulfilled and whether the relevant documents are complete and meaningful.	ARR, CHKL	2018-22
Industrial Processes	2.B.3+7, 2.D.1.(b), 2.D.3.(j)		Audit, CHKL	2016, 2019-22
Waste	5.A.1		NIR	2013
Energy	1.A.3.b., 1.A.3.d.(a), 1.A.4.c.iii., 1.B.2	Check whether the EF are plausible and complete (have no gaps and are completely documented) and up to date.	ARR, CHKL, NIR	2020-22
Industrial Processes	2.C.3.a, 2.H.2.		ARR, NIR	2018, 2021
Waste	5.A.1		ARR, NIR	2018-20
Industrial Processes	2.A.3	Check whether the AR are plausible and complete (have no gaps and are completely documented) and up to date.	ARR, Audit	2016, 2018
Waste	5.A.1., 5.E.1.(a)	Check whether data has been entered into the CSE correctly, including whether all numbers, units and conversion factors have been correctly entered and properly integrated.	CHKL	2021
Energy	1., 1.A.3.d.(a)	Check whether the NIR source category has been completely and logically described in terms of the required six sub-chapters for the NIR ("Source category description", "Methodological issues", etc.).	ARR, CHKL	2015+16, 2021
Industrial Processes	2.B.3+10.(i), 2.C.2+5+6.		CHKL	2019+20, 2022
Waste	5.A.1, 5.D.1+2, 5.E.1.(a)		ARR, CHKL	2018, 2022
Energy	1.A	Check whether any recalculations are required. If they are they must be documented in a logical manner.	ARR	2018
General	0.	Various types of required action.	Sonstige	2014, 2016
Energy	1.A.2.g.vii, 1.A.3.b+c+d(a+b), 1.A.4.a.ii+b.ii+c.ii+iii, 1.A.5.b., 1.B.2.c. - Flaring		CHKL	2015, 2017-22
Industrial Processes	2.B.7+8+10.(i), 2.C.3.a.		Audit, CHKL, NIR	2015+16, 2021+22
Agriculture	3.D		CHKL	2022
LULUCF	KP		ARR	2020
Waste	5.A.1, 5.D.2		ARR, Sonstige	2015+16, 2018
Energy	1.A.3.a+b	Initiated research projects for inventory improvement.	Audit	2016
Industrial Processes	2.A.4.b+c+d, 2.D.3.(b)		CHKL, Sonstige, NIR	2012, 2019, 2022
Waste	5.A.1, 5.D.1	Initiated research projects for inventory improvement.	ARR, NIR	2015+16, 2022

The first inventory plan was published together with the 2007 Submission. Since then, several thousand items for action or improvement have been addressed within the quality system.

As of the end of the current reporting year, the inventory plan comprises some 280 active items for required actions or improvements. Those items span about 70 categories.

In the course of the current round of reporting, about 30 additional required improvements have been identified, and about 100 required actions have been successfully completed. Among these are a recommendation from the 2020 UNFCCC ReviewThe 2020 ESD Review issued no required improvements.

The emphases of the required improvements that are still open and being processed have to do with the areas of documentation, verification and other improvements.

The overview in Table 10 presents more-detailed information on the improvement items that have been successfully addressed. Both tables (Table 9 & Table 10) include the review results from the years as of 2006, the statements made in the NIR relative to planned improvements for the period as of 2011, the other improvement items for the period as of 2008 and the CHKL results from the years as of 2010.

Detailed information regarding individual improvements, with respect to categories, priorities, deadlines, responsibilities, gases, fuels, required actions, etc., cannot be provided here, due to the volume of the information involved. With regard to successfully addressed Review results, more-detailed excerpts from the inventory plan are provided in Table 475 (Compilation of the Review recommendations successfully addressed as of the current report), while information relative to statements made in the NIR regarding planned improvements is provided in Table 476 (Compilation of a) the planned improvements completed as of the present report and of b) the planned improvements that are mentioned in NIR category chapters and are still pending).

Table 10: Inventory plan – Items for action/improvement that have been successfully addressed

Main Category	Category (CRF-Code)	Data quality objective	Source	Source-Reference-Year of Reporting
General	0.	Check whether requirements of IPCC-Guidelines pertaining to selection of calculation method and to procedures for applicable methods changes are fulfilled or if it´s necessary to adjust already existing calculation methods/modells.	ARR	2020
Industrial Processes	2.A.1		ARR	2018
LULUCF	4, 4.B.1, 4.B.2.+4.C.2., KP		ARR	2015+16, 2020
General	0.	Check whether uncertainties have been determined, are complete and up to date.	Audit	2016
Energy	1.A.2.g.vii., 1.A.3.b.+c, 1.A.4.a.ii.+b.ii.+c.ii.		CHKL	2014+15, 2021
Waste	5.D.1		CHKL	2021
General	0.	Check whether obligations pertaining to keeping of records and documentation are fulfilled and whether the relevant documents are complete, meaningful and up to date.	Audit	2016
Energy	1.A.2.g.vii., 1.A.3.c, 1.A.4.a.ii.+b.ii.+c.ii.		CHKL	2017, 2020+21
Agriculture	3., 3.B.3., 3.D.a.2.c + 3.D.b		ARR	2020
LULUCF	4., KP		ARR, Audit	2016, 2020
Waste	5.B.1.+2, 5.E.1.(a)		Audit, CHKL	2016, 2021
General	0.	Check whether data suppliers and contracted supporting entities are carrying out suitable routine quality controls, and whether the emissions-reporting requirements defined by the Single National Entity have been provided to such suppliers and entities and are being fulfilled.	Audit	2016
Energy	1.A.4.c.iii., 1.A.5.b.(iii),		CHKL	2016, 2020
Industrial Processes	2.B.9.		Audit	2016
General	0.	Check whether requirements for cross-checking and verification of data and their underlying assumptions have been fulfilled.	ARR, CHKL	2018, 2020
Energy	1.A.1		CHKL	2021
Industrial Processes	2.C.6		CHKL	2019
LULUCF	4.B, 4.B.1.+4.C.1., KP		ARR	2020
Waste	5.D.1		Sonstige	2020

General	0.	Check whether it was possible to take pointers from inventory reviews and inventory plan into account.	ARR	2018
Energy	1.A.5.b.(iii), 1.B.2.c. - Flaring	Check whether data-consistency requirements are fulfilled and whether the relevant documents are complete and meaningful.	CHKL	2018, 2021
Industrial Processes	2.E.3, 2.G.3, 2.G.4.(c)		ARR, CHKL	2020+21
LULUCF	4., 4.A, KP		ARR, Sonstige	2020, 2021
Waste	5.B.2, 5.D., 5.D.2.		ARR, CHKL, Sonstige	2016, 2020
Industrial Processes	2.A.3.	Check whether the EF are plausible and complete (have no gaps and are completely documented) and up to date.	Audit	2016
Industrial Processes	2.A.4.b, 2.C.2, 2.D.2	Check whether the AR are plausible and complete (have no gaps and are completely documented) and up to date.	ARR, Sonstige	2020+21
Waste	5.D.1		Sonstige	2021
Industrial Processes	2.B.2.+3	Check whether the NIR source category has been completely and logically described in terms of the required six sub-chapters for the NIR ("Source category description", "Methodological issues", etc.).	ARR	2015+16, 2018
Agriculture	3.A.1.		ARR	2018
Waste	5.D.2, 5.E.1.(a)		CHKL	2020+21
Industrial Processes	2.A.4.b., 2.D.1.(a)	Check whether any recalculations are required. If they are they must be documented in a logical manner.	ARR	2020
Energy	1.A.3.a.+c+d.(a), 1.A.4.c.iii., 1.D.1.a.	Various types of required action.	ARR, Audit, CHKL	2015+16, 2019, 2021
Industrial Processes	2.B.3.; 2.B.4; 2.B.8.a-e; 2.B.10.(i)		CHKL	2019
Waste	5.B.		Sonstige	2021
Industrial Processes	2.B.3.; 2.B.4.a.; 2.B.8.a-e	Check whether pertinent responsibilities need to be updated.	CHKL	2016, 2019

1.6.1.4 Audit

In April 2016, the Federal Environment Agency's Quality System for Emission Inventories (QSE) was externally audited. The aims of the audit were to:

- Check whether the QSE is conformal with the quality requirements of the 2006 IPCC Guidelines,
- Identify any potential for improvement,
- Identify any possible risks for the continuing maintenance of data quality.

An audit program was developed that covers considerably more than simply a representative cross-section of all emissions categories, since the audited staff, in most cases, also handle additional categories, and do so with procedures that differ little from those used in the directly considered cases.

In February 2016, the so-developed audit plan was used as a basis for carrying out a pre-audit for two categories, and for the coordinators of the Quality System for Emission Inventories (QSE), the Central System of Emissions (CSE) (the database) and the National System (NaSE), with a view to testing the audit's suitability and time requirements and to determining whether the audit plan needed to be adjusted in any way. In parallel with the revision of the audit plan, a schedule for the execution of the audit, with 5 auditors, was prepared. During the audit, the following procedure was normally carried out on three successive days: the responsible experts (Fachverantwortlicher; FV) and their specialised contact persons (Fachlicher Ansprechpartner;

FAP) were audited in pairs. This work covered a total of 44 of 148 categories. The reviewed procedures and workflows in the audited categories represent more than 80 % of the total emissions covered by the German greenhouse-gas inventory. In addition, all coordinators who had not already been covered in the pre-audit were included in the audit program, in the framework of individual audits.

The audit plan covered the following topic areas:

- Roles and responsibilities
- The use of general quality control procedures
- Implementation of requirements set forth in the QSE manual (inventory description, inventory plan, NIR)
- Category-specific quality controls for
  - emission factors
  - measurements
  - activity data
  - calculation procedures and determination of uncertainties

The key findings of the audit include:

1. The minimum requirements pertaining to quality control / quality assurance (QC/QA), as specified by the 2006 IPCC Guidelines, are being met, without exception. All target requirements are being met via the design and the implementation of the QSE.
2. The QSE's prescribed QC/QA procedures function effectively in assuring data quality, in conformance with the requirements of the IPCC Guidelines, and in ensuring that a continual improvement process takes place. The success of the system depends on consistent fulfillment of the QSE requirements via the involved staff and areas.
3. The QSE accomplishes much more than its goal of fulfilling the minimum requirements; for many aspects of the inventory process, it provides best-practice examples modelled after the 2006 IPCC Guidelines. The structure and the scope of the inventory description are worthy of particular mention. In nearly all categories studied, the description serves as a comprehensive, transparent tool for documentation of data, the processing status and the procedures applied. Only in the area of category-specific quality control – in a small number of aspects – is some room for improvement seen, and the relevant improvements could well be carried out in the longer term (such as preparation of standardised spread-sheet templates)
4. The risk that data quality could decrease is seen as very low, in light of the QSE's structure and design, as well as of the extensive, detailed information contained in the inventory descriptions. Risks might apply with regard to temporary gaps in the continual, consistent use of survey and calculation procedures, since extrapolation calculations, for reporting purposes, sometimes have to be carried out in cases in which experienced staff suddenly become unavailable. By no means does such unavailability lead to a loss of information, however – it would always be possible to subsequently restore the database, at the customary data quality levels.
5. In some categories, data quality could be improved still further via more-frequent review of the currentness of the data used. It thus could be useful to review, at mandatory intervals, whether emission factors are still current, or whether in the meantime data that would support use of higher-Tier approach (such as national factors, instead of the IPCC defaults) have become available or could be obtained. Where factors prove to require updating, the necessary studies could be included in the research budget.

6. Individual potential improvements for the categories studied, and for general areas, could also be determined. Such aspects would be included in the existing instruments for improvement (the inventory plan).

1.6.1.5 Workshops on the National System (Peer Review)

In November 2004, the Federal Environment Agency held a first workshop on the National System of Emissions Inventories. This created a forum that significantly promoted inclusion of associations and other independent organisations, as well as supporting implementation of Paragraph 15 (b) of the *Guidelines for National Systems*, which requires that inventories be reviewed by third parties (peer review).

Subsequently, several workshops were held with the purpose of facilitating review of the inventories by independent third parties, pursuant to Paragraph 15 (b) of the *Guidelines for National Systems*. In 2009, a second workshop focussed on selected specific categories of the inventory, such as "N_2O from product use," "emissions from non-energy-related use of fossil fuels" and "SF_6 emissions from the photovoltaics industry". The extensive and intensive discussions conducted during the workshop contributed significantly to overall improvement of the data – and, thus, to the quality of the reporting.

In 2011, an international experts' workshop on the German LULUCF-reporting system was carried out that reviewed the methodological changes made as a result of the In-Country Review of September 2010. All of the recommendations made by experts in that framework have been fully implemented.

Technical discussions on the topic of natural gas statistics were conducted with the Federal Statistical Office in 2012 and in summer 2015 (one discussion at each time). The participants in the technical discussion in 2012 included representatives of the Federal Statistical Office, the Federal Environment Agency (UBA) and the German Association of Energy and Water Industries (BDEW), as well as representatives of various gas companies and the German Institute for Economic Research (DIW; Working Group on Energy Balances (AGEB)). In preparation for revision of the national Energy Balance, the discussion focussed on the available natural gas statistics. In the process, measures were approved that will directly improve the Energy Balance and, thus, will improve the emissions inventory. In addition, agreement was reached on additional study that will be carried out in order to verify the available statistical data. The technical discussion in 2015 served the purpose of coordinating data exchange between the Federal Statistical Office and the Federal Environment Agency, also with regard to the new reporting requirements set forth in the 2006 IPCC Guidelines and the European Greenhouse gas Monitoring Mechanism Regulation (MMR).

In March 2014, a workshop was held with European inventory experts on the topic of implementation of the 2006 IPCC Guidelines in German greenhouse-gas reporting. That workshop, which had about 60 participants, focussed especially on the sectors of energy (CRF 1) and industrial processes and product use (CRF 2). With the help of the findings from experience that were shared during that event, it proved possible to significantly improve implementation of the new methods in German greenhouse-gas inventories.

1.6.1.6 Cross-Country Review on fluorinated gases

In February 2011, a group of experts met in Vienna for a cross-country review focussing on reporting on F gases. The participating countries included the UK, Austria and Germany. After basic presentations of data collection in the three countries, the various individual areas of application concerned were considered in detail and compared in terms of data sources, precision, emission factors and other criteria. In the process, it emerged that, of the three countries, Germany has the most extensive specialised knowledge resources and presumably is thus best able to assess the completeness and plausibility of the available data.

One of the key results that emerged from the cross-country review is that all three countries have to commit high levels of manpower to reporting on F gases. Any reduction in such resources commitments would mean that reporting would no longer be IPCC-conformal.

As a result of the meeting, a report was prepared that has entered into German reporting regarding F gases.

1.6.2 Activities for verification

1.6.2.1 Verification in selected categories

In the 2015/2016 reporting year, a verification project was carried out, in keeping with the 2006 IPCC Guidelines (Vol.1, Chapter 6). In the project, all of the inventory's categories were reviewed for any need for verification. The following categories were identified:

- 1.A.2.a Iron & Steel
- 1.A.3.e Other Transportation
- 1.B.1.a.ii Surface Mining
- 1.B.2.b.v.i Natural Gas: Other
- 2.A Mineral Industry
- 2.B.1 Ammonia Production
- 2.B.2 Nitric Acid Production
- 2.B.3 Adipic Acid Production
- 3 Agriculture
- 4 Land Use Matrix
- 4 Consistency between the descriptions in the NIR and the CRF tables
- 4.A Forest Land
- 5.A.1 Managed Waste Disposal

For each of the listed categories, verification has been carried out by the project holder. Upon completion of this work, the results will be listed in the relevant categories' verification chapters (i.e. the results for a given category will be listed in that category's verification chapter).

1.6.2.2 Verification of the national inventory with the help of independent data

The chronological sequence for the three most important greenhouse gases (CO_2, N_2O and CH_4), for purposes of the German emissions inventory, was verified with the help of the data sets recommended by the 2019 IPCC Refinements (Romano et al., 2019). These include, in particular, the JRC's Emissions Database for Global Atmospheric Research (EDGAR) (Crippa et al., 2021) and data of the ECMWF's Copernicus Atmospheric Monitoring Service (CAMS) (ECMWF, 2022). In addition, data of the Pollution Release and Transfer Register (PRTR) (Umweltbundesamt, 2022), and of the European Union's European Emissions Trading System (ETS) (EEA, 2022), were used for verification purposes. These four data sets are independent of the national totals used by the German inventory. For this reason, they can serve as an independent database for verification, as described in chapters 6.10.1-6.10.2 of the IPCC Guidelines (Romano et al., 2019). In this connection, the EDGAR database is used for comparison of trends for the aforementioned greenhouse gases, in the period 1990-2018. Such comparisons can be carried out directly, since EDGAR provides data – including both spatially distributed data and aggregated data – that are suitable for comparison with total national emissions quantities (Crippa et al., 2021). For comparisons with total national emissions quantities, the CAMS data, by contrast, first have to be aggregated both spatially and temporally. In the aforementioned period, only a comparison with the CAMS CO_2 data (Chevallier, 2020), and a comparison with its methane data (Seegers, Houweling and Tokaya, 2020), are possible, however. That source's data set for nitrous oxide is available only for the period as of 1996 (Thompson, 2021). The PRTR data and the ETS data are available for verification only for the period as of 2007 (Umweltbundesamt, 2022) and for the period as of 2005 (EEA, 2022), respectively. Further information about the data sets, and a detailed verification analysis of the German inventory's temporal trend (including LULUCF and AFOLU), is presented in Annex Chapter 22.1.4. The time frame for the comparison was defined in keeping with the largest overlapping time period within the analysed data sets. It consists of the period 1990-2018 (subject to variance depending on the temporal scope of the data set used for comparison). In this case, the EDGAR data set accurately reproduces the data of the German national inventory, as is apparent in Annex Chapter 22.1.4. The data of the CAMS service also reproduce the temporal trends of the German inventory data, with the exception of the trend for the nitrous oxide data (Thompson, 2021). This clearly highlights the great value that inverse-modelling data can have in the context of verification for a national emissions inventory, as noted in the IPCC 2019 Refinements (Romano et al., 2019). Nonetheless, additional scientific development work needs to be carried out, with a view to improving these results still further. At the European level, initiatives such as Verify and COCO2, and many future projects, are building / will build on this work, in the interest of obtaining even better results and data products in future. As soon as the relevant data sets are provided to the inventory community, they will enter into verification activities. The PRTR data and the ETS data show similar temporal trends when they are compared with the national inventory data (with correlation values of 0.8 for both data sets). Detailed analyses are provided in Annex Chapter 22.1.4.

1.6.2.3 Procedure for using monitoring data from European emissions trading

In efforts to fulfill mandatory quality criteria, a need has been seen – especially within the EU – to use data from the EU Emissions Trading Scheme (EU ETS) to improve greenhouse-gas emissions inventories.

A reliable database from emissions trading, showing relevant annual emissions, is available for the period since ETS monitoring commenced. Those data can be used, in aggregated form, to draw category-specific conclusions regarding the completeness and consistency of certain parts of emissions inventories. In addition, they provide a basis for reviewing emission factors used and for verifying activity data. Since emissions calculations within the emissions inventory are all based on the same activity data, for all components, such verification is of significance for all reported gases.

Emissions-trading data required for improvement of inventory data subject to reporting are available in electronic form, in the installations database of the German Emissions Trading Authority (DEHSt). In 2005, agreement was reached regarding a general procedure for individual data queries related to inventory preparation. In the main, this procedure involves direct communication between the Single National Entity and the German Emissions Trading Authority's section V 3.3, which is responsible for reports (cf. Chapter 1.3.3.1.8). To make it possible to use this "resource" on a regular basis, this formalised procedure for the pertinent required annual data exchanges, including deadlines and defined workflows, has been agreed.

Monitoring data from European emissions trading will be used to improve the quality of annual national emissions inventories with respect to categories that include installations subject to reporting obligations under the CO_2 Emissions Trading Scheme (ETS). Relevant information is provided in the category chapters on verification, although the detailed comparisons involved are presented only in some cases. For reasons of confidentiality, especially regarding certain inventory details, the results of the comparisons are usually simply described in text form. Tables with the data used can be made available only in connection with inventory reviews. The comparison of fuel-related CO_2 emission factors in the Annex, Chapter 18.8, provides a sample overview of a successful verification.

The process of data provision, from the German Emissions Trading Authority (DEHSt) to the responsible experts for the inventories, called for several instances of project-based support. Allocation rules were developed that make it possible to compare, on a yearly basis, data from verified emissions reports with the structure of the inventory database {ÖKO-INSTITUT, 2006}. In the process, it became clear that the data quantities the ETS provides for inventory calculations present challenges in terms of available resources and time. When discrepancies occur in existing aggregates that fulfill requirements for confidentiality of business and operational secrets, the underlying data sets for individual operational steps have to be checked. This obstacle was confirmed for the German situation, by experts of other countries, in the framework of an international workshop within the project (Handke et al., 2013). In another project, the situation relative to adjustment of the ETS requirements for the third trading period was studied (Herold et al., 2016).

Currently, standardised comparative data are regularly available that have been prepared on the basis of reporting obligations in the context of the EU regulations on greenhouse gases. The following data sets are provided in the CSE inventory database:

- Data broken down in accordance with the German Greenhouse Gas Emissions Trading Act (TEHG)): This data consists of emissions data aggregated from operator notifications to the Union Registry (the notifications are made available by the German Emissions Trading Authority (DEHSt)). Because the data show sums of fuel-related and process emissions, they are not directly suited for CRF comparisons.
- Data broken down in keeping with the CRF: Data from operators' checked emissions reports are provided by the DEHSt, in consultation with the Single National Entity, for the purpose of fulfillment of EU reporting obligations. Pursuant to a specification of the implementing regulation for the European Monitoring Mechanism Regulation (MMR), these data support a quantitative comparison of EU-ETS emissions data with GHG-inventory data.

The methods for preparation of the aforementioned aggregates are continuously being improved, and they are regularly discussed in expert consultations.

1.6.2.4 Verification of the national inventory with the help of independent data

The chronological sequence for the three most important greenhouse gases (CO_2, N_2O and CH_4), for purposes of the German emissions inventory, was verified with the help of the data sets recommended by the 2019 IPCC Refinements (Romano *et al.*, 2019). These include, in particular, the JRC's Emissions Database for Global Atmospheric Research (EDGAR) (Crippa *et al.*, 2021) and data of the ECMWF's Copernicus Atmospheric Monitoring Service (CAMS) (ECMWF, 2022). In addition, data of the Pollution Release and Transfer Register (PRTR) (Umweltbundesamt, 2022), and of the European Union's European Emissions Trading System (ETS) (EEA, 2022), were used for verification purposes. These four data sets are independent of the national totals used by the German inventory. For this reason, they can serve as an independent database for verification, as described in chapters 6.10.1-6.10.2 of the IPCC Guidelines (Romano *et al.*, 2019). In this connection, the EDGAR database is used for comparison of trends for the aforementioned greenhouse gases, in the period 1990-2018. Such comparisons can be carried out directly, since EDGAR provides data – including both spatially distributed data and aggregated data – that are suitable for comparison with total national emissions quantities (Crippa *et al.*, 2021). For comparisons with total national emissions quantities, the CAMS data, by contrast, first have to be aggregated both spatially and temporally. In the aforementioned period, only a comparison with the CAMS CO_2 data (Chevallier, 2020), and a comparison with its methane data (Seegers, Houweling and Tokaya, 2020), are possible, however. That source's data set for nitrous oxide is available only for the period as of 1996 (Thompson, 2021). The PRTR data and the ETS data are available for verification only for the period as of 2007 (Umweltbundesamt, 2022) and for the period as of 2005 (EEA, 2022), respectively. Further information about the data sets, and a detailed verification analysis of the German inventory's temporal trend (including LULUCF and AFOLU), is presented in Annex Chapter 22.1.4. The time frame for the comparison was defined in keeping with the largest overlapping time period within the analysed data sets. It consists of the period 1990-2018 (subject to variance depending on the temporal scope of the data set used for comparison). In this case, the EDGAR data set accurately reproduces the data of the German national inventory, as is apparent in Annex Chapter 22.1.4. The data of the CAMS service also reproduce the temporal trends of the German inventory data, with the exception of the trend for the nitrous oxide data (Thompson, 2021). This clearly highlights the great value that inverse-modelling data can have in the context of verification for a national emissions inventory, as noted in the IPCC 2019 Refinements (Romano *et al.*, 2019). Nonetheless, additional scientific development work needs to be carried out, with a view to improving these results still further. At the European level, initiatives such as Verify and COCO2, and many future projects, are building / will build on this work, in the interest of obtaining even better results and data products in future. As soon as the relevant data sets are provided to the inventory community, they will enter into verification activities. The PRTR data and the ETS data show similar temporal trends when they are compared with the national inventory data (with correlation values of 0.8 for both data sets). Detailed analyses are provided in Annex Chapter 22.1.4.

1.6.3 Handling of confidential information

Following the entry into force of the amended version of the Act on Energy Statistics of 26 July 2002, via the 3rd SME Relief Act (MEG – Mittelstandsentlastungsgesetz), the Federal Environment Agency (UBA) was granted access, for purposes of inventory preparation, to data of the Federal Statistical Office that are subject to statistical confidentiality. Such access was then assured via the amendment of the Act on Energy Statistics of 6 March 2017 (Federal Law Gazette (BGBl) I p. 392), in Section 13 of that amended version.

In addition, from associations and companies, the Single National Entity receives activity data, emission factors and emissions data that reflect operational and business secrets and that are otherwise confidential.

In storing and using such data, therefore, the Single National Entity must take special precautions, and apply special procedures, to protect the confidentiality of the data.

In particular, it must provide for strict separation (both spatial and in terms of staff assignments) of statistical work / analysis and any enforcement of legal provisions pertaining to the installations for which data are collected.

The Single National Entity and the affected sections of the Federal Environment Agency have taken various measures for the purpose of fulfilling these requirements. For example, as a basic rule, persons charged with enforcement of laws in a specific area are never permitted to carry out specialised tasks relative to emissions reporting in the same area.

In 2008, the Single National Entity commissioned a legal study with the aim of precisely assessing the requirements and possibilities pertaining to use and management of data for emissions reporting. The results entered into revision and refinement of the Single National Entity's concept for handling confidential data, and they were formally implemented via in-house directive No. 04/2019 – Assurance of conformance with confidentiality requirements pursuant to the Federal Statistics Act (BStatG), the Energy Statistics Act (EnStatG), the Environmental Statistics Act (UStatG) and the Manufacturing Industry Statistics Act (ProdGewStatG) – and via contractual arrangements in Division V.

Previously, access to the Central System on Emissions (CSE) database was already limited to a specified group of authorised persons. That measure represents the key precaution for dealing with confidential data. In particular, it makes it practicable to separate – in terms of the persons involved – the tasks of data analysis and legal control. In addition, in 2009 a special access-restricted area was set up, on a central server of the Federal Environment Agency, for confidential electronic data that are not centrally stored in the CSE (for example, energy data subject to statistical confidentiality, emissions-control declarations, data relative to large combustion plants, information about production processes, etc.).

Furthermore, data of the *Federal Statistical Office* are provided on a password-/access-protected server (i.e. available only for specifically authorised persons) of the *Federal Statistical Office*. In the Federal Environment Agency, such data are processed in a database protected by personalised access control (i.e. a database available only for specifically authorised persons).

1.7 General estimation of uncertainties

1.7.1 Greenhouse-gas inventory

The 2006 IPCC Guidelines (IPCC (2006a): characterise determination of uncertainties as a key element of any complete inventory. As a result of the need to continually improve the inventories, uncertainties in the inventories play an important role. Uncertainties information is used primarily as an aid for improving the precision of inventories, as well as for selecting methods and carrying out recalculations for inventories. The declared aim is to minimise uncertainties to the greatest possible degree, in order to maximise the inventories' accuracy. In a first step, the uncertainties for all categories and sinks have to be quantified, in order to enhance assessment of inventory quality – which assessment, in turn, is the key to effective inventory planning.

In general, two methods for determining uncertainties are differentiated. The Approach 1 method combines, in a simple way, the uncertainties in activity data and emission factors, for each category and greenhouse gas, and then aggregates these uncertainties, for all categories and greenhouse-gas components, to obtain the total uncertainty for the inventory. The Approach 2 method for uncertainties determination is the same, in principle, but it also considers the distribution function for uncertainties and carries out aggregation using Monte Carlo simulation. In the Approach 2 method, this process also necessarily includes determining a probability density function for all activity data and emission factors. Ideally, these functions can be determined via statistical evaluation of individual data items (such as measurements for a large number of facilities). In many cases, few relevant values are available, however, and thus the uncertainty is determined on the basis of experts' assessments.

Research project 202 42 266 (Handke et al., 2004) determined uncertainties, for the first time, in keeping with the Approach 1 and Approach 2 methods, pursuant to Chapter 6 of the 2000 Good Practice Guidance (IPCC, 2000). For the current report, the resulting data have been further improved, and additional uncertainties data for the greenhouse-gas inventory have been added. In addition, the provisions of the 2006 Guidelines (IPCC, 2006a) were adopted. In Germany, uncertainties are determined, on an annual basis, pursuant to both the Approach 1 and Approach 2 methods. The uncertainties for the activity data, emission factors and emissions data used were taken from the CSE database. They are based on information provided in the literature and on estimates of experts in relevant departments of the Federal Environment Agency and at external institutions.

1.7.1.1 Procedures for uncertainties determination

In keeping with Chapter 3 of the 2006 IPCC Guidelines (IPCC, 2006a), uncertainties are determined on the basis of the uncertainties for activity data, emission factors (EF) and emissions (EM), as determined on the lowest sub-category level, and as listed in the CSE. In the Approach 1 method, where asymmetric uncertainties data result, and a normal distribution is assumed, the larger of the two bound values is used as both the upper bound and the lower bound. The Approach 2 method, on the other hand, uses the complete data set in each case. In each sector, the uncertainties for the individual time series are aggregated to form a total uncertainty for the sector. The uncertainty of the inventory as a whole is obtained from aggregation of the sector uncertainties.

Due to a lack of data from the year of German reunification (1990), and the related technical limitations, the year 1995 is generally used, in a departure from the Guidelines, as the base year for calculation of base-year and trend uncertainties.

In general, in calculation of uncertainties, values for activity data can be assumed to be smaller than those for emission factors. In particular, activity data derived from fuel-use data, and based on the National Energy Balance, exhibit low uncertainties. On the other hand, uncertainties for activity data derived from disaggregated fuel use normally increase as the relevant disaggregation increases.

The following list presents a number of sector-specific details that underlie calculation of uncertainties:

- Pursuant to the results of an R&D project (Rentz et al., 2002), the uncertainties in emission factors for indirect greenhouse gases in stationary combustion systems (CRF 1.A.1) are relatively small, as a result of regular monitoring of such emissions. Higher uncertainties are listed for N_2O emission factors, since N_2O emissions are not normally monitored. The same applies to the emission factors for CH_4.
- In the category for the iron and steel industry (CRF 1.A.2.a), the uncertainties for the year 2017 have increased. This occurred because the steel industry association was unable to supply fuel input data via the BGS form, with the result that the trends had to be calculated on the basis of the development of production data from emissions trading. The association's inability to supply the BGS data occurred as a result of provisions of antitrust law.
- The uncertainties in the Transport category (primarily CRF 1.A.3) can generally be considered to be small, since precise relevant data on fuel use and vehicle fleets are available, due to taxation obligations. In addition, that category's emission factors have been very finely modelled and are normally determined via measurements. Some uncertainties may arise via systematic measuring errors or wrong disaggregation.
- In the category Fugitive emissions from fuels (CRF 1.B), the uncertainties for the activity data for oil and natural gas (CRF 1.B.2) are low, because the fuels are subject to taxation. Flaring of gases represents the only exception. The activity data for Coal mining (CRF 1.B.1) are also well-represented by production volumes. By contrast, the uncertainties for emission factors for fugitive emissions are likely to be higher. This results from the great number and diversity of the technical factors that affect fugitive emissions in transport, storage and processing of oil and natural gas.

- Considerable uncertainties are seen in many areas in the category of industrial processes (CRF 2). Activity rates based on production figures that must be reported to the Federal Statistical Office can be subject to uncertainties, especially as a result of discrepancies between reporting structures and relevant industry definitions. Activity rates determined from association information are subject to uncertainties that correlate, in each case, with the degree to which the relevant industrial sector is represented in the association in question. For emission factors, uncertainties – which can be considerable, depending on the greenhouse gas in question – result from the factors' strong dependence on technology, in combination with extensive technological diversification. Furthermore, equipment-specific emission factors often are tied to business secrets, particularly in sectors with few market players (for example, manufacturing of chemical products (CRF 2.B)), and this tends to make operators hesitant to publish such data or leads them to provide information in consolidated form. In addition, uncertainties can be higher for complex processes in which non-combustion-related activities generate emissions, if relevant emissions-generating processes are inadequately understood and the relevant contributions of pertinent individual activities are not known.
- In the area of production of alcoholic beverages, within the area of Food and drink production (CRF 2.H.2), the activity-rate uncertainties must be considered very small, since production of such beverages is subject to taxation regulations that require very precise determination of production volumes. On the other hand, statistics for sectors with large numbers of small and medium-sized enterprises (such as baked-goods production) tend to be significantly less precise, and thus the activity data for such sectors are subject to higher uncertainties. The uncertainties for the relevant emission factors are also larger, due to the sectors' extensive technological diversification.
- The uncertainties for emissions parameters for the categories Managed waste disposal in landfills (CRF 5.A.1, 5.B and 5.E) and Industrial wastewater treatment (CRF 5.D) are presumed to be high. This applies especially to the areas of composting, MBT and waste landfilling, which have high waste-type diversity that tends to reduce the reliability of data for the relevant emissions parameters. The reasons for the higher uncertainties seen for activity data include the fact that the underlying statistical data make use of non-standardised waste and recycling definitions. The general assumptions relative to the uncertainties of activity data also apply to thermal treatment of waste.

Further information about the uncertainties for individual source categories is provided in the relevant sector-specific chapters of this report.

1.7.1.2 Results of uncertainties assessment

The total uncertainty of the inventory for the year 2020, pursuant to Approach 1, is 3.6 %; pursuant to Approach 2, it is -3.2 / +3.5%. The following table provides a concise overview of the uncertainties of the inventory as a whole:

Table 11: Overview of the uncertainties for the inventory as a whole

	Base Year	2020	Trend	Method	Base year uncertainty		2020 uncertainty		Trend uncertainty	
	kt	kt	%		%		%		%	
National total incl. LULUCF	1,272,618	717,473	-43.62	Approach 1	4.47		3.56		3.95	
				Approach 2	-2.97	+3.14	-3.18	+3.45	-9.01	+9.45
National total w/o LULUCF	1,245,615	728,738	-41.50	Approach 1	4.52		3.62		3.35	
				Approach 2	-2.38	+2.59	-2.07	+2.64	-6.56	+7.01

The overview shows the uncertainties for the German inventory as a whole, both with and without CRF 4. For both perspectives, the uncertainties are listed for the base year, for 2019 and for the trend. In each case, the uncertainties have been determined both pursuant to Approach 1 and via use of Monte Carlo simulation (Approach 2). The latter method yields considerably better insights. For example, only Approach 2 uncertainties properly highlight the difference between the two lines (with and without LULUCF).

Detailed information about the applicable sector-specific uncertainties is provided in Annex 7 (cf. Chapter 22.2.3). The following section describes, in greater detail, several sectors that have a great influence on the uncertainty of the inventory as a whole:

- The CO_2 emissions of the sector Combustion of fuels (1.A) contribute an important share of the total uncertainty. The predominating components of that share include solid fuels in the sector Public electricity and heat production (1.A.1.a) and mobile sources (1.A.3), especially road transport (1.A.3.b) and combustion in the residential and commercial/institutional sectors (1.A.4.a/b/c).
- Nitrous oxide emissions overall also contribute significantly to the total uncertainty. This effect is shaped especially by nitrous oxide emissions from manure management (3.B) and from agricultural soils (3.D).
- The CO_2 sinks and sources in Sector 4 LULUCF also account for an important share of the total uncertainty.

Methane emissions from animal husbandry (Enteric fermentation, 3.A), and energy inputs in industrial sectors, in areas 1.A.2.a and 1.A.2.g, also make considerable contributions to the total uncertainty.

1.7.2 KP LULUCF inventory

Since the same data and methods are used, under both UNFCCC and KP, for reporting for categories 4.A-4.G, the uncertainties for the two reporting areas are comparable. The information provided in the previous chapter and in the relevant category chapters (cf. also Chapter 11.3.1.5) applies.

1.8 General checking of completeness

1.8.1 Greenhouse-gas inventory

Completeness information for the various individual categories is presented in CRF Table 9(a), which is summarised in NIR Chapter 21 (Table 575 and Table 576). The following are differentiated in Germany:

- Source-specific emissions and sinks that do not occur (NO – not occurring), and source-specific emissions and sinks that are not reported, either because they are not quantitatively relevant or because the necessary data for calculation are lacking (NE – not estimated), and

The following section touches on a few category-specific approaches for improving the completeness of the inventory.

All combustion-related activities (1 A) from the area of energy are recorded in full. At certain points, the Energy Balance of the Federal Republic of Germany is supplemented if it is evident that complete coverage is not achieved in selected sub-sections (such as the non-commercial use of wood, secondary fuels). In some categories, separation of combustion-related and non-combustion-related emissions from industry requires further verification. In general, avoidance of duplicate counting is an important part of quality assurance for such categories, however.

In the area of industrial processes, some use is made of production data from association statistics and of manufacturers' information. In the interest of the inventory's completeness and reliability, where emissions reporting is based on such sources, checking of category definitions and data-collection methods will continue to receive priority.

The emissions that are reported as "not estimated" (NE) consist of emissions that, pursuant to 24/CP.19 Annex I (cf. FCCC/CP/2013/10/Add.3), would be of secondary importance relative to the overall level and development of national emissions. An emission may be considered insignificant only if the emission is likely to account for less than 0.05 percent of the total national GHG emissions and if it does not exceed 500 kt CO_2 equivalent.

Some of the emissions data available to the Federal Environment Agency are confidential, due to data-protection requirements, and thus are reported only in aggregated form – although they are reported completely.

1.8.2 KP LULUCF inventory

Since, for reporting for categories 4.A-4.G, the data and methods used for reporting under UNFCCC do not differ from those used for reporting under KP, the information provided in the previous chapter applies.

2 Trends in Greenhouse Gas Emissions

Table 12 below shows the total emissions, as determined for this inventory, of direct and indirect greenhouse gases and of the acid precursor SO_2. Table 13 shows the annual progress achieved, with respect to 1990, for each pertinent year. Considerable emissions reductions were achieved for all substances, with the exception of a few F gases. In total, greenhouse-gas emissions, calculated as CO_2 equivalents, decreased by 41.3 %, with respect to 1990[17].

All detailed tables relative to discussion of trends are presented in Annex Chapter 22.3.

Trends, taking account of changes with respect to the previous year of the reporting period

With regard to the previous year, 2019, total emissions decreased by 8.9 %. The decrease is due primarily to a further reduction in the energy industry. Electricity generation with lignite and hard coal decreased as a result of low world-market prices for natural gas, as well as of a successful reform of the European emissions-trading system that led to higher CO_2 prices.

[17] All figures do not include emissions from the category of Land Use, Land-Use Change & Forestry (LULUCF).

Table 12: Emissions of direct and indirect greenhouse gases and SO_2 in Germany since 1990

Emissions Trends	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
		(kt)													
CO_2 emissions (without LULUCF)	**1,051,979**	**938,614**	**899,352**	**866,303**	**832,541**	**808,912**	**813,693**	**831,208**	**792,255**	**795,557**	**800,340**	**785,616**	**754,408**	**707,150**	**639,381**
Net CO_2 emissions/removals	1,076,570	911,628	887,392	867,709	814,811	789,854	784,512	804,688	766,386	771,823	774,608	760,212	730,929	688,886	624,731
CH_4 (without LULUCF)	**4,742**	**4,174**	**3,512**	**2,748**	**2,326**	**2,282**	**2,304**	**2,279**	**2,234**	**2,225**	**2,175**	**2,152**	**2,080**	**1,998**	**1,961**
CH_4 (including LULUCF)	4,800	4,231	3,569	2,812	2,395	2,352	2,374	2,350	2,306	2,298	2,247	2,225	2,158	2,073	2,036
N_2O (without LULUCF)	**195**	**185**	**122**	**126**	**103**	**104**	**104**	**105**	**106**	**106**	**106**	**104**	**100**	**97**	**95**
N_2O (including LULUCF)	198	189	126	130	108	108	109	109	111	111	111	109	105	102	100
F gases, sum (CO_2 equivalent, 1995 base year)	13,395	17,092	13,293	14,184	14,246	14,426	14,609	14,642	14,657	15,116	15,215	15,288	14,411	13,692	12,159
Total emissions (without LULUCF)(CO_2 equi.)	**1,241,919**	**1,115,305**	**1,036,926**	**986,709**	**935,768**	**911,244**	**916,901**	**933,987**	**894,465**	**897,954**	**901,442**	**885,729**	**850,542**	**799,734**	**728,738**
Total emissions / removals with LULUCF (CO_2 equi.)	1,268,922	1,090,716	1,027,337	991,058	921,074	895,267	890,853	910,653	871,834	877,519	878,975	863,618	830,492	784,842	717,473
NO_X	2,839	2,186	1,893	1,632	1,445	1,419	1,411	1,410	1,365	1,342	1,315	1,264	1,179	1,106	978
SO_2	5,460	1,742	643	473	403	387	368	357	335	334	309	301	289	259	233
NMVOC	3,892	2,342	1,806	1,487	1,362	1,272	1,257	1,212	1,174	1,147	1,141	1,145	1,099	1,072	1,036
CO	13,081	7,100	5,084	3,837	3,513	3,429	3,175	3,134	2,965	3,069	2,946	2,961	2,852	2,753	2,455

Table 13: Changes in emissions of direct and indirect GHG and SO_2 in Germany, since the relevant reference year (1990/1995)

Emissions Trends Changes compared to base year / prev. year (%)	Base Year	Base Year to 2019	Base Year to 20120	compared to prev. year (2019 – 2020)
CO_2 emissions (without LULUCF)	***1990***	**-32.8**	**-39.3**	**-9.6**
Net CO_2 emissions/removals	1990	-36.0	-42.0	-9.3
CH_4 (without LULUCF)	***1990***	**-57.9**	**-58.7**	**-1.9**
N_2O (without LULUCF)	***1990***	**-50.1**	**-51.4**	**-2.6**
F gases, sum	***1995***	**-19.9**	**-28.9**	**-11.2**
Total emissons (without LULUCF)	1990	**-35.6**	**-41.3**	**-8.9**
NO_X	***1990***	**-61.1**	**-65.6**	**-11.6**
SO_2	***1990***	**-95.2**	**-95.7**	**-10.4**
NMVOC	***1990***	**-72.5**	**-73.4**	**-3.4**
CO	***1990***	**-79.0**	**-81.2**	**-10.8**

2.1 Description and interpretation of trends in aggregated greenhouse-gas emissions

From 1990 through 2020, greenhouse-gas emissions were reduced considerably, by 41.3 %[18]. The individual greenhouse gases contributed to this development to varying degrees (cf. Table 1). Among the direct greenhouse gases, emissions of those gases that predominate in terms of quantity were markedly reduced, with the strongest reductions occurring for methane. The main reasons for these developments are found in the following areas:

- Transition from use of solid fuels to use of liquid and gaseous fuels, which have lower emissions, in the period since 1990;
- Growing use of renewable energies, and increasing, related, use of substitutes for fossil fuels;
- Increased plant (installation) efficiencies;
- Changes in animal-housing methods, and reductions of livestock populations;
- Fulfillment of legal regulations in the waste-management sector;

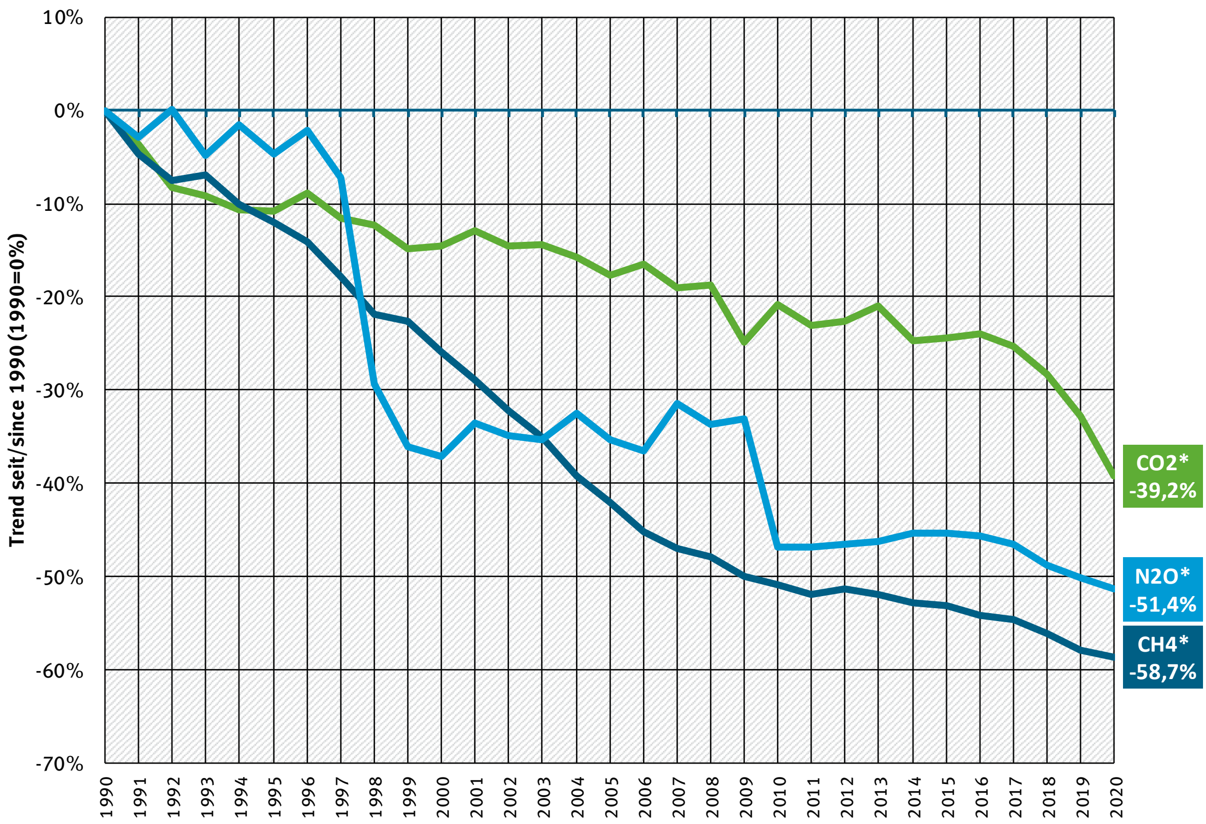
Such areas are considered in greater detail in the discussion below of trends for the various individual greenhouse gases.

Releases of carbon dioxide – the great majority of which are caused by stationary and mobile combustion processes – predominate in the overall picture of greenhouse-gas emissions. Due to a disproportionately large decrease in emissions of the other greenhouse gases, the proportion of total greenhouse gases attributable to CO_2 emissions has increased since 1990 (cf. Table 2). All other greenhouse gases together account for only slightly more than one-tenth of greenhouse-gas emissions. Germany's range of GHG emissions is typical for a highly industrialised country.

[18] All figures do not include emissions from the category of Land Use, Land-Use Change & Forestry (LULUCF).

2.2 Description and interpretation of emission trends, by greenhouse gases

Figure 14: Relative development of carbon dioxide, methane and nitrous oxide with respect to 1990



* Carbon dioxide emissions apart from LULUCF

Figure 14 shows the relative development of emissions of the various greenhouse gases since 1990. In the discussion, it must be remembered that the development of each of these greenhouse gases as shown here is largely dominated by specific developments in a single category.

2.2.1 Carbon dioxide (CO_2)

The reduction in CO_2 emissions is closely linked to trends in the energy sector. The sharp emissions reduction in this area seen in the early 1990s was primarily the result of restructuring in the new German Länder, including related conversions to cleaner fuels and decommissioning of obsolete facilities. The changes in the fuel mix have continued, to a somewhat lesser degree, through the current report year.

Use of gases, primarily natural gas, as substitutes for solid and liquid fuels is also reflected in emissions trends for stationary combustion systems. While CO_2 emissions from liquid fuels decreased by about 48 %, with respect to their levels in 1990, and emissions from solid fuels decreased by about 67 percent, emissions from gaseous fuels increased by nearly 41 percent.

When these emissions trends are viewed at the level of individual categories, a highly consistent picture emerges. In comparison to 1990 levels, emissions in all sub-categories of stationary combustion systems decreased by a total of nearly 371 million t CO_2.

The situation is somewhat different only in the transport sector, which is dominated by road transports: CO_2 emissions in this area increased through 1999, to 184 million t, and then decreased slightly as a result of reductions in consumption, shifting of refueling to other countries[19], substitution of diesel fuel for gasoline[20] and use of admixtures with biodiesel. In about 2007, the trend began stagnating, at a level of about 153 million t, in part as a result of ongoing increases in average engine power. In the years as of 2013, that stagnation gave way to an upwardly direction, as a result of further increases in transport densities and mileage travelled, and as a result of decreased use of biofuels. This trend peaked in 2017, at a level of 167 million t. Thereafter, emissions decreased again, to a level of slightly more than 160 million t. The level seen in 2020, at 145 million t, lies considerably below the long-term trend, and it is due primarily to various special effects.

Trends, taking account of changes with respect to the previous year of the reporting period

With respect to the previous year, CO_2 emissions of the energy sector, which is quantitatively predominant, again fell drastically (by -15.4 %, or nearly 38 million t). Also, emissions of the transport, commercial and institutional (commercial, trade, services), manufacturing and military sectors decreased considerably, primarily as a result of special effects, while those of households increased very slightly.

2.2.2 Nitrous oxide N_2O

Since 1990, N_2O emissions have decreased by about 51 %. The main emissions areas/sources include agricultural use of nitrogen-containing fertilisers, animal husbandry and fuel use. Smaller amounts of emissions are caused by wastewater treatment, by the chemical industry and by product use of N_2O (for example, as an anaesthetic). Industry has had the greatest influence on emissions reductions, especially in the area of adipic acid production – via installation of waste-gas-treatment systems in 1997 and 2009. Via technological reduction measures, the chemical industry's emissions have been reduced by 97 %, with respect to 1990. Since 1999, trends in the remaining emissions have been strongly influenced by economic trends in the chemical industry sector.

Trends, taking account of changes with respect to the previous year of the reporting period

Total emissions decreased with respect to the previous year (-2.6 %), especially as a result of further emissions decreases from mineral-fertiliser use in the agricultural sector, which is quantitatively predominant (decreases in that area: -1.6 %)

2.2.3 Methane (CH_4)

Methane emissions are caused mainly by animal husbandry in agriculture, waste landfilling and distribution of liquid and gaseous fuels; energy-related and process-related emissions, and emissions from wastewater treatment, play an almost negligible role. Methane emissions have been reduced by 58.7 % since 1990. This trend has been primarily the result of environmental-policy measures (waste separation, with intensified recycling and increasing energy recovery from waste) that have decreased landfilling of organic waste. A second important factor is that

[19] The emissions are calculated on the basis of domestic fuel sales. Fuel quantities not purchased in Germany thus do not enter into the German emissions inventory.

[20] Diesel fuel's share of total fuel consumption in road transports has increased sharply throughout the entire time period. In 1990, nearly two-thirds of road transport emissions were the result of gasoline consumption. Now, this ratio has nearly reversed itself.

use of mine gas from coal mining, for energy recovery, has increased, while overall production of such gas has decreased (via closure of hard-coal mines). As a result, emissions in category 1.B, Fugitive emissions from fuels, have decreased by more than 85 % since 1990. Yet another reason for the emissions reductions is that livestock populations in the new Federal Länder have been reduced, with reductions occurring especially in the first half of the 1990s. Repairs and modernisations of outdated gas-distribution networks in that part of Germany, along with improvements in fuel distribution, have brought about further reductions of total emissions.

Trends, taking account of changes with respect to the previous year of the reporting period

In comparison to the previous year, emissions decreased by 1.9 %. The largest emissions decreases, in quantitative terms, occurred in the areas of landfills, agriculture and fugitive emissions from fuels.

2.2.4 F gases

In 2020, emissions of F gases accounted for only about 1.7 % of total emissions. Since 1995 (the base year for F gases), they have decreased by 29 %. At the same time, the trends for the different individual substances and substance groups involved differ considerably:

HFC emissions increased primarily as a result of intensified use of HFCs as refrigerants in refrigeration and air-conditioning systems and of increasing disposal of such systems. This more than offset emissions reductions resulting from their reduced use in PUR installation foams.

The emissions reductions for **PFCs** were achieved primarily through efforts of primary aluminium producers and semiconductor manufacturers.

The **SF_6** emissions reduction that lasted until about 2003 was due primarily to decreasing use of the gas in automobile tyres since the mid-1990s. In this area, efforts to increase environmental awareness have been successful, resulting in emissions reductions of over 100 t and greenhouse-gas reductions of 2.5 million t of CO_2 equivalents. Similar success has been achieved with soundproof windows, for which production use of SF_6 has been reduced to nearly zero since 1995. And a large share of current and future SF_6 emissions (will) result from open disposal of old windows. Emissions from electricity-transmission facilities have also decreased considerably. Important remaining emissions sources include welding and production of optical glass fibre.

Since 2015, NF_3 has been used in Germany only in semiconductor production. Because those emissions are of such minor importance with regard to total GHG emissions, we have not carried out a separate trend analysis for them.

2.3 Description and interpretation of emission trends, by greenhouse gases

Energy

The emissions reduction in the energy sector results primarily from a sharp decrease in combustion-related CO_2 emissions (cf. in this regard also the results of the key-category analysis). On the other hand, emissions of other greenhouse gases are negligible in this sector. The situation is different solely for emissions that are not combustion-related (category 1.B.). In this area, CO_2 emissions are very low, while emissions trends are clearly shaped by CH_4 emissions caused by distribution of liquid and gaseous fuels.

On the whole, energy-related emissions of all greenhouse gases have decreased by 41.3 % since 1990. In that period, the transport emissions included in those emissions decreased – primarily as a result of special effects – by about 10.5 %. In the area of emissions from stationary combustion systems, the reductions have been achieved through fuel changeovers and higher energy and technical efficiencies. In addition, increasing use of renewable energy sources is having an effect, because such energy sources are primarily supplanting fossil-fuel-based electricity generation. That said, it should be noted that carbon dioxide from use of biomass is not reflected in the emissions trends. For distribution emissions, it has resulted from increased use of pit gas, modernisation of gas-distribution networks and introduction of vapour-recovery systems in fuel distribution.

Table 584 in the Annex shows the relevant emissions changes, in comparison to the previous year in each case, for the period since 1990. For CO_2 from the energy sector, for example, it is clear that largely temperature-related fluctuations over time – especially variations in winter temperatures – influence heating patterns. Such fluctuations thus affect energy consumption for space heating, thereby having a major impact on annual trends in energy-related emissions. Consequently, any trend analysis should always cover periods of several years.

Industrial processes (including product use)

In the area of emissions from industrial processes, carbon dioxide and nitrous oxide are the predominant greenhouse gases. Relatively noticeable changes in emissions of F gases, on the other hand, have no major impacts on overall trends, because such emissions account for only a small share of total emissions.

Emissions from industrial processes are closely tied to production levels. CO_2 emissions trends, in particular, reflect economic trends in the mineral, chemical and metal-producing industries.

The trend for N_2O emissions has been decoupled from production ever since adipic acid producers' emissions-reducing measures began taking effect. In 1997 and 2010 in particular, those measures yielded considerable reductions in this sector's N_2O emissions. Overall since 1990, the sector's N_2O emissions have decreased to about one-twentieth of their outset level.

For greenhouse gases since 1990, and for all industrial processes and product use combined, a reduction of 42.7 % GHG equivalents results, along with considerable emissions decreases with respect to the previous year, 2019.

Agriculture

The decrease in agricultural emissions since 1990, amounting to over 20.5 %, is due primarily to reductions in livestock populations, although it is also due to reductions in emissions from agricultural soils and from fertiliser use. In sum, the trend of the past few years has been continuing.

Land use, land-use changes and forestry

The reduction in greenhouse-gas removals via land-use changes and forestry is due primarily to a change of the sink function in the category "Forest Land remaining Forest Land". That change has been caused primarily by storm events that have damaged very large numbers of trees. In 1990, Germany was hit by a series of hurricanes that damaged about 70 million m^3 of timber. In 2007, hurricane "Kyrill" struck, leaving behind about 37 million m^3 of damaged timber. At present, as a result of drought and related beetle infestations in the period 2018 through mid-2020, timber damage is estimated to have reached about 178 million m^3 (BMEL, 2020). The figures reported for the years 2018-2020 do not yet reflect the full extent of all of this timber damage. Further changes resulted from adjustments of models, and from corrections in the emission factors used for conversions of Woody Grassland to Forest Land and for afforestation.

Waste and wastewater

The most significant emissions reduction, at 76.9 %, occurred in the area of waste & wastewater. In that area, intensified recycling of recyclable materials ("yellow sack" for recyclable materials, Ordinance on Packaging, etc.), and the ban, in effect since June 2005, on landfilling of biodegradable waste (achieved for the most part via mechanical-biological waste treatment), have reduced annual quantities of landfilled waste. All in all, these factors have reduced landfill emissions by 80.2 %. Emissions from wastewater treatment, which also belong to this category, are produced in considerably lower quantities than landfill emissions are. Nonetheless, they also decreased very sharply.

The relevant detailed data are presented in Table 585 in Annex Chapter 22.3.

Table 14: Changes in greenhouse-gas emissions in Germany, by categories, since 1990 / since the relevant previous year

Emissions change with respect to 1990; change in %	1990	1995	2000	2005	2010	2011	2012	2013	2014	2105	2016	2017	2018	2019	2020
1. Energy	0.0%	-11.5%	-16.1%	-19.7%	-22.7%	-25.0%	-24.4%	-22.7%	-26.6%	-26.1%	-25.8%	-27.6%	-30.5%	-35.0%	-41.3%
2. Industrial processes	0.0%	1.8%	-19.6%	-22.0%	-35.4%	-35.5%	-36.5%	-36.7%	-36.8%	-37.8%	-35.9%	-32.0%	-35.0%	-38.3%	-42.7%
3. Agriculture	0.0%	-13.2%	-13.6%	-17.7%	-18.2%	-18.0%	-17.1%	-16.0%	-14.2%	-14.4%	-15.0%	-16.0%	-18.3%	-19.4%	-20.5%
4. Land use, land-use changes & forestry	*0.0%*	-191.1%	-135.5%	-83.9%	-154.4%	-159.2%	-196.5%	-186.4%	-183.8%	-175.7%	-183.2%	-181.9%	-174.3%	-155.2%	-141.7%
5. Waste	0.0%	0.2%	-25.3%	-44.2%	-61.9%	-64.0%	-66.0%	-68.0%	-69.6%	-71.2%	-72.6%	-73.7%	-74.9%	-75.8%	-76.9%
Emissions change, in each case with respect to the previous year; change in %	**1990**	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
1. Energy	0.0%	-0.2%	-0.3%	-2.4%	5.0%	-3.0%	0.9%	2.2%	-5.0%	0.7%	0.3%	-2.4%	-4.0%	-6.5%	-9.7%
2. Industrial processes	0.0%	-1.7%	3.8%	-4.2%	-4.9%	-0.1%	-1.5%	-0.4%	-0.2%	-1.6%	3.1%	6.2%	-4.5%	-5.0%	-7.2%
3. Agriculture	0.0%	0.0%	-1.0%	-0.3%	-0.8%	0.1%	1.2%	1.3%	2.2%	-0.3%	-0.7%	-1.1%	-2.8%	-1.3%	-1.4%
4. Land Use, Land Use Change and Forestry (CO_2, CH_4 & N_2O)	*0.0%*	-21.3%	-68.1%	-45.6%	-25.8%	8.7%	63.0%	-10.4%	-3.0%	-9.7%	9.9%	-1.6%	-9.3%	-25.7%	-24.4%
5. Waste	0.0%	-2.5%	-5.2%	-6.0%	-7.2%	-5.4%	-5.6%	-5.9%	-4.9%	-5.3%	-5.0%	-4.0%	-4.3%	-3.7%	-4.6%

2.4 Description and interpretation of trends in emissions of indirect greenhouse gases and of SO_2

The relative development of emissions of indirect greenhouse gases and SO_2 are graphically depicted, in each case as time series since 1990, in Figure 15 and in Table 13. Over this period, considerable reductions of emissions of these pollutants have been achieved. For example, emissions of SO_2 decreased by 95.7 %, while those of CO decreased by 81.2 %, those of NMVOC decreased by 73.4 % and those of NO_X decreased by about 65.6 %.

The vast majority of emissions of sulphur dioxide, nitrogen oxide and carbon monoxide are caused by stationary and mobile combustion processes. In the category of NMVOC emissions, however, solvent use is the most important emissions factor.

A range of different factors are responsible for this trend. These factors, which differ in the significance and extent of their relevance, include:

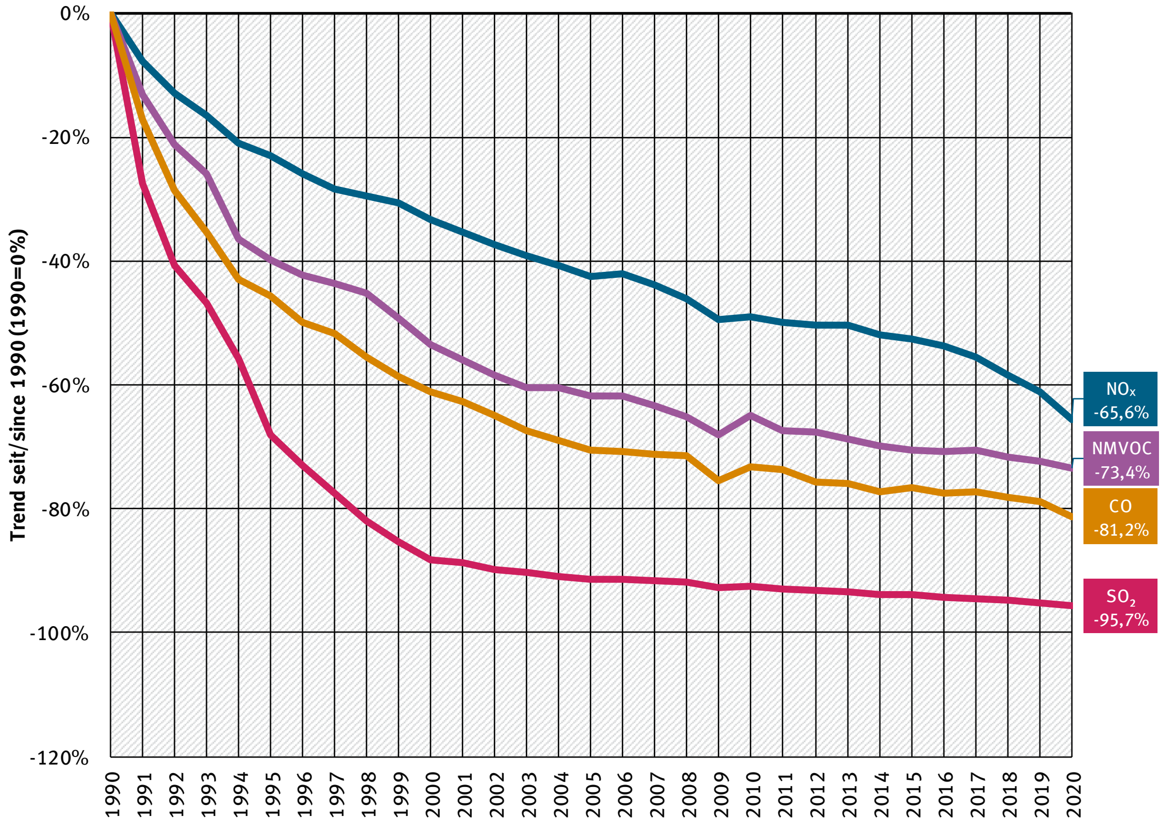
- As a result of Germany's reunification in 1990, emissions from the territory of the former GDR in particular made the starting level relatively high.

- In the years that followed, obsolete industrial facilities in the eastern part of Germany were decommissioned. Some of the old installations were replaced with new installations that met requirements for state-of-the-art systems at the time. Non-decommissioned old installations were extensively retrofitted with emissions-reduction and efficiency-enhancing equipment.
- In addition, changes were made in the mix of fuels used. In eastern Germany in particular, local-lignite fractions were reduced in favour of energy carriers such as natural gas and petroleum, which produce fewer emissions.
- In the transport sector, newer vehicles equipped with emissions-control technology were introduced.
- In the years since 1990, the immission-protection provisions of the former Federal Republic of Germany have become legally binding for eastern Germany. Following the expiration of provisional rulings, applicable laws have been repeatedly adapted in keeping with technological progress.
- Established legal regulations and market-economic incentives have led to thriftier use of energy and raw materials.
- International legislation, particularly from the European Community, has had an emissions-reducing effect.
- Increasing use of renewable energy sources (electricity/heat from solar and wind systems, and from geothermal systems) has also had an impact on emissions of indirect greenhouse gases, especially in recent years.

Descriptions of the emission calculations for these pollutants, along with additional, detailed parameters influencing the emissions trends for the various individual air pollutants involved, are provided on the website of the Federal Environment Agency[21].

[21] https://www.umweltbundesamt.de/themen/luft/emissionen-von-luftschadstoffen and within the Informative Inventory Report (IIR): http://iir.umweltbundesamt.de

Figure 15: Emissions trends for indirect greenhouse gases and SO_2



2.5 Description and interpretation of emissions trends with regard to the KP-LULUCF inventory, for aggregated emissions and by activity and greenhouse gas

Germany reports under KP-LULUCF Article 3 (3) (Afforestation/Reforestation, AR; Deforestation, D). In the second commitment period, Germany has to credit Forest Management (FM) activities pursuant to Article 3 (4) of the Kyoto Protocol. The following activities have been selected and reported as voluntary activities under Article 3.4 of the Kyoto Protocol:

- 1. Cropland management (CM)
- 2. Grazing land management (GM).

Emissions of the greenhouse gases carbon dioxide, methane and nitrous oxide are reported.

Under Article 3.3, it is reporting emissions of 549.05kt CO_2-eq. for the year 2020. The emissions consist of -725.09 kt CO_2-eq. of removals via afforestation and reforestation and 1,274.14 kt CO_2-eq. of emissions from deforestation. With regard to afforestation and deforestation, CO_2 emissions of 420.85 kt CO_2, CH_4 emissions of 60.74 kt CO_2-eq. and N_2O emissions of 67.45 kt CO_2-eq. are being reported.

Under Article 3.4, it is reporting removals of -17,081.05 kt CO_2-eq. in the year 2020. That figure comprises removals of -54,038.73 kt CO_2-eq. from forest management, and emissions of 16,551.80 kt CO2-eq. from cropland management and of 20,465.60 kt CO_2-eq. from grazing land management. The emissions for the three activities break down as follows by gases: CO_2: -19,465.71 kt; CH_4: 1,222.07 kt CO2-eq.; and N_2O: 1,162.59 kt CO_2-eq.

No trends are apparent in the areas of afforestation and deforestation, and of forest management, cropland management and grassland management. The annual values for the period as of 2013 fluctuate. In some years, they are lower than the average value for the period 2013 through 2020, and in some years they are higher.

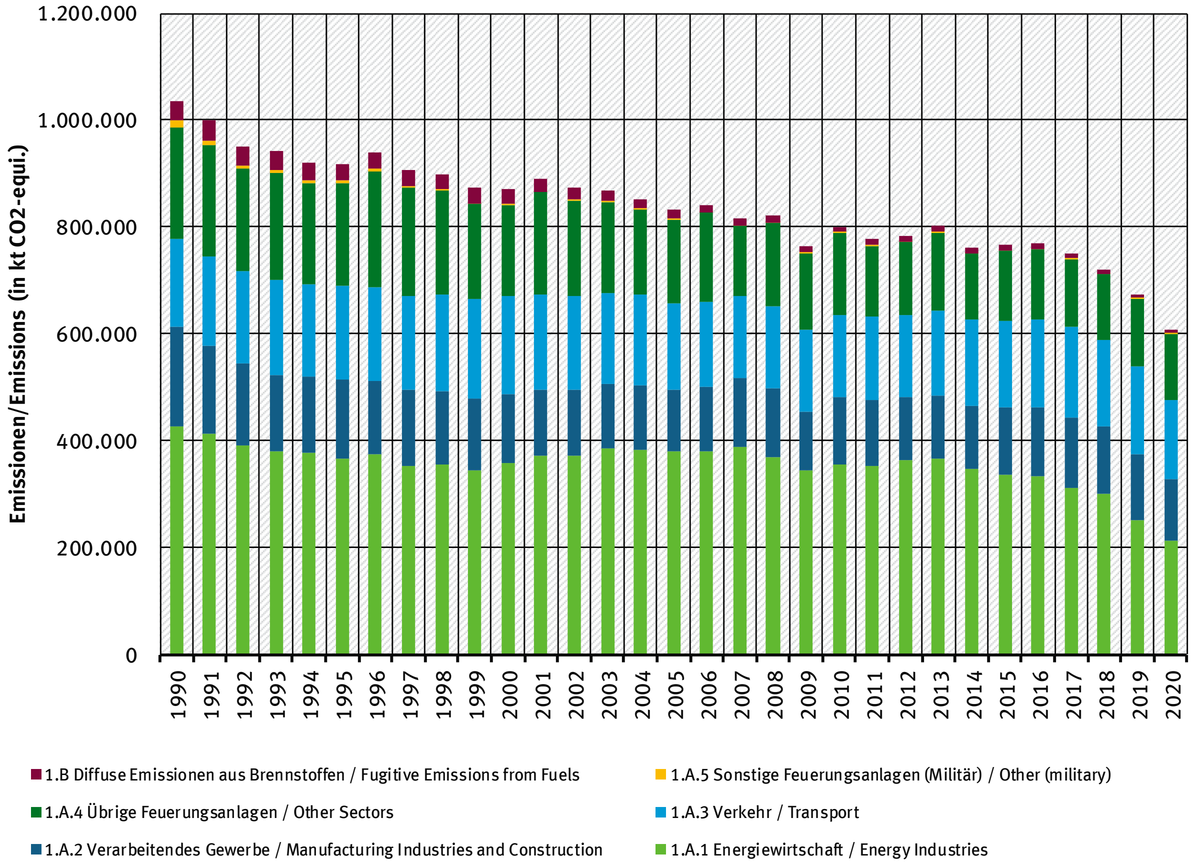
Table 15: Emissions in 2020 for the KP-LULUCF activities afforestation and deforestation, pursuant to Article 3.3, and for forest management, cropland management and grazing land management pursuant to Article 3.4.

Category	Emissions, 2020 [kt CO_2-eq.]
KP 3.3 Afforestation/Reforestation	-725.09
KP 3.3 Deforestation	1,274.14
KP 3.4 Forest Management	-54,098.45
KP 3.4 Cropland Management	16,551.80
KP 3.4 Grazing Land Management	20,465.60

3 Energy (CRF Sector 1)

3.1 Overview (CRF Sector 1)

Figure 16: Overview of greenhouse-gas emissions in CRF Sector 1[22,]



For determination of activity data from combustion, different models are used for mobile and stationary sources. The model used for stationary sources is the "Balance of Emissions Sources" ("Bilanz der Emissionsursachen" – BEU), while the model used for mobile sources is the "Transport Emission Estimation Model" (TREMOD). In both models, combustion-related activities are determined and then recorded in the "Central System of Emissions" (CSE) emissions database.

Within the CSE, relevant emissions are then calculated by multiplying these combustion-related activities by the pertinent emission factors (cf. Chapter 18.8). In the process, complete oxidation of the carbon contained in the fuels is assumed.

3.2 Combustion of fuels (1.A)

The activity data for stationary combustion are calculated in the "Balance of Emissions Sources" (BEU) model. This model, which was developed by the Federal Environment Agency, uses as its primary database the Energy Balance of the Federal Republic of Germany, which is prepared primarily on the basis of official statistics. The Energy Balance is described in detail in Chapters 18.1 through 18.4.

[22] CO_2 emissions from, and removals in, soils are reported under land-use changes and forestry.

With the help of additional statistics, and of various assumptions, these data on the various sectors of energy transformation and final consumption are then further disaggregated and supplemented to the extent necessary for adequate emissions representation. Relevant criteria for this work include permits under immissions-control laws, technologies and differentiation between certain fuels. The model consists of two parts: a sub-model for the old German Länder, covering the years 1987-1994, and a sub-model for all of Germany, covering the years as of 1995. The model for all of Germany has been revised and, in the reports of two research projects (FKZ 203 41 142: Graichen et al. (2005) and 204 41 132: Heilwig (2002)) documented in detail. Since 2009, relevant calculations have been carried out with the help of a database-supported system of the BEU that is based on MESAP software and that was developed in the framework of the research projects FKZ 204 42 203/03 and FKZ 360 16 010 (GICON, 2008), via an approach similar to that used for the sub-model for Germany. The energy-data model has been regularly updated since then, by the Federal Environment Agency. Data for the new German Länder, for the period 1990-1994, have already been entered into the CSE. The manner in which those data were obtained is described in detail in Chapter 19.1.1.

The following Energy Balance lines are used for determination of emissions-relevant fuel inputs from stationary sources:

A: Transformation inputs (Energy Balance lines 9 through 19)

1. **Public thermal power stations** (line 11) are plants whose operators are sited within the public utlity sector. This category also includes industrial plants which operate their power stations together with electricity utility companies, as joint-venture power stations. The fuel input for electricity generation is reported here. This line of the Energy Balance also includes the fuel input in public thermal power stations attributable to electricity production.
2. **Industrial thermal power stations** (line 12) comprise the following operator groups:
   - Power stations in the hard-coal-mining sector,
   - Power stations in the lignite-mining sector,
   - Power stations in the petroleum-processing sector (refinery power stations),
   - Power stations that generate single-phase power for Deutsche Bahn AG (German Railways) (until 1999, the relevant input amounts for Deutsche Bahn power stations were reported under 1.A.2.g.vii (EB line 12); as of 2000, they have been reported together with public power stations under 1.A.1.a (EB line 11)),
   - Industrial power stations (quarrying, other mining, manufacturing industry).

3. **Hydroelectric, wind-power, photovoltaic systems and other similar systems** (line 14) comprises all systems/plants that generate electricity from biogas, landfill gas, sewage-treatment gas or solid or liquid biomass and feed the electricity into the public grid. In addition, this section of the Energy Balance also reports on fuel inputs in mini-CHP systems fired with natural gas or light heating oil. Since no cut-off limit applies for such systems, this category includes very small systems in the residential and commercial/institutional sectors.
4. **Thermal (CHP) power stations** (line 15): only the fuel input which can be allocated to district heat generation is given. Adding lines 11 and 15 together produces the total fuel input in public thermal power stations. The district heat generated is fed into the public heating grid. These stations also supply industrial customers with process heat.
5. **District heating stations** (line 16): here, the fuel input for the public district heat supply, from heating stations, is given. The facilities are often used to cover peak loads in district heating networks in which the basic load is met by thermal power stations.

B: Energy consumption in the transformation sector (Energy Balance lines 33 through 39)

6. Lines 33 to 39 and the total line 40 (**Energy consumption in the transformation sector**) include the fuel input for heat generation which is needed to operate the transformation stations. No distinction is made here with regard to the type of heat generation involved. This means that fuel inputs for heat generation in combined heating and power stations, steam and hot water boilers and process firing installations are combined. There is an inconsistency in the Energy Balance with respect to summing-up for lignite pits and briquette plants. Since 1980, this own consumption has been listed together with production-related transformation inputs of briquette plants, in line 10. As a result, the emissions-causing inputs within own consumption can no longer be read out of the Energy Balance; they must be calculated from the transformation input. The fuel inputs used to generate heat in combined heat and power generation stations, together with fuel inputs used for electricity generation by the power stations of hard coal pits, lignite pits and refinery power stations, combine to form the total fuel input in such plants. Deduction, from the total listed in line 40, of fuel inputs for heat generation in power stations leaves the quantity of fuel used in process firing installations, steam and hot water boilers.

C: Final energy consumption (Energy Balance lines 46 through 67)

7. **Final energy consumption by industry** (line 60 of the Energy Balance) refers to the fuel used for heat generation which is required for both production purposes and space heating. Here as well, no distinction is made with regard to the type of heat generation involved. Hence, a part of the final energy consumption in these categories, together with industrial power stations' fuel input for generating electricity, constitutes the total fuel input in such facilities.
8. The data on **Final energy consumption in the residential sector** (line 66 of the Energy Balance) comprise fuel inputs for heat generation and include the application areas of heating, water heating and cooking.
9. The data on **final energy consumption in the commercial/institutional sector and by other consumers** (line 67 of the Energy Balance) comprise fuel inputs used for hot water production, space heating and process-heat generation in this sector/area.

The Energy Balance data scheme is no longer able to accommodate all of the diverse requirements of national and international energy and emissions reporting. For example, the Energy Balance combines fuel inputs

- in facilities with different requirements under immission protection legislation (e.g. large furnaces, medium-sized furnaces, small furnaces, waste incineration plants);
- in plants that operate according to different technical principles (e.g. steam turbine power stations, gas turbine power stations, combustion-engine stations);
- that exhibit regional peculiarities (e.g. different individual mining regions have different qualities of crude lignite);
- with different category allocations in national and international emissions reporting;
- that are listed in different Energy Balance lines, in keeping with their intended purpose (for electricity or heat generation), but are used in a single facility group (e.g. steam turbine power stations).

These characteristics have impacts on emissions behaviour. In order to make allowance for the various differing requirements that thus arise, the Energy Balance data in the model *Balance of Emission Causes* (BEU) are disaggregated, using additional statistics as well as the Federal Environment Agency's own calculations. The following Figure 17 provides an overview of the relevant structure:

Balance of emission causes (BEU)
The categories include: • Public thermal power stations, • Hard-coal mining (until 2013), • Lignite mining, • Deutsche Bahn AG (until 1999) • Production of refined petroleum products, • District heating stations, • Other energy transformation • Quarrying of non-metallic minerals, other mining and manufacturing industry (further sub-classification of process combustion), (The residential, commercial/institutional and other consumers sectors are listed and analysed directly within the CSE, outside of the BEU model.)
The types of facilities involved include: • Steam turbine power stations, • Gas turbine power stations, • Gas and steam turbine power stations, • Motor power stations, • Boiler furnaces (excluding power station boilers), • Process furnaces (sub-classified into 12 processes).
By fuels/energy sources: • About 40 different fuels
On the basis of immission protection legislation provisions, the following are differentiated: • Installations under the 13th Ordinance Implementing the Federal Immission Control Act (13. BImSchV), • Installations under the 1st Ordinance Implementing the Federal Immission Control Act (17. BImSchV), • Installations under the 1st Ordinance Implementing the Federal Immission Control Act (1. BImSchV), • Installations under the Technical Instructions on Air Quality Control (TA Luft) • Installations not subject to licensing

Abbreviations:

BImSchV	Ordinance Implementing the Federal Immission Control Act,
TA-Luft	First General Administrative Provision on the Federal Immission Control Act (Clean Air Directive)

Figure 17: Characteristics of the Federal Environment Agency's structure of the Balance of Emission Causes, with regard to disaggregation of the Energy Balance

The BEU model is designed to provide a data structure that can be used in meeting a range of different reporting obligations. In particular, finer disaggregation has been needed for determination of emissions of "classical" air pollutants, including calculation of nitrous oxide and methane emissions.

Despite the conversion of the Energy Balance to the classification of industrial sectors (WZ 93) and altered grouping of energy resources from the year 1995 onwards, it has been possible to fit the data within the outlined basic structure; this has facilitated preparation of consistent time series. As of 2008, classification of economic sectors (Wirtschaftszweige = WZ), in energy statistics, was again changed – from the "WZ 2003" standard to the "WZ 2008" standard. As a result, activity data relative to process combustion are now being taken from individual statistics, and documented, in keeping with the relevant key for the change (Statistisches Bundesamt (2008): "Umsteigeschlüssel WZ 2003 auf WZ 2008" (key for the change from WZ 2003 to WZ 2008))

The structure and the characteristics of the Balance of Emissions Sources (BEU) were presented and described in the 2011 National Inventory Report – in Figure 20 and in Tables 16 through 22 (in tabular form). Since there have been no structural changes in the BEU since then, here we simply refer to that source, which assigns the structural elements of the BEU to the database of the Central System of Emissions (CSE), via unique names.

In addition to being classified in the aforementioned structure, the various fuels and energy sources are listed individually in the database. In the main, the various fuel categories are oriented to the Energy Balance. In some cases, there is a need to subdivide the individual fuel categories. This is done with the help of energy statistics, coal-industry statistics and a smaller number of sets of association statistics. The various fuel-quality levels, with their various carbon-content levels, are combined, in keeping with reporting provisions, in the following five categories: gases, liquid fuels, solid fuels, biomass and other fuels. Because of the many different fuels involved, and because the fuels' shares of the various categories vary, the implied emission factors listed in the CRF tables often change.

To determine activity data for waste in waste incineration plants and for co-combustion in combustion systems in the sectors Public electricity and heat generation (1.A.1) and Manufacturing (1.A.2), the Federal Environment Agency, working in the framework of a research project of its own, has carried out a thorough evaluation of fuel inputs in energy statistics (Energiestatistik) 060 and 066 (Statistisches Bundesamt, FS 3, R 3.1.7) and waste statistics (Statistisches Bundesamt, 2021a) of the Federal Statistical Office. To ensure that all fuel quantities were taken into account, as completely as possible, the relevant waste quantities in both sets of statistics, broken down by individual industries and economic sectors, were compared. To that end, the waste quantities from waste statistics were allocated to the same fuel groups used in energy statistics: solid biomass, sewage sludge, household and settlement waste and industrial waste. In recent years, the fuel quantities recorded in energy statistics have continually increased. The reasons for this include the fact that in recent years more and more solid biomass (primarily waste and scrap wood) and processed settlement waste have been used for energy generation. Nonetheless, the waste quantities in energy statistics are still smaller than those in waste statistics. For that reason, the activity data for household/municipal and industrial waste are taken from the Energy Balance and then supplemented with the difference relative to waste statistics. In the Energy Balance, waste wood is listed as solid biomass, and not as waste. Consequently, to prevent double counting, in waste statistics it has to be deducted from the listed inputs for waste-incineration and combustion systems.

With regard to waste composition, as of the NIR 2006 the fossil and biogenic fractions of household / municipal waste are listed separately, in a ratio of 1:1. That split factor has been confirmed via a published research project, "Use of biogenic waste fractions for energy generation" ("Nutzung der Potenziale des biogenen Anteils im Abfall zur Energieerzeugung") (Hoffmann et al. (2011); Förderkennzeichen (funding reference number) 3707 33 303). The biogenic fractions of industrial waste vary widely by industrial sector and installation type. Accordingly, for the sector Manufacturing (1.A.2), and for the sectoral classifications iron and steel, paper, cement and lime, detailed substitute-fuel data continue to be used that are provided by the associations German Iron and Steel Institute (VDEh), German Pulp and Paper Association (VDP), the German Lime Association (BV Kalk) and the German Cement Works Association

(VDZ). The biogenic fraction of the industrial waste in the aforementioned sectors was determined via the research project "Inputs of secondary fuels" ("Einsatz von Sekundärbrennstoffen") (Lechtenböhmer et al. (2006c), funding reference number 20442203/02).

3.2.1 Verification of the sectoral approach for CRF 1.A

3.2.1.1 Comparison with the CO_2 Reference Approach

Reporting on combustion-related CO_2 emissions is centrally important within the context of international climate protection, because such emissions account for a predominant share of total emissions. To this end, industrialised countries adopt the sectoral approach, which addresses the level of individual energy consumption sectors and therefore permits greater differentiation in analysis of emissions structures.

In addition to being determined, via this "Sectoral Approach" (1.AA), the CO_2 emissions are determined with the Reference Approach (1.AB) pursuant to the 2006 IPCC Guidelines (IPCC (2006a) Vol. 2, Chapter 6: Reference Approach). This Reference Approach makes use of primary data relative to production, imports and exports of fuels, as well as of data on changes in stocks, that are taken directly from the National Energy Balances of the Working Group on Energy Balances (AGEB).

As with the Sectoral Approach, complete oxidation is assumed. In conformance with the 2006 IPCC Guidelines, the carbon emission factors used are equivalent to those of the Sectoral Approach and thus comprise nationally referenced values. The so-calculated CO_2 emissions data are used for verification of the Sectoral Approach.

The Reference Approach is carried out for all years as of 1990. In each case, the basis for relevant calculations consists of the National Energy Balances on primary energy consumption. At the time the inventory was being prepared, only a provisional balance was available for the year 2020.

The results of the Reference Approach (1.AB) are presented in Table 16 and in Chapter 19 in Annex 4 of this report. In Figure 18 and Figure 19, they are compared with other available data sets.

3.2.1.2 Verification with other data sets available for Germany

In the following, the results of the detailed sectoral calculation (i.e. the by-polluter calculation) of energy-related CO_2 emissions for Germany in keeping with the requirements of the *IPCC Guidelines* are compared, for verification purposes, with other national and international data sets available for Germany.

Specifically, the calculation results are compared with the following data sets:

- International Energy Agency (IEA): *CO_2 emissions from fuel combustion*
- Länder working group on Energy Balances (Länderarbeitskreis Energiebilanzen): CO_2 Balances: *CO_2 emissions, by fuels, and not including international air transports*[23]

Table 16 and Figure 18 compare the results of the different approaches for calculating CO_2 emissions, throughout the different years involved. The key development trends emerge in all calculation approaches, including the Reference Approach, albeit at differing levels. In Figure 19,

[23] https://www.lak-energiebilanzen.de/eingabe-dynamisch/?a=c150

the relative discrepancies in the data records are depicted in order to illustrate these level differences.

Nevertheless, on the whole, these comparisons clearly confirm the CO_2 emissions figures calculated for Germany. On an average for the years 1990 to 2019, the total national energy-related emissions calculated with the *Sectoral Approach* (cf. UBA (CRF 1.AA)) differ as follows from the relevant comparative data sets:

- IEA: 2.6 %
- LAK Energiebilanzen (Working Group on Energy Balances): 0.8 %

Table 16: Comparison of CO_2 inventories with other independent national and international results for CO_2 emissions

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Sectoral approach UBA (CRF 1.AA)	**985.3**	**951.4**	**906.2**	**896.6**	**877.9**	**877.6**	**899.6**	**868.9**	**862.3**	**837.1**
IEA: CO_2 emissions from fuel combustion	**940.3**	**917.8**	**877.8**	**872.0**	**859.2**	**856.6**	**887.2**	**855.0**	**847.0**	**815.0**
Discrepancy between IEA and UBA (1.AA)	45.0	33.6	28.4	24.6	18.6	21.0	12.4	13.9	15.3	22.0
	4.8%	3.7%	3.2%	2.8%	2.2%	2.5%	1.4%	1.6%	1.8%	2.7%
LAK: Energy-related CO_2, German Länder	**965.7**	**945.9**	**903.1**	**896.4**	**873.6**	**877.1**	**896.4**	**870.2**	**867.5**	**840.0**
Discrepancy with respect to UBA (1.AA)	**19.6**	**5.5**	**3.1**	**0.2**	**4.3**	**0.5**	**3.2**	**-1.3**	**-5.2**	**-2.9**
	2.0%	0.6%	0.3%	0.0%	0.5%	0.1%	0.4%	-0.1%	-0.6%	-0.3%
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Sectoral approach UBA (CRF 1.AA)	**836.2**	**859.0**	**844.3**	**841.1**	**827.1**	**808.7**	**819.9**	**794.6**	**800.2**	**744.2**
IEA: CO_2 emissions from fuel combustion	**812.3**	**831.6**	**818.0**	**820.8**	**804.8**	**786.7**	**799.3**	**766.8**	**775.3**	**720.3**
Discrepancy between IEA and UBA (1.AA)	23.9	27.4	26.3	20.2	22.3	22.0	20.6	27.8	25.0	23.9
	2.9%	3.3%	3.2%	2.5%	2.8%	2.8%	2.6%	3.6%	3.2%	3.3%
LAK: Energy-related CO_2, German Länder	**841.3**	**865.5**	**843.9**	**839.4**	**829.0**	**816.1**	**821.4**	**800.5**	**805.1**	**753.1**
Discrepancy with respect to UBA (1.AA)	**-5.0**	**-6.5**	**0.4**	**1.7**	**-1.9**	**-7.4**	**-1.5**	**-5.9**	**-4.9**	**-8.9**
	-0.6%	-0.8%	0.0%	0.2%	-0.2%	-0.9%	-0.2%	-0.7%	-0.6%	-1.2%
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Sectoral approach UBA (CRF 1.AA)	**781.5**	**757.6**	**763.1**	**780.8**	**741.9**	**746.8**	**749.8**	**731.4**	**702.5**	**657.7**
IEA: CO_2 emissions from fuel combustion	**758.8**	**731.3**	**744.8**	**763.9**	**723.3**	**729.7**	**730.8**	**718.8**		
Discrepancy between IEA and UBA (1.AA)	22.7	26.3	18.3	16.9	18.6	17.1	19.0	12.6		
	3.0%	3.6%	2.5%	2.2%	2.6%	2.3%	2.6%	1.8%		
LAK: Energy-related CO_2, German Länder	**787.5**	**760.2**	**768.1**	**774.7**	**750.1**	**750.7**	**758.7**	**742.5**	**729.7**	**683.8**
Discrepancy with respect to UBA (1.AA)	**-6.1**	**-2.6**	**-5.0**	**6.1**	**-8.2**	**-3.9**	**-8.9**	**-11.1**	**-27.2**	**-26.2**
	-0.8%	-0.3%	-0.7%	0.8%	-1.1%	-0.5%	-1.2%	-1.5%	-3.7%	-3.8%

Source: CO_2 Emissions from Fuel Combustion (2018 Edition), IEA, Paris.

Figure 18: CO_2 emissions in Germany – comparison of results of national and international calculations

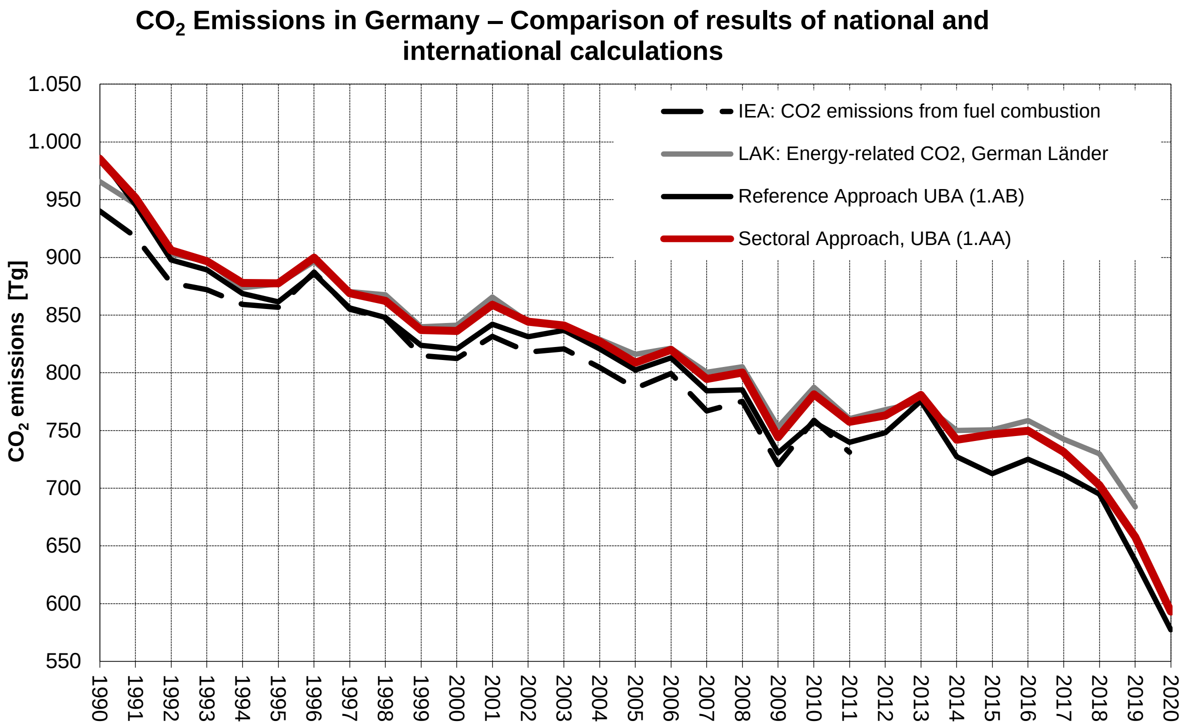
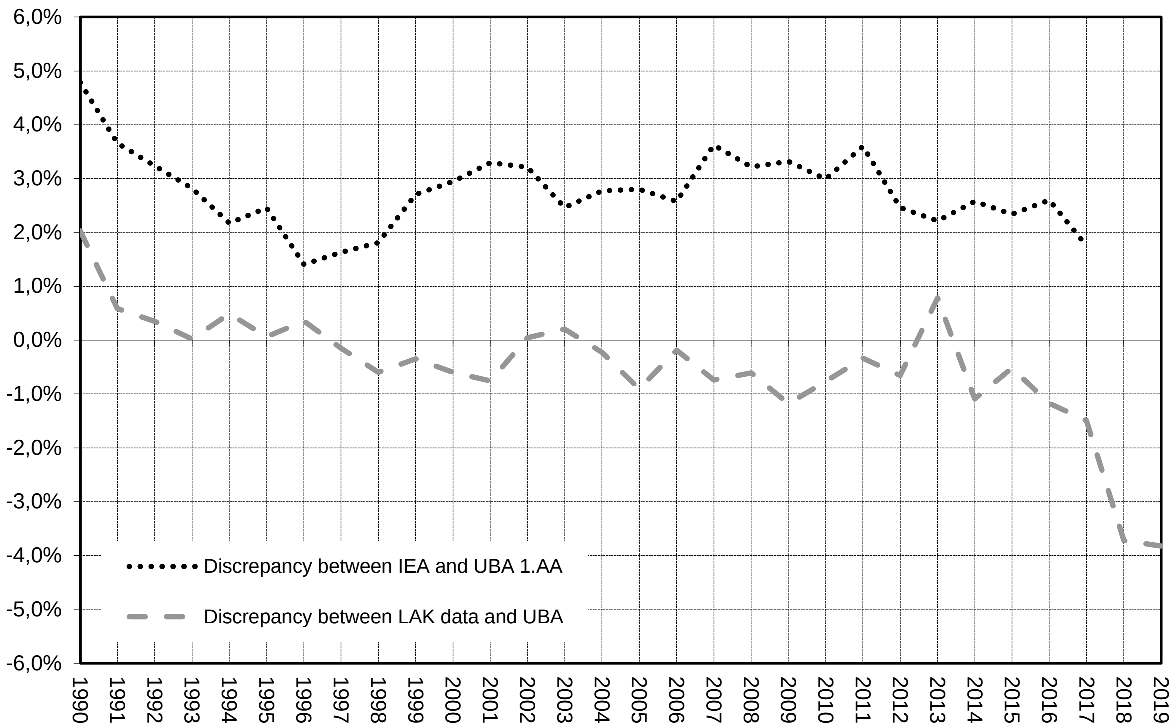


Figure 19: CO_2 emissions in Germany – comparison of relative discrepancies of national and international calculations



3.2.1.2.1 Comparison with the IEA results

The data used are data published annually, in updated form, by the IEA (most recently: OECD/IEA 2022). Since the method for determining, processing and applying the basic data used for this purpose currently is not precisely comparable with the national procedure in Germany at present, and relevant addition methodological information is lacking – particularly information with regard to the detailed data used – for now this comparison is provided only for reasons of completeness.

In spite of this restriction, the comparison with the results obtained with IEA's Sectoral Approach confirms the data obtained via the national, detailed method: The average discrepancy over the period to date – 28 years – is 2.6 %. In all of the years concerned, the comparable national emissions are higher than the pertinent results published by the IEA. The individual discrepancies vary throughout a range of -4.8 % (1990) to -1.4 % (1996).

3.2.1.2.2 Comparison with the data obtained for the individual Länder

The German Länder publish data on their own CO_2 emissions[24]. Regarding the relevant procedures, responsible and participating institutions, and methodological descriptions, we call the reader's attention to that Web site and to the pertinent more detailed remarks in the NIR 2009.

The following section presents a comparison, for energy-related CO_2 emissions, of a) available Länder results published to date in the Balance of Emissions Sources (BEU) and b) inventories calculated at the national level. One difficulty hampering the comparison is that pertinent information for the individual Länder is not always available in the form of complete time series. Gaps in the time series were closed primarily via interpolation. Because data for 2020 are currently available for only one of the German Länder, the comparison is limited to the period 1990 to 2019.

[24] Landesarbeitskreis Energiebilanzen – CO_2-Bilanzen http://www.lak-energiebilanzen.de/co2-bilanzen/

Table 17: Comparison of the results of CO_2 calculations of individual Länder with corresponding figures from the federal inventories

	1990	1991	1992	1993	1994 [Gg CO_2]	1995	1996	1997	1998	1999
Baden-Württemberg	74,305	78,779	78,059	78,821	74,144	77,844	81,331	78,233	79,635	77,045
Bavaria	83,702	88,436	86,617	89,651	86,903	87,504	91,765	89,378	91,320	89,086
Berlin	26,529	27,605	24,761	26,099	25,130	24,188	24,361	23,315	22,543	23,269
Brandenburg	80,236	64,579	57,680	55,972	52,951	50,255	49,820	50,302	58,613	57,839
Bremen	13,381	13,497	12,812	12,417	13,244	13,194	14,220	14,164	13,846	12,794
Hamburg	12,165	13,861	12,558	13,215	12,730	12,774	13,850	13,274	13,065	12,855
Hesse	42,674	46,353	45,991	47,344	46,999	46,902	50,172	47,191	47,060	43,868
Mecklenburg – West Pomerania	15,539	10,757	9,360	9,473	9,510	10,233	11,636	10,654	10,413	10,627
Lower Saxony	76,596	81,734	80,435	79,137	77,780	77,856	77,932	78,759	79,587	76,428
North Rhine – Westphalia	295,817	306,937	303,414	297,191	292,504	298,991	306,810	300,958	298,973	286,514
Rhineland-Palatinate	27,453	29,513	28,999	30,330	30,363	31,579	31,598	30,602	31,266	30,408
Saarland	23,680	25,750	24,378	23,194	24,289	23,109	23,829	21,802	23,769	22,800
Saxony	92,188	76,967	63,952	65,921	62,912	61,362	56,435	51,040	37,073	35,045
Saxony-Anhalt	49,522	35,226	31,172	26,901	25,715	24,865	25,250	24,538	24,735	26,566
Schleswig-Holstein	24,412	24,028	24,298	24,817	24,461	23,254	23,779	23,190	22,935	22,406
Thuringia	27,483	21,868	18,566	15,894	13,925	13,203	13,633	12,831	12,708	12,429
Total for all German Länder	**965,683**	**945,889**	**903,052**	**896,376**	**873,560**	**877,114**	**896,420**	**870,231**	**867,542**	**839,981**
National result (Sectoral approach - CRF 1.AA)	985,253	951,431	906,169	896,565	877,859	877,638	899,598	868,933	862,342	837,074
Difference between the Länder results and the national results (%)	**-19,569** **-2.0%**	**-5,542** **-0.6%**	**-3,117** **-0.3%**	**-188** **0.0%**	**-4,299** **-0.5%**	**-524** **-0.1%**	**-3,178** **-0.4%**	**1,298** **0.1%**	**5,201** **0.6%**	**2,906** **0.3%**

	2000	2001	2002	2003	2004 [Gg CO_2]	2005	2006	2007	2008	2009
Baden-Württemberg	74,176	79,606	76,299	75,895	74,989	77,135	77,931	70,610	72,394	66,223
Bavaria	87,025	88,905	82,905	81,610	80,325	77,523	78,620	71,679	76,580	73,597
Berlin	23,159	23,504	20,700	20,688	19,615	19,390	19,242	16,755	17,710	17,235
Brandenburg	60,475	60,773	61,470	58,184	58,900	59,585	57,887	58,458	57,289	53,859
Bremen	14,071	14,151	14,013	14,666	13,071	12,265	12,755	13,691	13,111	12,665
Hamburg	12,646	12,437	12,227	12,062	11,993	11,569	11,579	11,062	11,169	11,296
Hesse	44,479	46,524	43,585	43,965	43,132	42,255	41,462	38,819	39,259	37,743
Mecklenburg – West Pomerania	10,256	10,718	10,908	10,696	10,906	10,354	11,133	10,044	10,835	9,515
Lower Saxony	73,270	72,284	71,298	70,619	69,939	70,170	70,401	69,756	69,111	65,853
North Rhine – Westphalia	288,054	292,950	289,727	290,207	288,485	279,276	283,305	287,458	284,570	257,694
Rhineland-Palatinate	28,946	29,659	27,946	26,694	26,153	26,080	26,786	25,876	27,476	26,330
Saarland	23,409	23,213	22,914	23,232	23,900	24,776	23,555	25,697	22,947	18,498
Saxony	41,508	48,838	49,003	49,604	48,435	47,311	48,493	46,827	46,105	46,883
Saxony-Anhalt	25,857	26,463	27,039	27,554	26,591	27,275	27,205	25,890	26,843	26,662
Schleswig-Holstein	21,906	23,185	21,866	21,802	20,780	19,720	19,747	17,468	18,829	18,547
Thuringia	12,016	12,308	12,033	11,885	11,793	11,446	11,265	10,418	10,894	10,514
Total for all German Länder	**841,253**	**865,519**	**843,934**	**839,361**	**829,007**	**816,131**	**821,365**	**800,511**	**805,122**	**753,115**
National result (Sectoral approach - CRF 1.AA)	836,208	858,980	844,301	841,061	827,085	808,723	819,850	794,600	800,218	744,232
Difference between the Länder results and the national results (%)	**5,045** **0.6%**	**6,539** **0.8%**	**-367** **0.0%**	**-1,700** **-0.2%**	**1,922** **0.2%**	**7,408** **0.9%**	**1,514** **0.2%**	**5,911** **0.7%**	**4,905** **0.6%**	**8,883** **1.2%**

	2010	2011	2012	2013	2014 [Gg CO_2]	2015	2016	2017	2018	2019
Baden-Württemberg	67,831	66,069	65,357	70,525	65,420	66,786	68,670	69,201	65,488	62,706
Bavaria	76,684	74,860	74,910	75,540	71,185	72,223	73,674	73,491	72,277	73,584
Berlin	18,897	16,565	16,660	17,231	16,310	15,700	16,016	15,752	14,511	13,675
Brandenburg	56,478	56,215	57,744	57,220	56,004	56,077	56,317	55,841	56,351	48,844
Bremen	14,037	13,153	13,359	13,412	12,793	13,281	12,959	13,340	12,415	11,443
Hamburg	11,625	10,947	10,810	10,595	11,629	14,605	15,162	15,594	16,194	14,631
Hesse	38,562	36,764	36,819	36,521	33,896	35,569	36,990	36,011	34,240	34,179
Mecklenburg – West Pomerania	10,939	10,346	10,987	10,429	10,365	10,255	10,646	9,784	9,161	*9,161*
Lower Saxony	67,803	66,491	64,181	64,964	66,223	65,593	65,258	64,040	62,973	60,149
North Rhine – Westphalia	273,556	262,903	266,944	263,294	258,132	253,148	254,266	238,477	233,771	209,843
Rhineland-Palatinate	27,313	25,330	25,602	26,782	25,329	25,847	26,338	26,629	25,942	26,683
Saarland	19,287	20,898	21,753	22,991	20,864	21,638	*21,638*	*21,638*	*21,638*	*21,638*
Saxony	47,129	44,930	46,995	49,620	49,392	47,681	48,011	49,775	49,553	46,183
Saxony-Anhalt	27,287	27,144	27,625	26,999	25,509	25,125	25,403	25,383	26,894	24,056
Schleswig-Holstein	19,357	17,506	18,027	18,097	17,179	17,238	17,097	17,168	17,733	16,683
Thuringia	10,749	10,078	10,361	10,495	9,878	9,922	10,278	10,375	10,543	10,388
Total for all German Länder	**787,535**	**760,198**	**768,133**	**774,716**	**750,107**	**750,688**	**758,721**	**742,498**	**729,684**	**683,845**
National result (Sectoral approach - CRF 1.AA)	781,485	757,628	763,103	780,791	741,946	746,783	749,812	731,410	702,521	657,691
Difference between the Länder results and the national results (%)	**6,050** **0.8%**	**2,570** **0.3%**	**5,030** **0.7%**	**-6,075** **-0.8%**	**8,162** **1.1%**	**3,905** **0.5%**	**8,909** **1.2%**	**11,089** **1.5%**	**27,163** **3.7%**	**26,154** **3.8%**

Remark: The italicised figures, in grey table cells, are not part of consistent time series. They were generated via gap-closure procedures, or by extrapolation carried out on the basis of an expert estimate (see text).

Source: Länderarbeitskreis Energiebilanzen (Last revision: 5 March 2019)

In terms of trend, the comparison found excellent agreement between the combined Länder results and the Federal inventory. On an average for the 30 years in question, the total CO_2 emissions for the Länder differed by 0.8 % from the Federal result. The extremes of the deviations ranged from -2 % in 1990 to + 3.8 % in 2019.

3.2.1.2.3 Planned improvements

Following the reporting process, the results of the comparison are regularly discussed, and reviewed with regard to potential for improvement, with the representatives of the Länder Working Group on Energy Balances (Länderarbeitskreis Energiebilanzen). At present, no concrete plans for further improvements are in place.

3.2.2 International bunker fuels

3.2.2.1 Emissions from international transports (1.D.1.a/1.D.1.b)

The area of international transports is divided into international civil aviation (1.D.1.a) and international water-borne navigation (1.D.1.b).

3.2.2.2 Emissions from international aviation (1.D.1.a)

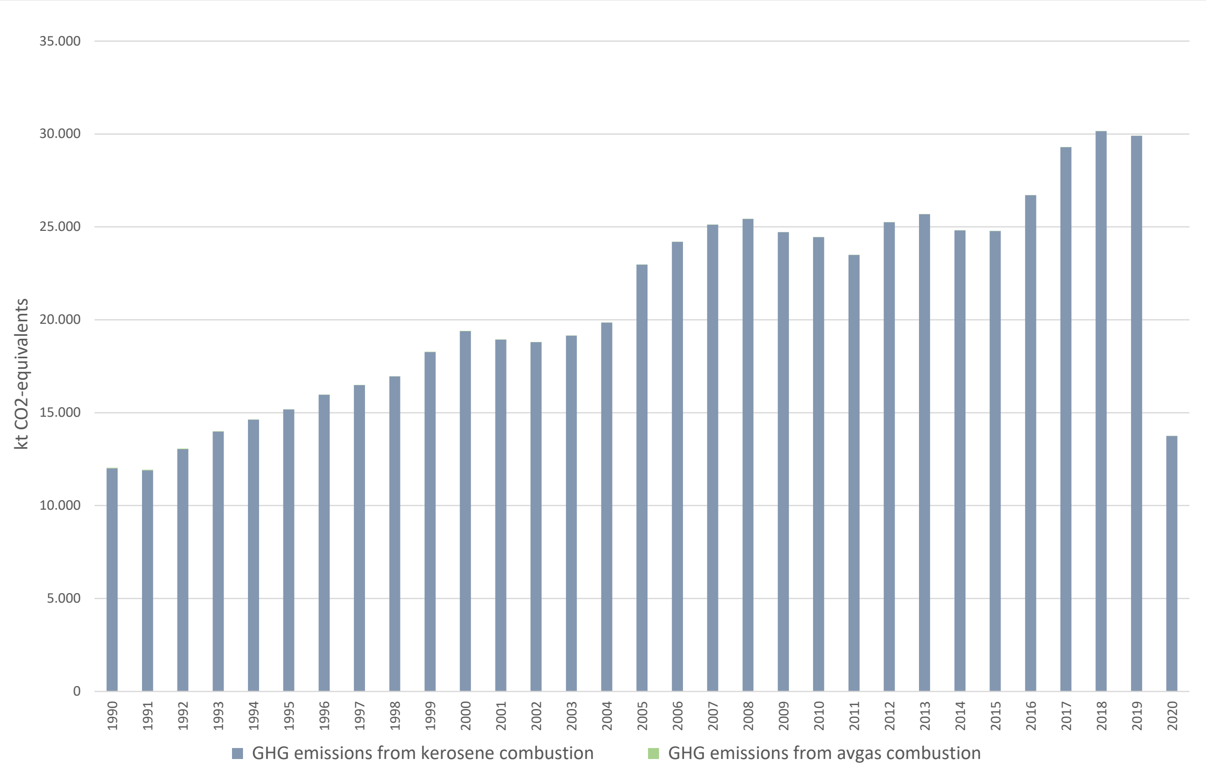
3.2.2.2.1 Category description (1.D.1.a)

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS (Tier 3)	NS/IS/M	CS / D [a]
CH_4	CS (Tier 3)	NS/IS/M	CS (M)
N_2O	CS (Tier 3)	NS/IS/M	CS (M)
NO_x, CO, NMVOC	CS (Tier 3)	NS/IS/M	CS (M)
SO_2	Tier 1	NS/IS/M	CS

[a] Co-combusted lubricants

The emissions from consumption of fuels for international civil aviation are included in the inventory calculations, but they are not reported as part of the national overall inventories, and thus they are not included in key-category analysis.

Figure 20: Greenhouse-gas emissions of international air transports departing from Germany, since 1990



3.2.2.2.2 Methodological issues (1.D.1.a)

Since German energy statistics do not break annual fuel quantities down by international and domestic air transports, that breakdown is carried out after the fact, on the basis of domestic air transports' annual shares of total fuel inputs. Those shares are calculated within TREMOD-AV (Knörr et al., 2021a).

International air transports' so-determined shares of the fuel quantities listed in AGEB (2021b), and in the official mineral-oil data (Amtliche Mineralöldaten) of the Federal Office of Economics and Export Control (BAFA, 2021), are as follows:

Table 18: International flights' annual shares of domestic deliveries of kerosene and avgas, in [%]

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Kerosene	83.9	87.9	88.2	90.3	91.4	91.8	92.1	92.7	92.7	92.7	92.8	93.2	93.3	93.1	93.0
Avgas	21.0	19.1	20.3	22.0	22.7	17.8	18.2	18.1	16.7	18.5	9.44	9.61	8.88	7.88	6.28

Source: TREMOD AV (Knörr et al., 2021a)

Additional information relative to the activity data and emission factors used is presented in Chapter 3.2.10.1 on national civil aviation.

In addition, pertinent quantities of co-combusted lubricants, along with the resulting CO_2 emissions, are recorded and reported. Pursuant to Wallfarth (2014), it is assumed that the quantities of co-combusted lubricants are equivalent to 0.01 % of the fuel quantities used (cf. the Annex Chapter 19.1.4).

3.2.2.2.3 Uncertainties and time-series consistency (1.D.1.a)

Cf. Domestic aviation, Chapter 3.2.10.1.3.

3.2.2.2.4 Source-specific quality assurance / control and verification (1.D.1.a)

Cf. Domestic aviation, Chapter 3.2.10.1.4.

3.2.2.2.5 Category-specific recalculations (1.D.1.a)

With respect to the 2021 submission, recalculations were carried out for all years concerned. This was done primarily to take account of the changes, with respect to total domestic sales, in the shares of avgas used for international flights.

Table 19: Revised annual shares of domestic deliveries of avgas, in percent

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
2022 Submission	21.0	19.1	20.3	22.0	22.7	18.5	9.44	9.61	8.88	7.88
2021 Submission	20.1	16.0	17.4	16.2	16.9	13.3	6.90	7.12	6.42	5.35
Absolute change	0.87	3.14	2.94	5.81	5.80	5.14	2.54	2.49	2.47	2.53
Relative change	4.3%	19.7%	16.9%	35.8%	34.4%	38.5%	36.9%	35.0%	38.5%	47.3%

Source: Own calculations, based on TREMOD AV

In addition, a very slight change resulted in the share, with respect to total sales in 2019, of the kerosene used for international flights.

The resulting change in fuel consumption is as follows:

Table 20: Revised fuel quantities, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Jet fuel / kerosene										
2022 Submission	162,259	205,197	262,146	310,569	330,659	335,097	361,113	396,137	407,774	404,342
2021 Submission	162,259	205,197	262,146	310,569	330,659	335,097	361,113	396,137	407,774	404,499
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-157
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.04%
Avgas										
2022 Submission	511	218	228	154	129	102	38.4	38.7	34.6	25.1
2021 Submission	490	182	195	113	95.8	73.8	28.1	28.7	25.0	17.1
Absolute change	21.3	35.9	32.9	40.6	32.9	28.4	10.4	10.0	9.60	8.07
Relative change	4.3%	19.7%	16.9%	35.8%	34.4%	38.5%	36.9%	35.0%	38.5%	47.3%
TOTAL FUEL INPUTS										
2022 Submission	162,770	205,415	262,373	310,723	330,788	335,200	361,152	396,176	407,809	404,367
2021 Submission	162,749	205,379	262,340	310,682	330,755	335,171	361,141	396,166	407,799	404,516
Absolute change	21.3	35.9	32.9	40.6	32.9	28.4	10.4	10.0	9.60	-149
Relative change	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	-0.04%

Source: Own calculations, based on TREMOD AV

These changes led to the following changes in greenhouse-gas emissions:

Table 21: Revised GHG emissions, in kt CO_2 equivalents

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Carbon dioxide – CO_2 [a]										
2022 Submission	11,922	15,047	19,220	22,762	24,232	24,555	26,456	29,022	29,874	29,622
2021 Submission	11,921	15,045	19,217	22,759	24,229	24,553	26,456	29,021	29,874	29,633
Absolute change	1.49	2.51	2.30	2.84	2.30	1.99	0.73	0.70	0.67	-11.0
Relative change	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	-0.04%
Methane – CH_4										
2022 Submission	0.200	0.145	0.139	0.143	0.139	0.139	0.149	0.168	0.179	0.162
2021 Submission	0.201	0.147	0.140	0.145	0.141	0.141	0.150	0.169	0.180	0.172
Absolute change	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.001	-0.001	-0.010
Relative change	-0.49%	-1.16%	-1.14%	-1.33%	-1.20%	-1.07%	-0.78%	-0.74%	-0.77%	-5.96%
Nitrous oxide – N_2O										
2022 Submission	0.38	0.47	0.61	0.72	0.77	0.78	0.84	0.92	0.95	0.94
2021 Submission	0.38	0.47	0.61	0.72	0.77	0.78	0.84	0.92	0.95	0.94
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Relative change	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	-0.05%
TOTAL GREENHOUSE GASES [a]										
2022 Submission	12,040	15,192	19,403	22,980	24,464	24,790	26,710	29,300	30,160	29,906
2021 Submission	12,038	15,190	19,401	22,977	24,461	24,788	26,709	29,299	30,160	29,917
Absolute change	1.48	2.50	2.29	2.82	2.28	1.97	0.70	0.68	0.64	-11.3
Relative change	0.01%	0.02%	0.01%	0.01%	0.01%	0.01%	0.00%	0.00%	0.00%	-0.04%

Source: own calculations;[a] not including CO_2 from lubricant co-combustion

3.2.2.2.6 Category-specific planned improvements (1.D.1.a)

Cf. Domestic aviation, Chapter 3.2.10.1.6.

3.2.2.3 Emissions from international water-borne navigation (1.D.1.b)

3.2.2.3.1 Category description (1.D.1.b)

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS (Tier 2)	NS/IS/M	D [a] / CS
CH_4	CS (Tier 2)	NS/IS/M	CS (M)
N_2O	CS (Tier 2)	NS/IS/M	CS (M)
NO_x, CO, NMVOC, SO_2	CS (Tier 2)	NS/IS/M	CS (M)

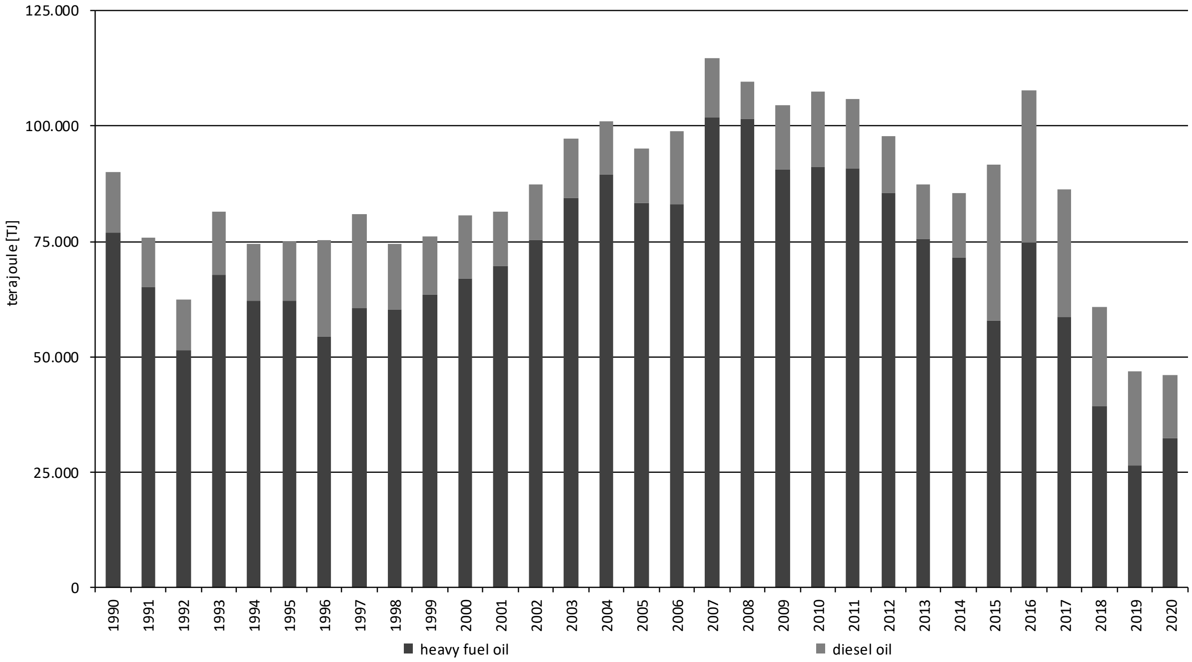
[a] Co-combusted lubricants

The emissions caused by international water-borne navigation from German ports are not reported as part of the national overall inventories, and thus they are not included in the key-category analysis.

Since 1984, consumption of heavy fuel oil has been increasing, as high oil prices have pushed up prices for diesel oil, the maritime-navigation sector has grown worldwide and use of diesel engines that can run on heavy fuel oil has increased.

The sold fuel quantities, and the emissions resulting from their combustion, are subject to wide annual fluctuations. This can be explained as the result of fuel-price differences between seaports (for example): since seagoing vessels do not have to take on fuel every time they are in port, they can avoid high fuel costs. In addition, sales are influenced by storage in ports.

Figure 21: Development of greenhouse-gas emissions from international water-borne navigation since 1990 [a]



3.2.2.3.2 Methodological issues (1.D.1.b)

Germany reports in keeping with Tier 1. This means that emissions are calculated as the product of fuel sales in Germany, country-specific emission factors for CO_2 and default emission factors for CH_4 and N_2O.

In general, the **activity data** for seagoing ships are taken from the Energy Balances of the Federal Republic of Germany (AGEB, 2021b). In Energy Balance line 6 (EBZ 6), those Balances list international bunkering for IMO-registered ships separately, because such bunkering is subject to different taxation.

For years for which an NEB does not become available on time, data published in (BAFA (2021); for the present context: Table 6j, column: "Bunker int. Schifffahrt" ("bunkering, international shipping")) are used that enter into the National Energy Balances.

As a rule, the bunkered quantities, included in these statistics, of ocean ships traveling domestic routes (freight and passengers (1.A.3.d), fisheries (1.A.4.c iii) and military (1.A.5.b iii)) are calculated separately, pursuant to Deichnik (2021), and deducted from the total quantities listed in EBZ 6. The resulting remainder is allocated to the international water-borne navigation departing from Germany.

The sharp increase seen between 2014 and 2015 in the quantities of diesel used, from about 15 % to over 30 % of the total fuel quantity involved, results from a de-facto ban on heavy fuel oil in "SECAs" *(Sulphur Emission Control Areas)*, which include the North Sea and the Baltic Sea. That ban is tied to the entry into force of considerably tighter standards for the sulphur content of ship fuels.[25]

[25] Since 1 January 2015: 0.10 %, instead of the previous maximum permitted level of 1.00 % (https://www.imo.org/en/OurWork/Environment/Pages/Air-Pollution.aspx)

In addition, pertinent quantities of co-combusted lubricants, along with the resulting CO_2 emissions, are reported. They are calculated on the basis of the quantities of fuel sold. Pursuant to Wallfarth (2014), it is assumed that the quantities of co-combusted lubricants are equivalent to 0.15 % of the fuel quantities used (cf. the Annex Chapter 19.1.4).

With regard to the pertinent **emission factors** for carbon dioxide, we refer to Chapter 18.8.

The pertinent methane and nitrous oxide emissions are calculated with the emission factors from Deichnik (2021) that are used for domestic water-borne navigation.

On the other hand, also with regard to co-combustion of lubricants, it is assumed that the pertinent N_2O and CH_4 emissions are already included in the emission factors for the fuels used and thus have to be reported here as IE *(included elsewhere)*.

3.2.2.3.3 Uncertainties and time-series consistency (1.D.1.b)

Cf. Chapter 3.2.10.4.3.

3.2.2.3.4 Source-specific quality assurance / control and verification (1.D.1.b)

Cf. Chapter 3.2.10.4.4.

3.2.2.3.5 Category-specific recalculations (1.D.1.b)

Recalculations were carried out with respect to the 2021 submission, to take account of a fundamental revision, covering all relevant years, carried out by the national maritime transport sector. (Cf. Chapter 3.2.10.4.5)

Table 22: Revised activity data, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Diesel fuel										
2022 Submission	13,162	13,096	13,709	11,820	16,417	33,958	32,832	27,463	21,473	20,231
2021 Submission	12,748	12,919	13,664	11,993	16,662	33,088	28,093	22,924	15,213	18,327
Absolute change	413	176	44.9	-173	-246	870	4,738	4,538	6,260	1,904
Relative change	3.24%	1.36%	0.33%	-1.44%	-1.48%	2.63%	16.9%	19.8%	41.1%	10.4%
Heavy fuel oil										
2022 Submission	76,942	62,066	67,080	83,224	91,169	57,792	74,807	58,707	39,308	26,565
2021 Submission	68,484	56,323	60,984	78,182	86,934	57,850	74,837	58,781	39,380	26,601
Absolute change	8,458	5,743	6,096	5,042	4,236	-57.9	-30.0	-74.1	-71.7	-35.9
Relative change	12.35%	10.20%	10.00%	6.45%	4.87%	-0.10%	-0.04%	-0.13%	-0.18%	-0.14%
TOTAL ENERGY INPUTS										
2022 Submission	90,239	75,275	80,910	95,187	107,747	91,888	107,800	86,299	60,872	46,866
2021 Submission	81,354	69,346	74,760	90,310	103,751	91,075	103,085	81,828	54,674	44,995
Absolute change	8,885	5,929	6,150	4,877	3,996	813	4,715	4,471	6,197	1,871
Relative change	10.9%	8.55%	8.23%	5.40%	3.85%	0.89%	4.57%	5.46%	11.3%	4.16%

Source: Own calculations, based on AGEB (2021b), Deichnik (2021) and Knörr et al. (2021c)

At the same time, the modelled emission factors for methane and nitrous oxide were revised. (cf. 3.2.10.4.4)

Table 23: Revised GHG emissions in 2018, in kt and kt CO_2-eq

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Diesel fuel: CH_4										
2022 Submission	0.969	0.969	0.969	0.969	0.969	0.888	0.878	0.884	0.875	0.880
2021 Submission	0.974	0.974	0.974	0.974	0.974	0.895	0.893	0.900	0.904	0.963
Absolute change	-0.005	-0.005	-0.005	-0.005	-0.005	-0.007	-0.016	-0.015	-0.028	-0.083
Relative change	-0.50%	-0.55%	-0.54%	-0.53%	-0.56%	-0.79%	-1.78%	-1.70%	-3.14%	-8.58%
Diesel fuel: N_2O										
2022 Submission	3.313	3.313	3.313	3.313	3.313	3.341	3.340	3.341	3.351	3.350
2021 Submission	3.314	3.314	3.314	3.314	3.314	3.366	3.355	3.357	3.353	3.346
Absolute change	-0.001	-0.001	-0.001	-0.001	-0.001	-0.025	-0.016	-0.016	-0.002	0.004
Relative change	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%	-0.74%	-0.46%	-0.48%	-0.07%	0.12%
Heavy fuel oil: CH_4										
2022 Submission	0.86	0.86	0.86	0.86	0.86	0.52	0.60	0.67	0.65	0.65
2021 Submission	0.73	0.73	0.73	0.73	0.73	0.60	0.74	0.61	0.57	0.65
Absolute change	0.13	0.12	0.12	0.13	0.12	-0.08	-0.13	0.07	0.08	0.00
Relative change	17.3%	17.0%	17.1%	17.1%	16.9%	-13.0%	-17.7%	11.0%	14.8%	0.75%
Heavy fuel oil: N_2O										
2022 Submission	3.45	3.45	3.45	3.45	3.45	3.52	3.50	3.52	3.53	3.54
2021 Submission	3.50	3.50	3.50	3.50	3.50	3.45	3.39	3.49	3.59	3.55
Absolute change	-0.05	-0.05	-0.05	-0.05	-0.05	0.07	0.11	0.03	-0.06	-0.01
Relative change	-1.48%	-1.46%	-1.47%	-1.47%	-1.46%	1.91%	3.28%	0.98%	-1.78%	-0.18%

The recalculated emissions quantities shown below result from the revised input data.

Table 24: Revised GHG emissions, in kt and kt CO_2-eq

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Carbon dioxide[a]										
2022 Submission	7,111	5,919	6,365	7,497	8,482	7,188	8,537	6,778	4,730	3,607
2021 Submission	6,405	5,448	5,875	7,108	8,162	7,128	8,188	6,448	4,272	3,469
Absolute change	705	471	490	388	319	59.7	348	330	458	138
Relative change	11.0%	8.65%	8.33%	5.46%	3.91%	0.84%	4.25%	5.12%	10.7%	3.98%
Methane										
2022 Submission	0.079	0.066	0.071	0.083	0.094	0.060	0.074	0.064	0.044	0.035
2021 Submission	0.063	0.054	0.058	0.069	0.080	0.064	0.080	0.056	0.036	0.035
Absolute change	0.02	0.01	0.01	0.01	0.01	0.00	-0.01	0.01	0.01	0.00
Relative change	26.0%	22.3%	22.1%	20.2%	17.6%	-6.22%	-7.58%	13.4%	23.0%	0.76%
Nitrous oxide										
2022 Submission	0.079	0.066	0.071	0.083	0.094	0.060	0.074	0.064	0.044	0.035
2021 Submission	0.063	0.054	0.058	0.069	0.080	0.064	0.080	0.056	0.036	0.035
Absolute change	0.016	0.012	0.013	0.014	0.014	-0.004	-0.006	0.008	0.008	0.000
Relative change	9.57%	7.29%	6.97%	4.08%	2.60%	1.83%	6.78%	5.87%	9.45%	3.95%
TOTAL GREENHOUSE GASES [a]										
2022 Submission	7,205	5,998	6,449	7,596	8,594	7,284	8,649	6,869	4,794	3,656
2021 Submission	6,491	5,521	5,954	7,204	8,272	7,222	8,294	6,534	4,331	3,516
Absolute change	714	477	495	393	323	61.3	355	335	463	140
Relative change	11.0%	8.63%	8.32%	5.45%	3.90%	0.85%	4.28%	5.13%	10.7%	3.98%

[a] Not including CO_2 from co-combustion of lubricants; source: own calculations

3.2.2.3.6 Category-specific planned improvements (1.D.1.b)

No improvements are currently planned, apart from ongoing routine revisions of the calculation model used.

3.2.3 Storage

This emissions are taken into account in the framework of the CO_2 Reference Approach.

3.2.4 CO_2 capture and storage (CCS) (CRF 1.C)

According to the operator of the only pilot installation in Germany, about 67 kt CO_2 have been sequestered to date for experimental purposes (GFZ, 2018). The installation's monitoring and measurement system has not registered any leakage since the sequestration was carried out. In the interest of conservative reporting, the so-stored quantities have not been deducted from the German inventory, however. For this reason, any possible leakage has already been taken into account.

In keeping with recommendations from the 2016 In-Country Review, the notation key *NO* is currently being used.

3.2.5 Special country-specific aspects

There are no special aspects that would influence reporting.

3.2.6 Public electricity and heat production (1.A.1.a)

3.2.6.1 Category description (1.A.1.a)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 A 1 a, Public Electricity and Heat Production**	**fossil fuels**	**CO_2**	**338,451.2**	**26.6%**	**180,749.0**	**25.2%**	**-46.6%**
-/-	1 A 1 a, Public Electricity and Heat Production		N_2O	2,407.5	0.2%	1,596.4	0.2%	-33.7%
L/T	**1 A 1 a, Public Electricity and Heat Production**		**CH_4**	**172.2**	**0.0%**	**2,211.8**	**0.3%**	**1,184.7%**

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	Tier 2	NS	CS
N_2O	Tier 2	NS	CS
NO_X, CO, NMVOC, SO_2	CS	NS	CS

The category *Public electricity and heat production* is a key category for CO_2 and CH_4 emissions in terms of level and trend.

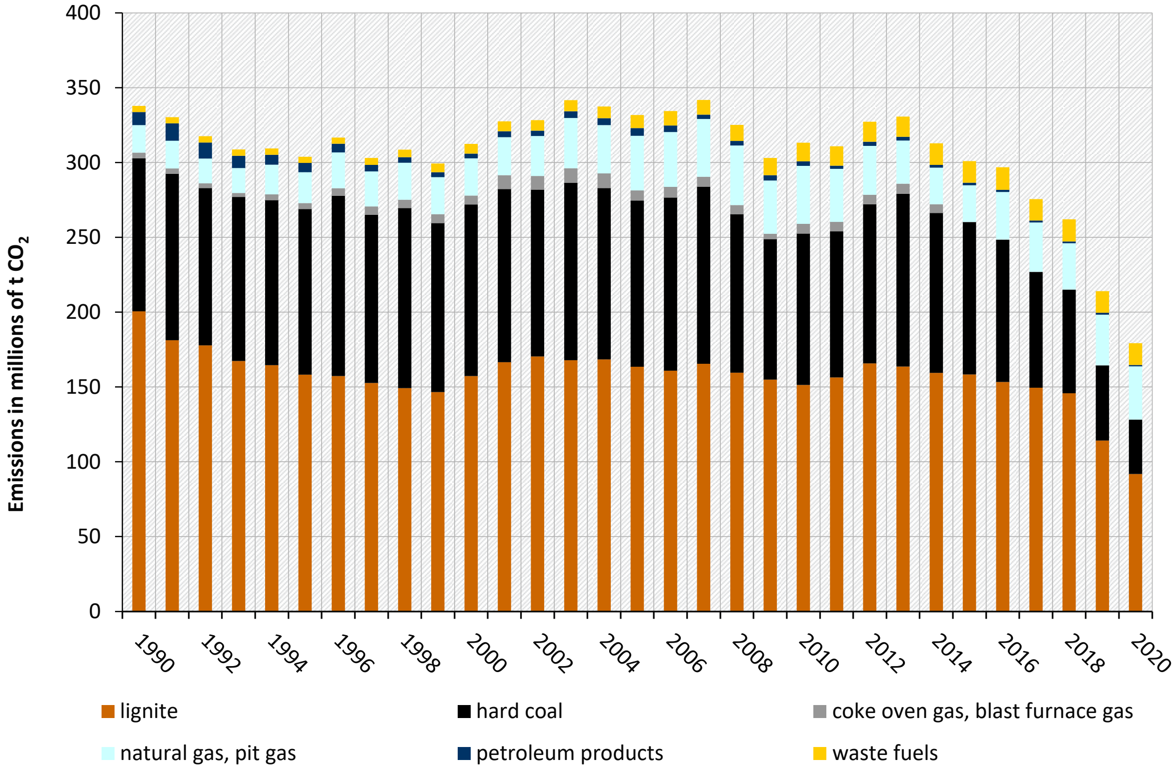
Under category 1.A.1.a, "Public electricity and heat production", the CSE includes district heating stations and electricity and heat production of public power stations. Plants that feed electricity produced from biomass into the public grid are also assigned to category 1.A.1.a.

Some 84 GW of net nominal capacity were in place in the public electricity generating sector at the end of 2020. Of this amount, about 77 GW were operated with fossil fuels or with transformation products of fossil fuels. Total public electricity generation amounted to 289 TWh. About 128 TWh of electricity were generated with lignite and hard coal.

In 2020, combined heat and power (CHP) stations contributed net electricity production of about 46 TWh, and net heat production of 99 TWh, to the public energy supply. The district-heat supply is supplemented with heat from heat-only boiler stations that are usually run in peak-load operation (Statistisches Bundesamt, 2021d).

The following figure presents an overview of development of CO_2 emissions in category 1.A.1.a:

Figure 22: Development of CO_2 emissions in category 1.A.1.a



Overall, emissions until 1999 show a falling trend, due primarily to closure of four lignite-fired installations in the new German Länder. Thereafter, a number of installations were replaced. As of 2000, then, the newly installed capacities, in the category of lignite-fired power stations, exceeded those of the decommissioned power stations, and thus emissions began increasing again. In 2012, and once again, several new power-station units went online, and this led to further increases in emissions from lignite. Thereafter, the emissions decreased as a result of plant closures. Throughout the entire time series, emissions from lignite-based electricity generation remained considerably below the corresponding level seen in 1990.

In the main, the emissions trend is shaped by the development and structures of the electricity generation installations involved, since those installations account for the majority of the pertinent emissions. From 1990 through 1993, electricity consumption decreased, as a result of the collapse of industry in the new German Länder. From 1994 until 2007, a marked increase in electricity consumption occurred in all sectors, sparking increases in electricity production. As a result, emissions from electricity production also increased. In addition, electricity exports increased. Those exports begin showing up in the overall balance as of 2003. The increasing trend continued through 2007, as low prices for emissions certificates prompted consumption of particularly large quantities of coal for electricity generation. Thereafter, beginning in 2008, a temporary marked emissions decrease occurred, as a result of increased use of nuclear power, natural gas and renewable energies. In 2009, the financial and economic crisis occurred, also affecting the public energy supply. In 2010, emissions increased again as a result of economic recovery. As seen via the relevant time series, hard-coal-fired power stations show higher fluctuations in fuel inputs than lignite-fired power stations do. The reason is that they, in contrast to lignite-fired power stations, are operated primarily in the medium-load range, where they respond more markedly to fluctuations in demand. What is more, they are dependent on import prices. Furthermore, as of the mid-1990s sectoral shifting occurred, from industry (1.A.1.c and 1.A.2.g) to the public electricity supply (1.A.1.a), as more and more operators reported their data in the public electricity supply category. In 2012, the classification for another major company in the hard-coal mining sector (1.A.1.c) shifted to the public electricity supply (1.A.1.a), and this led to a significant shift of emissions between the two sectors. Another reason for the emissions increase from hard-coal-fired power stations in source category 1.A.1.a is that world-market prices for hard coal have fallen considerably since 2012. In addition, natural gas prices have increased at the same time, and this has tended to shift the fuel mix in favour of hard coal. In 2016, this effect became reversed with respect to price ratios and fuel inputs. Petroleum plays only a minor role in Germany's electricity supply. It is used primarily for auxiliary and supplementary firing in coal-fired and waste-to-energy CHP power stations, as well as for peak-load generation. Use of petroleum in these roles has dropped by more than half since 1990. In the crisis year 2009, when petroleum became considerably cheaper than natural gas, use of petroleum for peak-load generation increased again somewhat. Since then, fuel inputs have been decreasing again, and thus emissions from use of petroleum have been decreasing as well.

Use of natural gas for electricity generation has increased markedly since 1990. That trend has not led to an equivalent emissions increase, however, since the specific CO_2 emissions of natural gas are considerably lower than those of coal. The significant increase in natural gas use seen since 2005 is due especially to the commissioning of a considerable number of major gas and steam turbine power stations and medium-sized gas-turbine power stations. What is more, natural gas is increasingly being used as balancing energy for electricity generation with fluctuating renewable energies. Use of natural gas for electricity generation began decreasing again in 2010, as of result of price factors. By 2015, gas consumption even fell considerably below its level in 2005. In 2016, gas consumption finally began increasing again. An increase also occurred in 2019.

Use of natural gas for electricity generation has increased markedly since 1990. That trend has not led to an equivalent emissions increase, however, since the specific CO_2 emissions of natural gas are considerably lower than those of coal. The significant increase in natural gas use seen since 2005 is due especially to the commissioning of a considerable number of major gas and steam turbine power stations and medium-sized gas-turbine power stations. What is more, natural gas is increasingly being used as balancing energy for electricity generation with fluctuating renewable energies. Use of natural gas for electricity generation began decreasing again in 2010, as of result of price factors. By 2015, gas consumption even fell considerably below its level in 2005. In 2016, gas consumption finally began increasing again. An slight increase also occurred in 2020.

In 2010, electricity generation with nearly all fossil fuels increased – sharply, in some cases – as a result of economic recovery, and this led to increased CO_2 emissions. Emissions continued to increase until 2013. This can be explained as the result of a high export surplus. On the other, it was tied to a considerable reduction in nuclear power's share of the electricity mix. Cold winters have been another reason why CO_2 emissions increased in 2010, 2012 and 2013. Overall, growing use of renewable energies has been tending to reduce emissions. CO_2 emissions have been decreasing again since 2014. The marked emissions reduction seen in 2015 is due primarily to statistical reclassification of steel industry power stations fired with blast furnace gas, as well as to considerable efficiency increases tied to ther commissioning of new hard-coal-fired power stations. Trends in 2016 and 2017 were led by price-related shifting, in the fuel mix, from hard coal to natural gas. That trend continued in 2020. Electricity consumption decreased as a result of the coronavirus pandemic. In addition, electricity generation decreased even more sharply than it otherwise would have, since less electricity was exported. Electricity generation from renewable energies increased for weather-related reasons. In addition, the prices for CO_2 certificates were higher than they had been in previous years. In sum, these effects led to an unexpectedly large emissions decrease in 2020. The most-pronounced emissions decrease, in absolute terms, occurred in use of lignite. Over the course of 2019, additional power-station units were placed in standby mode. This continued to have an emissions-reducing effect in 2020. Electricity generation from hard coal decreased still further, and considerably, in spite of the considerable decrease that occurred in the previous year and the commissioning of the Datteln 4 power station in 2020.

The trend for the greenhouse gas N_2O is determined primarily by coal use. Since energy generation plants are not known to have any measures in place for reducing N_2O emissions, the decreasing trend seen since 1990 is due to reductions in coal use.

CH_4 emissions, by contrast, have been increasing since 1990. The considerable increases in biogas use since 2003 have played an especially noticeable role in this trend. Biogas is used primarily in combustion engines that have high specific methane emissions.

3.2.6.2 Methodological issues (1.A.1.a)

Activity data

In the "Balance of Emissions Sources" model, the energy inputs listed in the Energy Balance are divided among several time series, with the help of statistical data. The aim of the calculations is to produce a database that is adjusted to the special technical characteristics of electricity and heat production. As a result, fuel-specific and technology-specific emission factors can be applied to the relevant activity data.

In 2014, the Federal Environment Agency (UBA) developed a procedure for taking account of known efficiencies (with the help of the UBA's power-station database) in calculations. This was done in order to make it possible to calculate use of natural gas and light heating oil for electricity and heat generation, in gas turbines, gas-and-steam (combined cycle) systems, steam turbines and gas engines. As a result, fuel inputs can now be calculated via the electricity-generation data for the aforementioned installation types as shown in energy statistics.

As of 2012, the Energy Balance lists mini-CHP systems as producers for the public grid (i.e. to be feeding energy into the grid). Consquently, emissions from combustion of natural gas, and of light heating oil, in these installations are reported in source category 1.A.1.a. The fuel inputs for heat generation are reported in source category 1.A.4.

For the 2006 report, the activity data for the new German Länder for the year 1990 were revised and substantiated in the framework of a research project (Zander and Merten (2006), FKZ 205 41 115 / sub-project A, "Revision and Documentation of Fuel Inputs for Stationary Combustion System in the new German Länder for the year 1990").

In the case of electricity and heat generation in waste incineration plants of public power stations, and of heat generation in waste incineration plants of public district heating stationsthe pertinent activity data for household and municipal waste, and for industrial waste, are taken both from the Energy Balance and from waste statistics (Statistisches Bundesamt, 2021a).

Until a few years ago, the waste quantities listed in energy statistics and in the Energy Balance were both considerably smaller than those shown in the waste statistics of the Federal Statistical Office (Statistisches Bundesamt, 2021a). The quality of the data provided by energy statistics has increased considerably in recent years. Such statistics now differentiate fuel data in a way that makes it possible, via calculation, to separate out figures for solid biomass (especially waste and scrap wood), biogenic gases, sewage sludge and waste heat. Industrial waste appeared as a fuel category in energy statistics for the first time in 2008. To ensure that all waste-related fuel inputs are taken into account as completely as possible, i.e. to close the gap that emerges with respect to energy statistics, it is necessary to make use of additional data from waste statistics.

As of the NIR 2006, the fossil and biogenic fractions of household / municipal waste are listed separately, in a ratio of 1/1. The fossil/biogenic composition of industrial waste varies in keeping with the type of facility involved. As a result, the biogenic fractions for co-combustion in lignite-fired and hard-coal-fired power stations, and for electricity and heat generation in public utilities' power stations fired with substitute fuels, are listed separately.

The activity data for other fuels are taken directly from the Energy Balance. Where pertinent statistical indications or experts' assessments are available, fuel inputs are additionally divided into two size classes (combustion systems smaller and larger than 50 MW). The dividing line between these two categories is based on legal regulations pertaining to licensing of combustion systems in the Federal Republic of Germany.

As of the NIR 2011, CO_2 emissions from blast-furnace-gas combustion in public power stations are reported in category 1.A.1.a. In 2015, all power stations fired with blast furnace gas that, until then, had reported in the public supply sector transferred their reporting to the industry sector. For this reason, category 1.A.1.a no longer includes use of blast furnace gas. The following table provides an overview of relevant emissions from use of blast-furnace gas, for the entire time series since 1990.

Table 25: CO_2 emissions from blast-furnace-gas combustion in public power stations

[Millions of t of CO2]									
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
3.244	3.291	3.015	2.631	3.647	3.764	4.816	5.305	5.465	5.808
2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
5.956	9.284	9.030	9.766	9.640	6.738	7.086	6.370	5.851	3.425
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**As of 2016**			
6.276	6.258	6.080	6.465	5.532	0.014	0.000			

Emission factors

Since CO_2 emissions depend on fuel quality, CO_2 emission factors are calculated and used on an overaching, inter-sectoral basis. A detailed description of the relevant procedures, and a list of the factors used, is presented in the Annex, Chapter 18.8.

The underlying data for the emission factors used for all other greenhouse gases and precursor substances is provided by the report on the research project "Ermittlung und Evaluierung von Emissionsfaktoren für Feuerungsanlagen in Deutschland für die Jahre 1995, 2000 und 2010" ("Determination and evaluation of emission factors for combustion plants in Germany for the years 1995, 2000 and 2010"; (Rentz et al., 2002)). The values for the intermediate years 1996 - 1999 and 2001 - 2009 are obtained via linear interpolation. That project, along with the linear interpolation for the intermediate years, has also provided the underlying data for the emission factors presented in Chapters , 3.2.7, 3.2.8 and 3.2.9, where the factors include power stations, gas turbines and boilers for generation of steam and hot/warm water. The research project was carried out by the Franco-German Institute for Environmental Research (Deutsch-Französisches Institut für Umweltforschung – DFIU) at the University of Karlsruhe, and it was completed at the end of 2002. The project aim was to determine and evaluate representative emission factors for the main air pollutants produced by combustion systems in Germany that are subject to licensing requirements, and to do so for the years 1995, 2000 and 2010. The procedure for achieving that aim consists primarily of analysing and characterising the relevant emitter structures, and the pertinent emission factors, for the year 1995, and then of adequately carrying that data forward for the years 2000 and 2010. The procedure systematically determines emission factors for the substances SO_2, NO_X, CO, NMVOC, particulates and N_2O. Furthermore, it differentiates between 12 coal fuels, 4 liquid fuels, 7 gaseous fuels and firewood. In addition, the available data relative to emission factors of other substances are also compiled; these other substances include PAH, PCDD/F, As and Cd for combustion systems subject to licensing requirements, and CH_4 for gas turbines and combustion systems subject to licensing requirements that fall under the TA Luft. Annex 3 (Chapter 19.1.2) discusses the procedure used in the research project.

In connection with a major research project that began at the end of 2008 and was completed in 2011 Fichtner et al. (2011), we have updated the described database for emission factors (except for that for CO_2). The reference year for the proposed values is 2004. On that basis, emission factors are being predicted for the years 2010, 2015 and 2020. As described in the reports for 2012, 2013 and 2014, numerous emission factors in the Central System of Emissions (CSE) have been updated on the basis of the research results. In Germany, N_2O is monitored only in exceptional cases; for this reason, no relevant data from regular measurements are available. On the other hand, relevant emissions behaviour in combustion of hard coal and lignite, especially in fluidised-bed combustion, has been specifically studied (this occurred primarily in the 1990s). The project Fichtner et al. (2011) has reviewed and updated the values used to date. Table 26 shows the results for large installations of public power stations (with thermal outputs from combustion of 50 megawatts or more), while Table 27 shows the results for smaller installations of the energy sector and of industry. These factors have been used as a basis for calculating the category-specific emission factors for the CSE.

Table 26: Technological emission factors for nitrous oxide from large combustion systems

Fuel / combustion technology	N_2O emission factor [kg/TJ]
Public power stations:	
Hard coal / dry firing	1.0
Hard coal / slag tap firing	1.9
Lignite / dry firing	3.5
Liquid fuel / boiler firing	1.0
Natural gas / boiler firing	0.5
Industrial power stations, industrial boilers and district heating stations:	
Hard coal / dry firing	1.0
Hard coal / slag tap firing	2.0
Hard coal / fluidised bed combustion	20
Hard coal / grate firing	4.0
Lignite / dry firing	3.4
Lignite / fluidised bed combustion	8.0
Lignite / grate firing	3.5
Liquid fuel / boiler firing	1.0
Natural gas / boiler firing	0.5
Gas turbines and gas and steam turbine plants:	
Natural gas	1.7
Light heating oil	2.0
Waste incineration plants	1.2

Table 27: Technological emission factors for nitrous oxide from systems < 50 MW furnace thermal output

Fuel / combustion technology	N_2O emission factor [kg/TJ]
Boiler firing with:	
Hard coal	10.0
Lignite	10.7
Biomass	3.0
Light heating oil	1.1
Heavy heating oil	3.0
Natural gas	0.6
Gas turbines and gas and steam turbine plants:	
Natural gas	1.7
Light heating oil	2.0

Table 28: Methane emission factors for combustion systems with at least 50 MW furnace thermal output and for gas turbines

Facility type	Fuel	CH_4 emission factor [kg/TJ]
Combustion systems ≥ 50 MW furnace thermal output	Hard coal	1.0
	Lignite	0.63
	Heating oil, heavy	4.1
	Heating oil, light	3.3
	Natural gas	2.0
Gas turbines (including gas-and-steam systems)	Heating oil, light	8.0
	Natural gas	10.925
Combustion engines	Natural gas	309.0
	Biogases	312.3
Waste incineration		1.8

In a research project carried out by the Institute for Future Studies and Technology Assessment (IZT), "Aufbereitung von Daten der Emissionserklärungen gemäß 11. BImSchV" ("Processing of data in emissions declarations pursuant to the 11th Ordinance on the Execution of the Federal Immission Control Act" (Jörß & Gronewäller, 2010)), special CH_4 emission factors for gas engines were determined. The average value for natural gas as a fuel, 309 kg/TJ, is markedly higher than the previously used value, 0.3 kg/TJ, which is approximately the same as the value for steam-turbine power stations. With emissions-monitoring data, it was possible to confirm that significant methane leakage occurs via leakage of unburned natural gas. The pertinent measurements can vary considerably, in keeping with the type of engine and engine-maintenance standards involved. For biogas, sewage gas and landfill gas, an average CH_4 emission factor of 312.3 kg/TJ is used. That value was determined in the project "Emissions analysis and quantification of material flows through biogas plants, with regard to ecological assessment of agricultural biogas production and to inventory-taking in the German agricultural sector" ("Emissionsanalyse und Quantifizierung von Stoffflüssen durch Biogasanlagen im Hinblick auf die ökologische Bewertung der landwirtschaftlichen Biogasgewinnung und Inventarisierung der deutschen Landwirtschaft"), carried out by the Deutsches Biomasseforschungszentrum (German biomass research centre (DBFZ, 2011)).

Most of the emission factors used for waste incineration have been obtained from a research project carried out by the waste-management and recycling firm ATZ, "Review of emission factors for waste incineration" ("Überprüfung der Emissionsfaktoren für die Abfallverbrennung" (Daschner et al., 2010)). The N_2O emission factors have been obtained from a Danish study, "Emissions from decentralized CHP plants 2007" (Nielsen, 2010). Since the emission factors for other pollutants agree well with those for German waste incineration plants, the relevant N_2O factors may be adopted for purposes of the German inventory. For co-combusted waste, weighted emission factors are used that vary in keeping with the pertinent shares for the various coal types that are used as the main fuel.

Information on process-related CO_2 emissions from flue-gas scrubbing (flue-gas desulphurisation) in large combustion systems is provided by Annex 3 in Chapter 19.1.2.2.

3.2.6.3 Uncertainties and time-series consistency (1.A.1.a)

Uncertainties for activity data were determined, for the first time ever, for the 2004 report year (Juhrich & Wachsmann, 2007). The method for determining the uncertainties is described in Annex 2, Chapter 13.6 of the NIR 2007.

Other aspects relative to time-series consistency of activity data are explained in Chapter 18.4 and Chapter 18.7.

The figures for the uncertainty of the CO_2 emission factor, and for the statistical distribution function for that uncertainty, have been estimated by the Federal Environment Agency. The figures are based on the range covered by the carbon contents of the various individual fuels.

The uncertainty of the determined emission factors was evaluated in the framework of the project (mentioned in Chapter 3.2.6.2) Rentz et al. (2002) and Fichtner et al. (2011).

3.2.6.3.1 Methods for determining uncertainties of emission factors

The uncertainties in emissions data result from several different factors. These include *precision*, which is influenced by chance and systematic errors in the framework of emission measurement, as well as by the completeness of the database with regard to available measurements. Another factor consists of *variability* of emissions. In this area, a distinction must be made between variability in emissions of a single plant, within the period in question (*intra-plant variability*) and differences between the emissions behaviours of the various sources considered (*inter-plant variability*).

Other sources of possible uncertainties can affect calculation of emissions with the help of emission factors. In the framework of IPCC-GPG (Penman et al. (2000): Chapter 6), methods – adapted, in each case, to data availability – are proposed:

Where *continuous* measurements have been carried out, uncertainties should be characterised via direct determination of statistical indexes such as standard deviation and the 95%-confidence interval.

In determination of *plant-specific emission factors*, any available local measurements should be used. In addition, any special operational states (start-up and shut-down processes) and load changes should be taken account of, and available measurements should be reviewed for representativeness in light of the relevant plant's emissions behaviour.

In use of *emission factors from the literature*, all of the data-quality information provided by the sources in question should also be used. Furthermore, transferability should be reviewed – to what extent is the emission factor in question representative of the situation in the relevant area being studied? If the factor is not representative, an experts' assessment should be carried out.

In general, use of *expert judgements* is recommended in cases in which available empirical data do not suffice for quantification. A sample explanation is provided in Annex 3, Chapter 14.1.2.2, of the NIR 2007.

3.2.6.3.2 Result for N_2O

The individual evaluations of the uncertainties for the N_2O emission factors are described in the final report of the research project Fichtner et al. (2011). A Monte Carlo simulation carried out by the research contractor yielded percentage uncertainties of up to +/- 50 % for CRF category 1.A.1.a (as well as for categories 1.A.1.b, 1.A.1.c and 1.A.2.gviii / all other) (remark: values for +/- ranges must be divided by 2; cf. IPCC-GPG (Penman et al. (2000): Chapter 6, p. 6.14). In the process, we continue to assume a uniform distribution of uncertainties.

3.2.6.3.3 Result for CH_4

Combustion systems in Germany are not subject to monitoring of CH_4 emissions; for this reason, no systematic-measurement data are available in this area. Consequently, relevant individual data items available in Germany and Switzerland have been relied on. As a result of this database limitation, the research project did not attempt any systematic correlation with source categories treated by the project (cf. Chapter 3.2.6.2). The CH_4 emission factors that were determined in the research project Fichtner et al. (2011) for various fuels, and that are used in the present report for combustion and gas-turbine systems (including gas-and-steam systems), have been compiled in Annex 19.1.2.2. As part of an expert judgement carried out by the research contractor, pursuant to Tier 1 of the IPCC-GPG (Penman et al. (2000): Chapter 6), an upper limit of +/- 50 % was estimated for the percentage uncertainty in source category 1.A.1.a (as well as in source categories 1.A.1.b, 1.A.1.c and 1.A.2.gviii / all other); in the process, we assume a uniform distribution of uncertainties – as was the case for N_2O.

3.2.6.3.4 Time-series consistency of the emission factors

The emission factors for N_2O were determined in the framework of a research project Fichtner et al. (2011), for the year 2004 (reference year). The research project saw no indications of changes over time in the individual emission factor. Earlier assumptions to the effect that at least the values for gas turbines might vary over time were not confirmed. For this reason, we have used constant values in each time series, for the period 1995 to 2020, and assumed that the values are valid predictive values for the period through 2020.

In this light, the time series for N_2O between 1995 and 2020 must be assessed as consistent overall. The time series of CH_4 emission factors for 1995 to 2020 were also reviewed and assessed as internally consistent.

In the NIR 2009, we reported on the period from 1990 to 1994.

To ensure time-series consistency, the CH_4 emission factors determined for combustion-engine systems were retroactively applied for the period back to 1990. Methane leakage is likely to have been higher in the early 1990s than it is with modern engine systems. Too little relevant measurement data is available for that period, however.

For most biogenic fuels, statistical fuel-input data are available only for the period since 2003. As a result, it is not possible to provide a consistent time series, for the period since 1990, for such fuels. That limitation affects only the trend for CH_4 emissions, which increases sharply as of the year 2003.

3.2.6.4 Source-specific quality assurance / control and verification (1.A.1.a)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

To document its quality-assurance measures in preparation of Energy Balances, the Working Group on Energy Balances (AGEB) submits pertinent quality reports to the Federal Environment Agency (UBA) (cf. Chapter 18.4.1). Since 2012, the AGEB has carried out systematic comparisons of the estimated Energy Balance of year x-1 (provisional) and the Energy Balance of year x-2 (final); this was done for the first time for the report year 2010 (cf. Chapter 18.4.1).

Quality assurance for official statistics is carried out via an internal quality system. That system's quality reports are available for inspection within the Internet publications of the *Federal Statistical Office*.

In addition to these measures, the AGEB plays a role in the annual review process, and regular exchanges take place with the AGEB in the framework of an annual meeting, or of a written circulation procedure, to which the Federal Environment Agency (UBA) invites all institutes that take part in preparing the Energy Balance. At such meetings, methodological issues are discussed, and general exchanges take place for the purposes of clarifying data-collection issues and verifying data. All of this is done in light of experience gained in inventory preparation and inventory review.

General measures for assuring the quality of emission factors for combustion plants, as used in the framework of the research projects Rentz et al. (2002) and Fichtner et al. (2011), are outlined in the methods description in Annex 3, Chapter 19.1.2.1 (after Figure 97). Their results were reported in the NIR 2005.

3.2.6.5 Category-specific recalculations (1.A.1.a)

Table 29: Recalculations, CRF 1.A.1.a

Units [kt]	2021 NIR	2022 NIR	Difference, absolute					Difference, relative
Year	Total	Total	gas	liquid	other	solid	Total	Total
2018	262,191	262,960	0	0	757	11	768	0.29%
2019	213,484	214,809	-523	306	515	1.026	1.325	0.62%

For the year 2019, recalculations were carried out for all fuels, as usual, to take account of the fact that provisional data were replaced by figures from the final Energy Balance.

3.2.6.6 Category-specific planned improvements (1.A.1.a)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.7 Petroleum refining (1.A.1.b)

3.2.7.1 Category description (1.A.1.b)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 A 1 b, Petroleum Refining**	**fossil fuels**	**CO_2**	**20.165.6**	**1.6%**	**18.553.1**	**2.6%**	**-8.0%**
-/-	1 A 1 b, Petroleum Refining		N_2O	100.4	0.0%	57.7	0.0%	-42.6%
-/-	1 A 1 b, Petroleum Refining		CH_4	16.1	0.0%	14.3	0.0%	-11.2%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	Tier 2	NS	CS
N_2O	Tier 2	NS	CS
NO_X, CO, NMVOC, SO_2	CS	NS	CS

The category *Petroleum refining* is a key category for CO_2 emissions in terms of emissions level and trend.

The figures given above apply for refinery power stations (part of category 1.A.1.b).

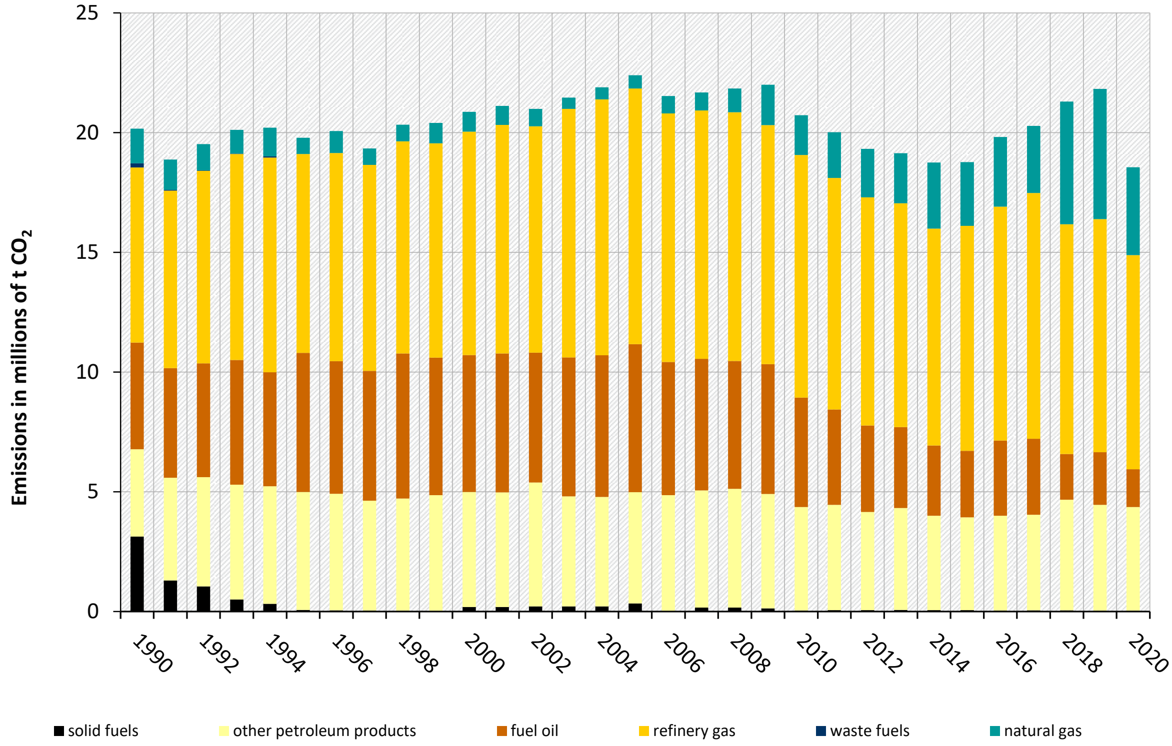
The crude oil distillation capacity of German petroleum refineries totalled around 103 Mt in 2020. In that period, 84.6 Mt of crude oil, along with 15.4 Mt of intermediate products, were input for processing. Production of petroleum products totalled 101 Mt, of which about 51 Mt consisted of fuels, about 20.3 Mt consisted of heating oils, about 7Mt consisted of naphtha and about 19.0 Mt consisted of other products. (MWV (2021b), Tab PRE1.1, Tab 4, Tab 5j).

Petroleum processing plants operate power stations with electrical output of about 1.0 GW. In 2020, those power stations generated 5.6 TWh of electricity (Statistisches Bundesamt, 2021c).

Under category 1.A.1.b, Petroleum refining, the CSE lists the sub-categories "refinery bottom-heating systems" and "electricity and heat production of refinery power stations".

The following figure provides an overview of emissions trends in category 1.A.1.b:

Figure 23: Development of CO_2 emissions in category 1.A.1.b



In the early 1990s, raw lignite was still being used in the new German Länder. Now, only a small quantity of coke-oven gas is reported under solid fuels in this category. Overall, the emissions show a slightly increasing trend through 2005. Thereafter, they decreased again. While some relevant installations have been decommissioned since 1990 – although such decommissioning has taken place on a smaller scale than that seen in the hard-coal and lignite mining sectors – production increased nevertheless. And while installation efficiencies were improved, increased production of lighter petroleum products, and intensified ultra-hydrodesulphurisation, initially led to increases in specific fuel consumptions. The emissions fluctuations that have occurred over the years can be explained as the result of differences in production quantities. The maximum production of petroleum products to date, totalling 123.6 million t, occurred in 2005. The pertinent emissions were correspondingly high. Thereafter, production decreased, to a level of 103.3 million t of petroleum products in 2011, and emissions decreased as a result. The market situation for oil refineries is still difficult, due to overcapacities – especially in Europe. One German refinery terminated its operations in 2010, thereby making it possible to increase capacity utilisation somewhat at the other German refineries. Emissions decreased in 2012, even though the overall production quantity increased slightly, to 104.4 million t. This trend is due to increased use of natural gas, which has lower emissions, and to improvements in plant efficiency. Following a production decrease in 2013 and 2014, gross refinery production has been increasing since 2015. CO_2 emissions also increased correspondingly in that period. Gross refinery production decreased in 2020. As a result of the coronavirus pandemic, considerably smaller quantities of fuels were sold. These decreases were not offset by the slight increases in heating-oil sales that occurred. This situation led to structural changes, and to a decrease in refineries' own consumption. Consequently, CO_2 emissions decreased noticeably.

3.2.7.2 Methodological issues (1.A.1.b)

Activity data

All Energy Balance data relative to production of petroleum products have been obtained from the Official Mineral Oil Statistics. The Mineral Oil Statistics provide a comprehensive picture of petroleum imports, of transformation inputs in refineries and of refineries' own consumption. To ensure consistency, reporting in this area adheres to the structure and the definitions used in Mineral Oil Statistics. In energy statistics, other types of companies and plants, such as companies that process coal and refineries for waste oil and lubricants, also report under industrial sector (Wirtschaftszweig) 19.2 Petroleum processing (Mineralölverarbeitung). Such installations are reported in category 1.A.1.c. Consequently, only crude oil processing is reported in category 1.A.1.b.

For purposes of reporting on emissions from crude oil refineries, the relevant plants are subdivided into refinery power stations and bottom-heating systems. The activity data for refinery-process bottom heating are obtained by subtracting fuel inputs in refinery power stations (as taken from the energy statistics) from refineries' own energy consumption (as taken from the Official Mineral Oil Statistics). While not relevant for calculation of greenhouse-gas emissions, the distinction between the two groups of plants is important for calculation of emissions of precursor substances and other air pollutants, since the two groups differ in their emissions behaviour.

The figures for own consumption of petroleum coke that are listed in the Official Mineral Oil Statistics represent coke burn-off in catalyst regeneration within the plants. Since the basis on which the plant operators calculate their petroleum-coke inputs is not known, it is not possible to obtain a suitable CO_2 emission factor. For the years 2005 through 2014, it has been possible to determine emission factors from data, available via emissions trading, on total emissions from coke burn-off in catalyst regeneration and from plants' own consumption of petroleum coke. As a result, therefore, it has been possible to determine emissions from coke burn-off in catalyst regeneration precisely, for the relevant current years, and in agreement with in the data available from emissions trading. To make it possible to determine the pertinent factors retroactively, back to 1990, first a specific factor was defined that is oriented to the capacity of the reforming plants involved. Various reviews have found that this procedure comes closest to the underlying reality, since the available statistics do not include data on inputs and outputs of the reformers and of fluid catalytic cracking (FCC) plants. The result obtained is that emissions from coke burn-off in catalyst regeneration were considerably lower in 1990 than they were in the current year. This seems plausible, since processing of heavy petroleum products has increased considerably since 1990.

For the years 1990 – 1993, no data on own consumption of petroleum coke are available for the new German Länder. As a result, the pertinent data for those Länder had to be calculated from the emission factor determined from the emissions-trading data.

Since virtually all of oil refineries' emissions result from combustion processes, the refineries' emissions are reported in category 1.A.1.b. In two exceptions, fugitive emissions from production of calcined petroleum coke, and flare emissions, are reported in category 1.B.2.a.iv.

Emission factors

A detailed description of the relevant procedures, and a list of the CO_2 emission factors used, is presented in the Annex, Chapter 18.8.

The emission factors for N_2O, CH_4 and precursor substances for refinery power stations have been taken from the research projects Rentz et al. (2002) and Fichtner et al. (2011). A detailed description of the procedure is presented in Chapter 3.2.6.2 and in Chapter 19.1.2.1 in Annex 3. The cited project does not provide any emission factors for the bottom-heating systems that supply process heat. To compensate for this gap, for bottom-heating systems the same values for N_2O and CH_4 were chosen that are used for refinery power stations.

3.2.7.3 Uncertainties and time-series consistency (1.A.1.b)

Uncertainties for the activity data were determined for the first time in reporting year 2004 (Juhrich & Wachsmann, 2007). The method for determining the uncertainties is described in Annex 2, in the Chapter "Uncertainties in the activity data of stationary combustion systems" (Chapter 13.6 of the NIR 2007).

3.2.7.3.1 Result for N_2O

The results of Chapter 3.2.6.3.2 apply mutatis mutandis.

3.2.7.3.2 Result for CH_4

The results of Chapter 3.2.6.3 apply mutatis mutandis.

3.2.7.3.3 Time-series consistency of emission factors

The results of Chapter 3.2.6.3.4 apply mutatis mutandis.

3.2.7.4 Source-specific quality assurance / control and verification (1.A.1.b)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

With regard to refineries, comparisons with data from the British inventory were carried out. The two countries' refinery capacities are roughly similar in size. To enhance comparability, numerous indicators were defined, for factors such as transformation inputs and production data, in addition to emissions-relevant own consumption. Comparisons of the indicators showed excellent agreement.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.6.4).

With regard to emission factors, the results of Chapter 3.2.6.3 apply mutatis mutandis.

3.2.7.5 Category-specific recalculations (1.A.1.b)

Table 30: Recalculations, CRF 1.A.1.b

Units [kt]	2021 NIR	2022 NIR	Difference, absolute				Difference, relative
Year	Total	Total	gas	liquid	solid	Total	Total
2019	21,757	21,824	125	-44	-14	67	0.31%

Provisional values for the year 2019 were replaced when the figures from the final Energy Balance for 2013 became available. That led to recalculations for all fuels.

3.2.7.6 Category-specific planned improvements (1.A.1.b)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.8 Manufacture of solid fuels and other energy industries (1.A.1.c)

3.2.8.1 Category description (1.A.1.c)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 A 1 c, Manufacture of Solid Fuels and Other Energy**	**fossil fuels**	**CO_2**	**65,289.1**	**5.1%**	**9,010.3**	**1.3%**	**-86.2%**
-/-	1 A 1 c, Manufacture of Solid Fuels and Other Energy		N_2O	659.2	0.1%	153.3	0.0%	-76.7%
-/-	1 A 1 c, Manufacture of Solid Fuels and Other Energy		CH_4	92.0	0.0%	129.6	0.0%	40.9%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	Tier 2	NS	CS
N_2O	Tier 2	NS	CS
NO_X, CO, NMVOC, SO_2	CS	NS	CS

The category *Manufacture of solid fuels and other energy industries* is a key category, in terms of both emissions level and trend, of CO_2 emissions.

The above figures refer to power stations, and to other boiler furnaces for production of steam and hot/warm water, in category 1.A.1.c.

Category 1.A.1.c includes hard-coal and lignite mining, coking and briquetting plants and extraction of crude oil and natural gas. Coke production in 2018 amounted to 9.2 million t (2017: 6.7 million t)[26]. Hard-coal mining was terminated in Germany at the end of 2018. In addition, no hard-coal briquettes have been produced in Germany since the beginning of 2008. Hard-coal coke is now produced in only 5 coking plants.

In 2020, a total of 107.4 million t of crude lignite was extracted in Germany (2019: 131.3 million t)[27]. Production of lignite briquettes and other lignite products (fluidised-bed lignite, dry lignite and lignite coke) amounted to 5.5 million t (2019: 6.0 million t). Steam for drying of raw lignite, for production of refined lignite products, is obtained from lignite-fired power stations with process-steam extraction (CHP plants). From these plants, steam is drawn off for drying crude lignite for production of lignite products.

German oil production in 2020 amounted to 1.91 million t (2019: 1.93 million t) (MWV, 2021b), while natural gas production in 2020 amounted to about 5,155 million m^3 (2019: about 6,062 million m^3) (BVEG, 2021b). The fuel inputs required for installations' own operations are reported in category 1.A.1.c.

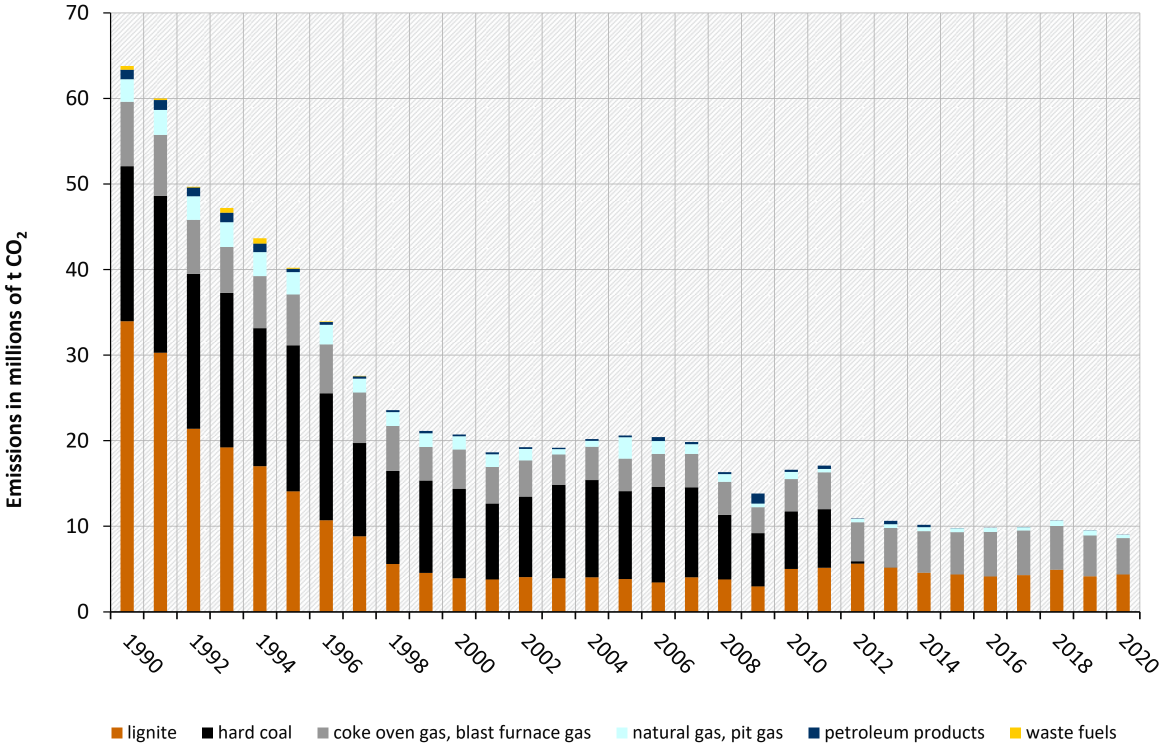
In the CSE, category 1.A.1.c Manufacture of solid fuels and other energy industries includes electricity and heat production in steam-turbine power stations, broken down by hard-coal mining and lignite mining (mine power stations); electricity and heat production in gas turbines, gas engines and diesel engines of all colliery and mine power stations; other heat production in industrial boilers within the transformation sector (not including refineries); and manufacture of hard-coal coke and operation of diesel engines for propulsion purposes in colliery and mine power stations. In reporting, they are broken down into the categories "large combustion systems" and "plants falling under the Technical Instructions on Air Quality Control" (TA Luft).

The following figure provides an overview of emissions trends in category 1.A.1.c:

[26] Verein deutscher Kokereifachleute (VdKF) – cf. https://www.vdkf-ev.de/web/site/index.php/produktionskennzahlen/

[27] cf. DEBRIV – https://kohlenstatistik.de/files/foerder.xlsx

Figure 24: Development of CO_2 emissions in category 1.A.1.c



The figure clearly shows how sharply emissions in this category have decreased since 1990. The largest emissions decrease occurred in the area of lignite, use of which decreased strongly in the new German Länder in the early 1990s. The industry of the former GDR was based centrally on lignite. From raw lignite, a range of refined products used to be produced for industry, households and small commercial operations. A comprehensive transition from lignite to other fuels then took place until the end of the 1990s. In a – then considerably reduced – number of industrial plants and commercial operations, use of hard coal, petroleum and natural gas intensified, while coal-burning stoves in homes were replaced with more modern heating systems fired with heating oil and natural gas. As a result, coal briquette and dust production in the new German Länder decreased from nearly 39 million t in 1990 to about 2.6 million t in 1997. Most lignite-processing plants were closed in that period, and thus emissions decreased sharply. As of 1998, energy for drying lignite products in the new German Länder was provided solely via process steam from public power stations. In the old German Länder, improvements in plants' efficiencies, along with reduced production in that area as well, until 2003, reduced emissions. Thereafter, slight increases occurred again, as a result of production increases.

Emissions from use of hard coal in sector 1.A.1.c have been decreasing markedly since 1990. That decrease is due, firstly, to a sharp reduction in hard coal mining – from more than 70 million t in 1990 to 0 (termination of production) in 2018. Secondly, the decrease is due to the fact that over the years some installations have shifted, for reporting purposes, from the hard coal mining category to the public electricity supply category, thereby shifting their emissions as well. The power stations remaining in category 1.A.1.c until 2011 also fed electricity into the public grid. Beginning in 2010, fuel inputs in the lignite-fired and hard-coal-fired power stations allocated to category 1.A.1.c. increased, as a result of economic recovery and related increased electricity demand. Another explanation for the increased lignite consumption is that some power stations have been taken from the public electricity generation sector and placed in the lignite mining sector. This has led to higher emissions overall.

Use of industrial gases (coke-oven gas, blast furnace gas and basic oxygen furnace gas) also decreased until the end of the 1990s. The primary reason for this is that city-gas production was phased out through 1996, in a process involving decommissioning of local gas works. Coke production also decreased markedly. Production of hard coal coke decreased from 19 million t in 1990 to just less than half of that figure in 2008. Production in 2009 amounted to only 6.7 million t, as a result of low steel production. In 2010, then, as the economic situation improved, hard-coal-coke production increased again, to about 8 million t. Production then remained at that level through the year 2013. As a result of the expansion of one coking plant, in 2014, coke production increased again, reaching 9.2 million t in 2018. Emissions from combustion of blast-furnace gas and coke oven gas also increased as a result. In 1990, a total of 8 mine coking plants were still in operation. Today, only five coking plants remain in operation, and all belong to the steel industry ("metallurgical coking plants"). Overall, plant closures and efficiency increases have decreased emissions markedly in this sector. As a result of the coronavirus pandemic, coke production decreased by about 11 % in 2020. CO_2 emissions from bottom-heating systems also decreased as a result.

In 2012, several important installations in the hard-coal mining sector were shifted, for reporting purposes, into the public sector. This very markedly reduced emissions in category 1.A.1.c. At the same time, this statistical effect led to an increase of emissions from hard-coal use in sector 1.A.1.a. For all sectors overall, emissions from hard-coal-fired electricity generation increased in 2012.

The slight emissions decrease seen in 2013 is due mainly to the closure of a mine-mouth power plant in the central German lignite-mining district and to decreased fuel inputs in mine-mouth power plants in the Rhineland area. The emissions decrease was considerably smaller, since natural gas inputs for "other energy producers" increased at the same time. Emissions remained largely stable in the years 2014 through 2017. In the years 2019 and 2020, CO_2 emissions from lignite processing decreased, since production of lignite products decreased.

3.2.8.2 Methodological issues (1.A.1.c)

The calculation method has been selected on the basis of the latest key-category analysis.

Fuel inputs for electricity production in power stations of the hard-coal and lignite mining sector are listed in Energy Balance line 12, "Industrial thermal power stations". Fuel inputs for heat production in the transformation sector are listed in Energy Balance lines 33-39 and in sum line 40 ("Total energy consumption in the transformation sector").

Fuel inputs for electricity production in power stations of the hard-coal mining sector are determined with the help of figures of the Federal Statistical Office (Statistisches Bundesamt, 2021c). The activity data for heat production in power stations of the hard-coal mining sector correspond to Energy Balance line 34 "Energy input in collieries and briquette plants of the hard-coal mining sector".

The listed fuel input for electricity production in mine power stations is based on association information (personal communication from DEBRIV, the federal German association of all lignite producing companies and their affiliated organisations). Inputs for heat production, especially for lignite drying for production of lignite products, are not shown in the Energy Balance. Those are calculated from figures for production of lignite products[28] and from the specific fuel inputs required for drying, and they are listed as "non- Energy-Balance inputs" in the CSE, and reported as such. The data are collected and updated via annual surveys.

[28] Statistik der Kohlewirtschaft 2019; cf. https:kohlenstatistik.de/19-0-Braunkohle.htm

The quantities of fuel used for production of hard-coal coke are taken directly from the Energy Balance, line 33 (coking plants). That line includes the coking plants' own consumption. Fuel combustion for bottom-heating systems is the largest emission source in the coking plant sector. In the coking process, fugitive emissions also occur before the coke is quenched, however; these are reported in category 1.B.1.b.

The fuel input for heat production in the other transformation sector is obtained by combining the energy consumption figures in Energy Balance lines 33 to 39 (total energy consumption in the transformation sector). Those figures include mines' own consumption; facilities for petroleum and natural gas production and for processing of waste oil; plants that produce coal products; plants for production and processing of fissile and fertile materials; and wastewater-treatment facilities' own consumption.

As of the 2011 report, CO_2 emissions from blast-furnace-gas combustion in coking plants are reported in category 1.A.1.c. The following table provides an overview of CO_2 emissions from use of blast-furnace gas in coking plants, for the entire time series since 1990.

Table 31: CO_2 emissions from blast-furnace-gas combustion in coking plants

[Millions of t of CO2]									
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
5.340	5.251	4.590	4.083	5.066	4.924	4.707	4.969	4.362	3.145
2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
3.652	3.741	3.684	3.029	3.356	3.247	3.281	3.226	3.226	2.500
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
3.245	3.895	4.289	4.341	4.554	4.648	4.872	4.905	4.809	4.479
2020									
3.943									

Revision of the data for 1990, and for the years 1991-1994, for the new German Länder is described in Annex Chapter 19.1.1.

Emission factors

A list of the CO_2 emission factors used, and a description of the relevant methods, are provided in the Annex, Chapter 18.8.

The emission factors for power stations and other boiler combustion for production of steam and hot/warm water, in category 1.A.1.c, have been taken from Rentz et al. (2002) and Fichtner et al. (2011). A detailed description of the procedure is presented in Chapter 3.2.6.2 and in Chapter 19.1.2.1 in Annex 3. Within the sector, the research projects differentiate between STEAG power stations, other power stations in the hard-coal mining sector, power stations in the lignite mining sector and other boiler combustion for production of steam and hot/warm water.

The majority of emission factors for coking plants have been obtained from Hensmann et al. (2012). That data source's emission factors for contained sources have been allocated to category 1.A.1.c, since those emissions result primarily from bottom-heating of coke ovens. By contrast, the emission factors determined for fugitive sources have been allocated, by definition, to category 1.B.1.b. In both categories, calculations cover CO emissions from coking plants, along with other pollutants.

3.2.8.3 Uncertainties and time-series consistency (1.A.1.c)

Uncertainties for the activity data were determined for the first time in reporting year 2004 (research project FKZ 204 41 132, Juhrich and Wachsmann (2007)). The method for determining the uncertainties is described in Annex 2, Chapter 13.6 of the NIR 2007.

The procedure for determining uncertainties for the emission factors is described in Chapter 3.2.6.3.1.

3.2.8.3.1 Result for N_2O

Relatively large numbers of fluidised-bed combustion systems are used in plants within the lignite-mining sector – which plants are part of sector 1.A.1.c. Such systems are known to have relatively higher N_2O emissions than systems using other types of coal-combustion technologies. On the other hand, relevant emissions behaviour in combustion of hard coal and lignite, particularly in fluidised-bed combustion, has been specifically studied, especially in the 1990s. For this reason, enough measurement data were available to permit systematic survey of N_2O emission factors in the research project. The remarks made in Chapter 3.2.6.3.2 apply mutatis mutandis.

3.2.8.3.2 Result for CH_4

The results of Chapter 3.2.6.3.3 apply mutatis mutandis.

3.2.8.3.3 Time-series consistency of emission factors

The results of Chapter 3.2.6.3.4 apply mutatis mutandis.

3.2.8.4 Source-specific quality assurance / control and verification (1.A.1.c)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The results of Chapter 3.2.6.2 apply mutatis mutandis.

3.2.8.5 Category-specific recalculations (1.A.1.c)

Table 32: Recalculations, CRF 1.A.1.c

Units [kt]	2021 NIR	2022 NIR	Difference, absolute					Difference, relative
Year	Total	Total	gas	liquid	other	solid	Total	Total
2019	9,581	9,519	-67	-1	0	7	-62	-0.64%

Provisional figures for the year 2019 were replaced with figures from the now-available final Energy Balance for that year. This led to recalculations for all fuels.

3.2.8.6 Planned improvements (category-specific) (1.A.1.c)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.9 Manufacturing industries and construction (1. A.2)

This category consists of several sub- source categories defined in close harmony with the IPCC categorisations (CRF). It is described in detail via the relevant sub-chapters.

The calculation algorithms for BEU structural elements in category 1.A.2 were revised, within the research project "Substantiation of the data quality of activity data" (FKZ 204 41 132, Juhrich and Wachsmann (2007)), and they are now governed by a consistent system. For the most part, they are based on reliable data of the Federal Statistical Office.

Sectoral differentiation of activity data was carried out solely for process combustion. A number of reallocations were carried out, as of the 2015 NIR, as a result of the new CRF categorisation.

As of 2008, classification of economic sectors (Wirtschaftszweige = WZ), in energy statistics, was again changed – from the "WZ 2003" standard to the "WZ 2008" standard. As a result, activity data relative to process combustion are now being taken from individual statistics, and documented, in keeping with the relevant key for the change (Statistisches Bundesamt (2008): "Umsteigeschlüssel WZ 2003 auf WZ 2008" (key for the change from WZ 2003 to WZ 2008))

As of the 2015 report, this creates difficulties in allocations to the new CRF categories of the 2006 Guidelines.

With respect to power and heat production, industrial power stations and boiler systems are aggregated by technologies (gas engines, gas turbines, gas and steam plants and steam turbines), as well as by permit-law provisions (TA-Luft and 13th BImSchV). The calculation of the split between installations subject to the TA Luft and installations approved pursuant to the 13th BImSchV was updated in 2018.

The various individual calculation algorithms were substantiated in detail in the aforementioned research project.

Following emission calculation at the structural-element level, the sum values for the sub-categories in 1.A.2 were produced pursuant to the 1996 Guidelines – through the 2014 NIR. As of the 2015 NIR, the sum values are produced pursuant to the 2006 Guidelines. In all cases, the aggregation is largely IPCC-conformal. Since the NIR 2006, most process combustion has been reported on a sector-specific basis. The available data do not permit fully IPCC-conformal disaggregation. For example, heat and power production of industrial power stations and thermal power stations cannot be completely oriented to specific sectors; for this reason, it is reported in combined form, under 1.A.2.gviii Other.

Differentiation of energy-related process combustion for heat and power production in industrial power stations and in boiler systems was carried out via Statistik 067 (Statistics 067; electricity-production systems of the manufacturing sector, and of the mining and quarrying sectors (Stromerzeugungsanlagen des Verarbeitenden Gewerbes sowie des Bergbaus und der Gewinnung von Steinen und Erden); (Statistisches Bundesamt, 2021c).

A change in Statistics 067 (op. cit.) of the Federal Statistical Office has led to a jump in the activity data for heat and electricity production. Until 2001, only the fuel inputs for electricity production in electricity production systems were listed. As of 2002, fuel inputs for heat and electricity production are listed. No data are available for inputs for heat production for years prior to 2002.

In March 2017, the Act on Energy Statistics (Energiestatistikgesetz) was amended. As a result of delays in data collection, this has led to jumps in the data in the period as of 2018. Fully quality-assured data from federally collected statistics are available only as of the 2022 report.

The ratio between the fossil and biogenic fractions of industrial waste is determined from waste statistics (Statistisches Bundesamt, 2021a), from the figures provided by the relevant industrial associations relative to substitute fuels and from the research project "Inputs of secondary fuels" ("Einsatz von Sekundärbrennstoffen") (Lechtenböhmer et al. (2006c), FKZ 204 42 203/02). All of the listed amounts of standard fuels used in all sub-categories have been taken from the Energy Balance of the Federal Republic of Germany and disaggregated in the Balance of Emission Causes (BEU). In addition to the figures provided from the Energy Balance, in various sub-categories substitute fuels have now been listed. The relevant amounts were determined in a research project Lechtenböhmer et al. (2006c) and are now updated annually with the help of association data (see below). This work has shown that substitute fuels are increasingly being used as replacements for more-expensive conventional fuels.

In the aforementioned research project "Inputs of secondary fuels" ("Einsatz von Sekundärbrennstoffen" (Lechtenböhmer et al., 2006c), the required improvements relative to the topic of "waste fuels" in the energy sector were found to be tied to substitute fuels in four industrial sectors, and the pertinent data were obtained from the relevant industrial associations. As a result, considerably improved, sector-specific data are now available relative to use of substitute fuels in process combustion, and in industrial power stations, in the industrial sectors pig-iron production, pulp and paper production and lime and cement production.

Special aspects of the various sub-categories are described in the relevant sub-chapters. Special note should be taken of the collective group 1.A.2.g Other.

The uncertainties for the new structural elements created in the research project "Substantiation of the data quality of activity data" (Juhrich & Wachsmann, 2007) were determined in keeping with the method described in the research project Lechtenböhmer et al. (2006c). That determination is described in the final report for the research project Juhrich and Wachsmann (2007) and in Annex 13.6 of the NIR 2007.

Carbon dioxide emissions predominate in CRF category 1.A.2. Other greenhouse gases account for only very small shares of total emissions.

A sharp reduction in greenhouse-gas emissions occurred in the period 1990 through 1994. It was caused by decommissioning of inefficient manufacturing plants in the new German Länder following the 1990 political transition in Germany.

The emissions fluctuations that occurred in subsequent years reflect production trends in Germany's manufacturing sector, which were tied to overall economic trends.

3.2.9.1 Manufacturing industries and construction – iron and steel (1.A.2.a)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 A 2 a, Iron and steel**	**fossil fuels**	**CO_2**	**35,269.3**	**2.8%**	**32,589.7**	**4.5%**	**-7.6%**
-/-	1 A 2 a, Iron and steel		N_2O	155.1	0.0%	97.7	0.0%	-37.0%
-/-	1 A 2 a, Iron and steel		CH_4	62.5	0.0%	54.8	0.0%	-12.3%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	CS	NS	CS
N_2O	CS	NS	CS
NO_X, CO, NMVOC, SO_2	CS	NS	CS

The category *Manufacturing industries and construction – iron and steel* is a key category, in terms of emissions level and trend, for CO_2 emissions.

The iron and steel industry (sub-category 1.A.2.a) is the second important CO_2-emissions source, along with the cement industry, in the area of process combustion.

3.2.9.1.1 Category description (1.A.2.a)

The category comprises the production areas of pig iron (blast furnaces), sponge iron (direct reduction), sinter, rolled steel, iron and steel casting, Siemens-Martin steel, electric steel and the power stations and boilers of the entire steel industry.

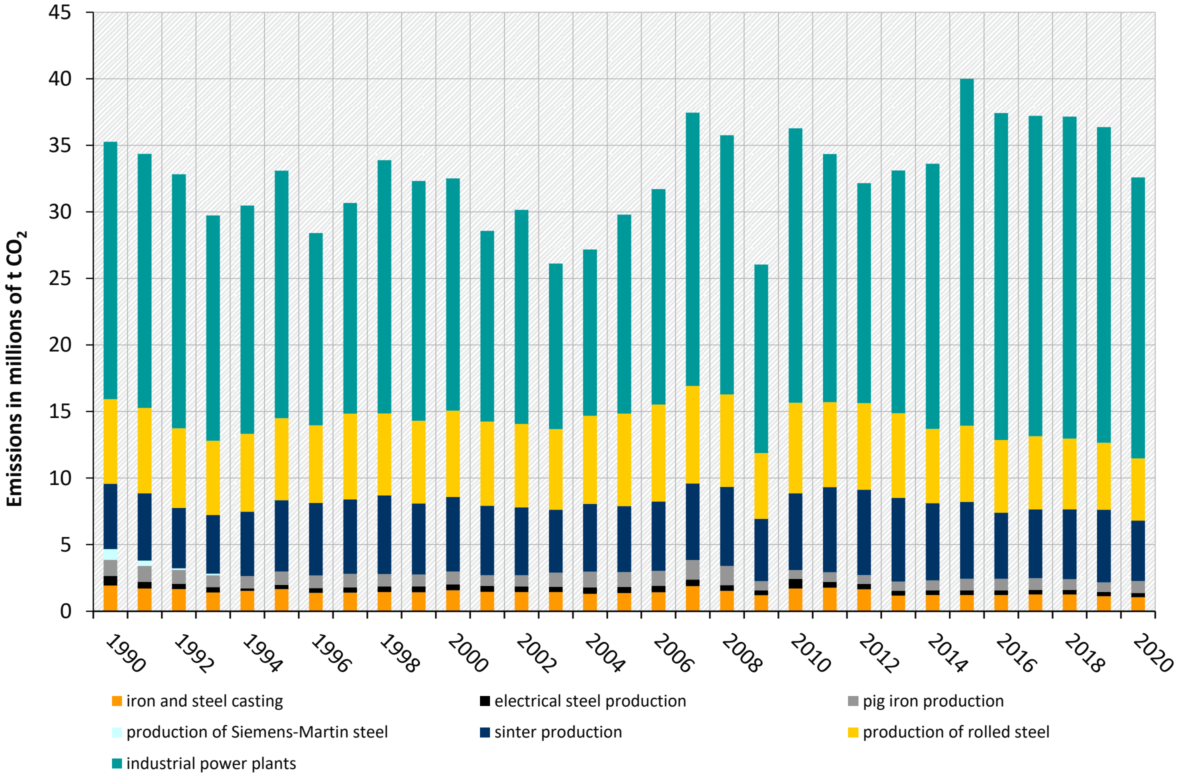
Production of Siemens-Martin steel generated emissions only in the new German Länder, and only until shortly after 1990. In the old German Länder, production of Siemens-Martin steel was discontinued before 1990.

Sponge iron (direct-reduced iron (DRI)) is produced in Germany only on a relatively small scale (about 0.6 million t per year), and only in one plant. The CO_2 emissions that occur in DRI production result from the use of natural gas, i.e. from use of a reducing-agent mixture, comprising H_2 and CO, obtained from natural gas. The relevent quantities of natural gas used are included, throughout the entire time series, in the natural-gas inputs that are reported under 1.A.2.a. Consequently, CO_2 emissions from DRI production are reported, throughout the entire time series, under 1.A.2.a. For reasons of confidentiality, it is not possible to list CO_2 emissions from production of sponge iron separately.

In production of pig iron, large amounts of the fuels used in blast furnaces are needed for the reduction processes that take place in the furnaces, while most of the fuel used in other production areas of the iron and steel industry is used for heat production.

The following figure provides an overview of CO_2 emissions in the various sub-categories in 1.A.2.a.

Figure 25: Development of CO_2 emissions in category 1.A.2.a



As the overview reveals, major fluctuations have occurred over the years. In most cases, those swings were tied to fluctuations in production. In the period 1990 through 1994, emissions reductions occurred primarily as a result of restructuring of the iron and steel sector in the new German Länder following the political transition of 1990.

The drop in CO_2 emissions is particularly pronounced in the crisis year 2009, in which the steel industry registered a sharp production decrease. The recurring emissions increase in 2010 resulted from an economic recovery in which the steel industry nearly reattained its production level of 2008. In general, the steel industry's CO_2 emissions trends to follow overall economic trends. Since oxygen steel production decreased slightly in 2019, as it had in the previous year, CO_2 emissions decreased slightly again in the current report year.

The noticeably high emissions increase in 2015 is due to shifting, for reporting purposes, of several power stations fired with blast furnace gas – from the public electricity supply (CRF 1.A.1.a) to industry (1.A.2.a). This has entailed a shifting of emissions. Overall, CO_2 emissions have been increasing only slightly as a result of the increase in production. This relationship is clearly apparent in Figure 41: CO2 emissions from use of reducing agents for primary steel production and from use of blast furnace gas – chronological sequence, and category allocation in Chapter 4.4.1 Metal production: Iron and steel production (2.C.1).

Installations in the areas of rolled-steel and sinter production account for the second-highest shares of emissions, after industrial power stations (which generate electricity for their own use from blast furnace gas and basic oxygen furnace gas). In the blast furnace category, only the natural-gas and coking-gas inputs required for furnace operation are reported in category 1.A.2.a. Process-related emissions are listed in category 2.C.1.

According to the Steel Institute VDEh, in blast furnaces, natural gas is increasingly being tested as a substitute for injected pulverised coal. This has not yet had a noticeable effect on emissions trends, however. The marked CO_2 emissions decrease that occurred in 2020 was the result of production decreases tied to the coronavirus pandemic.

3.2.9.1.2 Methodological issues (1.A.2.a)

This sub-category comprises process combustion in the various production areas of the iron and steel industry. The relevant fuel-use amounts, including those for secondary fuels, are contained in the Balance of Emission Causes (BEU).

As of report year 2011, activity data for conventional fuels in this category has been provided in the context of the "BGS" group (fuel, gas and electricity industries of blast furnaces, steelworks and rolling mills; and forging plants, press works and hammer mills, including the various other plants (without their own coking plants) locally connected to such operations). That source has improved disaggregation of energy data in the Balance of Emissions Sources (BEU). While the legal basis for surveys relative to the BGS group was no longer available as of reporting year 2012, the pertinent data have since been provided, in the same structure, on the basis of an agreement with the Wirtschaftsvereinigung Stahl German steel industry association. For reasons of data protection, as of 2018, data aggregated with respect to "total figure for Germany" are provided via a data trustee. This change has no impact on relevant calculations.

In addition to providing activity data for sintering plants, blast furnaces, basic oxygen furnaces (converters) and rolling mills, BGS-group data support additional disaggregation of the electric steel sector.

The BGS-group data also enable data-based differentiation of the solid-fuel categories "hard coal and hard coal briquettes"; "coke" and "coke breeze with particle size less than 10 mm." In the database, the fuel inputs for coke and coke breeze are listed in sum as "coke," since the energy statistics list the aggregated fuel "coke." The "liquid fuels" listed for the BGS group are classified under "heating oil, heavy."

The BGS-group data list fuel inputs in natural units. For the present purpose, those units are converted into energy units, using the relevant net calorific values listed by the Working Group on Energy Balances (AGEB) for the various solid and liquid fuels. For gases, the BGS-group data use a norm of 35.16912 MJ/m^3. That figure has been adopted in the methods for calculating activity data for blast-furnace gas, coke-oven gas, natural gas and basic oxygen furnace gas.

The method for calculating emissions from secondary fuels has been retained, in keeping with the results of the research project "Einsatz von Sekundärbrennstoffen" ("Inputs of secondary fuels"; Lechtenböhmer et al. (2006c), FKZ 204 42 203/02).

In the area of emissions from the iron and steel industry, a distinction is made, for the entire time series as of 1990, between process-related emissions and energy-related emissions. The method for calculation of process-related emissions is described in Chapter 4.4.1.2 of category 2.C.1.

3.2.9.1.3 Uncertainties and time-series consistency (1.A.2.a)

Uncertainties were determined for all fuels in 2004 (except for substitute fuels), and for substitute reducing agents, with regard to the entire time series. The method is explained in the research report Lechtenböhmer et al. (2006c). The uncertainties for the activity data were updated in the research project "Substantiation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten" (FKZ 204 41 132) and included in the relevant final report.

The statistical data used for calculation until the 2011 report, from the Federal Statistical Office's Fachserie 4 Reihe 8.1, were aggregated in keeping with the BGS-group framework in those statistics. When production of those statistics has been discontinued, the basic BGS-group data will be used directly for calculation.

Direct use of the BGS-group data does not increase the uncertainties. The uncertainties as determined on the basis of the research report were retained, in keeping with the conservative approach applied.

3.2.9.1.4 Source-specific quality assurance / control and verification (1.A.2.a)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.6.4).

The aforementioned agreement with the steel-industry association calls for the association to carry out quality assurance for the BGS-group data in keeping with the QSE manual. The association's quality report is provided along with the data.

3.2.9.1.5 Category-specific recalculations (1.A.2.a)

Provisional figures for the year 2019 were replaced with figures from the now-available final Energy Balance for that year.

Table 33: Recalculations in CRF 1.A.2.a

Units [kt]	2021 NIR	2022 NIR	Difference, absolute				Difference, relative
Year	Total	Total	gas	liquid	solid	Total	Total
2019	35,730	36,374	-19	-1	665	644	1.80%

3.2.9.1.6 Category-specific planned improvements (1.A.2.a)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.9.2 Manufacturing industries and construction – non-ferrous metals (1.A.2.b)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	1 A 2 b, Non-ferrous metals	fossil fuels	CO_2	1,629.2	0.1%	1,487.5	0.2%	-8.7%
-/-	1 A 2 b, Non-ferrous metals		N_2O	17.1	0.0%	7.9	0.0%	-53.8%
-/-	1 A 2 b, Non-ferrous metals		CH_4	1.4	0.0%	1.7	0.0%	19.6%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	CS	NS	CS
N_2O	CS	NS	CS
NO_X, CO, NMVOC, SO_2	CS	NS	CS

The category *Non-ferrous metals* is not a key category.

3.2.9.2.1 Category description (1.A.2.b)

This category aggregates process combustion of various areas of non-ferrous-metal production. The available data do not support more detailed description.

3.2.9.2.2 Methodological issues (1.A.2.b)

The pertinent fuel inputs are contained in the Balance of Emission Causes (BEU). The source for fuel inputs consists of statistics for the manufacturing sector (Statistik 060 – Energieverwendung des produzierenden Gewerbes (energy use in the manufacturing sector; (Statistisches Bundesamt, 2021b) (Melde-Nr. (reporting number) 27.43 (WZ 2003 old; WZ = classification system for economic data) → 24.43 (WZ 2008 new); Erzeugung und erste Bearbeitung von Blei, Zink und Zinn (production and initial processing of lead, zinc and tin) 27.44 (WZ 2003 old) → 24.44 (WZ 2008 new); Erzeugung und erste Bearbeitung von Kupfer (production and initial processing of copper)) and, for differentiations relative to heat and electricity production, Statistik 067 (Statistisches Bundesamt, 2021c).

Descriptions of calculation algorithms for activity data in the Balance of Emissions Sources (BEU) were revised in the interest of standardisation, consistency and transparency. As a result of such revision, production and initial processing of precious metals, aluminium and other non-ferrous metals are now taken into account in determination of activity data. The relevant calculation algorithms are described in detail in the final report for the research project "Substantiation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten") (FKZ 204 41 132).

The 1990 activity data for the new German Länder were revised and substantiated, with the help of new data, in the project "Base year and updating" ("Basisjahr und Aktualisierung") Zander and Merten (2006): FKZ 205 41 115); see Annex Chapter 19.1.1).

3.2.9.2.3 Uncertainties and time-series consistency (1.A.2.b)

Uncertainties for all activity data were determined in 2004. The relevant method is described in Annex Chapter 13.6 of the NIR 2007.

3.2.9.2.4 Source-specific quality assurance / control and verification (1.A.2.b)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.6.4).

3.2.9.2.5 Category-specific recalculations (1.A.2.b)

Table 34: Recalculations in CRF 1.A.2.b

Units [kt]	2021 NIR	2022 NIR	Difference, absolute				Difference, relative
Year	Total	Total	gas	liquid	solid	Total	Total
2019	1,624	1,571	-36	-15	-2	-52	-3.22%

Provisional values for the year 2018 were replaced when the figures from the final Energy Balance for 2013 became available. This has led to recalculations for all fuels.

3.2.9.2.6 Category-specific planned improvements (1.A.2.b)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.9.3 Manufacturing industries and construction – Chemicals (1.A.2.c)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2017 (kt CO_2-eq.)	(fraction)	Trend 1990-2017
-/-	1.A.2.c	All fuels	IE	IE	IE	IE	IE	IE

In the chemical industry, the main relevant plants consist of industrial power stations and boilers. Such installations are reported, for all sectors, in sub-category 1.A.2.g Other.

Fuel inputs in calcium-carbide production are process-related and are reported under CRF 2.B.5 (cf. Chapter 4.3.5).

This approach has been confirmed by the research project "Base year and updating" (Zander and Merten (2006), FKZ 205 41 115), for 1990 in the new German Länder (the most important production location): the relevant coke was used as a production material and not as a fuel for energy. Calcium-carbide production is thus not a source of energy-related CO_2 emissions.

The emissions for the entire sub-category 1.A.2.c are thus included elsewhere (IE). For this reason, sub-category 1.A.2.c is not listed separately in the key-category analysis.

The majority of the emissions in the chemical industry originate in combustion processes. Since fuel-input data for the chemical industry are available only as of the year 2003, no time series as of 1990 can be produced. For this reason, emissions from energy-related use of fuels in the chemical industry are reported together with emissions for other industrial sectors in category 1.A.2.gviii "Other". Nonetheless, the available data can be cross-checked against relevant available data from emissions trading. As this is done, double counting with the IPPU Sector has to be avoided. In addition, it is important to ensure that emissions from combustion of other produced gases are not underestimated. The comparison shows that the data reported in energy statistics for the period as of 2012 agree well with the fuel-quantity data from emissions trading. The gas quantities given by statistics for earlier years are too low overall. The first analytical step, therefore, was to identify the chemical industry areas in which other produced gases occur and are used for energy generation. Overall half of the total gas produced is used in production of other organic basic materials and chemicals. The next-largest share is used in production of other inorganic basic materials and in production of dyes and pigments. A still-smaller share of these gases is used in production of plastics in primary forms. For recalculation of the relevant gas consumption, the main products produced in each sector were determined. The pertinent data are available, for the period back to 1990, in the annual "Chemiewirtschaft in Zahlen" ("Chemical industry figures") reports of the VCI. Data are lacking only for the new German Länder in the year 1990. Since the Energy Balance lists major quantities of "fuel gases"

("Brenngase") for the new German Länder, it may be assumed that those gases have been taken into account at least in the area of energy use. With the help of the production data, and the gas-quantity data listed in the energy statistics for the year 2013, specific factors were developed, for each sub-sector, with which it was possible to calculate the pertinent fuel inputs retroactively.

3.2.9.4 Manufacturing industries and construction – Pulp, paper and print (1.A.2.d)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	1 A 2 d, Pulp, Paper and Print	fossil fuels	CO_2	3.6	0.0%	7.8	0.0%	114.0%
-/-	1 A 2 d, Pulp, Paper and Print		N_2O	2.8	0.0%	11.0	0.0%	293.7%
-/-	1 A 2 d, Pulp, Paper and Print		CH_4	0.7	0.0%	2.6	0.0%	293.7%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	CS	NS	CS
N_2O	CS	NS	CS
NO_X, CO, NMVOC, SO_2		IE	

The category *Pulp, paper and print* is not a key category.

3.2.9.4.1 Category description (1.A.2.d)

The energy consumption for production of pulp, paper and printed products – otherwise referred to as the "pulp and paper industry" for short – can be described only for substitute fuels, of which this industry uses large amounts.

Emissions from use of regular fuels in process combustion, and emissions generated by plants in own-power production, have not been listed separately. They are summarised under 1.A.2.g Other.

3.2.9.4.2 Methodological issues (1.A.2.d)

Only some of the substitute fuels used by the paper industry are listed in the Energy Balance. The fuels in question consist of waste from the relevant sectors' own production areas. The data on the types and amounts of substances used were provided by the German Pulp and Paper Association (VDP). The great majority of the substitute fuels used in the sector consist of wood and pulp fibres – and, thus, of biomass. The biogenic and fossil fractions of pertinent fuels were derived in the research project "Inputs of secondary fuels" ("Einsatz von Sekundärbrennstoffen") (Zander and Merten (2006), FKZ 204 42 203/02). In addition, CO_2 emission factors were derived on the basis of data on carbon content, water content and net calorific values.

The official statistical data on inputs of standard fuels in the paper industry were reviewed.

In the statistics for the manufacturing sector (Statistik 060 – Energieverwendung des produzierenden Gewerbes ("energy use in the manufacturing sector"); Statistisches Bundesamt (2021b)), under the new system for classification of economic activities (Wirtschaftszweigsystematik – WZ 2008 new), the source for the fuel inputs is assigned WZ number 17 "Herstellung von Papier, Pappe und Waren daraus" (production of paper, cardboard and related goods").

At present, the source for one time series cannot be unambiguously assigned in keeping with the old system for classification of economic activities (WZ 2003). The class WZ 17 within the new system for classification of economic activities (Wirtschaftszweigsystematik 2008) corresponds to classes WZ 17, 21, 22 and 36 under the old system, WZ 2003.

Currently, the individual fuel inputs cannot be listed in disaggregated form, due to the need to protect confidentiality. The same applies for Statistik 067 (Statistisches Bundesamt, 2021c), which is used for differentiation from electricity and heat generation.

3.2.9.4.3 Uncertainties and time-series consistency (1.A.2.d)

In the framework of a research project, the uncertainties of the CO_2 emission factors derived for substitute fuels were determined using the Monte Carlo method (Zander and Merten (2006), FKZ 204 42 203/02). In the procedure, figures for C content, water content and net calorific value were taken into account. Such figures are based on varying estimates, as well as on small numbers of measurements and analysis results, and thus show wide spreads. The CO_2 emission factors for secondary fuels, along with the relevant uncertainties, apply throughout the entire relevant time series, because no findings on trends are available. The time series are thus consistent.

3.2.9.4.4 Source-specific quality assurance / control and verification (1.A.2.d)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The paper industry has long kept records of inputs of secondary fuels. The data are published annually, in a performance report. In spite of small structural breaks in the time series in such records, the records clearly show the paper industry's increasing use of substitute fuels in place of regular fuels.

3.2.9.4.5 Category-specific recalculations (1.A.2.d)

No recalculations were required.

3.2.9.4.6 Category-specific planned improvements (1.A.2.d)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.9.5 Manufacturing industries and construction – Sugar production (1.A.2.e)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/T	**1 A 2 e, Food Processing, Beverages and Tobacco**	**fossil fuels**	**CO_2**	**2,015.9**	**0.2%**	**241.4**	**0.0%**	**-88.0%**
-/-	1 A 2 e, Food Processing, Beverages and Tobacco		N_2O	24.6	0.0%	2.2	0.0%	-90.9%
-/-	1 A 2 e, Food Processing, Beverages and Tobacco		CH_4	4.5	0.0%	0.2	0.0%	-95.9%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	CS	NS	CS
N_2O	CS	NS	CS
NO_X, CO, NMVOC, SO_2	CS	NS	CS

The *Sugar production* category is a key category for CO_2 emissions in terms of trend (cf. Table 6). Because relevant emissions have fallen sharply since 1990 (-89.6 %), and thus an extremely low emissions level has been attained, the Single National Entity has decided, as part of its resources prioritisation, not to apply the more stringent methods to this category that are required for key categories.

3.2.9.5.1 Category description (1.A.2.e)

This category includes only the sugar industry's process combustion. Plants generating their own power are not listed separately; they are reported under 1.A.2.g Other.

3.2.9.5.2 Methodological issues (1.A.2.e)

Descriptions of calculation algorithms for activity data in the Balance of Emissions Sources (BEU) were revised in the interest of standardisation, consistency and transparency. As a result of this revision, it was determined that the statistics publications Statistik 060 (Statistisches Bundesamt, 2021b) and Statistik 067 (Statistisches Bundesamt, 2021c) list all of the fuels required for calculation of the pertinent activity data and should be used as data sources.

The relevant calculation algorithms, and special analyses relative to fuel inputs, are described in detail in the final report for the research project "Substantiation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten" (Juhrich & Wachsmann, 2007)).

3.2.9.5.3 Uncertainties and time-series consistency (1.A.2.e)

For 2004, the uncertainties for all activity data were determined for the first time. The relevant method is described in Annex Chapter 13.6 of the NIR 2007.

3.2.9.5.4 Source-specific quality assurance / control and verification (1.A.2.e)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.6.4).

3.2.9.5.5 Category-specific recalculations (1.A.2.e)

Table 35: Recalculations in CRF 1.A.2.e

Units [kt]	2021 NIR	2022 NIR	Difference, absolute				Difference, relative
Year	Total	Total	gas	liquid	solid	Total	Total
2019	260	251	-7	10	-11	-9	-3.37%

Provisional figures for the year 2018 were replaced with figures from the now-available final Energy Balance for that year. That necessitated recalculations for nearly all fuels.

3.2.9.5.6 Category-specific planned improvements (1.A.2.e)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.9.6 Manufacturing industries and construction – Non-metallic minerals industry (1.A.2.f)

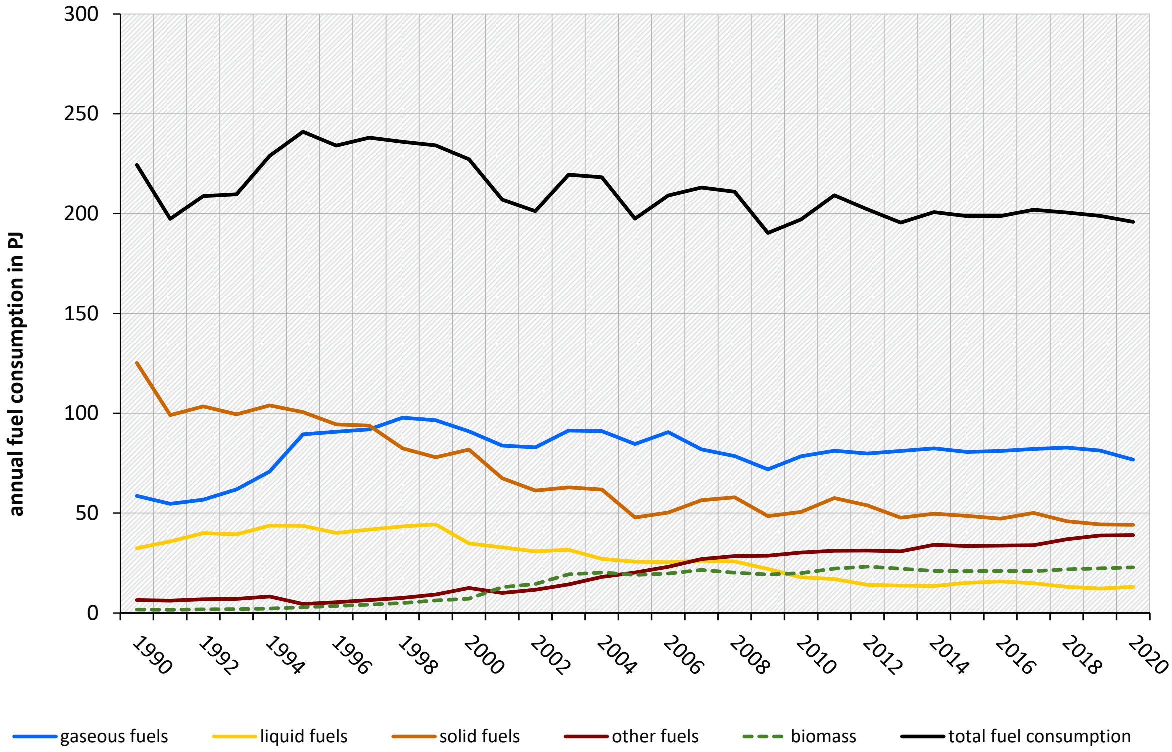
KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 A 2 f, Non-Metallic Minerals**	**fossil fuels**	**CO_2**	**18,507.4**	**1.5%**	**12,586.9**	**1.8%**	**-32.0%**
-/-	1 A 2 f, Non-Metallic Minerals		N_2O	205.3	0.0%	117.1	0.0%	-43.0%
-/-	1 A 2 f, Non-Metallic Minerals		CH_4	50.3	0.0%	14.9	0.0%	-70.4%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	CS	NS	CS
N_2O	CS	NS	CS
NO_x, CO, NMVOC, SO_2	CS/IE	NS/IE	CS/IE

The category *Manufacturing industries and construction – Non-metallic minerals industry*, which comprises all other sub-categories, is a key category, in terms of emissions level and trend, for CO_2 emissions.

In general in the inventory, those categories are listed separately in which combustion systems with a specific emissions behaviour – so-called "process combustion" systems – are used. For this reason, the sub-categories 1.A.2.f Cement (structural element "Production of cement clinkers (process combustion)"), 1.A.2.f Ceramics (structural element "Production of ceramics products (process combustion)"), 1.A.2.f Glass (structural element "Production of glass (process combustion)") and 1.A.2.f Lime (structural element "Production of lime (process combustion)") are listed individually.

Figure 26: Development of fuel inputs in category 1.A.2.f Non-metallic minerals



Two changes of fuels occurred in the area of the non-metallic minerals industry.

In the mid-1990s, gaseous fuels increasingly began to be used instead of solid fuels. These two fuel groups are currently predominant in this source category.

In the 2000s, the majority of liquid fuels (petroleum products) began to be replaced – first by waste and secondary fuels, and then by biomass.

3.2.9.6.1 Category description (1.A.2.f, Non-metallic minerals industry)

In this category, process combustion from burning of clinkers is listed. The final step in cement production, i.e. grinding and mixing, is not included. As a power-intensive process, it is included in power production (1.A.1). In addition, process combustion in the brick industry, and in production of other structural ceramics, are reported as well. In the glass industry, process combustion includes production of flat glass, hollow glass and glass fibres; shaping and processing of flat glass; and production and shaping of other types of glass and technical glassware. Process combustion in lime production is also taken into account. Some plants within this category also generate power for their own use; such generation is not listed separately, but is included under 1.A.2.gviii "Other".

3.2.9.6.1 Methodological issues (1.A.2.f, Non-metallic minerals industry)

The pertinent inputs of conventional fuels are contained in the Balance of Emission Sources (BEU). The fuel-input data for energy-related process combustion are obtained from the manufacturing sector's own statistics. The following numbers from the WZ classification of industrial sectors are relevant: Reporting number (Melde-Nr.) 26.51(WZ 2003 old) → 23.51 (WZ 2008 new), Cement production; Reporting number 26.40 (WZ 2003 old) → 23.32 (WZ 2008 new), Brick production, Production of other structural ceramics; Reporting number 26.1 (WZ 2003 old) → 23.1 (WZ 2008 new), Production of glass and glassware; and Reporting number 26.52 (WZ 2003 old) → 23.52 (WZ 2008 new), Lime production. As a result of the change in the reporting numbers, the data for lime can no longer be easily separated from those for gypsum. The necessary differentiation is achieved with the help of a split factor determined on the basis of old individual statistics. For differentiation from heat and electricity production, cf. Statistik 067 (Statistisches Bundesamt, 2021c).

As of 2002, the data for Statistik 067 (op. cit.) are found only among three-digit reporting numbers. This means that only data for reporting number 26.5 (WZ 2003 old) → 23.5 (WZ 2008 new) (production of cement, lime and burnt plaster) can be used as a basis.

The relevant calculation algorithms are described in detail in the final report for the research project "Substantiation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten" (Juhrich & Wachsmann, 2007)) and in the 2013 NIR, 3.2.9.7 through 3.2.9.10.

The fuel inputs for the new German Länder in 1990 were calculated on the basis of specific fuel consumption in 1989 and production in 1990.

The cement industry uses significant amounts of substitute fuels that do not appear in national statistics and in the Energy Balance. Relevant production figures and fuel-use quantities are taken from statistics of the relevant industry associations. The procedure used to compile activity data oriented to the old and new German Länder as of 1990, and to all of Germany as of 1995, is described in the final report of the research project "Inputs of secondary fuels" ("Einsatz von Sekundärbrennstoffen"; Lechtenböhmer et al. (2006c), FKZ 204 42 203/02). In a first step, fuel inputs were allocated to the groups "Biomass" or "Other fuels (waste)", in keeping with IPCC procedures. In the research project "Inputs of secondary fuels", the biogenic fractions of relevant fuels were derived and then entered into the calculations, with the help of split factors. In the same project, CO_2 emission factors were derived for substitute fuels, on the basis of data on carbon content, water content and net calorific value (Lechtenböhmer et al., 2006c).

3.2.9.6.2 Uncertainties and time-series consistency (1.A.2.f, Non-metallic minerals industry)

Uncertainties were determined for all fuels in 2004 and for the aforementioned substitute fuels with regard to the entire time series. The relevant methods are explained in Annex Chapter 13.6 of the NIR 2007 and in the final report of the research project (Lechtenböhmer et al., 2006c).

The uncertainties for the activity data were updated in the research project "Substantiation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten" (Juhrich & Wachsmann, 2007)) and included in the relevant final report.

The activity data for the new German Länder, for the base year and the subsequent years 1991-1994, were adjusted in keeping with the findings from the research project (Zander and Merten (2006): FKZ 205 41 115 / Teilvorhaben (sub-project) A "Revision and substantiation of fuel inputs for stationary combustion systems in the new German Länder, for the year 1990" ("Überarbeitung und Dokumentation der Brennstoffeinsätze für stationäre Feuerungsanlagen in den neuen Bundesländern für das Jahr 1990").

3.2.9.6.3 Category-specific quality assurance / control and verification (1.A.2.f, Non-metallic minerals industry)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.6.4).

3.2.9.6.4 Category-specific recalculations (1.A.2.f, Non-metallic minerals industry)

Table 36: Recalculations in CRF 1.A.2.f

Units [kt]	2021 NIR	2022 NIR	Difference, absolute					Difference, relative
Year	Total	Total	gas	liquid	other	solid	Total	Total
2019	13,286	12,856	-71	-201	0	-159	-431	-3.24%

For the year 2019, extensive recalculations for all conventional fuels were carried out, to take account of the fact that provisional data were replaced by figures from the final Energy Balance.

3.2.9.6.5 Planned improvements (category-specific) (1.A.2.f, Non-metallic minerals industry)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.9.7 Manufacturing industries and construction – Other energy production (1.A.2.g, Other, stationary + mobile)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 A 2 g, Other**	**fossil fuels**	**CO_2**	**127,739.5**	**10.0%**	**68,423.4**	**9.5%**	**-46.4%**
-/-	1 A 2 g, Other		N_2O	945.4	0.1%	543.7	0.1%	-42.5%
-/-	1 A 2 g, Other		CH_4	132.4	0.0%	197.8	0.0%	49.5%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	CS	NS	CS
N_2O	CS	NS	CS
NO_x, CO, NMVOC, SO_2	CS	NS	CS

The stationary and mobile sources in 1.A.2.g are grouped together for purposes of assignment to key categories. As a result, category *1.A.2.g Manufacturing industries and construction – Other energy production* is a key category for CO_2 in terms of emissions level and trend.

As a result of its function as a collective category for fuel inputs that cannot be disaggregated to the individual-sector level, this sub-category is particularly significant; it contributes substantially to the entire energy sector's CO_2 emissions.

3.2.9.7.1 Category description (1.A.2.g Other, stationary)

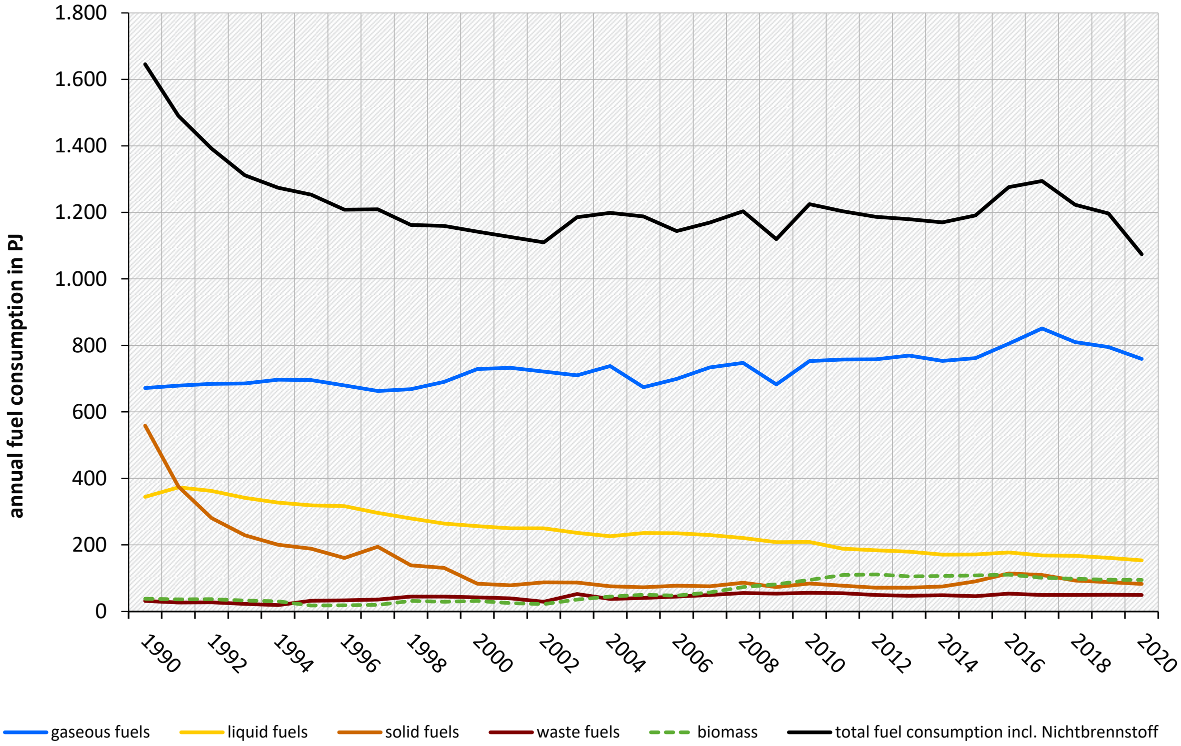
In this sub-category, all those emissions are reported for which the relevant energy inputs cannot be disaggregated in keeping with the categories in 1.A.2. This sub-category is responsible for about 70 % of all CO_2 emissions of category 1.A.2.

All electricity and heat generation in industrial power stations and boilers is listed in this sub-category, because such systems can justifiably be grouped together, in light of their emissions behaviour. Since the chemical industry primarily uses CHP systems and boilers, the pertinent emissions from category 1.A.2.c are reported in sub-category 1.A.2.gviii "Other". Any further subdivision of industrial power stations and boilers, among the otherwise planned sub-categories, would not improve the data, since such systems' emissions behaviour does not depend on the industrial sector involved. Time series are difficult to prepare, since in 1990 Germany consisted of two countries. Those two countries had two different statistical systems, and those systems were combined during a transition period lasting until 1994. Great efforts were made to provide the required documentation and quality data for the reference year, 1990. In addition, in 2003 the Act on Energy Statistics (Energiestatistikgesetz) was amended. This considerably improved data collection, especially for CHP systems. Such data for the period cannot be retroactively collected for the period 2002 – 1990, however. By and large, time-series consistency has been achieved at the aggregated level. Any further disaggregation would lead to breaks in the time series, however, because the data are not all available in disaggregated form, and cannot all be systematically allocated. Nonetheless, the possibilities for further disaggregation have been carefully reviewed. No successful solution for this problem has been found, however. Also, many energy data in Germany are subject to confidentiality restrictions, and thus often must be aggregated (aggregation safeguards confidentiality). In some sectors that have been listed separately to date, data for certain fuels now have to be combined, for reasons of confidentiality, and reported in category 1.A.2.gviii "Other". This considerably reduces the conclusiveness of the data in various individual sectors. The March 2017 amendment of the Act on Energy Statistics (Energiestatistikgesetz) brought no improvements with regard to the possibilities for disaggregating industrial power stations and boilers.

Ultimately, the boundary between the various individual industrial sectors and the public supply sector cannot be unambiguously drawn. The "autoproducers" described in the IPCC Guidelines hardly exist in reality in the clear-cut form outlined. Different companies manage their electricity and heat generation in different ways. Some companies operate power stations of their own that often also feed electricity into the public grid. Other companies draw electricity and/or heat from the public grid. As a result of energy-market liberalisation, the structures in this area often change. Since national statistics serve as the basis for inventory preparation, the inventory adopts those statistics' sectoral allocations of the various kinds of installations and plants involved. Such allocations do not remain constant throughout the time series, and they are not thoroughly consistent with the corresponding allocations in the emissions trading sector. As a result, they cannot be harmonized in the existing data records.

International comparisons of those sub-categories in which industrial power stations play the primary role are not feasible, since the pertinent supply structures differ considerably from country to country.

Figure 27: Development of fuel inputs in category 1.A.2.g viii Other



This category exhibits a marked change in fuel inputs.

The decrease in the use of solid fuels through 2014 – including, especially, a significant reduction in the use of lignite – is especially striking. From 2014 through 2016, use of solid fuels increased again slightly. Thereafter, use of such fuels remained at the new level it had reached. In addition, consumption of biomass and substitute fuels (waste) has also been increasing, with the result that total fuel consumption has been increasing again. Since use of natural gases dominates this category, total energy consumption follows the trend seen in gas consumption. In 2017, gas consumption increased markedly, driven by prices. As of 2018, gas consumption decreased. The decrease was due to renewed increases in gas prices and, in 2020, to decreases in energy requirements as a result of the coronavirus pandemic. A statistical discontinuity is seen in the area of biomass. Prior to the entry into force of the Act on Energy Statistics (Energiestatistikgesetz), biomass inputs for energy generation either were not recorded statistically or were recorded only in part. The biomass fraction has grown over the years.

3.2.9.7.2 Methodological issues (1.A.2.g Other, stationary)

The fuel inputs for electricity generation in industrial power stations are shown in Energy Balance line 12. The difference resulting after deduction of the fuel inputs for refinery power stations, mine power stations, power stations in the hard-coal-mining sector and, for the period until 1999, for the power stations of Deutsche Bahn (German Railways) consists of the activity data for other industrial power stations. These data cannot be further differentiated at present.

Additional data from the Federal Statistical Office are needed for allocation of fuel inputs to heat production in industrial power stations and boiler systems. Fuel inputs for heat production in CHP systems can be determined from relevant statistics. The activity data for boiler systems are calculated as the pertinent difference.

For both electricity generation and heat generation, the data are broken down into the categories steam turbines, gas turbines, gas-and-steam (combined cycle) systems and gas engines, since (for the present purpose) these different combustion technologies differ especially in terms of their methane emissions. This breakdown, which was extensively revised in the 2015 submission, is described under 1.A.1.a.

A detailed description of the relevant calculation algorithms, which were extensively revised for reporting year 2008, is provided in the final report for the research project "Substantiation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten"; (Juhrich & Wachsmann, 2007)).

Emission factors

A list of the CO_2 emission factors used, and a description of the relevant methods, are provided in the Annex, Chapter 18.8.

All other emission factors for greenhouse gases and precursor substances, for power stations and other boiler combustion for production of steam and hot/warm water, in category 1.A.2.gviii / all other, have been taken from Rentz et al. (2002) and Fichtner et al. (2011). A detailed description of the procedure is presented in Chapter 3.2.6.2 and in Chapter 19.1.2.1 in Annex 3. The research projects break down the relevant sector into power stations of Deutsche Bahn AG, other industrial power stations and other boiler combustion systems for production of steam and hot/warm water.

3.2.9.7.3 Uncertainties and time-series consistency (1.A.2.g, Other, stationary)

Activity data

The uncertainties were determined, for the first time, for 2004. The relevant method is described in Annex Chapter 13.6 of the NIR 2007.

The uncertainties for the activity data were updated in the research project "Substantiation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten" (Juhrich & Wachsmann, 2007)) and included in the relevant final report.

Emission factors

The procedure for determining uncertainties is described in Chapter 3.2.6.3.1.

Result for N_2O: The results of Chapter 3.2.6.3.2 apply mutatis mutandis.

Result for CH_4: The results of Chapter 3.2.6.3.3 apply mutatis mutandis.

The results obtained in Chapter 3.2.6.3.4 in determination of time-series consistency apply mutatis mutandis.

3.2.9.7.4 Category-specific quality assurance / control and verification (1.A.2.g, Other, stationary)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.6.4).

Activity data

The quality of the data was reviewed in the research project "Substantiation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten" (Juhrich & Wachsmann, 2007)) and improved via use of statistics of the Federal Statistical Office as a database. No other data sources with long-term availability have been identified.

Emission factors

The results obtained in Chapter 3.2.6.2, in the general procedure for source-specific quality assurance / control and verification, apply mutatis mutandis.

3.2.9.7.5 Category-specific recalculations (1.A.2.g, Other, stationary)

Table 37: Recalculations in CRF 1.A.2.gviii

Units [kt]	2021 NIR	2022 NIR	Difference, absolute					Difference, relative
Year	Total	Total	gas	liquid	other	solid	Total	Total
2019	69,959	67,899	-701	-1,082	33	-311	-2,060	-2.95%

Provisional values for the year 2019 were replaced when the figures from the final Energy Balance for 2013 became available. This has led to recalculations for all fuels.

3.2.9.7.6 Planned improvements (category-specific) (1.A.2.g, Other, stationary)

Activity data:

No further improvements are planned at present.

Emission factors:

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.9.8 Construction-sector transports (1.A.2.g vii)

3.2.9.8.1 Category description (1.A.2.g vii)

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1 [a], CS	NS/M	CS, D [a]
CH_4	CS (Tier 2)	NS/M	CS (M)
N_2O	CS (Tier 2)	NS/M	CS (M)
NO_x, CO, NMVOC, SO_2	CS (Tier 2)	NS/M	CS (M)

[a] Biodiesel: pursuant to (IPCC (2006a): Volume 2, Tab. 2.4)

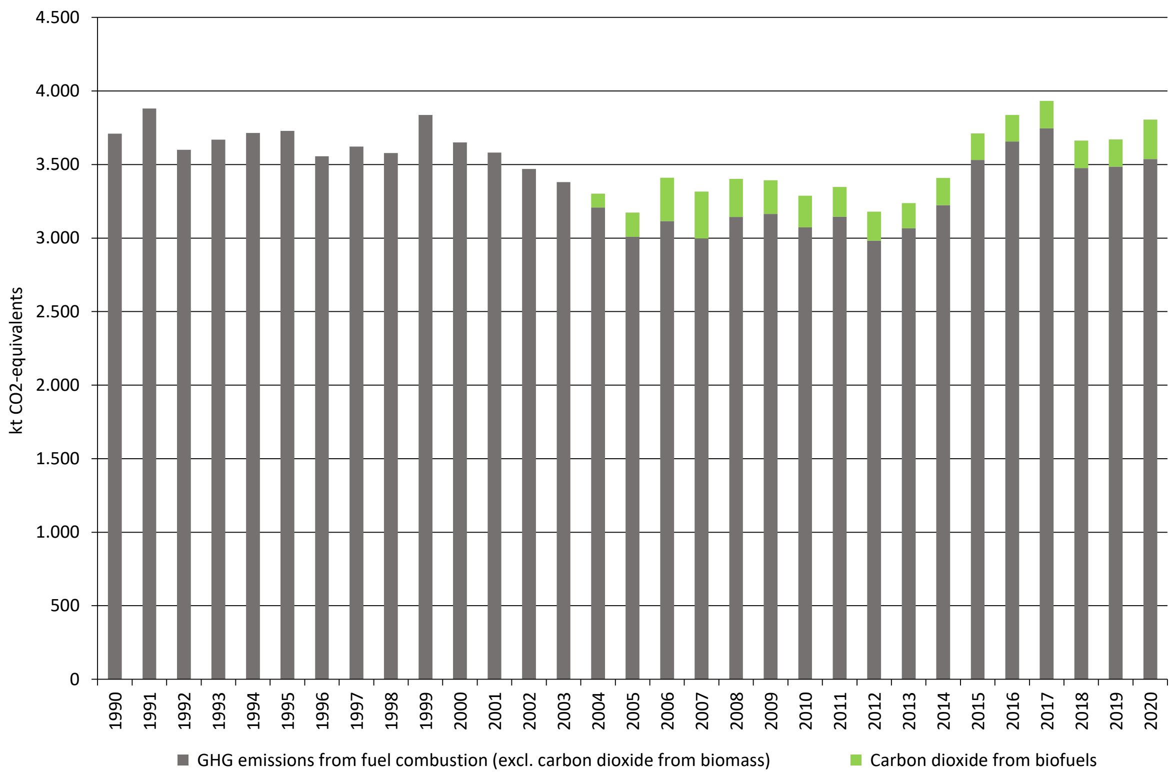
The stationary and mobile sources in 1.A.2.g are grouped together for purposes of assignment to key categories. (For an overview, cf. Chapter 3.2.9.7.). Accordingly, the category 1.*A.2.g vii – Other: Offroad vehicles and other machines*, in which emissions from construction-sector transports are taken into account, is a key category for CO_2 in terms of emissions level and trend.

3.2.9.8.2 Methodological issues (1.A.2.g vii)

Pursuant to the IPCC 2006 Guidelines (IPCC (2006a): page 3.33; equation 3.3.2), the emissions are calculated, using a Tier 2 method, as products of consumed fuels and technology-specific emission factors.

The CO_2 emissions from the fossil fractions of the biofuels used are listed separately, and allocated to the total national emissions (cf. the explanatory remarks in Chapter 19.1.5).

Figure 28: Development of GHG emissions from vehicles and mobile construction-sector machinery, since 1990



The **activity data** for fossil diesel fuel and petrol, including their biogenic admixtures, are calculated, following deduction of energy inputs for military transports, from the data in Energy Balance lines 79 (until 1994) and 67 *"Commercial and Institutional" ("commerce, trade, services and other consumers*"). For the years 2005 through 2009, figures of the Association of the German Petroleum Industry (MWV) are used in the area of diesel-fuel and petrol consumption in the various vehicle categories (cf. the following chapters on road and railway transports). To assure the necessary consistency with the relevant total quantities pursuant to the NEB, therefore, the primary data on which the figures for those five years are based are calculated within TREMOD. Inputs of biofuels are also determined via calculation, on the basis of the official admixture quotas.

Finer allocation of fuel quantities to mobile sources in the construction sector, commerce & trade (1.A.4.a ii) and agriculture and forestry (1.A.4.c ii) is achieved with the help of annually fluctuating split factors modelled in TREMOD-MM (Transport Emission Model-Mobile Machinery (Knörr et al., 2021b)).

The relevant **emission factors** are based on the results of various Federal Environment Agency research projects and expert opinions.

With regard to carbon dioxide, we refer in general to Chapter 18.8. Both country-specific and default values (biodiesel) are used. Further information regarding co-combustion of lubricants in particular is provided in Chapter 19.1.4.

For methane and nitrous oxide, country-specific values from Knörr et al. (2021b) are used. The development of these values reflects the gradual phasing-in of emissions standards, since the mid-1990s, for construction-sector machinery.

With regard to releases of methane and nitrous oxide from co-combustion of lubricants, it is assumed that such emissions are already taken into account in the pertinent emission factors for the fuels used and thus are to be reported as IE *(included elsewhere)*.

Table 38: Emission factors used for reporting year 2020, in kg/TJ

	CH_4	N_2O	Origin
Diesel & biodiesel	0.66 (4.15)	2.95 (28.60)	Pursuant to Knörr et al. (2021b)
Gasoline & bioethanol	18.9 (50)	1.41 (2.00)	Pursuant to Knörr et al. (2021b)

In parentheses: Defaults pursuant to IPCC (2006a): Volume 2 – Energy, Chapter 3 – Mobile , Tab. 3.3.1: Industry

3.2.9.8.3 Uncertainties and time-series consistency (1.A.2.g vii)

The uncertainty figures for the specific energy inputs, which are shaped primarily by the mathematical uncertainty in the distribution key developed in TREMOD MM (cf. above: Methodological aspects), are based on experts' assessments. The same holds for the carbon-dioxide emission factors used. While the emission factors for methane are based on results from Knörr et al. (2009), the emission factors for nitrous oxide – for the time being – have to be oriented to guideline values pursuant to the IPCC.

3.2.9.8.4 Category-specific quality assurance / control and verification (1.A.2.g vii)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Quality reports of the Working Group on Energy Balances (AG Energiebilanzen – AGEB) have been submitted to the Federal Environment Agency, for purposes of quality assurance of the Energy Balances.

Table 39: Overview of relevant data comparisons

	Comparison with...	Remark
CO_2	Alternative emissions inventories for Germany	No comparable data sets
CO_2	Default pursuant to IPCC (2006a): Volume 2, Chapter 3, Table 3.3.1: Industry	cf. Table 40
CH_4, N_2O	Default pursuant to IPCC (2006a): Volume 2, Chapter 3, Tab. 3.3.1: Industry	cf.
CO_2, CH_4, N_2O	IEF of other countries	cf. Table 41

Table 40: Comparison of a) the EF(CO_2) used and b) default values, in kg/TJ

	Inventory values [a]	Default [b]	*Lower bound*	*Upper bound*
Diesel fuel	74,027	74,100 [c]	*72,600*	*74,800*
Gasoline	75,276	69,300 [c]	*67,500*	*73,000*
Biodiesel	70,800 [d]		*59,800*	*84,300*
Bioethanol	71,607	70,800 [d]	*59,800*	*84,300*

[a] for reported year 2020; [b] pursuant to IPCC (2006a): Volume 2, [c] Chapter 3, Tab. 3.3.1; [d] Chapter 2, Tab. 2.4

The following table provides a comparison with specific implied emission factors of other countries. It should be noted that the comparison is hampered by the fact that the factors involved represent a heterogeneous group of source categories.

Table 41: International comparison of IEF for liquid fossil fuels, in kg/TJ

	CO_2	CH_4	N_2O
Germany	74,426	1.99	3.08
Denmark	73,463	2.35	3.41
France			
Netherlands	72,077	1.46	0.80
UK	74.224	11.9	2.95
EU-27			

Germany: IEF for report year 2020; all other countries: IEF for 2019, pursuant to 2021 CRF submission

3.2.9.8.5 Category-specific recalculations (1.A.2.g vii)

As described above, the activity data for construction-sector transports are part of the primary data given in Energy Balance line 67. The provisional data provided for the year 2019, in the 2021 Submission, have been replaced with the corresponding figures from the final 2019 NEB. At the same time, a revision of the 2018 NEB has been carried out. The quantities of consumed biofuels that were determined via the official admixture quotas have been recalculated as necessary.

Table 42: Revised primary activity data for 2019, in terajoules

	2015	2016	2017	2018	2019
Diesel fuel					
2022 Submission	101,911	105,895	108,752	101,513	102,836
2021 Submission	101,911	105,895	108,752	101,519	102,654
Absolute change	0	0	0	-6.00	182
Relative change	0.00%	0.00%	0.00%	-0.01%	0.18%
Gasoline					
2022 Submission	12,557	12,219	11,712	11,543	11,141
2021 Submission	12,557	12,219	11,712	11,274	11,046
Absolute change	0	0	0	269	95.0
Relative change	0.00%	0.00%	0.00%	2.39%	0.86%
Biodiesel					
2022 Submission	5,575	5,614	5,806	5,901	5,857
2021 Submission	5,575	5,614	5,806	5,901	5,845
Absolute change	0	0	0	0	12.4
Relative change	0.00%	0.00%	0.00%	0.00%	0.21%
Bioethanol					
2022 Submission	545	531	494	519	481
2021 Submission	545	531	494	507	476
Absolute change	0	0	0	12.1	4.10
Relative change	0.00%	0.00%	0.00%	2.39%	0.86%

Source: Energy Balances 2018 & 2019 (AGEB, 2021c), and own calculations on the basis of Knörr et al. (2021b)

At the same time, the calorific values of the fossil-based gasoline used in military vehicles were corrected for all years as of 2004, and the energy quantities delivered to the military and to all other consumers subsumed under Energy Balance line 67 were revised.

In sum, the above-described adjustments result in the following changes in the activity data most recently assigned to construction-related transports:

Table 43: Resulting revision of activity data (for the period as of 2004), in terajoules

	2003	2004	2005	2010	2015	2016	2017	2018	2019
Diesel fuel									
2022 Submission	40,706	38,439	35,884	38,160	43,686	45,281	46,495	43,087	43,509
2021 Submission	40,706	38,439	35,884	38,160	43,686	45,281	46,495	43,089	43,431
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-2.55	77.2
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.01%	0.18%
Gasoline									
2022 Submission	4,455	4,404	4,283	2,844	3,363	3,440	3,421	3,220	2,937
2021 Submission	4,455	4,403	4,272	2,799	3,326	3,406	3,393	3,123	2,992
Absolute change	0.00	1.42	10.63	45.21	36.96	34.17	27.51	97.07	-55.01
Relative change	0.00%	0.03%	0.25%	1.62%	1.11%	1.00%	0.81%	3.11%	-1.84%
Biodiesel									
2022 Submission	0	1,311	2,293	2,926	2,390	2,401	2,482	2,505	2,478
2021 Submission	0	1,311	2,293	2,926	2,390	2,401	2,482	2,505	2,473
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	-0.06	0.00	5.25
Relative change		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.21%
Bioethanol									
2022 Submission	0	5	29	110	146	149	144	145	127
2021 Submission	0	5	29	108	144	148	143	140	129
Absolute change	0.00	0.00	0.07	1.75	1.60	1.48	1.16	4.36	-2.37
Relative change		0.03%	0.25%	1.62%	1.11%	1.00%	0.81%	3.11%	-1.84%

Source: Own calculations, based on Knörr et al. (2021b)

The described corrections necessitated recalculations of the reported emissions.

Table 44: Revised emissions quantities (for the period as of 2004), in kt and kt CO_2-eq

	2003	2004	2005	2010	2015	2016	2017	2018	2019
Carbon dioxide[a]									
2022 Submission	3,339	3,167	2,969	3,033	3,487	3,611	3,699	3,432	3,442
2021 Submission	3,339	3,167	2,969	3,029	3,484	3,608	3,697	3,425	3,440
Absolute change	0.00	0.10	0.78	3.31	2.78	2.57	2.07	7.12	1.57
Relative change	0.00%	0.00%	0.03%	0.11%	0.08%	0.07%	0.06%	0.21%	0.05%
Methane									
2022 Submission	0.193	0.181	0.167	0.116	0.114	0.114	0.111	0.102	0.093
2021 Submission	0.193	0.181	0.167	0.115	0.114	0.113	0.111	0.100	0.094
Absolute change	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.002	-0.001
Relative change	0.00%	0.02%	0.13%	0.80%	0.67%	0.62%	0.51%	2.01%	-1.20%
Nitrous oxide									
2022 Submission	0.126	0.124	0.119	0.126	0.141	0.146	0.150	0.139	0.140
2021 Submission	0.126	0.124	0.119	0.126	0.141	0.146	0.150	0.139	0.140
Absolute change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Relative change	0.00%	0.00%	0.01%	0.05%	0.04%	0.03%	0.03%	0.10%	0.12%
TOTAL GREENHOUSE GASES [a]									
2022 Submission	3,381	3,209	3,009	3,073	3,532	3,657	3,747	3,476	3,486
2021 Submission	3,381	3,209	3,008	3,070	3,529	3,655	3,745	3,469	3,484
Absolute change	0.00	0.11	0.79	3.35	2.82	2.60	2.10	7.21	1.59
Relative change	0.00%	0.00%	0.03%	0.11%	0.08%	0.07%	0.06%	0.21%	0.05%

Source: Own calculations;[a] including fossil CO_2 from use of biofuels

3.2.9.8.6 Planned improvements (category-specific) (1.A.2.g vii)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.10 Transport (1.A.3)

3.2.10.1 Transport – Domestic aviation (1.A.3.a)

3.2.10.1.1 Category description (1.A.3.a)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	1 A 3 a, Domestic Aviation	fossil fuels	CO_2	2,410.9	0.2%	1,037.8	0.1%	-57.0%
-/-	1 A 3 a, Domestic Aviation		N_2O	24.3	0.0%	10.4	0.0%	-57.2%
-/-	1 A 3 a, Domestic Aviation		CH_4	2.6	0.0%	1.5	0.0%	-42.7%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1 [a], CS (Tier 3a)	NS/IS/M	D [a], *CS* [b]
CH_4	CS (Tier 3a)	NS/IS/M	CS [c] (M)
N_2O	CS (Tier 3a)	NS/IS/M	CS [c] (M)
NO_X, CO	CS (Tier 3a)	NS/IS/M	CS [c] (M)
NMVOC	CS (Tier 3a)	NS/IS/M	CS [c] (M)
SO_2	Tier 1	NS/IS/M	D

[a] Avgas: pursuant to IPCC (2006a), Chapter 3.6 – *Civil Aviation*, Table 3.6.4

[b] Derived from the default value of 3,150 kg/ t kerosene pursuant to IPCC et al. (1997) and from the specific net calorific value pursuant to AGEB (2021c)

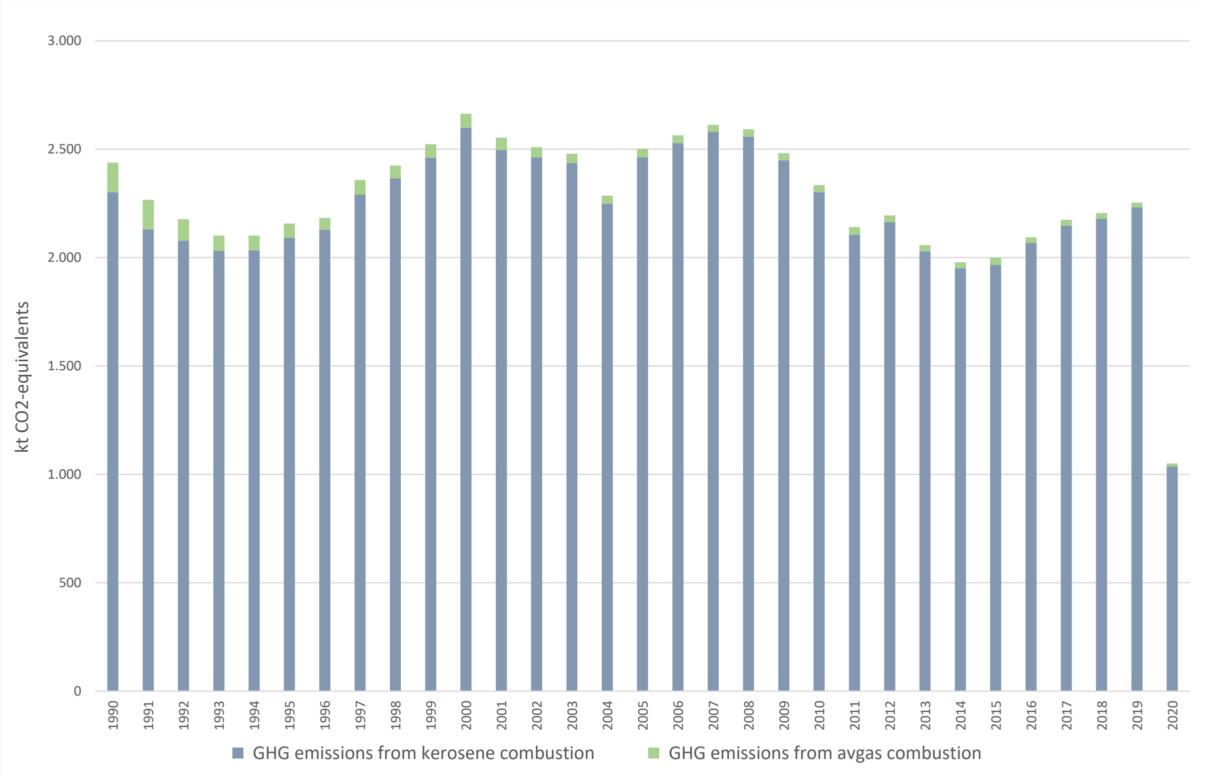
[c] Derived from Tier 3 default values pursuant to EMEP (2019)

The category *Civil aviation* is not a key category.

In terms of emissions origins, aviation differs considerably from land and water transports, since aircraft burn most of their fuel under varying atmospheric conditions that differ from those at ground level. The main factors that influence the combustion process in this sector include atmospheric pressure, surrounding temperature and humidity – all of which are factors that vary considerably with flight altitude.

In addition to considering carbon dioxide, the debate on the climate effects and airborne-emissions-related environmental impacts of aviation focuses mainly on water vapour and nitrogen oxides and, secondarily, on hydrocarbons, particulates, carbon monoxide and sulphur dioxide. In the framework of national emissions reporting, figures for other emissions are also required, however. The following remarks thus refer to emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O, laughing gas), nitrogen oxides (NO_X, i.e. NO and NO_2), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide (SO_2).

Figure 29: Development of GHG emissions in national civil air transports since 1990



3.2.10.1.2 Methodological issues (1.A.3.a)

Air-transport emissions are calculated in accordance with Tier 3a, i.e. taking account of the annual flight mileages logged by the relevant individual aircraft types, broken down by national and international flights, and taking account of the operational states LTO cycle (landing/take-off cycle, i.e. aircraft movements to an elevation of 3,000 feet / about 915 m) and cruise (cruising flight at elevations above 3,000 feet).

In general, emissions are determined on the basis of the National Energy Balance data for consumption of kerosene and aviation gasoline (AGEB, 2021b). For years for which no data are yet available, data from the Federal Office of Economics and Export Control (BAFA, 2021) are used. Within the TREMOD AV (TREMOD Aviation) (Knörr et al., 2015) model, flights are categorised as either intra-German or international flights. This breakdown plays a decisive role in reporting. The relevant flight data are collected by the Federal Statistical Office.

For reporting purposes, emissions are determined, in each case, by multiplying fuel consumption for the relevant flight phase by the pertinent specific emission factor. CO_2 and SO_2 emissions figures do not depend on what method is used; they depend solely on the quantities and characteristics of the fuel consumed. Emissions of NMVOC, CH_4, CO, NO_X and N_2O, on the other hand, depend on engines, flight altitudes, flight phases, etc., and thus they are described more precisely by higher-Tier methods.

In a departure from this approach, as proposed in (IPCC (2006a): Volume 2, Chapter 3: Mobile Combustion), the emissions caused by use of avgas are calculated separately, with adjusted emission factors and net calorific values.

The **activity data** (energy inputs) are in keeping with the aviation fuel sold in Germany pursuant to (AGEB (2021b); currently, for the period through 2020) and the *Official mineral-oil data for the Federal Republic of Germany* (Amtliche Mineralöldaten für die Bundesrepublik Deutschland) that are published by the Federal Office of Economics and Export Control *(BAFA, 2021)*.

The calculations made within TREMOD-AV, with regard to **kerosene**, take account of the numbers of flights, for the various aircraft types and great-circle distances involved, and for national and international air transports. In the process, the commercial flights recorded by the Federal Statistical Office, for certain airports, are included. The Federal Statistical Office breaks down flights from "other airfields", and non-commercial flights, only by weight or aircraft classes, but not by destinations. The great majority of the flights concerned are flights by small aircraft fueled with aviation gasoline.

Table 45: Domestic flights' annual shares of domestic kerosene deliveries, in [%]

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Kerosene	16.1	12.1	11.8	9.67	8.59	8.21	7.88	7.31	7.28	7.34	7.17	6.82	6.73	6.94	6.99
Avgas	79.9	84.0	82.6	83.8	83.1	86.6	86.6	87.4	88.5	86.7	93.1	92.9	93.6	92.1	93.7

Source: TREMOD AV (Knörr et al., 2021a)

Fuel consumption is broken down in accordance with the two flight phases landing / take-off (LTO cycle) and cruise, on the basis of data of the Federal Statistical Office, and via TREMOD-AV calculations. Those results make it possible to extract fuel consumption figures for the LTO flight phase for both domestic and international flights. Consumption in cruise flight is obtained as the following difference: total sales, pursuant to the NEB, less the LTO consumption.

The pertinent quantities of ***co-combusted lubricants*** are derived, pursuant to (VSI, 2014), from the relevant annual fuel quantities (cf. Chapter 19.1.4 in the Annex).

With regard to the **emission factors** used for carbon dioxide, we refer, in general, to Chapter 18.8.

The emission factor for *carbon dioxide* from use of ***kerosene*** was derived from the carbon content of kerosene; it is *3,150 g/kg*. That value, which has been substantiated by numerous published studies, is used for the entire aviation sector.

Nitrous oxide (laughing gas) is a product of nitrogen oxidation in the combustion chamber, and it can occur in traces. The available data for this substance are poor. Since the emission factors have to be broken down in accordance with the two flight phases, the emission factors for both nitrous oxide and *methane* have been taken from the IPCC emission factor database (EFDB) (cf. Table 545). For methane, it is assumed that emissions occur only during the LTO cycle (cf. IPCC (2006a): Volume 2, Chapter 3.6, Tab. 3.6.5). On the other hand, N_2O emissions are also calculated for cruising flight.

The other emissions are calculated separately for each flight phase, on the basis of the relevant emission factors. In the process, different sources are used.

The implied emission factors used for NO_X, CO and NMVOC consist of quotients obtained by dividing the aircraft-type-specific emissions calculated and aggregated in TREMOD by the applicable annual kerosene consumption. The detailed emissions data used for this purpose are calculated in TREMOD with aircraft-type-specific emission factors from the EMEP/EEA database.

Figures relative to the air pollutants additionally considered are presented in Chapter 19.1.3.1 in the Annex.

The emission factors expressed in the units [g/kg] are converted into the units [g/TJ] on the basis of a net calorific value of 43,000 kJ/kg (AGEB, 2021b).

For calculation of *CO_2 emissions* from use of **avgas**, the standard value pursuant to IPCC (2006a): Volume 2, Chapter 3: Mobile Combustion is used. In those guidelines (pages 3-64), the emission factors for *methane* and *nitrous oxide* are explicitly defined as equal to the relevant values given for kerosene use. That assumption has been adopted here.

In a procedure similar to that described above for kerosene, the implied emission factors used for NO_X, and CO are derived from aircraft-type-specific emissions calculated and aggregated in TREMOD and from the applicable annual avgas consumption.

CO_2 emissions from unintentional co-combustion of lubricants are reported in CRF 2.D.1. With regard to releases of methane and nitrous oxide, it is assumed that such emissions are already taken into account in the pertinent emission factors for the fuels used and thus are to be reported as IE *(included elsewhere)*.

Table 46: Emission factors used for report year 2020, in kg/TJ

	CH_4	N_2O	Origin
Kerosene: LTO	14.5	2.80 (2.00)	pursuant to TREMOD AV; derived from EFDB defaults in kg/LTO
Kerosene: Cruise	0.00	2.34 (2.00)	pursuant to TREMOD AV; derived from EFDB defaults in kg/t
Avgas: LTO	165 (-)	2.30 (-)	pursuant to TREMOD AV
Avgas: Cruise	0 (-)	2.30 (-)	pursuant to TREMOD AV
Lubricants	IE	IE	Included in the EF for fuels

Sources: Knörr et al. (2021a) and Gores (2021); in parentheses: Defaults pursuant to IPCC (2006a): Volume 2, Chapter 3.6, Tab. 3.6.5

3.2.10.1.3 Uncertainties and time-series consistency (1.A.3.a)

For determination of uncertainties, the individual components that enter into emissions calculation are identified, and their uncertainties (U_1 to U_n) are quantified. The total uncertainty U_{total} is obtained via additive linking of squared partial uncertainties, as explained in IPCC (2006a): Volume 1, Chapter 3, page 3.28, formula 3.1:

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \ldots + U_n^2}$$

For all time series and flight phases, uncertainties were estimated as mean values. The total uncertainties were calculated as is shown in Annex Chapter 19.1.3.1.2. The left column in that section contains the components that enter into the uncertainty calculation; the relevant partial uncertainties are listed in the neighbouring columns to the right. The columns that then follow to the right contain the values for the required total uncertainties. Some of these, in turn, are individual components of the uncertainties calculation for other values. For example, the uncertainty for national jet-kerosene consumption in the two relevant flight phases, LTO and cruise, is calculated from the partial uncertainties for total national jet-kerosene consumption and from the partial uncertainty for the LTO/cruise breakdown. The latter is based on the number of aircraft movements, as reported by the *Federal Statistical Office*, and on assumptions relative to the fleet composition. The total uncertainty for kerosene consumption during the LTO and cruise flight phases, in turn, serves as a partial uncertainty in determination of the uncertainties for emissions data.

3.2.10.1.4 Source-specific quality assurance / control and verification (1.A.3.a)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

For a growing share of aircraft types for which no specific data are available, emission factors have to be obtained via regressions carried out on the basis of take-off weight. Use of more current, and more complete, aircraft-type-specific data would further improve the quality of the calculations. Furthermore, expansion of the TREMOD-AV calculations, to include differentiation in accordance with the different engines used, would also improve the quality of the calculations.

Except for the emission factors for sulphur dioxide, international standard values were used, taken from the IPCC emission-factors database, the EMEP-EEA database and EMEP (2019). Country-specific consumption and emissions data provided by Eurocontrol are currently being used only for verification purposes.

Table 47: Overview of relevant data comparisons

	Comparison with...	Remark
CO_2, CH_4, N_2O	Alternative emissions inventories for Germany	No comparable data sets
CO_2	Specific Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter 3.6, Tab. 3.6.4	cf. Table 48
CH_4, N_2O	Specific Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter 3.6, Tab. 3.6.5	cf. Table 46
CO_2, CH_4, N_2O	specific IEF of other countries	cf. Table 49

Table 48: Comparison of the EF(CO_2) used in the inventory with default values [a], in kg/TJ

	Inventory value	Default[b]	*Lower bound*	*Upper bound*
Kerosene	73,256	71,500	*69,700*	*74,400*
Avgas	70,000		*67,500*	*73,000*

[a] pursuant to IPCC (2006a): Volume 2, Chapter 2, Table 2.4

The following table provides a comparison with specific implied emission factors of other countries.

Table 49: International comparison of reported IEF, in kg/TJ

	Kerosene			Avgas		
	CO_2	*CH_4*	*N_2O*	*CO_2*	*CH_4*	*N_2O*
Germany	73,256	4.01	2.47	70,000	21.0	2.30
Denmark	71,874	0.46	3.06	72,475	7.47	2.00
France	73,488	0.81	2.00	70,500	6.02	2.00
Netherlands	71,500	0.50	2.00	72,000	0.50	2.00
UK	71,739	1.35	2.28	69,818	57.3	2.23
EU-27	72,669	1.31	2.15	70,359	24.4	4.33

Germany: current IEF for report year 2020; all other countries: IEF for 2019, pursuant to 2021 CRF submission

3.2.10.1.5 Category-specific recalculations (1.A.3.a)

Recalculations with respect to the 2020 submission were carried out for all years under consideration, to take account of revision of domestic flights' annual shares, as recorded in the TREMOD AV model, of total domestic deliveries of kerosene.

Table 50: Revised annual shares, for domestic flights, of domestic fuel deliveries, in %

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Kerosene														
Subm. 2022	16.1	12.1	11.8	9.7	8.6	8.2	7.9	7.3	7.3	7.3	7.2	6.8	6.7	6.9
Subm. 2021	16.1	12.1	11.8	9.7	8.6	8.2	7.9	7.3	7.3	7.3	7.2	6.8	6.7	6.9
Abs. change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Rel. change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.52%
Avgas														
Subm. 2022	79.0	80.9	79.7	78.0	77.3	82.2	81.8	81.9	83.3	81.5	90.6	90.4	91.1	92.1
Subm. 2021	79.9	84.0	82.6	83.8	83.1	86.6	86.6	87.4	88.5	86.7	93.1	92.9	93.6	94.7
Abs. change	-0.87	-3.14	-2.94	-5.81	-5.80	-4.39	-4.77	-5.44	-5.26	-5.14	-2.54	-2.49	-2.47	-2.53
Rel. change	-1.1%	-3.7%	-3.6%	-6.9%	-7.0%	-5.1%	-5.5%	-6.2%	-5.9%	-5.9%	-2.7%	-2.7%	-2.6%	-2.7%

Source: TREMOD AV (Knörr et al., 2021a)

The quantities of fuel consumed for domestic flights were upwardly corrected by the same amount.

Table 51: Resulting revision of domestic consumption, in terajoules

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jet fuel / kerosene														
Subm. 2022	9,380	8,303	9,811	9,187	8,589	7,869	8,171	7,633	7,297	7,358	7,844	8,210	8,362	8,476
Subm. 2021	9,380	8,303	9,811	9,187	8,589	7,869	8,171	7,633	7,297	7,358	7,844	8,210	8,362	8,417
Abs. change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	58.42
Rel. change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.69%
Avgas														
Subm. 2022	245	119	113	72	57	65	58	52	50	58	47	44	45	37
Subm. 2021	368	346	311	293	236	248	237	234	237	246	234	232	248	229
Abs. change	-123	-227	-198	-222	-179	-183	-179	-182	-188	-188	-187	-188	-203	-192
Rel. change	-33%	-66%	-64%	-76%	-76%	-74%	-75%	-78%	-79%	-76%	-80%	-81%	-82%	-84%
TOTAL FUEL INPUTS														
Subm. 2022	9,625	8,422	9,924	9,259	8,646	7,934	8,229	7,686	7,347	7,416	7,891	8,254	8,407	8,513
Subm. 2021	9,748	8,649	10,122	9,481	8,825	8,117	8,408	7,868	7,534	7,604	8,078	8,442	8,610	8,647
Abs. change	-123	-227	-198	-222	-179	-183	-179	-182	-188	-188	-187	-188	-203	-134
Rel. change	-1.3%	-2.6%	-2.0%	-2.3%	-2.0%	-2.3%	-2.1%	-2.3%	-2.5%	-2.5%	-2.3%	-2.2%	-2.4%	-1.5%

Source: Own calculations

The relative changes in the reported greenhouse-gas emissions are largely in keeping with the fuel consumption data. Methane is the sole exception: Since it is assumed that no methane emissions occur during cruising flight, the reduction in the LTO-consumption figures has a disproportionately large effect in this area.

Table 52: Revised 2019 methane emission factors for LTO cycle, in kg / TJ

	Kerosene	Avgas
2022 Submission	10.15	164.89
2021 Submission	10.80	164.95
Absolute change	-0.65	-0.06
Relative change	-6.04%	-0.03%

Table 53: Revised GHG emissions, in kt and kt CO_2-eq

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Carbon dioxide – CO_2														
Subm. 2022	2,411	2,133	2,635	2,474	2,308	2,117	2,171	2,035	1,957	1,977	2,070	2,150	2,181	2,229
Subm. 2021	2,412	2,136	2,637	2,477	2,311	2,119	2,173	2,037	1,958	1,979	2,071	2,151	2,181	2,218
Abs. change	-1.49	-2.51	-2.30	-2.84	-2.30	-1.89	-1.86	-1.89	-1.74	-1.99	-0.73	-0.70	-0.67	11.0
Rel. change	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.5%
Methane – CH_4														
Subm. 2022	0.11	0.08	0.09	0.09	0.08	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09
Subm. 2021	0.12	0.11	0.12	0.12	0.11	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.13
Abs. change	-0.02	-0.04	-0.03	-0.04	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.04
Rel. change	-15%	-31%	-25%	-29%	-26%	-28%	-27%	-28%	-28%	-28%	-27%	-25%	-27%	-28%
Nitrous oxide – N_2O														
Subm. 2022	0.08	0.07	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08
Subm. 2021	0.08	0.07	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Abs. change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rel. change	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	0.0%	0.5%
Total for all greenhouse gases														
Subm. 2022	2,438	2,157	2,663	2,501	2,334	2,140	2,194	2,058	1,978	1,999	2,093	2,174	2,205	2,254
Subm. 2021	2,440	2,160	2,666	2,505	2,337	2,143	2,197	2,060	1,981	2,001	2,095	2,175	2,206	2,244
Abs. change	-1.98	-3.44	-3.10	-3.76	-3.03	-2.63	-2.58	-2.63	-2.49	-2.75	-1.47	-1.44	-1.50	10.2
Rel. change	-0.1%	-0.2%	-0.1%	-0.2%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.5%

Source: Own calculations

3.2.10.1.6 Category-specific planned improvements (1.A.3.a)

Now that the TREMOD AV model has been extensively revised, no major work in this area is planned at present. Continuing work in this area will focus mainly on regular updating of the model in keeping with the *Advanced Emission Model* (AEM) operated by the European Organisation for the Safety of Air Navigation (Eurocontrol)[29].

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.10.2 Transport – Road transportation (1.A.3.b)

3.2.10.2.1 Category description (1.A.3.b)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	1 A 3 b, Road Transport	fossil fuels	CO_2	151,886.3	11.9%	141,282.7	19.7%	-7.0%
-/T	1 A 3 b, Road Transport		CH_4	1,561.1	0.1%	208.6	0.0%	-86.6%
-/T	1 A 3 b, Road Transport		N_2O	1,343.5	0.1%	1,642.2	0.2%	22.2%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1 [a], CS (Tier 2)	NS / M	D [a], CS
CH_4	Tier 1 [b], CS (Tier 3)	NS / M	D [b], CS (M)
N_2O	Tier 1 [b], CS (Tier 3)	NS / M	D [b], CS (M)
NO_X, CO, NMVOC, SO_2	CS (Tier 3)	NS / M	CS (M)

[a] Biodiesel, petroleum, lubricants co-combusted in two-stroke engines; [b] LP gas

The category *Road transportation* is a key category for CO_2 emissions in terms of level and trend. For CH_4 and N_2O emissions, it is a key category only in terms of trend.

Emissions from motorised road transport in Germany are reported under this category. It includes transport on public roads within Germany, except for agricultural, forestry and military transports. Calculations are made for the vehicle categories of passenger cars (PCs), motorcycles, light duty vehicles (LDVs), heavy duty vehicles (HDVs), buses and motorcycles. For calculation purposes, the vehicle categories are broken down into so-called *vehicle layers* with the same emissions behaviour. To that end, vehicle categories are also broken down by type of fuel used, vehicle size (utility vehicles and buses by weight class; motorcycles by engine displacement) and pollution control equipment used, as defined by EU directives for emissions control ("EURO norms"), and by regional traffic distribution (outside of cities, in cities and on motorways).

3.2.10.2.2 Methodological issues (1.A.3.b)

- Cf. also Chapter 19.1.3.2 -

Since 1990, emissions of CH_4, NO_X, CO, NMVOC and SO_2 from road transport have decreased sharply, due to catalytic-converter use, to engine improvements resulting from continual tightening of emissions laws, and to improved fuel quality.

Between 1990 and 1993, the methane emission factor for gasoline dropped sharply. This was due especially to a massive reduction in the numbers of vehicles with two-stroke engines in the new German Länder. Further EF decreases have resulted from the aforementioned tightening of emissions standards.

For buses and heavy duty vehicles (over 3.5 t permissible total vehicle weight), maximum permissible levels of hydrocarbon (HC) emissions were lowered considerably (-40 %) via the introduction of the EURO III standard in 2000. Since EURO III vehicles were very quick to reach the market as of 2000, the emission factor for hydrocarbon emissions from diesel fuel – and the

[29] https://www.eurocontrol.int/model/advanced-emission-model

relevant emissions themselves – decreased considerably after 2000. A similar trend occurred for methane, emissions of which are calculated as a fixed share of total HC emissions.

N_2O emissions result primarily from incomplete reduction of NO to N_2 in 3-way catalytic converters. They are not limited by law. Initially, growth in numbers of cars with catalytic converters caused increases in N_2O emissions in comparison to the 1990 level. Newer catalytic converters are optimised to produce only small amounts of N_2O, however. As a result, N_2O emissions decreased during the period 2000-2006. Since then, such emissions have been increasing again. Those increases are due to increasing use of selective catalytic reduction (SCR) equipment in HDVs; under certain conditions, such equipment can produce N_2O as an undesired by-product.

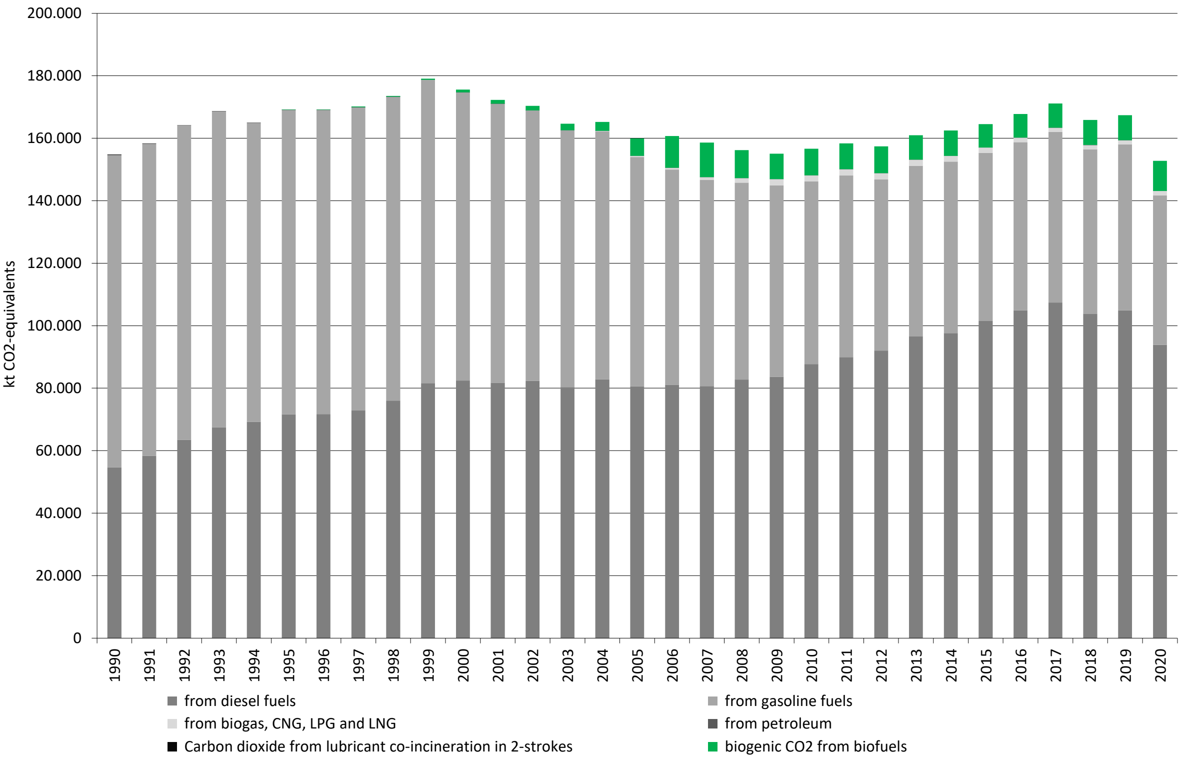
CO_2 emissions depend directly on fuel consumption. From 1990-1999, these emissions increased, since growth in mileage travelled outweighed improvements in vehicle fuel efficiency. In the 2000-2009 period, road-transport emissions from consumption of fossil fuels decreased for the first time. The likely reasons for this trend include reductions in specific fuel consumption, the marked shift toward diesel vehicles in new registrations, continual increases in fuel prices, use of biofuels – and consumers' growing tendency to travel to other countries in order to make their fuel purchases (see the following paragraphs).

The CO_2 emissions from the fossil fractions of the biofuels used are allocated to the total national emissions (cf. the explanatory remarks in Chapter 19.1.5).

In the years 2010 and 2011, the CO_2 emissions increased again, as the aforementioned trends slowed and overall mileage increased. In 2012, they decreased by over 1.3 million t, however, because traffic volumes and mileage decreased. As a result of renewed growth in overall mileage traveled, of decreases in inputs of biofuels and of continual increases – over a period of years now – in the average engine power of newly registered automobiles, however, CO_2 emissions increased again, by 7 %, through 2019. At that point, they were 5.6 million t higher than their level in 1990.

The majority of the considerable reduction seen in 2020 is ascribed to the effects of the pandemic, including the changes in mobility behavior that the pandemic brought about. Other emissions-reduction contributions – small ones, by comparison – came from an increase in electric vehicles' shares of new vehicle registrations and from an increase in the biofuel quota with respect to the previous year.

Figure 30: Development of GHG emissions in road transports, since 1990



CO_2 emissions from motorised road transports in Germany are calculated via a Tier-2 "*bottom-up*" approach pursuant to (IPCC (2006a): Volume 2, Chapter 3.2, page 3.12): In the pertinent process, the fuels sold in Germany (gasoline, (bio-) ethanol fuel, diesel fuel, biodiesel, LP and natural gas, petroleum (until 2002), biogas) are allocated, within the TREMOD ("Transport Emission Model") model, to the various relevant vehicle layers (cf. Chapter 19.1.3.2) (Knörr et al., 2021c)[30]. The consumption data that enter into the model, for each type of fuel, are obtained from the *Energy Balances*. The actual emission calculation is carried out in the Central System of Emissions (CSE), after the pertinent specific fuel consumption data and emission factors have been imported.

The procedure for calculation of non-CO_2 emissions is based on a Tier-3 method, implemented in TREMOD, in which the mileage data for the relevant individual vehicle layers are multiplied by the applicable specific emission factors. For PCs and LDVs, a "*cold start surplus*" is also added. The total consumption determined for each fuel type is cross-checked against consumption pursuant to the Energy Balance. Then, the relevant emissions as calculated in TREMOD are corrected with the help of correction factors obtained via such cross-checking. For gasoline-powered vehicles, the VOC-evaporation emissions are calculated as a function of the pollution-control technology used. From emissions and fuel consumption data for the individual TREMOD vehicle layers, fuel-based implied emission factors (IEF) in [kg/TJ] are derived, and entered into the Central System of Emissions (CSE). The IEF are differentiated solely by fuel type and road type (motorway, country road, urban streets).

The actual emission calculation is carried out in the Central System of Emissions (CSE), after the pertinent specific fuel consumption data and implied emission factors have been imported.

[30] To make it possible to derive and assess reduction measures, energy consumption and CO_2 emissions for the various vehicle categories are also calculated with TREMOD. The resulting values are subsequently checked against total consumption and total CO_2 emissions.

Table 54: Emissions from road transports, in kilotonnes

	CO_2 fossil [a]	CO_2 biogenic [b]	CH_4	N_2O	NO_x	CO	NMVOC [c]	SO_2
1990	151,886	0	62.4	4.51	1,306	7,324	1,479	72.2
1995	166,451	106	30.9	6.30	1,156	4,199	682	69.3
2000	172,541	869	19.3	5.65	1,000	2,488	346	19.7
2005	153,040	5,591	12.8	3.32	798	1,594	202	0.80
2010	146,752	8,530	9.36	3.77	650	1,196	124	0.78
2015	155,314	7,538	8.55	5.02	579	1,059	97.0	0.81
2016	158,429	7,561	8.80	5.33	556	1,034	94.7	0.83
2017	161,491	7,706	9.15	5.65	527	1,015	93.1	0.85
2018	155,928	8,024	8.93	5.64	471	954	87.3	0.82
2019	157,437	7,985	8.97	5.85	436	926	87.3	0.83
2020	141,283	9,649	8.35	5.51	355	780	82.2	0.75

Source: Own calculations, based on Knörr et al. (2021c)
[a] Including CO_2 from the fossil fractions of consumed biofuels and of the lubricants co-combusted in two-stroke engines
[b] CO_2 emissions from the biogenic fractions of the biofuels consumed are reported here solely for information purposes)
[c] Including emissions from fuel evaporation

For calculation with TREMOD, extensive basic data from generally accessible statistics and special surveys are used, co-ordinated, and supplemented. The main data sources used, and key assumptions made, are outlined only briefly here. A detailed description of the databases, including information on the sources used, and the calculation methods used in TREMOD, is provided in Knörr et al. (2021c).

For western Germany from 1990 through 1993, and for Germany as a whole as of 1994, total-automobile-fleet data are calculated on the basis of the officially published fleet and new registration statistics of the Federal Motor Transport Authority (KBA). The car ownership analysis for East Germany in 1990 was based on a detailed analysis of the Adlershof car-emissions-testing agency in 1992 and the time series in the statistical annuals of the GDR. For the period between 1991 and 1993, it was necessary to estimate the ownership figures with the aid of numerous assumptions.

The fleet data for reference years as of 2001 are obtained for TREMOD by querying the database of the KBA. The supplied data include vehicle fleets for each reference year, broken down as required for emissions calculation, i.e. in accordance with the following characteristics: type of engine (gasoline, diesel, other), size class, vehicle age and emissions standard. For each reference year, the mid-year fleet is assumed to be representative of the fleet's composition for the year.

Mileage data are updated on the basis of the "2014 Mileage Survey" ("Fahrleistungserhebung 2014"), the 2015 road transport census (Straßenverkehrszählung 2015) and data of the Federal Motor Transport Authority (Jamet & Knörr, unveröffentlicht)). For heavy duty vehicles, the data are also cross-checked against road-toll statistics.

With regard to the **emission factors** used for carbon dioxide, we refer, in general, to Chapter 18.8.

For petrol and natural gas, year-specific values, weighted in accordance with the fuel qualities produced in Germany, are available. For all other fuels, standardised values are used, throughout all relevant years. Further information – in particular, with regard to carbon dioxide from lubricant co-combustion – is also provided in Chapter 19.1.4.

All other emission factors are listed in the "Handbook Emission Factors for Road Transport 3.2" (HBEFA), which was prepared via a cooperative effort, involving Austria, Germany and Switzerland, aimed at deriving emission factors for road transports. In large part, the factors were obtained via measurement programmes of TÜV Rheinland and RWTÜV and via basic studies oriented to the reference years 1989/1990. In those studies, a new method was used, for both passenger cars and heavy duty vehicles, whereby emission factors were derived on the basis of driving habits and traffic situations. Emission factors for automobiles until the 1994 (automobile-)model year were updated with the help of field-monitoring data. Now, the Netherlands, Sweden and Norway also participate in the development of the HBEFA. HBEFA version 4.1 (Notter et al., 2019), which is used for the current emissions calculations, draws on findings of the EU working group COST 346, of measurement programmes of the participating countries and of the ARTEMIS research programme.

With regard to *unintentional co-combustion of lubricants*, it is assumed that the pertinent non-CO_2 emissions are already included in the emission factors for the relevant fuels and thus have to be reported here as IE *(included elsewhere)*. Carbon dioxide from *unintentional* co-combustion of lubricants is reported in 2.D.1, however, as emissions from product use. On the other hand, carbon dioxide from *intentional* co-combustion of lubricants, as part of the fuel mixtures used in road-vehicle two-stroke engines, is also assigned to road transports and, in the CRF tables, is reported in 1.A.3.b v.

Shifting of fuel purchases to other countries

Because fuel prices in Germany are higher – significantly, in some cases – than in several of Germany's neighbours, for some time the fuel used in Germany has included fuel quantities purchased in other countries and brought into the country as "grey" imports.

At present, no precise data are available on this phenomenon, which is significant for truck and automobile traffic in Germany's border regions and which is referred to as "refueling tourism" ("Tanktourismus"). Although several detailed studies have been carried out, no reliable overall picture of the situation is available (Lenk et al., 2004; Tietge et al., 2020).

The sources that have documented shifting of consumers' fuel purchases to other countries (along with the resulting negative impacts on neighbouring countries' own emissions inventories) have included a study published by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (Molitor et al., 2004). In any case, it is clear that the neighbouring countries in question profit to a not inconsiderable degree from additional tax revenue from the energy taxes on such fuel.

3.2.10.2.3 Uncertainties and time-series consistency (1.A.3.b)

In the framework of a study (Knörr et al., 2009), uncertainties were calculated for the activity data entered into TREMOD, for the emission factors generated in TREMOD and for the emissions calculated in the Central System of Emissions (CSE).

3.2.10.2.4 Source-specific quality assurance / control and verification (1.A.3.b)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Quality reports of the Working Group on Energy Balances (AGEB) have been submitted to the Federal Environment Agency, for purposes of quality assurance of the National Energy Balances. In addition, documentation on revision of Energy Balances as of 2003 has been published on the Internet[31].

[31] AG Energiebilanzen (Working Group on Energy Balances): explanations relative to revision of the Energy Balances 2003 – 2009; URL: http://www.ag-energiebilanzen.de/index.php?article_id=7&clang=0#revision_der_energiebilanzen_2003_bis_2009_05 (last checked on 18 Sept. 2013)

Table 55: Overview of relevant data comparisons

	Comparison with...	Remark
CO_2, CH_4, N_2O	Alternative emissions inventories for Germany	No comparable data sets
CO_2	Specific Tier 1 defaults pursuant to IPCC (2006a): Volume 2, Chapter 3, Table 3.2.1	No defaults for biofuels and petroleum
CO_2	Tier 1 defaults pursuant to IPCC (2006a): Volume 2, Chapter 3, Tab. 2.4	cf. Table 56
CH_4, N_2O	Specific Tier 1 defaults pursuant to IPCC (2006a): Volume 2, Chapter 3, Table 3.2.2	Results are inconclusive
CH_4, N_2O	Tier 1 defaults pursuant to IPCC (2006a): Volume 2, Table 2.4	Results are inconclusive
CO_2, CH_4, N_2O	specific IEF of other countries	cf. Table 57

Table 56: Comparison of a) the EF(CO_2) used and b) default values, in kg/TJ

	Inventory value [a]	Default [b]	Lower bound	Upper bound
Fossil-based diesel fuel	74,027	74,100	72,600	74,800
Fossil-based gasoline	75,276	69,300	67,500	73,000
Natural gas	55,826	56,100	54,300	58,300
LPG	66,334	63,100	61,600	65,600
Liquefied natural gas (LNG)	55,944	-	-	-
Petroleum	74,000	-	-	-
Co-combusted lubricants	73,300		71,900	75,200
Biodiesel	70,800		59,800	84,300
Bioethanol	71,607	70,800	59,800	84,300
Biogas	90,584	54,600	46,200	66,000

[a] used for reported year 2020; [b] pursuant to IPCC (2006a): Chapter 2, Table 2.4

The following table provides a comparison with specific implied emission factors of other countries as well as with the relevant values resulting for the EU(28).

Table 57: International comparison of reported IEF, in kg/TJ

	Gasoline			Diesel fuel			LPG			Natural gas		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Germany	75,276	8.78	0.48	74,027	1.69	3.85	66,334	3.73	1.12	55,826	15.9	0.26
Denmark	72,982	5.47	0.71	73,997	0.36	3.41	63,100	5.31	1.05	56,800	26.0	2.93
France	74.538	12.4	1.17	74,883	0.31	2.50	65,254	18.7	1.09	56,349	47.0	0.02
Netherlands	73,023	12.0	0.74	72,454	0.47	2.81	66,700	2.17	0.84	56,600	92.0	3.00
UK	70,214	7.08	0.66	73,838	0.25	3.46	63,886	0.88	0.62	IE	IE	IE
EU-27	72,782	10.6	0.84	74,040	0.95	3.07	65,267	9.50	0.36	56,942	36.3	4.98

Germany: current IEF for 2020; otherwise: IEF for 2019, pursuant to 2021 CRF submission

The comparatively high emission factor for carbon dioxide from gasoline is the result of an adjustment. The pertinent emission factor in [kg CO_2 / kg fuel] is in keeping with corresponding international values, however.

3.2.10.2.5 Category-specific recalculations (1.A.3.b)

With respect to the 2021 submission, recalculations have been carried out to take account of revised activity data and emission factors.

In addition, provisional energy-consumption figures in the 2019 Energy Balance have been replaced with final values.

Table 58: Revised energy inputs for 2019, in terajoules

	Diesel	Biodiesel	Gasoline	Biogasoline	Natural gas	LPG	LNG	Biogas	Lubricants*
2022 Submission	1,390,837	79,219	699,835	30,184	5,848	14,602	697	2,378	76.25
2021 Submission	1,392,585	79,291	699,936	30,188	5,198	17,332	703	2,378	81.82
Absolute change	-1.748	-72.2	-101	-4.10	650	-2.730	-6.16	0.00	-5.57
Relative change	-0.13%	-0.09%	-0.01%	-0.01%	12.5%	-15.8%	-0.88%	0.00%	-6.81%

Source: Knörr et al. (2021c) based on AGEB (2021b) and (MWV, 2021b)
Lubricants: as part of 1:50 two-stroke fuel mixtures; burned in two-stroke gasoline engines

Changes have been made in the specific Tier 3 emission factors for methane and nitrous oxide, in keeping with the relevant changes in TREMOD. It is not possible to present the relevant revised data records here in any useful way.

The following table presents a finalising comparison of the emissions quantities reported in the current submission and the 2021 Submission.

Table 59: Revised greenhouse gas emissions, in kt CO_2 equivalents

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
1.A.3.b i – automobiles										
2022 Submission	114,752	117,271	113,960	104,796	95,178	99,526	101,541	103,759	99,513	99,861
2021 Submission	114,752	117,271	113,960	104,796	95,178	99,523	101,556	103,743	99,465	99,960
Absolute change	0.00	0.00	0.00	0.00	-0.61	2.18	-15.2	16.0	48.0	-98.7
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.01%	0.02%	0.05%	-0.10%
1.A.3.b ii – light duty vehicles										
2022 Submission	4,024	6,410	8,313	8,532	8,407	10,080	10,712	11,380	11,384	11,722
2021 Submission	4,024	6,410	8,313	8,532	8,407	10,089	10,730	11,406	11,448	11,845
Absolute change	0.00	0.00	0.00	0.00	0.00	-8.74	-17.6	-26.0	-63.7	-123
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	-0.09%	-0.16%	-0.23%	-0.56%	-1.04%
1.A.3.b iii – Heavy duty vehicles (including buses)										
2022 Submission	34,137	43,928	50,620	39,274	43,050	46,006	46,551	46,801	45,530	46,404
2021 Submission	34,137	43,928	50,620	39,274	43,049	45,998	46,516	46,752	45,512	46,458
Absolute change	0.04	0.15	0.06	0.02	0.78	7.62	35.3	48.6	18.0	-53.6
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.08%	0.10%	0.04%	-0.12%
1.A.3.b iv – Motorised two-wheelers (motorcycles and mopeds)										
2022 Submission	1,695	1,459	1,806	1,742	1,468	1,406	1,428	1,456	1,399	1,412
2021 Submission	1,695	1,459	1,806	1,742	1,468	1,407	1,431	1,461	1,407	1,427
Absolute change	0.00	0.00	0.00	0.00	0.00	-1.32	-2.44	-4.12	-7.96	-15.6
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	-0.09%	-0.17%	-0.28%	-0.57%	-1.10%
CO_2 from co-combustion of lubricants in two-stroke gasoline engines										
2022 Submission	183	32.8	5.90	5.64	5.97	5.65	5.67	5.65	5.54	5.59
2021 Submission	183	32.8	5.90	5.64	5.97	5.66	5.68	5.67	5.87	6.00
Absolute change	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.33	-0.41
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	-0.09%	-0.17%	-0.28%	-5.61%	-6.81%
1.A.3.b - TOTAL GREENHOUSE GAS EMISSIONS										
2022 Submission	154,791	169,100	174,706	154,351	148,108	157,023	160,238	163,403	157,831	159,404
2021 Submission	154,791	169,100	174,706	154,351	148,108	157,023	160,238	163,368	157,837	159,696
Absolute change	0.04	0.15	0.06	0.02	0.17	-0.18	0.13	34.6	-5.88	-292
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.00%	-0.18%

Source: Own calculations

The recalculations for the individual segments (automobiles, light duty vehicles, heavy duty vehicles, motorcycles) are considerable, in some areas – even in relation to the road transport sector as a whole. This is due to changes in the way mileage and consumption data are modelled within TREMOD.

3.2.10.2.6 Category-specific planned improvements (1.A.3.b)

Apart from annual regular revision of the TREMOD model, no source-specific improvements are planned.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.10.3 Transport – Railways (1.A.3.c)

3.2.10.3.1 Category description (1.A.3.c)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 A 3 c, Railways**	**fossil fuels**	**CO_2**	**3,122.1**	**0.2%**	**783.1**	**0.1%**	**-74.9%**
-/-	1 A 3 c, Railways		CH_4	17.6	0.0%	0.3	0.0%	-98.5%
-/-	1 A 3 c, Railways		N_2O	7.7	0.0%	2.0	0.0%	-74.3%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1 [a], CS (Tier 2)	NS	D [a], CS
CH_4	CS (Tier 2)	NS	D [b, c, d]
N_2O	CS (Tier 2)	NS	D [d], CS
NO_x, CO, NMVOC, SO_2	CS (Tier 2)	NS	CS

[a] Biodiesel: pursuant to (IPCC (2006a): Tab. 2.4); [b] Diesel: pursuant to (EMEP (2019): 1.A.3.c – *Railways*; Tab. 3-2 through 3-4); [c] hard coal & hard-coal coke: pursuant to (IPCC (2006a): Tab. 3.4.1); [d] Lignite: pursuant to (IPCC (2006a): Tab. 2.5)

The category *Railway transports* is a key category for CO_2 emissions in terms of emissions level and trend.

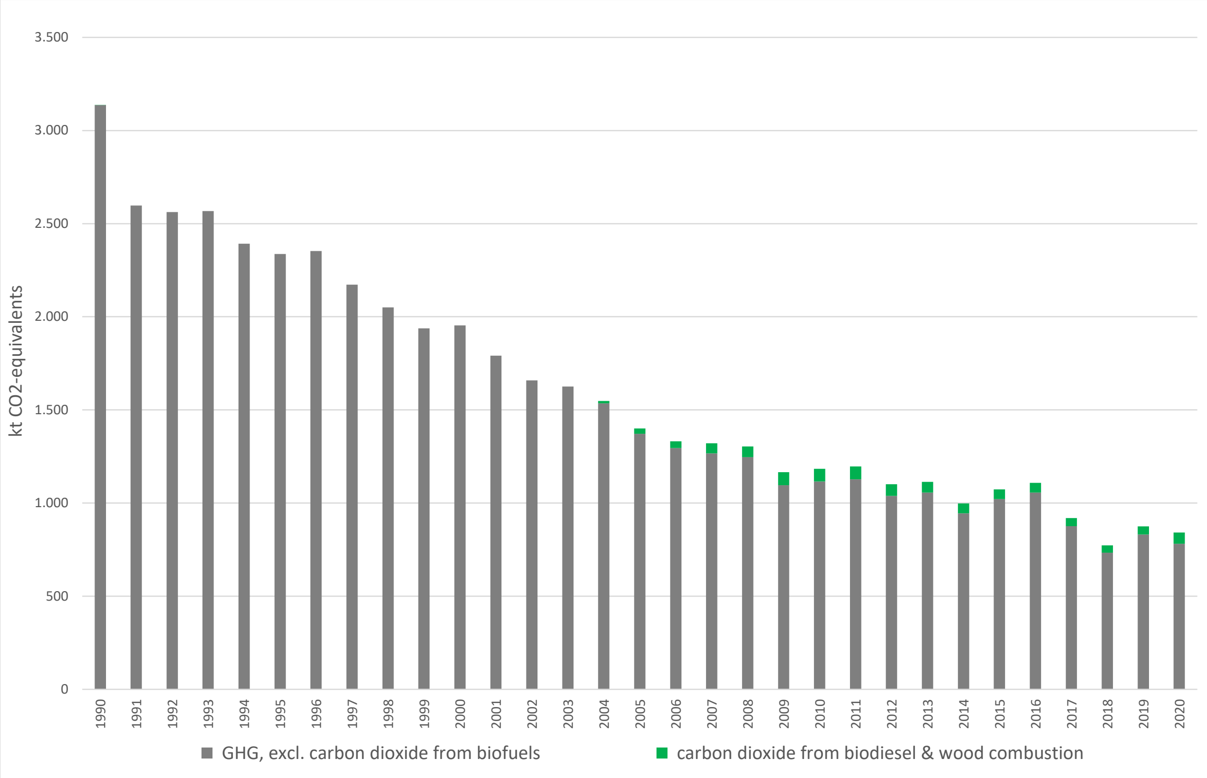
Germany's railway sector is undergoing a long-term modernisation process, aimed at making electricity the main energy source for rail transports. Its share of the energy used for traction is currently about 78 % (AGEB, 2021b). Railways' power stations for generation of required traction current are allocated to the stationary component of electricity generation in public power stations (1.A.1.a) and are not included in the following section.

In energy input for trains operating in Germany, diesel fuel is the only energy source that plays a significant role apart from electric power. Since 2004, biodiesel has also been used, as an additive.

In historic vehicles, small quantities of solid fuels are also used.

Use of other fuels – such as vegetable oils or gas – in private narrow-gauge railway vehicles has not been included to date and may be considered negligible.

Figure 31: Development of greenhouse-gas emissions of railway transports, since 1990



* not including greenhouse gases from generation of traction current, and not including CO_2 from unintentional co-combustion of lubricants

3.2.10.3.2 Methodological issues (1.A.3.c)

The relevant emissions are thus calculated as the product of fuel consumption and the relevant country-specific emission factors. This procedure conforms to the general Tier 2 method and the basic calculation rule pursuant to Equation 3.4.2 of the 2006 IPCC Guidelines (Volume 2, page 3.42).

In the present report, the CO_2 emissions from the fossil fractions of the biofuels used are listed separately, for the first time, and allocated to the total national emissions (cf. the explanatory remarks in Chapter 19.1.5).

In general, the **activity data** (energy inputs) are taken from Energy Balance lines 74 (through 1994) and 64 (as of 1995) (AGEB, 2021b). In a departure from this procedure, and for methodological reasons, the figures for the years 2005 through 2009 are based on sales figures of the Association of the German Petroleum Industry (MWV) that are published in the annual report "Petroleum Data" ("Mineralöl-Zahlen"; the table "Sectoral consumption of diesel fuel" ("Sektoraler Verbrauch von Dieselkraftstoff")) (MWV, 2021b).[32]

Due to inadequacies in the available statistical data, annual figures for biodiesel consumption continue to be calculated, for the time being, on the basis of the official mixture percentages.

[32] AG Energiebilanzen (Working Group on Energy Balances): explanations relative to revision of the Energy Balances 2003 – 2009; URL: http://www.ag-energiebilanzen.de/index.php?article_id=7&clang=0#revision_der_energiebilanzen_2003_bis_2009_05 (last checked on 4 Oct. 2014)

In the official Energy Balances, evaluatable consumption data for relevant solid fuels are available as follows: for lignite, solely for the period until 2002; for hard coal, for the period until 2000. Interpolations and extrapolations, and the results of three surveys, carried out in 2012, 2016 and 2021 (Hasenbalg & Sohnke, 2021; Hedel & Kunze, 2012; Illichmann, 2016), are used as complementary sources.

Table 60: Overview of the statistics and other sources used

Fuel	Source(s) used
Diesel	until 2004: AGEB; 2005-2009: MWV; as of 2010: AGEB
Biodiesel	Calculated in keeping with official admixture quotas
Hard coal	until 1994: AGEB; 1995-2004: Interpolation; as of 2005: Survey
Hard-coal coke	until 1997: AGEB; 1998-2004: Interpolation; as of 2005: Survey
Crude lignite	until 2002: AGEB; not used thereafter
Lignite briquettes	until 2002: AGEB; through 2014: Interpolation; as of 2015: Survey

With regard to the **emission factors** used for carbon dioxide, we refer, in general, to Chapter 18.8.

For methane and nitrous oxide, country-specific values pursuant to (Knörr et al. (2021c): liquid fuels) or default values pursuant to (IPCC (2006a): solid fuels) are used. With regard to releases of methane and nitrous oxide from co-combustion of lubricants, it is assumed that such emissions are already taken into account in the pertinent emission factors for the fuels used and thus are to be reported as IE *(included elsewhere)*.

Table 61: Emission factors used for reporting year 2020, in kg/TJ

	CH_4	N_2O	Origin
Diesel & biodiesel	0.87 (4.15)	0.56 (28.60)	CH_4: pursuant to Knörr et al. (2021c); N_2O: Tier 2 default pursuant to EMEP (2019)
Crude lignite	300 (-)	1.50 (-)	*not used in 2020*
Lignite briquettes	300 (-)	1.50 (-)	derived from stationary small combustion systems
Hard coal (coke)	2.00 (2.00)	1.50 (1.50)	Sector-specific IPCC defaults for *"sub-bituminous coal"*
Firewood	100	1.00	derived from stationary small combustion systems
Lubricants	IE	IE	Already included in the EF for liquid fuels

In parentheses: Sector-specific prescribed values pursuant to IPCC (2006a), Volume 2, Chapter 3.4 - *Railways*

3.2.10.3.3 Uncertainties and time-series consistency (1.A.3.c)

In the framework of a study (Knörr et al., 2009), uncertainties were calculated for the activity data entered into TREMOD, for the emission factors generated in TREMOD and for the emissions calculated in the Central System of Emissions (CSE).

The activity-rate time series for lignite briquettes, hard coal and hard-coal coke exhibit inconsistencies resulting from statistical conversion as of 1994/1995; these inconsistencies cannot be eliminated at present.

3.2.10.3.4 Source-specific quality assurance / control and verification (1.A.3.c)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Quality reports of the Working Group on Energy Balances (AGEB) have been submitted to the Federal Environment Agency, for purposes of quality assurance of the National Energy Balances. In addition, documentation on revision of Energy Balances as of 2003 has been published in the Internet.

Table 62: Overview of relevant comparisons

	Comparison with...	Remark
CO_2, CH_4, N_2O	Alternative emissions inventories for Germany	No comparable data sets
CO_2	Specific Default EF pursuant to IPCC (2006a): Volume 2,	not for all relevant fuels
CO_2	Default EF pursuant to IPCC (2006a): Volume 2, Chapter 2,	cf. Table 56
CH_4, N_2O	Specific Default EF pursuant to IPCC (2006a): Volume 2,	cf.
CH_4, N_2O	Default EF pursuant to IPCC (2006a): Volume 2, Chapter 2,	Results are inconclusive
CO_2, CH_4, N_2O	IEF of other countries	cf. Table 64

Table 63: Comparison of a) the EF(CO_2) used and b) default values [a], in kg/TJ

	Inventory value [b]	Default[b]	*Lower bound*	*Upper bound*
Fossil-based diesel fuel	74,027	74,100	*72,600*	*74,800*
Lignite briquettes	99,212	97,500	*87,300*	*109,000*
Crude lignite	105,953	101,000	*90,900*	*115,000*
Hard coal	93,572	94,600	*89,500*	*99,700*
Hard-coal coke	108,317	107,000	*95,700*	*119,000*
Biodiesel	70,800		*59,800*	*84,300*

[a] for reported year 2020; [b] pursuant to IPCC (2006a): Volume 2, Tab. 2.4

The following table provides a comparison with specific implied emission factors of other countries as well as with the relevant values resulting for the EU(28).

Table 64: International comparison of reported IEF, in kg/TJ

	Fossil liquid fuels			Fossil solid fuels		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Germany [a]	74,027	0.87	0.56	93,603	3.08	1.50
Denmark	74,000	1.08	2.24	NO	NO	NO
France	74,885	10.6	2.95	IE	IE	IE
Netherlands	72,454	4.26	0.56	NO	NO	NO
UK	74,938	1.51	2.84	96,100	87.6	0.70
EU-27	74,111	3.24	11.6	95,077	48.4	1.10

Sources: [a] IEF for reported year 2020; otherwise: IEF for 2019, pursuant to 2021 CRF submission

3.2.10.3.5 Category-specific recalculations (1.A.3.c)

Almost all recalculations carried out with respect to the 2021 submission have been carried out to take account of revised or newly obtained activity data.

In the process, the energy inputs for diesel fuels, which had still been provisional, were replaced with final values for 2019. This led to a corresponding correction of the figure for biodiesel used as an admixture. At the same, the official admixture quotas for biodiesel, for the period as of 2004, were corrected. Most importantly, the recorded quantities of solid fuels were revised for all years in question.

Table 65: Correction of fuel inputs, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
					Diesel fuel					
2022 Submission	38,458	31,054	25,410	18,142	14,626	13,321	13,775	11,344	9,425	10,747
2021 Submission	38,458	31,054	25,410	18,142	14,626	13,321	13,775	11,344	9,425	9,531
Absolute change	0	0	0	0	0	0	0	0	0	1.216
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	12.8%
					Biodiesel					
2022 Submission				401	957	727	729	606	548	612
2021 Submission				401	957	727	729	606	548	543
Absolute difference				0	0	0	0	0	0	69
Relative difference				0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	12.8%
					Hard coal					
2022 Submission	576	232	223	267	324	351	361	367	365	362
2021 Submission	576	250	250	255	314	339	340	340	340	340
Absolute difference	0	-18	-27	12	9	12	21	27	25	22
Relative difference	0.00%	-7.12%	-10.7%	4.88%	3.01%	3.46%	6.19%	7.85%	7.39%	6.37%
					Hard-coal coke					
2022 Submission	200	86	1.33	0.79	0.79	0.66	0.63	0.46	0.46	0.43
2021 Submission	NE	86	1.33	0.79	0.79	0.75	0.75	0.75	0.75	0.75
Absolute difference	200	0	0.00	0.00	0.00	-0.09	-0.12	-0.29	-0.29	-0.32
Relative difference		0.00%	0.0%	0.00%	0.00%	-12.2%	-15.7%	-38.7%	-38.7%	-42.5%
					Lignite briquettes					
2022 Submission	2,000	1,309	431	14.6	7.32	0.02	1.19	1.21	1.20	1.20
2021 Submission	NE	NE	431	NE	NE	NE	NE	NE	NE	NE
Absolute difference	2,000	1,309	0	14.6	7.3	0.0	1.2	1.2	1.2	1.2
Relative difference			0.00%							
					Firewood					
2022 Submission	0.004	0.002	0.001	0.000	0.000	0.001	0.001	0.001	0.001	0.001
2021 Submission	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Absolute difference	0.004	0.002	0.001	0.000	0.000	0.001	0.001	0.001	0.001	0.001
					TOTAL ENERGY INPUTS					
2022 Submission	41,234	32,681	26,065	18,826	15,915	14,400	14,867	12,318	10,340	11,722
2021 Submission	39,034	31,390	26,092	18,799	15,898	14,388	14,845	12,290	10,314	10,414
Absolute difference	2.200	1.291	-27	27	17	12	22	28	26	1.308
Relative difference	5.64%	4.11%	-0.10%	0.14%	0.11%	0.08%	0.15%	0.22%	0.25%	12.6%

Sources: AGEB (2021b); Knörr et al. (2021c)

The emission factors for methane from diesel and biodiesel were corrected for the years as of 2011. Otherwise, the emission factors have not been changed with respect to the 2021 report.

Table 66: Corrected emission factors for methane from diesel fuels, in kg/TJ

	2011	2012	2013	2014	2015	2016	2017	2018	2019
2022 Submission	1.33	1.10	1.03	1.01	0.95	0.94	0.91	0.87	0.84
2021 Submission	1.34	1.10	1.03	1.01	0.95	0.94	0.91	0.87	0.86
Absolute change	-0.004	-0.002	-0.002	-0.001	-0.001	0.000	0.000	0.000	-0.021
Relative change	-0.30%	-0.22%	-0.21%	-0.10%	-0.15%	0.00%	0.00%	-0.01%	-2.45%

Source: Knörr et al. (2021c)

The above-described adjustments lead to the following recalculated emissions quantities:

Table 67: Revised emissions quantities, in kt and kt CO_2 equivalents

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
					Carbon dioxide – CO_2 [a]					
2022 Submission	3,122	2,458	1,945	1,370	1,114	1,019	1,054	874	732	830
2021 Submission	2,901	2,331	1,947	1,367	1,112	1,018	1,052	872	729	737
Absolute change	222	127	-2.51	2.62	1.61	1.09	2.08	2.57	2.43	92.1
Relative change	7.64%	5.45%	-0.13%	0.19%	0.15%	0.11%	0.20%	0.30%	0.33%	12.5%
					Methane – CH_4					
2022 Submission	0.704	0.469	0.186	0.034	0.023	0.014	0.015	0.012	0.010	0.011
2021 Submission	0.104	0.077	0.186	0.030	0.021	0.014	0.014	0.012	0.009	0.009
Absolute change	0.600	0.393	0.000	0.004	0.002	0.000	0.000	0.000	0.000	0.001
Relative change	577%	512.16%	-0.03%	14.7%	10.8%	0.06%	2.79%	3.58%	4.39%	13.6%
					Nitrous oxide – N_2O					
2022 Submission	0.026	0.020	0.015	0.011	0.009	0.008	0.009	0.007	0.006	0.007
2021 Submission	0.022	0.018	0.015	0.011	0.009	0.008	0.009	0.007	0.006	0.006
Absolute change	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Relative change	14.7%	10.8%	-0.3%	0.4%	0.3%	0.2%	0.4%	0.6%	0.6%	12.3%
					TOTAL GREENHOUSE GASES [a]					
2022 Submission	3,147	2,476	1,954	1,374	1,117	1,022	1,057	877	734	832
2021 Submission	2,910	2,339	1,956	1,371	1,116	1,021	1,055	874	731	740
Absolute change	238	137	-2.52	2.74	1.68	1.10	2.10	2.60	2.45	92.4
Relative change	8.17%	5.88%	-0.13%	0.20%	0.15%	0.11%	0.20%	0.30%	0.33%	12.5%

Source: Own calculations; [a] including fossil CO_2 from use of biodiesel

3.2.10.3.6 Category-specific planned improvements (1.A.3.c)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.10.4 Transport – Water-borne navigation (1.A.3.d)

3.2.10.4.1 Category description (1.A.3.d)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/-	**1 A 3 d, Domestic Navigation**	**fossil fuels**	**CO_2**	**3,001.2**	**0.2%**	**1,094.3**	**0.2%**	**-63.5%**
-/-	1 A 3 d, Domestic Navigation		N_2O	20.9	0.0%	7.7	0.0%	-63.3%
-/-	1 A 3 d, Domestic Navigation		CH_4	1.9	0.0%	0.5	0.0%	-76.5%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS (Tier 2)	NS/IS/M	D a, CS
CH_4	CS (Tier 2)	NS/IS/M	CS (M)
N_2O	CS (Tier 2)	NS/IS/M	CS (M)
NOx, CO, NMVOC, SO_2	CS (Tier 2)	NS/IS/M	CS (M)

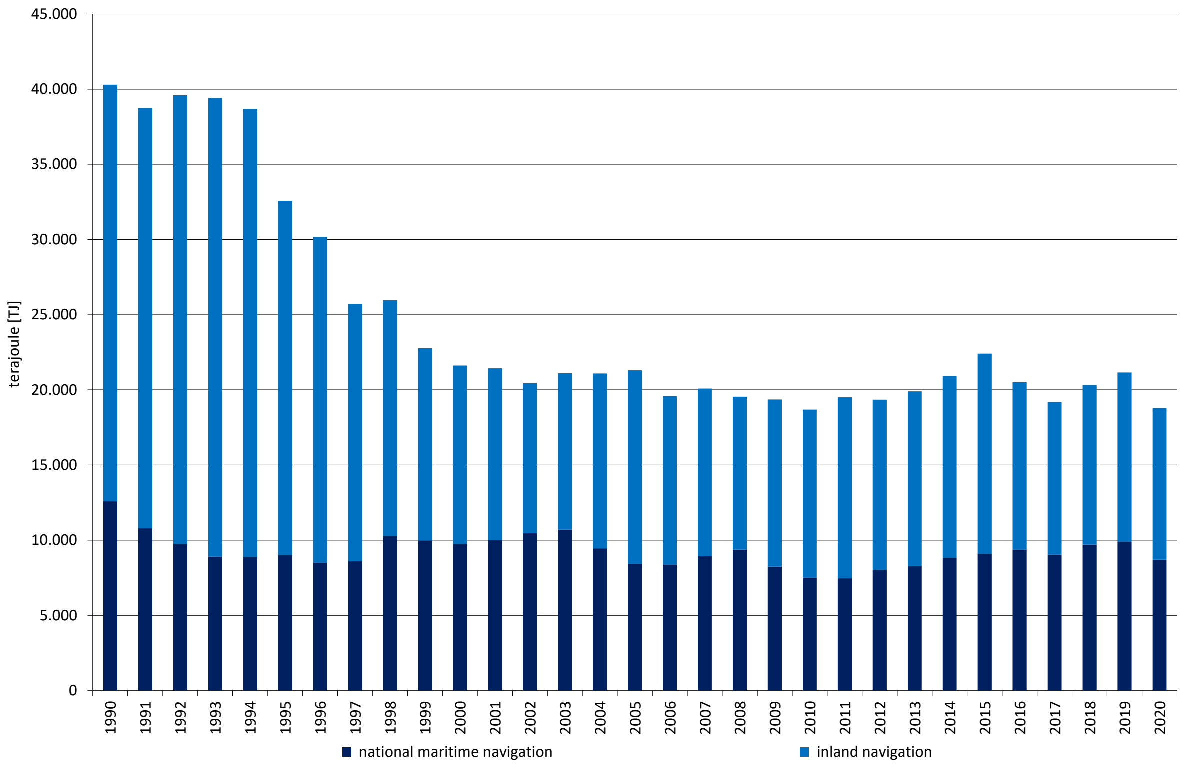
The category *Domestic water-borne navigation* is a key category for CO_2 emissions in terms of emissions level.

Water-borne navigation is broken down into the categories "domestic water-borne navigation," "inland navigation" and "international water-borne navigation." Emissions from international water-borne navigation are listed in the emissions inventories, as a memo item, but they are not included in total emissions.

In the CSE, both inland navigation and domestic water-borne navigation, i.e. travel between German ports, are assigned to category 1.A.3.d – domestic water-borne navigation.

The following figure shows the development of GHG emissions from domestic water-borne navigation, since 1990, broken down into inland navigation and domestic water-borne navigation.

Figure 32: Development of GHG emissions from domestic water-borne navigation, since 1990



3.2.10.4.2 Methodological issues (1.A.3.d)

For the area of *Domestic water-borne navigation*, all primary input data are combined in a model operated by the Federal Maritime and Hydrographic Agency (BSH), in keeping with the Tier 3 method pursuant to (EMEP (2019): Sectoral guidance chapters, 1.A.3.d Navigation (shipping)) (Deichnik, 2021). The underlying AIS data used in the process are currently available only as of the year 2012. For the period 1990 through 2011, the specific consumption fractions for national and military water-borne navigation, and for fisheries, have been derived on the basis of annual trends in relevant indicators (including data on traffic volumes in the Kiel Canal, and data on development of military and fishery fleets).

The input data of the European Maritime Safety Agency (EMSA), which the Federal Maritime and Hydrographic Agency (BSH) had used to calculate emissions from domestic water-borne navigation, were incomplete for the year 2020. The incompleteness was due to a data-archive conversion at EMSA that resulted in a 4 % loss of AIS data. The extent to which shares of domestic and international ship travel have been affected by this loss cannot yet be assessed at present.

Closing this data gap will necessitate extensive adjustment of the model used to make alternative data sets usable. Consequently, such closure cannot be carried out until next year's report.

For the *Inland navigation* category, primary data are combined, via a Tier 2 method, in TREMOD (Knörr et al., 2021c). The model integrates emission values from test-bench measurements and data on specific energy consumption. The latter data have been linked with a traffic-quantity model based on the Federal Statistical Office's statistics on inland water-borne navigation, and they can be broken down by ship types, sizes and loads, and by applicable water-body types.

In general, the source for the **activity data**, as for the entire sector 1.A, is (AGEB (2021b), based on BAFA and MWV). The data for the years 2005 through 2009 are based on sales data of the MWV, which differ from the pertinent data in the NEB, and which are published in the annual report "Petroleum Data" (*"Mineralöl-Zahlen"*; in this case: page 52, Table *"Sectoral consumption of diesel fuel"* (*"Sektoraler Verbrauch von Dieselkraftstoff"*)) (MWV, 2019).

Both AGEB and BAFA divide the data into the categories *domestic* (AGEB: "Coastal and inland water-borne navigation" = BAFA: *"an die Binnenschifffahrt" ("for inland shipping")*) and *international* (AGEB: "high-seas bunkering" = BAFA: *"Bunker int. Schifffahrt"*), in keeping with the different taxation rates applied to different ship fuels.

With respect to ship transports, the NEB – as described, solely based taxation aspects – differentiates between international marine bunkers (Energy Balance line 6) and coastal and inland navigation (Energy Balance line 64). Energy Balance line 6 lists the fuel quantities bunkered by ocean-going ships registered with the *International Maritime Organization* (IMO), as "sea-going ships" (IMO number). This category includes cargo, fishing and military ships that can operate on both domestic (between two German seaports) and international routes (from Germany to international ports). Energy Balance line 64, on the other hand, lists the fuel quantities that were a) taken on by inland vessels or b) bunkered by ocean vessels that have *not* been certified by the IMO (a category that includes smaller ships that operate only on domestic routes). For the breakdown into national and international *sea* transports, therefore, the fuel quantities listed in Energy Balance line 6 have to be divided in accordance with the categories of domestically operating and internationally operating sea-going ships. In addition, those relevant specific quantities of fishing and military ships that are reported separately under 1.A.4.c iii and 1.A.5.b are deducted.

Table 68: Sources for the activity data used

Material	Source statistics	included therein, in lines as indicated	
Diesel fuel	NEB	77 (through 1994) and 64 (since 1995)	"Coastal and inland water-borne navigation"
Biodiesel	NEB	64 (since 2004)	
Heavy fuel oil	NEB	6	"International marine bunkers"

Domestic water-borne navigation

The activity data for *Domestic water-borne navigation* consists of the data for the *non*-IMO-certified seagoing vessels listed in Energy Balance line 64 and of the data for the nationally operating IMO-certified seagoing vessels listed in Energy Balance line 6 (in each case, less the figures for fisheries and military). To determine these fractions, the specific consumption figures of the domestically operating seagoing vessels are calculated – in the aforementioned BSH model – on the basis of their AIS signals (currently, as of 2010; see above) and then aggregated into annual total quantities. Since the model differentiates between IMO-certified and non-IMO-certified sea-going ships, the sub-quantities included in NEB lines 6 and 64 are available. By deducting the former of the two sub-quantities (fuel consumption in domestically operating IMO-certified sea-going vessels) from the bunkered quantities listed in NEB line 6, one obtains a remaining quantity, bunkered by internationally operating sea-going vessels in Germany, that serves as a basis for calculating the separately listed emissions for international water-borne navigation (departing from Germany) pursuant to Tier 1 (cf. Chapter 3.2.2.3).

The fuel quantities taken on annually by *inland vessels* in Germany are obtained by deducting the second sub-quantity (fuel consumption in domestically operating, non-IMO-certified sea-going vessels) from the total quantity listed in NEB line 64. As a result of variations in the navigability of inland waterways, the annual fuel consumption levels of inland ships vary widely. Since the mid-1990s, those levels have been tending to decrease, as many ships have been refueling abroad in order to take advance of lower prices. The abrupt decrease that occurred in 1994/1995 was due to a change in the National Energy Balance, however.

In the framework of the UNFCCC's review process, Germany has been repeatedly requested (most recently, during the 2016 In Country Review) to separately list emissions from fuels that inland vessels take on in Germany and then consume outside of Germany. For such separate listing, which the available statistics and models do not directly support, extremely involved regular surveys would have to be carried out, and then data for the period back to 1990 would have to be developed from their results. Presumably, inland vessels that operate internationally rarely refuel in Germany[33], and thus the value of such an effort seems questionable. Nonetheless, the review team's request is being duly considered, and a solution that is acceptable for all sides, and scientifically reliable, is being sought.

With regard to the **emission factors** used for carbon dioxide, we refer, in general, to Chapter 18.8. Further information – in particular, with regard to carbon dioxide from lubricant co-combustion – is also provided in Chapter 19.1.4.

With regard to releases of methane and nitrous oxide from co-combustion of lubricants, it is assumed that such emissions are already taken into account in the pertinent emission factors for the fuels used and thus are to be reported as IE *(included elsewhere)*.

All other emission factors for the sub-sector *Domestic water-borne navigation* have been taken from Deichnik (2021).

For the area of *inland navigation*, CH_4 emission factors from Knörr et al. (2021c) are used. They are calculated on the basis of test-bench measurements, and of data, relative to the required propulsion energy, broken down by ship types, sizes and loads, and by waterway types. The emission factors for N_2O are in keeping with Federal Environment Agency (UBA) experts' assessments based on the UBA study "Air Quality Control '88" ("Luftreinhaltung '88") and on analogies to heavy duty vehicles without emissions-control equipment.

Table 69: Emission factors used for reporting year 2020, in kg/TJ

	CH_4	N_2O	Origin
Inland navigation			
Diesel	1.41 (-)	1.00 (-)	Country-specific value pursuant to Knörr et al. (2021c)
Domestic water-borne navigation			
Diesel	0.87 (-)	3.33 (2.00)	Pursuant to Deichnik (2021)
Heavy fuel oil	0.73 (7.00)	3.54 (2.00)	Pursuant to Deichnik (2021)
Overarching			
Lubricants			Included in the EF for the individual fuels

In parentheses: Default values pursuant to IPCC (2006a): Volume 2, Chapter 3.5, p. 3.50, Table 3.5.3

The EF for biodiesel are in keeping with the values for fossil-based diesel fuel

[33] Because fuel prices in other countries along the Rhine and Danube rivers are consistently lower than they are in Germany, and because large inland vessels can easily travel several thousand kilometers on one tankful of fuel, inland ships making international trips presumably refuel in Germany only in exceptional cases.

3.2.10.4.3 Uncertainties and time-series consistency (1.A.3.d)

For domestic inland water-borne navigation, the pertinent uncertainties were available in Knörr et al. (2009). For the area of domestic water-borne navigation, the IPCC default uncertainties still have to be applied, however.

The activity-data time series for coastal and inland water-borne navigation exhibit inconsistencies, resulting from the Energy-Balances transition between 1994 and 1995, which cannot be eliminated at present.

The emission-factor time series exhibit no inconsistencies.

3.2.10.4.4 Source-specific quality assurance / control and verification (1.A.3.d)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Quality reports of the Working Group on Energy Balances (AGEB) have been submitted to the Federal Environment Agency, for purposes of quality assurance of the National Energy Balances. In addition, documentation on revision of Energy Balances as of 2003 has been published on the Internet[34].

Table 70: Overview of relevant data comparisons

	Comparison with...	Remark
CO_2, CH_4, N_2O	Alternative emissions inventories for Germany	No comparable data sets
CO_2	Specific Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Table 3.5.2	cf. Table 71
CH_4, N_2O	sector-specific Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Table 3.5.3	Sea-going: cf. Inland: no defaults
CH_4, N_2O	Tier 1 default EF pursuant to (IPCC (2006a): Volume 2, Table 2.4	Inland: Results are inconclusive
CO_2, CH_4, N_2O	specific IEF of other countries	cf. Table 72

Table 71: Comparison of the EF(CO_2) used for reporting year 2020 with IPCC default values

	Inventory value [a]	Default[b]	*Lower bound*	*Upper bound*
Fossil-based diesel fuel	74,027	74,100	*72,600*	*74,800*
Heavy fuel oil	79,671	77,400	*75,500*	*78,800*
Biodiesel	70,800		*59,800*	*84,300*

[a] pursuant to IPCC (2006a): Volume 2, Table 2.4

The following table provides a comparison with specific implied emission factors of other countries and of the EU (28).

[34] AG Energiebilanzen (Working Group on Energy Balances): explanations relative to revision of the Energy Balances 2003 – 2009; URL: http://www.ag-energiebilanzen.de/index.php?article_id=7&clang=0#revision_der_energiebilanzen_2003_bis_2009_05 (last checked on 18 Sept. 2013)

Table 72: International comparison of reported IEF, in kg/TJ

	Diesel fuel			Heavy fuel oil		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Germany	74,027	1.24	1.72	79.671	0.73	3.54
Denmark	73,961	1.86	1.82	77,944	2.27	1.83
France	74,733	7.06	1.88	78.000	7.50	2.00
Netherlands	72,454	7.00	2.00	NO	NO	NO
UK	75,168	0.81	3.42	76,414	1.27	3.64
EU-27(28)	74,304	3.68	4.44	77,521	6.18	2.21

Germany: current IEF for report year 2019; all other countries: IEF for 2018, pursuant to 2020 CRF submission

3.2.10.4.5 Category-specific recalculations (1.A.3.d)

With respect to the 2021 submission, recalculations have been carried out to take account of updated activity data and emission factors. The model used for domestic water-borne navigation, which is managed by the Federal Maritime and Hydrographic Agency, was thoroughly revised, across all time series. As part of this revision, energy inputs that had previously been erroneously allocated to domestic water-borne navigation were shifted to international water-borne navigation leaving from German seaports (cf. Chapter 3.2.2.3).

In the process, provisional Energy Balance data for the year 2019 have been replaced with the corresponding final data.

Table 73: Revised energy inputs, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Diesel fuel										
2022 Submission	37,199	30,389	19,231	19,250	16,872	22,301	20,466	19,110	20,064	20,756
2021 Submission	36,604	29,855	18,648	18,596	16,183	22,781	24,167	22,400	23,847	21,556
Absolute change	596	535	584	654	689	-480	-3.701	-3.290	-3.783	-800
Relative change	1.63%	1.79%	3.13%	3.52%	4.26%	-2.11%	-15.3%	-14.7%	-15.9%	-3.71%
Heavy fuel oil										
2022 Submission	3,103	2,186	2,382	2,054	1,810	108	37	81	262	394
2021 Submission	11,723	8,041	8,577	7,172	6,114	50	7	7	190	358
Absolute change	-8,619	-5,855	-6,195	-5,118	-4,304	58	30	74	72	36
Relative change	-74%	-73%	-72%	-71%	-70%	116%	425%	1057%	38%	10%
TOTAL FUEL INPUTS										
2022 Submission	40,303	32,575	21,613	21,304	18,682	22,409	20,503	19,191	20,326	21,150
2021 Submission	48,326	37,896	27,224	25,768	22,297	22,831	24,174	22,407	24,037	21,914
Absolute change	-8,024	-5,320	-5,611	-4,464	-3,615	-422	-3,672	-3,216	-3,711	-764
Relative change	-16.6%	-14.0%	-20.6%	-17.3%	-16.2%	-1.8%	-15.2%	-14.4%	-15.4%	-3.5%

Source: Own calculations, based on Deichnik (2021), and Knörr et al. (2021c)

At the same time, the implied emission factors derived from the models used were updated.

Table 74: Revised emission factors, in kg/TJ

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Domestic water-borne navigation – diesel fuel: CH_4										
2022 Submission	0.97	0.97	0.97	0.97	0.97	0.89	0.88	0.88	0.88	0.88
2021 Submission	0.97	0.97	0.97	0.97	0.97	0.90	0.89	0.90	0.90	0.96
Absolute change	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.03	-0.08
Relative change	-0.50%	-0.55%	-0.54%	-0.53%	-0.56%	-0.79%	-1.78%	-1.70%	-3.14%	-8.58%
Domestic water-borne navigation – diesel fuel: N_2O										
2022 Submission	3.313	3.313	3.313	3.313	3.313	3.341	3.340	3.341	3.351	3.350
2021 Submission	3.314	3.314	3.314	3.314	3.314	3.366	3.355	3.357	3.353	3.346
Absolute change	-0.001	-0.001	-0.001	-0.001	-0.001	-0.025	-0.016	-0.016	-0.002	0.004
Relative change	-0.02%	-0.02%	-0.02%	-0.02%	-0.02%	-0.74%	-0.46%	-0.48%	-0.07%	0.12%
Domestic navigation – heavy fuel oil: CH_4										
2022 Submission	0.86	0.86	0.86	0.86	0.86	0.52	0.60	0.67	0.65	0.65
2021 Submission	0.73	0.73	0.73	0.73	0.73	0.60	0.74	0.61	0.57	0.65
Absolute change	0.13	0.12	0.12	0.13	0.12	-0.08	-0.13	0.07	0.08	0.00
Relative change	17.3%	17.0%	17.1%	17.1%	16.9%	-13.0%	-17.7%	11.0%	14.8%	0.75%
Domestic navigation – heavy fuel oil: N_2O										
2022 Submission	3.45	3.45	3.45	3.45	3.45	3.52	3.50	3.52	3.53	3.54
2021 Submission	3.50	3.50	3.50	3.50	3.50	3.45	3.39	3.49	3.59	3.55
Absolute change	-0.05	-0.05	-0.05	-0.05	-0.05	0.07	0.11	0.03	-0.06	-0.01
Relative change	-1.48%	-1.46%	-1.47%	-1.47%	-1.46%	1.91%	3.28%	0.98%	-1.78%	-0.18%
Inland navigation – diesel fuel: CH_4										
2022 Submission	2.37	2.16	1.91	1.78	1.65	1.51	1.49	1.47	1.44	1.43
2021 Submission	2.37	2.16	1.91	1.80	1.70	1.56	1.53	1.50	1.47	1.45
Absolute change	0.00	0.00	0.00	-0.03	-0.05	-0.05	-0.04	-0.03	-0.03	-0.02
Relative change	0.00%	0.00%	0.00%	-1.51%	-3.18%	-2.91%	-2.50%	-2.12%	-1.78%	-1.38%

Source: Deichnik (2021) and Knörr et al. (2021c)

The following recalculated emissions quantities result from these extensive corrections:

Table 75: Revised GHG emissions, in kt and kt CO_2-eq

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Carbon dioxide[a]										
2022 Submission	3,024	2,441	1,628	1,601	1,405	1,673	1,531	1,434	1,520	1,582
2021 Submission	3,645	2,851	2,064	1,947	1,685	1,690	1,790	1,659	1,781	1,624
Absolute change	-620	-410	-437	-346	-281	-17.1	-258	-225	-261	-42.5
Relative change	-17.0%	-14.4%	-21.2%	-17.8%	-16.6%	-1.01%	-14.4%	-13.6%	-14.6%	-2.62%
Methane										
2022 Submission	0.078	0.059	0.032	0.031	0.026	0.028	0.025	0.023	0.024	0.025
2021 Submission	0.073	0.057	0.031	0.031	0.026	0.027	0.027	0.024	0.026	0.025
Absolute change	0.004	0.002	0.001	0.000	0.000	0.002	-0.002	-0.002	-0.002	0.000
Relative change	6.11%	4.15%	3.40%	0.86%	-0.80%	5.67%	-6.74%	-6.50%	-8.26%	0.06%
Nitrous oxide										
2022 Submission	0.07	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2021 Submission	0.11	0.08	0.08	0.07	0.06	0.05	0.06	0.06	0.06	0.06
Absolute change	-0.04	-0.03	-0.03	-0.03	-0.02	-0.01	-0.02	-0.02	-0.02	-0.01
Relative change	-38.9%	-36.1%	-41.5%	-38.4%	-37.1%	-19.9%	-32.2%	-30.7%	-31.4%	-20.0%
TOTAL GREENHOUSE GASES [a]										
2022 Submission	3,024	2,441	1,628	1,601	1,405	1,673	1,531	1,434	1,520	1,582
2021 Submission	3,681	2,878	2,088	1,968	1,703	1,707	1,809	1,677	1,800	1,641
Absolute change	-656	-436	-460	-366	-298	-34.1	-278	-243	-280	-59.7
Relative change	-17.8%	-15.2%	-22.0%	-18.6%	-17.5%	-1.99%	-15.3%	-14.5%	-15.6%	-3.64%

Source: Own calculations;[a] including fossil CO_2 from use of biofuels

3.2.10.4.6 Category-specific planned improvements (1.A.3.d)

With regard to *Domestic water-borne navigation*, various types of maintenance work on the model are carried out, as necessary, in the framework of annual model updating. Such work cannot be described in detail at present, however.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.10.5 Transport – Other transportation (1.A.3.e)

3.2.10.5.1 Category description (1.A.3.e)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	1 A 3 e, Other Transportation	fossil fuels	CO_2	1,083.3	0.1%	767.5	0.1%	-29.1%
-/-	1 A 3 e, Other Transportation		N_2O	14.5	0.0%	6.7	0.0%	-53.7%
-/-	1 A 3 e, Other Transportation		CH_4	5.3	0.0%	3.8	0.0%	-29.3%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	ETS	CS
CH_4	Tier 2	ETS	CS
N_2O	Tier 2	ETS	CS

The *category 1.A.3.e - Transport – other transportion* is not a key category

Reporting in category *1.A.3.e – Other transportation* includes only emissions from *gas turbines in natural-gas compressor stations of the transport network*. The emissions from gas turbines of pumping stations are reported in category 1.A.1.c. Fugitive emissions from compressors are reported under 1.B.2.b.iii & iv. Additional gas compressors are operated in the chemical industry. In keeping with the relevant statistical structure, they are reported in category 1.A.2.g Other.

3.2.10.5.2 Methodological issues (1.A.3.e)

Activity data:

Calculation of fuel inputs for natural gas compressors was completely revised for the NIR 2012. As of 2005, the fuel inputs reported for purposes of emissions trading, and aggregated by the emissions-trading authority, are being used directly, as a new data source. In this area, the only data used from that data set are the data for natural gas compressors that are allocated to the transport network. Natural gas compressors of pumping stations are identified via energy statistics and thus are already included in category 1.A.1.c. This allocation approach prevents double-counting in the inventory.

In light of the new data situation, it seemed likely that the fuel inputs used were too low, throughout the entire time series. Only the value shown in the 2002 Energy Balance seemed plausible. While fuel inputs for natural gas compressors in the period 1995-2002 were reported in the context of statistics, it may be assumed that the recorded levels were too low. To establish consistency in the relevant time series, therefore, recalculations back to 1990 were carried out. Since the relevant fuel inputs fluctuate annually, in keeping with primary energy consumption, simple interpolation would not have led to the desired consistency. For that reason, a mean for the pertinent relationship (fuel inputs / primary energy consumption) was calculated for the period 2005-2009, and then that mean was used for the calculations back to 1990. This procedure has produced a plausible and consistent time series.

Emission factors:

The emission factors for natural-gas use in **natural gas compressor stations** are based, for each specific gas, on the results of various Federal Environment Agency research projects and expert opinions:

- With regard to CO_2, the reader's attention is called to the pertinent documentation in the Annex 2 chapter "CO_2 emission factors."
- The CH_4 and N_2O EF have been obtained from the report Fichtner et al. (2011). The procedure used in the studies is described in Chapter 3.2.6.2.

3.2.10.5.3 Uncertainties and time-series consistency (1.A.3.e)

Uncertainties for the activity data were determined for the first time in reporting year 2004 (Juhrich & Wachsmann, 2007). The method for determining the uncertainties is described in Annex 2, in the Chapter "Uncertainties in the activity data of stationary combustion plants," of the NIR 2007.

The procedure for determining uncertainties for the EF of natural gas compressor stations is described in Chapter 3.2.6.2. Results for N_2O are presented in Chapter 3.2.6.3.2, while those for CH_4 are presented in Chapter 3.2.6.3.3.

3.2.10.5.4 Source-specific quality assurance / control and verification (1.A.3.e)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The results of Chapter 3.2.6.2 apply mutatis mutandis.

3.2.10.5.5 Category-specific recalculations (1.A.3.e)

No recalculations were carried out.

3.2.10.5.6 Category-specific planned improvements (1.A.3.e)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.11 Other: Residential, commercial/institutional, agriculture, forestry and fisheries (1.A.4 Stationary)

3.2.11.1 Category description (1.A.4 stationary)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 A 4 a, Commercial/Institutional**	**fossil fuels**	**CO_2**	**64,111.3**	**5.0%**	**27.615.8**	**3.9%**	**-56.9%**
-/T	**1 A 4 a, Commercial/Institutional**		**CH_4**	**1,461.7**	**0.1%**	**83.2**	**0.0%**	**-94.3%**
-/-	1 A 4 a, Commercial/Institutional		N_2O	147.4	0.0%	89.1	0.0%	-39.6%
L/T	**1 A 4 b, Residential**	**fossil fuels**	**CO_2**	**128,635.8**	**10.1%**	**89,770.8**	**12.5%**	**-30.2%**
-/-/T2	**1 A 4 b, Residential**		**CH_4**	**2,484.7**	**0.2%**	**785.9**	**0.1%**	**-68.4%**
-/-	1 A 4 b, Residential		N_2O	768.8	0.1%	290.2	0.0%	-62.3%
L/-	**1 A 4 c, Agriculture/Forestry/Fishing**	**fossil fuels**	**CO_2**	**10,177.9**	**0.8%**	**6,013.2**	**0.8%**	**-40.9%**
-/-	1 A 4 c, Agriculture/Forestry/Fishing		CH_4	241.4	0.0%	171.7	0.0%	-28.9%
-/-	1 A 4 c, Agriculture/Forestry/Fishing		N_2O	61.0	0.0%	67.4	0.0%	10.5%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1*, CS	NS/M	CS, D*
CH_4	CS (Tier 2)	NS/M	CS (M)
N_2O	CS (Tier 2)	NS/M	CS (M)
NO_x, CO, NMVOC, SO_2	CS (Tier 2)	NS/M	CS (M)

* biodiesel and co-combusted lubricants

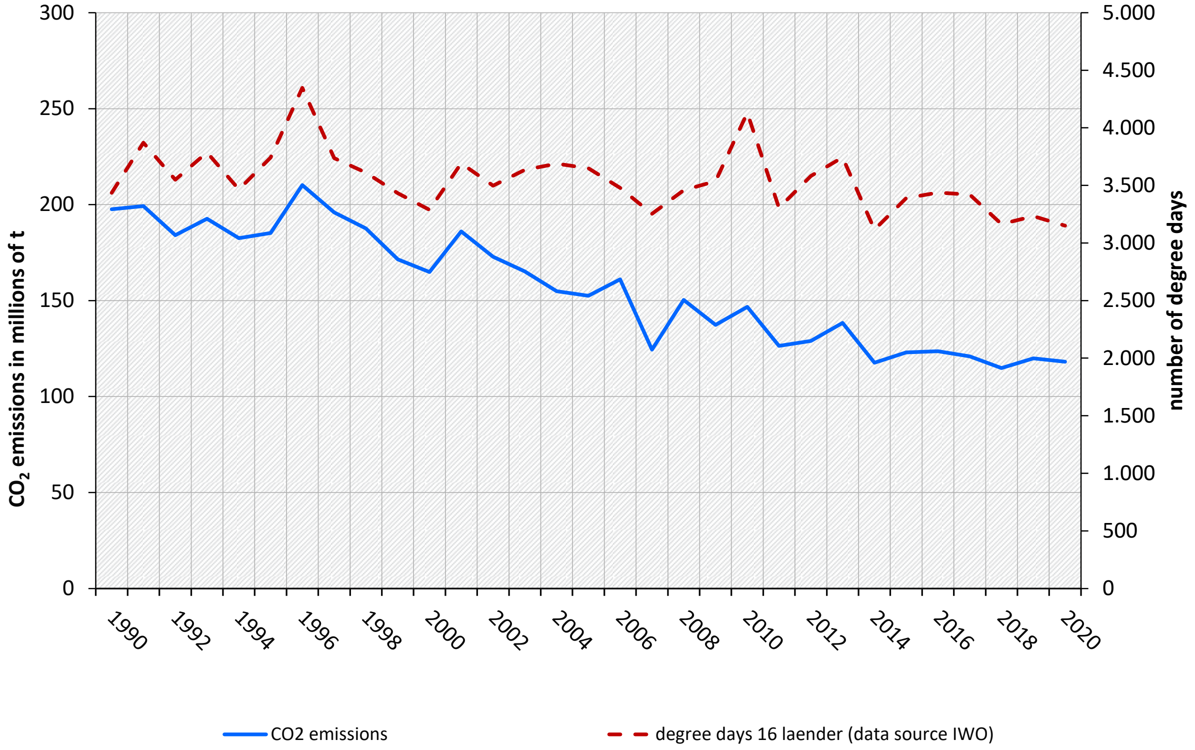
The stationary and mobile sources categories in 1.A.4 are grouped together for purposes of determination of key-category status (for an overview, cf. Chapter 3.2.11.1). Such determination shows that the category 1.A.4 *Other* is a key category for CO_2 emissions in sub-categories 1.A.4.a & b, in terms of emissions level and trend, and a key category for CO_2 emissions in sub-category 1.A.4.c, in terms of emissions level only. For CH_4 emissions, category 1.A.4.a is a key category in terms of trend. Also, sub-category 1.A.4.b has been identified, via Approach 2 analysis, as a key category for CH_4.

Category 1.A.4 Stationary comprises combustion systems in the areas *Commercial and Institutional, Residential* and *Agriculture*.

Heat-generation systems in small combustion systems of small commercial and institutional users are reported in sub-category 1.A.4.ai Commercial and institutional.

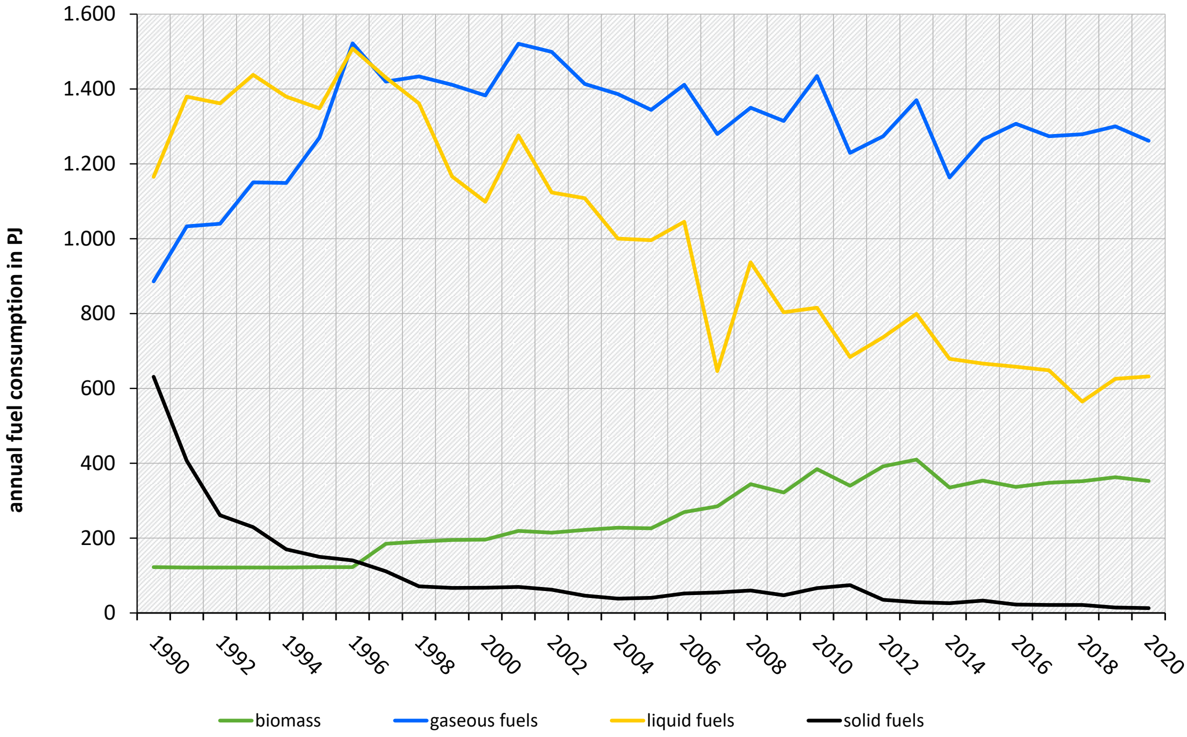
Emissions from residential combustion systems are reported in sub-category 1.A.4.bi. Sub-category 1.A.4.ci comprises the areas of agriculture, forestry and fisheries. Reporting under this category includes emissions from heat generation in small and medium-sized combustion systems.

Figure 33: Change in total emissions of 1.A.4, as a function of temperature



The main driver of CO_2 emissions in 1.A.4 is energy consumption for purposes of space heating. Consequently, fluctuations in consumption can usually be attributed to differences in periods of winter cold. The trend toward lower CO_2 emissions is a result of higher standards for new buildings, of successful energy-efficiency-oriented modernisations of existing buildings and of switching to fuels with low CO_2 emissions. CO_2 emissions from electrically driven heat pumps, which are being used more and more frequently in new buildings, are reported not here but under 1.A.1.a.

Figure 34: Trends in energy consumption in 1.A.4 (stationary), for 4 fuel categories



Shifting from liquid fuels (almost exclusively heating oil) and solid fuels (mainly coal) to gaseous fuels (natural gas) and biomass has brought about considerable CO_2-emissions reductions in the reporting period since 1990. Improvements in energy efficiency have also helped lower consumption. On top of this long-term trend, energy consumption has fluctuated at shorter intervals – for example, via changes in prices for fuels for which – as is the case for light heating oil – consumption data are determined on the basis of sales, and not consumption per se. The heat market also plays a key role in annual energy-use trends; that market is strongly influenced by weather conditions during the winter heating period. Over the years, these factors have caused energy consumption – especially, consumption of light heating oil and natural gas – to fluctuate sharply.

The economic and sociopolitical impacts of the coronavirus pandemic in the services sector were the primary factors driving declining natural-gas consumption. On the other hand, low oil prices led to increasing sales of heating oil. Longer-term trends, such as increases in energy efficiency, greater reliance (= substitutions) on renewable energies in the energy mix and relatively mild weather, also had effects. Measured in terms of degree days (and averaged over 16 measuring stations), the weather in 2020 was somewhat warmer overall than it was in the previous year. In the assessment of the AGEB (AGEB, 2021a), the consumption-dampening effect of the mild weather was offset by stockpiling of light heating oil. Over the course of the year, energy prices decreased noticeably, and this led to slightly increased energy requirements. All in all, these effects contributed to a decrease of CO_2 emissions in 2020.

The group of combustion systems in the residential and commercial/institutional sectors is very diverse with regard to installation design and size. It covers a spectrum that includes individual room furnaces for solid fuels with a rated thermal output of approximately 4 kW (e.g. fireplaces, ovens), oil and gas furnaces used for space heating and water heating (e.g. central heating boilers), hand-fed and automatically fed wood-burning furnaces in the commercial sector and commercial/institutional users' licensable combustion systems with a rated thermal output of several megawatts, to name but a few examples. In total in 2010, more than 36.3 million combustion systems were installed (i.e. were in place) in Germany in the Residential and Commercial and Institutional sectors (Tebert et al., 2016). Gas-fired combustion systems accounted for a majority of these systems, or some 16.2 million, while combustion systems using solid fuels accounted for some 14.2 million systems and oil-fired furnaces accounted for some 5.9 million systems.

Data on wood consumption in the residential and commercial / institutional sectors – like data on consumption of other biofuels in the various consumption sectors – are based on data provided by the Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat)), which is responsible for providing renewable energies data in fulfillment of various reporting obligations, at the national, EU-wide and international levels, of the Federal Government[35].

The results for the residential sector are based on surveys of consumption carried out in the framework of the "Rohstoffmonitoring Holz" ("Monitoring of raw materials – wood") project.[36] That project collected data both on firewood purchased via commercial sellers and wood gathered in forests. For interim years, a regression model is applied that takes account of numbers of degree days, the price indexes for conventional fuels, and the heating systems, broken down by types, used in residential buildings. Conversions of volume units into energy units are carried out in conformance with the accepted conversion conventions of AGEE-Stat.

Wood consumption in heat-generation-only systems of the commercial and institutional sector is derived via a remainder calculation. In the process, the data on total wood consumption (outside of private households), as determined via the "Rohstoffmonitoring Holz" surveys and via regression models, are blended with the relevant wood-quantity data from official energy statistics and the applicable wood-quantity data given by other relevant models. The wood consumption data derived via this approach, which relate to data on heat generation by CHP systems, are also part of the data on total wood consumption in the commercial and institutional sector.

3.2.11.2 Methodological issues (1.A.4, stationary)

Activity data

The activity data in category 1.A.4 are based on the Energy Balances for the Federal Republic of Germany, as prepared by the Working Group on Energy Balances (AGEB). For years prior to 1995 separate Energy Balances are used for the a) old German Länder and b) new German Länder. For years as of 1995, lines 66 (residential) and 67 (commercial and institutional and other consumers) are the standard.

Since the data in Energy Balance line 67 – commercial and institutional and other consumers – also include military consumption, such military consumption must be deducted from the relevant positions in line 67 (cf. Chapter 3.2.13.2 with regard to stationary and mobile sources in the military sector).

As of the 2021 NIR, AGEB data are being used for the fossil fuels within the energy inputs in *Combustion plants in agriculture (1.A.4.ci)* (energy inputs that are also included in line 67 of the Energy Balance). The AGEB data are available as a time series beginning with the year 2010. These data are determined, via an estimation procedure, on the basis of the agricultural sector's energy expenditures as given by the Statistisches Jahrbuch über Ernährung, Landwirtschaft, und

[35] cf. also https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Arbeitsgruppe/arbeitsgruppe_ee.html
[36] https://www.kiwuh.de/projekte-und-foerderung/projekte/holzbereitstellung/rohstoffmonitoring-holz/

Forsten (BLE, 2021) (Statistical yearbook on food, agriculture and forests). The structure of the relevant energy sources is described in the AGEB study "Implementation of a procedure for regular, current determination of energy consumption in areas not covered by official statistics" ("Umsetzung eines Verfahrens zur regelmäßigen und aktuellen Ermittlung des Energieverbrauchs in nicht von der amtlichen Statistik erfassten Bereichen") (AGEB, 2016). In the AGEB Evaluation Tables on the Energy Balance[37], the pertinent data are listed as a subset of the Energy Balance.

Emission factors

A detailed description of the relevant procedures, and a list of the CO_2 emission factors used, is presented in the Annex, Chapter 18.8.

The underlying data for the emission factors used for N_2O and CH_4 emissions of stationary combustion systems is the research report "Ermittlung und Aktualisierung von Emissionsfaktoren für das nationale Emissionsinventar bezüglich kleiner und mittlerer Feuerungsanlagen der Haushalte und Kleinverbraucher" ("Determination and updating of emission factors for the national emissions inventory, with regard to small- and medium-sized combustion systems in the residential and commercial/institutional sectors") (Tebert et al., 2016). Within the context of that project, device-related and category-specific emission factors for combustion systems in the residential and commercial/institutional sectors were calculated, with a high level of detail, for all important emissions components for the reference years 2010 and 2015.

Determination of emission factors is based on a category-specific "bottom-up" approach that, in addition, to differentiating (sub-)categories and fuels, also differentiates system technologies in detail. In the process, several system-specific emission factors are aggregated in order to obtain mean emission factors for all systems within the categories in question. Use of system-specific / category-specific emission factors ensures that all significant combustion-related characteristics of typical systems for the various categories are taken into account. The procedure is in keeping with the Tier 2/3 method described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a).

The emission factors are structured in accordance with the relevant fuels involved in final energy consumption in Germany:

- Fuel oil EL
- Natural gas,
- Lignite (briquettes from the Rhine (Rheinisch) and Lusatian (Lausitz) coal fields; imported briquettes),
- Hard coal (coke, briquettes, anthracite) and
- Wood (unprocessed wood, wood pellets, residual wood).

In addition, emission factors for combustion systems are determined in accordance with device design, age level, output category and typical mode of operation. The emissions behaviour of combustion systems was documented via an extensive evaluation of the pertinent literature. Transfer factors were used to take account of the fact that emissions in a test-bench environment tend to be lower than those of corresponding installed systems.

The breakdown of the overall pool of installed combustion systems, by system types, was obtained by carrying forward data in Struschka et al. (2008), and drawing on sales statistics for the relevant industrial associations. Those data were used to estimate the energy inputs for

[37] https://ag-energiebilanzen.de/10-0-Auswertungstabellen.html

various system types, to make it possible to determine sectoral emission factors weighted by energy inputs. Table 76 shows the sectoral emission factors used.

Table 76: Sectoral emission factors for combustion systems in the residential and commercial/institutional sectors for reference year 2010

1.A.4.bi – Residential	CH_4 [kg/TJ]	N_2O [kg/TJ]
Hard coal	134	11.5
Briquettes	368	9.7
Hard-coal coke	13	0.9
Lignite briquettes	237	5.2
Unprocessed wood	97	1.6
Heating oil EL	0.03	0.55
Natural gas	3	0.25
1.A.4.ai & ci – Commercial and Institutional		
Hard coal	100	8.5
Briquettes	-	-
Hard-coal coke	20	0.8
Lignite briquettes	-	-
Wood fuels	43	0.53
Heating oil EL	0.03	0.56
Natural gas	0.16	0.33

The emission factors for 2010 were used, without change, for subsequent years.

3.2.11.3 Uncertainties and time-series consistency (1.A.4, stationary)

Annex 2, Chapter 13.6 in the NIR 2007 describes the method used to determine the uncertainties for the **activity data**.

A complex procedure is required to calculate reliable emission factors in the installation sector. Apart from emission figures, it is also necessary to obtain other information; for example, one must make allowance for the relevant mode of operation (loads), installation structure and device-specific final energy consumption. In data surveys during the aforementioned research and development project, this approach was for the most part followed; nevertheless, given the sheer number of facilities concerned and the wide range of combustion systems and fuels used, the data must be assumed to have a fairly large "basic uncertainty".

For some installation types, moreover, only inadequate data or no data at all were available on emissions behaviour in connection with certain fuels. It is important to remember that the law does not require the greenhouse-gas emissions of combustion systems of residential and commercial/institutional users to be measured. When calculating the emission factors, therefore, in most cases (with the exception of CO_2, which is largely independent from furnace design) the researchers only had recourse to a few results from individual measurements on selected installations. Gaps in the data were closed via adoption of emission factors of comparable combustion systems.

The uncertainties listed for the emission factors for CH_4 and N_2O, for stationary combustion systems, were determined via expert estimation pursuant to IPCC-GPG (Penman et al. (2000): Chapter 6). That assessment, which is based on the emissions data obtained for the aforementioned research project, was carried out in the framework of that project by experts of the University of Stuttgart's Institute of Process Engineering and Power Facility Technology (Institut für Verfahrenstechnik und Dampfkesselwesen). Uncertainties were estimated separately for all combustion technologies and fuels. The following sources of error entered into the estimates for N_2O and CH_4 :

- Measuring errors in determination of pollutant concentrations;
- Uncertainties in estimating transfer factors (systematic differences between test-bench and field measurements);
- Uncertainties resulting from having too little emissions data;
- Uncertainties resulting from use of different measuring procedures;
- Uncertainties in the installation data used (overall group structure in terms of type, age and performance and fuel consumption)

In gas-fired systems, another error occurs in determination of start-up / shut-down emissions. During start-up/shutdown processes, some unburned CH_4 is emitted from natural gas. These emissions, which occur upstream and downstream from the actual combustion process, cf. Chapter 3.3.2.2 (natural gas), are a significant reason why CH_4 emission factors for gas-combustion systems are subject to high levels of uncertainties.

As to the distribution of uncertainties, a log-normal distribution is assumed for N_2O emission factors. In all likelihood, the deviations are considerably more pronounced in the vicinity of larger values than they are in the vicinity of smaller values. The emission factors for CH_4 and N_2O were determined for the year 2005, in the framework of the aforementioned research project, and are assumed to have remained constant since then.

3.2.11.4 Category- specific quality assurance / control and verification (1.A.4, stationary)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Information on quality assurance for **activity data** is provided in Chapter 3.2.6.4. For further information on quality assurance, cf. Chapter 18.4.1.

For the purposes of quality assurance for data relative to *stationary combustion systems*, in the context of the aforementioned research and development project, all the input data used from literature and from the research contractor's own investigations were reviewed for validity. As a general principle, in description of the emissions behaviour of combustion systems, emissions data were included in subsequent calculations only if the relevant literature sources contained complete, undisputed data on the fuel used, the design of the furnace, and the furnace's operating mode during measurements. All resources of significance for inventory preparation were documented by the research contractor.

In the framework of a quality review carried out by Federal Environment Agency experts, the country-specific emission factors for CH_4 and N_2O, determined in accordance with the Tier 2 standard, were compared with the IPCC Tier 2 default factors in the IPCC Guidelines for emissions inventories (IPCC, 2006a). For most fuels, the values agreed well (discrepancies within one order of magnitude), although the default values for CH_4 tended to be higher than the country-specific values.

In the framework of quality assurance, calculation with the Tier 1 default values was carried out, in addition to emissions determination pursuant to Tier 2/3, for the residential and commercial/institutional sectors for the year 2015. The results are shown in Table 77.

Table 77: Emissions calculation with country-specific Tier 2/3 emission factors and with the Tier 1 default emission factors pursuant to (IPCC 2006) IPCC (2006a)

	CH_4 [t]				N_2O [t]			
	Residential		Commercial and institutional		Residential		Commercial and institutional	
emission factors	Tier 1 default	Country-specific EF	Tier 1 default	Country-specific EF	Tier 1 default	Country-specific EF	Tier 1 default	Country-specific EF
Heating oil EL	4,694	76	1,723	6	277	256	101	97
Fuel gases	4,223	2,534	1,763	55	84	212	35	115
Coal fuels	7,388	5,776	44	85	37	177	2	7
Wood	66,780	21,074	9,011	1.465	890	352	120	25
Total	**83,085**	**29,459**	**12,541**	**1,611**	**1,289**	**997**	**258**	**244**

The emissions of the commercial and institutional sector include the emissions of the areas of agriculture, forestry and fisheries.

For N_2O, the emissions-calculation results obtained with both methods showed good agreement. Larger discrepancies were seen in determination of CH_4 emissions. Presumably, this is due to the fact that methane emissions of combustion systems depend strongly on the combustion technology used. Country-specific differences in installation structures (i.e. in sector composition) thus manifest themselves much more strongly in total emissions (as determined) than they do in nitrous-oxide emissions. The default emission factor for heating oil, in particular, is very high. The technology-specific emission factor given in IPCC 2006 for boilers shows considerably better agreement with the pertinent country-specific factor for Germany.

No data sources are known that would support a comparison with the data reported here for mobile sources in the residential, agricultural and fisheries sectors. In addition, the country-specific IEF were compared with those of other countries. Due to the heterogeneous composition of the sub-categories involved, however, that comparison is largely inconclusive – especially with regard to methane and nitrous oxide.

3.2.11.5 Category-specific recalculations (1.A.4, stationary)

Table 78: Recalculations in CRF 1.A.4 (stationary)

Units [kt]	2021 NIR	2022 NIR	Difference, absolute				Difference, relative
Year	Total	Total	gas	liquid	solid	Total	Total
2019	122,009	119,849	687	-2,869	23	-2,160	-1.77%

For the year 2019, major recalculations were carried out, since the provisional figures in the 2021 Submission have been replaced with final figures from the Energy Balance.

3.2.11.6 Planned improvements, category-specific (1.A.4, stationary)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.12 Other: Residential, commercial/institutional, agriculture, forestry and fisheries (1.A.4 mobile)

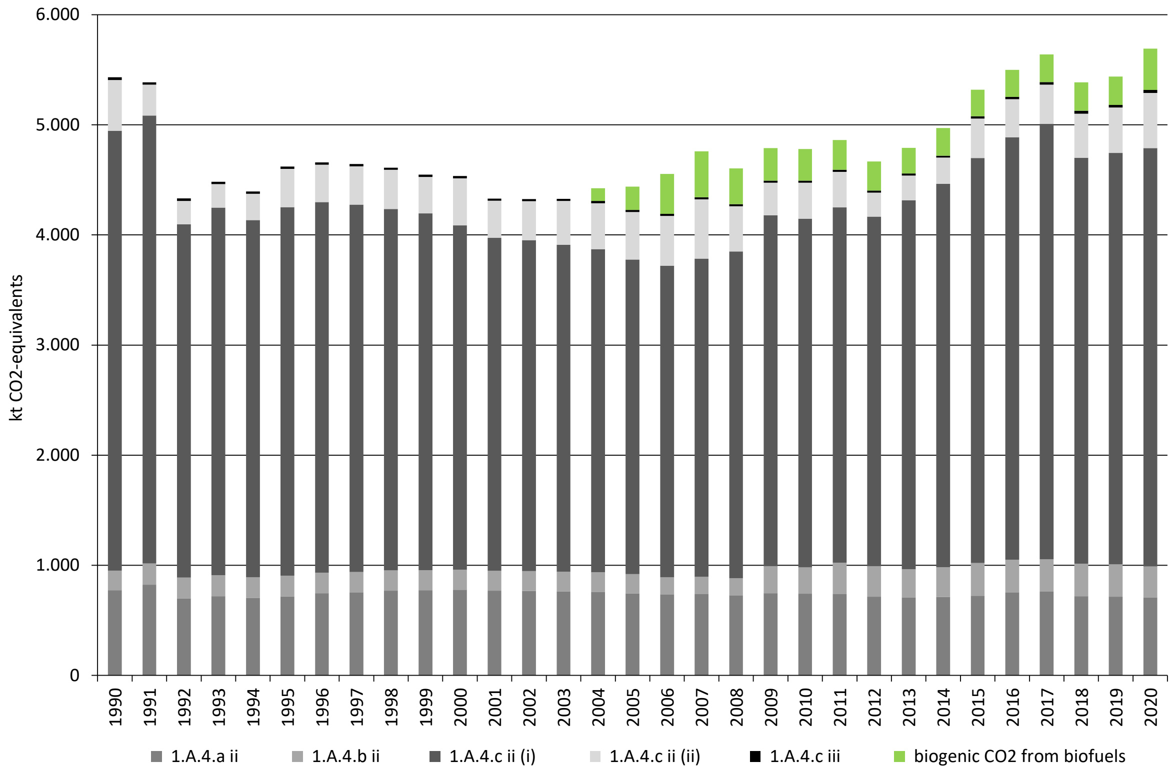
3.2.12.1 Category description (1.A.4 mobile)

The stationary and mobile sources categories in 1.A.4 are grouped together for purposes of determination of key-category status (for an overview, cf. Chapter 3.2.11.1). The category 1.A.4

Other is a key category for CO_2 emissions, in terms of both emissions level and trend, in all of its sub-categories. For CH_4 emissions, categories 1.A.4.a & b are a key category in terms of trend.

Category 1.A.4 – mobile comprises various mobile sources in sub-categories 1.A.4.a ii – Commercial and Institutional (commerce, trade and services), 1.A.4.b ii – Residential, 1.A.4.c ii – Agriculture and forestry and 1.A.4.c iii – Fisheries.

Figure 35: Development of GHG emissions in the various considered sub-sectors since 1990



3.2.12.2 Methodological issues (1.A.4 mobile)

The **activity data** in source category 1.A.4, like those for stationary combustion systems, are taken from AGEB (2021a).

The quantities of gasoline fuels listed in Energy Balance line 66 – *Residential* are all allocated to *Mobile sources* (*1.A.4.b ii*).

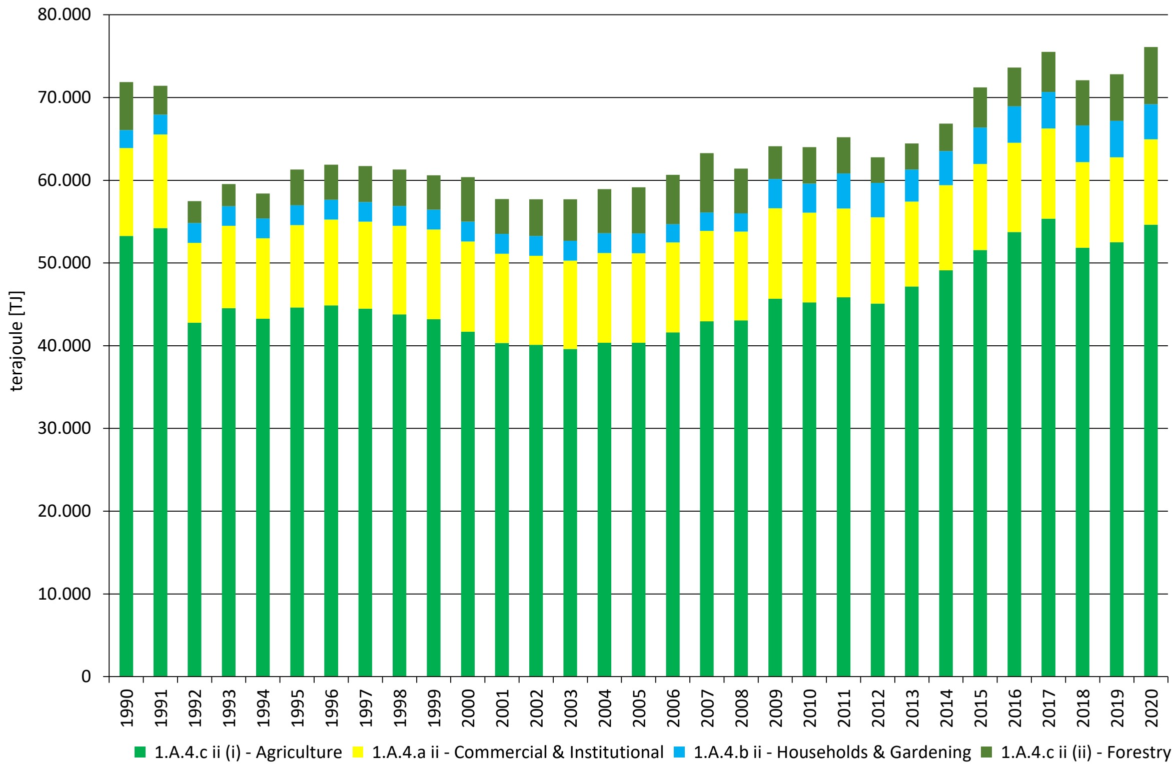
NEB line 67 – Commercial and Institutional also includes fuel consumption areas of the military sector that are that are separately recorded in statistics of BAFA (2021); those areas can thus be deducted here (cf. Chapter 3.2.14 regarding mobile sources in the military sector). The additional breakdown into mobile sources in *Agriculture (1.A.4.c ii (i) and Forestry (1.A.4.c ii (ii), Construction vehicles and machinery (1.A.2.g vii),* and mobile sources in *1.A.4.a ii* (primarily forklifts), is carried out on the basis of an annual distribution key generated in Knörr et al. (2021b).

The activity data for the coastal and high-seas fisheries included under *1.A.4.c (iii) – Fisheries* are calculated, in the framework of the BSH model described in 1.A.3.d, on the basis of AIS data (data of the IMO's Automatic Identification System).

In general, the pertinent quantities of *unintentionally* co-combusted lubricants are derived, pursuant to Wallfarth (2014), from the relevant annual fuel quantities. For two-stroke gasoline engines (in the residential and forestry sectors), on the other hand, those quantities, as part of the lubricants co-combusted with fuel mixtures, are obtained as a two-percent addition to the quantities of gasoline used for refueling of (cf. also Chapter 19.1.4).

The CO_2 emissions from the fossil fractions of the biofuels used are allocated to the total national emissions (cf. the explanatory remarks in Chapter 19.1.5).

Figure 36: Development of fuel consumption within the various considered sub-categories since 1990



With regard to the **emission factors** used for carbon dioxide, we refer, in general, to Chapter 18.8. Further information – in particular, with regard to carbon dioxide from lubricant co-combustion – is also provided in Chapter 19.1.4.

For methane and nitrous oxide, country-specific values pursuant to Knörr et al. (2021b) and Deichnik (2021) are used. With regard to releases of methane and nitrous oxide from co-combustion of lubricants, it is assumed that such emissions are already taken into account in the pertinent emission factors for the fuels used and thus are to be reported as IE *(included elsewhere)*.

Table 79: Emission factors used for report year 2020, in kg/TJ

	CH_4	N_2O	Origin
1.A.4.a ii – Mobile sources in the Commercial and Institutional (commerce, trade and services) sector			
Diesel & biodiesel	1.02 (4.15)	2.89 (28.60)	Pursuant to Knörr et al. (2021b)
LPG	7.41 (-)	3.45 (-)	Pursuant to Knörr et al. (2021b)
1.A.4.b ii – Mobile sources of the residential sector			
Gasoline (two-stroke engines)	205 (180)	0.45 (0.40)	Pursuant to Knörr et al. (2021b)
Gasoline (four-stroke engines)	26.4 (120)	1.32 (2)	Pursuant to Knörr et al. (2021b)
1.A.4.c ii (i) – Mobile sources of the agricultural sector			
Diesel & biodiesel	1.72 (4.15)	2.88 (28.6)	Pursuant to Knörr et al. (2021b)
1.A.4.c ii (ii) – Mobile sources of the forestry sector			
Diesel & biodiesel	0.43 (4.15)	3.11 (28.6)	Pursuant to Knörr et al. (2021b)
Gasoline (two-stroke engines)	219 (170)	0.46 (0.40)	Pursuant to Knörr et al. (2021b)
1.A.4.c (iii) – Fisheries (here: *high-seas fisheries)*			
Diesel & biodiesel	0.94 (-)	3.34 (-)	Pursuant to Deichnik (2021)
Heavy fuel oil	NA	NA	Use of heavy fuel oil ended in 2014
Overarching			
Lubricants	IE	IE	Included in the EF for the individual fuels

In parentheses: Default values pursuant to IPCC (2006a): Volume 2, Chapter 3.3 – *Off-road transportation*, p. 3.36, Table 3.3.1

The EF for biodiesel and bio-ethanol are in keeping with the values for their fossil-based counterparts.

3.2.12.3 Uncertainties and time-series consistency (1.A.4 mobile)

The uncertainty figures for the specific energy inputs, which are shaped primarily by the mathematical uncertainty in the distribution key developed in TREMOD MM (cf. above: Methodological aspects), are based on experts' assessments. The same holds for the carbon-dioxide emission factors used. While the emission factors for methane are based on results from Knörr et al. (2009), the emission factors for nitrous oxide – for the time being – have to be oriented to guideline values pursuant to the IPCC.

3.2.12.4 Category-specific quality assurance / control and verification (1.A.4 mobile)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Table 80: Overview of relevant data comparisons

	Comparison with...	Remark
CO_2, CH_4, N_2O	Alternative emissions inventories for Germany	No comparable data sets
CO_2	Specific Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter 3, Tables 3.3.1 and 3.5.2 (1.A.4.c iii)	cf. Table 81
CH_4, N_2O	Specific Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter 3, Tables 3.3.1 and 3.5.3 (1.A.4.c iii)	cf. Table 79
CO_2, CH_4, N_2O	specific IEF of other countries	cf. Table 82

Table 81: Comparison of the EF(CO_2) used in the inventory with default values*

	Inventory values[a]	Default [b]	*Lower bound*	*Upper bound*
Diesel fuel	74,027	74,100	*72,600*	*74,800*
Gasoline		69,300	*67,500*	*73,000*
Two-stroke engines [b]	*75,237*			
Four-stroke engines	*75,276*			
LPG	66,334	63,100	*61,600*	*65,600*
Heavy fuel oil	n.a.	77,400	*75,500*	*78,800*
Lubricants	73,300		*71,900*	*75,200*
Biodiesel	70,800		*59,800*	*84,300*
Biogasoline		70,800	*59,800*	*84,300*
Two-stroke engines [c]	*71,641*			
Four-stroke engines	*71,607*			

[a] Inventory values for 2020; [b] pursuant to IPCC (2006a): Volume 2, Chapter 2, Table 2.4

[c] including 2 % lubricants (EF = 73,300 kg/TJ) in 1:50 two-stroke fuel mixtures

The following table provides a comparison with specific implied emission factors (IEF) of other countries as well as with the relevant values resulting for the EU(28). It should be noted that the comparison is hampered by the fact that the factors involved represent an extremely heterogeneous group of categories.

Table 82: International comparison of reported IEF, in kg/TJ

	1.A.4.a ii			1.A.4.b ii			1.A.4.c ii		
	Liquid fuels			Liquid fuels			Diesel		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Germany	70,976	3.71	3.13	75,454	61.9	0.48	74,027	1.72	2.88
Denmark	73,240	26.5	1.88	73,000	52.4	1.17	73,999	0.78	3.56
France							74,883	0.84	28.7
Netherlands	72,492	2.47	0.60	73,023	46.8	0.60	72,454	1.11	0.60
UK				70,526	9.49	0.89	74,938	3.56	3.10
EU-27							73,934	2.40	16.4
	1.A.4.c ii						1.A.4.c iii		
	Gasoline			Heavy fuel oil			Diesel		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Germany	75,237	219	0.46	NO	NO	NO	74,027	0.94	3.34
Denmark	72,994	152	1.41	77,931	2.33	1.80	73,852	2.28	1.69
France	74,538	165	0.55	NO	NO	NO	74,523	7.04	1.88
Netherlands	73,023	282	0.60	77,400	7.00	2.00	72,454	7.00	2.00
UK	70,214	48.7	0.34	*76,485*	*1.53*	*3.82*	75,313	1.03	3.41
EU-27	72,981	162	1.79	76,616	6.49	2.17	74,008	5.54	2.06

Germany: Current IEF for report year 2020; all other countries: IEF for 2019, pursuant to 2021 CRF submission

3.2.12.5 Category-specific recalculations (1.A.4 mobile)

As described above, the activity data for the emissions sources considered here are part of the primary data listed in Energy Balance line 67. The provisional data provided for the year 2019, in the 2021 Submission, have been replaced with the corresponding final figures. The quantities of consumed biofuels that were determined via the official admixture quotas have been recalculated as necessary.

Table 83: Revised primary activity data, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
Diesel fuel										
2022 Submission	126,920	105,800	96,425	85,293	89,516	101,911	105,895	108,752	101,513	102,836
2021 Submission	126,920	105,800	96,425	85,293	89,516	101,911	105,895	108,752	101,519	102,654
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-6.00	182
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.01%	0.18%
Gasoline										
2022 Submission	28,213	19,659	17,276	16,546	12,583	12,557	12,219	11,712	11,543	11,141
2021 Submission	28,213	19,659	17,276	16,546	12,583	12,557	12,219	11,712	11,274	11,046
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	269	95.0
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.39%	0.86%
LPG										
2021 Submission	0	7,963	9,238	28,246	24,605	19,916	23,260	16,971	19,426	22,054
2020 Submission	0	7,963	9,238	28,246	24,605	19,916	23,260	16,971	19,426	20,844
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.210
Relative change		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	5.81%
Biodiesel										
2021 Submission	0	0	0	5,460	6,863	5,575	5,614	5,806	5,901	5,857
2020 Submission	0	0	0	5,460	6,863	5,575	5,614	5,806	5,901	5,845
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.4
Relative change				0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.21%
Biogasoline										
2021 Submission	0	0	0	114	486	545	531	494	519	481
2020 Submission	0	0	0	114	486	545	531	494	507	476
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.1	4.10
Relative change				0.00%	0.00%	0.00%	0.00%	0.00%	2.39%	0.86%

Source: Revised NEB 2019 (AGEB, 2021b) and own calculations

At the same time, for the military transports included in the primary activity data, and for the period as of 2004, the calorific value for gasoline used for conversion into energy quantities was corrected. Also, the energy inputs in high-seas fisheries were revised, for all years. The large discrepancies, with respect to the 2021 submission, seen in category 1.A.4.c.iii, amounting to about -40% to -80%, result from a revision of the EMMA model (v. 3.1.11). In the process, erroneous previous allocation of power data for drive systems, and for auxiliary machines, was corrected.

The changed energy inputs, shown below, for the various sub-sectors considered, have resulted from these adjustments.

Table 84: Revised energy inputs for sub-sectors, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
1.A.4.a ii										
2022 Submission	10,634	9,958	10,907	10,803	10,844	10,383	10,807	10,892	10,346	10,276
2021 Submission	10,634	9,958	10,907	10,803	10,844	10,383	10,807	10,892	10,347	10,266
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.34	10.9
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.11%
1.A.4.b ii										
2022 Submission	2,177	2,395	2,395	2,411	3,510	4,411	4,412	4,406	4,418	4,410
2021 Submission	2,177	2,395	2,395	2,411	3,510	4,411	4,412	4,406	4,253	4,221
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	165	190
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.88%	4.50%
1.A.4.c ii (i)										
2022 Submission	53,263	44,622	41,696	40,366	45,246	51,580	53,732	55,367	51,855	52,509
2021 Submission	53,263	44,622	41,696	40,366	45,246	51,580	53,732	55,367	51,858	52,415
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.07	-2.90	94.2
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.01%	0.18%

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
1.A.4.c ii (ii)										
2022 Submission	5,788	4,336	5,375	5,569	4,409	4,843	4,677	4,853	5,465	5,619
2021 Submission	5,788	4,336	5,375	5,562	4,383	4,824	4,660	4,840	5,409	5,646
Absolute change	0.00	0.00	0.00	7.57	25.9	19.3	16.5	13.4	56.3	-26.5
Relative change	0.00%	0.00%	0.00%	0.14%	0.59%	0.40%	0.35%	0.28%	1.04%	-0.47%
1.A.4.c iii										
2022 Submission	338	266	264	250	251	284	298	293	356	322
2021 Submission	735	567	549	504	489	555	1,117	1,208	2,529	512
Absolute change	-397	-301	-285	-254	-238	-271	-819	-915	-2.174	-190
Relative change	-54.0%	-53.1%	-51.9%	-50.4%	-48.6%	-48.8%	-73.3%	-75.7%	-85.9%	-37.1%

Source: Own calculations, based on AGEB (2021b), Knörr et al. (2021b) and Deichnik (2021)

At the same time, the implied emission factors modelled for the various individual mobile emitters were updated.

The following recalculated emissions quantities result from these extensive corrections:

Table 85: Revised emissions quantities, in kilotonnes of CO_2-eq

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
1.A.4.a ii										
2022 Submission	775	718	778	745	743	724	755	761	720	716
2021 Submission	775	718	778	745	743	724	755	761	720	715
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	0.76
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.11%
1.A.4.b ii										
2022 Submission	178	191	187	186	260	329	329	328	328	328
2021 Submission	178	190	186	185	261	329	329	329	316	314
Absolute change	0.25	0.92	1.16	0.63	-0.37	-0.35	-0.40	-0.45	12.0	13.9
Relative change	0.14%	0.48%	0.62%	0.34%	-0.14%	-0.11%	-0.12%	-0.14%	3.81%	4.42%
1.A.4.c ii (i)										
2022 Submission	3,994	3,346	3,126	2,856	3,165	3,678	3,837	3,952	3,686	3,736
2021 Submission	3,994	3,346	3,126	2,856	3,165	3,678	3,837	3,952	3,686	3,729
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.22	6.64
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.01%	0.18%
1.A.4.c ii (ii)										
2022 Submission	462	349	429	431	326	357	345	358	401	412
2021 Submission	462	349	429	430	324	356	344	357	396	414
Absolute change	0.00	0.00	0.00	0.63	2.09	1.50	1.28	1.05	4.87	-1.63
Relative change	0.00%	0.00%	0.00%	0.15%	0.65%	0.42%	0.37%	0.29%	1.23%	-0.39%
1.A.4.c iii										
2022 Submission	25.6	20.1	20.0	18.9	19.0	21.3	22.4	22.0	26.7	24.2
2021 Submission	55.3	42.7	41.3	37.9	36.8	41.6	83.8	90.7	190	38.4
Absolute change	-29.7	-22.5	-21.4	-19.0	-17.8	-20.3	-61.5	-68.6	-163	-14.2
Relative change	-53.8%	-52.8%	-51.7%	-50.1%	-48.4%	-48.8%	-73.3%	-75.7%	-85.9%	-37.1%
1.A.4 - MOBILE EMITTERS, TOTAL										
2022 Submission	5,434	4,623	4,541	4,237	4,514	5,109	5,287	5,421	5,162	5,216
2021 Submission	5,464	4,645	4,561	4,255	4,530	5,129	5,348	5,489	5,308	5,210
Absolute change	-29.5	-21.6	-20.2	-17.7	-16.1	-19.2	-60.6	-68.0	-146	5.41
Relative change	-0.54%	-0.47%	-0.44%	-0.42%	-0.35%	-0.37%	-1.13%	-1.24%	-2.76%	0.10%

Source: Own calculations; including fossil CO_2 from use of biofuels

3.2.12.6 Category-specific planned improvements (1.A.4 mobile)

No concrete improvements are currently planned, apart from ongoing routine review and revision of the models used.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.13 Other sectors (1.A.5.a stationary)

Category 1.A.5 comprises the combustion-related emissions of the military sector. It is divided into the categories 1.A.5.a *"Stationary"* and 1.A.5.b *"Mobile"*.

3.2.13.1 Category description (1.A.5.a stationary)

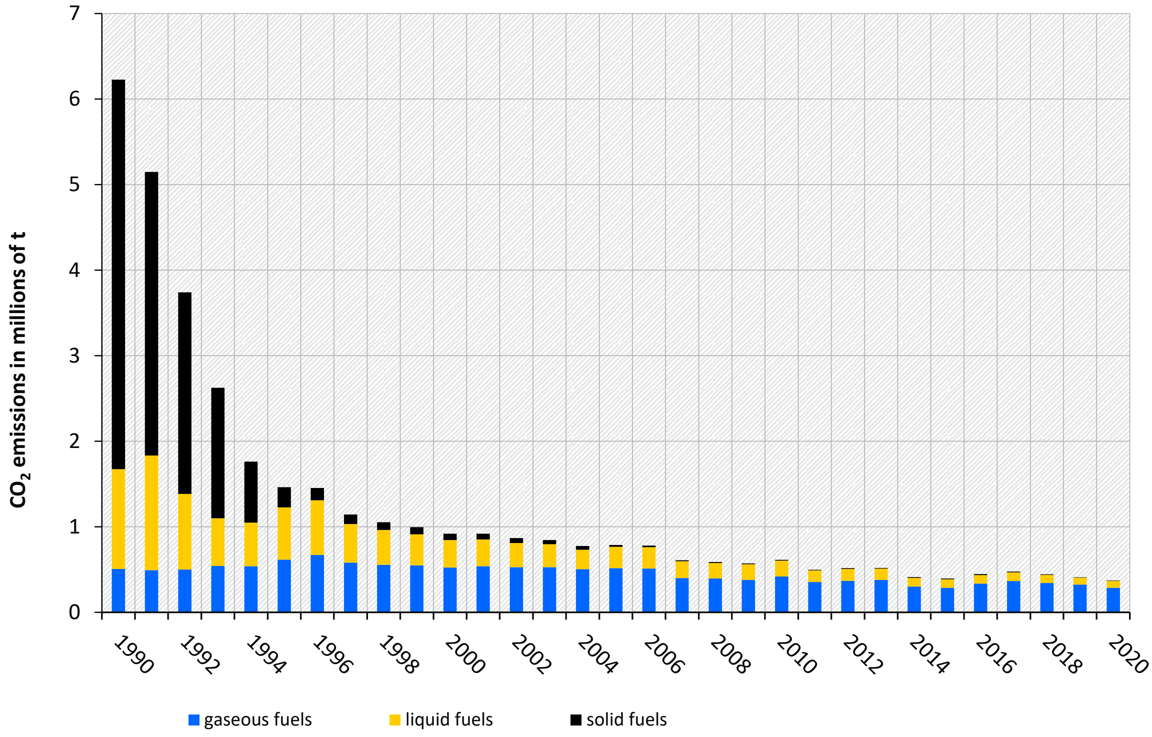
KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 A 5, Other: Military**	**fossil fuels**	**CO_2**	**11,752.9**	**0.9%**	**744.4**	**0.1%**	**-93.7%**
-/-	1 A 5, Other: Military		CH_4	279.4	0.0%	1.3	0.0%	-99.5%
-/-	1 A 5, Other: Military		N_2O	60.9	0.0%	3.3	0.0%	-94.6%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS, Tier 1	NS	CS/D
CH_4	CS, Tier 1, Tier 3	NS/M	CS/D/M
N_2O	CS, Tier 1, Tier 3	NS/M	CS/D/M

The stationary and mobile sources in 1.A.5 are grouped together for purposes of assignment to key categories. The category *Other* is a key category for CO2 emissions in terms of both emissions level and trend.

The following figure shows the emissions trend since 1990.

Figure 37: Development of CO_2 emissions in category 1.A.5.a



The especially large emissions reduction is the result of closure of many military agency locations, as well as of considerable shifting from use of solid fuels to use of gaseous and liquid fuels.

3.2.13.2 Methodological issues (1.A.5.a, stationary)

Activity data

The Energy Balance of the Federal Republic of Germany (AGEB) provides the basis for the activity data used. As of 1995, the NEB no longer lists the final energy consumption of military agencies separately, and instead includes that consumption in line 67, under "Commercial and

Institutional" (commerce, trade, services and other consumers). As a result, figures of the Federal office for infrastructure, environmental protection and services of the German Armed Forces (Bundesamt für Infrastruktur, Umweltschutz und Dienstleistungen der Bundeswehr) (BAIUDBw, 2020) are used. That office reports "energy inputs for heat generation in the German Armed Forces" ("Energieeinsatz zur Wärmeerzeugung in der Bundeswehr"), broken down by fuels, to the Federal Environment Agency (most recently, this was done for the period 2000-2020). Those figures are deducted from the figures in Energy Balance line 67 (commercial, institutional) and are reported in 1.A.5, rather than in 1.A.4. As of report year 2008, use of wood in category 1.A.5.a is also reported. As of report year 2020, the database for the time series as of 2003 is provided by the Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat)).

Emission factors

A detailed description of the relevant procedures, and a list of the CO_2 emission factors used, is presented in the Annex, Chapter 18.8.

The database for the emission factors used for all other pollutants consists of the results of a research project carried out by the University of Stuttgart, under commission to the Federal Environment Agency (Struschka et al., 2008). Within that project, device-related and category-specific emission factors for combustion systems in military agencies were calculated, with a high level of detail, for all important emissions components for the reference year 2005. The method used to determine the factors conforms to the procedure described for category 1.A.4. Table 86 shows the sectoral emission factors used.

Table 86: Sectoral emission factors for the military sector

	CH_4	N_2O
	[kg/TJ]	
Stationary combustion in military agency locations		
Hard coal	2.0	4.8
Lignite briquettes	242	0.37
Heating oil EL	0.017	0.56
Natural gas	0.042	0.29

3.2.13.3 Uncertainties and time-series consistency (1.A.5.a, stationary)

Information regarding the uncertainties for the emission factors is provided in the description for category 1.A.4. Annex 2 Chapter 13.6 in the NIR 2007 describes how the uncertainties for the activity data were determined.

3.2.13.4 Category-specific quality assurance / control and verification (1.A.5.a, stationary)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Since no other sources of data for Germany are known, it is currently not possible to verify the emissions reported here via comparison.

3.2.13.5 Category-specific recalculations (1.A.5.a, stationary)

Minor recalculations in the area of solid fuels were carried out for the year 2019, to take account of updating of net calorific values.

3.2.13.6 Planned improvements, category-specific (1.A.5.a, stationary)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.14 Other (1.A.5.b Mobile)

3.2.14.1 Category description (1.A.5.b mobile)

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1 [a], CS	NS/M [b]	D [a], CS
CH_4	CS, Tier 1, Tier 3	NS/M [b]	CS (M)
N_2O	CS, Tier 1, Tier 3	NS/M [b]	CS (M)
NO_x, CO, NMVOC, SO_2	CS, Tier 1, Tier 3	NS/M [b]	CS (M)

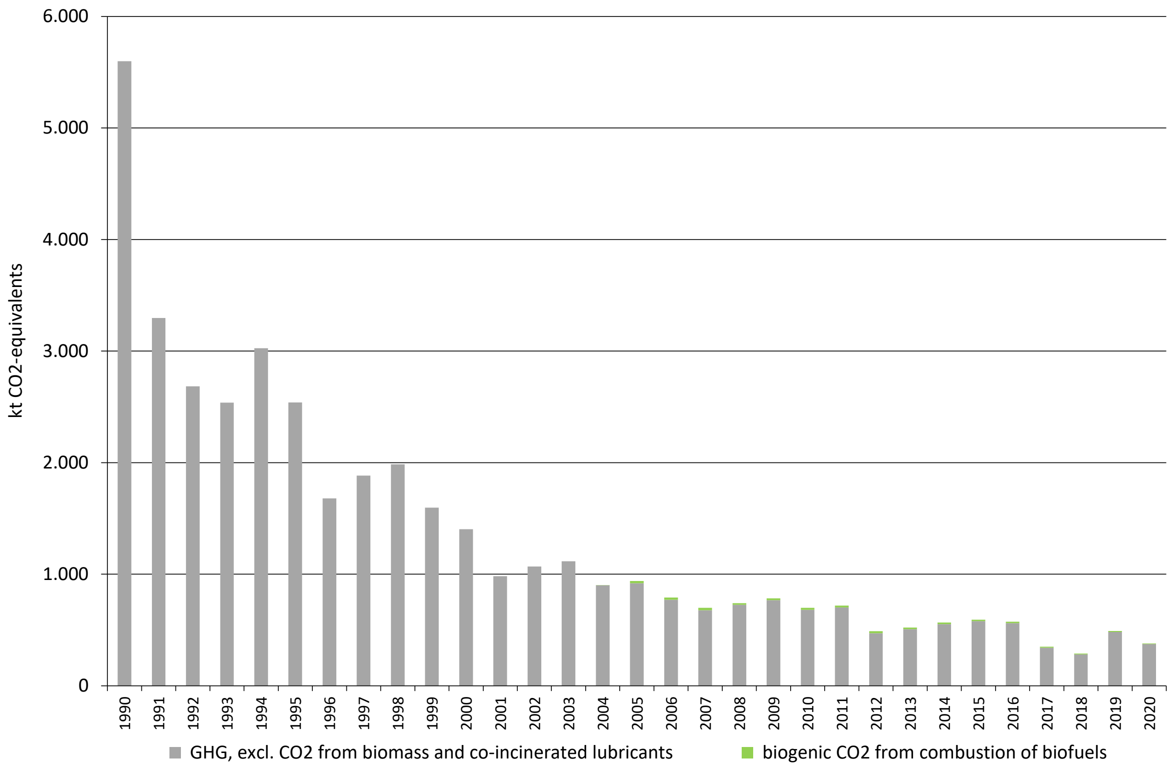
[a] for biodiesel and avgas: Default EF pursuant to IPCC (2006a): Volume 2, Chapter 2, Table 2.4

[b] Military Ship transports: calculated in Deichnik (2021)

The key category analysis for *1.A.5 – Other* is carried out on an overarching basis, for both stationary and mobile sources (cf. Chapter 3.2.13.1). The analysis shows that category *1.A.5* is a key category for CO2 emissions in terms of both emissions level and trend.

The following figure shows the development of GHG emissions since 1990.

Figure 38: Development of GHG emissions of mobile sources in the military sector since 1990



3.2.14.2 Methodological issues (1.A.5.b mobile)

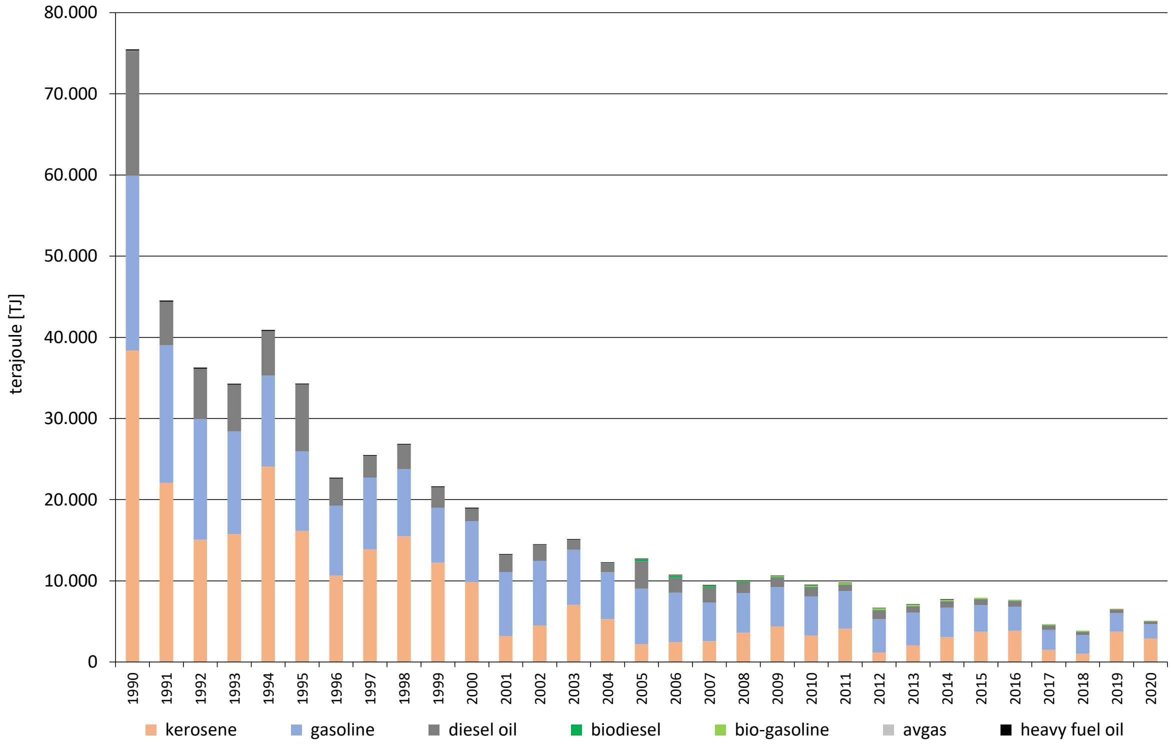
Activity data

The **activity data** used are based on the Energy Balance of the Federal Republic of Germany (AGEB), which provides directly usable fuel-input data for military air and ground transports (diesel fuel and gasoline – including any biogenic admixtures – and kerosene and avgas) only for the period until 1993. As of 1994, data of BAFA (2021) are used. The consumption figures in that source, which are given in units of 1000 t, are converted into terajoules on the basis of the pertinent listed net calorific values (AGEB, 2021c). On the other hand, the fuel inputs in the naval sector are only a sub-quantity of the quantities listed in *Energy Balance line 6 – International marine bunkers*. They are thus calculated separately, as described in Chapter 19.1.4.

In addition, the quantities of co-combusted lubricants are derived, via co-combustion rates pursuant to Wallfarth (2014), from the total quantities of the fuels used in sub-categories 1.A.5.b i through iii (cf. also Chapter 19.1.4).

The CO_2 emissions from the fossil fractions of the biofuels used are allocated to the total national emissions (cf. the explanatory remarks in Chapter 19.1.5).

Figure 39: Development of fuel inputs since 1990



Emission factors

With regard to the **emission factors** used for carbon dioxide, we refer, in general, to Chapter 18.8. Both country-specific and default values (biodiesel, avgas) are used. Further information regarding co-combustion of lubricants in particular is provided in Chapter 19.1.4.

For methane and nitrous oxide, country-specific values are also used for ground transports and for use of avgas. For jet kerosene, IPCC default figures are used, in light of the fact that the aircraft used by the sector differ strongly from those used in civil aviation. The emission factors used for the naval sector are taken from Deichnik (2021). With regard to releases of methane and nitrous oxide from co-combustion of lubricants, it is assumed that such emissions are already taken into account in the pertinent emission factors for the fuels used and thus are to be reported as IE *(included elsewhere)*.

Table 87: Emission factors used for report year 2020, in kg/TJ

	CH_4	N_2O	Origin
1.A.5.b i – Military ground vehicles and machinery			
Diesel & biodiesel	2.97 (-)	0.81 (-)	IEF derived from 1.A.3.b: heavy duty vehicles
Gasoline & bioethanol	7.04 (-)	0.72 (-)	IEF derived from 1.A.3.b
1.A.5.b ii – Military air transports[a]			
Kerosene	0.50 (0.50)	2.00 (2.00)	Tier 1 Default value pursuant to IPCC (2006a)
Avgas	20.4 (-)	2.30 (-)	IEF derived from 1.A.3.a
1.A.5.b iii – Military maritime transports / naval transports [b]			
Diesel	0.71 (7.00)	3.43 (2.00)	Pursuant to Deichnik (2021)
Heavy fuel oil	n.a.	n.a.	Use ended in 2014
Overarching			
Lubricants	IE	IE	Included in the EF for fuels

In parentheses: Default values pursuant to IPCC (2006a): Volume 2, Chapter3: [a] Tab. 3.6.5; [b] Tab. 3.5.3

The EF for biodiesel and bio-ethanol are in keeping with the values used for their fossil-based counterparts.

3.2.14.3 Uncertainties and time-series consistency (1.A.5.b mobile)

Within sub-sectors 1.A.5.b i and ii, default uncertainties pursuant to IPCC are used. In a departure from that procedure, specific uncertainties for activity data and emission factors for military maritime transports were derived in (BSH, 2015).

3.2.14.4 Category-specific quality assurance / control and verification (1.A.5.b mobile)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Table 88: Overview of relevant data comparisons

	Comparison with...	Remark
CO_2	Alternative emissions inventories for Germany	No comparable data sets
CO_2	Specific Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter	for 1.A.5.b ii & iii: cf. Table 89
CO_2	Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter 2, Table	for 1.A.5.b i: cf. Table 89
CH_4, N_2O	Specific Tier 1 default EF pursuant to IPCC (2006a)	for 1.A.5.b ii & iii: cf. Table 86
CH_4, N_2O	Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter 2, Table	1.A.5.b i: cf. Table 86
CO_2	specific IEF of other countries	cf. Table 82

Table 89: Comparison of the EF(CO_2) used with default values, in kg/TJ

	Inventory values[a]	Default[b]	*Lower bound*	*Upper bound*
Diesel fuel	74,027	74,100	*72,600*	*74,800*
Gasoline	75,276	69,300	*67,500*	*73,000*
Kerosene	73,256	71,500	*69,800*	*74,400*
Avgas	70,000		*67,500*	*73,000*
Biodiesel	70,800		*59,800*	*84,300*
Bioethanol	71,607	70,800	*59,800*	*84,300*

[a] for reported year 2020; [b] pursuant to IPCC (2006a): Volume 2, Chapter 2, Table 2.4

The following table provides a comparison with specific implied emission factors of other countries.

Table 90: International comparison of IEF for liquid fossil fuels, in kg/TJ

	CO_2	CH_4	N_2O
Germany	**74,693**	**2.95**	**1.56**
Denmark	73.171	3.39	2.60
France	IE	IE	IE
Netherlands	74,034	6.45	3.90
UK	72,819	1.86	2.62
EU-27	81,006	3.62	3.63

Germany: current IEF for 1.A.5.b for report year 2020; all other countries: IEF for 2019, pursuant to 2021 CRF submission

3.2.14.5 Category-specific recalculations (1.A.5.b Mobile)

With respect to the 2021 submission, recalculations have been carried out to take account of updated activity data and emission factors. In the process, provisional Energy Balance data for the year 2019 have been replaced with the corresponding final data.

At the same time, the calorific value used for conversion of consumed gasoline into energy quantities was corrected, for all years as of 2004, and the energy inputs in military water-borne navigation were revised, for all years.

Table 91: Revised activity data, in terajoules

	1990	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019
Military land transports & mobile machinery											
Subm. 2022	36,545	17,801	8,841	6,761	10,306	6,029	4,041	3,696	3,004	2,699	2,663
Subm. 2021	36,545	17,801	8,841	6,764	10,324	6,102	4,099	3,748	3,046	2,741	2,663
Change, absolute	0.00	0.00	0.00	-2.39	-18.3	-72.8	-57.8	-52.1	-41.9	-42.0	0.00
Change, relative	0.00%	0.00%	0.00%	-0.04%	-0.18%	-1.19%	-1.41%	-1.39%	-1.38%	-1.53%	0.00%
Military Air transports											
Subm. 2022	38,400	16,149	9,863	5,281	2,200	3,286	3,726	3,845	1,507	1,025	3,746
Subm. 2021	38,400	16,149	9,863	5,281	2,200	3,286	3,726	3,845	1,507	1,025	3,746
Change, absolute	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Change, relative	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Military Maritime transports											
Subm. 2022	532	366	318	249	239	209	154	141	156	133	164
Subm. 2021	983	665	563	431	410	347	273	359	489	436	558
Change, absolute	-451	-298	-245	-181	-171	-138	-119	-218	-333	-303	-394
Change, relative	-45.9%	-44.9%	-43.5%	-42.1%	-41.7%	-39.7%	-43.5%	-60.7%	-68.1%	-69.6%	-70.6%
MILITARY MOBILE EMITTERS, TOTAL											
Subm. 2022	75,477	75,477	75,477	75,477	75,477	75,477	75,477	75,477	75,477	75,477	75,477
Subm. 2021	75,928	75,928	75,928	75,928	75,928	75,928	75,928	75,928	75,928	75,928	75,928
Change, absolute	-451	-451	-451	-451	-451	-451	-451	-451	-451	-451	-451
Change, relative	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%	-0.59%

Source: Own calculations, based on BAFA (2021), and Deichnik (2021)

In addition, the implied emission factors for military water-borne navigation were adjusted.

These extensive adjustments lead to changes in the reported greenhouse-gas emissions, for all years considered.

Table 92: Revised emissions data, in kt CO_2 equivalents

	1990	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019
Military land transports & mobile machinery											
Subm. 2022	2,733	1,327	658	498	745	427	293	268	218	195	193
Subm. 2021	2,733	1,327	658	498	746	432	297	271	221	198	193
Change, absolute	0.00	0.00	0.00	-0.18	-1.34	-5.18	-4.21	-3.79	-3.06	-3.05	0.00
Change, relative	0.00%	0.00%	0.00%	-0.04%	-0.18%	-1.20%	-1.42%	-1.40%	-1.39%	-1.54%	0.00%
Military Air transports											
Subm. 2022	2,836	1,193	729	390	162	243	275	284	111	76	277
Subm. 2021	2.836	1.193	729	390	162	243	275	284	111	76	277
Change, absolute	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Change, relative	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Military Maritime transports											
Subm. 2022	28.7	19.8	17.2	13.5	12.9	11.3	11.6	10.6	11.7	10.0	12.3
Subm. 2021	73.8	49.9	42.2	32.3	30.8	26.0	20.5	27.0	36.7	32.7	41.9
Change, absolute	-45.1	-30.1	-25.0	-18.8	-17.8	-14.7	-8.9	-16.4	-25.0	-22.8	-29.6
Change, relative	-61.1%	-60.3%	-59.3%	-58.2%	-57.9%	-56.5%	-43.5%	-60.7%	-68.1%	-69.6%	-70.6%
MILITARY MOBILE EMITTERS, TOTAL											
Subm. 2022	5,598	2,540	1,403	901	920	681	580	562	341	281	482
Subm. 2021	5,643	2,570	1,428	920	939	700	593	582	369	307	512
Change, absolute	-45.1	-30.1	-25.0	-19.0	-19.2	-19.9	-13.1	-20.2	-28.1	-25.8	-29.6
Change, relative	-0.80%	-1.17%	-1.75%	-2.06%	-2.04%	-2.84%	-2.21%	-3.46%	-7.61%	-8.41%	-5.78%

Source: Own calculations; including fossil CO_2 from use of biofuels

3.2.14.6 Category-specific planned improvements (1.A.5.b Mobile)

No specific improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.2.15 Military

The German emissions inventories do not record emissions from international missions of the German Armed Forces, under NATO or UN mandates; instead, they list them as "not estimated" (NE) memo items. The reason for this is a lack of information regarding the fuel quantities (activity data) required/used in the framework of such mandates.

Emissions from stationary combustion systems of military agencies, and from *domestic* operation of military vehicles and machinery, are recorded and described in the German emissions inventories, however – under category *1.A.5 – Other*.

3.3 Fugitive emissions from fuels (1.B)

During all stages of fuel production and use, from extraction of fossil fuels to their final use, fuel components can escape or be released as fugitive emissions. While methane emissions are the most important emissions within the source category areas of fugitive emissions from solid fuels and fugitive emissions from natural gas, fugitive emissions of oil and natural gas also include substantial amounts of NMVOC. Carbon dioxide plays a role in category 1.B in connection with processing of solid fuels, with processing of sour gas, and with refinery processes. In connection with natural gas leaks, it also plays a role as a component of natural gas. Source category 1.B. is not a source for fluorinated gases.

3.3.1 Solid fuels – coal mining and handling (1.B.1)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**1 B 1, Solid Fuels**		**CH_4**	**25,553.4**	**2.0%**	**136.7**	**0.0%**	**-99.5%**
-/-	1 B 1, Solid Fuels	fossil fuels	CO_2	1,832.8	0.1%	629.5	0.1%	-65.7%

The category *Coal mining and handling* is a key category for CH_4 emissions in terms of emissions level and trend.

In mining, a distinction is made between surface mining, in which deposits are extracted from pits open to the surface, and underground mining, in which deposits are extracted from sites underground. Since 2003, lignite has been mined in Germany only in open-pit mines. Hard coal mining was terminated in 2018.

This category is subdivided as follows:

Source category			Included emissions
1.B.1.a. Coal mining			
	i.	**Underground mining**	
		Mining activities	Total emissions from active hard-coal mines, consisting of emissions from a) mine ventilation and b) mine-gas extraction, less the quantity of mine gas recovered and utilized (since 2019, "NO" is reported here)
		Follow-up mining activities	Emissions from processing, storage and transport of hard coal (since 2019, "NO" is reported here)
		Decommissioned coal mines	Emissions from decommissioned hard-coal mines and emissions from flaring
	ii.	**Open-pit mining**	
		Mining activities	Emissions from active open-pit lignite mining. Here, the entire potential methane content of German lignite is used as the basis – this methane is assumed to be emitted, in its entirety, during mining. Any later emissions of methane, during further processing, are thus already taken into account. No pit-gas collection or use takes place in open-pit mining.
		Follow-up mining activities	No separate listing – the emissions are already included in "mining activities"
1.B.1.b. Solid fuel transformation – coal processing and charcoal production			Emissions from coal processing and charcoal production. This area takes account of specific emissions that occur in hard-coal processing. Methane emissions from lignite processing are already included in 1.B.1.a.ii "Mining activities". The assumed activity data cover the total for all processed products from hard coal and lignite.
1.B.1.c. Other			No emissions are currently being reported in this category.

Emissions and trend (1.B.1)

3.3.1.1 Underground mining – hard coal

Hard coal is no longer mined in Germany.

3.3.1.2 Open-pit mining – lignite

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	AS	CS

3.3.1.2.1 Category description (open-pit mining – lignite)

Activity data

Table 93: Usable output of lignite, in millions of t.

1990	1995	2000	2005	2010	2015	2017	2019	2020
356.5	192.7	167.7	177.9	169.4	178.1	171.3	131.3	107.3

(Statistik der Kohlenwirtschaft, 2021)

Emission factors

In keeping with figures of the DEBRIV German lignite-industry association (DEBRIV, 2004), an average emission factor of 0.015 m³ CH_4/t (corresponds to 0.011 kg CH_4/t) is assumed for German lignite. This emission factor is based on a 1989 study of RWE Rheinbraun AG (DEBRIV, 2004) and has been substantiated by publications of the German Society for Petroleum and Coal Science and Technology (DGMK) (DGMK, 1992).

No lignite storage takes place; usage is "mine-mouth", i.e. extracted coal is moved directly to processing and to power stations.

Table 94: Emissions in category 1.B.1.a.ii – open-pit mining

Emission factors	m^3 CH_4/t	kg/t
CH_4 from extraction	0.015	0.011

Emissions and trend

Table 95: Emissions in category 1.B.1.a.ii – open-pit mining

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	3.9 kt	1.4 kt	1.2 kt	-69 %	-14 %	The emissions have been decreasing as a result of reductions in lignite production.

3.3.1.2.2 Methods (open-pit mining – lignite)

The emissions from open-pit lignite mining are calculated with the Tier 2 method.

3.3.1.2.3 Uncertainties and time-series consistency (open-pit mining – lignite)

The emission factor used for calculating methane emissions from lignite production is based on maximum methane content levels and thus represents the upper limit of possible methane emissions. It thus already includes possible emissions from transport and storage. Numerous studies have shown that a negative uncertainty of - 33 % must be assumed (DEBRIV / DGMK research report / Forschungsbericht 448-2, DGMK (1992)).

For the emission factor and the activity data, a consistent source is used throughout the entire time series.

3.3.1.2.4 Category-specific quality assurance/control and verification (open-pit mining – lignite)

General and category specific quality control and quality assurance, have been carried out in conformance with the requirements of the QSE-manual and its associated applicable documents, by the Single National Entity.

In the framework of verification for the current report, various data sources for activity data in coal mining, and the relevant EF used, were compared with the corresponding sources and EF of other countries (cf. Table 96). A by-country comparison of specific emission factors for open-pit mining shows a broad range, with Germany in the lower part of the range, in a position comparable to that of Poland. The 2011 NIR (p. 103) noted that the Czech Republic uses the average IPCC default factor, in keeping with the fact that the coal mined in that country, in comparison to the coal mined in Poland and Germany, consists to a larger extent of sub-bituminous coal. The degree of coalification (rank) – and, thus, the methane content – of such coal is higher than that of the lignite found in Poland and Germany (sources: NaSE-Workshop (2004), personal communication of DEBRIV (2004)). This conclusion was also reached by a report prepared by VERICO (Betzenbichler et al., 2016b).

Table 96: IEF for open-pit lignite mining: Germany as compared with neighbouring countries (pursuant to NIR 2014)

	Extracted lignite	Reported emissions	IEF
Germany	**185.4 million t**	**2.0 kt**	**0.011 kg/t**
Poland	64.3 million t	0.8 kt	0.012 kg/t
Czech Republic	43.5 million t	33.5 kt	0.770 kg/t
IPCC GL 2006			0.2 – 1.3 kg/t

The IPCC emission factors have been derived from figures for American bituminous coal and thus, according to national experts, cannot be applied to German lignite, which did not exceed a temperature of 50°C during the coalification process. Significant methane releases occur only at temperatures above 80°C (DGMK, 1992).

3.3.1.3 Decommissioned hard-coal mines

When a hard-coal mine is decommissioned, methane can escape from neighbouring rock, and from coal remaining in the mine, into the mine's network of shafts and passageways. Since the mine is no longer artificially ventilated, the methane collects and can then reach the surface via gas pathways in the overlying rock or via the mine's own shafts and passageways.

Such mine gas was long seen primarily as a negative environmental factor. Recently, increasing attention has been given to the gas' positive characteristics as a fuel (use for energy recovery). In the past, use of mine gas was rarely cost-effective. This situation changed fundamentally in 2000 with the Renewable Energy Sources Act (EEG). Although mine gas is a fossil fuel in finite supply, its use supports climate protection, and thus the gas was included in the EEG. The Act requires network operators to accept, and provide specified compensation for, electricity generated with mine gas and fed into the grid.

The emissions are determined in keeping with the DMT model ((Meiners, 2018)).

3.3.1.4 Solid fuel transformation

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	AS	CS
CO_2	Tier 2	AS	CS
NMVOC	Tier 2	AS	CS
CO	Tier 2	AS	CS
SO_2	Tier 2	AS	CS

The 2006 IPCC Guidelines do not specify this category, and thus no pertinent decision tree is available.

3.3.1.4.1 Category description (solid fuel transformation)

Activity data

Table 97: activity data for processed products [figures in tonnes]

	1990	1995	2000	2005	2010	2015	2019	2020
Lignite briquettes	40,045,000	5,010,829	1,819,263	1,489,922	2,024,103	1,709,000	1,471,790	1,285,809
Lignite coke	3,355,937	191,883	179,453	173,443	175,932	170,000	155,672	145,525
Lignite dust	3,791,431	2,700,110	2,678,926	2,923,620	3,632,333	4,398,000	4,321,543	3,799,643
Hard-coal coke	17,580,000	11,102,000	9,115,000	8,397,000	8,171,000	8,800,000	8,821,502	7,872,481

(Statistik der Kohlenwirtschaft, 2021); figures of the German Emissions Trading Authority (DEHSt)

Emission factors

The methane emission factor used for calculation of CH_4 emissions from hard-coal-coke production (coking plants) is 0.049 kg methane per tonne of hard-coal coke (Meiners, 2005). It is used for the entire time series. The CO_2 emission factor is determined on the basis of the conservative assumption that about 1% of the coke is lost, in the form of fugitive emissions, between the time the blast-furnace door is opened and the coke is quenched. The activity data used consists of the total relevant quantities of hard-coal and lignite coke.

The emission factors for the non-greenhouse gases have been obtained from the research project "Emission factors for the iron and steel industry, for purposes of emissions reporting" ("Emissionsfaktoren zur Eisen- und Stahlindustrie für die Emissionsberichterstattung") (Hensmann et al., 2011).

Table 98: Emission factors for the production of hard-coal coke

Gas	Emission factor	Units
CH_4	0.049	kg/t
CO_2	2,777[38]	kg/t
CO	0.015	kg/t
NH_3	243.3	mg/t
NMVOC	0.310	kg/t
SO_2	0.076	kg/t

No methane emissions are to be expected from processing of lignite products, since the EF used for 1.B.1.a.ii corresponds to the gas content of the lignite occurring in Germany. The other identified emissions are based on measurements made by the sole (at present) German producer of lignite coke at the Fortuna-Nord hearth-furnace plant.

Small quantities of charcoal are produced in Germany – by one major charcoal-factory operator and in a number of demonstration charcoal kilns. The pertinent quantities are determined by the Federal Statistical Office and are subject to confidentiality requirements. The emission factors were obtained from US_EPA 1995 (Neulicht, 1995). Use of charcoal is reported under 2.G.4.

[38] The emission factor covers the area of production of hard-coal and lignite coke

Emissions and trend

Table 99: Emissions in category 1.B.1.b – solid fuel transformation

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	2.4 kt	2.1 kt	1.8 kt	-25 %	-14 %	The methane emissions are affected primarily by charcoal production. The emissions from coking plants have fallen since 1990, as a result of reductions in coke production.
Carbon dioxide	1,819 kt	647 kt	629 kt	-65 %	-3 %	The emissions have fallen since 1990, as a result of reductions on coke production.

CO_2 emissions from charcoal production are considered "biogenic" and are reported within the memo-items section.

3.3.1.4.2 Methodological aspects (solid fuel transformation)

Emissions from hard-coal-coke production have been calculated via the Tier 2 method, along the lines of the IPCC Reference Manual's equation for CH_4 emissions from coal mining:

$$\text{Emissions [kt } CH_4\text{]} = \text{EF [m}^3\ CH_4\text{ /t] * } AR_{\text{transformation product}}\text{* conversion factor [kt/10}^6\text{m}^3\text{]}$$

3.3.1.4.3 Uncertainties and time-series consistency (solid fuel transformation)

The uncertainties for the emission factors for processing of coal have been estimated by experts as 10% to 25%.

For the activity data, a consistent source is used throughout the entire time series.

3.3.1.4.4 Category-specific quality assurance / control and verification (solid fuel transformation)

General and category specific quality control and quality assurance, have been carried out in conformance with the requirements of the QSE-manual and its associated applicable documents, by the Single National Entity.

In consideration of emission factors, the IPCC conversion factor of 0.67 Gg/10^6m^3 at 20°C and 1 atmosphere should be applied to the units used in Germany: normal cubic metres at 1.01325 bar and 0°C (DIN 2004, DIN No. 1343). The German practice of using normal cubic metres should also be noted in consideration of the IPCC default EF, and of figures from other published sources. In use of EF data published in Germany, it is assumed that the relevant figures use normal cubic metres (substantiated via survey of experts at the NaSE-Workshop (2004)).

The guideline figures are oriented to 20°C and 1,013 mbar. In keeping with methane's isobaric proportionality, the factor 1.07 can be used to convert Nm^3 into m^3.

Conversion factor, normal cubic metres ⇔ kilogrammes:

0.717 Nm³/kg (1.01325 bar, 0°C) **= 0.67 Gg/10⁶m³** (20°C, 1 atmosphere) ***** **1.07 Nm³/m³**

No comparisons with the corresponding data of other countries are possible in this category, since the pertinent CRF tables do not yield the required precise quantities and compositions of the transformed coal products involved. What is more, the IPCC Guidelines provide neither methods nor default emission factors for such a comparison in this category.

3.3.1.5 Category-specific recalculations (1.B.1 all)

The +10% change in hard-coal-coke production for 2019 has led to recalculations, of a similar order, for methane and carbon dioxide.

3.3.1.6 Planned improvements, category-specific (1.B.1 all)

No new improvements are planned.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

3.3.2 Oil and natural gas and fugitive emissions from energy production (1.B.2)

This category is subdivided as follows:

Source category				Included emissions
1.B.2. Oil, natural gas and fugitive emissions from energy production				
a	**Oil**			
	i)	**Exploration**		Total emissions from exploratory drilling for oil and gas
	ii)	**Production**		Fugitive emissions from oil production and from oil processing (separation of water and accompanying gases)
	iii)	**Transport**		Emissions from transport of crude oil via pipelines and inland-waterway tankers
	iv)	**Refining / storage**		Emissions from oil desulphurisation and refining, from storage of crude oil and of petroleum products and from cleaning of storage tanks
	v)	**Distribution of oil products**		Emissions from distribution of petroleum products, from refuelling processes and drip losses and from cleaning of tanks of transport vehicles
	vi)	**Other**		No emissions in this category
b	**Gas**			
	i)	**Exploration**		The emissions are assigned to category 1.B.2.a.i, since no differentiation is possible
	ii)	**Production**		Fugitive emissions from natural gas production
	iii)	**Processing**		Emissions from desulphurisation and processing of sour gas and from processing of town gas
	iv)	**Transport**		Emissions from long-distance high-pressure pipelines and from underground gas storage (caverns and porous-rock reservoirs)
	v)	**Distribution**		Emissions from natural-gas distribution lines, and from above-ground storage facilities, and fugitive leaks from tanks of vehicles for natural-gas transport
	vi)	**Other**		Fugitive emissions from installations in the residential, institutional and commercial (small consumers) and industry sectors
c	**Venting and flaring**			
	i)	**Venting**		
			Oil	The emissions are included in the categories 1.B.2.a.iii and 1.B.2.a.v
			Gas	The emissions are included in the categories 1.B.2.b.iv and 1.B.2.b.v
			Combined	No emissions in this category
	ii)	**Flaring**		
			Oil	Flaring emissions related to oil production and refining
			Gas	Flaring emissions related to natural gas production and to processing of sour gas
			Combined	No emissions in this category

Source category				Included emissions
	d	Other		
		i)	Geothermal energy	No fugitive CO_2, CH_4 or N_2O emissions occur in ongoing operations. Fugitive F-gas emissions are assigned to the category 2.F.9

3.3.2.1 Oil (1.B.2.a)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	1 B 2 a, Oil		CO_2	477.6	0.0%	393.3	0.1%	-17.7%
-/-	1 B 2 a, Oil		CH_4	241.8	0.0%	17.0	0.0%	-93.0%
-/-	1 B 2 a, Oil		N_2O	0.3	0.0%	0.3	0.0%	-21.5%

The category 1.B.2.a. "Oil" is not a key category.

3.3.2.1.1 "Oil, Exploration" (1.B.2.a.i)

Gas	Method used	Source for the activity data	Emission factors used
CO_2, CH_4	Tier 1	AS	D
NMVOC	Tier 2	AS	CS

3.3.2.1.1.1 Category description, "Oil, exploration" (1.B.2.a.i)

This category's emissions consist of emissions from activities of drilling companies and of other participants in the exploration sector. Gas and oil exploration takes place in Germany. The pertinent statistics do not differentiate between drilling solely for oil and drilling solely for natural gas.

Activity data

Table 100: Number of exploratory wells (sum total for oil and natural gas)

1990	1995	2000	2005	2010	2015	2019	2020
12	17	15	23	16	18	26	12

(BVEG, 2021a)

Table 101: Total length of all exploratory wells, in m (sum total for oil and natural gas)

1990	1995	2000	2005	2010	2015	2019	2020
50,140	109,187	41,378	63,994	51,411	32,773	43,416	6,220

(BVEG, 2021a)

Emission factors

Table 102: Emission factors used for category 1.B.2.a.i

Gas	Emission factor	Method	Source
CO_2	0.48 kg / No	Tier 1	IPCC GPG 2000
CH_4	64 kg / No	Tier 1	IPCC GPG 2000
NMVOC	576 kg / No	Tier 2	Expert estimate

The emission factors have been taken from the 2000 IPCC Good Practice Guidance (Penman et al., 2000), since the IPCC GL 2006 ((IPCC, 2006a): Table 4.2.4) refer to production quantities and not to exploratory wells. Therefore, those factors cannot be used in the present context.

Emissions and trend

Table 103: Emissions in category 1.B.2.a.i

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	768 kg	1,664 kg	768 kg	0 %	-46 %	The emissions have increased with respect to their level in 1990, as a result of increased drilling.
Carbon dioxide	5.76 kg	12.48 kg	5.76 kg	0 %	-46 %	
NMVOC	6,912 kg	14,976 kg	6,912 kg	0 %	-46 %	

3.3.2.1.1.2 Methodological aspects of the category "Oil, exploration" (1.B.2.a.i)

According to the WEG, virtually no fugitive emissions occur in connection with drilling operations, since relevant measurements are regularly carried out at well sites (with use of methane sensors in wellhead-protection structures, ultrasound measurements and annulus manometers), and since old / decommissioned wells are backfilled and normally covered with concrete caps.

Since pertinent measurements are not available for the individual wells involved, a conservative approach is used whereby well emissions are calculated on the basis of the default factor pursuant to IPCC GPG 2000 (Penman et al., 2000) for carbon dioxide and methane, using the Tier 1 method. For a conservative estimate, the sum of the emission factors for "drilling," "testing," and "servicing" was used.

3.3.2.1.1.3 Uncertainties and time-series consistency, category "Oil, exploration" (1.B.2.a.i)

The uncertainties in the activity data for oil and gas exploration have been quantified as +/- 5 %. The emission factors are assigned the default uncertainties from the Good Practice Guidance 2000, +/- 25 %.

For the activity data and the emission factors, a consistent source is used throughout the entire time series.

3.3.2.1.1.4 Category-specific quality assurance / control and verification, category "Oil, exploration" (1.B.2.a.i)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Due to a lack of country-specific data, an external assessment (Bender, 2009b) was commissioned. In its source-category analysis, that assessment found that the default factors are applicable to Germany. It was not possible to carry out a comparison with the results for other countries, because the relevant data lack basic comparability – for example, they use a range of units that are not mutually convertible.

3.3.2.1.2 "Oil, production and preprocessing" (1.B.2.a.ii)

Gas	Method used	Source for the activity data	Emission factors used
CO_2, CH_4	Tier 2	AS	CS
NMVOC	Tier 2	AS	CS

3.3.2.1.2.1 Category description, "Oil, production and preprocessing" (1.B.2.a.ii)

This category's emissions are produced in the petroleum industry's extraction (crude oil) and pre-treatment of raw materials (petroleum). Because Germany's oil fields are old, oil production in Germany is highly energy-intensive (thermal extraction, operation of pumps to inject water into oil-bearing layers).

The first treatment that extracted petroleum (crude oil) undergoes in processing facilities serves the purposes of removing gases, water and salt from the oil. Crude oil in the form in which it appears at wellheads contains impurities, gases and water, and thus does not conform to requirements for safe, easy transport in pipelines. No substance transformations take place. Impurities – especially gases (petroleum gas), salts and water – are removed, in order to yield crude oil of suitable quality for transport in pipelines.

Activity data

Table 104: Extracted quantity of petroleum, in kt

1990	1995	2000	2005	2010	2015	2019	2020
3,606	2,959	3,113	3,573	2,516	2,414	1,927	1,907

(BVEG, 2021a)

Emission factors

Table 105: Emission factors used for production and processing

Gas	Emission factor	Method	Source
CO_2	115 g/m³	Tier 2	Expert estimate
CH_4	14 g/m³	Tier 2	Expert estimate
NMVOC	16 g/m³	Tier 2	Expert estimate

Emissions and trend

Table 106: Emissions in category 1.B.2.a.ii

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	1,081 t	32 t	22 t	-98 %	-31 %	The emissions have decreased with respect to 1990, as a result of decreasing production and improved emissions-reduction technologies in the areas of production and processing.
Carbon dioxide	460 t	254 t	254 t	-45 %	0 %	
NMVOC	108 t	35 t	35 t	-68 %	-1 %	

3.3.2.1.2.2 Methodological aspects of the category "Oil, production and preprocessing" (1.B.2.a.ii)

The emissions from production and processing are measured, or calculated, by the operators, and the pertinent data are published in the annual reports of the Federal association of the natural gas, oil and geothermal energy industries (BVEG, 2021a). The emission factors are determined from the reported emissions and the activity data shown in Table 104.

The emissions are calculated in keeping with the Tier 2 method.

3.3.2.1.2.3 Uncertainties and time-series consistency in the category "Oil, production and preprocessing" (1.B.2.a.ii)

In this category, the uncertainty for the activity data is given as 5 to 10 %. The figures are based on estimates of BVEG experts and national experts.

The uncertainties for the emission factors in the category amount to 25 %.

3.3.2.1.2.4 Category-specific quality assurance / control and verification for the category "Oil, production and preprocessing" (1.B.2.a.ii)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The emission factors that have been used are of the same order of magnitude as those given in the 2006 IPCC Guidelines (IPCC, 2006a).

Table 107: Comparison of IEF with the relevant IPCC default values

Gas	CS emission factor used Units in [g/m³]	IPCC GL 2006 (Table 4.2.4) Units in [Gg/1000m³]	Units in [g/m³]
CO_2	115 g/m³	$1.1*10^{-07}$ to $2.6*10^{-04}$	0.11 – 260.00
CH_4	14 g/m³	$1.5*10^{-06}$ to $6.0*10^{-02}$	1.50 – 60,000
NMVOC	16 g/m³	$1.8*10^{-06}$ to $4.5*10^{-03}$	1.80 – 4500.0

3.3.2.1.3 "Oil, transport" (1.B.2.a.iii)

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	AS	CS
NMVOC	Tier 2	AS	CS

3.3.2.1.3.1 Category description, "Oil, transport" (1.B.2.a.iii)

This category's emissions are tied to activities of logistics companies and of operators of pipelines and pipeline networks. Following first treatment, crude oil is transported to refineries.

Almost all transports of crude oil take place via pipelines. Pipelines are stationary and, normally, run underground. In contrast to other types of transports, petroleum transports are not interrupted by handling processes.

Activity data

Table 108: Transports of domestically produced crude oil, in kt

1990	1995	2000	2005	2010	2015	2019	2020
3,606	2,959	3,113	3,573	2,516	2,414	1,927	1,907

(BVEG, 2021a)

Table 109: Transports of imported crude oil, in kt

1990	1995	2000	2005	2010	2015	2019	2020
84,043	86,063	89,280	97,474	93,270	91,275	85,991	83,049

(BAFA, 2021)

Table 110: Crude-oil transports via inland-waterway tankers, in kt

1990	1995	2000	2005	2010	2015	2019	2020
88.9	66.6	111.8	176.4	5.6	43.1	47.2	46.4

(DESTATIS, 2021)

Emission factors

Table 111: Activity data and emission factors used for category 1.B.2.a.iii, "Transport of crude oil"

Source category	Activity data	Units	Gas	Emission factor (EF)	Units
Transports of imported crude oil	83.0	Millions of t/a	NMVOC	0.0064	kg/t
			CH_4	0.0064	
Transports of domestically produced crude oil	1.9		NMVOC	0.13	
			CH_4	0.013	
Crude oil transports via inland-waterway tankers	46.2	kt/a	NMVOC	0.34	
			CH_4	0.034	
			CH_4	0.013	

Emissions and trend

Table 112: Emissions in category 1.B.2.a.iii

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
NMVOC	5,885 t	5,770 t	5,579 t	-2 %	-3 %	The increasing trend is driven primarily by increases in the quantities of transported oil.
CH_4	588 t	577 t	558 t	-2 %	-3%	

3.3.2.1.3.2 Methodological aspects of the category "Oil, transport" (1.B.2.a.iii)

The emissions are calculated in keeping with the Tier 2 method.

For pipelines, the emission factor for methane has been taken from the 2006 IPCC Guidelines (IPCC, 2006a), while for inland-waterway tankers that factor has been estimated by experts. The pertinent emission factors have been confirmed by the research project "Determination of emission factors and activity data in areas 1.B.2.a.i through vi" ("Ermittlung von Emissionsfaktoren und Aktivitätsraten im Bereich 1.B.2.a.i bis vi" (Theloke et al., 2013)). Since long-distance pipelines are continually monitored, and since disruptive incidents in such pipelines are very rare (CONCAWE – "Performance of European cross country oil pipelines" (Cech et al., 2017)), emissions occur – in small quantities – only at their transfer points. The emission factor is thus highly conservative.

The emission factor covers the areas of transfer / injection into pipelines at pumping stations, all infrastructure (connections, control units, measuring devices) along pipelines and transfer at refineries, and it has been determined on the basis of conservative assumptions. For imported quantities, only one transfer point (only the withdrawal station) is assumed, since the station for input into the pipeline network does not lie on Germany's national territory.

3.3.2.1.3.3 Uncertainties and time-series consistency in the category "Oil, transport" (1.B.2.a.iii)

The uncertainties for the emission factors have been quantified as +/- 20 %, while those for the activity data have been determined to be +/- 10 %. The emission factors and the activity data are consistent throughout the entire time series.

3.3.2.1.3.4 Category-specific quality assurance / control and verification for the category "Oil, transport" (1.B.2.a.iii)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The emission factors that have been used are of the same order of magnitude as those given in the 2006 IPCC Guidelines.

In the 2016 ESD Review, it was noted that Germany reports no CO_2 emissions in this category, although the 2006 IPCC Guidelines give a pertinent Tier 1 default value. In a telephone conversation involving experts of the Federal Environment Agency and experts of the Association of the German Petroleum Industry (MWV) (Bittkau, 2017), the MWV experts confirmed that no CO_2 emissions from transport pipelines occur.

Table 113: Comparison of IEF with the relevant IPCC default values

Gas	CS emission factor used	IPCC GL 2006 (Table 4.2.4)	
	Units in [g/m³]	Units in [Gg/1000m³]	Units in [g/m³]
CH_4	6 g/m³	$5.4*10^{-06}$	5.4
NMVOC	55 g/m³	$5.4*10^{-05}$	54.0

3.3.2.1.4 "Oil, refining and storage" (1.B.2.a.iv)

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	AS	CS
CH_4	Tier 2	AS	CS
SO_2	Tier 2	AS	CS
CO	Tier 2	AS	CS
NO_x	Tier 2	AS	CS
NMVOC	Tier 2	AS	CS

3.3.2.1.4.1 Category description, "Oil, refining and storage" (1.B.2.a.iv)

This category's emissions consist of emissions from activities of refineries and of refining companies in the petroleum industry. Crude oil and intermediate petroleum products are processed in Germany. For the most part, the companies concerned receive crude oil for refining and processing. Such processing takes place in state-of-the-art plants.

Refinery tank storage systems are used to store both crude oil and intermediate and finished petroleum products. They thus differ from non-refinery tank storage systems in terms of both the products they store and the quantities they handle. Tank-storage facilities outside of refineries are used especially for interim storage of heating oil, gasoline and diesel fuel. The storage capacities of caverns used for storing petroleum products are listed separately. In light of the ways in which caverns are structured, it may be assumed that no emissions of volatile compounds occur. This is taken into account in the emissions calculation.

Tanks are emptied and cleaned for purposes of tank inspections and repairs. In tank cleaning, a distinction is made between crude-oil tanks and product tanks. Because of the sediment deposits involved, cleaning of crude-oil tanks, in comparison to cleaning of product tanks, is a considerably more involved process. Product tanks contain no sedimentable substances and thus are cleaned only when the products they contain are changed. In keeping with an assessment of Bender (2009a), the emission factors for storage of crude oil and of petroleum products may be assumed to take cleaning processes into account.

Activity data

Table 114: Quantity of crude oil refined, in kt

1990	1995	2000	2005	2010	2015	2019	2020
107,058	96,475	107,632	114,589	95,378	93,391	87,013	83,990

(MWV, 2021a)

Table 115: Capacity utilisation in refineries, in percent

1990	1995	2000	2005	2010	2015	2019	2020
106.2	92.1	95.3	99.5	81.1	91	84.8	81.8

(MWV, 2021a)

Table 116: Crude-oil-refining capacity in refineries, in kt

1990	1995	2000	2005	2010	2015	2019	2020
100,765	104,750	112,940	115,630	117,630	103,080	102,655	105,655

(MWV, 2021a)

Table 117: Tank-storage capacity in refineries and pipeline terminals, in millions of m^3

1990	1995	2000	2005	2010	2015	2019	2020
27.2	28.4	24.9	24.0	22.5	22.1	20.7	20.7

(MWV, 2021a) (Koj, 2021)

Table 118: Storage capacity of tank-storage facilities outside of refineries, including caverns, in millions of m^3

1990	1995	2000	2005	2010	2015	2019	2020
15.4	15.9	18.1	17.0	15.95	15.3	15.4	15.3

(MWV, 2021a) (Koj, 2021)

Table 119: Storage capacity of caverns, in millions of m^3

1990	1995	2000	2005	2010	2015	2019	2020
26.6	25.3	27.9	27.2	27.3	25.5	26.7	25.5

(MWV, 2021a) (Koj, 2021)

Emission factors

Table 120: Emission factors used for category 1.B.2.a.vi, "Fugitive emissions at refineries"

Gas	Emission factor	Method	Source
CH_4	0.225 g/t	Tier 2	Expert estimate
CO	0.494 g/t	Tier 2	Expert estimate
CO_2	537.01 g/t	Tier 2	Expert estimate
SO_2	0.854 g/t	Tier 2	Expert estimate
NMVOC	7.24 g/t	Tier 2	Expert estimate
NO_x	6.02 g/t	Tier 2	Expert estimate

Table 121: Emission factor used for category 1.B.2.a.vi, "Anode production at refineries"

Gas	Emission factor	Method	Source
CO_2	190.4 kg/t	Tier 2	Expert estimate

Table 122: Emission factors used for category 1.B.2.a.vi, "Storage and cleaning of crude oil in tank-storage facilities of refineries"

Gas	Emission factor	Method	Source
CH_4	0.172 g/t	Tier 2	Expert estimate
NMVOC	0.0227 kg/t	Tier 2	Expert estimate

Table 123: Emission factors used for category 1.B.2.a.vi, "Storage of liquid petroleum products (fuels) in tank-storage facilities outside of refineries"

Gas	Emission factor	Method	Source
CH_4	5 g/m^3	Tier 2	Expert estimate
NMVOC	100 g/m^3	Tier 2	Expert estimate

Emissions and trend

Table 124: Emissions in category 1.B.2.a.iv

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Carbon dioxide	477,166 t	411,109 t	393,070 t	-18 %	-4 %	The trend for CO_2 is influenced by calcining, the Claus plant and anode production. The falling trend for methane and NMVOC is driven by improved emissions-reduction technologies in refineries and in storage of refinery products.
Methane	8,003 t	37.3 t	37.1 t	- 99 %	-1 %	
NMVOC	73,151 t	3,912 t	3,897 t	- 95 %	-1 %	

3.3.2.1.4.2 Methodological aspects of the category "Oil, refining and storage" (1.B.2.a.iv)

The emissions for all sub-areas are calculated in keeping with the Tier 2 method.

Processing

The emission factors used for NMVOC, CH_4, CO_2, CO, NO_x and SO_2 were determined via evaluation of the emissions declarations of the period 2004 through 2016, in the framework of a research project (Bender & von Müller, 2019).

Anode production

The activity data are calculated from the relevant quantity of petroleum coke, minus the own consumption (coke burn-off in catalyst regeneration – cf. 1.A.1.b). The data have been obtained from the Official Mineral Oil Statistics. This "green coke" is processed via calcining. The emission factor is calculated from the pertinent activity data and from the emissions data of the EU Emissions Trading System (ETS).

Tank-storage facilities in refineries

In keeping with the results of the research project "Processing of data of emissions declarations pursuant to the 11th Ordinance Implementing the Federal Immission Control Act – the area of storage facilities" ("Aufbereitung von Daten der Emissionserklärungen gemäß 11. BImSchV - Bereich Lageranlagen") (Bender, 2009a), the crude-oil-distillation capacity is used as the activity data for estimation of emissions from storage in refineries. The fugitive-VOC-emissions value specified in VDI Guideline 2440 (VDI, 2000), 0.16 kg/t, may be used as the emission factor. The EF for methane was derived from it (5-10 % of 0.16 kg) and then suitably deducted.

Tank-storage facilities outside of refineries

According to Müller-BBM (Bender, 2009a), no emission factors can be derived, via evaluation of emissions declarations for storage systems, that would be representative of individual systems. This is due, so the same source, to the clearly widely differing emissions behaviour of different individual systems. It was possible, however, to form aggregated emission factors. For each relevant group of data, this was done by correlating the sums of all emissions with the sums of all capacities. For non-refinery tank-storage systems, storage of liquid petroleum products can be differentiated from storage of gaseous petroleum products, since the relevant data are suitably differentiated. The emissions of gaseous petroleum products are assigned to the area of storage of chemical products (CRF 2.B.10). In addition, liquid petroleum products are broken down, with the help of a split factor, into the areas of a) fuels and b) chemical products. While fuels are reported in 1.B.2, chemical products are reported in 2.B.10.

Claus plants

The emission factors used for NMVOC, CO, NO_x und SO_2 were determined via evaluation of refineries' emissions declarations of the period 2004 through 2016, in the framework of a research project (Bender & von Müller, 2019). Since no data were available for earlier years, the data so obtained were used for all years as of 1990.

3.3.2.1.4.3 Uncertainties and time-series consistency in the category "Oil, refining and storage" (1.B.2.a.iv)

Uncertainties of +/- 20 % are assumed for the emission factors for refining of crude oil. The uncertainties for the activity data are assumed to be +/- 10 %. The total uncertainties for the emissions from the area of storage and cleaning are estimated at +/- 40 %. These figures are based on estimates of national experts, as well as on the research report of Müller-BBM (Bender, 2009a) and (Theloke et al., 2013).

The emission factors and the activity data are consistent throughout the entire time series.

3.3.2.1.4.4 Category-specific quality assurance / control and verification for the category "Oil, refining and storage" (1.B.2.a.iv)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Due to the complexity of the category, the data cannot be cross-checked against those of other countries. This was also confirmed at the 2014 EU Workshop (Harthan et al., 2017).

3.3.2.1.5 "Oil, distribution of oil products" (1.B.2.a.v)

Gas	Method used	Source for the activity data	Emission factors used
NMVOC	Tier 2	AS	CS

3.3.2.1.5.1 Category description, "Oil, distribution of oil products" (1.B.2.a.v)

The category comprises transports and handling of petroleum products, via inland-waterway tankers, pipelines, railway tank cars, road tankers and canisters, as well as cleaning of transport vehicles.

Activity data

Table 125: Filling stations in Germany (number)

1990	1995	2000	2005	2010	2015	2019	2020
19,317	17,957	16,324	15,187	14,744	14,531	14,449	14,459

(MWV, 2021a)

Table 126: Distributed quantities of petroleum products, in kt

	1990	1995	2000	2005	2010	2015	2019	2020
Diesel fuel	21,817	26,208	28,922	28,531	32,128	36,756	37,848	35,163
Jet fuel	4,584	5,455	6,939	8,049	8,465	8,550	10,239	4,725
Light heating oil	31,803	34,785	27,875	25,380	21,005	16,127	15,061	15,558
Gasoline	31,257	30,333	28,833	23,431	19,634	18,226	17,966	16,218

(BAFA, 2021)

Emission factors

The emission factors listed below have been verified by the study (Theloke et al., 2013). The model used for calculation of petrol emissions is described in Chapter 3.3.2.1.5.2.

Petroleum products are transported by inland-waterway tanker ships, product pipelines, railway tank cars and road tankers, and they are transferred from tanks to other tanks. Experts consider the emissions from refueling of aircraft to be non-existent, since the equipment used for such refuelling is fitted with dry couplings. The emissions from filling of private heating-oil tanks are also very low, thanks to high safety standards.

In this category, petroleum products are handled and distributed that have undergone fractional distillation in refineries, i.e. processes in which gaseous products are separated out. For this reason, no significant methane emissions are expected. Only in storage of certain petroleum products can small quantities of methane escape.

Table 127: NMVOC emission factors used for category 1.B.2.a.v "Distribution of gasoline“

Process responsible for emissions	Emission factor [kg/t]	Method	Source
Drip losses in refuelling at filling stations	0.117 kg/t	Tier 2	Expert estimate
Transfers from road tankers to filling stations (20th Ordinance Implementing the Federal Immission Control Act – vapour displacement)	1.4[39] kg/t	M (Tier 2)	Expert estimate
Ventilation in connection with transports with inland-waterway tankers	0.025 kg/t	Tier 2	Expert estimate
Transfers from filling station tanks to vehicle tanks (21st Ordinance Implementing the Federal Immission Control Act – vapour recovery)	1.4 kg/t	M (Tier 2)	Expert estimate

Table 128: NMVOC emission factors used for category 1.B.2.a.v "Distribution of diesel fuels"

Process responsible for emissions	Emission factor [kg/t]	Method	Source
Drip losses in refuelling at filling stations	0.1 kg/t	Tier 2	Expert estimate
Transports from refineries to transport vehicles	0.008 kg/t	Tier 2	Expert estimate
Transfers from filling-station tanks to vehicle tanks	0.003 kg/t	Tier 2	Expert estimate

Table 129: NMVOC emission factors used for category 1.B.2.a.v "Distribution of light heating oil"

Process responsible for emissions	Emission factor [kg/t]	Method	Source
Drip losses in refuelling at transfer stations	0.0011 kg/t	Tier 2	Expert estimate
Transports from refineries to transport vehicles	0.0053 kg/t	Tier 2	Expert estimate
Transfers from filling-station tanks to vehicle tanks	0.0063 kg/t	Tier 2	Expert estimate

Table 130: NMVOC emission factors used for category 1.B.2.a.v "Distribution of jet fuels"

Process responsible for emissions	Emission factor [kg/t]	Method	Source
Drip losses in refuelling at transfer stations	0 kg/t	Tier 2	Expert estimate
Transports from refineries to transport vehicles	0.055 kg/t	Tier 2	Expert estimate
Transfers from filling-station tanks to vehicle tanks	0.02 kg/t	Tier 2	Expert estimate

Table 131: NMVOC emission factors used for category 1.B.2.a.v, "cleaning"

Process responsible for emissions	Emission factor [kg/t][40]	Method	Source
Cleaning of road tankers	0.8 g/t	Tier 2	Expert estimate
Cleaning of railway tank cars	0.4 g/t	Tier 2	Expert estimate
Cleaning of inland shipping tankers	0.004 g/t	Tier 2	Expert estimate

[39] The factor does not include reduction measures – cf. Table 133

[40] The reference figure is the total quantity of gasoline transported in Germany with the relevant type of vehicle.

Emissions and trend

Table 132: Emissions in category 1.B.2.a.v

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
NMVOC	87.8 kt	16.9 kt	15.8 kt	- 82 %	-6 %	The emissions decreases are due primarily to the introduction of the 20th and 21st Ordinances Implementing the Federal Immission Control Act (BImSchV), which phased in requirements for vapour-balancing and vapour-recovery systems.

3.3.2.1.5.2 Methodological aspects of the category "Oil, distribution of oil products" (1.B.2.a.v)

Transport

Inland-waterway tankers that transport gasoline retain considerable quantities of gasoline vapours in their tanks after their gasoline has been unloaded. When the ships change loads or spend time in port, their tanks have to be ventilated (Bauer et al., 2010).

The gasoline fuels transported and handled in Germany, via ***railway tank cars***, produce annual emissions of about 1,400 t VOC (Joas et al., 2004). The pertinent logistics chain comprises filling of tank cars, transport, emptying of tank cars, and cleaning of tank cars. In all likelihood, the emissions from transport and from emptying of tank cars are negligible.

Half of all filling stations receive deliveries directly from refineries, **via road tankers**. The other half receives deliveries from interim storage facilities, of which one out of three are served by pipelines (Winkler, 2004).

As transport media, **pipelines** produce no significant emissions (Winkler, 2004). Pursuant to the German Society for Petroleum and Coal Science and Technology (DGMK), the diffuse losses that occur at pipeline pumps or flanges are negligible (Theloke, 2013).

Filling stations

Significant quantities of fugitive VOC emissions are released into the environment during transfers from tanker vehicles to storage facilities and during refuelling of vehicles. For emissions determination, a standardised emission factor of 1.4 kg/t is used. This refers to the saturation concentration for hydrocarbon vapours – and, thus, corresponds to the maximum possible emissions level in the absence of reduction measures.

The immission-control regulations issued in 1992 and 1993 (20. BImSchV, 2017; 21. BImSchV, 2017) that required filling stations to limit such emissions promoted a range of reduction measures. The relevant reductions affect both the area of transfer and storage of gasoline (20. BImSchV, 2017) and the area of fuelling of vehicles, with gasoline, at filling stations (21. BImSchV).

Use of required emissions-control equipment, such as vapour-balancing (20th BImSchV) and vapour-recovery (21st BImSchV) systems, along with use of automatic monitoring systems (via the amendment of the 21st BImSchV on 6 May 2002), have brought about continual reductions of VOC emissions; the relevant high levels of use of such equipment are shown in the table below (Table 133).

In emissions calculation, the two ordinances' utilisation and efficiency requirements for filling stations in service are taken into account. The following assumptions, based on the technical options currently available, are applied:

Table 133: Utilisation and efficiency requirements, for filling stations, of the 20th and 21st Ordinances Implementing the Federal Immission Control Act (BImSchV)

Ordinance		Factor	
20th BImSchV	Vapour balancing	Degree of utilisation	98 %
		Efficiency	98 %
21st BImSchV	Vapour recovery	Degree of utilisation	98 %
		Efficiency	85 %

The emissions are calculated with the following formula:

Emissions = activity data * unreduced emission factor (from Table 127) * (level of use * (1 - efficiency) + (1 - level of use))

In addition, permeation of hydrocarbons occurs in tank hoses. The DIN EN 1360 standard sets a limit of 12 ml / hose meter per day for such permeation. From analysis of measurements, UBA experts have adopted a conservative factor of 10ml/m per day. That factor is used to determine the NMVOC emissions. The calculation is carried out in accordance with the pertinent formula of the University of Stuttgart's Institute for Machine Components (Haas, 2015):

Number of service stations * number of fuel pumps per service station * number of hoses per fuel pump * hose length * emission factor.

Refuelling from canisters

Refuelling of recreational motorboats by pouring of fuel from canisters into fuel tanks releases small quantities of fugitive VOC emissions into the environment. As in determination of emissions from filling stations, these emissions are determined with the help of a unified emission factor of 1.4 kg/t that is obtained from the saturation concentration of hydrocarbon vapours – and, therefore, from the maximum possible emissions quantity. The following assumptions are also made: the average canister volume is 15 l; the drip loss is 1 kg/t (estimation): 0.24% of the country's population owns a motorboat in Germany (Mell, 2008); a total of 1.9 million refuelling operations take place per year. The calculations exclude all instances of refuelling at filling stations for boats – emissions from such refuelling are already included in the "filling stations" category.

Cleaning of transport vehicles

Tank interiors are cleaned prior to tank repairs, prior to safety inspections, in connection with product changes and with lease changes.

The inventory currently covers cleaning of railway tank cars. The residual amounts remaining in railway tank cars' tanks after the tanks have been emptied – normally, between 0 and 30 litres (up to several hundred litres in exceptional cases) – are not normally able to evaporate completely. They thus produce emissions when the insides of tanks are cleaned.

Each year, some 2,500 cleaning operations are carried out on railway tank cars that transport gasoline. The emissions released, via exhaust air, in connection with cleaning of tank cars' interiors amount to about 40,000 kg/a VOC (Joas et al., 2004), p. 34.

Any additional prevention and reduction measures could affect emissions in this category only slightly. At the same time, emissions can be somewhat further reduced from their current levels via a combination of various technical and organizational measures. Emissions during handling – for example, during transfer to railway tank cars – are produced especially by residual amounts of gasoline that remain after tanks have been emptied. Such left-over quantities in tanks can release emissions via manholes the next time the tanks are filled. Study is thus underway to determine the extent to which "best practice" is being followed at all handling stations, and whether this extent has to be taken into account in emissions determination. In addition, improvements of fill nozzles enhance efficiency in prevention of VOC emissions during refuelling.

The 1/3 to 2/3 relationship given by the report is assumed to be also applicable to the emissions occurring in connection with cleaning.

3.3.2.1.5.3 Uncertainties and time-series consistency in the category "Oil, distribution of oil products" (1.B.2.a.v)

The uncertainties in the category are quantified as follows: for the emission factors data, +/- 20% (95 % confidence interval, normal distribution); for the activity data, +/- 5% (Theloke et al., 2013).

3.3.2.1.5.4 Category-specific quality assurance / control and verification for the category "Oil, distribution of oil products" (1.B.2.a.v)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The data cannot be compared with those of other countries, since the CRF tables do not indicate what factors influenced the reported emissions. What is more, in the 2013 submission only Spain and Sweden reported NMVOC emissions in this category. With regard to methane emissions, IEF can be derived only for Iceland and Croatia. No cross-checking against the 2006 IPCC Guidelines is possible, since those Guidelines do not list any default factors.

3.3.2.2 Natural gas (1.B.2.b)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/-	**1 B 2 b, Natural Gas**		**CH_4**	**7,997.4**	**0.6%**	**4,765.0**	**0.7%**	**-40.4%**
-/-	1 B 2 b, Natural Gas		CO_2	986.5	0.1%	470.8	0.1%	-52.3%

The category 1.B.2.b "Natural gas" is a key category of CH_4 emissions in terms of emissions level.

3.3.2.2.1 "Natural gas, exploration" (1.B.2.b.i)

Gas	Method used	Source for the activity data	Emission factors used
CH_4	IE	IE	IE
NMVOC	IE	IE	IE

3.3.2.2.1.1 Category description, "Natural gas, exploration" (1.B.2.b.i)

Category 1.B.2.b.i is considered together with category 1.B.2.a.i (Oil, exploration). Consequently, the aggregated, non-subdivided data of 1.B.2.b.i are included in category 1.B.2.a.i.

3.3.2.2.1.2 Methodological aspects of the category "Natural gas, exploration" (1.B.2.b.i)

The possibility of breaking exploration down into oil exploration and natural gas exploration was reviewed (Herold et al., 2014), but then abandoned due to a lack of statistics and to the very small emissions quantities involved. The emissions are thus listed completely, for both oil exploration and gas exploration, under 1.B.2.a.i.

3.3.2.2.1.3 Uncertainties and time-series consistency of the category "Natural gas, exploration" (1.B.2.b.i)

See 1.B.2.a.i for explanations of uncertainties and time-series consistency.

3.3.2.2.1.4 Category-specific quality assurance / control and verification, category "Natural gas, exploration" (1.B.2.b.i)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

3.3.2.2.2 "Natural gas, production" (1.B.2.b.ii)

Gas	Method used	Source for the activity data	Emission factors used
CO_2, CH_4	Tier 2	AS	CS
NMVOC	Tier 2	AS	CS

3.3.2.2.2.1 Category description, "Natural gas, production" (1.B.2.b.ii)

The emissions of this category consist of emissions related to production.

Activity data

Table 134: Extracted quantity of natural gas, in billions of m³

1990	1995	2000	2005	2010	2015	2019	2020
15.3	19.1	20.1	18.8	12.7	8.6	6.1	5.2

(BVEG, 2021a)

Emission factors

Table 135: Emission factors used for production

Gas	Emission factor	Method	Source
CO_2	0.1 g/m³	Tier 2	Expert estimate
CH_4	0.05 g/m³	Tier 2	Expert estimate
NMVOC	0.002 g/m³	Tier 2	Expert estimate

Emissions and trend

Table 136: Emissions in category 1.B.2.b.ii

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	5,799 t	273 t	258 t	-96%	-5%	The air-pollution emissions of the exploration and production industry are determined in keeping with a procedure accepted throughout the industry[41]. For this reason, the annual emissions figures vary somewhat from year to year and do not yield a straight line. The emissions have decreased with respect to 1990, as a result of decreasing production and improved emissions-reduction technologies.
Carbon dioxide	1,450 t	667 t	512 t	-65%	-23%	
NMVOC	580 t	30 t	10 t	-98%	--66%	

3.3.2.2.2.2 Methodological aspects of the category "Natural gas, production" (1.B.2.b.ii)

Since 1998, the Federal association of the natural gas, oil and geothermal energy industries (BVEG) has determined the emissions from production and published the relevant data in its statistical report (BVEG, 2021a). For the period prior to 1998, the emissions have been determined with the help of default factors from the 2006 IPCC Guidelines. The emissions are calculated in keeping with the Tier 2 method.

[41] WEG: "Leitfaden zu Erfassung der Umweltdaten der WEG Mitgliedsfirmen", published in-house, and last revised in Dec. 2016

3.3.2.2.2.3 Uncertainties and time-series consistency of the category "Natural gas, production" (1.B.2.b.ii)

In this category, the uncertainty for the activity data is given as 5 %. The figures are based on estimates of BVEG experts and national experts.

The uncertainties for the emission factors in the category amount to 25 %.

3.3.2.2.2.4 Category-specific quality assurance / control and verification, category "Natural gas, production" (1.B.2.b.ii)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The emission factors that have been used are of the same order of magnitude as those given in the 2006 IPCC Guidelines.

Table 137: Comparison of IEF with the relevant IPCC default values

Gas	CS emission factor used	IPCC GL 2006 (Table 4.2.5)	
	Units in [g/m³]	Units in [Gg/10⁶m³]	Units in [g/m³]
CO_2	0.1 g/m³	$1.4*10^{-05}$ to $1.8*10^{-04}$	0.014 – 0.18
CH_4	0.05 g/m³	$3.8*10^{-04}$ to $2.4*10^{-02}$	0.380 – 24.0
NMVOC	0.002 g/m³	$9.1*10^{-05}$ to $1.2*10^{-03}$	0.091 – 1.20

3.3.2.2.3 Natural gas, processing (1.B.2.b.iii)

Gas	Method used	Source for the activity data	Emission factors used
CO_2, CH_4	Tier 2	AS	CS
CO	Tier 2	AS	CS
SO_2, NMVOC	Tier 2	AS	CS

3.3.2.2.3.1 Category description (1.B.2.b.iii)

The emissions of this category consist of emissions from the activities of pretreatment and processing.

After being brought up from underground reserves, natural gas is first treated in drying and processing plants. As a rule, such pretreatment of the natural gas takes place in facilities located directly at the pumping stations. Such processes separate out associated water from reserves, along with liquid hydrocarbons and various solids. Glycol is then used to remove the water vapour remaining in the gas (WEG (2008))[42]: p. 25). Natural gas dehydration systems are closed systems. For safety reasons, all of such a system's overpressure protection devices are integrated within a flare system. When such protection devices are triggered, the surplus gas is guided to a flarehead, where it can be safely burned. After drying, the natural gas is ready for sale and can be delivered to customers directly, via pipelines (EXXON, 2014). The relevant quantities of flared gas are reported under 1.B.2.c.

The natural gas drawn from Germany's Zechstein geological formation contains hydrogen sulphide. In this original state, the gas – known as "sour gas" – has to be subjected to special treatment. Such gas is transported via separate, specially protected pipelines (due to the hazardousness of hydrogen sulphide) to German processing plants that wash out its hydrogen sulphide via chemical and physical processes. About 40 % of the natural gas extracted in Germany is sour gas (WEG, 2008).

[42] WEG 2008a: Erdgas-Erdöl, Entstehung-Suche-Förderung, Hannover, 34 p.

The natural gas that leaves processing plants is ready for use. The hydrogen sulphide is converted into elementary sulphur and is used primarily by the chemical industry, as a basic raw material.

Biogas / Biomethane

Production of Biogas is reported under CRF 3.B. Such biogas is used directly on site for electricity generation (the pertinent emissions are reported under CRF 1.A); in addition, it is fed into the gas network, as biomethane. Prior to being fed into the gas network, it has to be processed to natural-gas standards (the pertinent emissions are reported under CRF 3.B). Pursuant to the 2006 IPCC Guidelines, fossil and biogenic fractions of methane are not differentiated. For this reason, no such fossil-biogenic differentiation is provided in CRF 1.B.2.

Activity data

Table 138: Sulphur production from natural gas production in Germany, in kt

1990	1995	2000	2005	2010	2015	2019	2020
915	1,053	1,100	1,050	832	628	460	353

(BVEG, 2021a)

Figures for natural gas production are presented in Chapter 3.3.2.2.2.1, in Table 134.

Emission factors

Table 139: Emission factors used for category 1.B.2.b.iii, "Processing"

Gas	Emission factor	Method	Source
NMVOC	0.004 kg / 1,000 m³		
CH_4	0.05 kg / 1,000 m³	Tier 2	Association data
CO_2	325 kg / 1,000 m³		

Emissions and trend

Table 140: Emissions in category 1.B.2.b.iii

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	5,340 t	121 t	103 t	-98%	-15%	The air-pollution emissions of the exploration and production industry are determined in keeping with a procedure accepted throughout the industry[43]. For this reason, the annual emissions figures vary somewhat from year to year and do not yield a straight line.
Carbon dioxide	983 kt	623 kt	496 kt	-50%	-20%	
NMVOC	12 t	10 t	8 t	-33%	-20%	

3.3.2.2.3.2 Methodological issues (1.B.2.b.iii)

The emissions were calculated in keeping with the Tier 2 method.

For processing of sour gas, data of the BVEG (the former WEG) for the period since 2000 are used. Those data are the result of the WEG members' own measurements and calculations. For the period prior to 2000, the average CO_2 emission factor reported by Austria, 0.23 t / 1,000 m³, is used, since, according to the BVEG, the German desulphurisation plant is comparable to the Austrian plant.

[43] WEG: "Leitfaden zu Erfassung der Umweltdaten der WEG Mitgliedsfirmen", published in-house, and last revised in Dec. 2016

For calculation of emissions from sour-gas processing, a split factor of 0.4 relative to the activity data is applied. That split factor is based on the WEG report on sour-gas processing (WEG, 2008).

3.3.2.2.3.3 Uncertainties and time-series consistency (1.B.2.b.iii)

For the emissions data, the category uncertainties are given as 10 to 30 %. Those figures are based on estimates of national experts, and they lie within the range listed for relevant default emission factors (IPCC (2003), Chapter 2.7.1.6.).

3.3.2.2.3.4 Source-specific quality assurance / control and verification (1.B.2.b.iii)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Table 141: Comparison of IEF with the relevant IPCC default values

Source	CS emission factor used Units in [g/m³]	2006 IPCC GL (Table 4.2.4)[44] Units in [Gg/10⁶m³]	Units in [g/m³]
CO_2	225	$7.9*10^{-06}+ 3.6*10^{-3}+ 6.3*10^{-2}$	66.608
CH_4	0.05	$9.7*10^{-05} + 2.4*10^{-6}$	0.099
NMVOC	0.004	$6.8*10^{-05} + 1.9*10^{-6}$	0.068

A comparison with the IPCC default factors [Table 4.2.4 in the 2006 IPCC GL] shows that the national emission factors for methane lie within the range given for the default factors. The factor for carbon dioxide greatly exceeds the relevant default factor, however. Nonetheless, Germany's value in this category is of the same order of magnitude as Austria's (cf. the following table). The discrepancies with the IPCC default values result in that the German emission factors include the relevant sulphur production. Pursuant to the BVEG, one sixth of the emissions may be ascribed to sulphur production.

No cross-checking against the corresponding figures of other countries could be carried out, since the CRF tables do not indicate what shares of processed natural gas must be assigned to the "sour gas" category.

Table 142: Comparison of emission factors for carbon dioxide (2017)

Source	CS emission factor used Units in [g/m³]
Austria	230
Germany	238

3.3.2.2.4 Gas, transmission (1.B.2.b.iv)

Gas	Method used	Source for the activity data	Emission factors used
CH_4 (transmission)	Tier 3	AS	CS
CH_4 (storage)	Tier 2	AS	CS

3.3.2.2.4.1 Category description (1.B.2.b.iv)

The emissions of this source category consist of emissions from the activities of the gas-supply sector. In Germany, natural gas is transported from production and processing companies/plants to gas suppliers and other processors. In addition, natural gas is imported and transmitted via long-distance pipelines.

Almost all of the pipelines used to transmit natural gas are steel pipelines (Zöllner, 2014).

[44] Addition of fugitive emissions, flare emissions and raw-CO_2 venting

Activity data

Table 143: Length of long-distance high-pressure pipelines, in km

1990	1995	2000	2005	2010	2015	2019	2020
22,696	29,866	32,214	34,086	35,503	34,270	35,476	33,809

(Kiesel, 2020) own enquiry submitted to FNB Gas, the association of supra-regional gas transmission companies in Germany

Some of the natural gas is stored in underground reservoirs, to guard against the possibility of interruptions of pipeline transports (i.e. to assure the reliability of the gas supply).

Table 144: Underground gas-storage volume, in billions of m³

	1990	1995	2000	2005	2010	2015	2019	2020
Cavern reservoirs	2.8	4.8	6.1	6.8	9.2	14.3	15.3	15.1
Porous-rock reservoirs	5.2	8.5	12.5	12.4	12.1	9.8	8.6	8.6

(BVEG, 2021a)

One important emissions pathway consists of the compressors that are used to maintain pressure in pipelines. They are spaced at intervals of about 100 km along lines (GASUNIE, 2014). At present, the compressors involved have a total power output of about 2,667 MW (FNB, 2020). The pipelines are also fitted with shut-off devices (sliding sleeves), which are safety mechanisms located at intervals of about 30 km along high-pressure pipelines, and with systems for regulating and measuring gas pressure.

In pipeline inspection and cleaning, tools known as pipeline inspection gauges ("pigs"). In a pipeline system, a pig moves, driven by the gas flow, from a launching station to a receiving station (pig trap). Systems for launching and catching pigs can be either fixed or portable. Small quantities of methane are emitted in both insertion and removal of pigs. In addition, pig traps can develop leaks. Normally, however, such traps are regularly monitored for leaks and repaired as necessary. Not all types of pipelines can be pigged; diameter reductions, isolation valves, bends, etc. in pipelines can block pigs. These emissions have been estimated in the framework of a study carried out by the firm of DBI Gas- und Umwelttechnik GmbH (Grosse, 2021).

Emission factors

Most of the gas extracted in Germany is moved via pipelines from gas fields and their pumping stations (either on land or off the coast). Imported gas is also transported mainly via pipelines.

Table 145: Emission factors used for methane emissions in category 1.B.2.a.iv, "Transmission"

System or mechanism	Value	Method	Source
Long-distance high-pressure pipeline	159 kg/km	T3	Expert estimate
Compressor	30,229 m³/MW	T2	Expert estimate
Sliding sleeve hub	46,845 m³/No.	T2	Expert estimate
Systems for regulating and measuring gas pressure	764 m³/No	T2	Expert estimate
Cavern reservoirs	0.05 kg / 1,000 m³ (Vn)[45]	T2	Expert estimate
Porous-rock reservoirs	0.05 kg / 1,000 m³ (Vn)[45]	T2	Expert estimate

45 Available volume of working gas, normed to 273 K and 1013 hPa.

Table 146: Emission factors used for carbon dioxide emissions in category 1.B.2.a.iv, "Transmission"

System or mechanism	Value	Method	Source
Long-distance high-pressure pipeline	1.3 kg/km	T3	Expert estimate
Compressor	183 m^3/MW	T2	Expert estimate
Sliding sleeve hub	271 m^3/No.	T2	Expert estimate
Systems for regulating and measuring gas pressure	4.5 m^3/No	T2	Expert estimate
Cavern reservoirs	0.6 g / 1,000 m^3 (Vn) [45]	T2	Expert estimate
Porous-rock reservoirs	0.6 g / 1,000 m^3 (Vn) [45]	T2	Expert estimate

Emissions and trend

Table 147: Emissions in category 1.B.2.b.iv

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	45 kt	78 kt	72 kt	62%	-8%	The emissions have been increasing as a result of addition of new long-distance high-pressure pipelines, including the attendant compressors and measuring and safety mechanisms.
Carbon dioxide	216 t	335 t	300 t	39%	-10%	
NMVOC	1134 t	1967 t	1815 t	60%	-8%	

3.3.2.2.4.2 Methodological issues (1.B.2.b.iv)

The emissions from natural gas transmission were calculated in keeping with the Tier 3 method.

The emissions from natural gas storage, from compressor stations, from systems for regulating and measuring gas pressure and from sliding sleeve hubs were calculated in keeping with the Tier 2 method.

The emission factor for underground natural gas storage was derived via surveys of operators and analysis of statistics on accidents / incidents Bender and Langer (2012), and it is valid for pore-storage and cavern-storage facilities. It is seen as very conservative. The emission factor for the compressor systems and the sliding sleeve hubs has been obtained from the research project Zöllner (2014).

Results for above-ground gas storage facilities are reported in 1.B.2.b.v.

3.3.2.2.4.3 Uncertainties and time-series consistency (1.B.2.b.iv)

For the emissions data, the category uncertainties are given as 10 to 30 %. Those figures are based on estimates of national experts, and they lie within the range listed for relevant default emission factors (IPCC (2003), Chapter 2.7.1.6.). For underground storage facilities, an uncertainty of -50% is assumed, since the factors used were obtained via a highly conservative approach.

3.3.2.2.4.4 Source-specific quality assurance / control and verification (1.B.2.b.iv)

General and category specific quality control and a quality assurance have been carried out by the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents. The additional quality control and quality assurance were conducted by an external contractor (Grosse, 2021).

A comparison of the category with the relevant IPCC default factors (Table 4.2.8) indicates that the emission factors for methane lie within the range given. For comparison values are available for carbon dioxide.

Table 148: Comparison of IEF with the relevant IPCC default values

System or mechanism	CS emission factor	2006 IPCC GL – Table 4.2.8
Compressor	30,229 m³/MW	6,000 – 100,000 m³/MW
Shut-off devices (sliding sleeve hubs) [46]	46,845 m³/No.	1,000 – 50,000 m³/No

The emission factors for the compressors and the shut-off devices lie within the range for the pertinent IPCC factors. The emission factor for compressors was determined in the projects Zöllner (2014) and Müller-Syring and Schütz (2014). Due to a lack of data, it does not take account of emissions reduction measures (such as the utilisation of sealing gas in heating systems) and should thus be considered conservative. The factor for sliding sleeve hubs has been obtained from a study carried out for the Russian transport network (Lechtenböhmer et al., 2005). It has been used due to a lack of national emission factors. This approach may be considered highly conservative.

3.3.2.2.5 Natural gas, distribution (1.B.2.b.v)

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 3	AS	CS

3.3.2.2.5.1 Category description (1.B.2.b.v)

The emissions caused by gas distribution have decreased slightly, even though gas throughput has increased considerably and the distribution network has been enlarged considerably with respect to its size in 1990. One important reason for this improvement is that the gas-distribution network has been modernised, especially in eastern Germany. In particular, the share of grey cast iron lines in the low-pressure network has been reduced, with such lines being supplanted by low-emissions plastic pipelines. Another reason for the reduction is that fugitive losses in distribution have been reduced through a range of technical improvements (tightly sealing fittings such as flanges, valves, pumps, compressors) undertaken in keeping with emissions-control provisions in relevant regulations (TA Luft (1986) and TA Luft (2002)).

Activity data

Table 149: Gas distribution network; figures in km

Parameter	1990	1995	2000	2005	2010	2015	2019	2020
Total length of pipeline network[47]	282,612	366,987	362,388	402,391	471,886	474,570	489,100	503,543

(Kiesel, 2019); own survey

Table 150: Number of natural-gas-powered vehicles in Germany

	1990	1995	2000	2005	2010	2015	2018	2019
Number	0	0	7,500	28,500	90,000	97,804	96,531	98,460

Own survey, using data of the German Federal Motor Transport Authority (KBA)

46 The emission factor is calculated with regard to the components blow pump and valve (Zöllner, 2014); it is assumed that the listed IPCC default factor, due to its very high values, refers to sliding sleeves and not to measuring stations.

47 The data given include building-connection lines

Table 151: Emission factors used for methane emissions in category 1.B.2.b.v

System or mechanism	Value	Method	Source
Low-pressure pipeline made of steel and ductile cast iron	372 kg/km	Tier 3	Expert estimate
Low-pressure plastic pipeline	51 kg/km	Tier 3	Expert estimate
Low-pressure grey-cast-iron pipeline	445 kg/km	Tier 3	Expert estimate
Medium-pressure pipeline made of steel and ductile cast iron	207 kg/km	Tier 3	Expert estimate
Medium-pressure plastic pipeline	28 kg/km	Tier 3	Expert estimate
High-pressure pipeline made of steel and ductile cast iron	62 kg/km	Tier 3	Expert estimate
High-pressure plastic pipeline	0.3 kg/km	Tier 3	Expert estimate
Above-ground storage facilities	5 kg / 1,000 m^3 (Vn)[48]	Tier 2	Expert estimate
Gas-pressure-regulation (measuring) equipment	256 kg / No	Tier 2	Expert estimate
Natural-gas-powered vehicles	0.33 kg / vehicle	Tier 2	Expert estimate

Table 152: Carbon dioxide emission factors used for category 1.B.2.b.v

System or mechanism	Value	Method	Source
Low-pressure pipeline made of steel and ductile cast iron	3.1 kg/km	Tier 3	Expert estimate
Low-pressure plastic pipeline	0.4 kg/km	Tier 3	Expert estimate
Low-pressure grey-cast-iron pipeline	3.7 kg/km	Tier 3	Expert estimate
Medium-pressure pipeline made of steel and ductile cast iron	1.7 kg/km	Tier 3	Expert estimate
Medium-pressure plastic pipeline	0.2 kg/km	Tier 3	Expert estimate
High-pressure pipeline made of steel and ductile cast iron	0.5 kg/km	Tier 3	Expert estimate
High-pressure plastic pipeline	2.5 g/km	Tier 3	Expert estimate
Above-ground storage facilities	34 g / 1,000 m^3 (Vn)[48]	Tier 2	Expert estimate
Gas-pressure-regulation (measuring) equipment	1.7 kg / No	Tier 2	Expert estimate
Natural-gas-powered vehicles	2.3 g / vehicle	Tier 2	Expert estimate

Table 153: Emissions and trend in category 1.B.2.b.v

Gas	Total emissions			Trend		Gas
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	234 kt	87 kt	89 kt	-63%	2%	The emissions have been decreasing as a result of use of emissions-reducing materials in the pipeline network – and, especially, via replacement of grey cast iron pipes.
NMVOC	5.5 kt	2.2 kt	2.2 kt	22%	0%	
Carbon dioxide	1.8 kt	0.6 kt	0.6 kt	-89%	0%	

3.3.2.2.5.2 Methodological issues (1.B.2.b.v)

Pipeline network

The calculation was carried out using the Tier 3 method, on the basis of the available network statistics of the German Association of Energy and Water Industries (BDEW) (138. Gasstatistik 2016 (2016 gas statistics) and of our own surveys. In the early 1990s, emissions from distribution of town gas were also taken into account in calculations. In 1990, the town-gas distribution network accounted for a total of 16 % of the entire gas network. Of that share, 15 % consisted of grey cast iron lines and 85 % consisted of steel and ductile cast iron lines.

[48] Available volume of working gas, normed to 273 K and 1013 hPa.

The emission factors for the distribution network were verified in 2012 (Gottwald et al., 2012) and 2014 (Müller-Syring & Schütz, 2014).

The methane-emission factor used, 256 kg / station for the gas-pressure-regulation (-measuring) systems in the distribution network, was determined by Federal Environment Agency experts on the basis of data from the study Müller-Syring and Schütz (2014).

Storage reservoirs

Man-made above-ground storage facilities, for storage of medium-sized quantities of natural gas, help meet and balance rapid fluctuations in demand. In Germany, spherical and pipe storage tanks, and other types of low-pressure containers, are used for this purpose. Results from a relevant research project Bender and Langer (2012) have made it possible to derive new country-specific emission factors for this area. The emissions have been calculated in accordance with the Tier 2 method.

Natural-gas-powered vehicles, and CNG fuelling stations

Use of vehicles running on natural gas continues to increase in Germany. Such vehicles are refueled at CNG fuelling stations connected to the public gas network. In such refuelling, compressors move gas from high-pressure on-site tanks. Some 900 CNG fuelling stations are now in operation nationwide (Bender & Langer, 2012). In keeping with the stringent safety standards applying to refueling operations and to the tanks themselves, the pertinent emissions are very low – about 30 t per year. In the main, emissions result via tank pressure tests and emptying processes. The emissions have been calculated in accordance with the Tier 2 method.

Liquefied natural gas (LNG)

Natural gas can be liquefied, at a temperature of -161°C, for ease of transport. The liquefaction process is highly energy-intensive, however, and is normally used only in connection with long-distance transports. Germany has no LNG terminals at present (Bender & Langer, 2012). Gas imports arrive mostly in gaseous form, via long-distance pipelines, and they are included in 1.B.2.b.iv.

Germany now has one natural gas liquefaction facility and two satellite LNG storage facilities. Since the storage and transfer processes at those facilities are subject to the most stringent standards possible, emissions there can be ruled out. Gas can escape only in connection with maintenance work, and the gas quantities involved are extremely small. The quantities do not exceed more than a few hundred kilograms (Bender & Langer, 2012).

3.3.2.2.5.3 Uncertainties and time-series consistency (1.B.2.b.v)

For the emissions data, the category uncertainties are given as 20-30 %. Those figures are based on estimates of experts, and they lie within the range listed for relevant default emission factors (IPCC (2006a), Table 4.2.4).

3.3.2.2.5.4 Source-specific quality assurance / control and verification (1.B.2.b.v)

General and category specific quality control and a quality assurance have been carried out by the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents. The additional quality control and quality assurance were conducted by an external contractor (Grosse, 2021).

It was not possible to compare the results for this category with the corresponding results of other countries, due to a lack of convertibility of pertinent units.

Table 154: Comparison of IEF with the relevant IPCC default values

Method	EF	AD	EM
CS (only the distribution network)	97 kg/km[49]	503,543.00 km	49 kt
IPCC 2006	1.1 * 10^{-3} Gg / millions of m³	87 billion m³[50]	96 kt
IPCC Refinement 2019	0.62 t / million m³	87 billion m³[51]	54 kt

All three methods yield emissions on the same order of magnitude.

3.3.2.2.6 Natural gas, other leakage (1.B.2.b.vi)

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	AS	CS

3.3.2.2.6.1 Category description (1.B.2.b.vi)

The category describes emissions from leakage in the industrial sector and in the residential and institutional/commercial sectors. The activity data are based on results of the German Association of Energy and Water Industries (BDEW) ("Gasstatistik" – gas statistics) and of our own surveys. The BDEW gas statistics appear with a time lag of up to three years. Data of the Working Group on Energy Balances (AGEB) working group are used to bridge the resulting gap.

Activity data

Table 155: Activity data used for category 1.B.2.b.vi, "Fugitive emissions at sites of natural gas use"

	1990	1995	2000	2005	2010	2015	2019	2020
Number of gas meters in the residential and institutional/commercial sectors [millions]	10.3	12.7	12.8	13.3	12.9	13.0	13.1	13.1
Energy consumption of industry [TWh]	323	361	370	399	335	377	420	408

(Kiesel, 2019), (AGEB, 2021a)

49 Weighted EF

50 The value is from (BVEG, 2018)

51 The value is from (BVEG, 2018)

Emission factors

Table 156: Methane emission factors used for category 1.B.2.b.vi, "Fugitive emissions at sites of natural gas use"

Operational site	Gas	Value	Method	Source
Gas meters and fittings in the residential and institutional/commercial sectors	CH_4	2 m³/No[52]	Tier 2	Expert estimate
Fittings in industrial facilities	CH_4	0.4 m³ / 1,000 m³	Tier 2	Expert estimate

Emissions and trend

Table 157: Emissions in category 1.B.2.b.vi

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	29.1 kt	29.7 kt	29.3 kt	0%	-1%	The emissions development is influenced primarily by consumption increases in industry.
NMVOC	0.7 kt	0.7 kt	0.7 kt	0%	0%	
Carbon dioxide	0.2 kt	0.2 kt	0.2 kt	0%	0%	

3.3.2.2.6.2 Methodological issues (1.B.2.b.v)

The emission factors are country-specific, and they were determined via the research project "Methanemissionen durch den Einsatz von Gas in Deutschland von 1990 bis 1997 mit einem Ausblick auf 2010" ("Methane emissions via gas use in Germany from 1990 to 1997, with an outlook for 2010"); Frauenhofer ISI, 2000. Pursuant to Arbeitsblatt [Worksheet] G 600 (Technische Regel für Gasinstallationen [Technical rule for gas installations], DVGW (2018)) of the German Technical and Scientific Association for Gas and Water (DVGW), a leakage rate of 0-1 l/h has no affect on an installation's functionality. When a leak test shows that an installation is leaking a rate higher than that figure, the installation has to be repaired within the short term. National experts thus consider a value of 2 m^3/year to be suitable.

The emissions are calculated in keeping with the Tier 2 method.

3.3.2.2.6.3 Uncertainties and time-series consistency (1.B.2.b.v)

For the emissions data, the category uncertainties are given as 20 %. Those figures are based on estimates of experts, and they lie within the range listed for relevant default emission factors (Penman et al. (2000), Chapter 2.7.1.6.).

3.3.2.2.6.4 Source-specific quality assurance / control and verification (1.B.2.b.v)

General and category specific quality control and a quality assurance have been carried out by the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents. The additional quality control and quality assurance were conducted by an external contractor (Grosse, 2021).

Betzenbichler et al. (2016b) compared the results for this category with other countries' corresponding results. This comparison yielded considerable differences between Germany's results and those of neighbouring countries. While a number of countries have emissions in this category, other countries' results are, on average, two orders of magnitude smaller than the

[52] Average factor with respect to natural gas loss per number of gas meters in residences

German results. While the 2006 IPCC Guidelines provide no method description for this category, their Table 4.2.8 presents a range for the expected emissions.

Table 158: Comparison of IEF with the relevant IPCC default values

System or mechanism	CS emission factor	2006 IPCC GL – Table 4.2.8
Losses at the point of use	2 m³/No.[53]	2 to 20 m³/No.

3.3.2.3 Venting and flaring (1.B.2.c)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	1 B 2 c, Venting and Flaring		CO_2	543.5	0.0%	321.3	0.0%	-40.9%
-/-	1 B 2 c, Venting and Flaring		N_2O	2.0	0.0%	0.7	0.0%	-66.2%
-/-	1 B 2 c, Venting and Flaring		CH_4	1.6	0.0%	0.5	0.0%	-67.0%

The categories in the overarching group of fugitive emissions from 1.B.2.c "Venting and flaring" cover greenhouse-gas and air-pollutant emissions either vented or flared directly into the atmosphere. The emissions from venting processes are included in the category 1.B.2.a.iv for oil, and in categories 1.B.2.b.iii and 1.B.2.b.iv for natural gas.

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	AS	CS
CH_4	Tier 2	AS	CS
N_2O	Tier 2	AS	CS
NMVOC	Tier 2	AS	CS

The category 1.B.2.c "Venting and flaring" is not a key category.

3.3.2.3.1.1 Category description, "Venting and flaring" (1.B.2.c)

Pursuant to general requirements of the Technical Instructions on Air Quality Control TA Luft (2002), gases, steam, hydrogen and hydrogen sulphide released from pressure valves and venting equipment must be collected in a gas-collection system. Wherever possible, gases so collected are burned in process combustion. Where such use is not possible, the gases are piped to a flare. Flares used for flaring of such gases must fulfill at least the requirements for flares for combustion of gases from operational disruptions and from safety valves. For refineries and other types of plants in categories 1.B.2, flares are indispensable safety components. In crude-oil refining, excessive pressures can build up in process systems, for various reasons. Such excessive pressures have to be reduced via safety valves, to prevent tanks and pipelines from bursting. Safety valves release relevant products into pipelines that lead to flares. Flares carry out controlled burning of gases released via excessive pressures. When in place, flare-gas recovery systems liquify the majority of such gases and return them to refining processes or to refinery combustion systems. In the process, more than 99 % of the hydrocarbons in the gases are converted to CO_2 and H_2O. When a plant has such systems are in operation, therefore, its flarehead will seldom show more than a small pilot flame.

Activity data

Table 159: Refined crude-oil quantity, in millions of t.

1990	1995	2000	2005	2010	2015	2018	2019	2020
107	96	108	115	95	93	87.7	87.0	84.0

(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2020a)(MWV, 2021a)

[53] It was not possible to include the emission factor for industry emissions within the comparison, since the relevant units cannot be converted.

Table 160: Flared natural gas, in millions of m³

1990	1995	2000	2005	2010	2015	2018	2019	2020
36	33	36	19	12	10	11	16	14

(BVEG, 2021a)

Emission factors

Flaring takes place at extraction and pumping systems and in refineries. In refineries, flaring operations are subdivided into regular operations and start-up / shut-down operations in connection with disruptions.

Table 161: Emission factors used for category 1.B.2.c, "Flaring emissions in natural gas extraction"

Gas	Value	Method	Source
CO_2	1.777 kg/m³	Tier 2	Expert estimate
NO	$2*10^{-8}$ kg/m³	Tier 1	IPCC default value

Table 162: Emission factors used for category 1.B.2.c, "Flaring emissions at petroleum production facilities"

Gas	Value	Method	Source
CO_2	9.1 kg/t	Tier 2	Expert estimate
N_2O	0.55 g/t	Tier 1	IPCC default value

Methane and NMVOC emissions are included under production. Pursuant to the Federal association of the natural gas, oil and geothermal energy industries (BVEG), the pertinent nitrous oxide emissions are extremely insignificant. A pertinent study reached the same conclusion (Theloke, 2013). In the interest of maintaining a conservative approach, the IPCC default value has been used in the relevant calculation.

Table 163: Emission factors used for category 1.B.2.c "Flaring emissions at refineries: normal flaring operations"

Gas	Value	Method	Source
CH_4	0.225 g/t	Tier 2	Expert estimate
CO_2	2.60 kg/t	Tier 2	Expert estimate
N_2O	0.03 g/t	Tier 2	Expert estimate
CO	0.76 g/t	Tier 2	Expert estimate
NMVOC	4.14 g/t	Tier 2	Expert estimate
SO_2	3.28 g/t	Tier 2	Expert estimate
NO_x (as NO_2)	0.49 g/t	Tier 2	Expert estimate

Table 164: Emission factors used for category 1.B.2.c "Flaring emissions at refineries: disruptions of flaring operations"

Gas	Value	Method	Source
CH_4	0.095 g/t	Tier 2	Expert estimate
CO_2	1.47 kg/t	Tier 2	Expert estimate
N_2O	0.3 mg/t	Tier 2	Expert estimate
CO	0.71 g/t	Tier 2	Expert estimate
NMVOC	0.73 g/t	Tier 2	Expert estimate
SO_2	7.48 g/t	Tier 2	Expert estimate
NO_x (as NO_2)	4.18 g/t	Tier 2	Expert estimate

The emission factors have been derived from the 2004 and 2008 emissions declarations (Theloke et al., 2013). In 2019, they were updated for CH_4, N_2O, CO, NMVOC, NO_x and SO_2, on the basis of Bender and von Müller (2019).

Emissions and trend

Table 165: Emissions in category 1.B.2.c "Venting and flaring"

Gas	Total emissions			Trend		Remark
	1990	2019	2020	Since 1990	With respect to the previous year	
Methane	66 t	24 t	23 t	- 64 %	- 1 %	Emissions from flaring systems have decreased continuously as a result of improvements in gas-recovery methods.
Carbon dioxide	544 kt	345 kt	321 kt	-41 %	-7 %	
NMVOC	522 t	359 t	334 t	-36 %	- 7 %	The air-pollution emissions of the exploration and production industry are determined in keeping with a procedure accepted throughout the industry[54]. For this reason, the annual emissions figures vary somewhat from year to year and do not yield a straight line.
Nitrous oxide	6.5 t	2.5 t	2.3 t	- 65 %	- %	

3.3.2.3.1.2 Methodological aspects of the category "Venting and flaring" (1.B.2.c)

Venting emissions are taken into account in category 1.B.2.b.iii. The SO_2 emissions are obtained from the activity data for the flared natural gas (Table 160) and an emission factor of 0.140 kg / 1,000 m^3, a factor which takes account of an average H_2S content of 5 % by volume.

The emission factors are determined on the basis of emissions reports, crude-oil-refining capacity and total capacity utilisation at German refineries. The guide for this work consists of the evaluation assessment of Theloke et al. (2013).

The emissions are calculated in keeping with the Tier 2 method.

3.3.2.3.1.3 Uncertainties and time-series consistency for the category "Venting and flaring" (1.B.2.c)

The quantitative uncertainties for the emission factors for flaring processes during normal operations are assumed to be +/-10 % (95 % confidence interval, normal distribution). The uncertainties for the activity data are assumed to be +/- 5 % (95 % confidence interval, normal distribution).

The uncertainties for the emission factors for disruption-related flaring processes (operations during disruptions; start-up / shut-down operations) are much larger, since the emissions quantities can vary widely from year to year. They are estimated to be -90 % / +300 % (95% confidence interval, log-normal distribution). The uncertainties for the activity data are assumed to be +/- 5 % (95 % confidence interval, normal distribution) (Theloke et al., 2013).

3.3.2.3.1.4 Category-specific quality assurance / control and verification, category "Venting and flaring" (1.B.2.c)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

A comparison of the category with the IPCC Guidelines reveals considerable differences in individual factors. At the EU Workshop held in Dessau (cf. Harthan et al. (2017)), the

[54] WEG: "Leitfaden zu Erfassung der Umweltdaten der WEG Mitgliedsfirmen", published in-house, and last revised in Dec. 2016

participating experts agreed that the default values are considerably higher than the emission factors currently used in Europe.

Table 166: Comparison of IEF with the relevant IPCC default values

Gas and system	CS emission factor used[55]	IPCC GL 2006 (Table 4.2.4)	
	Units in [g/m³]	Units in [Gg/1000m³]	Units in [g/m³]
CO_2 in refinery flares	3,503	$3.4*10^{-02}$	34,000
CH_4 in refinery flares	0.27	$2.1*10^{-05}$	21
NMVOC in refinery flares	4.86	$1.7*10^{-05}$	17
CO_2 in oil production systems	7.759	$4.1*10^{-02}$	41,000
CO_2 in natural gas production systems	1532	$1.2*10^{-03}$	1,200

3.3.2.4 Geothermal energy (1.B.2.d)

3.3.2.4.1 Category description (1.B.2.d)

The category 1.B.2.d "Geothermal energy" is not a key category.

Geothermal energy is a renewable form of energy. Geothermal energy systems that tap geothermal heat to a depth of 400 metres are classified as "near-surface" geothermal energy systems. Near-surface geothermal systems generate heating and cooling energy by means of heat pumps. They are also used for heating service water. Geothermal energy systems that tap geothermal heat at depths greater than 400 metres are classified as "deep" geothermal energy systems. Geothermal heating stations use the heat in their thermal-water flows directly, and provide heating and cooling to end consumers, via district heating and cooling networks. Geothermal power stations convert the heat in their thermal-water flows into electricity. In most cases, they produce heat as well, via processes for combined heat/power (CHP) production.

As of the end of 2020, a total of 42 deep geothermal power stations were in operation. In sum, they have an electrical output of 47 MW and a thermal output of 350 MW.

Operation of geothermal power stations and heat stations in Germany produces no emissions of climate-relevant gases. The thermal-water circuits of such installations are closed and airtight, both above and below ground level. As a result, no emissions occur during their operation. Even a release of the gases dissolved in the heat-carrying fluid – primarily, H_2, CH_4, CO_2 and H_2S – would not lead to concentrations worthy of reporting (cf. Kaltschmitt (2007): Chapter A.2.3.5). For this reason, the emissions are reported as "NE". In the report year, all geothermal energy systems met their own power requirements (primarily power for operating pumps) by drawing electricity from the grid. In the report, that use is listed in the relevant categories.

3.3.2.4.2 Methodological issues (1.B.2.d)

The IPCC Reference Manual does not describe any methods for category 1.B.2.d "Other" (IPCC et al. (1997): Volume 3, p. 1.132f)

No emission factors for greenhouse gases and pollutants that could escape in connection with drilling for tapping of geothermal energy (both near-surface and deep energy) are known for Germany at present. In drilling operations, even those not oriented to hydrocarbon exploration, releases of gases trapped underground – including climate-relevant gases – must always be expected (cf. Kaltschmitt (2007): Chapter A.2.1.5). In drilling operations for near-surface geothermal energy, as in drilling of wells for drinking water, only low emissions levels are normally encountered, due to the low gas concentrations found near the surface. In the interest

[55] For refineries, determined as a mean value between normal operation and operation during disruptions

of preventing gas releases, drilling of deep geothermal wells is subject to the same safety regulations that apply to hydrocarbon exploration, including obligations to use Christmas trees and blowout preventers, to prevent accidents. Theloke et al. (2013) estimates that the fugitive emissions related to deep geothermal wells are on the order of kilograms. The emissions in this category are reported as NE, therefore, because their contribution to the total emissions is less than 0.05 % of the overall inventory or 500 kt CO_2 equivalents (pursuant to FCCC/SBSTA/2013/L.29/Add.1), and since it cannot be assured that annual inventories of such emissions (pursuant to FCCC/SBSTA/2013/L.29/Add.1, para 37) will be carried out. In Chapter 5, the pertinent emissions contribution to the overall inventory is presented (on a one-time basis). A compilation of all sources for which the entry "not estimated" is retained is presented in Annex 5 (Chapter 21).

3.3.2.4.3 Uncertainties and time-series consistency (1.B.2.d)

No explanations of uncertainties and time-series consistency are required.

3.3.2.4.4 Category-specific quality assurance / control and verification (1.B.2.d)

No explanations relative to source-specific quality assurance / control and verification are required.

3.3.2.5 Category-specific recalculations (1.B.2 all)

The figures for the past two years have been recalculated, because some of the statistics on which they had been based were provisional. This work led to the following inventory improvements, entailing marginal recalculations. In addition, the 2022 report includes, for the first time in such reports, emissions from refuelling of motorboats from canisters. In addition, the category "Storage of petroleum products" has been divided, in keeping with the IPCC Guidelines, into the categories "Storage of fuels" (1.B.2) and "Storage of chemical products" (2.B.10).

Table 167: Recalculations in category 1.B.2 – NMVOC emissions, in kt

	1990	1995	2000	2005	2010	2015	2019
2021 Submission	183.5	124.6	84.9	54.2	44.3	40.6	39.9
2022 Submission	175.4	116.3	75.3	45.0	35.7	32.2	31.6
Difference, 1.B.2	8.038	8.394	9.644	9.183	8.653	8.337	8.30
Emissions allocated to 2.B.10	8.1	8.4	9.7	9.2	8.7	8.4	8.4
Difference, 1.B.2, taking account of the reallocation to 2.B.10	-0.055	-0.056	-0.056	-0.056	-0.055	-0.056	-0.06

Table 168: Recalculations in category 1.B.2 – methane emissions, in kt

	1990	1995	2000	2005	2010	2015	2019
2020 Submission	332	345	251	219	196	194	195
2021 Submission	330	343	249	216	194	191	193
Difference	2.380	2.468	2.806	2.635	2.473	2.377	2.44

Table 169: Recalculations in category 1.B.2 – carbon dioxide emissions, in kt

	1990	1995	2000	2005	2010	2015	2019
2021 Submission	2,008	2,127	2,213	2,212	1,898	1,672	1,343
2022 Submission	2,008	2,127	2,213	2,212	1,898	1,672	1342
Difference	0.00	0.00	0.00	0.00	0.00	0.00	0.15

3.3.2.6 Planned improvements, category-specific (1.B.2 all)

At present, several measurement campaigns are underway in Germany for the purpose of determining emission factors for pipelines for natural gas transport (2020 FNB methane measurement programme) and distribution ((DVGW, 2020); (Maazallahi, 2020). These measurements are oriented to the guidelines of the "Oil and Gas Methane Partnership (OGMP)" created by the Climate and Clean Air Coalition (CCAC) and the United Nations Environmental Programme (UNEP).

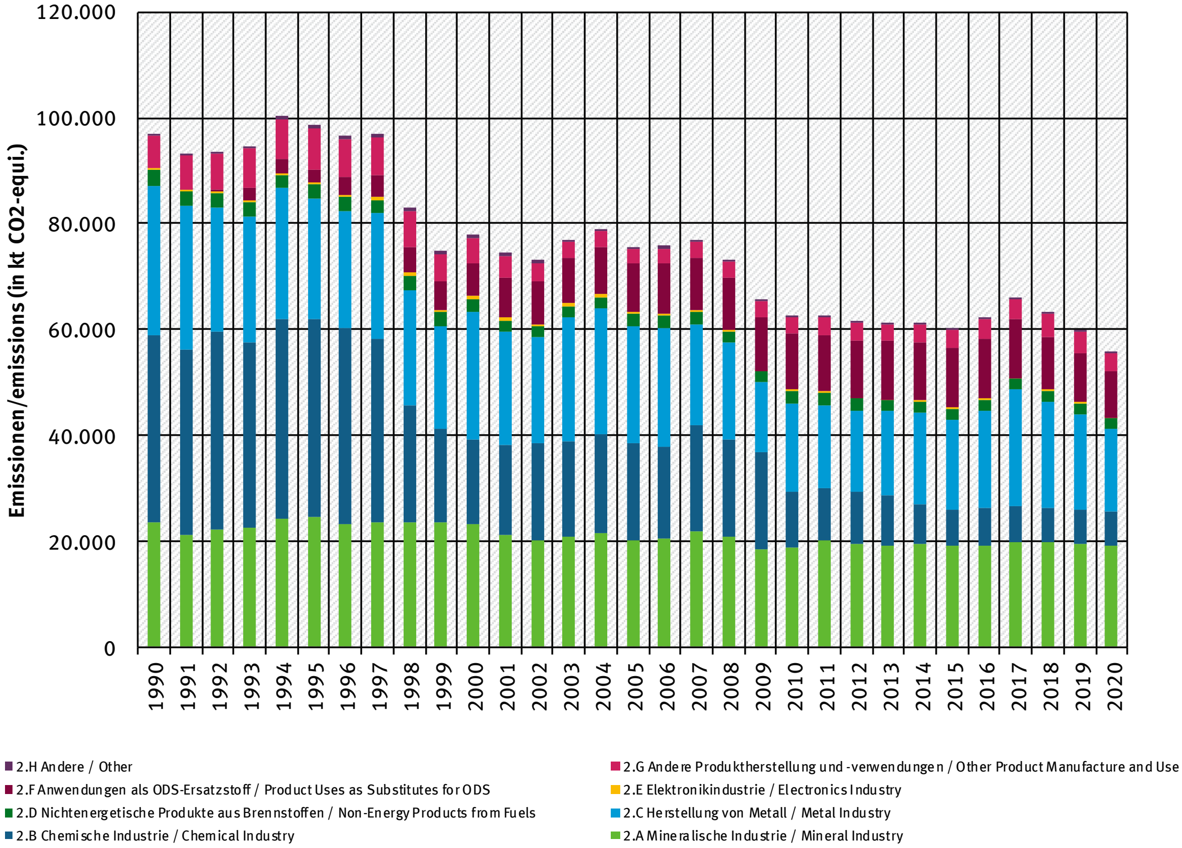
FNB Gas already has initial data that indicate that the present inventory considerably overestimates the emissions (FNB Gas, 2021). In particular, the inventory's data for sliding sleeve hubs and gas compressor stations are seen to differ from the actual data by a factor of 3. Plans call for integrating the findings from these campaigns, once they have been completed, within the inventory.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4 Industrial processes (CRF Sector 2)

4.1 Overview (CRF Sector 2)

Figure 40: Overview of greenhouse-gas emissions in CRF Sector 2



4.2 Mineral industry (2.A)

The CRF category 2.A Mineral industry is divided into sub-categories 2.A.1 through 2.A.4. These categories include:

- cement clinker production (2.A.1, Chapter 4.2.1),
- lime burning (2.A.2, Chapter 4.2.2),
- glass production (2.A.3, Chapter 4.2.3)
- ceramics production (2.A.4.a, Chapter 4.2.4.1),
- other soda ash use (2.A.4.b, Chapter 4.2.4.2),
- production of non-metallurgic magnesium products (2.A.4.c, Chapter 4.2.4.3)
- other limestone and dolomite use (2.A.4.d, Chapter 4.2.4.4).

4.2.1 Mineral industry: Cement production (2.A.1)

4.2.1.1 Category description (2.A.1)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	2 A 1, Cement Production		CO_2	15,297.3	1.2%	13,357.5	1.9%	-12.7%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	AS	CS
NO_X, SO_2	Tier 1	AS	CS

The category *Cement production* is a key category for CO_2 emissions in terms of emissions level and trend. The remarks below refer only to production of cement clinkers, because clinker grinding is not relevant as a dust source in the present context. In Table 170, cement production is included solely for reference purposes, without emissions relevance in this context.

The clinker-burning process emits climate-relevant gases. CO_2 accounts for the great majority of these emissions. The CO_2 emissions from pertinent raw materials are tied directly to the quantities of cement clinkers that are produced. Pursuant to the German Emissions Trading Authority (DEhSt, 2021), clinker production in 2020 amounted to 24,709 kt.. Raw-material-related CO_2 emissions are calculated from plant-specific data, and taking account of discharged bypass dust, with a country-specific emission factor, as determined by the *German Cement Works Association (VDZ)*, of 0.53 t CO_2 / t cement clinker. On this basis, clinker production is seen to have produced raw-material-related CO_2 emissions of 13,357 kt CO_2 in 2020.

Table 170: Production and raw-material-related CO_2 emissions in the German cement industry

Year	Clinker production + discharged bypass dust[56] [kt/a]	Emission factor [t CO_2/t]	Raw-material-related CO_2 emissions [kt/a]	Cement production (kt/a)
1990	28,863	0.53	15,297	37,772
1991	25,927	0.53	13,741	34,341
1992	27,253	0.53	14,444	37,331
1993	27,417	0.53	14,531	36,649
1994	28,945	0.53	15,341	40,512
1995	29,363	0.53	15,562	35,862
1996	27,945	0.53	14,811	34,318
1997	28,821	0.53	15,275	34,148
1998	29,329	0.53	15545	35,601
1999	29,757	0.53	15,771	37,438
2000	28,779	0.53	15,253	35,414
2001	25,479	0.53	13,504	32,118
2002	24,194	0.53	12,823	31,009
2003	25,485	0.53	13,507	32,749
2004	26,544	0.53	14,068	31,854
2005	24,622	0.53	13,050	31,009
2006	25,170	0.53	13,340	33,630
2007	27,262	0.53	14,449	33,382
2008	25,620	0.53	13,579	33,581
2009	23,696	0.53	12,559	30,441

[56] The bypass-dust quantity is calculated via an expert assessment, oriented to actual clinker production, and applying the following assumptions: 1 % for the years 1990-2008; 2 % as of 2009.

Year	Clinker production + discharged bypass dust[56] [kt/a]	Emission factor [t CO_2/t]	Raw-material-related CO_2 emissions [kt/a]	Cement production (kt/a)
2010	23,456	0.53	12,431	29,915
2011	25,270	0.53	13,393	33,540
2012	25,073	0.53	13,289	32,432
2013	23,591	0.53	12,503	31,308
2014	24,348	0.53	12,905	32,099
2015	23,822	0.53	12,626	31,160
2016	23,892	0.53	12,663	32,674
2017	25,298	0.53	13,408	33,991
2018	24,958	0.53	13,228	33,655
2019	25,069	0.53	13,287	34,186
2020	25,203	0.53	13,357	35,485

Source: Own calculations, derived from BDZ (2005) for the period through 1994; from VDZ (2016), for the period as of 1995; and from DEHSt (2016), DEHSt (2017), DEHSt (2018), DEHSt (2019), DEhSt (2020) and (DEhSt, 2021) for the period as of 2015.

4.2.1.2 Methodological issues (2.A.1)

Activity data

Activity data are determined via summation of figures for individual plants (until 1994, activity data were determined on the basis of data of the BDZ German cement-industry association). As of 1995, following optimisation of data collection within the association, activity data were compiled by the VDZ, and by its cement-industry research institute (located in Düsseldorf), via surveys of German cement works and use of BDZ figures. In the main, the data consist of data published in the framework of CO_2 monitoring, supplemented with data for plants that are not BDZ members (in part, also VDZ estimates). This corresponds to the Tier 2 approach of the IPCC Guidelines (IPCC (2006a): Volume 3, Chapter 2.2.1.1).

For internal reasons, the VDZ association was unable to provide the data for the years as of 2015. As a result, the cement-clinker figures are based on aggregated, plant-specific data of the DEHSt. A comparison covering the previous years 2005-2014 showed that the DEHSt's relevant emissions-trading figures and the VDZ's data on cement-clinker production differed by a constant percentage of about 1 %, meaning that a high degree of agreement between the two data sets may be assumed. In general, completeness is thus assured if one of the two data sets is used.

According to the VDZ, the applicable fraction of bypass dust, with respect to clinker production in the years 2009 through 2016, ranged between 1 and 2 %. The VDZ is unable to provide suitably quality-assured data annually on this dust fraction, and is unlikely to be able to do so in the future. For this reason, in calculations, a conservative approach is taken whereby a 2 % bypass-dust fraction is assumed since the year 2009. This approach is in accordance with the IPCC Guidelines (IPCC, 2006a). No detailed information on the applicable fraction of bypass dust is available for the years prior to 2009. In a conservative approach, it is assumed to have been a constant 1 % in the years 1990 through 2008.

Table 170 presents the activity data for cement clinkers, including the factors discharged bypass dust and cement.

Emission factors

The emission factor used for emissions calculation, 0.53 t CO_2 / t cement clinkers, is based on mass-weighted figures for individual plants, i.e. the VDZ determined the emission factor by aggregating plant-specific data relative to fractions of CaO and other metal oxides (MgO; in raw materials, and containing carbonate) in clinkers. The emission factor was determined in the framework of a research project, and it was confirmed by the VDZ in subsequent years. The procedure is in keeping with the Tier 2 method given in the IPCC Guidelines (IPCC (2006a): Volume 3, Chapter 2.2.1.2).

In the German cement industry, dust separated from furnace exhaust gas is returned to the burning process. As a result, carbonate release from clinker raw materials can be determined directly from clinkers' metal-oxide content, without any need to take account of significant losses via the exhaust-gas pathway. In addition, the dust discharged via the bypass pathway is taken into account, for the entire time series, in determination of raw-material-related CO_2 emissions.

The emission factor of 0.53 t CO_2 / t cement clinkers was applied to the entire time series. Applying the conservative assumption that the bypass dust in question is completely deacidified, the same emission factor is used for this substance flow.

Raw-material-related CO_2 emissions in the cement industry are determined, in accordance with the *IPCC Guidelines* ((IPCC, 2006a): Volume 3, Equation 2.2, in conjunction with Equation 2.5), via the following equation:

$$CO_2 \text{ emissions} = \text{emission factor } (EF_{clinkers}) \text{ x clinker production} + \text{emission factor } (EF_{clinkers}) \text{ x bypass dust (\%) x clinker production}$$

Table 170 shows the raw-material-related CO_2 emissions of the German cement industry, as determined with inclusion of bypass-dust discharge from clinker production, for the years covered by the report.

4.2.1.3 Uncertainties and time-series consistency (2.A.1)

For the activity data, time-series consistency is assured via the association's long history of data collection. For the years as of 2015, it is assured in that emissions-trading data has been proven, via excellent data agreement in previous years, to be a suitable alternative. For the emission factor, it is assured in that a consistent approach has been used for all years concerned.

The uncertainties given were determined via expert assessment.

Most companies are required to report clinker-production data within the framework of CO_2-emissions trading. The EU monitoring guidelines for emissions trading specify a maximum accuracy of 2.5 %. The uncertainties for the activity data used were thus estimated at -2.5 % and +2.5 %.

The uncertainty for the emission factor used was estimated at +/- 2 %. This was confirmed via surveys in the framework of a research project (Ruppert et al., 2009).

4.2.1.4 Source-specific quality assurance / control and verification (2.A.1)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

For purposes of quality assurance, all data used, including data from the BDZ, from the VDZ and from emissions trading, and comparative data from the literature, were checked for plausibility. During the inventory review (ICR 2016), materials of the VDZ were used to demonstrate that QSE-conformal procedures are being used. Those materials were accepted by the review team as proof. The emission factor determined for raw-material-related CO_2 emissions has been compared with the relevant figures of other countries. The small deviation (about 1 %) from the

IPCC Tier 1 default factor, 0.52 t CO_2 / t clinkers ((IPCC, 2006a): Volume 3, Equation 2.4), results from the higher lime content found in some German clinkers.

The emission factor used differs only slightly (1 %) from the average emission factors used in connection with the ETS in Germany, emission factors that are checked by authorities and reviewed in light of companies' obligations to provide records. To date, no calculations relative to the emission factor prior to the year 2000 are available. The same figure – the result of an expert assessment – has been used for all relevant years in that period.

4.2.1.5 Category-specific recalculations (2.A.1)

No recalculations are required.

4.2.1.6 Category-specific planned improvements (2.A.1)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.2.2 Mineral industry: Lime production (2.A.2)

4.2.2.1 Category description (2.A.2)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	2 A 2, Lime Production		CO_2	5,986.6	0.5%	4,180.9	0.6%	-30.2%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	AS	D
NO_X, SO_2	Tier 1	AS	CS

The category *Lime production* is a key category for CO_2 emissions in terms of emissions level and trend.

The statements made below regarding category 2.A.2 refer solely to the amounts of burnt lime and dolomite lime produced in German lime works. Additional relevant lime kilns, in addition to the lime-burning facilities covered by this chapter, have been identified in the iron and steel industry and sugar industry sectors. Those facilities are covered not in the present chapter, but in the sections for the relevant categories, 2.C.1 (Chapter 4.4.1) and 2.H.2 (Chapter 4.9.2). Information on other limestone-using sectors is provided in Chapter 4.2.4.4 (CRF 2.A.4d).

In 2020, about 8 % less burnt lime, and about 10 % less dolomite lime, was produced than was produced in the previous year.

Table 171: Production and CO_2 emissions in the German lime industry

Year	Lime		Dolomite lime	
	Production [Millions of t]	CO_2 emissions [Millions of t]	Production [Millions of t]	CO_2 emissions [Millions of t]
1990	7.324	5.463	0.603	0.523
1991	6.475	4.830	0.605	0.525
1992	6.563	4.896	0.587	0.509
1993	6.853	5.112	0.527	0.457
1994	7.512	5.604	0.516	0.447

Year	Lime		Dolomite lime	
	Production [Millions of t]	CO_2 emissions [Millions of t]	Production [Millions of t]	CO_2 emissions [Millions of t]
1995	7.611	5.678	0.556	0.482
1996	7.019	5.236	0.556	0.482
1997	7.115	5.308	0.542	0.470
1998	6.799	5.072	0.570	0.494
1999	6.815	5.084	0.491	0.425
2000	6.994	5.217	0.536	0.465
2001	6.665	4.972	0.523	0.453
2002	6.591	4.917	0.527	0.457
2003	6.732	5.022	0.446	0.386
2004	6.693	4.993	0.469	0.407
2005	6.535	4.875	0.474	0.411
2006	6.646	4.958	0.472	0.409
2007	6.874	5.128	0.469	0.406
2008	6.868	5.124	0.464	0.402
2009	5.501	4.104	0.342	0.296
2010	6.124	4.569	0.342	0.296
2011	6.331	4.723	0.350	0.304
2012	6.036	4.503	0.242	0.210
2013	6.190	4.618	0.218	0.189
2014	6.397	4.772	0.228	0.197
2015	6.247	4.660	0.248	0.215
2016	6.212	4.634	0.232	0.201
2017	6.120	4.566	0.241	0.209
2018	6.200	4.625	0.238	0.206
2019	5.833	4.352	0.228	0.198
2020	5.367	4.004	0.204	0.177

Source: Production: Basic data from (BVKalk, 2021); supplemented by UBA

Because the applicable emission factor in this category is constant, CO_2 emissions and lime / dolomite-lime production depend linearly on each other; as a result, the above statements regarding activity data apply to CO_2 emissions mutatis mutandis.

4.2.2.2 Methodological issues (2.A.2)

In burning of limestone and dolomite, CO_2 is released, and it reaches the atmosphere via the exhaust gas of the process. The pertinent emissions level is obtained by multiplying the amount of product in question (lime or dolomite lime) by the relevant emission factor. Use of the emission factors explained below, together with country-specifically determined lime-production figures, is a Tier 2 method within the meaning of the *2006 IPCC Guidelines* (IPCC (2006a): Volume 3, Chapter 2.3.1.1).

Emission factors

The pertinent CO_2 emissions are calculated with the following factors:

EF_{lime} 0.746 t CO_2/t lime (stoichiometric 0.785 * oxide fraction 0.95)
$EF_{dolomite\ lime}$ 0.867 t CO_2/t dolomite lime (stoichiometric 0.913 * oxide fraction 0.95)

The emission factors used are based on the stoichiometric factors, as well as on the assumption that 95 % of the burnt lime consists of CaO, that 95 % of the dolomite lime consists of CaO • MgO and thus that 5 % of the total mass consists of impurities that are not CO_2-relevant. This approach is in accordance with the *2006 IPCC Guidelines* (IPCC (2006a): Volume 3, Chapter 2.3.1.2).

Activity data

The German Lime Association (BVK) collects the production data for the entire time series, on a plant-specific basis, and makes them available for reporting purposes. The quantities produced by plants that are not included in the German Lime Association's association statistics are estimated on the basis of existing information (such as operator figures, and data published in the framework of emissions trading) and then added to the German Lime Association's figures. This ensures that all of German lime production is taken into account. Ever since the relevant method was changed to conform with the 2006 IPCC Guidelines, it is also being assumed that, in all years of the reporting period as of 1990, 2 % of the burnt lime is being separated out as dust, via suitable waste-gas-scrubbing systems, and is not being returned to the burning process. This is taken into account via a fictive 2 % increase in the pertinent activity data. The 2 % increase has no longer been applied since 2015, however, because since that year the activity data provided by the BV Kalk German lime-industry association have included the quantities of dust that are filtered out.

On an annual basis, the Federal Environment Agency supplements the activity data provided by the BV Kalk German lime-industry association with data from a smaller reference work that is not surveyed by the association. The estimates given by that work have normally been based on allocation-quantity figures in the relevant operator holding account in the German Emissions Trading Authority (DEHSt) framework. Since 2013, the actual CO_2 emissions listed in the operator holding account covered by that work have been published. They lie below the allocated quantity. It is now possible to access the operator holding account's data on actual CO_2 emissions at the time the data are collected.

The manner in which the activity data are determined conforms with the Tier 2 approach of the *2006 IPCC Guidelines* (IPCC (2006a): Volume 3, Chapter 2.3.1.3).

4.2.2.3 Uncertainties and time-series consistency (2.A.2)

The EU monitoring guidelines for emissions trading call for activity data to have an accuracy of 2.5 %. Since a) the German Lime Association's (BV Kalk's) lime-production data are based on operators' figures as provided in the framework of CO_2-emissions trading, b) those data have been obtained via two separate, parallel channels and thus are quality-assured, and c) the plants not included in the association's statistics (and thus assessed after the fact) represent only a small share of the total number of plants concerned, the **uncertainties** for the **activity data** used are estimated to be 2.5 % and +2.5 %. These figures apply to both burnt lime and dolomite lime.

The uncertainties for the emission factors used for burnt lime were estimated at -11 % and +5 %. The uncertainties for the emission factors used for dolomite lime were estimated at -30 % and +2 %.

4.2.2.4 Source-specific quality assurance / control and verification (2.A.2)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The BV Kalk German lime-industry association determines the production quantities by carrying out two surveys within the association. These surveys, of which one has a technical focus and one has a commercial focus, query the individual plants within the association, and they are cross-checked against each other. Any plant-specific discrepancies between the two surveys are clarified before the activity data are forwarded to the Federal Environment Agency (UBA). The activity data provided to UBA thus undergo adequate quality assurance (Tier 2).

The comparison with the available information from the ETS yielded discrepancies that can be explained as the result of differences in methods: on the one hand, as differences between the specifications in the ETS and on the part of the IPCC, and, on the other, as the result of methodological changes made between ETS trading periods. During the inventory review (ICR 2016), graphic comparisons were successfully used to show that the discrepancies, which are of methodological origin, provide no grounds to doubt the quality of the inventories' data.

The IPCC default factors used are suitable for the country-specific method.

The comparison with the emissions-trading figures for process-related emissions showed good agreement.

4.2.2.5 Category-specific recalculations (2.A.2)

No recalculations are required.

4.2.2.6 Category-specific planned improvements (2.A.2)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.2.3 Mineral industry: Glass production (2.A.3)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 A 3, Glass Production		CO_2	780.5	0.1%	857.3	0.1%	9.8%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	AS	CS
NO_X, NMVOC, SO_2	Tier 2	AS	CS

The category *Mineral products*: *Glass production* is not a key category.

4.2.3.1 Category description (2.A.3 Glass production)

Germany's glass industry produces a wide range of different glass types with different chemical compositions. Germany's glass sector comprises the following sub-sectors: container glass, flat glass, domestic glass, special glass and mineral fibres (glass and stone wool). The sub-sectors with the highest production shares are container glass (accounting for about half of total glass production) and flat glass (about one-fourth of total glass production) (BV Glas, 2021). The inventory calculations do not include the category "water-glass production". All relevant soda-ash quantities for water-glass production are taken into account in 2.A.4.b (Chapter 4.3.7).

In production, homogeneous glass mixtures combining primary and secondary raw materials are melted down at temperatures between 1,450 °C and 1,650 °C. The process-related CO_2 emissions under consideration here are released from the raw-material carbonates during the melting process in the furnace. CO_2 emissions – in small amounts – also occur in neutralisation of HF, HCl and SO_2 in exhaust gases, with the help of limestone or other carbonates. Because the amounts involved are so small, these emissions are not considered here.

The following table shows the trends, since 1990, in activity data, process-related CO_2 emissions and the implied emission factors resulting for all glass types overall.

Table 172: Activity data and process-related CO_2 emissions since 1990; IEF covering all glass types

Year	Activity data [t]	Process-related CO_2 emissions [t]	IEF for all glass types [t CO_2 / t glass]
1990	6,561,849	780,480	0.119
1991	7,202,807	821,376	0.114
1992	7,228,752	810,610	0.112
1993	7,074,837	778,104	0.110
1994	7,760,000	747,225	0.096
1995	7,621,300	881,306	0.116
1996	7,519,600	853,395	0.113
1997	7,392,000	833,771	0.113
1998	7,314,000	803,411	0.110
1999	7,442,239	822,236	0.110
2000	7,505,000	846,300	0.113
2001	7,293,000	846,289	0.116
2002	7,084,000	800,501	0.113
2003	7,205,720	788,726	0.109
2004	7,088,900	791,150	0.112
2005	6,948,400	802,746	0.116
2006	7,285,600	842,228	0.116
2007	7,535,300	829,060	0.110
2008	7,513,900	824,868	0.110
2009	6,784,100	745,664	0.110
2010	7,163,600	828,828	0.116
2011	7,341,600	835,138	0.114
2012	7,079,700	823,341	0.116
2013	7,255,900	860,111	0.119
2014	7,458,900	891,901	0.120
2015	7,397,900	916,423	0.124
2016	7,476,817	923,498	0.124
2017	7,552,202	882,713	0.117
2018	7,607,725	898,409	0.118
2019	7,377,607	866,171	0.117
2020	7,356,100	857,264	0.117

It is clear that emissions tend to follow the trend in activity data. At the same time, the implied emission factors indicate that the correlation is not rigid; some discrepancies do occur. The discrepancies are due to annual fluctuations in production quantities of various individual glass types, and in cullet inputs. They are thus logical and calculatorily correct. The IEF has been increasing overall, for all types of glass. This is due to absolute and relative increases of products causing higher emissions – especially mineral fibres.

Emissions of "precursor substances," which also occur in connection with glass production, are not discussed in the present context. Due to limitations in the UNFCCC software, they cannot be reported in the present category, however; they are reported in Chapter 4.2.4.4.

4.2.3.2 Methodological issues (2.A.3 Glass production)

The CO_2 emissions (the main pollutant) are calculated via a Tier 2 method, because the detailed activity data are tied to specific emission factors (that are in keeping with the relevant carbonate concentrations). The following carbonates are taken into account as the main sources of CO_2 formation during the melting process: Calcium carbonate ($CaCO_3$), soda ash / sodium carbonate (Na_2CO_3), magnesium carbonate ($MgCO_3$) and barium carbonate ($BaCO_3$). In the present context, the CO_2 emissions from all carbonates are reported as a sum; inputs of raw-materials – soda ash – are considered under 2.A.4.b (cf. 4.2.4.2). Here, it should be noted that the calculated soda-ash-input quantities cannot be published, because data on soda ash production are subject to statistical confidentiality and must not be derivable from balance sheets.

The production figures (**activity data**) are taken from the regularly appearing annual reports of the Federal Association of the German Glass Industry (Bundesverband Glasindustrie). "Production" refers to the amount of glass produced, which is considered to be equivalent to the amount of glass melted down. It must be remembered that a fraction of the molten glass, corresponding to the quantity of internal cullet, is not included in production statistics (see also the remarks below regarding cullet inputs). As a result, the figures given in the statistics correspond not to the actual quantities of molten glass involved, but to the molten-glass quantities consisting of primary raw materials and external cullet. Further processing and treatment of glass and glass objects are not considered.

The following activity data were determined for 2020:

Table 173: Glass: Activity data for the various industry sectors (types of glass)

Industry sector	Activity data, 2020 [t]
Container glass	4,011,120
Flat glass	2,115,694
Glass fibre and wool	378,034
Special glass	355,940
Stone wool	644,501
Domestic glass	46,914

Source: (BV Glas, 2021)

The following sector-specific cullet percentages are assumed:

Table 174: Cullet percentages for the various types of glass

Industry sector	Cullet percentage [%] in the input raw material
Container glass	58 – 65 (annually varying)
Flat glass	10 (entire time series)
Domestic glass	5 (entire time series)
Special glass	5 (entire time series)
Glass fibre and wool	40 (entire time series)
Stone wool	40 (entire time series)

Source: Gitzhofer et al. (2008) and surveys of BV Glas (BV Glas, 2020)

The cullet percentage for container glass is known only for the western German Länder as of 1990. For Germany as a whole, it is known for the period since 1995. No data are available for the new German Länder for the period from 1990 to 1994. For that reason, an average cullet percentage input was estimated on the basis of the various glass sectors' average percentages of total glass production. In 2007, the firm of Gesellschaft für Glasrecycling und Abfallvermeidung mbH (GGA) was forced to cease operations, under cartel law. As a result, no reliable cullet-input data have been available from that source since 2007. Since 2012, the Federal Association of the German Glass Industry (BV Glas) has provided data, from association surveys, on cullet inputs in the container-glass industry for the period as of 2007(BV Glas, 2020). The Association (BV Glas) also, on the basis of member data provided to it, verifies the other cullet fractions that enter into reporting. The various sectors' cullet fractions contain only external cullet, since internal cullet is not included in production statistics, which are the basis for the relevant activity data. An industrial operation's total cullet fractions in its vats can be considerably higher, depending on how much internal cullet is produced in production (for example, in connection with a change of colour).

Since the exhaust gases occurring during the melting process are drawn off together with combustion-related exhaust gases – i.e. as a collective exhaust-gas stream – measurements cannot be used to determine the CO_2 quantities produced by the German glass industry. For this reason, a calculation procedure is used that is based on the weight shares for the aforementioned carbonates and on cullet input in the container-glass and flat-glass industry. Figures on the chemical composition of the various types of glass produced in Germany have been taken from VDI-Richtlinie (guideline) 2578 (VDI, 2017) and from the ATV-DVWK Merkblatt (standards sheet of the German Association for Water, Wastewater and Waste) 374 (ATV, 2004).

The procedure used to determine **emission factors** for the various glass oxides involved and the pertinent emissions is described in detail in the NIR 2007 (Chapter 4.1.7.2, p. 251ff.).

The emission factors below were calculated for the various industry sectors. The factors vary annually in keeping with variations in cullet inputs (ranges are given for container glass).

Table 175: CO_2-emission factors for various glass types (calculated in comparison with figures from the 2006 IPCC Guidelines)

Glass type	Calculated emission factor [kg CO_2/ t $_{molten\ glass}$] – stoichiometric / incl. cullet input –			Default emission factors [kg CO_2/ t $_{molten\ glass}$] - pursuant to 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Tab. 2.6)-		
Container glass	193	/	49 – 86*		210	
Flat glass	208	/	187		210	
Domestic glass	120	/	114		100	
Special glass	113	/	107	30	–	200
Glass fibre	198	/	119	190	–	250
Stone wool	299	/	179		-	
Unspecified	174	/	139		-	

* Most recently, 81 kg CO_2 per t of molten glass

The stoichiometrically calculated emission factors are very similar to the default factors. The emission factors, with inclusion of cullet inputs, are considerably lower than the default values, since cullet inputs tend to be very high in Germany. In the sole exception, this EF relationship does not apply to household and table glassware – possibly, as a result of the high quality requirements involved, which entail low cullet inputs.

4.2.3.3 Uncertainties and time-series consistency (2.A.3 Glass production)

The production data have been taken from the internal statistics of the Federal Association of the German Glass Industry (BV Glas). Since that association represents nearly all of Germany's container-glass and flat-glass manufacturers, the sectoral data it provides are highly accurate. An uncertainty of 5 % was thus assumed. The association's representation of all other glass sectors is incomplete, and thus the association cannot guarantee the completeness of the data for such other sectors. For this reason, an uncertainty of 10 % was assumed for those areas. Until about 2002, BV Glas also cross-checked the data against data of the *Federal Statistical Office*.

The uncertainty in the cullet figures for container glass lies within the customary range for statistical determinations. For the new German Länder, an uncertainty of 20 % has been assumed, because no statistical survey has been carried out; only an estimate is available. Use of data from the association's own internal surveys, relative to cullet use as of 2007, increases the uncertainties. For example, surveys take account only of production sites' internal cullet and external container-glass cullet, and do not cover any quantities of flat glass that may be used in container-glass production.

The figures on cullet use for all other glass types are considerably less precise, however, since only estimates are available for those areas. An uncertainty of 20 % was thus assumed.

For the CO_2 emission factors, an uncertainty of 14 % is used in the case of container glass, and a figure of 22 % is used for all other types of glass.

4.2.3.4 Category-specific quality assurance / control and verification (2.A.3 Glass production)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The calculated emission factors were compared with several different sources, including the IPCC Guidelines (IPCC, 2006a) and the "Baden-Württemberg 2004 emissions declaration" ("Emissionserklärung 2004 Baden-Württemberg"; (UMEG, 2004)), an emission-factor manual. According to that comparison, the calculated emission factors may be considered accurate. In addition, the IEF was compared with those of the following countries, which also report on soda ash use only as an integrated part of glass production, i.e. do not report on it separately: Spain (0.10), Italy (0.10) and Portugal (0.09). These values are comparable to the German IEF for the glass industry (which fluctuates around 0.1).

The calculated emissions were also cross-checked against the ETS data for Germany. This showed that the calculated emissions were about 1.2% lower than the emissions pursuant to ETS. This can be attributed to differences in allocation of materials to process- and energy-related emissions.

The information provided regarding the chemical composition of the various glass types continues to be considered correct in the present context. The applicable rate of cullet input, for which the data still need to be improved (cf. Chapter 4.2.3.3), has considerable influence in this regard.

4.2.3.5 Category-specific recalculations (2.A.3 Glass production)

No recalculations were required.

4.2.3.6 Planned improvements, category-specific (2.A.3 Glass production)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.2.4 Mineral industry: Other process uses of carbonates (2.A.4)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 A 4, Other Process Uses of Carbonates		CO_2	1,458.0	0.1%	647.8	0.1%	-55.6%

The overarching category 2.A.4 – *Mineral products: Other process uses of carbonates* is not a key category. This category's characteristics are determined primarily by the ceramics industry, with regard to both emissions quantities and the relevant methods' level of detail.

4.2.4.1 Mineral industry: Ceramics (2.A.4.a)

4.2.4.1.1 Category description (2.A.4.a Ceramics)

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	NS	CS
NO_X, NMVOC, SO_2	Tier 1	NS	CS

Germany's ceramics industry, like its glass industry, is highly diverse. It produces many different products, with many different chemical compositions, for many different applications. Along with clay (the main raw material involved), sand and other natural raw-material mixtures, the industry also uses synthetically produced substances, such as aluminium oxide and silicon dioxide. The following application areas can be differentiated within Germany's ceramics sector: Structural ceramics (bricks, tiles, drain pipes), structural ceramics (toilet bowls, washbasins), ceramic tableware (dinnerware, household porcelain), technical ceramics (insulators, structural components), fireproof ceramics (furnace walls, refractory concrete), ceramic bonded abrasives and expanded clay (VDI Guideline 2585) (VDI, 2006). The largest production quantities, in terms of percentages, are achieved in the bricks sector (about 80 % of total ceramics production), followed by the fireproof products (about 10 %) and tiles (about 6 %) sectors.

In ceramics production, homogeneous mixtures consisting largely of primary raw materials – and only small quantities of secondary raw materials – are fired, primarily in tunnel kilns and hearth furnaces, at temperatures between 800 and 1,300 °C. The firing durations, which normally amount to several hours (BREF CER 2007)(European Commission, 2007a), can vary, depending on the products involved. Significantly higher firing temperatures are used in connection with refractory products and technical ceramics. The process-related CO_2 emissions under consideration here are released during firing processes in kilns. Emissions are produced from both carbonate and fossil components of raw materials. In some cases, process-related CO_2 emissions are also produced by pore-forming agents (such as sawdust, papermaking sludges and polystyrene), which are used especially in brick production (clay blocks). In determination of CO_2 emission factors, only non-biogenic fractions are taken into account.

The "ceramics products" time series (cf. Table 176) comprise the activity data and process-related CO_2 emissions of the entire ceramics industry in Germany, for the period since 1990[57]. The non-CO_2 emissions (NO_X, NMVOC, SO_2, etc.) for the entire ceramics industry are calculated via these activity data.

Table 176: Activity data and process-related CO_2 emissions in the ceramics industry (CRF 2.A.4.a), since 1990

	Activity data [kt]		Process-related CO_2 emissions [kt][58]
	Total ceramics production	CO_2-relevant ceramics production[58]	
1990	17,691	15,628	1,122
1991	18,401	16,415	1,188
1992	19,551	17,629	1,308
1993	21,731	19,829	1,495
1994	25,128	23,334	1,815

[57] Expanded clay is not included here, since no pertinent data (production quantities / activity data) are available

[58] clay blocks, facing bricks, bricks for floor and road surfaces, roof tiles and accessories, tiles, stoneware, vitrified clay pipes and other structural formed products, household and sanitary ceramics: Porcelain, household and sanitary ceramics: stoneware, earthenware

	Activity data [kt]		Process-related CO_2 emissions [kt][58]
	Total ceramics production	CO_2-relevant ceramics production[58]	
1995	25,167	23,254	1,742
1996	22,671	20,943	1,557
1997	22,691	20,949	1,554
1998	22,461	20,714	1,499
1999	21,841	20,222	1,445
2000	20,649	18,914	1,314
2001	17,416	15,775	1,072
2002	16,094	14,418	969
2003	15,960	14,262	955
2004	16,135	14,398	940
2005	14,199	12,547	772
2006	15,123	13,352	849
2007	15,164	13,269	836
2008	13,242	11,376	697
2009	10,814	9,498	574
2010	11,921	10,254	607
2011	12,877	11,113	653
2012	12,329	10,732	627
2013	12,032	10,480	611
2014	11,909	10,313	582
2015	11,645	10,084	552
2016	11,702	10,170	565
2017	12,039	10,421	571
2018	11,971	10,401	556
2019	12,039	10,586	569
2020	11,611	10,371	552

Source: Own calculations (UBA)

4.2.4.1.2 Methodological issues (2.A.4.a Ceramics)

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories 2006 contain information for calculation of process-related CO_2 emissions for the ceramics industry (IPCC (2006a): Volume 3, Chapter 2.5.1 "Ceramics"). In general, the following product groups are normally allocated to this industrial production sector: roof tiles and masonry bricks, stoneware pipes, refractory products, expanded clay, wall and floor tiles, household ceramics, sanitary ceramics, technical ceramics, inorganic bonded abrasives. With regard to produced quantities, the product groups roof tiles and masonry bricks, refractory products and wall and floor tiles are especially relevant. In keeping with the available data, the emissions calculations take account of nearly all the products involved.

With regard to assessment of methods, the 2006 IPCC Guideline provide only sketchy information pertaining to carbonate inputs. Because the present method takes account of additional CO_2 sources, it is considered to be a country-specific Tier 2 method.

Activity data

In the area of production data (activity data), data of the Federal Statistical Office are used (W. Statistisches Bundesamt, 2021a). In the interest of completing the database for all product categories of the ceramics industry – also with regard to determination of process-related CO_2 emissions – the annual production quantities were determined for each product category, in the framework of an expert opinion prepared in cooperation with the Federal Statistical Office (Gottwald et al., 2017). The project covered the period 1990 – 2015, and its scope has been expanded since then. The number of product categories from official statistics that have to be considered, as a result, ranges from 52 to 67. As of the last adjustment, carried out as of 2019, a total of 57 product reporting numbers are now involved. The data provided by the Federal Statistical Office vary with regard to the units used (tonnes, square meters, unit counts, value). To enable the data to be processed in a consistent manner, all units have been converted into tonnes [t]. Where produced quantities are not available in units of tonnes [t], conversion factors have to be applied. The conversion factors used are given in the project report.

As of data year 2019, quantities of tiles – which are reported in square meters – are converted in keeping with an adjusted method. Previously, ten statistical reporting numbers were used, to cover a range of different tile products. As of data year 2019, the numbers are being grouped, for publication, into three new reporting groups, and arranged via a new system oriented to water-absorption capacity. In the process, parts of the old groups have been distributed among the new groups. As a result, the previously used conversion factors are now unsuitable. In August 2020, discussions were held with Bundesverband Keramische Fliesen e.V. (the Federal association of the German ceramic tile industry) regarding the average weights per unit area that are needed for conversion into units of tonnes, and the resulting weights were assigned to the relevant tile types (Bundesverband Keramische Fliesen, 2020).

In a departure from reliance on the aforementioned expert opinion, the conversion factors for facing bricks, clay blocks and roof tiles were revised, at the suggestion of the German brick and tile industry association (Bundesverband der Deutschen Ziegelindustrie e. V.), on the basis of technical discussions with representatives of environmental and industrial associations. In the revision, average raw-density values for clay blocks were used. The values were determined for the years 1994 and 2016. The raw densities involved decrease continuously over time, since the share of porous products, and the products' degree of porosity, have both been growing. The values for the years between 1994 and 2016 have been linearly interpolated.

Emission factors

The process-related CO_2 emissions originate in the raw materials used for the production of ceramic products. Normally, these consist of locally available loams and clays containing varying fractions of non-biogenic carbon (such as carbonates) and organic carbon. In addition, small quantities of process-related CO_2 emissions are produced by pore-forming agents, which are added to raw materials used for production of clay blocks. Most of the porosity agents used are renewable resources (such as sludges from the paper industry, including some with fossil components, and paper fibres). Small quantities of non-renewable substances (especially polystyrene) are also used, however. (Organic) binders, which are also used, in small quantities, in production of refractory and abrasive products, also contribute to process-related CO_2 emissions – in insignificant quantities, however.

The emission factors suitable for Germany have been developed in two stages: First, via suitable labelling of the statistical figures for CO_2-relevant product groups (Gottwald et al., 2017); second, via calculation, by the German Emissions Trading Authority (DEHSt), of specific emission factors (Rothe, 2017). In the process, verified installation data (emissions reports, product allocations, production quantities, ash contents of raw-material samples) available to the DEHSt for the years 2012 through 2015 were used[59]. Data on product groups considered of relevance with regard to CO_2 emissions, but for which the DEHSt was unable to determine emission factors directly, have been supplemented (expert assessments) with the help of assumptions and of analogies to other

[61] This value differs from the CO_2 IEF given in the CRF tables because that IEF (i.e. in the tables) includes the total activity data for all ceramic products. In so doing, it also subsumes products that, due to their raw-material composition and intended quality levels, include no carbonates or CO_2-relevant additives.

product groups (raw-material composition)[60]. As a result of this step-by-step assessment process, refractory products, ornamental articles, technical ceramics and abrasives were excluded from the CO_2 calculations. Table 177 shows the CO_2 emission factors determined for the various product groups.

Table 177: CO_2 emission factors for various ceramics product groups

Product group	CO_2 emission factor [t_{CO2} / $t_{product}$]	Remarks
tiles, stoneware	0.018	DEHSt
backing bricks	0.1047	DEHSt
facing bricks	0.0189	DEHSt
bricks for floor and road surfaces	0.016	DEHSt / UBA*
roof tiles, accessories	0.0112	DEHSt
ceramic pipes and other structural formed products	0.0112	DEHSt / UBA*
household and sanitary ceramics: porcelain	0.009	DEHSt / UBA*
household and sanitary ceramics: stoneware, earthenware	0.018	DEHSt / UBA*

* Emission factors determined via expert assessment (see the above description)

The implied emission factor (IEF) for the German ceramics industry is obtained from the process-related CO_2 emissions and the activity data for CO_2-relevant ceramics production for the relevant year (cf. Table 176). With this approach, an IEF of 0.053 $t_{CO2}/t_{product}$ has been calculated for 2018[61]. This value, which is considerably lower than the corresponding value in the 2019 NIR, results from use of the new conversion factors for the raw density of bricks and tiles, in that the new factors decrease the production-mass fraction of the product types accounting for the largest quantities and greatest emissions relevance in the sector.

4.2.4.1.3 Uncertainties and time-series consistency (2.A.4.a Ceramics)

In keeping with the required conversions of unit counts, volume data and area data to produced masses (tonnes [t]), as well as with the uncertainties tied to determination of production statistics, the uncertainties for the activity data are estimated as + 6 % / - 7 %.

The uncertainties for the **CO_2 emission factors** used for the product groups listed in Table 177 vary – in part, considerably. For example, the uncertainties for the clay blocks product group are -18 % / +18 %, while those for tiles are -53 % / +53 %. Most of the determined uncertainties are tied to the empirical data of the DEHSt. For emission factors that were not determined directly (such as those for ceramic pipes, etc.), uncertainties shares for analogies used have been added (for household and sanitary ceramics, for example, the result is -57 % / +57 %).

Time-series consistency, relative to activity data, is assured for the majority of the product groups listed in Table 177 and for the pertinent CO_2 emission factors. The time series for a few product groups have breaks (as a result of changes in the availability of statistical data, or of past changes in product grouping); such breaks have been noted and described in Gottwald et al. (2017). With regard to the CO_2 emissions for this area, such time-series breaks are either irrelevant or negligible.

[61] This value differs from the CO_2 IEF given in the CRF tables because that IEF (i.e. in the tables) includes the total activity data for all ceramic products. In so doing, it also subsumes products that, due to their raw-material composition and intended quality levels, include no carbonates or CO_2-relevant additives.

[61] This value differs from the CO_2 IEF given in the CRF tables because that IEF (i.e. in the tables) includes the total activity data for all ceramic products. In so doing, it also subsumes products that, due to their raw-material composition and intended quality levels, include no carbonates or CO_2-relevant additives.

4.2.4.1.4 Category-specific quality assurance / control and verification (2.A.4.a Ceramics)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The calculated CO_2 emissions are transparent and, magnitude-wise, on the order of the relevant emissions recorded in the ETS.

It is not feasible to compare the emission factors with the IPCC default emission factors, because the Guidelines' emission factors are based solely on raw materials, while the country-specific emission factors are based on products.

The CO_2 IEF for the German ceramics industry, like the IEFs of most other countries, lies within the lower or middle section of the pertinent range. The IEF values of some countries are higher by a factor 5 to 10, however, and thus do not seem suitable for comparison.

4.2.4.1.5 Category-specific recalculations (2.A.4.a Ceramics)

The activity data for 2019 were corrected retroactively, in one position, in the official statistics. For this reason, the activity data for 2019 are not identical with those given in the previous year's report. No CO_2 emission factor has been allocated to the position in question. Consequently, the change has no impact on the CO_2 emissions reported for 2019.

4.2.4.1.6 Planned improvements, category-specific (2.A.4.a Ceramics)

Currently, no improvements are planned, apart from the review referred to in Chapter 4.2.4.1.4.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.2.4.2 Non-metallic minerals industry: other soda ash use (2.A.4.b)

4.2.4.2.1 Category description (2.A.4.b)

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1	NS	D

The overarching category 2.A.4 – *Mineral products: Other process uses of carbonates* is not a key category.

Soda ash is used in a wide range of industrial applications. The most important areas of use include the glass industry, production of detergents and cleansers and the chemical industry. It is assumed that the carbon contained in soda ash is released sooner or later, regardless of the use involved, into the air as CO_2.

Emissions resulting solely from use of soda ash correlate in a fixed way to the pertinent calculated quantities used – in this context, outside of the glass industry (cf. the methodological issues in the following chapter):

Table 178: Activity data and use-related CO_2 emissions outside of the glass industry, since 1990

Year	Activity data [t]	CO_2 emissions [kt]
1990	809,885	336.1
1995	340,793	141.4
2000	411,281	170.7
2005	517,159	214.6
2006	484,871	201.2
2007	550,966	228.7
2008	538,477	223.5
2009	457,076	189.7
2010	528,885	219.5
2011	587,144	243.7
2012	516,444	214.3
2013	591,149	245.3
2014	516,915	214.5
2015	470,288	195.2
2016	495,780	205.7
2017	494,922	205.4
2018	459,160	190.6
2019	340,998	141.5
2020	230,069	95.5

Source: Calculations of the Federal Environment Agency (UBA); for pertinent derivation, cf. the following chapter

4.2.4.2.2 Methodological issues (2.A.4.b)

Activity data

Since the 2010 inventory review, those soda ash inputs are determined that are not taken into account, for emissions calculations, in other categories. The relevant calculations are oriented to the greatest possible emissions from the applicable soda ash use. The total quantity of soda ash used in Germany is determined via balancing (quantity produced plus imports and less exports) (a). The relevant import and export quantities are taken from the foreign-trade statistics of the Federal Statistical Office (Statistisches Bundesamt, o.J.-a). Emissions from soda ash use in the glass industry are already taken into account, category-specifically, under category 2.A.3 (b). The soda ash quantities used in that category are deducted from the soda ash use of relevance in the present section. The activity data in the above table (c) have been obtained in accordance with the following formula:

c = a minus b

In preparation of the Energy Balance since the year 2017, an earlier foreign-trade balance was carried forward, because the Federal Statistical Office provided an exports figure that seems very high. Because that value does not provide a plausible framework for a balance, an average value for the five preceding years has been carried forward. In the meantime, consultations have been held with manufacturers and statistical offices, with the aim of correcting the published data. At the time the inventory was being prepared, clarification of those figures was still underway.

Emission factor

Stoichiometrically, the emission factor for soda ash use is 415 kg CO_2 per tonne of soda ash, under the assumption that release is complete (a conservative approach).

4.2.4.2.3 Uncertainties and time-series consistency (2.A.4.b)

Activity data

The calculations of the relevant quantities of soda ash used exhibit large uncertainties (maximally, -18%/+18%), as a result of statistical fluctuations in soda-ash production, and in foreign trade in soda ash, and as a result of the calculatory assumptions on which the above derivation is based.

The low values for the period since 2017 lead to a decreasing trend, one that cannot be explained from a technical industry standpoint and that would seem to arise calculatorily from the balance-sheet method used.

Emission factor

The emission factor for soda ash use is subject to small, explained uncertainties in the area of product purity and the completeness of the chemical transformations involved (-5%/+0%).

4.2.4.2.4 Source-specific quality assurance / control and verification (2.A.4.b)

General quality control and quality assurance, have been carried out in conformance with the requirements of the QSE-manual and its associated applicable documents, by the Single National Entity.

It is not possible at present to verify quantitatively the input quantities of soda ash that cannot be allocated to the glass industry. The pertinent estimates are conservative, however; they do not underestimate the quantities of relevance for the inventory. Qualitatively, the pertinent calculation results do not contradict the sales figures of soda-ash producers obtained on a sample basis.

The stoichiometric emission factor is in keeping with the default figures given in the IPCC Guidelines (IPCC (2006a): Volume 3, Chapter 2, Table 2.1).

4.2.4.2.5 Category-specific recalculations (2.A.4.b)

No source-specific recalculations were required.

4.2.4.2.6 Category-specific planned improvements (2.A.4.b)

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter. No additional improvements are planned at present.

4.2.4.3 Production of non-metallurgical magnesium products (2.A.4.c)

4.2.4.3.1 Category description (2.A.4.c)

The greenhouse-gas emissions from this category amount to less than 0.05 % of the total inventory (not including LULUCF), and they are less than 500 kt CO_2-equivalents. What is more, relevant annual surveys cannot be assured (UNFCCC, 2013a). For this reason, we are not reporting on this area. The present chapter thus presents a one-time quantitative estimation of the emissions that are not covered by the inventory as a result. In addition, a compilation of all sources listed as "not estimated" is presented in Annex 5 in Chapter 21 of the present report.

4.2.4.3.2 Methodological issues (2.A.4.c)

It was not possible to identify any suitable activity data for this category segment in the official statistics. Some product types, such as refractory bricks, are already included in the activity data for the ceramics industry (CRF 2.A.4.a, Chapter 4.2.4). The additionally identified category "production of other carbonates" is a collective in which magnesium carbonates are a nonquantifiable sub-quantity. The resulting time series shows only production quantities less than 300,000 t. The lowest threshold for inclusion would be about one million tonnes of a product with large fractions of CaO and MgO. That production threshold is not achieved with any relevant product type. This also applies to the product types already included in other categories.

Because the pertinent statistics contain collective categories, the potential CO_2 emissions cannot be precisely calculated. They are estimated to be considerably less than 100,000 t of carbon dioxide.

4.2.4.3.3 Uncertainties and time-series consistency (2.A.4.c)

No conclusions relative to uncertainties and time-series consistency can be drawn.

4.2.4.3.4 Source-specific quality assurance / control and verification (2.A.4.c)

Due to resources limitations, and to the area's minimal relevance, no QC/QA has been carried out for reporting in this area.

An initial relevant estimate was made in the framework of a research project. It was then reviewed by the specialised contact person within the Federal Environment Agency (UBA) and confirmed in the above-described manner.

4.2.4.3.5 Category-specific recalculations (2.A.4.c)

Recalculations are not considered here, due to the fact that the relevant emissions are not listed.

4.2.4.3.6 Category-specific planned improvements (2.A.4.c)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.2.4.4 Non-metallic minerals industry: other limestone and dolomite use (2.A.4.d)

4.2.4.4.1 Category description (2.A.4.d)

This category's carbon-dioxide emissions are not reported separately; instead, they are reported in the sections for the categories that use limestone and dolomite (they are thus included elsewhere – IE). In the relevant categories, they are also taken into account in key-category analysis.

Emissions of the precursor substances SO_2, NO_X, CO and NMVOC are reported in this category whenever the UNFCCC's 'CRF Reporter Inventory Software' does not permit them to be entered in sub-categories. Specifically, the pertinent emissions include the following:

- NO_X and NMVOC from 2.A.1, 2.A.2 and 2.A.3,
- SO_2 from 2.A.2 and 2.A.3, including a statistical figure for the territory of the "New German Länder" (states) in 1990.
- CO from 2.A.2 and 2.A.3,
- As a result of this allocation, no figures for pertinent activities can be given in the CRF tables.

All other precursor substances are reported in the categories to which the emissions are assigned (no restrictions in the CRF-Reporter software apply).

Until the 2014 Submission, and in supplementation to the requirements set forth in the 1996 IPCC Guidelines, in this category all production and use of limestone and dolomite were considered in balance form, and the results were compared with the inventory categories. This "limestone balance" (Röhling & Kludt, 2010) appeared most recently in the 2014 NIR.

No findings are available regarding use of limestone in emissions-relevant sectors other than the categories listed below.

4.2.4.4.2 Methodological issues (2.A.4.d)

The following section provides an overview of national limestone inputs (source-category references). Emissions calculations are carried out for those categories in which CO_2 emissions are produced via limestone use:

- 1.A.1.a Flue-gas desulphurisation in power stations (limestone inputs)
- 2.A.1 Cement-clinker production (limestone fraction in the relevant raw materials)
- 2.A.2 Limestone production (limestone inputs)
- 2.A.3 Glass production (limestone fraction in the relevant raw materials)
- 2.A.4.a Ceramics production (carbonate fraction in the raw materials)
- 2.B.7 Soda ash production (limestone inputs)
- 2.C.1 Iron and steel production (limestone inputs and lime kilns)
- 2.H.2 Sugar production (lime furnaces)
- 3.G Soil liming in agriculture and forestry (limestone and dolomite)

The pertinent data are updated in the relevant categories (cf. the above list). In addition, pertinent methodological aspects are explained in the relevant category chapters.

4.2.4.4.3 Uncertainties and time-series consistency (2.A.4.d)

Information regarding uncertainties for activity data and emission factors for the relevant limestone uses is provided in the relevant category chapters.

4.2.4.4.4 Source-specific quality assurance / control and verification (2.A.4.d)

The activity data and the emission factors for the relevant limestone uses are verified and updated in the relevant categories.

4.2.4.4.5 Category-specific recalculations (2.A.4.d)

Recalculations have been carried out in the relevant categories.

4.2.4.4.6 Category-specific planned improvements (2.A.4.d)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3 Chemical industry (2.B)

Category 2.B is divided into the sub-categories 2.B.1 through 2.B.10. These include ammonia production (2.B.1), nitric acid production (2.B.2), adipic acid production (2.B.3), caprolactam, glyoxal and glyoxylic acid production, (2.B.4), carbide production (2.B.5), titanium dioxide production (2.B.6), soda ash production (2.B.7), petrochemical and carbon black production (2.B.8) and production of fluorinated chemicals (2.B.9).

In the category *Other* (2.B.10), only precursor substances from production of fertilisers and sulphuric acid are reported. Production of dodecanedioic acid is described in 2.B.10, while process-related N_2O emissions are reported under 2.G.3, for reasons of confidentiality.

4.3.1 Chemical industry: Ammonia production (2.B.1)

4.3.1.1 Category description (2.B.1)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	2 B 1, Ammonia Production		CO_2	6,025.0	0.5%	4,133.0	0.6%	-31.4%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 3	PS	PS
NO_X			D

The category *Chemical industry*: *ammonia production* is a key category for CO_2 emissions in terms of emissions level and trend.

Ammonia is produced on the basis of hydrogen and nitrogen, using the Haber-Bosch process, which also forms CO_2. Hydrogen is produced from synthetic gas (usually) based on natural gas, via a highly integrated process, *steam reforming*, while nitrogen is produced via air dissociation.

The various plant types for the production of ammonia cannot be divided into individual units and be compared as independent process parts, due to the highly integrated character of the procedure. In *steam reforming*, the following processes are distinguished:

- ACP – *advanced conventional process* with a fired primary reformer and secondary reforming with excess air (stoichiometric H/N ratio)
- RPR – *reduced primary reformer process*, carried out under mild conditions in a fired primary reformer, and with secondary splitting with excess air (sub-stoichiometric H/N ratio)
- HPR – *heat exchange primary reformer process* – autothermic splitting with heat exchange using a steam reformer heated with process gas (heat exchange reformer) and a separate secondary reformer or a combined autothermic reformer using excess air or enriched air (sub-stoichiometric or stoichiometric H/N ratio).

The following procedure is also used:

- Partial oxidation – gasification of natural gas, fractions of heavy mineral oil or vacuum residues in production of synthetic gas.

As of mid-2014, ammonia is being produced in Germany at only four locations. The production operations use both the steam-reforming and partial-oxidation processes.

The production decrease of more than 15 % (corresponding to an amount of nearly 300 kt) in the first year after German reunification was the result of a market shake-up, over 2/3 of which was borne by the new German Länder. The production level then remained nearly constant in the succeeding years until 1994. It has not been possible to determine the reason for the renewed growth as of 1995, which returned production to the level seen in 1990. However, the growth could be due to resumption of production processes in the new German Länder, following extensive modernisations. Since 1995, production levels have fluctuated only slightly. The nearly 8% production decrease that occurred in 2009 was due to the global economic crisis. Until 2013, the IEF was higher than that of other countries, since in Germany heavy fuel oil is used for partial oxidation, in addition to natural gas. Heavy fuel oil produces significantly higher CO_2 emissions than natural gas does. Since mid-2013, partial oxidation has been carried out primarily with natural gas. In addition, sizable quantities of CO_2 are being captured and processed into urea for use in AdBlue, as well as for use as fertilizer. As a result, the IEF no longer differs significantly from those of other countries.

4.3.1.2 Methodological issues (2.B.1)

In keeping with this category's classification as a key category for CO_2 emissions, since the 2010 report the emissions data for this category have been collected and reported pursuant to Tier 3, apart from the data for one plant. Until 2012, those data were obtained pursuant to the Tier 2 method; a default figure for carbon content was used. As of 2013, all plant data have been obtained pursuant to the Tier 3 method. This is being carried out on the basis of a co-operation agreement with the relevant plant operators for delivery of plant-specific data.

The operators transmit their plant-specific data to the Industrieverband Agrar (IVA) agrochemical industry association. That association anomymises the data, for reasons of confidentiality, and then transmits it, in plant-specific form, to the Federal Environment Agency (UBA). The Federal Environment Agency carries out quality assurance and then aggregates the data.

The plant operators report:

- the ammonia quantities produced (**activity data**),
- the quantities of raw materials used in the process (natural gas, heavy mineral oil), less the pertinent fuel quantities used for energy purposes and so reported in the Energy Balance (TFR_i),
- the raw materials' carbon content factor (CCF_i) and carbon oxidization factor (COF_i),
- the quantity of CO_2 that undergoes further processing (R_{CO2}), and the purpose for which it is used.

CO_2 emissions:

The CO_2 emissions are calculated in keeping with Equation 3.3 in the 2006 IPCC Guidelines (IPCC, 2006a):

$$E_{CO2} = \sum (TFR_i * CCF_i * COF_i * 44/12 - R_{CO2})$$

The recovered quantity of CO_2 that is used in other production processes – such as urea production – (and is reported in connection with those other processes) is not included in the non-reported emissions.
As of 2013, all ammonia plants are subject to emissions trading requirements. As a result, all plants meet emission-trading requirements pertaining to determination of carbon content.

One producer uses a standard factor that has been obtained via ongoing operational analysis (C content = 86.1 % by weight). Until 2013, a second producer used the IPCC default value for natural gas. For the other gases – the gas mixtures used – that producer determined the applicable C content levels analytically, on the basis of the C content levels of the individual gases contained and their quantity shares of the mixtures. In two cases, producers use the data provided by the relevant natural gas suppliers.

Emission factor for NO_x:

The emission factor that has been used for NO_X is the default emission factor given by the *CORINAIR Guidebook*, 1 kg/t HNO_3 (EMEP (2009): EMEP EEA Emission Inventory Guidebook, TFEIP-endorsed draft, May 2009).

4.3.1.3 Uncertainties and time-series consistency (2.B.1)

The uncertainties reported by the operators are aggregated by UBA, in keeping with Equation 3.2 (IPCC (2006a): Vol. 1, Ch. 3), and entered into the tables.

The uncertainty for the activity data is ± 0.6 %. The uncertainty for the emissions is ± 1 %.

4.3.1.4 Source-specific quality assurance / control and verification (2.B.1)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

4.3.1.5 Category-specific recalculations (2.B.1)

No recalculations have been carried out.

4.3.1.6 Category-specific planned improvements (2.B.1)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.2 Chemical industry: Nitric acid production (2.B.2)

4.3.2.1 Category description (2.B.2)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	2 B 2, Nitric Acid Production		N_2O	3,257.5	0.3%	377.8	0.1%	-88.4%

Gas	Method used	Source for the activity data	Emission factors used
N_2O	Tier 3	PS	PS

The category *Chemical industry*: *Nitric acid production* is a key category for N_2O emissions in terms of emissions level and trend.

In production of nitric acid, nitrous oxide occurs in a secondary reaction. In Germany, there are currently nine nitric acid production plants.

HNO_3 production occurs in two process stages:

- **Oxidation** of NH_3 to NO and
- **Conversion of** NO to NO_2 and **absorption** in H_2O.

Details of the process are outlined below:

Catalytic oxidation of ammonia

A mixture of ammonia and air at a ratio of 1:9 is oxidised, in the presence of a platinum catalyst alloyed with rhodium and/or palladium, at a temperature of between 800 and 950 °C. The relevant reaction, according to the Ostwald process, is as follows:

$$4\,NH_3 + 5\,O_2 \rightarrow 4\,NO + 6\,H_2O$$

Simultaneously, nitrogen, nitrous oxide and water are formed by the following undesired secondary reactions:

$$4\,NH_3 + 3\,O_2 \rightarrow 2\,N_2 + 6\,H_2O$$

$$\mathbf{4\,NH_3 + 4\,O_2 \rightarrow 2\,N_2O + 6\,H_2O}$$

All three oxidation reactions are exothermic. Heat may be recovered to produce steam for the process and for export to other plants and/or to preheat the residual gas. The reaction water is condensed in a cooling condenser, during the cooling of the reaction gases, and is then conveyed into the absorption column.

4.3.2.2 Methodological issues (2.B.2)

In keeping with the 2006 IPCC Guidelines (IPCC, 2006a), nitric-acid production is now reported plant-specifically, in accordance with the Tier 3 standard. This is being carried out on the basis of a co-operation agreement with the relevant plant operators for delivery of plant-specific data. Through the 2014 reporting round, six operators sent data to the Industrieverband Agrar (IVA) industrial association. After carrying out quality assurance, the IVA aggregated the data, to protect confidentiality, and then transmitted the so-aggregated data to the Federal Environment Agency (AD and EF). Two companies sent their data (AD, EF and N_2O emissions, and information about any reduction equipment used) directly to the Federal Environment Agency. After carrying out quality assurance, the Federal Environment Agency then aggregated those companies' data with the data provided by the IVA and entered the so-aggregated data into the CSE emissions database.

The relevant cooperation agreement was adapted for the new commitment period and in keeping with the new 2006 IPCC Guidelines. The Federal Environment Agency now receives the plant-specific data for six operators, for a total of seven plants, in anonymised form, via the IVA. Two other operators send their data directly to the Federal Environment Agency.

The plant operators report:

- the quantities of nitric acid produced (**activity data**);
- the EF;
- the N_2O emissions measured in the raw gas;
- where emissions-reduction equipment is used, the N_2O emissions measured in the emissions-reduced exhaust gas;
- the uncertainties for the activity data, the emission factor and emissions reductions.

The reduction technologies used are selective catalytic reduction (SCR) and EnviNOx technology, the latter of which reduces N_2O emissions by over 99% . Catalytic decomposition reduces both N_2O and NH_3 emissions. One installation has been retrofitted with a second waste-gas-treatment system (SCR).

Until 2006, production quantities correlated with the N_2O emissions. Subsequently, a considerable decoupling of production quantities and N_2O emissions has become apparent that is due to use of emissions-reduction equipment. In 2017, one plant's catalytic converter was replaced. The effects of the replacement are seen in 2018 in the form of a reduced EF.

NO_X emission factor:

The emission factors used for NO_X are the T2 default emission factors given by the *CORINAIR Guidebook* (EMEP (2009): EMEP EEA Emission Inventory Guidebook, TFEIP-endorsed draft, May 2009). In the process, the relevant emission factors for systems with and without waste-gas treatment were used, in keeping with the development over time, and the equipment used. Further details are available in the Informative Inventory Report (IIR).

4.3.2.3 Uncertainties and time-series consistency (2.B.2)

Activity data:

The activity-rate uncertainty has been determined by the Federal Environment Agency in keeping with Equation 3.2 (IPCC (2006a), Vol. 1, Ch. 3), on the basis of figures provided by the operators. The pertinent uncertainty is ± 1 %.

Emission factor:

For the N_2O emission factor, the operators give an uncertainty of ± 5 %.

4.3.2.4 Source-specific quality assurance / control and verification (2.B.2)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

4.3.2.5 Category-specific recalculations (2.B.2)

No recalculations have been carried out.

4.3.2.6 Category-specific planned improvements (2.B.2)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.3 Chemical industry: Adipic acid production (2.B.3)

4.3.3.1 Category description (2.B.3)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	2 B 3, Adipic Acid Production		N_2O	18,076.7	1.4%	189.1	0.0%	-99.0%

Gas	Method used	Source for the activity data	Emission factors used
N_2O	Tier 3	PS	PS
NO_X, CO	Tier 3	PS	PS

The category *Chemical industry*: *adipic acid production* is a key category for N_2O emissions in terms of emissions level and trend.

On an industrial scale, adipic acid is produced via oxidation of a mixture of cyclohexanol and cyclohexanone with nitric acid. In that reaction, considerable amounts of nitrous oxide (N_2O) are formed.

Until the end of 1993, the two sole German producers emitted all of their nitrous oxide directly into the atmosphere. One producer has since put into operation a system for thermal decomposition of nitrous oxide into nitrogen and oxygen. Decomposition takes place nearly completely. In 2009, a second, additional (i.e. redundant) thermal N_2O-decomposition facility was added. N_2O-decomposition rates of over 99% are now being achieved.

At the end of 1997, the other producer put a catalytic N_2O-decomposition system into operation that, in constant operation, achieves an N_2O-decomposition rate of 97-98 %. At the end of 2009, a second, redundant decomposition reactor was added.

Since 2010, N_2O emissions have decreased further, significantly, since the two producers have each installed a redundant waste-gas-treatment facility.

In March 2002, a third producer, with one plant, began production. That plant also uses the thermal N_2O-decomposition process. Since 2013, that producer also has had the option of using a redundant emissions-reduction system if his primary system should fail. N_2O-decomposition rates of over 99% can now be achieved.

The overall fluctuations in the decomposition rates – and, thus, in the residual emissions – are the result of functional impairments in the emissions-control equipment, of planned interruptions in their operation and of variances in production volumes.

From 1990 to the present, production has nearly doubled, as a result of growth in demand.

4.3.3.2 Methodological issues (2.B.3)

Since 1990, N_2O emissions from adipic acid production have been calculated on the basis of plant-specific data.

In those years in which no systems for reducing nitrous oxide emissions were in operation, the two producers only provided production-quantity data. The nitrous oxide emissions for that period – until 1994, for one facility, and until 1997, for the other – were calculated with the IPCC default emission factor. The calculation of N_2O emissions for those years is in keeping with a Tier 2 approach. For the subsequent period, the two producers continuously measured their nitrous oxide emissions and, in addition to providing data on production and on N_2O emissions, also provided the background information, on a confidential basis, that is needed to assess the precision of the reported data. The third producer has been measuring emissions continuously since 2013. In the period prior to that year, that producer had calculated, on the basis of the quantities of produced adipic acid and a suitable emission factor, the quantities of nitrous oxide that were emitted in two possible plant states (unreduced and reduced operation). Those calculations also took into account a) the periods of time for which each plant state was maintained, and b) the plant load levels. An emission factor, taking account of the quantities of adipic acid produced and the results of nitrous-oxide-concentration measurements, was determined for each of the two operational states.

Determination of N_2O emissions on the basis of continuous nitrous oxide measurement is in keeping with the Tier 3 method set forth in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC (2006a): Vol. 3, Ch. 3.4.2.1).

4.3.3.3 Uncertainties and time-series consistency (2.B.3)

For installations with thermal decomposition, the 2006 IPCC GL (IPCC (2006a): Vol. 3, Tab. 3.4) give uncertainties for the N_2O-decomposition rate of +/- 0.5%; for installations with catalytic decomposition, they give uncertainties of +/- 2.5%.

According to producers' information, the uncertainties for the emissions, regardless of what reduction process is used, lie within a range of about +/-1 to 6%. The range for the uncertainties relative to production quantities is given as <0.1% to about 1%. The uncertainty for the EF is thus set at 6 %, while that for the production quantities is set at 2%.

The third producer's emissions have not been recalculated retroactively to the year 2002, following the changes in the survey method for this area, because non-comparable emissions values are involved, due to the simultaneous commissioning of the redundant reduction system.

4.3.3.4 Source-specific quality assurance / control and verification (2.B.3)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Information provided by producers enjoys a high degree of confidentiality protection. For this reason, only emissions figures can be listed in the CRF tables. The reported emissions and activity data have been reviewed by a Federal Environment Agency expert and cross-checked against other data sources.

Comparisons of the IEF with the IEFs of other countries are possible only to a limited degree; only Italy and the U.S. consistently report an emission factor for N_2O. The lower of those two IEFs is comparable to the German national emission factor. For this category, comparisons with PRTR data are not feasible.

Two of the three producers have each carried out a JI project. The results of those projects can be downloaded from the JI and CDM project database[62] of the German Emissions Trading Authority (DEHSt) (the relevant project IDs are DE-1000017 and DE-1000018). The inventory data have been compared with the projects' corresponding figures for the period 2008 through 2012 – and confirmed by that comparison.

The emissions data for the period 2013 through 2019 have been cross-checked against the ETS data. The check shows that the data sets are in good agreement.

4.3.3.5 Category-specific recalculations (2.B.3)

No recalculations have been carried out.

4.3.3.6 Planned improvements, category-specific (2.B.3)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.4 Chemical industry: Caprolactam, glyoxal and glyoxylic acid (2.B.4)

4.3.4.1 Category description (2.B.4)

The category *Chemical industry*: *Caprolactam, glyoxal and glyoxylic acid* is not a key category.

Industrially, ε-caprolactam is the most important lactam. It is used primarily for production of PA 6. There are two producers in Germany.

Glyoxal is used in the production of a wide range of products. It serves to improve product properties. There is one producer. The process used by that producer for glyoxal production (oxidation of ethylene glycol during the gas phase) is not a source of process-related nitrous oxide emissions.

The producer reports that no glyoxal delivered to customers in Germany is processed into glyoxylic acid. We are not aware of any glyoxylic acid production in Germany from other raw materials.

4.3.4.2 Methodological issues (2.B.4)

Caprolactam

Both producers use a synthesis pathway via hydroxylammonium sulfate (HAS), in the production of which ammonia is oxidised. Ammonia oxidation is the factor primarily responsible for the N_2O emissions in the production process.

Both producers also employ a thermal waste-gas treatment system to destroy nitrous oxide. Both producers' systems have a redundant design. The temperatures involved are much higher than the decomposition temperature of nitrous oxide. As a result, only very small quantities of emissions occur.

For one of the two producers, the pertinent N_2O emissions are assigned to nitric acid production (2.B.2), in the interest of consistency with emissions trading data. A Tier 3 reporting method is used. For that system, therefore, "IE" is entered under 2.B.4a in the CRF Table.

With regard to the other producer's installation, the Single National Entity has access to detailed information that indicates that the pertinent post-combustion system can be assumed to

[62] Cf.: https://www.jicdm.dehst.de/promechg/pages/project1.aspx

completely eliminate the nitrous oxide quantities involved. But since the operator of that system is not subject to measurement obligations, and in order to prevent any underestimation of nitrous oxide emissions from other emission sources, the N_2O emissions have been quantitatively estimated, on a one-time basis, using a Tier 2 method. For the estimate, a production capacity is derived from press reports[63], and from the 2006 IPCC-RL the N_2O standard emission factor for the production of caprolactam (9 kg N_2O/t caprolactam, pursuant to IPCC (2006a): Vol. 3, Chapter 3.5, Table 3.5) is used. In addition, standard factors for thermal waste-gas treatment in adipic acid production (98.5 % reduction rate, and 99.91 % capacity utilisation, pursuant to IPCC (2006a): Vol. 3, Chapter 3.4, Table 3.4), are used. The capacity utilisation factor for the redundantly designed waste-gas-treatment system is obtained from the 97% capacity utilisation factor for the main installation, and the 97% factor for the second installation that is used for the 3% during which the main system cannot be used. In using standard factors given by the IPCC-RL, Germany is following recommendations provided by the Expert Review Team for the 2016 In Country Review. For the year 2015, the estimate is 10.7 kt CO_2-eq. for this installation. On the basis of the installation's emissions level, the permissibility of reduced emissions reporting pursuant to FCCC/SBSTA/2013/L.29/Add.1, para 37(b) has been reviewed. To that end, the other installation's N_2O emissions were calculated on the basis of standard emission factors and the applicable production capacity. A total of 17.9 kt CO_2-eq. resulted for both installations taken together. Since the calculated N_2O emissions from the category account for less than 0.05 % of the total inventory (not including LULUCF), since they do not exceed 500 kt CO_2 equivalents, and since annual recording cannot be carried out (in keeping with FCCC/SBSTA/2013/L.29/Add.1, para 37), we opt not to report on this area (IPCC (2006a): Vol. 3, Ch. 3.5). In addition, a compilation of all sources listed as "not estimated" is presented in Annex 5 in Chapter 21 of the present report. In the CRF Table, the two installations are listed under 2.B.4.a, and marked as "IE" and "NE," respectively. That notation is in keeping with the information and recommendations provided in the In Country Review.

4.3.4.3 Uncertainties and time-series consistency (2.B.4)

For the activity data, an uncertainty of ± 30% is assumed. For the standard factors, the pertinent uncertainties given in the 2006 IPCC-GL (IPCC, 2006a) apply.

4.3.4.4 Source-specific quality assurance / control and verification (2.B.4)

Due to resources limitations, and to the area's minimal relevance, no QC/QA has been carried out for reporting in this area.

Only a few sources are available that can serve as a basis for verification of the producer information given in press reports. For the years 1995 through 2008, quantity data for ε-caprolactam production are available (Statistisches Bundesamt (FS 4, R 3.1), Produzierendes Gewerbe, Produktion im Produzierenden Gewerbe ("manufacturing industry, production in the manufacturing industry"). Since 2009, produced quantities of ε-caprolactam have no longer been listed separately, as a result of adaptations to international classifications. As a result, statistical surveys of produced quantities of ε-caprolactam have not been possible since then. ε-caprolactam does continue to be listed separately in foreign-trade statistics. Data on import quantites since 1996, and on export quantities since 2009, are available in such statistics. The import and export quantities have remained relatively stable.

[63] Inter alia BASF Press information P293/16 – "BASF richtet Caprolactam-Produktion in Europa" ("BASF sets up caprolactam production in Europe")
New in https://www.basf.com/documents/corp/de/news-and-media/news-releases/2016/09/P293_Neuausrichtung_Caprolactam_Produktion_Europa.pdf (Aufruf 25.10.2017)

4.3.4.5 Category-specific recalculations (2.B.4)

No recalculations are required.

4.3.4.6 Category-specific planned improvements (2.B.4)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.5 Chemical industry: Carbide production (2.B.5)

4.3.5.1 Category description (2.B.5)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 B 5, Carbide Production		CO_2	443.2	0.0%	4.5	0.0%	-99.0%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 3	PS	PS (CaC2) NO (SiC)

The category *Chemical industry*: *Carbide production* is not a key category.

During the reunification period, calcium carbide production took place primarily in the new German Länder. A short time later, production there was discontinued, while only one producer remained in the old German Länder. According to the responsible specialised association within the VCI, no silicon carbide has been produced in Germany since 1993. Emissions from this sector thus no longer occur.

4.3.5.2 Methodological issues (2.B.5)

Activity data:

Since Germany has only one producer, the relevant data must be kept confidential. The producer communicates the data directly to the Federal Environment Agency on an annual basis. The data, as of the data for 1997, were obtained from the operator's life cycle assessment and from his annual environmental declarations pursuant to the EMAS (the facility has been certified since 1997). The only published data consists of those for amounts produced in the former GDR. Those data were published, until 1989, by that country's central statistical authority. Those figures were used, in combination with existing estimates for 1991 and 1992, to interpolate production in the new German Länder in 1990.

Emission factor:

The stoichiometric emission factor for CO_2 is 688 kg per tonne of calcium carbide (44 g mol^{-1} / 64 g mol^{-1}). Until 1992, this emission factor was used for production in the new German Länder.

Using covered furnaces, producers collect all of the carbon monoxide produced in the process and use it for energy generation. The resulting carbon dioxide serves as auxiliary material in production of calcium cyanamide and derived products. Reactions in these processes yield carbon dioxide in mineral form, as black chalk. In this form, it is used in agriculture. In 2012, carbide-furnace operations were smoothed out in a way that considerably reduced the amount of surplus furnace gas that had to be flared off. The new operational mode has also enabled the furnaces to run more "calmly", meaning that they produce fewer pressure surges that have to be buffered via raw-gas flares. The emission factor also includes the CO_2 emissions from flare use.

As a result, the emission factor for carbon dioxide from calcium carbide production is now substantially lower than it has been in previous years.

Upon request, the relevant producer provides the Federal Environment Agency with data on total emissions and on quantities produced. The emission factor is obtained by dividing the emissions quantity by the activity data.

4.3.5.3 Uncertainties and time-series consistency (2.B.5)

The uncertainties relative to the data provided by the producer are considered slight overall.

4.3.5.4 Source-specific quality assurance / control and verification (2.B.5)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Producers' relevant figures enjoy a high degree of confidentiality protection. For this reason, only emissions figures can be listed in the CRF tables. No calculations for verification could be carried out. It may be noted, however, that some of the figures have also been provided to licensing authorities and thus are considered trustworthy.

4.3.5.5 Category-specific recalculations (2.B.5)

No category-specific recalculations were carried out.

4.3.5.6 Category-specific planned improvements (2.B.5)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.6 Chemical industry: Titanium dioxide production (2.B.6)

There are several producers of titanium dioxide in Germany. One of the plants involved produces titanium dioxide via the chloride process. The others produce using the sulfate process, and emit no process-related CO_2. The estimate of the pertinent CO_2 emissions is an expert estimate. It has been made on the basis of the production capacity and of an emission factor that itself is based on an expert estimate. This estimate was made with confidential data that, by virtue of their confidentiality, cannot be presented here.

Since the greenhouse-gas emissions from the category titanium dioxide production account for less than 0.05 % of the total inventory (not including LULUCF), *and* since they would not exceed 500 kt CO_2 equivalents (significance thresholds pursuant to FCCC/SBSTA/2013/L.29/Add.1), and since annual recording cannot be assured (in keeping with FCCC/SBSTA/2013/L.29/Add.1, para 37), we opt not to report on this area (IPCC (2006a): Vol. 3, Ch. 3.7). In addition, a compilation of all sources listed as "not estimated" is presented in Annex 5 in Chapter 21 of the present report.

4.3.7 Chemical industry: Soda-ash production (2.B.7)

4.3.7.1 Category description (2.B.7)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 B 7, Soda Ash Production		CO_2	667.2	0.1%	361.0	0.1%	-45.9%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1	NS	CS

The category *Soda ash production* is not a key category.

In Germany, soda ash is produced only chemically. The country has 3 production facilities that use[64] the Solvay process[65]. In principle, the CO_2 contained within the calcium carbonate used in the process is bound within the product, soda ash (Na_2CO_3), and is released – if at all – only when that product is used (cf. category 2.A.4.b in Chapter 4.2.4.2). But since production via the Solvay process yields a CO_2 surplus, process-related CO_2 emissions result.

In the calcination part of the process, coke / anthracite is also used, and this produces additional (energy-related) carbon-dioxide emissions.

4.3.7.2 Methodological issues (2.B.7)

Activity data

The *Federal Statistical Office* determines the total amounts of soda ash produced in Germany. From 1995 to 2008, the categories *light soda* (production number 2413 33 103, disodium carbonate in powder form, with a fill density of less than 700 g/l) and *heavy soda* (production number 2413 33 109, other disodium carbonate) were listed separately. Since 2009, light and heavy soda have been reported in combination, in one position (notification number 2013 43 100). Of that quantity, only the portion "intended for sale" ("zum Absatz bestimmt") is taken into account. This prevents double-counting, since heavy soda is produced from light soda. Since Germany has only two producers, the production-quantity data, which are taken from official statistics, must be kept confidential.

Emission factor

The emission factor is calculated from the carbon dioxide emissions, as determined in keeping with the pertinent ETS-CO_2 balance, and from the production quantities involved. Since the production-quantity data, as taken from official statistics, has to be kept confidential, the relevant EF cannot be given here.

The coke quantity used in burning the relevant lime has been included in the Energy Balance as a non-energy-related use (i.e. without inclusion of CO_2 emissions).

4.3.7.3 Uncertainties and time-series consistency (2.B.7)

Activity data

There are uncertainties regarding the production statistics given by the Federal Statistical Office, since – for example – the relation between light and heavy soda ash fluctuates widely, especially in the first years for which separate statistics are provided.

[64] Other processes that are less important in terms of the production quantities involved are not considered here, because they use carbon dioxide from sources other than limestone.

[65] Ammonia-soda process pursuant to Ernst Solvay

The uncertainty of these statistical figures is confirmed by the producers, whose information is in agreement with notifications in the EU-ETS framework.

Emission factor

The uncertainty of the emission factor, with regard to production of soda ash, is calculated from the uncertainties for the ETS emission balance and the uncertainties for the pertinent production data.

4.3.7.4 Source-specific quality assurance / control and verification (2.B.7)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The CO_2 balance for determination of the relevant emissions is produced with the help of data from emissions trading. Those data have been fully checked and verified in the framework of the EU Emissions Trading System (ETS).

The production data are currently being evaluated by the producer with whom cooperation agreements are being sought.

4.3.7.5 Category-specific recalculations (2.B.7)

No recalculations are required.

4.3.7.6 Category-specific planned improvements (2.B.7)

Plans call for improving the data quality via the agreements with producers that are currently being sought. It is not known whether such improvements can have significant impacts on the pertinent emissions levels, however.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.8 Chemical industry: Petrochemical and carbon black production (2.B.8)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 B 8, Petrochemical and Carbon Black Production		CO_2	974.0	0.1%	792.9	0.1%	-18.6%
-/-	2 B 8, Petrochemical and Carbon Black Production		CH_4	333.7	0.0%	503.4	0.1%	50.9%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2 (carbon black) CS (petrochemical industry)	NS	D (carbon black) CS (petrochemical industry)
CH_4	Tier 1	NS	D
CO, SO_2	Tier 1 (carbon black)	NS	D (carbon black)
NMVOC	Tier 1 (petrochemical industry)	NS	C & CS (petrochemical industry)

The category *Chemical industry: Petrochemical and carbon black production* is not a key category. Carbon-black production predominates in this category, accounting for about 75 % of its emissions.

4.3.8.1 Chemical industry: Petrochemicals (2.B.8 Petrochemicals)

4.3.8.1.1 Category description (2.B.8 Petrochemicals)

The petrochemicals sector produces basic organic chemicals, from natural gas and from petroleum fractions, that are processed into a great many different intermediate and end products (primarily polymers). Under 2.B.8, the 2006 IPCC Guidelines (IPCC, 2006a) list production of the basic chemicals (a) methanol, (b) ethylene, (c) ethylene chloride and vinyl chloride, (d) ethylene oxide and (e) acrylonitrile on account of the carbon dioxide and methane emissions such production can entail.

Production of petrochemicals and derivatives, along with production of pharmaceuticals, production of fine and specialty chemicals and production of polymers, is one of the most important sectors of the chemical-pharmaceutical industry in terms of production value[66].

4.3.8.1.2 Methodological issues (2.B.8 Petrochemicals)

Activity data

No installation-related data are available with regard to production of the above products; only nationally aggregated production quantities are available. The data, for the period as of 1990, are provided to the Federal Environment Agency by the Federal Statistical Office on the basis of its Fachserie 4, Reihe 3.1, "Produzierendes Gewerbe, Produktion im Produzierenden Gewerbe" (Statistisches Bundesamt, FS 4, R 3.1). They include confidential data.

In official production statistics, petrochemicals and derivatives are listed as "other basic organic substances and chemicals" ("sonstige organische Grundstoffe und Chemikalien") under WZ-Nummer (number within the German Classification of Economic Activities) 20.14.

The data on acrylonitrile-production quantities are subject to confidentiality requirements. The production-quantity data for methanol and ethylene dichloride are subject to confidentiality requirements in certain years. For these reasons, all production quantities for the products in groups a) through e) are aggregated and then reported, together with the pertinent CO_2 and CH_4 emissions, under 2.B.8.g.

For determination of NMVOC emissions, production of products that have to be reported under the CLRTAP is also taken into account, in addition to production of the products in groups a) through e). Detailed reporting on products that have to be reported under the CLRTAP is provided in the Informative Inventory Reports (IIR) pursuant to the CLRTAP.

CO_2 emission factors

Since 2013, pursuant to Annex 1 Part 2 Activity No. 27 German Greenhouse Gas Emission Allowance Trading Act (TEHG), all of the installations located in Germany for production of the aforementioned organic basic chemicals have been subject to the EU Emissions Trading System (ETS), because their production outputs are greater than 100 t/d (36,500 t/a).

A comparison of a) the total CO_2 emissions of the ETS installations pursuant to a) through e) that have been reported for purposes of the greenhouse-gas-emissions-trading system with b) the CO_2 emissions for the year 2013 as calculated with the new IPCC standard emission factors shows that the standard emission factors lead to higher emissions. And this proves to be the case even though the total installation-related emissions from emissions trading include both emissions from combustion processes and other process-related emissions. In the German greenhouse-gas inventory, most combustion-related emissions are already taken into account via the energy statistics for the energy sector. The standard emission factors thus cannot be used – their use would result in double-counting.

Along with combustion processes in boilers and cracking furnaces, the CO_2 emission sources to be considered include combustion processes in flares, decoking processes and other process-related emissions.

[66] Chemiewirtschaft in Zahlen 2016, Verband der Chemischen Industrie e.V. (2017): https://www.vci.de/services/publikationen/broschueren-faltblaetter/chemiewirtschaft-in-zahlen.jsp

It would not be justified to quantify the other process-related emissions, since the installation-related CO_2 emissions of steam cracker units, which are far and away the largest group of emitters considered in this context, occur almost exclusively via combustion in cracking furnaces, auxiliary boilers or flares. With the exception of flares in the petrochemical industry, such combustion-related emissions are included in the energy-sector section in 1.A.2.c.

The CO_2 emissions from flaring losses are quantified, however, in order to fulfill the inventory aim of recording emissions as completely as possible. In future, decoking processes will also be included. Only that fraction of flare gases is considered that can be allocated to the aforementioned products in groups a) through e).

Since pre-2013 ETS data are not available for all of the aforementioned products, the CO_2 emissions are calculated on the basis of a CO_2 emission factor derived for 2013 and of the annually produced quantities of the relevant products.

Because residual gases and flare gases are often transported between installations (with different installations producing different products), it seems useful to use an emission factor that is aggregated over all of the products considered in this category. As a result of this aggregation, uncertainties in allocation of emissions of the aforementioned production processes to the products listed under a) through e) are taken into account, especially because CO_2 emissions from flares of the aforementioned installations are not necessarily tied to just one of the products in categories a) through e). At chemical industry sites, gases from various different production processes that need to be flared are often flared in a central flare that, in terms of its licensing, is allocated only to one production installation. As a result, in such cases, the emissions quantity allocated to a given product can be greater than the emissions quantity actually caused by the relevant production process. On the other hand, gases from processes a) through e) that need to be flared may be transported to a flare in an installation that is not considered in the present context, with the result that the emissions quantity considered is lower than the actual product-related emission quantity involved.

The flare emissions (ETS data) allocated to the various relevant chemical-industry installations for the year 2013 have been summed and then divided by the total production quantity for all products in a) through e) that were produced in 2013; this yields the emission factor for flaring losses (EFflaring). The flare emissions of the steam cracker units are refinery sites have been determined via the units' known capacities. The resulting EFflaring for the aforementioned petrochemicals is 28 kg/t product. That emission factor has been used to retroactively calculate annual emissions, using a Tier 1 method, back to 1990.

CH_4 emission factors

The IPCC Guidelines list all of the aforementioned installations as potential emission sources.

Pursuant to Point 5.2.5 of the TA Luft (Technical Instructions on Air Quality Control), German plants subject to the TA Luft must meet a standard of 50 mg/m^3 (total carbon) for total mass concentration of organic substances (NMVOC and CH_4, but not including organic substances in dust form). The current state of the art provides for thermal post-combustion of volatile organic substances from plants for production of primary organic chemicals.

A major German producer has reported that the methane emissions occurring in areas involving ethylene, methanol, ethylene dichloride and styrene are negligible, thanks to the thermal post-combustion processes employed since the 1980s.

No data from emissions trading can be used for reporting on methane emissions from chemical industry installations, since the currently valid German Greenhouse Gas Emission Allowance Trading Act (TEHG) of July 2011 does not mandate reporting on CH_4. Furthermore, since no information from other installation operators is available that could be used for quantification of CH_4 emissions, the methane emissions for all petrochemical industry installations as a whole are calculated via a Tier 1 method, with the 2006 IPCC standard emission factors (IPCC (2006a): Vol. 3, Ch. 3.9.2.2).

NMVOC emission factors

The NMVOC EF have been obtained from the relevant BREF (Best Available Techniques Reference Document) and from confidential figures provided by German producers. Until 1994, the default factors in EMEP/CORINAIR Emission Inventory Guidebook were used. Relevant detailed reporting is provided in the Informative Inventory Report pursuant to the CLRTAP.

4.3.8.1.3 Uncertainties and time-series consistency (2.B.8 Petrochemical industry)

CO_2

The "backward projection" of the aforementioned production-related emission factor for flaring losses, from the 2013 emissions reports to earlier years (back through 1990) is subject to large uncertainties. On the one hand, in many cases the flare emissions reported in the ETS for report year 2013 were determined and reported on the basis of estimates. On the other, it must be assumed that CO_2 emissions from the flares allocated to the relevant installations, under licensing law, cannot be completely assigned to production of the products in groups a) through e). For example, gases (including waste gases) from other production processes are burned in the flares under consideration here. What is more, over time, installations can make local internal changes in routing of waste gases from various processes. Such changes further increase the uncertainty of "back-calculated" product-specific emissions. In addition, the ratios of production quantities to flare gases, for the installations considered, can differ considerably in various years from the corresponding ratios in 2013.

Due to limited data availability, the possibility that some energy-sector items are being double-counted cannot be completely ruled out. Extrapolation of flare emissions of steam cracker units also contributes to the uncertainty of the emission factor. An uncertainty of ± 50 % is thus being assumed.

Consistency of the time series is assured, because a consistent method was used to calculate the emissions back through 1990, and because there are no gaps in the activity data and no jumps (discontinuities) in the emission factor.

CH_4

In the 1980s, thermal post-combustion was introduced on a large scale. As a result, point-source emissions of organic substances from German plants are likely to be low. Use of standard emission factors is probably leading to overestimation of the emissions. Since the resulting uncertainties cannot be estimated, the Tier-1-method uncertainties given in Table 3.27 of the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3) have been used.

Consistency of the time series is assured, because a consistent method was used to calculate the emissions back through 1990, and because there are no gaps in the activity data and no jumps (discontinuities) in the emission factors.

Activity data

The activity data have been taken from official statistics for which inaccuracies of ±20 in statistical data collection are assumed.

4.3.8.1.4 Category-specific quality assurance / control and verification (2.B.8 Petrochemical industry)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The quantity of ethylene produced in 2013, as reported by the Federal Statistical Office, was compared with capacity data provided by the Association of Petrochemical Producers in Europe (APPE; Petrochemicals Europe[67]). The resulting national standard capacity-utilisation factor of 0.858 is comparable to the standard capacity-utilisation factor pursuant to Article 18 (2) of Commission Decision 2011/278/EU (European Commission, 2011).

It is not possible to compare the national emission factor for CO_2 with the standard CO_2 emission factors given in the 2006 IPCC Guidelines, and with the emission factors of the other countries, because those emission factors do not include any CO_2 emissions from flares.

No further sources are available for data verification.

4.3.8.1.5 Category-specific recalculations (2.B.8 Petrochemical industry)

No recalculations are required.

4.3.8.1.6 Planned improvements, category-specific (2.B.8 Petrochemical industry)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.8.2 Chemical industry: Carbon black production (2.B.8 Carbon black)

4.3.8.2.1 Category description (2.B.8 Carbon black)

Carbon black is produced via incomplete combustion of gaseous or liquid hydrocarbons. Defined specifications for carbon black are achieved by carefully controlling and monitoring production processes. In Germany, carbon black is produced from hard-coal-tar oils (anthracene oils) and from oils produced by petroleum refineries (pyrolysis / cracking oils).

A total of 90 % of the carbon black produced in Germany is produced via the furnace black process. The remaining 10 % is produced via the flame-pressure and gas black processes.

4.3.8.2.2 Methodological issues (2.B.8 Carbon black)

CO_2 emissions

A comparison of the CO_2-emissions figures reported to date, on the basis of production data of the Federal Statistical Office, with the figures reported to the German Emissions Trading Authority (DEHSt) showed that the figures reported to the DEHSt are considerably lower. An additional installation, which is not subject to emissions-trading requirements, has been considered in this regard, but its CO_2 emissions do not suffice to explain this difference. Consultations with the existing data supplier suggested that sales figures – instead of production figures – are being reported in some cases for the production statistics being used. The activity data used to date was thus too high, to a considerable degree. As of 2005, therefore, the DEHSt emissions figures are used and, with the default emission factor from the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 3.23, Furnace Black Process (default process), primary feedstock),

[67] Website: http://www.petrochemistry.eu

the activity data are back-calculated. The emissions of one installation that is not subject to emissions-trading requirements are reported by the operator directly to the Federal Environment Agency (UBA). One installation (subject to emissions-trading requirements) was decommissioned in 2016. Five installations, operated by a total of two operators, are still in operation in Germany.

CH_4 emission factors

The international guidelines give very little attention to this source category. The IPCC Guidelines list carbon black production as a potential emission source.

Pursuant to Point 5.2.5 of the TA Luft (Technical Instructions on Air Quality Control), German plants subject to the TA Luft must meet a standard of 50 mg/m^3 (total carbon) for total mass concentration of organic substances (NMVOC and CH_4, but not including organic substances in dust form). In keeping with these technical standards, the three German producers of carbon black report an emission factor of 0.027 kg methane per tonne of carbon black. Since the relevant technology has been in service since the 1970s, this EF is rounded off to 0.03 kg/t and applied to the entire time series.

Emission factors for NMVOC, CO and SO_2

For pollutants other than the methane considered above, the emission factors listed in the following table were used for Germany.

Table 179: Emission factors used in Germany for other pollutants

	Carbon black [kg CO / t]	Carbon black [kg SO_2/t][68]
1990	4.8 / 5	19.5 / ([69])
1991	4.6 / 5	19 / 20
1992	4.4 / 5	18.5 / 20
1993	4.2	18
1994	4	17.5
1995	3.75	17
1996	3.5	16
1997	3.25	15
1998	3	14
1999	2.9	13.4
2000	2.8	12.8
2001	2.7	12.54
2002	2.65	12.28
2003	2.6	12.0
2004	2.55	11.7
2005	2.5	11.5
2006	2.5	11.2
2007	2.5	10.9
2008	2.5	10.6
2009	2.5	10.3
As of 2010	2.5	10.0

The EF figures for CO and SO_2, for production of carbon black, are based on the BREF Large Volume Inorganic Chemicals - LVIC – S (European Commission, 2007b) and are identical with the default values presented in the 2008 CORINAIR manual (first order draft).

[68] Where two EF are listed, the second figure refers to the new German Länder.

[69] No EF is listed for the new German Länder, since these SO_2 emissions can be taken account of only as a lump sum.

Activity data

The production statistics of the Federal Statistical Office include the following products (cf. the following table).

Table 180: Reporting numbers (Meldenummern) from production statistics

Line	Carbon black
through 1994	4113 70
from 1995 through 2005	2413 11 300

The figure for carbon-black production in the new German Länder in 1990 was taken from the Statistical Yearbook (Statistisches Jahrbuch) for the Federal Republic of Germany (Statistisches Bundesamt (1992): p. 234); the figures for 1991 and 1992 were estimated, due to confidentiality requirements. The other data for carbon black production as of 1990 have been taken from the Federal Statistical Office (Statistisches Bundesamt (FS 4, R 3.1): Produzierendes Gewerbe, Produktion im Produzierenden Gewerbe ("Manufacturing industries, production in manufacturing industries")). For the period as of 2005, the activity data are back-calculated from the CO_2 emissions, using the default CO_2 emission factor.

4.3.8.2.3 Uncertainties and time-series consistency (2.B.8 Carbon black)

While the activity data are seen to fluctuate somewhat over time, their fluctuations are largely in keeping with global economic fluctuations.

4.3.8.2.4 Category-specific quality assurance / control and verification (2.B.8 Carbon black)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

4.3.8.2.5 Category-specific recalculations (2.B.8 Carbon black)

No recalculations are required.

4.3.8.2.6 Planned improvements, category-specific (2.B.8 Carbon black)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.9 Chemical industry: Production of halocarbons and SF_6 (2.B.9)

KC	Category	Activity	EM of	1995 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1995-2020
L/T	**2 B 9 a, By-product Emissions**		**HFC-23**	**C**	**C**	**C**	**C**	**C**
-/-	2 B 9 b, Fugitive Emissions		HFC-134a	C	C	C	C	C
-/-	2 B 9 b, Fugitive Emissions		HFC-227ea	C	C	C	C	C
-/-	2 B 9 b, Fugitive Emissions		CF_4	C	C	C	C	C
-/-	2 B 9 b, Fugitive Emissions		SF_6	159.6	0.0%	0.9	0.0%	-99.4

Gas	Method used	Source for the activity data	Emission factors used
HFCs	Tier 3	PS	PS
SF_6	Tier 3	PS	PS

The category *Production of halocarbons* is a key category, in terms of emissions level and trend, for HFC-23 emissions from by-products. It is subdivided into 2.B.9.a By-product emissions and 2.B.9.b Fugitive emissions.

4.3.9.1 By-product emissions (2.B.9.a)

4.3.9.1.1 Category description (2.B.9.a)

For process-related reasons, production of HCFC-22 produces up to 3 % HFC-23 as a by-product. For technical reasons, even when the HFC-23 is subjected to further processing (for example, to produce refrigerants) or is collected and then broken down into other substances, some HFC-23 is always released into the atmosphere.

Germany formerly had two production plants for HCFC-22. Those two plants, which were operated by a single company, were located in Frankfurt and Bad Wimpfen. In 1995, a CFC-cracking plant went into operation in Frankfurt that cracked, at high temperature, excess HFC-23 produced during production of HCFC-22 and that recovered hydrofluoric acid; i.e. no significant emissions were produced. HFC-23 produced at the second German production facility was captured in large amounts at the production system itself; the substance was then sold as a refrigerant or – following further distillative purification – as an etching gas for the semiconductor industry. Beginning in 1999, the excess amount that could not be sold was delivered to the cracking facility in Frankfurt. That measure substantially reduced emissions. In mid-2010, HCFC-22 production was terminated at one site. At the other site, it was significantly reduced, and all remaining production serves teflon production. The production quantities have remained at a constant low level since then. Since the installation is directly connected to a CFC-cracking plant, only very slight emissions occur.

4.3.9.1.2 Methodological issues (2.B.9.a)

In keeping with manufacturer information from 1996, HFC -23 emissions are assumed to have remained constant in the years 1990 through 1994.

Beginning in 1995, the producer calculated emissions, via a mass-balance procedure, on the basis of HCFC-22 production, HFC-23 concentrations in exhaust gas (as measured annually), sales of HFC-23 and quantities of HFC-23 delivered to the cracking plant. For reporting year 1995, emissions-reduction measures (the cracking plant) for the first production plant were assumed to have been in place since mid-year. Since report year 2011, the relevant production quantities have been estimated by experts, and the resulting estimates have been used to determine the emissions. The estimates are made in light of comparable production facilities in other European countries. In 2019, the relevant assumptions were reviewed with the responsible industry representative.

Activity data

There is only one HCFC producer in Germany. That company's data, therefore, are subject to confidentiality. Until 2010, the emissions and production quantities were reported to the Federal Environment Agency, but only in aggregated form. Since 2011, data of the Federal Statistical Office have been used. The activity data for HFC-23 are reported together with those for HFCs, PFCs and SF_6, as an "unspecified mix," in 2.B.9.

Emission factors

It is assumed that unwanted quantities of HFC-23 on the order of 0.03kg / kg HCFC-22 have been produced since 2011. The relevant emission factor is thus 0.015 kg / kg HCFC-22. Although unwanted production of R23 is now lower, the possibility that such production will increase again in future cannot be ruled out. For this reason, the emission factor has not been reduced.

Since the relevant plant is connected to a pipeline network that is connected directly to an HCFC-cracking plant, the resulting emissions quantities are very small. The emissions factor of 0.015 kg / kg HCFC-22 lies within the emission-factor range given in the Guidebook. Under Table 3.28

(2006 IPCC GLs, Vol 3), the Guidebook notes, "EF for optimized large plants may go down to 0.014 kg HFC-23 / kg HCFC-22 produced."

Emissions

Until 2010, the relevant HFC-23 emissions were reported by the producer. Since 2011, experts' assessments have been relied on as well.

Since there are fewer than three producers in Germany, the emissions data are confidential. The HFC-23 emissions are reported as an "unspecified mix" in 2.B.9, as an aggregate of 2.B.9a and 2.B.9b.

4.3.9.1.3 Uncertainties and time-series consistency (2.B.9.a)

The assumptions on which the emissions calculations are based are reviewed, at long, regular intervals, with industry. With uncertainties of 3%, they are considered to be quite precise.

4.3.9.1.4 Source-specific quality assurance / control and verification (2.B.9.a)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

No other data sources, apart from the data provided by the Federal Statistical Office and the producer, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. Comparisons with other countries have revealed no requirements for improvements. The emission factors are of the same order of magnitude as those of other European countries.

4.3.9.1.5 Category-specific recalculations (2.B.9.a)

No recalculations are required.

4.3.9.1.6 Category-specific planned improvements (2.B.9.a)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.9.2 Production-related emissions (2.B.9.b)

4.3.9.2.1 Category description (2.B.9.b)

In Germany, one company produces these gases; its HFC und SF_6 production takes place at two locations. Emissions trends are tied to trends in amounts produced. While SF_6 and HFC-134a are produced in Germany, until 2008 no complete synthesis of HFC-227ea was carried out in Germany. Part of the HFC-227ea produced in Tarragona, Spain, undergoes subsequent distillation, in Germany, to pharmaceutical purity (use in dosing aerosols). That process produces emissions as a result of minor gas losses.

HFC-134a has been produced since 1994, while HFC-227ea has been produced since 1996.

Emissions of HFC-134a have remained relatively constant since 2011. The fluctuations seen result from slight differences in annual production quantities.

Emissions of HFC-227ea have been increasing since 2009, in parallel with increases in production quantities. An exception is seen in 2012, in which less HFC-227ea was sold, and thus the emissions level was lower.

Between 1990 and 1994, CF_4 (PFC-14) was also produced in Germany.

Emissions from SF_6 production have decreased sharply since 2014, when a plasma torch for waste-air treatment was installed.

4.3.9.2.2 Methodological issues (2.B.9.b)

Emission factors

Emission factors have been calculated from the emissions and production quantities reported by the producer until 2009. Emissions-reducing measures have further lowered the emission factor for SF_6 for the period as of 2014. In 2019, all emission factors were reviewed via discussions with industry representatives.

Activity data

Since in Germany each HFC is produced by only one producer, the relevant companies' data are confidential. Until 2010, the emissions and production quantities were reported to the Federal Environment Agency, but only in aggregated form. Since 2011, data of the Federal Statistical Office have been used.

4.3.9.2.3 Uncertainties and time-series consistency (2.B.9.b)

The production figures used as a basis for emissions calculation may be considered highly accurate, since they come directly from the producer's internal records or from official statistical surveys. The uncertainties for the emissions are assumed to be 3%.

4.3.9.2.4 Source-specific quality assurance / control and verification (2.B.9.b)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

No other data sources, apart from the data provided by the Federal Statistical Office, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. Comparisons with other countries have revealed no requirements for improvements. The emission factors are of the same order of magnitude as those of other European countries.

4.3.9.2.5 Category-specific recalculations (2.B.9.b)

No recalculations are required.

4.3.9.2.6 Category-specific planned improvements (2.B.9.b)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.3.10 Chemical industry – other: Emissions from other production processes (2.B.10)

KC	Category	Activity	EM of	1995 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1995-2020
-/-	2 B 10, Other		N_2O	IE	IE	IE	IE	IE
-/-	2 B 10, Other		CH_4	59.5	0.0%	59.5	0.0%	-0.1%

The category *Other: Emissions from other production processes* is not a key category.

4.3.10.1 Category description (2.B.10)

The GHG precursor substances from production of fertilisers and sulphuric acid are reported in this category. While N_2O emissions from production of dodecanedioic acid are described here, they are included in 2.G.3, for reasons of confidentiality. Among dicarboxylic acids, dodecanedioic acid ranks second, in terms in terms of the quantities involved. It is surpassed only by adipic acid in this regard. There is one producer in Germany.

In addition, in the area of "Storage of chemical products" all petroleum products are considered that are not used as fuels (cf. in this regard Chapter 3.3.2.1.4).

Table 181: Emission factors used for category 2.B.10, "Storage of liquid petroleum products in tank-storage facilities outside of refineries"

Gas	Emission factor	Method	Source
CH_4	5 g/m³	Tier 2	Expert estimate
NMVOC	100 g/m³	Tier 2	Expert estimate

Table 182: Emission factors used for category 2.B.10, "Storage of gaseous petroleum products in tank-storage facilities outside of refineries"

Gas	Emission factor	Method	Source
CH_4	150 g/m³	Tier 2	Expert estimate
NMVOC	500 g/m³	Tier 2	Expert estimate

4.3.10.2 Methodological issues (2.B.10)

N_2O emissions

The N_2O emissions are calculated via a Tier 2 method. The relevant production-quantity data were taken from a one-time query of the producer. The data are carried forward. The N_2O emissions have been greatly reduced, via waste-gas treatment in a treatment facility.

Tank-storage facilities outside of refineries

According to Müller-BBM (Bender, 2009a), no emission factors can be derived, via evaluation of emissions declarations for storage systems, that would be representative of individual systems. This is due, so the same source, to the clearly widely differing emissions behaviour of different individual systems. It was possible, however, to form aggregated emission factors. For each relevant group of data, this was done by correlating the sums of all emissions with the sums of all capacities. For non-refinery tank-storage systems, storage of liquid petroleum products can be differentiated from storage of gaseous petroleum products, since the relevant data are suitably differentiated. The emissions of gaseous petroleum products are assigned to the area of storage of chemical products (CRF 2.B.10). In addition, liquid petroleum products are broken down, with the help of a split factor, into the areas of a) fuels and b) chemical products. While fuels are reported in 1.B.2, chemical products are reported in 2.B.10.

4.3.10.3 Uncertainties and time-series consistency (2.B.10)

Time-series consistency is assured, because the data set resulting from one-time data collection has also been applied to the other years involved. Since the figures are based on qualitative information provided by the producer, and refer only to one year, uncertainties of ± 20 % have to be assumed.

4.3.10.4 Source-specific quality assurance / control and verification (2.B.10)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

4.3.10.5 Category-specific recalculations (2.B.10)

The reclassification of the area of stored petroleum products led to recalculations in categories 1.B.2.a and 2.B.10. The total sum of emissions did not change as a result, however.

4.3.10.6 Category-specific planned improvements (2.B.10)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.4 Metal production (2.C)

Category 2.C is divided into the sub-categories 2.C.1 through 2.C.7. In the CSE emissions database, the sub-category Iron and steel production (2.C.1) includes sinter production, pig-iron production, production of direct-reduced iron (DRI), iron and steel production and production of tempered castings. Production of ferroalloys (2.C.2) has only minor importance in Germany. For this reason, it is not further subdivided in the present report. Aluminium production (2.C.3) is sub-divided into primary aluminium and resmelted aluminium. Use of SF_6 in aluminium and magnesium production (2.C.4) is not further sub-divided. In the Central System of Emissions (CSE), sub-point (2.C.5) comprises lead production. (2.C.6) comprises zinc production. (2.C.7) includes copper production (2.C.7a), nickel production (2.C.7b) and other production (2.C.7c). No greenhouse-gas emissions result in Germany from these categories.

4.4.1 Metal production: Iron and steel production (2.C.1)

4.4.1.1 Category description (2.C.1)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**2 C 1, Iron and Steel Production**		**CO_2**	**22,810.3**	**1.8%**	**14,538.1**	**2.0%**	**-36.3%**
-/-	2 C 1, Iron and Steel Production		N_2O	26.5	0.0%	12.0	0.0%	-54.9%
-/-	2 C 1, Iron and Steel Production		CH_4	4.7	0.0%	4.4	0.0%	-6.4%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	NS	CS
CH_4	Tier 2	NS	CS
N_2O	CS	NS	CS
NO_X, CO, NMVOC, SO_2	Tier 2	NS	CS

The category *Iron and steel production* is a key source of CO_2 emissions in terms of emissions level and trend. Along with carbon dioxide, slight emissions of methane and nitrous oxide also occur in this category. The methane emissions result from production of rolled steel and from production of iron, steel and malleable cast iron. The nitrous oxide originates in primary steel production, in connection with use of blast furnace gas in hot-blast stoves.

Since the CRF-Reporter software does not allow nitrous oxide to be allocated to 2.C.1, it is reported in 2.C.7 instead.

In 2020, a total of 24.1 t million t of raw steel, from ore, was produced in Germany in six integrated steel works. Electric steel production amounted to 11.5 million t.

4.4.1.2 Methodological issues (2.C.1)

This sector comprises process-related emissions from primary steel production (via sinter plants, blast furnaces and oxygen-steel plants) and from electric steel plants.

Other structural elements in this category (foundries: iron and steel casting (including malleable casting); steel production: rolled-steel production) are used for calculation of other pollutant emissions (not greenhouse-gas emissions).

Process-related CO_2 emissions from primary steel production in integrated smelters result primarily from use of reducing agents in blast furnaces. $_2$ emissions from limestone inputs in sinter plants and in pig-iron production (including the CO_2 emissions from the lime kilns operated by the steel industry), and $_2$ emissions from electrode consumption in electric steel production, are added to the process-related emissions in sector 2.C.1.

Very little direct-reduced iron (DRI; sponge iron) is produced in Germany (only about 0.6 million t. per year). Annual production-quantity data are available for the entire time series, but they are confidential, because they refer solely to a single installation.

The CO_2 emissions that occur in DRI production result from the use of natural gas, i.e. from use of a reducing-agent mixture, comprising H_2 and CO, obtained from natural gas. The relevant quantities of natural gas used are included, throughout the entire time series, in the natural-gas inputs in the steel industry that are reported under 1.A.2.a. Consequently, the CO_2 emissions resulting from DRI production are also included, throughout the entire time series, in the emissions reported under 1.A.2.a.

The process-related CO_2 emissions from DRI production cannot be listed separately under 2.C.1, because a) no separate data on the pertinent natural gas quantities consumed are available, for reasons of confidentiality; and b) because such disclosures could be used to derive the confidential production-quantity data for the relevant installation.

Method for calculating the CO_2 emissions resulting from use of reducing agents in blast furnaces

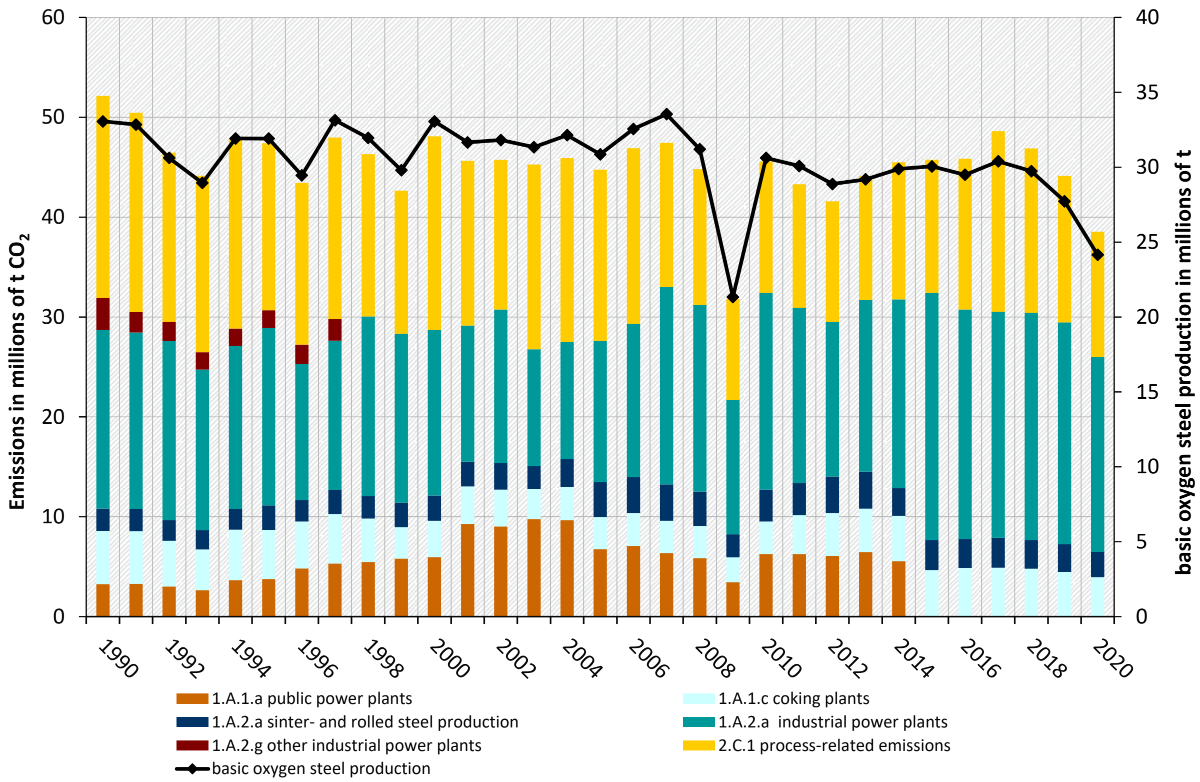
Pursuant to the IPCC Guidelines, the CO_2 emissions in category 2.C.1 are to be determined via a carbon balance. The reason for this requirement is that virtually all of the carbon used for primary steel production is subsequently released into the atmosphere, as CO^2, in later energy-related use, or in flaring of the blast furnace gas that forms in the blast furnace or of the basic oxygen furnace gas that forms in the oxygen steel converter. The fraction of pig iron that is not converted into steel is less than 1 %. For this reason, the carbon fraction it contains is not relevant (about 0.1 %) by comparison with the CO_2 emissions tied to inputs of reducing agents. A similar situation applies with regard to the carbon fraction in manufactured steel. A rough calculation places the size of that fraction at about 60,000 t/a, meaning it is equivalent to the carbon inputs via the input raw materials (ores and scrap)[70].

The inputs of reducing agents in blast furnaces, and material inputs in converters, are statistically recorded in great detail. The German Steel Federation (WV Stahl) provides the

[70] The average carbon fraction in the more than 2,000 types of steel produced in Germany is not recorded statistically. According to the steel plants taking part in emissions trading, the average carbon content of manufactured raw steel is estimated to be 0.15 %. A rough calculation indicates that the non-energy-related carbon discharge via the manufactured steel is equivalent to the carbon input via iron ore (which has a carbon content of about 0.1 %) and recycled scrap (a carbon content of about 0.15 %),

relevant data to the Federal Environment Agency annually. The carbon content in the various materials used is calculated from emissions trading data. CO_2 emission factors for use of blast furnace gas and basic oxygen furnace gas are also available from emissions trading. The input gas quantities are taken from energy statistics. Calculation on the basis of a) carbon inputs and of b) carbon removals via use of blast furnace gas / basic oxygen furnace gas yields a difference. Those CO_2 emissions are reported in category 2.C.1. Only part of all energy-related use of blast furnace gas and basic oxygen furnace gas takes place in category 2.C.1 (this the energy-related use in hot-blast stoves in blast furnaces). Such gas is also used for other process combustion in the iron and steel industry (1.A.2.a); in coking plants, for bottom heating of coking furnaces (1.A.1.c); and for electricity generation in public power stations (1.A.1.a) and industrial power stations (1.A.2.f). Energy statistics provide data on consumption of blast furnace gas and basic oxygen furnace gas in all of the aforementioned categories. Consequently, the CO_2 emissions resulting from reducing-agent inputs for primary steel production are divided among all categories in which blast furnace gas and basic oxygen furnace gas are burned and, thus, CO_2 is actually emitted (cf. the following figure).

Figure 41: CO_2 emissions from use of reducing agents for primary steel production and from use of blast furnace gas – chronological sequence, and category allocation



The sum of the CO_2 emissions shown correlates well with the activity data reported for primary steel production (cf. the black line). Annual fluctuations in the individual categories are probably due to changes in allocation of individual plants within official statistics. Such fluctuations have practically no impact on the total sum of reported emissions, however.

Table 183: CO_2 emissions from primary steel production (including use of blast-furnace gas)

Mt CO_2	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
1.A.1.a Public power stations	3.244	3.291	3.015	2.631	3.647	3.764	4.816	5.305	5.465	5.808
1.A.1.c Coking plants	5.340	5.251	4.590	4.083	5.066	4.924	4.707	4.969	4.362	3.145
1.A.2.a Sinter and rolled-steel production	2.228	2.256	2.046	1.936	2.081	2.445	2.151	2.419	2.255	2.444
1.A.2.a Industry power stations	17.886	17.660	17.927	16.098	16.326	17.759	13.624	14.935	17.975	16.933
1.A.2.f Other industry power stations	3.206	2.025	1.942	1.707	1.720	1.770	1.932	2.144	0.000	0.000
2.C.1 Process emissions	20.228	19.961	16.942	17.693	19.074	16.736	16.204	18.194	16.255	14.317
Mt CO_2	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
1.A.1.a Public power stations	5.956	9.284	9.030	9.766	9.640	6.738	7.086	6.370	5.851	3.425
1.A.1.c Coking plants	3.652	3.741	3.684	3.029	3.356	3.247	3.281	3.226	3.226	2.500
1.A.2.a Sinter and rolled-steel production	2.520	2.487	2.629	2.265	2.788	3.461	3.603	3.642	3.437	2.315
1.A.2.a Industry power stations	16.573	13.627	15.406	11.709	11.695	14.164	15.351	19.748	18.675	13.429
1.A.2.f Other industry power stations	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.C.1 Process emissions	19.379	16.493	14.979	18.509	18.418	17.154	17.586	14.452	13.614	10.135
Mt CO_2	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
1.A.1.a Public power stations	6.276	6.258	6.080	6.465	5.533	0.014	0.000	0.000	0.000	0.000
1.A.1.c Coking plants	3.245	3.895	4.289	4.341	4.554	4.648	4.872	4.905	4.809	4.479
1.A.2.a Sinter and rolled-steel production	3.198	3.217	3.646	3.715	2.787	3.015	2.912	2.987	2.872	2.752
1.A.2.a Industry power stations	19.705	17.553	15.512	17.173	18.890	24.735	22.955	22.631	22.757	22.224
1.A.2.f Other industry power stations	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2.C.1 Process emissions	13.144	12.367	12.046	12.429	13.717	13.344	15.101	18.075	16.450	14.667
Mt CO_2	**2020**	**2.021**	**2.022**	**2.023**	**2.024**	**2.025**	**2.026**	**2.027**	**2.028**	**2.029**
1.A.1.a Public power stations	0.000									
1.A.1.c Coking plants	3.943									
1.A.2.a Sinter and rolled-steel production	2.544									
1.A.2.a Industry power stations	19.495									
1.A.2.f Other industry power stations	0.000									
2.C.1 Process emissions	12.573									

In the iron and steel industry, secondary fuels are used only in pig iron production in blast furnaces. To date, these materials have not yet been included in national statistics and the Energy Balance. For this reason, the data used consisted of figures provided by the Wirtschaftsvereinigung Stahl steel-industry association. Since the secondary fuels are used solely as substitute reducing agents, in place of coke, the CO_2 emissions resulting from their use are also included in the CO_2 emissions determined via inputs of blast furnace gas and basic oxygen furnace gas and do not have to be calculated separately.

Determination of CO_2 emissions from limestone inputs in pig iron production

CO_2 emissions from limestone use are determined in accordance with Tier 1 (Lechtenböhmer et al. (2006a), FKZ 20541217/02). The steel industry uses limestone ($CaCO_3$) in sintering plants and in pig iron production in blast furnaces. In oxygen-steel and electrical-steel plants, on the other hand, burnt steelworks lime (CaO) is used as a slag former. As a rule, it is purchased from the lime industry. The CO_2 emissions released in production of such purchased burnt lime are already being reported in 2.A.2. Only one steel mill meets its lime requirements with the help of lime kilns of its own whose production quantities, and related CO_2 emissions, are not included in the data reported under 2.A.2. The quantities produced by these lime kilns has been estimated on the basis of available figures for the mill's crude-steel production (for a more precise description, cf. the 2016 NIR).

From the so-determined activity data, only the raw-material-related CO_2 emissions, calculated via a stoichiometric EF, are reported in 2.C.1 – in a procedure similar to that used for 2.A.2 (cf. Table 184). The CO_2 emissions from energy inputs in steel mills' own lime kilns, emissions which are not separately listed in the Energy Balance, are included in the emissions reported under 1.A.2.a.

Until 2004, limestone inputs in sinter and pig iron production were published as part of iron and steel statistics ((Statistisches Bundesamt, FS 4, R 8.1)). Since then, they have to be calculated from the production quantities of sinter and pig iron reported by the association, via specific input factors (i.e. kg of limestone per tonne of sinter or pig iron) (reported in the framework of the so-called "BGS form" (Fuel, gas and electricity industries of blast furnaces, steelworks and rolling mills; and forging plants, press works and hammer mills, including the various other plants (without their own coking plants)). Multiplying the activity data for limestone inputs by the stoichiometric emission factor for limestone produces the CO_2-emissions figures given in Table 184.

Table 184: Limestone inputs in the steel industry; and the steel industry's own production of burnt lime, and the resulting CO_2 emissions

Year	Limestone input [t/a]		Own production	CO_2 emissions [t/a]		
	Blast furnaces AD	Sinter plant AD	Burnt lime [t/a] AD	Limestone inputs EF 440 kg/t	Lime production EF 746 kg/t	Total
1990	755,737	4,680,775	153.918	2,392,065	114,823	2,506,888
1991	757,000	4,532,000	147,439	2,327,160	109,990	2,437,150
1992	666,000	4,198,000	136,560	2,140,160	101,874	2,242,034
1993	627,000	3,891,000	129,458	1,987,920	96,575	2,084,495
1994	733,000	4,173,153	140,003	2,158,707	104,443	2,263,150
1995	751,000	4,600,000	139,973	2,354,440	104,420	2,458,860
1996	686,000	4,350,000	129,177	2,215,840	96,366	2,312,206
1997	629,000	4,471,000	145,351	2,244,000	108,432	2,352,432
1998	677,000	4,588,000	140,157	2,316,600	104,557	2,421,157
1999	817,000	4,144,000	130,704	2,182,840	97,505	2,280,345
2000	924,000	4,273,000	144,991	2,286,680	108,163	2,394,843
2001	866,000	4,136,000	138,859	2,200,880	103,588	2,304,468
2002	831,000	3,940,000	139,538	2,099,240	104,096	2,203,336
2003	832,525	4,046,711	137,468	2,146,864	102,551	2,249,415
2004	847,689	4,209,871	140,977	2,225,326	105,169	2,330,495
2005	787,724	4,306,067	134,550	2,241,268	100,374	2,341,642
2006	822,920	4,410,408	162,500	2,302,664	121,225	2,423,889
2007	840,868	4,608,067	149,500	2,397,531	111,527	2,509,058
2008	790,216	4,541,174	136,500	2,345,812	101,829	2,447,641
2009	547,680	3,496,405	97,500	1,779,397	72,735	1,852,132
2010	799,679	4,045,042	130,000	2,131,677	96,980	2,228,657
2011	782,420	4,097,270	123,500	2,147,063	92,131	2,239,194
2012	757,355	3,912,824	117,000	2,054,879	87,282	2,142,161
2013	760,932	3,926,706	130,000	2,062,561	96,980	2,159,541
2014	782,447	3,945,838	130,000	2,080,446	96,980	2,177,426
2015	794,999	3,987,196	149,500	2,104,166	111,527	2,215,693
2016	780,445	3,750,267	149,500*)	1,993,514	111,527*)	2,105,041
2017	797,856	4,120,243	149,500*)	2,163,964	111,527*)	2,275,491
2018	779,356	3,926,906	149,500*)	2,070,755	111,527*)	2,182,282
2019	727,895	4,003,122	149,500*)	2,081,647	111,527*)	2,193,174
2020	644,097	3,375,375	149,500	1,768,568	111,527*)	1,880,095

Source: Until 2004: Calculation of limestone inputs by the "limestone balance" project ((Lechtenböhmer et al., 2006a), FKZ 20541217/02);
as of 2005: Calculation via the product-specific factors determined in the aforementioned project
*) Updated via expert judgement, due to a lack of data on raw-steel production of the relevant plant

Determination of CO_2 emissions from electrode consumption in production of electrical steel

In electrical steel production, CO_2 emissions occur directly via consumption (combustion) of graphite electrodes. These emissions must also be allocated to process-related CO_2 emissions for steel production. They are calculated from the quantity of produced electrical steel, via an emission factor (7.4 kg/t) that was updated in 2009, in a research project (Hensmann et al., 2012), and that is based on the specific electrode consumption per tonne of electrical steel (2.06 kg/t), its carbon content (98%) and the relevant stoichiometric factor (3.667 t CO_2 / t C). The contribution from electrode combustion in electrical steel production, at about 0.2% of total CO_2 emissions in iron and steel production, is insignificant.

Determination of the total CO_2 emissions from iron and steel production to be reported under 2.C.1

The total process-related emissions to be reported under 2.C.1 consist of the following:

1. the CO_2 emissions resulting from use of reducing agents in primary steel production, where the relevant blast furnace gas and basic oxygen furnace gas is not used in other categories and thus reported under other categories as CO_2 emissions,
2. the CO_2 emissions from limestone inputs in pig iron production and from the steel industry's own production of burnt lime, and
3. the CO_2 emissions from electrode consumption in electrical steel production.

The relevant so-determined emissions quantities are shown in Table 185.

Table 185: Total process-related emissions to be reported under 2.C.1

Year	CO_2 emissions from use of reducing agents, where not reported in other categories [t/a]	CO_2 emissions from limestone inputs and from the steel industry's own production of burnt lime [t/a]	CO_2 emissions from electrode consumption [t/a]	2.C.1 total [t/a]
1990	20,228,163	2,506,888	75,242	**22,810,293**
1991	19,960,553	2,437,150	68,464	**22,466,167**
1992	16,942,152	2,242,034	64,358	**19,248,544**
1993	17,692,711	2,084,495	59,840	**19,837,046**
1994	19,074,282	2,263,150	65,783	**21,403,215**
1995	16,736,415	2,458,860	74,794	**19,270,069**
1996	16,204,219	2,312,206	76,291	**18,592,716**
1997	18,193,667	2,352,432	87,552	**20,633,651**
1998	16,255,161	2,421,157	89,196	**18,765,514**
1999	14,316,676	2,280,345	90,456	**16,687,477**
2000	19,378,698	2,394,843	98,250	**21,871,792**
2001	16,493,071	2,304,469	96,959	**18,894,499**
2002	14,978,738	2,203,335	97,379	**17,279,452**
2003	18,508,674	2,249,415	99,046	**20,857,135**
2004	18,418,361	2,330,495	104,981	**20,853,837**
2005	17,153,961	2,341,642	100,778	**19,596,381**
2006	17,586,218	2,423,890	108,203	**20,118,311**
2007	14,451,531	2,509,058	110,718	**17,071,307**
2008	13,614,398	2,447,641	107,945	**16,169,984**
2009	10,134,642	1,852,132	83,587	**12,070,361**

Year	CO_2 emissions from use of reducing agents, where not reported in other categories [t/a]	CO_2 emissions from limestone inputs and from the steel industry's own production of burnt lime [t/a]	CO_2 emissions from electrode consumption [t/a]	2.C.1 total [t/a]
2010	13,144,494	2,228,658	97,446	**15,470,598**
2011	12,367,111	2,239,195	104,741	**14,711,047**
2012	12,046,280	2,142,161	101,676	**14,290,117**
2013	12,428,654	2,159,541	99,245	**14,687,440**
2014	13,716,522	2,177,426	96,314	**15,990,262**
2015	13,344,183	2,215,693	93,401	**15,652,946**
2016	15,100,844	2,105,041	93,193	**17,298,748**
2017	18,075,302	2,275,491	97,530	**20,446,702**
2018	16,450,331	2,182,283	93,669	**18,726,283**
2019	14,667,114	2,193,174	88,099	**16,948,075**
2020	12,572,923	1,880,095	85,360	**14,538,074**

4.4.1.3 Uncertainties and time-series consistency (2.C.1)

The time series is consistent, since the activity data have been determined for all plants and since the same method has been used to determine the emissions for all years concerned. As a result of problems under competition law, the German Steel Federation (WV Stahl) was unable to provide the activity data for the year 2017 as agreed. For this reason, aggregated data from emissions trading have been used as substitutes for the 2017. The consistency of the emissions trading data has been checked against comparable values for previous years. Those checks have shown that the pertinent discrepancies are less than 1%, with the exception of those for sinter production (slightly higher; up to a maximum of + 8%).

Regarding CO_2 emissions from limestone inputs, a discontinuity in methods occurred from 2004 to 2005. It resulted because the data source used until 2004 was no longer available after 2004. The time-series trend seems plausible in spite of this discontinuity. In keeping with the required calculation, the uncertainty for the activity data here is ± 10%. The uncertainty is also relatively high for the activity data for the steel industry's own production of burnt lime, which production has been estimated on the basis of several assumptions. The related CO_2 emissions are comparatively insignificant, however.

The uncertainty of the emission factor for electrode consumption is ± 3 %, while the uncertainty for the other data is ± 5 %. The uncertainties are due solely to imprecision in measurement and analysis.

4.4.1.4 Source-specific quality assurance / control and verification (2.C.1)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Pursuant to a cooperation agreement with the Wirtschaftsvereinigung Stahl German steel industry association, that association compiles the activity data and transmits them to the Federal Environment Agency on an annual basis. The relevant time series seems plausible and shows no inconsistencies. It is assumed that collection of these data conforms to quality assurance criteria, in keeping with the agreement.

Determining emissions in categories 1.A.2.a and 2.C.1 is a complex task, since the Energy Balance, emissions reporting, emissions trading and association statistics differ widely in terms of their underlying methods. In the interest of data quality assurance, and as the occasion requires, industry experts and experts of the Single National Entity carry out regular experts' discussions for the purpose of comparing and evaluating data. As a result of the methodological differences, plausibility checks of the determined emissions quantities, using data of the German emissions trading authority, are possible only at a highly aggregated level.

The implied emission factors (IEF) obtained by the Climate Secretariat cannot be used to carry out plausibility checks of the emissions determined for this category.

1. The reasons for this include the wide differences, from country to country, in primary steel production's (such production is highly CO_2-intensive) share of total steel production;
2. the differences in the ways that different countries allocate the resulting emissions to categories 1.A.2.a, 2.C.1, and to any other categories in which the process gases occurring in connection with iron and steel production are used for energy generation; and
3. differences in the ways that countries report activity data under 2.C.1; and the fact that in some cases such data is added, even though such addition

is inappropriate. The aforementioned factors result in extreme scattering of the IEF obtained for the source categories mentioned, and thus those IEF do not support any conclusions regarding the "correctness" of the determined emissions.

4.4.1.5 Category-specific recalculations (2.C.1)

Recalculations have been carried out for the year 2019, to take account of replacement of data from the provisional Energy Balance with data from the final Energy Balance.

4.4.1.6 Category-specific planned improvements (2.C.1)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.4.2 Metal production: Ferroalloys production (2.C.2)

4.4.2.1 Category description (2.C.2)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 C 2, Ferroalloys Production		CO_2	429.0	0.0%	5.9	0.0%	-98.6%
-/-	2 C 2, Ferroalloys Production		CH_4	8.6	0.0%	1.6	0.0%	-81.2%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	IS	CS
NO_x, CO, NMVOC, SO_2			NE

The category *Ferroalloys production* is not a key category. Ferroalloys are aggregates that are alloyed with steel. There are five ferroalloy producers in Germany; ferrochromium, ferrosilicon and silicon metal are each produced by only one company, and other ferroalloys are produced only in small quantities. The only process in use since 1995 is the electric arc process, a process that releases only small amounts of process-related CO_2, with such releases occurring in electrode consumption.

Until 1995, the blast-furnace process, which produces relatively higher CO_2 emissions, was used to some extent.

4.4.2.2 Methodological issues (2.C.2)

The **emission factors** for the aforementioned two processes (blast-furnace and electric-arc processes) were determined in the research project "NEW CO_2" ("NEU-CO_2") (FKZ 203 41 253/02; Weiß et al. (2006)).

The **activity data** for the years 1990 through 1994 have been taken from official production statistics of the Federal Statistical Office. Since 1995, data of the British Geological Survey (Brown et al., 2019) have been used, because the official production statistics no longer contain usable data for this context. The currently available data are from 2019. The activity data have been carried forward into 2020.

4.4.2.3 Uncertainties and time-series consistency (2.C.2)

The activity data provided by the British Geological Survey Brown et al. (2019) are based partly on estimates and thus are subject to relatively large uncertainties.

The relevant data of the British Geological Survey Brown et al. (2019) are regularly compared with those of the U.S. Geological Survey (USGS). While the USGS data are of the same order of magnitude as the BGS data, they are less detailed and have a higher degree of aggregation. For this reason, we have chosen to use the BGS data.

For the period 2001 – 2006, data of the Federal Statistical Office on sales of ferroalloys are available. Those data are lower, by a factor of 0.7, than the production data of the BGS, however. In the interest of the consistency of the time series, the BGS data have thus also been used for those years.

The considerable decrease in the CO_2 emission factor that took place from 1994 to 1995 does not represent any inconsistency; it is the result of the change in the production process.

4.4.2.4 Source-specific quality assurance / control and verification (2.C.2)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The activity data used, which come from the BGS, have been verified with data of the Federal Statistical Office and the USGS (see above).

4.4.2.5 Category-specific recalculations (2.C.2)

Recalculations were required because the activity data carried forward last year have been updated. Those recalculations led to slight changes in last year's emissions. Such recalculations are carried out regularly, since the underlying statistics are provided only at two-year intervals.

4.4.2.6 Category-specific planned improvements (2.C.2)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.4.3 Metal production: Aluminium production (2.C.3)

4.4.3.1 Category description (2.C.3)

KC	Category	Activity	EM of	1990 / 1995 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990/1995-2020
-/T	**2 C 3, Aluminium Production**		**CF_4**	**1,544.5**	**0.1%**	**64.0**	**0.0%**	**-95.9%**
-/-	2 C 3, Aluminium Production		CO_2	1,011.9	0.1%	723.2	0.1%	-28.5%
-/-	2 C 3, Aluminium Production		C_2F_6	256.2	0.0%	12.7	0.0%	-95.0%
-/-	2 C 3, Aluminium Production		SF_6	C	C	C	C	C

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 3	AS	CS
CH_4	-	-	NE
PFC	Tier 3	AS	CS
SF_6	CS	NS	CS
NO_X	-	-	NE
CO, SO_2		AS	CS

Primary aluminium – by-product emissions

In keeping with its classification in category 2.C.3 Aluminium production, the category *Primary aluminium production* is a key category for CF_4 emissions in terms of trend.

In Germany, aluminium is produced at four foundries, in electrolytic furnaces with pre-burnt anodes. The principal emission sources are the waste gases from the electrolytic furnaces and fugitive emissions via the plant roofs. CO, CO_2, SO_2, CF_4 and $C_2F_6$are among the most important climate-relevant substances and air pollutants that are emitted.

Production of primary aluminium continues to be the largest source of PFC emissions in Germany, in spite of the considerable reductions that have been achieved since 1990. Thanks to extensive modernisation measures in German aluminium foundries, and to decommissioning of production capacities, absolute emissions from this sector have fallen by more than 90 % since 1995. As to the future development of PFC emissions, stagnation at a low level can be expected.

Secondary aluminium – use of F gases in foundries

In keeping with its classification in category 2.C.3 Aluminium production, the category *Use of SF_6 in secondary aluminium production* (aluminium foundries) is not a key category for SF_6 emissions.

Generally speaking, inert gases without additives are sufficient for rinsing secondary molten aluminium. A purification system of inert gases, with added SF_6 at a concentration of 1 or 2.5 %, has been used in the past, however, in a few – usually smaller – aluminium foundries and in laboratories. Such purification systems were last used in 1999 (no sales have taken place in Germany since 2000). From 1990 to 1999, SF_6 consumption remained relatively constant, at 0.5 t/a.

Since 1999, pure SF_6 has been used again as a purification gas, in isolated cases.

4.4.3.2 Methodological issues (2.C.3)

Primary aluminium – by-product emissions

The relevant activity data are reported annually to the Federal Environment Agency by the WirtschaftsVereinigung Metalle metal-industry association. The average anode consumption in production of primary aluminium is 430 kg of petrol coke per tonne of aluminium. Table 186 shows the process-related emission factors.

The total quantity of waste gas incurred per tonne of aluminium during the production of primary aluminium was multiplied by an average concentration value formed from several individual figures, from various different plants, with appropriate weighting. The emission factors also make allowance for fugitive emission sources, such as emissions via plant roofs. The emission figures used for CO are the results of emission measurements within the context of investment projects.

The emission factors for SO_2 and CO_2 were calculated from the specific anode consumption. The anodes consist of petrol coke; this material has specific sulphur concentrations of about 1.2 %, from which an SO_2 emission factor of 10.4 kg/t Al can be calculated. The CO_2-emission factor is calculated on the basis of the specific carbon content of petrol coke, 857 kg per t. (cf. Chapter 18.8). By multiplying the average anode consumption by the mean carbon content and carrying out stoichiometric conversion to CO_2, one obtains a CO_2-emission factor of 1367 kg/t aluminium. Theoretically, the CO_2-emission factor must be reduced by the proportion resulting from a CO fraction of 180 kg/t Al, since CO can also form only via consumption of anodes. The CO_2 factor listed below does not take this into account. The procedure is in keeping with the Tier 2 method pursuant to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a).

The emission factors shown in Table 186 were checked against the emission data in Best Available Techniques Reference Documents (BREF)[71] and other sources (such as VDI Guideline 2286 VDI (1998): Sheet 1) and the relevant data from the EU Emissions Trading System (ETS).

Table 186: Activity data and process-related emission factors for primary aluminium production in 2013

	AD		Emission factors				
	Number of smelters	Production [t]	CO_2 [kg/t]	NO_X [kg/t]	SO_2 [kg/t]	C total [kg/t]	CO [kg/t]
Primary aluminium	4	492,368	1367	N. e.	10.4	N. e.	180

Emissions data are available for PFC emissions from primary aluminium smelters, thanks to a voluntary commitment on the part of the aluminium industry. Since 1997, the aluminium industry has reported annually on the development of PFC emissions from this sector. The measurement data are not published, but they are made available to the Federal Environment Agency.

The measurements conducted in all German smelters in the years 1996 and 2001 form the basis for calculation of CF_4 emissions. In this context, specific CF_4 emission figures per anode effect[72] were calculated, in keeping with the technologies used. The number of anode effects is recorded and documented in the foundries. The total CF_4 emissions were calculated by multiplying the total anode effects determined for the relevant year by the specific CF_4 emissions per anode effect determined in 2001. The total emission factor for CF_4 is obtained by adding the CF_4 emissions of the smelters and then dividing the sum by the total aluminium production of the smelters. C_2F_6 and CF_4 occur in a constant ratio of about 1:10. The above-described method was applied to the time series through 2010, and the emissions for the years 1990 to 1996 were filled in via recalculations. For purposes of emissions trading, the aluminium industry has made a transition to the IAI method for calculating PFC emissions (the method is equivalent to UNFCC default Tier 2). The default slope factor used with that method is used by all other European

71 cf. http://www.bvt.umweltbundesamt.de/kurzue.htm

72 "...Organic fluorides occur only under certain conditions, and such conditions occur in the furnace repeatedly, at intervals of hours to severals days. These conditions are referred to as the "anode effect". ... The gas at the anode changes in composition from CO_2 to CO and 5 to 20 % CF_4...." (Winfried Schwarz, 1996).

operators, and it is accepted in the framework of European emissions trading. In the interest of consistency, as of 2010 the aluminium industry has also used the IAI method to determine emissions data for purposes of emissions reporting.

Secondary aluminium – use of F gases in foundries

For aluminium foundries, plant-specific measurements have made it possible to determine the relevant emission factor – and, thus, the pertinent emissions – more precisely.

Reports and archived survey records from 1996 have been used as a basis for the reporting years 1990 through 1994.

For reasons of confidentiality, the SF_6 emissions are reported together with figures in 2.C.4 Magnesium production.

Emission factor for secondary aluminium

On the basis of confidential measurement records certified by the pertinent permit authority, the SF_6 emission factor for aluminium foundries, for the period 1999 through 2008, has been reduced to 3 %. Via structural conversions, the emission factor has been further reduced, to 1.5%, as of 2009. That value has also been confirmed by confidential measurement reports that have been approved by the licensing authority.

Activity data for secondary aluminium

SF_6-consumption data are obtained via surveys of gas sellers. At the same time, the survey for reporting year 2000 revealed that there have been no sales of this gas mixture since 2000.

Data on the SF_6 used in pure form since 1999 have been obtained via direct surveys of users and have been compared with relevant data of gas sellers.

Since the 2006 reporting year, the data have been obtained by the Federal Statistical Office via surveys of gas sellers with regard to SF_6-sales figures (UStatG 2005).

4.4.3.3 Uncertainties and time-series consistency (2.C.3)

Primary aluminium – by-product emissions

The figures for PFC, CO, CO_2 and SO_2 emissions are in keeping with the Tier 3b approach and thus are considered very accurate. The time series for CO, CO_2 and SO_2 are consistent.

On the other hand, no survey of the plant-specific number of anode effects in 1991, 1992, 1993 and 1995 was conducted, in the framework of voluntary commitments, and no calculation was carried out for those years (cf. 4.4.3.6).

In addition, the years 1991 through 1994 were years of deep crisis for the German aluminium industry, due to sharp drops in the world-market prices for primary aluminium. For this reason, a number of plants were decommissioned. While all smelter types were affected, smelters that had recently been modernised, with point-feeder technology, were most strongly affected. Their capacity decreased by 43 %, with regard to the relevant levels in 1990. This also explains the sudden increase and stagnation in the implied emission factor for CF_4 in these years. In absolute terms, the primary smelters emitted only 26 tonnes of CF_4 in 2007, while they emitted 45 tonnes in 2005. This drop was due to a decrease in production. With regard to 2006, production increased slightly, however, because partial shutdowns of furnaces in the Stade plant were more than offset by production increases at the Hamburg production site. In 2009, the economic crisis and other factors led to drastic reductions of production at the Rheinwerk Neuss site. In the period thereafter, all German primary smelters faced difficult economic situations and had to start up and shut down processes frequently, thereby incurring process instabilities. Those instabilities led to higher numbers of anode effects and, thus, to higher PFC emissions. The economic situation stabilised noticeably in 2010. That made it possible to run continuous, stable processes. As a result, the numbers of anode effects decreased to such a degree that absolute PFC emissions decreased, by comparison to their level in 2009, in spite of the production increases. That trend continued in subsequent years. PFC emissions increased again, slightly, in 2018. This was the first increase seen in such emissions since 2010. One smelter carried out a conversion of its anode format, and this triggered a temporary increase in numbers of anode effects. Another smelter was forced to use lower-quality aluminium oxide, for limited periods of time, owing to delivery problems resulting from low water levels in the Rhine River (which hampered shipping) and to temporary shutdowns of aluminium oxide (alumina) refineries. This also led to higher numbers of anode effects.

Secondary aluminium – use of F gases in foundries

As studies have shown, part of the SF_6 used in aluminium production is broken down during such use. For the aluminium industry, the emission factor has been applied to the highest measured emissions level, and an uncertainty of 50 % has been assumed for lower levels, since measurements have shown that emissions are frequently considerably lower than the maximum levels.

4.4.3.4 Source-specific quality assurance / control and verification (2.C.3)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The activity data for primary aluminium production are based on surveys taken by the WirtschaftsVereinigung Metalle metal-industry association. They are reported to the Federal Environment Agency annually. The relevant time series seems plausible and shows no inconsistencies. It is assumed that such data collection conforms to quality assurance criteria.

4.4.3.5 Category-specific recalculations (2.C.3)

No recalculations are required.

4.4.3.6 Category-specific planned improvements (2.C.3)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.4.4 Metal production: Magnesium production (2.C.4)

4.4.4.1 Category description (2.C.4)

KC	Category	Activity	EM of	1995 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1995-2020
-/-	2 C 4, Magnesium Production		SF_6	C	C	C	C	C
-/-	2 C 4, Magnesium Production		HFC-134a	0.0	0.0%	8.3	0.0%	-

Gas	Method used	Source for the activity data	Emission factors used
SF_6	D	PS	D
HFCs	D	PS	CS

The category *SF_6 and HFC-134a in magnesium production* is not a key category.

No primary magnesium is produced in Germany. Only cast parts made of magnesium alloys are produced. In magnesium casting, since the mid-1970s, SF_6 has been used as a cover (protective) gas over molten magnesium to prevent the magnesium's oxidation and ignition. The amount of SF_6 used per tonne of magnesium (specific SF_6 coefficient) has decreased sharply from its level in 1995. This is due to the fact that HFC-134a has increasingly been used as a substitute since 2003. SF_6 is used in both a) the sand-casting process, for production of prototypes, individual parts and small series, and b) the pressure-casting process, in which it serves as a cover gas.

Pursuant to Article 13 der Regulation (EU) No. 517/2014 on fluorinated greenhouse gases, as of 1 January 2018 use of SF_6 in magnesium pressure die-casting is prohibited even in small production installations. As of 1 January 2008, magnesium die-casting foundries with annual SF_6 consumption exceeding 850 kg were already prohibited from using SF_6 as a cover gas. The German installations affected by this prohibition have gradually switched to HFC-134a.

4.4.4.2 Methodological issues (2.C.4)

Use of SF_6 as a cleaning agent and cover gas, in magnesium production, is an open use, i.e. all of the SF_6 used in the process is emitted into the atmosphere. The practice of assuming the equivalence between consumption (activity data) and emissions conforms to the method set forth in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Chapter 4.5).

The 2006 IPCC Guidelines contain no information regarding the emission factor for use of HFC-134a. For this reason, the emission factor previously chosen has been identical with that for use of SF_6 in magnesium production. In 2018, the emission factor was retroactively set to 50 %, for the entire time series.

For reasons of confidentiality, the SF_6 emissions from 2.C.3.b Secondary aluminium are also reported here.

Emission factors

For magnesium foundries, a default emission factor of EF_{use} = 100% is assumed for SF_6, due to a continuing lack of precise destruction-rate data that would support a more-precise estimate.

As of reporting year 2017, the emission factor has been retroactively set to 50%, for the entire time series (i.e. for the period as of 2003). In 2017, the IPCC Emission Factor Data Base (EFDB) added "Destruction rates of cover gas HFC-134a," in the amounts of 71% and 77%, as non-binding guidelines for the national emissions inventories. Those values are equivalent to emission rates of 29% and 21%, respectively. In 2007, studies commissioned by the U.S. Environmental Protection Agency (EPA) found that the destruction rates of HFC-134a depend on a range of parameters, including the temperature of the melt, the carrier gas used, the flow rate of the cover gas and the concentration of the HFC-134a. In light of the lack of further studies on this subject, the experts have proposed use of an emission factor of 50%, which would include a safety margin (Gschrey et al., 2018).

Activity data for magnesium production

In 1996, a survey was carried out, under commission to the Federal Environment Agency, of all domestic magnesium foundries that use SF_6. That survey determined the amounts consumed in the years 1990 to 1995.

Until report year 2007, data on the amounts used were obtained directly from users. Since report year 2006, the data have been obtained via surveys of gas sellers with regard to SF_6-sales figures. In report year 2006, the two methods were compared.

Since report year 2007, data of the Federal Statistical Office (UStatG 2005) have been used.

4.4.4.3 Uncertainties and time-series consistency (2.C.4)

As studies have shown, part of the SF_6 and the HFC-134a used in magnesium production is broken down during such use. As a result of the assumptions regarding the emission factors, the pertinent emissions of SF_6, and, to some degree, those of HFC-134a, are probably too high.

4.4.4.4 Source-specific quality assurance / control and verification (2.C.4)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

No other data sources, apart from the data provided by the Federal Statistical Office, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. Comparisons with other countries have revealed no requirements for improvements. The emission factor for SF_6 is in keeping with the default emission factor given in the 2006 IPCC Guidelines(IPCC, 2006a). To ensure that all emissions are indeed covered, the emission factor for HFC-134a is higher than the corresponding factors in the IPCC Emission Factor Data Base (EFDB).

4.4.4.5 Category-specific recalculations (2.C.4)

No recalculations are required.

4.4.4.6 Category-specific planned improvements (2.C.4)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.4.5 Metal production: Lead (2.C.5)

4.4.5.1 Category description (2.C.5)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 C 5, Lead Production		CO_2	157.9	0.0%	73.6	0.0%	-53.4%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1	AS	D/CS

The category *Metal production*: *Lead* is not a key category.

In Germany, lead is produced from primary lead concentrates and secondary raw materials such as lead-containing scrap and lead acid batteries.

All primary lead production in Germany takes place via the direct smelting (DS) process, either in bath smelting furnaces (Isasmelt-Ausmelt) or in QSL reactors. Process-related CO_2 emissions occur primarily via addition of carbon-containing reducing agents (such as coal dust). The imperial smelting process (in imperial smelting furnaces (ISF)) is no longer used in Germany.

Recycling of lead acid batteries is the key factor shaping secondary lead production in Germany. The relevant sector uses both short rotary furnaces and shaft furnaces. Process-related CO_2 emissions occur primarily via addition of carbon-containing reducing agents (for example, coke).

The relevant activity data are reported annually to the Federal Environment Agency by the WirtschaftsVereinigung Metalle metal-industry association.

4.4.5.2 Methodological issues (2.C.5)

The **emission factors** that have been used have been taken from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC (2006a): values from Table 4.21) and are in keeping with Tier 1 methods. The only lead-production processes used in Germany are the direct smelting (DS) process, for primary lead production, and the secondary lead production (S) process.

4.4.5.3 Uncertainties and time-series consistency (2.C.5)

The default uncertainties set forth in 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a) have been used.

4.4.5.4 Category-specific recalculations (2.C.5)

No recalculations are required.

4.4.5.5 Source-specific quality assurance / control and verification (2.C.5)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The activity data are based on confidential surveys taken by the WirtschaftsVereinigung Metalle metal-industry association. They are reported to the Federal Environment Agency annually. The relevant time series seems plausible and shows no inconsistencies. It is assumed that such data collection conforms to quality assurance criteria.

4.4.5.6 Category-specific planned improvements (2.C.5)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.4.6 Metal production: Zinc (2.C.6)

4.4.6.1 Category description (2.C.6)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 C 6, Zinc Production		CO_2	670.8	0.1%	284.3	0.0%	-57.6%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1	AS	D

The category *Metal production*: *Zinc* is not a key category.

In Germany, zinc is produced from primary zinc concentrates and secondary raw materials such as zinc-containing scrap and steel mill dust.

All primary zinc production in Germany takes place via the hydrometallurgical process. The imperial smelting process, a pyrometallurgical process, is not used.

In this sector in Germany, process-related greenhouse-gas emissions occur primarily in secondary zinc production. Process-related CO_2 emissions occur via use of coke as a reducing agent, especially in processing of zinc-containing secondary materials in rotary kilns.

The relevant activity data are reported annually to the Federal Environment Agency by the WirtschaftsVereinigung Metalle metal-industry association.

4.4.6.2 Methodological issues (2.C.6)

The CO_2 emission factor set forth in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC (2006a): default factor) has been used. It is in keeping with the Tier 1 method.

4.4.6.3 Uncertainties and time-series consistency (2.C.6)

The default uncertainties set forth in 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a) have been used.

4.4.6.4 Category-specific recalculations (2.C.6)

No recalculations are required.

4.4.6.5 Source-specific quality assurance / control and verification (2.C.6)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The activity data are based on confidential surveys taken by the WirtschaftsVereinigung Metalle metal-industry association. They are reported to the Federal Environment Agency annually. The relevant time series seems plausible and shows no inconsistencies. It is assumed that such data collection conforms to quality assurance criteria.

4.4.6.6 Category-specific planned improvements (2.C.6)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.4.7 Metal production: Other (2.C.7)

Since the CRF-Reporter software does not allow nitrous oxide emissions to be allocated to 2.C.1, such emissions are reported in 2.C.7 instead. Otherwise, no greenhouse-gas emissions are reported in category 2.C.7; that category is of relevance only for other pollutant emissions.

4.4.7.1 Category description (2.C.7)

The nitrous oxide emissions reported in 2.C.7 result from use of blast furnace gas and basic oxygen furnace gas in hot-blast stoves of blast furnaces (source category 2.C.1).

In Germany, this category primarily includes copper production and hot-dip galvanising. The greenhouse-gas emissions that occur in connection with hot-dip galvanising originate solely in process combustion, however; consequently, they are reported in 1.A.2.

The majority of greenhouse-gas emissions in the copper industry also originate in process combustion and are reported in 1.A.2.b. Process emissions from fire refining in anode furnaces are also reported in 1.A.2.b, since manufacturing-industry statistics do not record use of the reducing agent used for such refining – natural gas – separately from process combustion. Furthermore, the greenhouse-gas emissions that do not originate in process combustion are very low by comparison.

4.4.7.2 Methodological issues (2.C.7)

The nitrous oxide emissions, which should actually be allocated to 2.C.1, are calculated on the basis of statistical data on use of blast furnace gas and basic oxygen furnace gas in hot-blast stoves of blast furnaces, and with use of an emission factor, for combustion systems in Germany, that was developed in the framework of a research project of the Federal Environment Agency (Rentz et al., 2002).

No emission factors are available for other greenhouse-gas emissions in 2.C.7.

4.4.7.3 Uncertainties and time-series consistency (2.C.7)

No information.

4.4.7.4 Category-specific recalculations (2.C.7)

No recalculations are required.

4.4.7.5 Source-specific quality assurance / control and verification (2.C.7)

The activity data are based on confidential surveys taken by the WirtschaftsVereinigung Metalle metal-industry association. They are reported to the Federal Environment Agency annually. The relevant time series seems plausible and shows no inconsistencies. It is assumed that such data collection conforms to quality assurance criteria.

4.4.7.6 Category-specific planned improvements (2.C.7)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.5 Use of non-energy-related products from fuels and solvents (2.D)

4.5.1 Lubricant use (2.D.1)

4.5.1.1 Category description (2.D.1)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 D 1, Lubricant Use		CO_2	188.6	0.0%	182.0	0.0%	-3.5%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	NS	CS

The category *Lubricant use* is not a key category for CO_2 emissions.

Lubricants are used to reduce friction and wear in moving machine parts. They can also be used for transmission of power and heat. Furthermore, lubricants are used as sealants, and they are used to prevent build-up of deposits and to guard against corrosion. Process oils, which are also considered to be lubricants, are also used as raw materials and as auxiliary and working materials. In addition, various other industrial oils are used in non-lubrication applications.

Apart from an economically related reduction in 2009, consumption of lubricants in Germany has been relatively constant since 1990. In 2020, consumption, not including mobile applications, amounted to 457,013 kt, which was about 30% lower than in preceding years.

4.5.1.2 Methodological issues (2.D.1)

Lubricant use is divided into the two major areas of a) use in motor vehicles, including other mobile sources, and b) use in industry; this is due to the different calculation methods involved.

The German greenhouse-gas inventory covers CO_2 emissions from co-combustion of lubricants for all mobile sources. In keeping with emissions reporting requirements, emissions from two-stroke petrol engines are allocated directly to the pertinent emission sources, since in those cases lubricants are seen as part of the relevant fuels (fuel mixtures for two-stroke engines). A description of the relevant calculation methods is provided in Chapter 19.1.4. On the other hand, all co-combustion emissions that are not caused by two-stroke engines are considered to result from product use and are reported in section 2.D.1, along with emissions from stationary lubricant use in industrial sectors.

Stationary lubricant use

The activity data for lubricant use in industry consist of domestic delivery data (units: tonnes) given by the "Official Mineral Oil Statistics for the Federal Republic of Germany" ("Amtliche Mineralöldaten für die Bundesrepublik Deutschland" – Mineral Oil Statistics) of the Federal Office of Economics and Export Control (BAFA) (Table 10j). Those statistics differentiate the following groups of lubricant types:

- Compressor oils
- Turbine oils
- Gear oils
    - Automobile oils
    - Automatic transmission fluid (ATF)
    - Industrial-gear oils
- Hydraulic oils
- Electrically insulating oils
- Machine oils
- Other industrial oils not used for lubrication
- Process oils
- Metal processing oils
    - Hardening oils
    - Water-miscible
    - Not water-miscible
    - Anticorrosive oils
- Greases
    - Among these, for automobiles
- Basic oils
- Extracts from lubricant refining

BAFA regularly publishes sales figures (monthly and annual) for these type groups. The published figures are based on companies' reported data. A list of the companies that report in this framework – the "survey-group list" (Erhebungskreisliste)[73] is available for inspection.

The 2006 IPCC Guidelines do not specify which emission sources the lubricant use category includes. Losses can occur on the input side (filling), during use and on the output side (removal). In the interest of clarity, and to increase the precision of the emission calculation, an expert opinion was commissioned (Zimmermann & Jepsen, 2018). In that project, the various lubricant-type groups were considered individually, and emission factors were derived that would permit use of a Tier 2 method. The study was able to prove that while various types of losses occur, among the different lubricant-type groups, those losses result in emissions into the air only in part.

73 http://www.bafa.de/SharedDocs/Downloads/DE/Energie/Mineraloel/moel_erhebungskreisliste.xls;jsessionid=8F5CC4170FEBCC89A69DE21218062873.2_cid378?__blob=publicationFile&v=4

The typical losses on the input side, i.e. in connection with filling at the planned site of use (for example, the filling of an automobile motor, a transmission, or a machine (machine parts)) include:

- drip losses and other handling-related losses,
- Residues in containers

Many different types of losses can occur during product use. The possible types of losses include:

- evaporation
- (co-) combustion
- leakage
- exports (applies especially to automobile lubricants)
- conversions into products
- adhesion to products

On the output side, i.e. in connection with the removal of used lubricants, the following types of losses can occur:

- drip losses and other handling-related losses,
- residues adhering to some part of the usage site

With respect to *gaseous* emissions, the most significant emissions include releases of greenhouse gases from (co-) combustion of lubricants, the formation of VOC as a result of leakage, and emissions via open applications (which depend on prevailing usage conditions in each case (especially temperature)).

On the basis of the analyses carried out in the project, the following emission factors, oriented to lubricant-type groups, were derived:

Table 187: Emission factors for specific lubricant-type groups, in percent

Lubricant-type group	Shares of total sales for the period as of 1990, expressed as ranges	NMVOC		
		Ø	*Min*	*Max*
Compressor oils	≤ 1 %	1.5 %	*1 %*	*2 %*
Turbine oils	< 1 %	0.5 %	*0 %*	*1 %*
Automobile-transmission oils	5-10 %	1 %	*0 %*	*2 %*
Industrial-gear oils	2-3 %	1.5 %	*1 %*	*2 %*
Hydraulic oils	6-15 %	1.5 %	*1 %*	*2 %*
Machine oils	1-7 %	2.5 %	*0 %*	*5 %*
Other industrial oils not used for lubrication	2-7 %	25 %	*0 %*	*50 %*
Metal processing oils	5-9 %	5 %	*0 %*	*10 %*
Basic oils	4-16 %	10 %	*5 %*	*15 %*
Electrically insulating oils	1-2 %			
Process oils	4-20 %			
Greases	2-4 %			
Extracts from lubricant refining	≤ 5 %			

The relevant NMVOC emissions are calculated via a Tier 2 method in which the emission factors are applied to the entire time series.

To ensure conformity with the 2006 IPCC Guidelines and the EU's emissions reporting procedures, the NMVOC emissions are converted into CO_2 emissions. The carbon content on which that process is based is the same as that described for 2.D.3.

For purposes of reporting of air pollutants in the *Informative Inventory Report* (IIR), the NMVOC emissions are allocated to section 2.D.3.i.

In 1995, a number of Mineral Oil Statistics categories were changed. In 1995, three type groups were introduced that had not appeared in the Mineral Oil Statistics prior to that year (four other categories had been used for those purposes). This necessitated a slight adjustment of the procedure for the years 1990-1994. The following table shows the affected categories for the years 1990-1994, as well as the ways in which they were handled in the calculation.

Table 188: Handling of categories in BAFA statistics, 1990-1994

Category	Remarks concerning the procedure	Emission factor
Other lubricating oils, specialty Other lubricating oils, non-specialty	These are handled like the "machine oils" group, which is lacking in the 1990-1994 period. This group includes various specialty and non-specialty lubricating oils.	2.5 %
Other mineral oils for special applications	This category contains no lubricating oils. It is handled like the category "Other industrial oils not used for lubrication," which is lacking in the 1990-1994 period.	25 %
Light-coloured plasticisers and extender oils	Extender oils and plasticisers are classified with the process oils. They are handled accordingly.	0 %

Mobile lubricant use

The data on the total lubricant quantities used in connection with lubricant co-combustion in four-stroke gasoline engines and in other engines in vehicles and mobile sources are very spotty. As a result, the co-combusted quantities are calculated largely on the basis of figures provided by the *Verband Schmierstoff-Industrie* e. V. (VSI; the association of the German lubricant industry) on the relevant fuel quantities Wallfarth (2014).

Pursuant to Wallfarth (2014), the following co-combustion fractions, with respect to the relevant fuel quantities used, are achieved in the various usage areas:

Table 189: Overview of the specific co-combustion fractions used

Sector	Fuel	Fraction	Source / remark
1.A.2.g vii	OK DK	0.00 % 0.10 %	Assumption, based on Wallfarth (2014)
1.A.3.a, 1.D.1.a, 1.A.5.b ii	Ke & FB	0.01 %	Avgas: like kerosene
1.A.3.b	All	-	Calculation via TREMOD
1.A.3.c	DK	0.05 %	
1.A.3.d, 1.D.1.b. 1.A.4.c iii, 1.A.5.b iii	DK & HOS	0.15 %	Heavy fuel oil: like diesel fuel
1.A.4.a ii	DK LPG	0.10 % 0.10 %	Like 1.A.3.b Like 1.A.3.b
1.A.4.b ii	OK	0.00 %	Assumption, based on Wallfarth (2014)
1.A.4.c ii (i)	OK DK	0.00 % 0.10 %	Assumption, based on Wallfarth (2014) Like 1.A.3.b
1.A.4.c ii (ii)	DK	0.10 %	Like 1.A.3.b
1.A.5.b i	OK DK	0.00 % 0.15 %	Assumption, based on Wallfarth (2014) Like 1.A.3.d; takes account of heavy armored vehicles
	HOS	0.15 %	Like diesel fuel

OK: gasolines (including bioethanol), only four-stroke engines; DK: diesel fuel (including biodiesel), Ke: kerosene; FB: avgas; HOS: heavy fuel oil; LPG: LPG

The quantities of co-combusted lubricants are calculated on the basis of the energy quantities used in some sectors in non- two-stroke engines, as well as of the aforementioned co-combustion fractions. Those lubricant quantities are then used, with the help of the unified emission factor of 73,300 kg CO_2 / TJ, to calculate the sector-specific unintended carbon dioxide emissions from lubricant co-combustion.

Table 190: Carbon dioxide from lubricants co-combusted unintentionally in mobile non- two-stroke engines, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
1.A.2.g vii	3.52	3.32	3.27	2.80	3.01	3.38	3.50	3.59	3.34	3.37	3.49
1.A.3.a	0.24	0.21	0.26	0.25	0.23	0.20	0.21	0.22	0.22	0.22	0.10
1.A.3.b	86.10	103.99	114.47	117.60	121.29	128.85	130.71	132.31	132.95	134.05	118.53
1.A.3.c	1.41	1.14	0.93	0.68	0.57	0.51	0.53	0.44	0.37	0.42	0.40
1.A.3.d	4.43	3.58	2.38	2.34	2.05	2.46	2.25	2.11	2.23	2.33	2.07
1.A.4.a ii	0.78	0.73	0.80	0.79	0.79	0.76	0.79	0.80	0.76	0.75	0.76
1.A.4.b ii	Here, only use of two-stroke gasoline engines										
1.A.4.c ii	3.90	3.27	3.06	2.96	3.32	3.78	3.94	4.06	3.80	3.85	4.01
1.A.4.c iii	0.20	0.10	0.15	0.18	0.20	0.23	0.22	0.23	0.26	0.28	0.34
1.A.5.b i	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04
1.A.5.b ii	1.65	0.88	0.15	0.38	0.12	0.07	0.07	0.05	0.03	0.03	0.02
1.A.5.b iii	0.28	0.12	0.07	0.02	0.02	0.03	0.03	0.01	0.01	0.03	0.02
Total	103	117	126	128	132	140	142	144	144	145	**130**
1.D.1.a	1.19	1.50	1.92	2.28	2.42	2.46	2.65	2.90	2.99	2.96	1.36
1.D.1.b	9.91	8.26	8.88	10.45	11.83	10.09	11.83	9.47	6.68	5.15	5.07

Source: Own calculations

4.5.1.3 Uncertainties and time-series consistency (2.D.1)

The uncertainties for the specific emission factors for the type groups, for the area of industrial lubricant uses, result from the emission-factor ranges shown in Table 187.

On the basis of an expert judgement, reached via a study of incorrect notifications in the Mineral Oil Statistics, the uncertainties for the activity data are assumed to be 5 %.

In 1995, a change was made in the Mineral Oil Statistics' lubricant-type classification scheme, but that change has not had any noticeable impacts on the lubricant quantities recorded for statistical purposes. The change solely involved moving lubricants from categories for unspecified applications into categories for specified applications. Possibly, the emissions calculated for the years 1990-1994 may be too high, by between 5 and 25%.

4.5.1.4 Category-specific recalculations (2.D.1)

For *stationary* lubricant applications, recalculations were carried out for the period back through 1990, in order to take account of motor-vehicle transmission oils. These uses are assigned to stationary lubricant uses for the reason that they do not involve any co-combustion of lubricants.

Table 191: Revised quantities of lubricants used in stationary applications, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
2022 Submission	729	752	752	692	728	781	760	770	739	731
2021 Submission	668	688	686	619	669	694	663	671	636	629
Absolute change	61.2	63.9	66.0	72.8	58.9	87.2	96.5	99.4	103	103
Relative change	9.16%	9.28%	9.62%	11.8%	8.80%	12.6%	14.6%	14.8%	16.3%	16.3%

Source: Own calculations

Since the transmission oils in question evaporate only to a very small extent, the change in the CO_2 emissions from all stationary applications is considerably smaller than the change in the activity data.

Table 192: Revised CO_2 emissions from stationary uses, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
2022 Submission	86.0	63.0	65.7	58.8	62.0	78.1	82.0	89.4	82.3	80.6
2021 Submission	84.7	61.6	64.2	57.2	60.7	76.1	79.9	87.2	80.0	78.4
Absolute change	1.35	1.41	1.45	1.60	1.29	1.92	2.12	2.19	2.27	2.26
Relative change	1.59%	2.28%	2.26%	2.80%	2.13%	2.52%	2.66%	2.51%	2.84%	2.88%

In the area of *mobile* lubricant use, the unintentionally co-combusted quantities of lubricants were revised with respect to the 2021 submission.

Table 193: Revised unintentionally co-combusted quantities, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
2022 Submission	1,400	1,602	1,714	1,747	1,796	1,914	1,941	1,963	1,965	1,983
2021 Submission	1,413	1,611	1,723	1,754	1,802	1,922	1,945	1,974	1,973	1,993
Absolute change	-13.3	-9.01	-9.43	-7.35	-5.99	-8.05	-3.99	-10.8	-8.07	-9.77
Relative change	-0.94%	-0.56%	-0.55%	-0.42%	-0.33%	-0.42%	-0.21%	-0.55%	-0.41%	-0.49%

Source: TREMOD and TREMOD MM

The CO_2 emissions from this unintentional co-combustion have been adjusted accordingly.

Table 194: Revised CO_2 emissions from unintentional co-combustion, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
2022 Submission	103	117	126	128	132	140	142	144	144	145
2021 Submission	104	118	126	129	132	141	143	145	145	146
Absolute change	-0.98	-0.66	-0.69	-0.54	-0.44	-0.59	-0.29	-0.79	-0.59	-0.72
Relative change	-0.94%	-0.56%	-0.55%	-0.42%	-0.33%	-0.42%	-0.21%	-0.55%	-0.41%	-0.49%

Source: Own calculations

The total quantity consisting of a) the carbon dioxide emissions as calculated from the released NMVOC (stationary lubricant uses) and b) the carbon dioxide emissions from unintentional co-combustion (mobile uses) has changed as follows:

Table 195: Revised CO_2 emissions from stationary and mobile uses, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
2022 Submission	188.6	180.4	191.2	186.8	193.6	186.6	195.3	199.8	225.6	218.4
2021 Submission	188.3	179.7	190.5	185.8	192.8	185.6	194.2	198.5	224.3	217.0
Absolute change	0.31	0.70	0.73	1.04	0.83	1.05	1.13	1.31	1.30	1.31
Relative change	0.17%	0.39%	0.38%	0.56%	0.43%	0.57%	0.58%	0.66%	0.58%	0.60%

Stationary: Own calculations; stationary uses: indirect CO_2 calculated from quantities of released NMVOC

4.5.1.5 Source-specific quality assurance / control and verification (2.D.1)

For stationary sources: General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

For mobile sources: General quality control and quality assurance, have been carried out in conformance with the requirements of the QSE-manual and its associated applicable documents, by the Single National Entity.

When the standard emission factor given by the 2006 IPCC Guidelines is used, it is not possible to differentiate between uses in which primarily CO_2 emissions occur, via co-combustion of lubricants, and uses that lead mainly to NMVOC emissions. The CO_2 emissions from industrial use of lubricants would double if a Tier 1 method were used.

Extensive quality controls were carried out in the aforementioned studies. They are described in section 4.5.1.5 of the 2021 NIR.

4.5.1.6 Category-specific planned improvements (2.D.1)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.5.2 Paraffin wax use (2.D.2)

4.5.2.1 Category description (2.D.2)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 D 2, Paraffin Wax Use		CO_2	242.7	0.0%	452.5	0.1%	86.4%
-/-	2 D 2, Paraffin Wax Use		N_2O	0.7	0.0%	1.3	0.0%	86.4%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1	NS	D
N_2O	Tier 1	NS	D

The category *Paraffin wax use* is not a key category.

The most important use of waxes is in candles. Packaging, synthetic wood and hot melt adhesives also represent significant areas of application.

Surveys of industry experts, carried out in the framework of a research project (Zimmermann & Jepsen, 2018), have confirmed the assumption that, apart from candles, no other wax uses are of relevance for emissions reporting – because, apart from the burning of candles, no other uses, under normal conditions, can be expected to produce emissions. For this reason, with regard to wax uses, the inventory continues to take account only of uses in candles. The research project also evaluated two studies, dating from 2002 and 2010, that estimated the fractions of renewable resources in candles at 15 % (Matthäi & Petereit, 2004) and 22 % (Matthäi et al., 2010), respectively. In addition to beeswax (2 %), the renewable resources involved include animal and vegetable fats (12 %) and stearins (8 %). The latter are produced primarily from palm oils.

Germany is an important market for candles within the European Union. In 2016, its share of the overall market amounted to nearly 27 % (European Candle Association, 2017). From 1990 to 2013, the demand for candles grew in Germany, in contrast to the trend in Europe as a whole. The increasing demand was met via imports. Since 2013, production has been decreasingly markedly, and the growing imports are not completely offsetting the production decreases.

4.5.2.2 Methodological issues (2.D.2)

The calculation model is based on the assumption that all candles are consumed within a year of their purchase and are burned completely.

The CO_2 and N_2O emissions are calculated via a Tier 1 method.

Activity data

The production-quantity data, and the data on the imported and exported quantities of candles, for the years as of 1996, were obtained from the Federal Statistical Office (Statistisches Bundesamt (FS 4, R 3.1), Produzierendes Gewerbe, Produktion im Produzierenden Gewerbe sowie der Außenhandelsstatistik ("manufacturing industry; production in the manufacturing industry and foreign-trade statistics").

The quantities consumed are calculated in keeping with the formula Production + Imports – Exports. In determination of CO_2 emissions, a fixed biogenic fraction of 15% is deducted. The N_2O emissions, however, include the biogenic fraction. Consumption in 2020 amounted to 180,657.5 t wax, including the biogenic fraction.

For the years 1990 through 1995, the quantities consumed are calculated from the per-capita consumption, which has been derived from the data for the years 1996 through 2013. In the process, it is assumed that consumption also grew linearly in those (earlier) years.

Emission factors

The emission factor for CO_2 is 2.9467 t/t product; for N_2O, the factor is 0.024 kg/t product.

The emission factors, which have been applied to the entire time series, have been derived on the basis of standard values (IPCC (2006a): Vol. 2, Chapter 1, Table 1.2, and IPCC, 2006: Vol. 2, Chapter 2, Table 2.4).

4.5.2.3 Uncertainties and time-series consistency (2.D.2)

A Tier 1 method and standard values from the 2006 IPCC Guidelines have been used, and thus that source's uncertainties for the activity data and emission factors apply (IPCC (2006a): Vol. 3, Chapter 5).

In keeping with the fixed biogenic fraction applying for all years concerned, the uncertainty for the activity data is estimated at +30% / -10%.

4.5.2.4 Category-specific recalculations (2.D.2)

The CO_2 and N_2O emissions had to be corrected for 2019, as a result of adjustments to foreign-trade statistics. The relevant usage quantities – and, thus, the relevant CO_2 and N_2O emissions – increased by only 0.06 % for that year, however. In addition, changes amounting to up to 0.00006 % resulted via retroactive compensation for rounding differences, for the years back through 1990. Because these changes are so slight, we have opted not to present them in a table.

4.5.2.5 Source-specific quality assurance / control and verification (2.D.2)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

No other national data, apart from the data provided by the Federal Statistical Office, are available for review of the relevant import, export and production quantities, for purposes of verification of the consumption-quantity data. The official Mineral Oil Statistics do not list uses in candles as a separate category. Furthermore, the European Candle Association (ECA) relies on data of EUROSTAT. A comparison with the data of EUROSTAT was carried out.

A comparison with the calculation methods of other countries was carried out in connection with the 2018 report. Differences were found only in determination of the applicable wax quantities.

4.5.2.6 Category-specific planned improvements (2.D.2)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.5.3 Other: Solvents – NMVOC (2.D.3 Solvents)

4.5.3.1 Category description (2.D.3 Solvents)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	2 D 3, Other		CO_2	2,551.1	0.2%	1,263.3	0.2%	-50.5%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	D	NS	D
NMVOC	Tier 2	NS	CS

The category indirect CO_2 from NMVOC emissions, within the category *Solvent and other product use* (CRF 2.D.3), is not a key category, due to its inclusion within the overarching category *2.D.3 – Other*.

The NMVOC emissions released through use of solvents and solvent-containing products all belong to sub-categories of this category.

The four reporting categories of this category vary widely in structure. To take account of this variation, inventory data were calculated in keeping with the UNECE/EMEP sub-structures based on the CORINAIR97 (CORINAIR: COordination d' INformation Environmentale; sub-project AIR) SNAP system[74].

The categories 2.D.3.a, d, e, f, g, h and i include the following applications and activities:

2.D.3.a: Household use of solvents, including fungicides

i) Residential use of solvents

- **Soaps**
- **Detergents, dishwashing agents and cleansers** (softeners; general-purpose detergents; detergents; auxiliary washing preparations; dishwashing detergents; cleansers for floors and carpets; cleansers for cars; window cleaners; cleaning agents for toilets and bathrooms);
- **Shoe polishes, shoe- and leather-care products, furniture and floor polishes; car-care washes and waxes**
- **Preparations for polishing metal**
- **Fragrances** (for rooms, perfumes, eau de toilette, aftershaves)
- **Cosmetics and make-up** (make-up; preparations for hand, nail and foot care; face-care products; body-care products; sunscreen products and other preparations)
- **Shampoos and hair-care products** (shampoos; perm-care products and hair straighteners; hairsprays; hair cremes and brilliantines; tinting shampoos, hair-colouring agents, hair-bleaching agents and other care products)
- **Other personal care products** (shaving creams; body deodorants and antiperspirants; bath essences; intimate-care products, hair removers, beauty products and other)
- **Anti-freezes for motor vehicles**

ii) Household use of pharmaceutical products

2.D.3.d: Use of paints and lacquers

i) Decorative paints and lacquers, architectural coatings

- **Motor-vehicle repair**

[74] In the present area, this involves "SNAP Level 3" detailing.

- **Professional uses of paints and lacquers in structures and buildings** (emulsion paints for interiors; facade paints / silicate; polymer plasters / silicate; architectural paints / glazes; primers / coatings; other applications)
- **Do-it-yourself uses of paints and lacquers in structures and buildings** (emulsion paints for interiors; facade paints / silicate; polymer plasters / silicate; architectural paints / glazes; primers / coatings; other applications)
- **Wood coatings** (wooden interiors; carpentry and cabinet-making)

ii) Industrial coatings

- **Motor-vehicle manufacturing** (primers, fillers, topcoats and clearcoats)
- **Repair of utility vehicles and other vehicles**
- **Coil coatings**
- **Coatings for maritime applications**
- **Wood coatings** (furniture)
- **Other industrial coatings** (spray paints (without propellants); electrical fittings and appliances / household; machine tools; auto accessories/ metal; metal products, sheet metal packaging; wire enamels; impregnation and casting materials; structural elements without strip coatings; plastics; paper / foil; other processing)

iii) Other non-industrial colour coatings (marking paints; anti-corrosives; other)

2.D.3.e Degreasing

- **Metal degreasing**
- **Production of electronic components**
- **Other industrial cleaning** (precision mechanics, optics, watch-making)

2.D.3.f Chemical cleaning (dry cleaning)

- **Dry cleaning**

2.D.3.g Production and processing of chemical products

- **Processing of polyester**
- **Processing of polyvinyl chloride**
- **Processing of polyurethane**
- **Processing of polystyrene foam**
- **Rubber processing** (tyre manufacturing)
- **Production of pharmaceutical products**
- **Production of paints and lacquers**
- **Production of printing inks and dyes**
- **Production of glues**
- **Production of adhesives, magnetic tape, films and photographs**
- **Production of products containing solvents**
    - Production of wood preservatives
    - Production of building-material additives
    - Production of consumer goods containing solvents
    - Production of surface-cleaning agents
    - Production of anti-freezes and de-icing agents
    - Production of waxes and wax removers
    - Production of paint strippers
- **Treatment of bitumen (asphalt blowing)**

2.D.3.h Printing industry – printing applications

- Coldset-offset printing (newspaper printing)
- Sheet-fed offset printing (conventional, UV-bases)
- Heatset-offset printing
- Endless-offset printing
- Book printing
- Flexographic printing for packaging (solvent-based, water-based)
- Gravure printing for packaging (solvent-based, water-based)
- Illustration gravure printing
- Screen printing
- Other printing applications
- Paints for artists, in sets
- Paints for artists, not in sets
- Inks for writing and drawing, etc., including inks in concentrate or solid form (not including printing inks)

2.D.3.i: Other applications

- **Treatment of glass and rock wool**
- **Extraction of oils and fats**
- **Use of glues and adhesives** (paper and packaging; construction, wood; transport; shoes; do-it-yourself applications; other)
- **Use of wood preservatives**
- **Undersealing and wax treatments for automobiles**
- **Automobile-wax stripping**
- Other
  - Use of pesticides
  - Dichloroethane for paint stripping
  - Paint and varnish removal (improperly coated aluminium components, steel parts and steel hangers)
  - Concrete additives
  - De-icing (aircraft; working spaces; other)
  - Scientific laboratories

In keeping with an expert opinion dating from 2018, NMVOC emissions from use of metal-processing oils (cooling lubricants) and of other lubricants (industrial lubricants) are not reported in source category 2.D.3.i. – "Other applications." We have now included these two source categories, along with the emissions from all other lubricant uses – with the exception of transport-related emissions – within source category 2.D.1. "Lubricant use."

"NMVOC" is defined in keeping with the VOC definition found in the EC solvents directive (European Parliament and Council of the European Union, 2010)[75]. For purposes of the definition of solvents, the term "solvent use" is also defined in keeping with the EC solvents directive[76].

[75] In this definition, volatile organic compounds (VOC) include all organic compounds that are volatile at 293.15 K, at a vapour pressure of at least 0.01 kPa or under the usual conditions for their use.

[76] In this definition, an organic solvent is a volatile organic compound that, either by itself or in combination with other raw materials, products or waste substances, and without changing chemically, either dissolves or is used as a cleanser for dissolving dirt accumulations, as a solvent, as a dispersing agent, as an agent for adjusting viscosity or surface tension, or as a softener or preservative.

It is important to note that some volatile organic compounds are used both as solvents and as chemical reactants – for example, toluene, which is used as a solvent in lacquers and glues and as a reactant for production of toluenediisocyanate (TDI), and methyl ethyl ketone (butanone), which is used as a solvent in printing inks and as a base material for synthesis of methyl ethyl ketone peroxide. Consequently, VOC (either substances or fractions of substances or products) used as chemical reaction components are not included in this category.

Delimitation of this category as outlined above takes a highly diverse range of emissions-causing processes into account. The factors considered with regard to such processes include:

- Concentrations and volatility of VOC used.
  (The relevant spectrum includes use of volatile individual substances as solvents – for example, in cleansing; use of products with solvent mixtures – for example, in paints and lacquers; and applications in which only small parts of mixtures used (also) have solvent properties (as is the case, for example, in polystyrene-foam production)).
- The great differences in emissions conditions.

Solvent uses can be open to the environment – as is the case in use of cosmetics – or largely closed to the environment – as in extraction of essential oils or cleaning in chemical dry-cleaning systems.

4.5.3.2 Methodological issues (2.D.3 Solvents)

Except in the area of asphalt blowing, NMVOC emissions are calculated via an approach oriented to product consumption. In this approach, the NMVOC input quantities allocated to these source categories, via solvents or solvent-containing products, are determined and then the relevant NMVOC emissions (for each source category) are calculated from those quantities via specific emission factors. This method is explicitly listed, under "consumption-based emissions estimating", as one of two methods that are to be used for emissions calculation for this category.

Use of this method is possible only with valid input figures – differentiated by source categories – in the following areas:

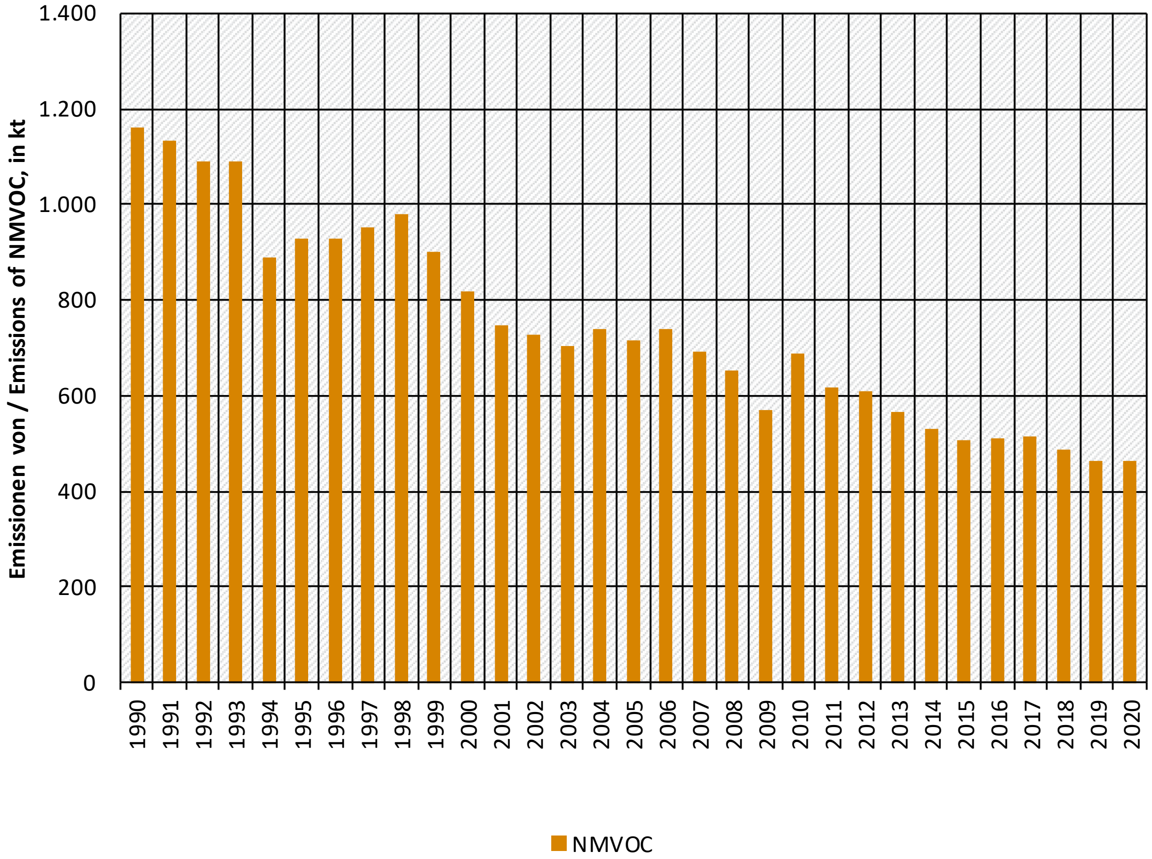
- the quantities of VOC-containing (pre-) products and agents used in the reporting year,
- the VOC concentrations in these products (substances and preparations),
- the relevant application and emission conditions (or the resulting specific emission factor).

To take account of the highly diverse structures throughout this category, these input figures are determined on the level of 37 differentiated emissions-causing processes (as noted above, in a manner similar to that used for CORINAIR SNAP Level 3), and the calculated NMVOC emissions are then aggregated. The product / substance quantities used are determined at the product-group level with the help of production and foreign-trade statistics. Where possible, the so-determined domestic-consumption quantities are then further verified via cross-checking with industry statistics.

The values used for the average VOC concentrations of the input substances, and the emission factors used, are based on experts' assessments (expert opinions and industry dialog) relative to the various categories and category areas. Not all of the necessary basic statistical data required for calculation of NMVOC emissions for the most current relevant year are available in final form; as a result, the data determined for the previous year are used as a basis for a forecast for the current report. The forecast for NMVOC emissions from solvent use for the relevant most current year is calculated on the basis of specific activity trends. As soon as the relevant basic statistical data are available for the relevant most current year, in their final form, the inventory data for NMVOC emissions from solvent use are recalculated.

Since 1990, NMVOC emissions from use of solvents and solvent-containing products have decreased by more than 50% overall.

Figure 42: Total NMVOC emissions from solvents-based products and applications (2.D.3.a,d-i)



The greatest part of this emissions reduction occurred in the years 1999 through 2009. This successful reduction has occurred especially as a result of regulatory provisions such as the Ordinance, under chemicals law, for limiting emissions of volatile organic compounds (VOC) through limitations on the placing on the market of solvent-containing paints and varnishes *(Chemikalienrechtliche Verordnung zur Begrenzung der Emissionen flüchtiger organischer Verbindungen (VOC) durch Beschränkung des Inverkehrbringens lösemittelhaltiger Farben und Lacke (Lösemittelhaltige Farben- und Lack-Verordnung - ChemVOCFarbV)*, the 31st Ordinance on the Execution of the Federal Immission Control Act (Ordinance on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain facilities – 31. *BImSchV)*, the 2nd such ordinance *(Ordinance on the limitation of emissions of highly volatile halogenated organic compounds* – 2. *BImSchV)* and the Technical Instructions on Air Quality Control (TA Luft). The German "Blauer Engel" ("Blue Angel") environmental quality seal, which is used to certify a range of products, including paints, lacquers and glues with low solvent concentrations, has also played an important role in this development.

While product sales increased in some areas – even over periods of several years – thereby adding to emissions, the above-described measures have largely offset this trend. These successes, which have occurred especially in recent years, are reflected in the updated emissions calculations – which, thanks to methods optimisation, now feature greater differentiation of VOC concentrations and emission factors.

Since the 2009 report, indirect CO_2 emissions are calculated from NMVOC.

Since compatibility with EU greenhouse-gas reporting is the primary methodological backdrop for conversion of NMVOC emissions into indirect CO_2 emissions, for the current report we have used the Reference Approach proposed in *Vol. 1 Chapter 7 Precursors and Indirect Emissions* of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories:

$$EM_{Indirect\ CO2} = EM_{NMVOC} * \text{molar mass } CO_2 / \text{molar mass C} * 60\ \%$$

In the framework of an expert assessment, and with the help of technical discussions with the affected sectors in the years 2013, 2015 and 2017, the solvent content levels of various paints, coatings and printing inks have been adapted to the current state of the art – and, thus, reduced. In addition, the NMVOC emissions from use of metal-processing oils (cooling lubricants) and of other lubricants (industrial lubricants) have been assigned to another category (2.D.1. "lubricant use") (cf. Chapter 4.5.3.1).

The NMVOC emissions that result from asphalt blowing are calculated with an emission factor oriented to the quantity of so-treated bitumen in each case. The pertinent NMVOC emission factor was derived taking account of the maximum permitted levels and reduction-measures requirements specified in the Technical Instructions on Air Quality Control (TA Luft). The emission factor, which remains constant for all years in question, amounts to 27.2 mg/t.

The applicable quantities of treated bitumen are calculated from the total-bitumen-production figures published annually by the Federal Office of Economics and Export Control (BAFA), in its official mineral-oil data (Amtliche Mineralöldaten) (BAFA, 2021). The applicable percentage share of blown asphalt (bitumen) was obtained from a one-time data survey of the association Arbeitsgemeinschaft der Bitumenindustrie e.V (bitument industry working group) that was carried out for the year 1994, in the framework of a project commissioned by the Federal Environment Agency (UBA). The percentage share remains constant for all years in question, and it amounts to 10%.

A more-detailed explanation of the methods used to determine and analyse trends for NMVOC emissions from solvents-based products and applications is available in the Informative Inventory Report (IIR)[77].

4.5.3.3 Uncertainties and time-series consistency (2.D.3 Solvents)

At the time of the report, errors had been estimated for NMVOC emissions; this was carried out using the error-propagation method and on the basis of experts' assessments for all input figures (in all 37 differentiated categories). The main source of current uncertainties consists of inadequate precision in separation of basic statistics (production and foreign-trade statistics), with regard to categorisation in VOC-containing and VOC-free products, and with regard to use in different categories with highly differing emissions conditions.

In the framework of an expert judgement, the consistency of the inventory in this area was checked via documentation of the database and the calculation methods for the 37 SNAP codes. The emissions time series from 2005 onward were reviewed with regard to major jumps (>10 % from year to year), and the causes of any jumps were analysed. For all jumps identified, the causes behind the jumps were clarified. As a result, we conclude that there are no inconsistencies in the time series.

[77] Informative Inventory Report – Germany http://iir.umweltbundesamt.de

4.5.3.4 Category-specific quality assurance / control and verification (2.D.3 Solvents)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

4.5.3.5 Category-specific recalculations (2.D.3 Solvents)

The data used in the emissions inventory for the NMVOC emissions of the previous year are subjected to routine source-specific recalculations. That procedure, which is grounded in the methodology oriented to product consumption, is required because the relevant final data from foreign-trade statistics do not become available until after the report for the pertinent reporting year has been completed.

The NMVOC emissions of the year 2018 had to be corrected, only slightly, to take account of slight adjustments / updates in foreign-trade statistics (WA2018).

Because staffing shortages prevented revision of the NIR for the 2021 report, that report carried emissions data for the year 2018 forward. For this reason, the emissions data for the years 2019 and 2020 have been completely recalculated for this year's report. In the process, changes in national production statistics (updated national classification of goods for production statistics (GP 2019)) and in foreign-trade statistics (nomenclature of goods for foreign-trade statistics ((WA 2019), (WA 2020)) were taken into account.

The change in the calculation method for production of blown asphalt necessitated a recalculation back through 1990. The changes' impacts on 2.D.3g. amount to a maximum of 0.6 %.

4.5.3.6 Planned improvements, category-specific (2.D.3 Solvents)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.5.4 Other: Bitumen for roofing (2.D.3 Bitumen)

Gas	Method used	Source for the activity data	Emission factors used
NMVOC	Tier 1	AS	CS
CO_2	NE	NE	NE

As far as is currently known, the category *Bitumen for roofing* produces no greenhouse-gas emissions and thus is not a key category[78].

4.5.4.1 Category description (2.D.3 Bitumen)

Bitumen is used in production and laying of roof and sealing sheeting.

The quantities of roof and sealing sheeting that are produced and used in Germany are shown in Table 196. The discrepancy between the two figures (production and use) is due to an export surplus. In such production, liquid bitumen is applied, at temperatures of 150°C to 220°C, as a saturating or coating agent. This process produces emissions of organic substances (combined here as NMVOC).

Roof and sealing sheeting is laid by means of both hot and cold processes. The hot process, involving welding of sheeting, produces significant emissions of organic substances. The relevant emissions trends depend primarily on trends in quantities of polymer bitumen sheeting

[78] Cf. the discussion relating to indirect CO_2 emissions, under "Methodological aspects".

produced. Use of solvent-containing primers is not considered here; it is covered via the solvents model – cf. Chapter 4.5.1.

Emissions from production of roof and sealing sheeting have remained about the same, and production quantities have hardly decreased at all. Emissions from laying of roof and sealing sheeting can increase slightly, even when the quantities of sheeting used decrease, because use of bitumen roofing sheets is accounting for a growing share of this sector.

Substances other than NMVOC are of only subordinate relevance in terms of emissions (cf. footnote [78]).

4.5.4.2 Methodological issues (2.D.3 Bitumen)

Data on quantities of roof and sealing sheeting that are produced and used (**activity data**) are provided by the VDD association of the bitumen, roof sheeting and sealing sheeting industry (VDD, 2021), on the basis of a cooperation agreement dating from 2009. At present, no data supplementation or extrapolation is being carried out. To obtain internationally comparable figures, production quantities are converted into quantities of input bitumen (the conversion relationship, depending on the type of sheeting concerned, varies from 1.3 to 3.3 bitumen kg/m^2).

Because of their predominating importance, only NMVOC emissions are considered and taken into account in the emissions inventory. In the process, a distinction is made between emissions from production and emissions from laying of roof and sealing sheeting.

The **emission factor** for production of roof and sealing sheeting was obtained via a calculation in accordance with current technological standards of German manufacturers (VDD, 2009). The emission factor for laying of polymer bitumen sheeting has been taken from an ecological balance sheet (Kreißig, 1996). That emission factor has also been adopted, by analogy, for sheeting glued primarily with hot bitumen. Thin sheeting is not glued; it is attached via nailing and produces no emissions. The implied emission factor for the category has been increasing slightly, as a result of the increasing importance of polymer bitumen sheeting.

NMVOC emissions are calculated in keeping with a Tier 1 method, since no pertinent detailed data are available.

Table 196: Production and laying of roof and sealing sheeting with bitumen, and relevant activity data and emission factors

	Produced or used area in 2020 [millions of m^2]	EF/ IEF [kg/ m^2]
Production of roof and sealing sheeting with bitumen	170	NMVOC 0.000358
Laying of roof and sealing sheeting containing bitumen	146	NMVOC 0.000027 – 0.000042

The carbon dioxide emissions, which could be obtained by multiplying the NMVOC emissions by a carbon-content factor of 80% and then converting to CO_2, are negligibly low. For this reason, they are not listed as such; in the CRF tables, they are marked as "NE".

4.5.4.3 Uncertainties and time-series consistency (2.D.3 Bitumen)

Information relative to the uncertainty of the data of the VDD was obtained via consultation between the VDD and the Federal Environment Agency. The total uncertainty for the activity data for production and laying of sheeting is estimated to be about +/-1 %. That figure, in turn, leads to a higher uncertainty, of about +/-2.5 %, for the calculated bitumen consumption.

The uncertainty for the combined emission factors for production and laying of roof and sealing sheeting is estimated to be about +/-5 %.

4.5.4.4 Category-specific quality assurance / control and verification (2.D.3 Bitumen)

Due to resources limitations, and to the area's minimal relevance, no QC/QA is carried out for reporting relative to precursors. A QC/QA checklist was completed and confirmed in the framework of the agreement with the VDD.

The manner in which the activity data were determined is considered to be plausible. The emission factors accord with findings from pertinent Federal Environment Agency research projects and are plausible. In particular, the validity of the emission factors is justified in that no emissions from use of solvent-containing coatings and primers have to be taken into account in this section (that takes place in the solvents model, as noted above).

4.5.4.5 Category-specific recalculations (2.D.3 Bitumen)

No recalculations are required.

4.5.4.6 Planned improvements, category-specific (2.D.3 Bitumen)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.5.5 Other: Road paving with asphalt (2.D.3 Asphalt)

Gas	Method used	Source for the activity data	Emission factors used
NO_X, NMVOC, SO_2	Tier 1	AS	CS
CO_2	NE	NE	NE

As far as is currently known, the category *Road paving with asphalt* produces no greenhouse-gas emissions and thus is not a key category[79].

4.5.5.1 Category description (2.D.3 Asphalt)

Currently, the report tables list produced quantities of mixed asphalt products and NMVOC, NO_X and SO_2 emissions (with regard to CO_2, cf. footnote [79]).

In 2020, a total of about 38 million t of asphalt (DAV, 2021) was produced in Germany, in a total of about 600 asphalt-mixing plants (DAV, 2016). Asphalt is used primarily in road construction, where it competes directly with hydraulically bound concrete. In 1991, total production increased considerably; since 2000 it has been decreasing again.

The relevant emissions trend depends primarily on trends in production quantities, and production has stagnated in recent years.

4.5.5.2 Methodological aspects (2.D.3 Asphalt)

No special calculation procedure is available for calculating fuel inputs in category 1.A.2. Nonetheless, fuel inputs are taken into account via Energy Balance evaluation, and they are coupled with suitable emission factors.

The applicable quantity of mixed asphalt products produced (**activity data**) has been taken from communications of the Deutscher Asphaltverband (DAV; German asphalt association).

[79] Cf. the discussion relating to indirect CO_2 emissions, under "Methodological aspects".

The **emission factors** were determined country-specifically, in accordance with Tier 2 criteria. Emission factors for substances other than CO_2 were determined on the basis of emissions measurements for over 400 asphalt-mixing plants, for the period 1989 to 2000. The majority of the emissions occur during drying of pertinent mineral substances. Almost all of the NMVOC emissions originate in the organic raw materials used, and they are released primarily in parallel-drum operation, as well as from mixers and loading areas. On average, about 50% of the NO_X and SO_2 involved come from the mineral substances used (proportional process emissions). CO occurs primarily in incomplete combustion processes. CO emissions are calculated solely in connection with fuel inputs.

Table 197: Emission factors for production of mixed asphalt products

	NOx	NMVOC	SO_2
EF [kg/ t]	0.015	0.030	0.030

Only emissions from asphalt production are reported. Figures relative to emissions released during laying of asphalt have not yet been adequately reviewed.

The carbon dioxide emissions, which could be obtained by multiplying the NMVOC emissions by a carbon-content factor of 80 % and then converting to CO_2, are negligibly low. For this reason, they are not listed as such; in the CRF tables, they are marked as "NE".

4.5.5.3 Uncertainties and time-series consistency (2.D.3 Asphalt)

As the extensive measurement data show, the emissions lie within a comparatively narrow range. The large volume of measurement data available makes it possible to form highly reliable mean values. The only large uncertainties are found in breakdown of emissions amounts into fuel-related and process-related emissions.

The production-amount data may be considered very accurate, since the product in question is a sale-ready product, and operators report the relevant amounts to the DAV.

4.5.5.4 Category-specific quality assurance / control and verification (2.D.3 Asphalt)

Due to resources limitations, and to the area's minimal relevance, no QC/QA is carried out for reporting relative to precursors.

4.5.5.5 Category-specific recalculations (2.D.3 Asphalt)

No recalculations are required.

4.5.5.6 Planned improvements, category-specific (2.D.3 Asphalt)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.5.6 CO_2 emissions from use of AdBlue® in road transports and off-road vehicles (2.D.3 Other: AdBlue)

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS / M	CS / M	D

4.5.6.1 Category description (2.D.3 Other: AdBlue)

The numbers of vehicles in service in Germany that are equipped with SCR catalytic converters have been increasing since 2004. Such catalytic converters control NO_x emissions with the help of a liquid-reductant agent, an aqueous urea solution.[80] When the urea solution is chemically converted, carbon dioxide is released. In Germany, virtually the only the product used for this purpose is AdBlue® (VDA, 2013).

4.5.6.2 Methodological issues (2.D.3 Other: AdBlue)

Since no comprehensive statistics or market studies on AdBlue® sales are currently available, the input AdBlue® quantities, and the resulting CO_2 emissions, are calculated within TREMOD (Knörr et al., 2021c) on the basis of fuel-consumption data for vehicles equipped with SCR catalytic converters.

Table 198: Modelled quantities of AdBlue® used, in tonnes

	2004	2005	2010	2015	2016	2017	2018	2019	2020
Automobiles	0	0	2,995	53,252	97,364	142,392	178,728	212,677	199,268
Light-duty vehicles	0	0	0	604	4,620	18,123	37,654	56,164	66,819
Trucks	203	7,627	350,366	570,076	616,240	654,977	686,529	706,169	702,965
Buses	51	200	17,320	37,525	42,955	47,283	52,740	57,116	48,021
Σ Road transports	**254**	**7,827**	**370,680**	**661,457**	**761,179**	**862,774**	**955,650**	**1,032,126**	**1,017,074**
Construction sector	0	0	0	5,901	16,027	28,961	41,704	54,120	66,584
Commercial and institutional	0	0	0	876	2,405	4,347	6,256	8,132	10,018
Agriculture	0	0	0	2,363	6,749	13,098	20,145	27,241	35,105
Forestry sector	0	0	0	334	1,064	2,129	3,786	5,235	7,552
Σ Offroad	**0**	**0**	**0**	**9,474**	**26,244**	**48,535**	**71,892**	**94,728**	**119,260**
Total quantity	**254**	**7,827**	**370,680**	**670,930**	**787,423**	**911,309**	**1,027,542**	**1,126,854**	**1,136,334**

Source: Knörr et al. (2021b); Knörr et al. (2021c)

The resulting CO_2 emissions are calculated in keeping with the following formula, pursuant to (IPCC (2006a): Volume 2, Chapter 3.2 – Road Transportation, p. 3.12, Formula 3.2.2):

$$EM_{CO_2} = AR_{AdBlue®} \times \frac{12}{60} \times \frac{32,5}{100} \times \frac{44}{12}$$

The following table presents the so-calculated CO_2 emissions.

Table 199: CO_2 emissions resulting from use of AdBlue®, in kilotonnes

	2004	2005	2010	2015	2016	2017	2018	2019	2020
Automobiles	0.00	0.00	0.71	12.7	23.2	33.9	42.6	50.7	47.5
Light-duty vehicles	0.00	0.00	0.00	0.14	1.10	4.32	8.97	13.4	15.9
Trucks	0.05	1.82	83.5	136	147	156	164	168	168
Buses	0.01	0.05	4.13	8.94	10.2	11.3	12.6	13.6	11.4
Σ Road transports	**0.06**	**1.87**	**88.3**	**158**	**181**	**206**	**228**	**246**	**242**
Construction sector	0.00	0.00	0.00	1.41	3.82	6.90	9.94	12.9	15.9
Commercial and institutional	0.00	0.00	0.00	0.21	0.57	1.04	1.49	1.94	2.39
Agriculture	0.00	0.00	0.00	0.56	1.61	3.12	4.80	6.49	8.37
Forestry sector	0.00	0.00	0.00	0.08	0.25	0.51	0.90	1.25	1.80
Σ Offroad	**0.00**	**0.00**	**0.00**	**2.26**	**6.25**	**11.6**	**17.1**	**22.6**	**28.4**
Total quantity	**0.06**	**1.87**	**88.3**	**160**	**188**	**217**	**245**	**269**	**271**

Source: Knörr et al. (2021b); Knörr et al. (2021c)

In the German GHG inventory, these emissions are reported, pursuant to footnote (6) to CRF Table 2(I).A-Hs2, under *2.D.3 – Non-energy products from fuels – Other*.

[80] Average urea concentration pursuant to DIN 70070: 32.5 %

4.5.6.3 Uncertainties and time-series consistency (2.D.3 Other: AdBlue®)

The underlying uncertainties figures have been obtained from expert judgements. The relevant data sources, methods and emission factors are used consistently throughout the entire time series.

4.5.6.4 Category-specific quality assurance / control and verification (2.D.3 Other: AdBlue®)

General quality control and quality assurance, have been carried out in conformance with the requirements of the QSE-manual and its associated applicable documents, by the Single National Entity.

The data cannot be verified on the basis of inventories comparable to the German inventory. The last comparison with inventories of other countries was carried out in summer 2018, in the framework of an EU-wide exchange on new emission sources.

4.5.6.5 Category-specific recalculations (2.D.3 Other: AdBlue®)

Table 200: Revised annual fuel consumption of vehicles with SCR systems, in terajoules

	2004	2005	2010	2015	2016	2017	2018	2019
2022 Submission	204	6,402	366,267	972,677	1,099,81	1,210,75	1,300,24	1,375,80
2021 Submission	204	6,402	366,315	972,273	1,099,71	1,209,00	1,295,57	1,369,48
Absolute change	0.0	0.0	-47.9	404	100	1,751	4,673	6,322
Relative change	0.00%	0.00%	-0.01%	0.04%	0.01%	0.14%	0.36%	0.46%

Source: Own calculations, based on Knörr et al. (2021b); Knörr et al. (2021c)

The quantities of AdBlue® used were recalculated to take account of revision of the fuel consumption of SCR vehicles. It should be noted that those quantities do not change 1:1 with fuel consumption. The reason for this is that the off-road vehicles considered use more urea solution, on average, per liter of diesel fuel than road vehicles do.

Table 201: Revised quantities of AdBlue® used, in tonnes

	2004	2005	2010	2015	2016	2017	2018	2019
2022 Submission	254	7,827	370,680	670,930	787,423	911,309	1,027,5	1,126,8
2021 Submission	254	7,827	370,732	670,864	787,907	910,361	1,024,7	1,125,2
Absolute change	0.0	-0.1	-51.6	65.9	-483	948	2,774	1,611
Relative change	0.00%	0.00%	-0.01%	0.01%	-0.06%	0.10%	0.27%	0.14%

Source: Own calculations, based on Knörr et al. (2021b); Knörr et al. (2021c)

The corrections of the AdBlue® quantities lead to the CO_2-emissions adjustments shown below.

Table 202: Revised CO_2 emissions, in kilotonnes

	2004	2005	2010	2015	2016	2017	2018	2019
2022 Submission	0.06	1.87	88.3	160	188	217	245	269
2021 Submission	0.06	1.87	88.4	160	188	217	244	268
Absolute change	0.00	0.00	-0.01	0.02	-0.12	0.23	0.66	0.38
Relative change	0.00%	0.00%	-0.01%	0.01%	-0.06%	0.10%	0.27%	0.14%

Source: Own calculations

4.5.6.6 Planned improvements, category-specific (2.D.3 Other: AdBlue®)

At present, no improvements are planned on top of the general maintenance of the underlying TREMOD and TREMOD MM models that is normally carried out.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.6 Electronics industry (2.E)

KC	Category	Activity	EM of	1995 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1995-2020
-/-	2 E, Electronics Industry		C_2F_6	162.5	0.0%	42.9	0.0%	-73.6%
-/-	2 E, Electronics Industry		CF_4	102.6	0.0%	65.8	0.0%	-35.9%
-/-	2 E, Electronics Industry		SF_6	47.3	0.0%	27.2	0.0%	-42.5%
-/-	2 E, Electronics Industry		C_6F_{14}	25.4	0.0%	0.0	0.0%	-100.0%
-/-	2 E, Electronics Industry		HFC-23	17.1	0.0%	14.0	0.0%	-17.9%
-/-	2 E, Electronics Industry		NF_3	5.3	0.0%	10.8	0.0%	104.2%
-/-	2 E, Electronics Industry		HFC-32	0.0	0.0%	0.0	0.0%	
-/-	2 E, Electronics Industry		C_3F_8	0.0	0.0%	12.2	0.0%	
-/-	2 E, Electronics Industry		c-C_4F_8	0.0	0.0%	5.7	0.0%	

Gas	Method used	Source for the activity data	Emission factors used
HFCs	Tier 3	AS, NS	PS
PFC	CS	AS, NS	CS
SF_6	CS	AS, NS	CS
NF_3	CS	AS, NS	CS

The category *Electronics industry* is not a key category.

4.6.1 Semiconductor and circuit-board production (2.E.1)

4.6.1.1 Category description (2.E.1)

The semiconductor industry currently emits PFCs (CF_4, C_2F_6, C_3F_8, c-C_4F_8), HFC (CHF_3, CH_2F_2), nitrogen trifluoride (NF_3) and sulphur hexafluoride (SF_6)) from production processes. These gases are used for etching structures on thin layers and for cleaning reaction chambers following chemical vapour deposition (CVD). In the production process, some of the PFCs fed into plasma chambers are converted partly into CF_4.

The semiconductor industry's emissions depend partly on the degree to which the industry uses waste-gas-scrubbing equipment. They also depend directly on semiconductor-production levels (in the present case, annual levels). As a result of these dependencies, emissions tend to fluctuate from year to year.

In printed circuit board (PCB) production, drilled holes are cleaning with systems that use CF_4. As a repeat survey carried out in 2019 found, this area of application undergoes few changes.

4.6.1.2 Methodological issues (2.E.1)

Emission factors

During the etching process, only about 15 % of the added CF_4 reacts chemically. The emission factor, an inverse reaction quota, thus amounts to 85 % of the CF_4 consumption.

The emissions cannot be determined solely on the basis of input quantities (sales by gas vendors), however, because the difference between consumption and emissions depends on a number of factors – especially the effects of downstream waste-gas-scrubbing systems, in addition to only-partial chemical transformation in plasma reactors. The relevant figures are thus aggregated and reported on a plant-specific basis, by the pertinent industrial association.

Activity data

The quantities of SF_6 used (since report year 2006) and NF_3 use (since report year 2015) are determined by the Federal Statistical Office, via surveys of gas sellers (UStatG 2005). The usage-quantity data for the other substances are collected by the Federal Statistical Office, assigned to the semiconductor industry and confirmed by that industry.

Reliable emissions data are available for 1990 and 1995. Linear interpolation was carried out for the years 1991 to 1994.

Until reporting year 2000, emissions data were based on surveys carried out by the EECA-ESIA (European Electronic Component Manufacturers Association – European Semiconductor Industry Association). National manufacturers were queried regarding production capacities, amounts of substances used and waste-gas treatment equipment.

As the result of a voluntary commitment by the semiconductor industry, emissions figures are available for this sub-category, for all individual substances, from the year 2001 onwards. In keeping with a standardised calculation formula (Tier 2c approach), the emissions data are calculated for each production site, from annual consumption, aggregated and then reported by the German Electrical and Electronic Manufacturers Association (Zentralverband Elektrotechnik- und Elektroindustrie eV. – ZVEI; Electronic Components and Systems Division) to the Federal Environment Agency.

The emissions from the semiconductor industry either increase slightly or remain constant, depending on the substances involved. The emissions from printed circuit board (PCB) production have remained constant.

4.6.1.3 Uncertainties and time-series consistency (2.E.1)

The uncertainties for the semiconductor industry have been determined completely. According to the association, the uncertainties for the emissions amount to U_{max}= 12 % and U_{min}= 7 %.

The uncertainties (U_{min}/U_{max}) for emissions from printed circuit board (PCB) production are 15%.

4.6.1.4 Category-specific recalculations (2.E.1)

No recalculations are required.

4.6.1.5 Source-specific quality assurance / control and verification (2.E.1)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The data have undergone the above association's internal quality assurance and quality control process.

Quality control (pursuant to Tier 1) and quality assurance, in conformance with the requirements of the QSE manual and its associated applicable documents, have been carried out.

No other data sources, apart from the data collected by the association, and the data provided by the Federal Statistical Office, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. Comparisons with other countries have revealed no requirements for improvements. The emission factors are of the same order of magnitude as those of other countries.

4.6.1.6 Category-specific planned improvements (2.E.1)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.6.2 TFT (2.E.2)

No TFT flat screens are produced in Germany.

4.6.3 Photovoltaics (2.E.3)

4.6.3.1 Category description (2.E.3)

In wafer production in Germany, SF_6 and other fluorine compounds have been used for structure etching and for cleaning of reaction chambers during production processes. Since the purity of the process gas is lower than that of the gas used in the similar production process in the semiconductor industry, use for *photovoltaics* is reported separately. In Germany, use of SF_6 in solar technology began in 2003.

The time series shows a continuous emissions increase between 2003 and 2006; this is due to increases in production. A large jump occurred in 2007 and 2008, when quantities of produced wafers and, thus, the quantities of SF_6 used, increased sharply. As of 2010, decreases in produced quantities have led to a new reduction of emissions. From 2014 onward, no wafer production with SF_6 has taken place in Germany.

Beginning 2008, NF_3 substituted for SF_6 in all new production lines for production of Si thin-film cells. Production of the substance was phased out by 2015.

In addition, in 2002/2003 the perfluorinated hydrocarbon CF_4 was introduced for "edge insulation" of crystalline solar cells. The procedure using that substance was soon supplanted by a different procedure that is easier to handle, however. Consumption of CF_4, which peaked in 2004, has been decreasing sharply since then. In 2014, production was largely discontinued.

4.6.3.2 Methodological issues (2.E.3)

Like emissions in the semiconductor industry, emissions in photovoltaics occurred during production. It was not possible to determine the relevant production emissions solely on the basis of the quantities used (sales by the gas trade). The differences between consumption and emissions resulted from a) the fact that chemical conversion in plasma reactors was only partial and b) the effects of downstream waste-gas-scrubbing systems.

Emission factors

In 2009, only one producer in Germany did not have a waste-gas-scrubbing system. For this reason, the IPCC default emission factor of 40 % was used only for the first year of pertinent use, 2003. Thereafter, the emission factor decreased, as the percentage of wafer production connected to downstream waste-gas-scrubbing systems increased. In 2010, it was just less than 6 %. As of 2011, all production facilities that used SF_6 had waste-gas-scrubbing systems in place, and the emission factor has been 4 % since that year.

In wafer production with NF_3, the emission factor had a value of 4 %, since all national production facilities operated waste-gas-scrubbing systems. It was thus considerably lower than the IPCC default emission factor of 20 %.

The emission factor for edge insulation with CF_4 is 7 %.

Activity data

The annual consumption figures were obtained via surveys, carried out by the Federal Statistical Office, of gas suppliers (UStatG 2005), with regard to their domestic sales. In addition, the data have been checked in a separate study (Schwarz 2009).

4.6.3.3 Uncertainties and time-series consistency (2.E.3)

The uncertainties have been completely determined. According to expert judgements, the uncertainties for the emissions (U_{min}/U_{max}) are 10 % for SF_6, 20% for NF_3 and 50 % for CF_4.

4.6.3.4 Category-specific recalculations (2.E.3)

No recalculations were required.

4.6.3.5 Source-specific quality assurance / control and verification (2.E.3)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

No other data sources, apart from the data provided by the Federal Statistical Office and the research contractor, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. Comparisons with other countries have revealed no requirements for improvements. The emission factors are of the same order of magnitude as those of other countries that operate production facilities with waste-gas-scrubbing systems.

4.6.3.6 Category-specific planned improvements (2.E.3)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.6.4 Heat transfer fluids (2.E.4)

4.6.4.1 Category description (2.E.4)

The PFC C_6F_{14} has been used as a heat transfer fluid in the semiconductor industry and in some ICE power cars. C_6F_{14} was widely used in the semiconductor industry in the 1990s. In 2015, such use was discontinued, and hydrofluoroether has been used instead. Emissions thus occur only from existing applications and in disposal. Until 2009, C_6F_{14} was used as a coolant in ICE power heads.

4.6.4.2 Methodological issues (2.E.4)

The emission factors are assumed to be 1 % for filling, 5 % for emissions from existing applications and 15 % for disposal. The 2006 IPCC Guidelines (IPCC, 2006a) do not provide default emission factors for a Tier 2 approach.

The quantities used, and the emission factors, were determined via surveys of sector experts (Deutsche Bahn, ZVEI), and via studies of available reference materials, in the framework of a research project (Gschrey et al. 2015).

The average lifetime of installations with heat transfer fluids, in the semiconductor industry, amounts to 12 years.

For reasons of confidentiality, the source category is reported in CRF 2.H.3.

4.6.4.3 Uncertainties and time-series consistency (2.E.4)

The uncertainties have been completely determined. According to expert judgements, the uncertainties for the activity data and emission factors (U_{min}/U_{max}) amount to 20 %.

4.6.4.4 Category-specific recalculations (2.E.4)

No recalculations were required.

4.6.4.5 Source-specific quality assurance / control and verification (2.E.4)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

No other data sources, apart from the data collected by the research contractor, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. Comparisons with other countries have revealed no requirements for improvements. The emission factors are of the same order of magnitude as the pertinent factors used in other countries.

4.6.4.6 Category-specific planned improvements (2.E.4)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.7 Product uses as substitutes for ODS (2.F)

KC	Category	Activity	EM of	1995 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1995-2020
L/T	**2 F, Product Uses as Substitutes for ODS**		**HFC-134a**	**2,268.2**	**0.2%**	**4,760.2**	**0.7%**	**109.9%**
L/T	**2 F, Product Uses as Substitutes for ODS**		**HFC-125**	**149.9**	**0.0%**	**2,079.4**	**0.3%**	**1,287.4%**
-/-	2 F, Product Uses as Substitutes for ODS		HFC-152a	90.1	0.0%	31.1	0.0%	-65.5%
-/T	**2 F, Product Uses as Substitutes for ODS**		**HFC-143a**	**71.3**	**0.0%**	**1,257.5**	**0.2%**	**1662.9%**
-/-	2 F, Product Uses as Substitutes for ODS		C_3F_8	19.9	0.0%	1.3	0.0%	-93.7%
-/-	2 F, Product Uses as Substitutes for ODS		HFC-23	16.3	0.0%	61.7	0.0%	279.8%
-/-	2 F, Product Uses as Substitutes for ODS		HFC-32	0.8	0.0%	215.8	0.0%	28443.8%
-/-	2 F, Product Uses as Substitutes for ODS		HFC-227ea	0.6	0.0%	87.2	0.0%	13384.0%
-/-	2 F, Product Uses as Substitutes for ODS		C_2F_6	0.0	0.0%	2.7	0.0%	-
-/-	2 F, Product Uses as Substitutes for ODS		HFC-43-10mee	C	C	C	C	C
-/-	2 F, Product Uses as Substitutes for ODS		HFC-236fa	C	C	C	C	C
-/-	2 F, Product Uses as Substitutes for ODS		HFC-245fa	C	C	C	C	C
-/-	2 F, Product Uses as Substitutes for ODS		HFC-365mfc	C	C	C	C	C
-/-	2 F, Product Uses as Substitutes for ODS		C_6F_{14}	C	C	C	C	C

Gas	Method used	Source for the activity data	Emission factors used
HFC, PFC	cf. Table 203/Table 204	cf. Table 203/Table 204	cf. Table 203/Table 204

The category *Product Uses as Substitutes for ODS* is a key category for HFC-134a and HFC-125 emissions in terms of level and trend, and a key category for HFC-143a emissions only in terms of trend.

Category 2.F includes Refrigeration and air conditioning systems (2.F.1), Foam production (2.F.2), Fire extinguishing agents (2.F.3), Aerosols (2.F.4), Solvents (2.F.5) and other applications; ODS substitutes fall under (2.F.6). In the interest of more precise data collection, these sub-categories are broken down further, as described in the following sub-chapters.

Use of relevant substances as refrigerants in stationary and mobile refrigeration applications, which accounts for over three-fourths of relevant emissions, is the largest source of HFC emissions in this category. The remaining emissions are distributed among the sources foams and aerosols and, in small amounts, fire extinguishers and solvents.

The PFC emissions originate in use of certain refrigerant mixtures in refrigeration and air-conditioning systems.

Table 203: Overview of methods and emission factors used for the current report year in category 2.F.1 – *Refrigeration and air-conditioning systems*.

	QG	Method	Gas		Lifetime	Production	Application	Waste management	
			HFC	PFC	[years]	Emission factor (dimensionless)	Emission factor (dimensionless)	Residual charge level (dimensionless)	Recovery rate (dimensionless)
Air-conditioning and refrigeration systems	**2.F.1**								
Commercial refrigeration	2.F.1a								
- Plug-in appliances		Tier 2a	HFC		10 (D)	0.005 (D)	0.01 - 0.014 (D)	0.90 (CS)	0.326 - 0.6 (D)
- Condensing units					12 (D)	0.01 (D)	0.049 - 0.097 (CS)	0.85 (D)	0.475 - 0.8 (D, CS)
- Central systems				PFC	10 - 14 (D)	0.01 (D)	0.0805 - 0.195 (D, CS)	0.875 (D)	0.429 - 0.8 (D, CS)
Household refrigeration	2.F.1b								
- Household refrigeration appliances		Tier 2a	HFC		15 (D)	NO	0.003 (D)	0.955 (CS)	0.733 (CS)
- Ice cream machines		Tier 2a	HFC		15 (CS)	NO	0.003 (CS)	0.955 (CS)	0.53 - 0.65 (CS)
Industrial refrigeration	2.F.1c								
- Plug-in appliances		Tier 2a	HFC		10 (CS)	0.005 (D)	0.01 - 0.014 (CS)	0.9 (D)	0.337 - 0.6 (D)
- Large refrigeration systems				PFC	10 - 30 (D)	0.01 (D)	0.0455 - 0.088 (D)	0.85 (D)	0.45 - 0.8 (D)
Refrigerated transports	2.F.1d								
- Refrigerated vehicles		Tier 2a	HFC	PFC	10 (CS)	5 g/system (CS, D)	0.15 - 0.3 (D)	0.875 (CS)	0.657 (D)
- Refrigerated containers					14 (CS)	NO	0.05 - 0.1 (CS)	0.875 (CS)	0.657 (D)
Mobile air conditioning systems	2.F.1e								
- Utility vehicles		Tier 2a	HFC		15 (D)	5 g/system (CS, D)	0.15 (D)	0.34 (D)	0.38 - 0.5 (D)
- Automobiles					15 (D)	3 g/system (CS, D)	0.1 (D)	0.34 (D)	0.38 - 0.5 (D)
- Buses					15 (D)	50 g/system (D)	0.15 (D)	0.34 (D)	0.38 (D)
- Ships					25 (CS)	0.01 (CS)	0.1 - 0.35 (CS)	NO	NO
- Railway vehicles					25 (CS)	0.005 (D)	0.06 (CS)	0.875 (CS)	0.756 - 0.8 (CS)
- Agricultural machines					10 (CS)	5 g/system (CS)	0.15 - 0.25 (CS)	0.34 (CS)	0.117 (CS)
- Aircraft					-	NO	0.05 (CS)	NO	NO
Stationary air conditioning systems	2.F.1f								
- Large air conditioning systems		Tier 2a	HFC		15 - 25 (D)	0.005 (D)	0.028 - 0.06 (D)	0.9 (D)	0.658 - 0.8 (D)
- Heat pumps					15 (D)	0.005 (D)	0.02 - 0.025 (D)	0.75 (D)	0.5 - 0.65 (D)
- Heat-pump dryers					15 (CS)	0.005 (CS)	0.003 (CS)	NO	NO
- Dishwashers					12 (CS)	0.01 (CS)	0.003 (CS)	0.955 (CS)	0.82 - 0.85 (CS)
- Mobile Room air conditioners					10 (D)	NO	0.025 - 0.034 (D)	0.75 (D)	0.242 - 0.4 (D)
- Single-split units					10 (D)	0.1 (CS)	0.05 - 0.069 (D)	0.875 (CS)	0.379 - 0.6 (D)
- Multi-split units					13 (D)	0.01 (D)	0.042 - 0.079 (D)	0.875 (CS)	0.62 - 0.8 (D)
- VRF devices					13 (D)	0.01 (D)	0.049 - 0.081 (D)	0.875 (CS)	0.72 - 0.8 (D)

Table 204: Overview of methods and emission factors used, for the current report year, in categories 2.F.2 (Foam blowing), 2.F.3 (Fire extinguishers), 2.F.4 (Aerosols), 2.F.5 (Solvents) and 2.F.6 (Other applications that use ODS substitutes)

	QG	Method	Gas		Lifetime	Emission factor (dimensionless)		
			HFC	PFC	[years]	Production	Application	Waste management
Foam production	**2.F.2**							
closed-cell	2.F.2a							
- PUR hard foam with 134a					50 (D)	0.1 (D)	0.005 (D)	NO
- PUR hard foam with 227ea/245fa/365mfc		Tier 2a	HFC		50 (D)	0.1 - 0.15 (D)	0.01 (D)	NO
- XPS foam with 134a/1234ze					50 (D)	C	0.0066 (CS)	NO
open-cell	2.F.2b							
- XPS foam with 152a		Tier 2a			-	1 (CS)	NO	NO
- PUR integral foam with 134a/227ea/245fa/365mfc		Tier 2a	HFC		-	1 (CS)	NO	NO
- PU one-component foam with 134a/152a		Tier 2a			-	0.5 - 1.5 g / can (CS)	1 (CS)	NO
Fire extinguishers	**2.F.3**	CS	HFC		20 (D)	0.001 (CS)	0.01 - 0.04 (D)	0.01 (CS)
Aerosols	**2.F.4**							
Metered dose inhalers	2.F.4a	Tier 2a	HFC		-	0.015 (CS)	1 (CS)	NO
Other aerosols / novelties	2.F.4b/c	Tier 2a			-	0.015 (CS)	1 (CS)	NO
Solvents	**2.F.5**	Tier 2a	HFC		-	NO	0.5 (D)	NO
Other applications that use ODS substitutes	**2.F.6**					NO	NO	NO

Halocarbons are used in a number of different applications. Whereas in some, so-called "open" applications, consumed quantities are emitted completely, in the same year in question, in other applications large quantities are stored (stocks). The substances then are emitted, either partially or completely, from such "stocks" throughout the entire usage phase and in relevant waste management. Most of the emission factors (EF) used are either country-specific (CS) or IPCC default (D).

The emissions as listed in the inventory tables consist of the quantities of HFCs and PFCs that, during a report year, slowly escape from "stocks" and are emitted in production and waste management.

In general, the emissions data collected for the various product groups comprise emissions from production, use and waste disposal. Except where indicated otherwise in connection with the pertinent methods, these emissions are calculated as follows:

1. Production emissions are determined via new domestic consumption, as activity data:

   Equation 1:

   $$EM_{production} = \text{New domestic consumption} * EF_{production}$$

2. Application emissions are based on the final stocks of relevant pollutants (the activity data), and they are calculated via the following formula:

   Equation 2:

   $$EM_{use} = \text{Final stocks} * EF_{use}$$

   The final stocks for the current year are calculated by summing annual new additions, from the first reporting year to the current one. The new additions for a given year consist of the new domestic consumption for that year, minus production emissions and losses from removals. The calculation thus requires consideration of foreign trade.

3. Disposal emissions refer to new additions for the year that is x years (depends on product lifetime) prior to the current reporting year n:

Equation 3:

$EM_{disposal}$ = New additions (n-x) * $EF_{disposal}$

10. For refrigeration and air-conditioning systems, the disposal emissions are calculated in keeping with Vol. 3, Equation 7.14 of the 2006 IPCC Guidelines:

Equation 4:

$EM_{disposal}$ = new additions (n-x) * residual charge level * (1 - recovery factor)

In this chapter, the sections *Uncertainties and time-series consistency, Category-specific quality assurance / control and verification, Category-specific recalculations and Planned improvements* vary in their reference – some refer to the entire relevant category, some to the sub-category in question and some to only a part of a sub-category. In each case, the reference involved is apparent from the CRF number in the section heading.

4.7.1 Refrigeration and air conditioning systems (2.F.1)

4.7.1.1 Category description (2.F.1)

This category is divided into the sub-categories of commercial refrigeration, household refrigeration, industrial refrigeration, transport refrigeration, mobile air conditioning systems and stationary air conditioning systems (cf. Table 203).

In Germany, the leading HFC refrigerants, far and away, are HFC-134a and HFC-1234yf and the mixtures R404A, R407C, R410A, R422D and R507A. HFC-1234yf is not subject to reporting obligations under the UN Framework Convention on Climate Change, however.

For calculation of HFC emissions from the sub-categories of refrigeration and stationary air conditioning systems, individual data are collected, or refrigerant models are used. Any refrigerant models used are described in connection with the relevant method.

The emission factors used have been obtained via surveys of experts. Disposal emissions in this category first occurred in 2000, in sub-categories 2.F.1.a (commercial refrigeration) and 2.F.1.e (mobile air-conditioning systems).

4.7.1.2 Methodological issues (2.F.1)

4.7.1.2.1 Commercial refrigeration (2.F.1.a)

Commercial refrigeration is the largest and most diverse area of (H)FC application. It is subdivided into the areas of plug-in devices, condensing units and central systems. The great diversity seen in the area of central systems, with regard to model, size, type of refrigerant and emissions-tightness, results from the fact that most relevant systems are customised systems. Less diversity is found in the areas of plug-in devices and condensing units.

Use of (H)FCs as refrigerants grew only gradually. For example, HFC-134a was not used on any significant scale until mid-1993. Use of the refrigerant mixtures R404A and R407C also did not begin until 1993. The various R422 mixtures, which served as "drop-in" refrigerants in conversions of HCFC-22 systems, were used between 2009 and 2013. In addition, from 1993 on small quantities of PFC-containing refrigerant mixtures, such as R403A/B, R413A, Isceon 89 and

R508A/B, were also used as drop-in refrigerants. Since 2007, R410A has been used in small central systems. For conversions of central systems with R404A, the refrigerant mixture R449A has been used since 2013. R448A has also been used for such conversions since 2014. Since 2016, R449A, R452A and R513A have also been used in condensing units. Since 2019, HFC-1234ze (which is not subject to reporting obligations), R454C and R455A have also been used in such units. R454C and R455A are also used in plug-in units. CO_2 (R744) has also been used as a halogen-free alternative since 2002, and propane (R290) has been used as such an alternative since 2010.

Along with HFC-134a, the mixtures R404A and R449A are the most important HFC refrigerants found in existing stationary commercial refrigeration units. R744, a halogen-free refrigerant, also plays an important role. As of 2020, the EU F-Gas Regulation prohibits sales of commercial refrigerators and freezers that use HFC refrigerants with a GWP of 2,500. As of 2022, the GWP limit in this regard will drop to 150. Sales of stationary refrigeration units with refrigerants with GWPs of 2,500 or more are also prohibited as of 2020 (F-GasV, 2014). The impacts of these prohibitions are already apparent – since 2019, new units and appliances have no longer been filled with R404A.

In light of the extremely large number of companies specialising in refrigeration, detailed statistical surveys of refrigerant stocks are not practicable. Therefore, a different calculation method is used.

- For calculation of emissions from *central systems* for commercial refrigeration, in the food retail sector, the following refrigerant model is used (Schwarz et al. 2012):
- Foreign trade with locally installed refrigeration systems plays a negligible role, and thus annual HFC consumption for new systems is the same as new HFC additions in new systems.
- The starting point for the calculations is not the number of plants involved or the installed cooling capacity, but the sales floor area of the relevant food retail stores, since that figure is statistically recorded, on an annual basis. Discount stores in Germany have sales floor areas of about 800 m^2, and that figure is a relatively constant one. All such stores are assumed to have basically the same refrigeration requirements and, thus, to use the same quantities of refrigerants. This is why in this case the number of discount stores involved serves as the basis for further calculations. The numbers of discount stores are also statistically recorded on an annual basis.
- On the basis of a study of the EPEE[81] (SKM Enviros 2010), the coefficient "kilograms per square meter of sales floor area" is derived for a typical, average-size supermarket. It has the value 0.23 kg/m^2. For discount stores, the coefficient "kilograms per discount store" is determined. It has the value 80 kg / store. With the help of these coefficients, the annual refrigerant stocks are calculated for the three store classes discount stores, small supermarkets and large supermarkets.
- The refrigerant stocks for the various store formats, subdivided by refrigerant types, are determined with the help of applicable percentage shares for the types of refrigerants that are used. The refrigerant shares are derived with the help of static calculation models based on experts' assessments. For this purpose, the following store classes are differentiated: large supermarkets (with sales floor areas greater than 1,500 m^2) , small supermarkets (with sales floor areas between 400 and 1,500 m^2) and discount stores (sales floor areas of 800 m^2).
- Division of refrigerant stocks by the systems' average lifetime (10 years for discount stores; 14 years for all other types of stores) yields the HFC additions via new systems.

[81] EPEE: The European Partnership for Energy and the Environment.

- The production emissions and emissions from stocks are calculated with Equation 1 and Equation 2. Production normally takes place at the relevant sites.
- Replacement of CFCs and HCFCs in old systems is considered separately.
- Disposal emissions occurred in connection with central systems for the first time in 2000. Removals of refrigerants are calculated with the help of the average lifetime – 10 years for central systems in discount stores, and 14 years for central systems in all other types of stores. In each case, the nominal quantity for disposal is equivalent to the added new quantity a system had when it was commissioned. In practice, however, the quantities of refrigerants that systems contain when they are disposed of are smaller than the corresponding nominal charges, since systems are normally not recharged before they are decommissioned. For this reason, the actual charge upon disposal, the "effective" quantity for disposal, is determined with the help of applicable percentage values for residual charges. The most important factor that enters into the determination of residual charges is the refrigerant-loss level at which a system has to be recharged in order to maintain its proper function. The effective charge at the end of a device's / system's service lifetime is larger, by half of the difference between that minimum "technical" charge and the nominal charge, than the minimum "technical" charge. For central systems, it amounts to 87.5 % of the nominal charge.
- The disposal emissions are calculated by multiplying the so-determined "effective" quantity for disposal by the inverse of the recovery factor, using Equation 4:
- Emissions of HFC-1234yf and HFC-1234ze from the refrigerant mixtures R448A and R449A, emissions which are not subject to reporting obligations, are voluntarily reported, pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), as "additional greenhouse gases." Those emissions are aggregated with other emissions that are not subject to reporting obligations, and they are listed in Chapter 4.9.3 under CRF 2.H.3.

Also in the case of *condensing units* for commercial refrigeration, the refrigerant stocks are the central point of reference for the refrigerant model for emissions calculation:

- The starting point for such calculations consists of the number of operation sites in the numerous sectors in which condensing units are used; the relevant sector selection is based on a study of the German Engineering Federation (2011). Such sectors include cash-and-carry beverage stores, service station shops, nurseries (garden centers), flower shops, flower wholesalers, cafeterias, caterers, hospitals, nursing homes, restaurants and hotels, butcher shops and franchise outlets for meat products, bakeries and franchise bakery outlets, discount stores, small food retailers and specialty food retailers. The number of sites involved is updated annually, from publicly accessible statistics.
- The refrigerant stocks for the various individual sectors are calculated as the product of the relevant number of operational sites, the sector-specific charges (as determined from the literature and via surveys of experts) and the percentage shares for the refrigerant types that are used. The percentage shares for the refrigerants are derived via a static calculation model (Winfried Schwarz et al., 2012).
- Division of total refrigerant stocks by the average lifetime of condensing units (12 years) yields the HFC additions via new systems.
- The production emissions and emissions from stocks are calculated with Equation 1 and Equation 2.

- The disposal emissions are calculated via Equation 4. The nominal quantity for disposal is identical, in terms of both quantity (amount) and refrigerant shares, with the corresponding initial-charge quantity from 12 years earlier. For condensing units, the effective charge at the end of units' service lifetime amounts to 85 % of the nominal charge.
- Emissions of HFC-1234yf and HFC-1234ze, from use of the refrigerant mixtures R448A, R449A, R452A, R454C, R455A and R513A, and from single-substance uses, are not subject to reporting obligations, but they are voluntarily reported, pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), as "additional greenhouse gases." Those emissions are aggregated with other emissions that are not subject to reporting obligations, and they are listed in Chapter 4.9.3 under CRF 2.H.3.

The application sectors for hermetically sealed *plug-in units* are largely the same as those for condensing units. This group also includes vending machines, such as beverage coolers, and refrigerated centrifuges. Emissions for such appliances are calculated in keeping with the refrigerant-model approach described for condensing units. Such appliances have an average lifetime of 10 years, and their residual charge upon disposal amounts to 90 % of the nominal charge.

Emission factors

The emission factors used are the result of surveys of experts and literature evaluations.

As a rule, charging of refrigeration systems produces only small quantities of emissions. For "initial emission" in Vol. 3, Table 7.9, the 2006 IPCC Guidelines give values of 0.5 to 3 percent of the initial charge for plug-in devices and for medium-sized and large commercial refrigeration systems. The country-specific $EF_{production}$, at 0.5 % for plug-in devices and at 1 % for central systems and condensing units, lie within this range.

Ongoing (H)FC emissions from stationary refrigeration systems in the *commercial refrigeration* category vary widely in keeping with the type of system concerned. The refrigerant loss ranges from 1 to 1.4 %, for plug-in individual units, to 4.9 to 9.7 %, for condensing units and to 8.1 to 19.5 % for central systems. The emission factors for application have decreased continuously since 1993 for all devices and systems in the area of commercial refrigeration (cf. Table 203), in keeping with the increasing degree of care taken in handling HFC refrigerants. Measured against the value ranges given in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 1 to 15 % for individual units and 10 to 35 % for medium-sized and large commercial refrigeration systems, the emission factors used either lie within low sections of the ranges (individual units and central systems, until report year 2014) or lie below the ranges (condensing units and central systems, as of report year 2015).

The average lifetimes prior to disposal are 10 years (individual units; central systems in discount stores), 12 years (condensing units) and 14 (central systems in all types of stores other than discount stores). The lifetime-figures used thus lie within the relevant ranges given in the 2006 IPCC Guidelines (IPCC, 2006a), 10 to 15 years (individual units) and 7 to 15 years (medium-sized and large commercial refrigeration systems).

The residual charges in the devices and systems, at the end of their lifetimes, and with respect to the initial charge in each case, are 90 % (individual units), 85 % (condensing units) and 87.5 % (central systems). The 2006 IPCC Guidelines give value ranges of 0 – 80 % (individual units) and 50 – 100 % (medium-sized and large commercial refrigeration systems). The residual charge applied for individual units thus lies above the specified value range. All other values are default values.

The recovery factors have been increasing continuously, and thus the losses occurring upon disposal, with respect to initial charge / residual charge, have been decreasing over the years concerned. For plug-in devices, the recovery factor was 32.6 % in 2003 and 60 % in 2020. For condensing units, the recovery factor was 47.5 % in 2005 and 80 % in 2020, while for central systems the recovery factor increased from 42.9 % in 2000 to 80 % in 2020. As a result, most of the recovery factors used lie within the range given in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 0 to 70 %. Only the recovery factors used for central systems as of report year 2009, and those used for condensing units as of report year 2016, exceed the IPCC values.

Activity data

The sales floor areas of grocery stores are surveyed annually, by two market-research institutes[82]. The EHI Retail Institute also monitors the numbers of discount stores. In addition, the applicable numbers of commercial sites are updated annually from various publicly available statistics (Winfried Schwarz et al., 2012).

The annual new additions of PFC-116 (C_2F_6), PFC-218 (C_3F_8), HFC-125 and HFC-23, which are contained in the refrigerant mixtures R508A, R508B, Isceon MO 89 and R413A (HFC-23 is also used as a single-component refrigerant), are obtained from the annual national survey pursuant to the Environmental Statistics Act (Umweltstatistikgesetz) (UStatG, 2005).

The quantities and types of refrigeration and freezer systems typically used by businesses are determined from the literature and via estimation by experts. The coefficients "kilograms per square meter of sales floor area" and "kilograms per discount store" have been determined semiempirically by experts, with the help of the relevant technical literature (SKM Enviros (2010), Clodic and Barrault (2011) and Clodic et al. (2012)). The charges for condensing units and plug-in appliances have been determined via techical discussions with German manufacturers of refrigeration / freezer systems and via study of the relevant literature.

4.7.1.2.2 Household refrigeration (2.F.1.b)

In 1994, domestic producers of *household refrigerators and freezers* in Germany made a changeover from CFC-12 to HFC-134a. A short time later, they then switched to isobutane (R600a). Small numbers of devices containing HFC-134a, representing a small share of all relevant appliances, were imported in between 1993 and 2014. Under the EU F-Gas Regulation (F-Gas R, 2014), imports of household refrigerators and freezers that use refrigerants with GWPs of 150 or higher are prohibited as of 2015 (F-GasV, 2014).

Production losses and new consumption for domestic purposes do not have to be determined, since all filling with HFC took place abroad.

Equation 2 is used to calculate annual HFC emissions on the basis of final stocks. This is done by determining and aggregating the annual HFC new additions since 1993 and then subtracting the aggregated annual removals via disposal.

Disposal emissions occurring as of the year 2008, following an average lifetime of 15 years, are calculated with Equation 4.

In Germany since the end of the 1990s, a number of foreign companies have marketed ice cream machines for home use. Compressor-operated ice cream machines function just like regular refrigeration systems that use refrigerants. Since 1997, the refrigerants used have been HFC-

[82] EHI – EHI Retail Institute, Cologne; The Nielsen Company GmbH, Frankfurt am Main.

134a and the refrigerant mixture R404A. Since 2015, increasing numbers of appliances with R600a are also being used. Depending on machines' sizes, ice cream machines' HFC-refrigerant charges range from about 30 g to over 100 g. These figures translate into an average HFC charge of about 75 g.

Since no domestic production takes place, no domestic production emissions occur.

The annual HFC emissions are calculated with Equation 2, on the basis of final stocks. The final stocks are calculated from the aggregated annual new HFC additions since 1997, less the aggregated annual removals via disposal.

Units have an average lifetime of 15 years, and thus disposal began in 2012. The resulting emissions are calculated with Equation 4.

Emission factors

Current HFC emissions from household refrigerators and freezers are estimated at 0.3 %, which is within the value range given by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 0.1 to 0.5 %.

The average lifetime prior to disposal is 15 years. The system lifetimes used thus lie within the range given by the 2006 IPCC Guidelines, 12 to 20 years.

The residual charges in devices, with respect to initial charge, average 95.5 %. The relevant values given in the 2006 IPCC Guidelines range from 0 to 80 %. The value used is thus higher than the range given in the 2006 IPCC Guidelines. The value is justified in light of the low refrigerant losses that occur during the use phase (0.3 % per year; 4.5 % throughout the entire use phase); those losses do not substantiate use of lower values for the residual charge level.

The recovery factor is 73.3 %, which is slightly above the range given in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 0 to 70 %. The higher recovery factor has been brought about by legislation (the Electrical and Electronic Equipment Act – Elektrogesetz (ElektroG, 2015)) governing the disposal of household appliances.

The 2006 IPCC Guidelines provide no specifications for ice cream machines (IPCC, 2006a). All of the values used for the calculation are thus country-specific(cf. Table 203). The emissions from stocks are estimated to be 0.3 %. The average lifetime is 15 years. As is the case for household refrigeration appliances, the residual charge, with respect to the initial charge, is 95.5 %. The recovery factor is estimated to range from 53% (2012) to 65 % (2020).

Activity data

The figure of 1 % for annual new additions of household refrigerators and freezers is an estimate of leading refrigerator manufacturers.

With the help of information provided by a leading manufacturer of ice cream machines, the number of ice cream machines in Germany in 2016 was estimated as equivalent to 1.5 % of the total number of households in the country. The annual new additions have been at a constant level of 6.7 % (Warncke et al., 2018).

4.7.1.2.3 Industrial refrigeration (2.F.1.c)

The industrial refrigeration included in this sector refers to refrigeration for production of products – mostly food and drink – that are refrigerated or frozen. Refrigeration systems in this category, as in the category of *commercial refrigeration*, are usually not purchased directly from series production. They tend to be customised systems, and thus emissions for this category have to be calculated with the help of a refrigerant model.

Use of fluorine-based refrigerants has not yet become standard practice in industry, especially the food industry. In addition, natural refrigerants – primarily ammonia (NH_3) – are used much more frequently in this sector than they are in other sectors. The fluorine-based refrigerants used in industrial refrigeration are R404A, HFC-134a, R407C, R507A and R422D. The last of these serves as a substitute refrigerant for converted HCFC-22 systems. HFC-23 und PFC-116 are also used, in low-temperature systems, while the refrigerant HFC-227ea is used in air-conditioning systems for cranes and in high-temperature heat pumps.

Use of fluorine-based refrigerants began in Germany in 1993. Disposal emissions began occurring in 2002, from converted CFC-12 and HCFC-22 systems.

The following refrigerant model is used for *industrial refrigeration*:

- The refrigerant stocks serve as the central point of reference for the model. It is broken down into twelve major industrial refrigeration sectors: beer breweries, wine production, meat production, dairies, cold-storage facilities, chocolate production, production of frozen foods and of juices, skating rinks, milk refrigeration in the agricultural sector, other industry (80 % chemical industry) and hermetically sealed appliances in manufacturing. The basis for calculation of the refrigerant stocks consists of the quantities of produced goods. They are updated annually via publicly accessible merchandise statistics.
- In the three smaller sectors of industrial refrigeration, air-conditioning for cranes, high-temperature heat pumps and low-temperature refrigeration with HFC-23 (primarily in the plastics industry) and R508A/B, the annual new additions are used as the starting value for calculating stocks and all emissions.
- On the basis of the relevant production quantities, a conversion is made to the installed cooling capacity required for cooling goods and products in the twelve major sectors. The key factors required for that conversion, "installed cooling capacity per units of annual goods production", have been determined empirically, on the basis of the technical literature.
- The refrigerant quantities required for the resulting cooling capacity are estimated on the basis of refrigerant-use rates for plus and minus refrigeration and for direct and indirect refrigeration. The refrigerant-use rates were also determined via study of the literature, including Clodic and Barrault (2011) and Clodic et al. (2012). They range from 2 kg/kW for indirect plus refrigeration to 8.8 kg/kW for direct minus refrigeration. The typical charges per installed unit of cooling capacity are calculated, for the twelve sectors, by combining these values with the applicable sector-specific weightings for the four basic forms of refrigeration.
- Foreign trade with locally installed refrigeration systems plays a negligible role, and thus annual HFC consumption for new systems is the same as new HFC additions in new systems.
- The refrigerant stocks also provide the basis for calculating the quantity for disposal. For each sector, that quantity is calculated by dividing the stocks by devices' service lifetimes. For most sectors, the applicable service lifetime is 30 years. For dairy farms and skating rinks, it is 20 years, and for plug-in appliances, air conditioners for cranes, high-temperature heat pumps and low-temperature applications, it is 10 years.
- The percentage shares for the types of refrigerants that are used, which vary over time for stocks, new additions and quantities for disposal, are derived for each sector via a static calculation model (Winfried Schwarz et al., 2012).
- Replacement of CFCs and HCFCs in old systems is considered separately.
- The production emissions and emissions from stocks are calculated with Equation 1 and Equation 2.

- Disposal emissions are calculated with Equation 4. The nominal quantity for disposal is identical with the initial-fill quantity. The effective charge at the end of devices' service lifetimes is 85 % of the nominal charge, for all sectors except plug-in appliances, for which it is higher – 90 %.

Emission factors

The emission factors on which the emissions data are based are listed in Table 203.

The emission factors used are the result of surveys of experts and literature evaluations.

As a rule, charging of industrial refrigeration systems produces only small quantities of emissions. In Vol. 3, Table 7.9, the 2006 IPCC Guidelines (IPCC, 2006a) give for "initial emission" values of 0.5 to 3 percent of the initial charge quantity. The country-specific $EF_{production}$ for the sectoral application areas is 1 %, while it is 0.5 % for plug-in appliances. The EF thus lie within the lower part of the range given by the Guidelines.

In all sectors except hermetically sealed appliances, ongoing HFC emissions from industrial refrigeration systems have been decreasing continually, changing from 8.8 % in 1993 to 4.55 % in 2020. The reason for this trend is that refrigeration systems' capacity for retaining their refrigerants has improved as a consequence of national and European legal regulations. Such emissions now lie within the lower part of the range, or even slightly below the range, given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9 – 7 % to 25 %. For plug-in appliances, the decrease has been comparable to that seen in commercial refrigeration: from 1.4 % in 1994 to 1 % as of 2009.

The average applicable lifetimes prior to disposal are as follows: 10 years (plug-in individual units, air-conditioners for cranes, high-temperature heat pumps, low-temperature applications and plastics industry); 20 years (dairy operations, skating rinks); and 30 years (food industry, cold-storage systems, chemical industry). The lifetimes used – with the exception of the 10-year lifetimes for certain application areas – thus lie within the value range given by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 15 to 30 years.

The residual charges in the devices and systems, at the end of their lifetimes, and with respect to the initial charge level in each case, are 90 % (individual units) and 85 % (sectoral application areas). The 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9) give values of 50 to 100 % for industrial refrigeration systems. All of the values used are thus default values.

The recovery factors have been increasing continuously, and thus the losses occurring upon disposal, with respect to initial charge / residual charge, have been decreasing over the years concerned. For plug-in individual units, the recovery factor was 33.7 % in 2004 and 60 % in 2020. For refrigeration systems of sectoral application areas, the recovery factor was 45 % in 2002 and 80 % in 2020. As a result, the recovery factors used lie within the range given in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 0 to 90 %.

Activity data

Numerous time series for food-production quantities are found in statistics of the Federal Ministry of Food and Agriculture (BMEL) and in statistics of the Federal Statistical Office. In addition, data are available from industrial associations such as the German association of cold-storage facilities and cold-chain logistics companies (VDKL) and the Association of the German Confectionary Industry (BDSI), as well as from specialised institutes, such as the German Wine Institute.

The unit-number figures for plug-in appliances have been taken from a study of the German Engineering Federation VDMA (2011) and from information provided by industry experts.

The annual new additions of HFC-227ea and HFC-23 (air-conditioning for cranes, high-temperature heat pumps and low-temperature cooling) are obtained from the annual national survey conducted pursuant to the Environmental Statistics Act (Umweltstatistikgesetz) (UStatG, 2005).

The "installed cooling capacity per units of annual goods production" indices, and the refrigerant-use rates for plus and minus cooling and for direct and indirect cooling, were determined on the basis of information provided in the relevant technical literature.

4.7.1.2.4 Transport refrigeration (refrigerated vehicles and containers) (2.F.1.d)

HFCs have been used as refrigerants in *refrigerated vehicles* since 1993. Today, HFC-134a, along with the refrigerant mixtures R404A and R410A, are most commonly used. Since 2015, R452A has also been in common use. The sizes and refrigerant charges of refrigeration systems vary in keeping with the load volumes of the refrigerated vehicles in question.

Refrigerated containers are used primarily for transports of perishable goods by ocean-going ships. Since their emissions take place primarily in international waters, their refrigerant emissions are divided, in each case, in keeping with the relevant country's share of world trade. Germany is assigned 10 % of global emissions from refrigerated containers. Since 1993, the most commonly used refrigerant has been HFC-134a. R404A has also been used since 1997, and the refrigerant blends R452A and R513A have increasingly been used since 2018.

The following refrigerant model is applied to *refrigerated vehicles* (Warncke et al., 2018):

- Refrigerated vehicles are divided into five weight-based size classes: Vans <3.5 t, vans weighing 3.5-7.5 t, trucks weighing 7.5-12 t, trucks > 12 t and trailer > 26 t gross vehicle weight.
- Refrigerant types, and specific refrigerant charge amounts, are assigned to the various size classes. Each refrigerant is also assigned a percentage share of each size class.
- For a long period, the refrigerant R404A predominated in the class of trailers > 26 t gross vehicle weight, with annual shares of 95 % (1993-1994) and 85 % (1995-2014). As of 2018, R404A's share has fallen to zero. R452A has been used increasingly since 2015 and, since 2017, has even been dominating the market. In 2015, that refrigerant's share amounted to 13 %, and by 2019 it had already reached 85 %. In addition, HFC-134a (5 %) has been used since 1993, and R410A (10 %) has been used since 1995.
- For trucks with gross vehicle weight > 12 t, the shares for R404A were 90 % (1993-1994) and 80 % (1995-2014). Beginning in 2015, that refrigerant's share decreased continuously, and it reached zero in 2019. The shares for HFC-134a (as of 1993) and R410A (as of 1995) each amounted to 10 %. R452A has been used increasingly since 2015, and since 2018 it has been the most frequently used refrigerant in this size class. Its share in 2019 amounted to 80 %.
- Since 1993, R404A and HFC-134a have been used in trucks with 7.5 – 12 t gross vehicle weight. As of 1993, the share of HFC-134a was 30 %, while that of R404A was 70 % (1993-1994). R404A's share then dropped to 60 % (1995-2014), and as of 2015 it continued to drop, reaching 15 % in 2018 and zero in 2019. As of 1995, R410A was also used; it had a share of 10 %. In 2015, the share for R452A still amounted to 1 %. It then increased continuously until 2019, when it reached 60 %.
- Since 1993, 70 % R404A and 30 % HFC-134a have been used in vans with 3.5 – 7.5 t total weight. In 2018, R404A's share was only 15 %, and its use was discontinued completely in 2019. As of 2018, R452A was used instead; its share in 2019 was 70 %.

- In vans with gross vehicle weight less than 3.5 t, only HFC-134a was used in the period 1993 through 2005. From 2006 through 2017, the refrigerant R404A was used in 70 % of all vans, while HFC-134a was used in the remaining 30 %. Since 2018, the refrigerant R452A has also been used. Its share had already reached 70 % in 2019. On the other hand, R404A's share decreased to zero in 2019.
- The number of newly licensed refrigerated vehicles, and the number of refrigerated vehicles charged within the country (broken down by refrigerants), are determined for each year.
- The production emissions are calculated using Equation 1, on the basis of the new consumption required for charging domestically produced refrigerated vehicles.
- The annual new additions of refrigerants result from the numbers of newly licensed refrigerated vehicles and the above assumptions.
- From 1996 to 1999, HFCs were substituted for CFC-12 in a certain number of old systems. These amounts have to be included in the annual new additions.
- The year-end final stocks are obtained by aggregating the annual HFC new additions since 1993 and then subtracting the removals via disposal.
- Equation 2 is used to calculate annual HFC emissions on the basis of final stocks.
- Disposal emissions occurred in connection with refrigerated vehicles for the first time in 2003. They are calculated by means of Equation 4. The nominal quantity for disposal is identical to the new additions 10 years earlier (or 7 years earlier in the case of converted CFC-12 systems). The effective charge level at the end of units' service lifetimes amounts to 87.5 % of the nominal charge level.
- Emissions of HFC-1234yf from the refrigerant mixture R452A, emissions which are not subject to reporting obligations, are voluntarily reported, pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), as "additional greenhouse gases." Those emissions are aggregated with other emissions that are not subject to reporting obligations, and they are listed in Chapter 4.9.3 under CRF 2.H.3.

For *refrigerated containers*, the following refrigerant model is used:

- The number of refrigerated containers produced worldwide is determined for each year.
- The worldwide HFC additions for refrigerated containers are determined on the basis of annual unit figures from global production, in combination with the relevant charges and charge percentages for the various relevant refrigerants.
- From 1993 to 1995, HFC-134a was increasingly used, in addition to HCFC-22, in refrigerated containers. In 1996, HFC-134a had a 100 % share of refrigerants in new refrigerated containers. Starting in 1997, the refrigerant R404A was then also used. Its share of refrigerants ranged from 10 to 20 %. Since 2018, the refrigeration units of refrigerated containers have also been charged with the refrigerants R452A and R513A. Their shares in 2000, at 2.5 % and 4.5 %, respectively, were still small, however.
- The average charges in refrigerated containers depend on the refrigerants used. They range from 4 kg (R452A) to 6 kg (HFC-134a, used in the years 1993 through 2011).
- Germany's HFC additions are determined from worldwide additions, in keeping with Germany's share of global trade, which amounts to 10 %.
- Since refrigerated containers are produced only outside of Germany, no emissions from charging occur in Germany.
- The year-end final stocks are obtained by aggregating the annual HFC new additions since 1993 and then subtracting the removals via disposal.
- Emissions from stocks are calculated with Equation 2.

- Refrigerated containers have an average lifetime of 14 years, and disposal emissions from such containers occurred for the first time in 2007. They are calculated by means of Equation 4.

Emission factors

The emission factors on which the emissions data are based are listed in Table 203.

The emission factors used are the result of surveys of experts and literature evaluations.

As a rule, charging of refrigerated vehicles produces only small quantities of emissions. The losses of refrigerant during charging are estimated at 5 grams per system, regardless of system size. That is a standard value for hose losses during on-site charging. When emissions from charging are calculatorily considered in relation to new consumption, emission factors between 0.06 und 0.25 % result. For "initial emission" in transport refrigeration, the 2006 IPCC Guidelines give figures, in Vol. 3, Table 7.9, of 0.2 to 1 percent of the initial charge. As a result, the great majority of the values used lie below the range recommended in the 2006 IPCC Guidelines (IPCC, 2006a).

Since no domestic production of refrigerated containers takes place, no emissions from charging of such containers occur.

The ongoing HFC emissions from new refrigeration units of refrigerated vehicles, for the three size classes trucks with 7.5 – 12 t, trucks > 12 t and trailers > 26 t (in each case, gross vehicle weight), are estimated to be 15 %. For vans in the weight classes (gross total weight) <3.5 t and 3.5 – 7.5 t, the emission factor is 30 %. For old units in refrigerated vehicles (converted CFC-12 systems), the emission factor for emissions from stocks is estimated to average 25 %, for all unit size classes. The emission factors for refrigerated vehicles thus lie at the lower end of the range given in Vol. 3, Table 7.9 of the 2006 IPCC Guidelines, 15 to 50 %.

For refrigeration units of refrigerated containers, the emission factor for emissions from stocks remained at a constant 10 % from 1993 through 2011. Since then, it has been decreasing continuously (cf. Table 203), in keeping with the increasing care being taken in managing and handling HFC refrigerants. By 2020, it had decreased to a level of only 5 %. All of the emission factors used lie below the range given in Vol. 3, Table 7.9 of the 2006 IPCC Guidelines, 15 to 50 %.

The lifetime of old systems in refrigerated vehicles is 7 years, while that of new systems in refrigerated vehicles is 10 years. The average lifetime for refrigerated containers prior to disposal is 14 years. The lifetimes used – with the exception of those for old systems in refrigerated vehicles – thus lie within the value range given by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 6 to 9 years.

The residual charges in refrigerated vehicles and refrigerated containers, with respect to initial charge, average 87.5 %. The 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9) give values of 0 to 50 % for transport refrigeration systems. All of the values used are larger than those given in the Guidelines, since it must be assumed that transport refrigeration systems that only have 50 % of their initial charges left no longer function properly and thus would compromise the cold chain, with the result that the chain would no longer be seamless. The act of allowing that to happen would violate German law.

The recovery factor for refrigerated vehicles and refrigerated containers is 65.7 %. The recovery factors used thus lie within the range given in the 2006 IPCC Guidelines, in Vol. 3, Table 7.9, 0 to 70 %, and thus are default values.

Activity data

Until 2008, and as of 2011, the registration figures for refrigerated vehicles, broken down by weight classes, were taken from statistical reports of the Federal Motor Transport Authority (KBA). Since the Federal Motor Transport Authority did not carry out separate surveys of refrigerated vehicles in 2009 and 2010, the numbers of new refrigerated vehicles for those two years have been determined via extrapolation from the registration figures for utility vehicles. Charges in refrigeration systems, information on refrigerants used, and details on CFC-12 replacement were provided by experts of the leading providers of refrigeration units for refrigerated vehicles.

New additions of refrigerants in the area of refrigerated containers are determined via a refrigerant model based on the numbers of refrigerated containers produced worldwide, with the numbers provided by the "World Cargo News" information service for the industry. A 10 % share is allocated to Germany. The applicable charges and refrigerant fractions were determined on the basis of surveys of experts carried out by leading manufacturers of refrigerated containers.

4.7.1.2.5 Mobile air-conditioning systems (2.F.1.e)

The mobile air-conditioning systems category includes air-conditioning systems in/on automobiles, trucks and utility vehicles, buses, agricultural machinery (tractors, combines, field choppers), railway vehicles, ships, aircraft and helicopters. Hydrofluorocarbons (HFCs) have been used in mobile air-conditioning systems since 1991. HFC-134a is a commonly used HFC refrigerant. Since 2012, HFC-1234yf has also been used in automobile air-conditioning systems, and since 2016 it has also been used in light commercial vehicles falling into EU vehicle category N1.

The time series show a significant increase in HFC-134a emissions from 1995 through 2015. This increase, which has occurred in spite of decreases in charge quantities, is a direct result of increased use of mobile air conditioning systems in vehicles. Thereafter, the emissions decreased, via replacement of HFC-134a, in new systems, with HFC-1234yf, which is not subject to reporting obligations, and of resulting reductions of HFC-134a stocks in service.

- For *automobiles*, the following refrigerant model is applied:
- The production figures for German automobile production are available, on an annual basis, from the publicly accessible statistics of the German Association of the Automotive Industry (VDA). Those figures provide the database for calculating consumption data relative to charging.
- The annual percentages of automobiles equipped with air-conditioning systems are obtained via extensive surveys of manufacturers, since they are not provided by any official or publicly available statistics. This also applies to the average refrigerant (charge) quantities, which are determined from the technical data for the various automobile models and from information provided by industry experts.
- The quantities consumed in charging such air conditioners are calculated by multiplying the numbers of automobiles produced by the annual percentages of automobiles equipped with air-conditioning systems and by the average per-unit refrigerant (charge) quantities.
- Production emissions are computed with Equation 1.

- The annual numbers of new vehicle registrations as recorded by the Federal Motor Transport Authority (KBA) are not used in determining annual new additions and the refrigerant stocks in automobile air conditioning systems, since it is not possible to quantitatively estimate early departures of vehicles (i.e. prior to vehicles' reaching the end of their average lifetimes) from the registration cohorts that form the basic fleet. Instead, the refrigerant stocks are determined on the basis of the numbers of registered vehicles on the road, divided according to age since the initial registration. Relevant official data are available from the statistical communications (Statistische Mitteilung) of the Federal Motor Transport Authority (KBA) (Kraftfahrtbundesamt, Versch. Jahrgänge), for all required years, i.e. as of 1991. They make it possible to determine, on a continuous, chronological basis, the numbers of vehicles in the total fleet, divided by registration cohorts.
- The annual percentages of automobiles equipped with air conditioning systems, for newly registered vehicles, are also obtained via extensive surveys of manufacturers. Those numbers are not identical with the corresponding percentages of automobiles produced in Germany and equipped with air conditioning systems, since cars produced abroad also have to be taken into account. The necessary percentages are thus also obtained via surveys of foreign companies. This also applies to strategies for determining the average per-unit refrigerant (charge) quantities in newly registered vehicles.
- The refrigerant stocks in each registration cohort are calculated by multiplying the specific charges for the year in question by the numbers of automobiles equipped with air conditioners. The total stocks are equivalent to the sum of the refrigerant stocks for all registration cohorts since 1991.
- Emissions from stocks are calculated with Equation 2.
- Replacement of CFCs in old systems, and air-conditioner retrofits in older vehicles, are considered separately.
- In determination of quantities for disposal, only the old vehicles are taken into account that are handled each year by German dismantling facilities. Those figures are obtained from the official data on numbers of old vehicles (Statistisches Bundesamt, FS 19, R 1). The refrigerant model does not take account of exports of used cars and old cars, since the relevant disposal emissions occur in the pertinent destination countries and double-counting has to be avoided.
- An average lifetime of 15 years is assumed for dismantled vehicles. The total quantity of refrigerants that are disposed of is determined by multiplying the number of dismantled vehicles by the applicable percentage of vehicles equipped with air conditioning systems and the average per-unit refrigerant (charge) quantity for the relevant new-registration cohort of 15 years earlier.
- Disposal emissions occurred for the first time in 2002. They are calculated with Equation 4.
- Pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), Germany voluntarily reports emissions of HFC-1234yf, which are not subject to reporting obligations, under "additional greenhouse gases." The HFC-1234yf emissions are aggregated with other emissions that are not subject to reporting obligations, and they are reported in Chapter 4.9.3 under CRF 2.H.3.

The refrigerant models for *utility vehicles and buses* are structured similarly to the model for automobiles. A detailed description of the models is provided by (Winfried Schwarz et al., 2012).

The refrigerant model used for *agricultural machinery*, *ships and railway vehicles* is as follows:

- For ships and railway vehicles, refrigerant emissions are determined on the basis of annual new installations of air conditioning systems in ships (outset data: newly built ships for the German fleet) and in railway vehicles (outset data: new procurements by German Railways (DB) and private companies), as well as the relevant charges.
- The refrigerant model for air conditioning systems in agricultural machinery is based on the number of new vehicle registrations for each year, the average percentage of vehicles equipped with air conditioning systems and the average charges in the various types of agricultural machinery concerned.
- The annual new additions of HFC-134a, as well as the final stocks, are determined, for each area, from the relevant previous set of data.
- Emissions from stocks are obtained, using Equation 2, by multiplying the final stocks, for each area, by the relevant EF_{use}.
- Domestic consumption of HFC-134a, for production of mobile air conditioning systems, is determined on the basis of unit-number production data. Production emissions are computed with Equation 1.
- Disposal emissions are calculated with Equation 4. In the agricultural machinery category, such emissions occurred for the first time in 2004, at the end of the average lifetime for units in the category, 10 years. In the railway vehicles category, disposal emissions occurred for the first time in 2017, when the systems' 25-year average lifetime periods began ending. For ships, disposal will not begin until 2022, at the end of a 25-year lifetime.

For *aircraft and helicopters*, the following refrigerant model is applied:

- The refrigerant stocks in air-conditioning systems of medium-sized, multi-engine aircraft (registration class I) and helicopters (registration class H), and in the on-board refrigeration systems of passenger aircraft in registration classes A, B and C, are determined on the basis of the relevant numbers of aircraft and helicopters registered in Germany. The pertinent official figures are available, for all required years (i.e. as of 1993), in the statistics annually published by the German Federal Aviation Office (Luftfahrt-Bundesamt) (Luftfahrt-Bundesamt, Versch. Jahrgänge, Bestand an Luftfahrzeugen).
- In passenger aircraft of registration classes A, B and C, an average of three HFC-134a chillers, with per-unit charges of 500 grams, are used for on-board refrigeration during flights lasting longer than four hours.
- According to manufacterers, in aircraft of registration classes I and in helicopters, an average of 2 kilograms of HFC-134a are used, per aircraft/helicopter, for cooling of instruments and for air-conditioning.
- The pertinent refrigerant stocks are calculated by multiplying the aircraft-specific charge by the number of registered air-conditioned / refrigerated aircraft involved.
- Emissions from stocks are calculated with Equation 2.
- To date, no disposal emissions have occurred, due to the long lifetimes of the aircraft involved.

Emission factors

The emission factors on which the emissions data are based are listed in Table 203.

The emission factors used have been obtained via: studies of the literature (for example, Winfried Schwarz (2003); Siegl et al. (2002); Clodic and Barrault (2011); Clodic et al. (2012); Winfried Schwarz et al. (2012), Hafner et al. (2019)), measurements (automobiles), evaluations of records of automotive-service shops, extensive surveys of experts and surveys of automotive-service shops and dismantling facilities. In addition to regular emissions during operation, emissions also arise as a result of accidents and other external influences.

As a rule, charging of mobile air-conditioning systems produces only small quantities of emissions. For automobiles, the refrigerant losses upon charging are estimated as 3 grams per system. For utility vehicles and agricultural machinery, they are placed at 5 grams per system, and for buses they are considered to be 50 grams per system. These figures are standard values for hose leakage in connection with on-site charging. When the emissions from charging are seen, mathematically, in relation to new consumption, the following emission factors result: 0.25 - 0.63 % (automobiles), 0.36 - 0.66 % (utility vehicles), 0.28 - 0.35 % (agricultural machinery) and 0.42 - 0.45 % (buses). The ranges are the result of annual variations in initial charges. For railway vehicles, the emission factor for charging is 0.5 %, while for ships, it is 1 %. For "initial emission" for mobile air-conditioning systems (automobiles, utility vehicles, buses and railway vehicles), the 2006 IPCC Guidelines give figures, in Vol. 3, Table 7.9, of 0.2 to 0.5 percent of the initial charge. The great majority of the values used for the vehicles described in the 2006 IPCC Guidelines (IPCC, 2006a) thus lie within the relevant ranges proposed by the Guidelines. The 2006 IPCC Guidelines provide no values for agricultural machinery, ships and aircraft.

Current HFC emissions are estimated at 10 % for automobiles; at 15 % for utility vehicles and buses; at 6 % for railway vehicles; for agricultural machinery, at 15 % (tractors) and 25 % (combines and field choppers); for ships, at 10 % (passenger ships on inland waterways), 20 % (ocean liners) and 35 % (ocean-going cargo ships); and at 5 % for aircraft. The EF_{use} used thus lie largely within the range proposed in Vol. 3, Table 7.9 of the 2006 IPCC Guidelines (IPCC, 2006a), 10 to 20 % for air-conditioning systems in automobiles, utility vehicles, buses and railway vehicles. No proposals have been provided for agricultural machinery, ships and aircraft.

The average lifetimes prior to disposal are 15 years (automobiles, utility vehicles, buses), 10 years (agricultural machinery) and 25 years (railway vehicles, ships). With the exception of those for systems in railway vehicles and on ships, the lifetimes lie within the value range given by the 2006 IPCC Guidelines for systems in automobiles, utility vehicles, buses and railway vehicles, 9 to 16 years.

The residual charges remaining in air-conditioning systems, with respect to initial charge, average 34 % (automobiles, utility vehicles, buses, agricultural machinery). They average 87.5 % for railway vehicles, since the maintenance intervals for such vehicles are kept shorter, in the interest of passenger comfort. The 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9) give values of 0 to 50 % for this area. All of the values used, with the exception of the value for railway vehicles, are default values.

As a result of the disposal and recycling of end-of-life vehicles as required by the End-of-Life Vehicles Ordinance (Altfahrzeug-Verordnung) since 2002, the recovery factors for automobiles and utility vehicles have been increasing continuously, with the result that losses occurring upon disposal, with respect to initial charge or residual charge, have been decreasing over time. For automobiles and utility vehicles, the recovery factors amounted to 38 % in 2000, and to 50 % in 2020. The estimated recovery factors are as follows: 38 % for buses, 11.7 % for agricultural machinery and 75.6 % (2017) to 80 % (2020) for railway vehicles. As a result, the recovery factors used for automobiles, utility vehicles and buses lie within the range given in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 0 to 50 %. The country-specific value for railway vehicles is considerably higher than the default value, because considerably greater care is taken in disposal from railway vehicles. The 2006 IPCC Guidelines provide no proposals for agricultural machinery.

Activity data

The Federal Motor Transport Authority (KBA) reports numbers of registered automobiles, utility vehicles and buses, and new registrations of agricultural tractors. The number of registered aircraft has been obtained from the German Federal Aviation Office (Luftfahrt-Bundesamt). The sources for production figures include the German Association of the Automotive Industry (VDA), the German Engineering Federation (VDMA), other statistics and surveys of manufacturers.

The charges in automobile air conditioners, and the annual percentages of automobiles equipped with air-conditioning systems, are determined via direct surveys of automobile companies. For systems in other types of vehicles, the charges and percentages are obtained by combining official statistics, information from surveys of manufacturers and experts' assessments.

4.7.1.2.6 Stationary air conditioning systems (2.F.1.f)

The area of stationary air conditioning systems includes room air conditioners, chillers for air conditioning of buildings and industrial refrigeration of liquids, heat-pump systems, heat-pump laundry dryers and commercial dishwashers with heat pump systems.

4.7.1.2.6.1 Room air conditioners

Room air conditioners are used to cool the interiors of individual rooms, entire floors or small-to-medium-sized buildings. Their performance levels tend to be lower than those of large air conditioning systems. The following refrigerants are in use: since 1998, the HFC mixture R407C; since 2003, the mixture R410A; and since 2014, HFC-32. Since 1997, R290 has also been used in mobile room air-conditioners, as a halogen-free alternative.

There is no domestic production of room air conditioners. Room air conditioners are normally already filled when imported. Installation of factory-manufactured single-split, multi-split and VRF-multi-split units involves installation of refrigerant lines, and these have to be charged on site, however. Such charging of lines is not required in connection with mobile, plug-in room air conditioners.

The following refrigerant model is used for room air conditioners:

- *Room air conditioners* are divided into four categories. The applicable numbers of new systems produced each year in each category are determined via surveys of manufacturers and via the data published in pertinent international publications. The categories are: small mobile units, single-split units, multi-split units with constant-volume refrigerant flow and VRF-multi-split systems with variable-volume refrigerant flow.
- For each category, the charges, and the percentage shares for the various types of refrigerants used, are determined in keeping with the numbers of new systems sold each year. The annual new consumption, which is identical to annual new additions of refrigerants, is obtained from sales statistics and the above assumptions. The year-end final stocks are obtained by aggregating the annual HFC new additions since 1993 and then subtracting the removals via disposal.
- No production emissions occur. Charging losses do occur, however, in installation of stationary single-split units, multi-split units and VRF multi-split systems. Surveys of experts have indicated that the applicable losses during installation are 5 g per unit (10 % of the initial charge) for single-split units, 20 g per unit (1 % of the initial charge) for multi-split units and 45 g per system (1 % of the initial charge) for VRF multi-split systems.

- Emissions from stocks are calculated with Equation 2.
- Disposal emissions occurred for the first time in 2008. The average lifetime of mobile units and single-split units is 10 years, while the average lifetime of multi-split units and VRF multi-split systems is 13 years. Disposal emissions are calculated with Equation 4.

Emission factors

The emission factors used have been obtained via surveys of experts and evaluations of the literature; they are listed in Table 203.

The country-specific $EF_{production}$ = 1 % for multi-split units and VRF multi-split units lies within the value range given by the 2006 IPCC Guidelines, in Vol. 3, Table 7.9 – 0.2 to 1 %. For single-split units, the emission factor is 10 %, which corresponds to a loss of 5 g of refrigerant per 50 g charge, and which is above the range given in the Guidelines.

For all devices, the emission factors for use decrease continually throughout the time series, beginning with the first year of use (cf. Table 203). For mobile room air conditioners, they range from 3.4 % (1999) to 2.5 % (as of 2010); for single-split units, they range from 6.9 % (1998) to 5 % (as of 2010); for multi-split units, they range from 7.9 % (1998) to 4.2 % (2020); and for VRF multi-split units, they range from 8.1 % (2003) to 4.9 % (2020). The emission factors for use thus lie within the range given in Vol. 3, Table 7.9 of the 2006 IPCC Guidelines, 1 to 10 %.

The estimated lifetimes for such units, 10 years (mobile room air-conditioners, single-split units) and 13 years (multi-split units, VRF multi-split units), lie within the value range given in Vol. 3, Table 7.9 of the 2006 IPCC Guidelines, 10 to 20 years.

The residual charge upon disposal is 75 % for mobile room air-conditioners and 87.5 % for all other types of units. The 2006 IPCC Guidelines (IPCC, 2006a), in Vol.3, Table 7.9, recommend values ranging from 0 to 80 %. The residual-charge figure used for mobile room air-conditioners is thus a default value, while the values used for the other types of units lie above the range given in the Guidelines.

The recovery factors have been increasing continuously, and thus the losses occurring upon disposal, with respect to initial charge / residual charge, have been decreasing over the years concerned. For mobile room air-conditioners, the recovery factor was 24.2 % in 2009 and 40 % in 2020; for single-split units, it was 37.9 % in 2008 and 60 % in 2020; while for multi-split units, it was 62 % in 2011 and 80 % in 2020. For VRF multi-split units, it was 72 % in 2016 and 80 % in 2020. As a result, the recovery factors used lie within the range given in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 0 to 80 %.

Activity data

The numbers of units sold in Germany, of the various types of units and systems involved, are determined on an annual basis via technical publications(JARN, Versch. Jahrgänge) and surveys of sellers.

4.7.1.2.6.2 Chillers

Chillers for air-conditioning of buildings and industrial refrigeration of liquids are divided into three performance categories: chillers with a cooling capacity of less than 100 kW, chillers with a cooling capacity of more than 100 kW and turbo-compressor systems (with cooling capacities above 1500 kW). The types of compressors used in chillers include piston, scroll and screw compressors.

In turbo-compressor systems, HFC-134a has been used since 1993, and HCFC-1233zd, which is not subject to reporting obligations, has been used since 2017. In the years 1995 through 1999, HFC-134a was also used for conversions of CFC-12 turbo-compressor systems. The most important refrigerants used in chillers include HFC-134a (used as of 1993), R407C (as of 1998) and R410A (as of 2004). HFC-1234ze, which is not subject to reporting obligations, has also been used since 2013, and the refrigerant mixture R513A has been used since 2017.

The following refrigerant model is applied to *chillers*:

- Chillers are divided into three categories. The number of new systems in each of the following categories is determined each year via surveys of experts and international sales statistics: chillers ‹100 kW cooling capacity; chillers ›100 kW cooling capacity; and turbo-compressor systems in the performance range above 1,500 kW.
- For each category, the average charge, and the percentage shares for the various types of refrigerants used, are determined. The sizes of the charges are 10 kg for chillers <100 kW; 95 kg (HFC-134a, R407C and R410A), 150 kg (R513A) and 630 kg (HFC-1234ze) for chillers > 100 kW; and 630 kg for turbo-compressor systems.
- Data on annual HFC additions to domestic stocks are obtained from the numbers of new systems, in connection with the above assumptions. Consumption for CFC replacements in old systems has to be taken into account.
- The year-end refrigerant stocks can be calculated from the previous-year stocks, the new additions and the removals.
- The year-end refrigerant stocks can be calculated from the previous-year stocks, the new additions and the removals.
- Production emissions are calculated by multiplying the quantities consumed in charging by the $EF_{production}$, pursuant to Equation 1.
- Emissions from stocks are calculated with Equation 2.
- Disposal emissions occurred for the first time in 2003 (in conversion of systems for CFC substitutes). They are calculated with Equation 4.
- Emissions of HFC-1234ze and HFC-1233zd, which are not subject to reporting obligations, from use as individual substances, and of HFC-1234yf from use of the refrigerant mixture R513A, are voluntarily reported, pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), as "additional greenhouse gases." Those emissions are aggregated with other emissions that are not subject to reporting obligations, and they are listed in Chapter 4.9.3 under CRF 2.H.3.

Emission factors

The emission factors used have been obtained via surveys of experts. They are listed in Table 203.

The loss from charging, at 0.5 %, lies within the range given in the 2006 IPCC Guidelines ((IPCC, 2006a): Vol. 3, Table 7.9), 0.2 to 1 %. To take account of the fact that large numbers of chillers are imported as pre-filled units, $EF_{production}$ = 1 %, the actual $EF_{production}$, is not used.

The ongoing HFC emissions through 2000 are estimated at 6 % for all cooling-capacity classes / compressor models, age classes and refrigerant types. Thereafter, the EF_{use} decreases continuously, to 2.8 % (2020). All of the values used thus lie within the lower part of the range proposed by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Chapter 7.9), 2 to 15 %.

The 2006 IPCC Guidelines, in Vol. 3, Table 7.9, give a service lifetime of 15 to 30 years for liquid chiller systems. The values used in the present case lie within that range: 15 years for chillers with cooling capacities either less or more than 100 kW, and 25 years for turbo-compressor systems.

The residual charge upon disposal is 90 %, for all chiller types. The 2006 IPCC Guidelines, in Vol. 3, Table 7.9, recommend values ranging from 80 to 100 %. The residual-charge figures used are thus default values.

The recovery factors have been increasing continuously, as a result of technical progress and greater care taken in handling refrigerants, and thus the losses occurring upon disposal, with respect to initial charge / residual charge, have been decreasing over the years concerned. The recovery factor for chillers, including units with cooling capacity less than 100 kW and greater than 100 kW, was 65.8 % in 2003 and 80 % in 2020, while the factor for turbo-compressor systems was 69.5 % in 2003 and 80 % in 2020. The recovery-factor figures used thus lie within the range given in Vol. 3, Table 7.9 of the 2006 IPCC Guidelines, 0 to 95 %.

Activity data

The numbers of new systems are determined annually via surveys of manufacturers' experts and consultation of international sales statistics (for example, BSRIA Limited (Versch. Jahrgänge)).

The average charges, and the percentage shares for the various types of refrigerants used, were determined in the framework of expert consultations with industry representatives.

4.7.1.2.6.3 Heat-pump systems

Via a refrigeration cycle, heat pumps draw heat from the air, ground or groundwater and make it available for heating or cooling indoor areas or for heating water. Devices that directly use heat from the outdoor environment to warm indoor air fall within the category of room air conditioners.

Since 1995, HFC-134a and the HFC mixtures R404A and R407C have been used as refrigerants in heat pumps. Since 2019, HFC-32 has also been used, and since 2001, R410A has been used as well. Since 1995, propane (R290) has also been used as a halogen-free alternative in heat pumps for heating, and since 2018 CO_2 (R744) has been used as such an alternative in heat pumps for hot process water.

Methodologically, the refrigerant model for *heat pumps* is structured like the model for room air conditioners.

- Three categories of heat pumps for heating are differentiated: air – water; ground (groundwater) – water; ground (brine) – water. Heat pumps for pumping hot process water are treated as a fourth category.
- The starting and reference point for calculations consists of the annual numbers of newly installed heat-pump units in each of the four categories. These data are published annually by the German heat-pump association (BWP). The numbers of newly installed heat pumps for hot process water are also used as production quantities. The produced quantities of heat pumps for heating are larger, by a factor of 2, than the numbers of newly installed pumps. On the basis of the data for new additions, the various heat-pump types are assigned average HFC charges and percentage shares of the various types of HFCs. The model also includes service-life and emissions-rate figures.
- Production emissions are calculated by multiplying the quantities consumed in charging by the $EF_{production}$, pursuant to Equation 1, while emissions from stocks are calculated with Equation 2.
- Heat pumps with HFCs have been produced and sold since 1995. Since the units have an average service life of 15 years, disposal-related emissions began occurring in 2010. They are calculated with Equation 4.

Emission factors

The emission factors (EF) on which the emissions data are based are listed in Table 203.

The emission factors used have been obtained via surveys of experts.

The charging loss is 0.5 %. As a result, the $EF_{production}$ lies within the range proposed by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 0.2 to 1 %.

The annual HFC emissions for heating-system heat pumps are estimated at 2.5 %, while the emissions for water-heating heat pumps are placed at 2 %. The EF_{use} used thus lie within the range proposed by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 1 to 10 %.

The average lifetime prior to disposal is 15 years. The system lifetimes used thus lie within the range given in the 2006 IPCC Guidelines (Vol. 3, Table 7.9), 10 to 20 years.

The residual charges in heat pumps, with respect to initial charge, average 75 %. The 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9) give values of 0 to 80 % for this area. The value used is thus a default value.

The recovery factor for heat pumps has been increasing continuously, as a result of the greater care taken in handling refrigerants, and thus the losses occurring upon disposal, with respect to initial charge / residual charge, have been decreasing over the years concerned. The recovery factor was 50 % in 2010 and 65 % in 2020. As a result, all the recovery factors used lie within the range given in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.9), 0 to 80 %.

Activity data

Each year, the German heat-pump association (BWP) publishes the numbers of new heat pumps installed domestically. Those figures serve as the basis for the relevant emissions calculation.

The production / installation ratio used is based on information provided by heat-pump producers.

4.7.1.2.6.4 Heat-pump clothes dryers

Heat-pump clothes dryers with HFC refrigerants have been sold on the German market since 2008. The use the refrigerant HFC-134a. From 2008 to 2018, they were also charged with the refrigerant mixture R407C. The charges in hermetically sealed units range from 220 g to 485 g. In heat-pump clothes dryers, use of propane (R290), a halogen-free alternative, has been increasing sharply since 2015.

From 2008 to 2012, one domestic company produced heat-pump clothes dryers charged with the refrigerant HFC-134a. At the end of 2012, that company transferred its production abroad.

The refrigerant model for *heat-pump clothes dryers* is structured similarly to the models for room air conditioners:

- The most important starting values are a) the unit-number figures for domestic sales and domestic production, and b) the split applied to the refrigerants used (the refrigerant-use figures are tied to the domestic-sales figures). The total numbers of devices are calculated from the sums of new additions.
- Production emissions are calculated by multiplying the quantities consumed in charging by the $EF_{production}$, pursuant to Equation 1, while emissions from stocks are calculated with Equation 2.
- Heat-pump dryers with HFCs have been produced and sold since 2008. Since the units have an average service life of 15 years, disposal-related emissions will begin occurring in 2023.

Emission factors

The emission factors used are based on information from experts. They are listed in Table 203.

The charging loss is 0.5 %. The $EF_{production}$ is country-specific, since the 2006 IPCC Guidelines do not cover these appliances.

The ongoing HFC emissions of these hermetically sealed units are estimated at 0.3 %. In this area as well, the 2006 IPCC Guidelines provide no specifications.

Activity data

Heat-pump dryers are a relatively new product for which little statistical data and technical information are available. The pertinent refrigerant model is thus based almost exclusively on information provided by manufacturers (Winfried Schwarz et al., 2012).

4.7.1.2.6.5 Dishwashers with heat-pump systems

Since 2005, a number of commercial dishwashers with heat-pump systems have been available on the German market. Such systems, intended for large, commercial kitchens, make use of the dishwashers' waste heat. The refrigerant HFC-134a has been used in such systems since 2005, and the refrigerant mixture R513A has been used in them since 2020. The average charge is 2.5 kg.

In Germany, there are two producers of commercial dishwashers with heat-pump systems. Production of the dishwashers began in 2005 and now serves nearly the entire national market. While the dishwashers themselves are built in Germany, their heat-pump systems are imported, pre-charged, from external suppliers located abroad. When the heat-pump systems are fitted to the dishwashers, in production located in Germany, additional charges of about 200 g per unit are added.

The national market for commercial dishwashers is quite stable. It has remained at a relatively constant level for a number of years now.

The refrigerant model for *Dishwashers with heat-pump systems* is structured like the model for room air conditioners (Warncke et al., 2018):

- The most important outset values are the unit-number figures for domestic sales and domestic production. The stocks (pool of relevant devices) are calculated from the sum of new additions, less the removals via disposal.
- Production emissions are calculated by multiplying the quantities consumed in charging by the $EF_{production}$, pursuant to Equation 1, while emissions from stocks are calculated with Equation 2.
- Commercial dishwashers with heat-pump systems have been produced and sold since 2005. Since the units have an average service life of 12 years, disposal-related emissions began occurring in 2017. They are calculated with Equation 4.

Emission factors

The emission factors used are based on information from experts. They are listed in Table 203.

The charging loss is 1 %. The $EF_{production}$ is country-specific, since the 2006 IPCC Guidelines do not cover these appliances.

The ongoing HFC emissions of dishwashers with heat-pump systems are estimated to be 0.3 %. In this area as well, the 2006 IPCC Guidelines provide no specifications.

The average lifetime prior to disposal is 12 years. The 2006 IPCC Guidelines provide no information on this point.

The residual charges in dishwashers, with respect to initial charge, average 95.5 %. The 2006 IPCC Guidelines (IPCC, 2006a) provide no values in this regard. The value used is thus also a country-specific value.

As is the case with heat pumps and room air-conditioners, the recovery factor has been increasing continually. In 2017, it was 82 %, and in 2020, it had reached 85 %. No comparisons with corresponding figures in the 2006 IPCC Guidelines (IPCC, 2006a) are possible.

Activity data

Very little statistical data and technical information are available for the area of commercial dishwashers with heat-pump systems. The pertinent refrigerant model is thus based almost exclusively on information provided by manufacturers (Warncke et al., 2018).

4.7.1.3 Uncertainties and time-series consistency (2.F.1 all)

The emission factors are subject to considerable uncertainties. The broad range of emission factors found in the literature (see the refrigerant models) for identical applications is only partly a consequence of technical modifications, of how well systems are sealed or of national differences. To a large extent, it also results from real uncertainties, since too little solid empirical study of such factors has been carried out Schwarz (2007).

As a result of the aforementioned uncertainty with regard to emission factors, and to the large number of individual applications (systems) involved, the emissions data are considered to be too imprecise. In order to improve the quality of the data, the data were compared with manufacturers' (substance-oriented) sales data.

Until the 2001 reporting year, Germany reported only aggregated emissions, covering all sub-source categories. Within the context of emissions surveys for the years 1999 through 2001, and the emissions survey for reporting year 2002, the emissions for the reporting years 1995 through 1998 were reviewed and updated on the basis of new findings on input quantities and emission factors. All data are thus being improved on an ongoing basis. A comprehensive review of the currentness of the refrigerant models, outset data and emission factors used was carried out in 2012. Additional areas of HFC-refrigerant use continue to be added on an ongoing basis. Most recently, in 2018, the categories of ice cream machines and commercial dishwashers were added to the national inventory.

The quality of the data on emissions from mobile air conditioning systems is good. The reason for this is that annual HFC consumption can be determined, quite precisely, via statistics on registered vehicles and new registrations, and on production, imports and exports of automobiles, which account for the largest part of this sector, as well as via annual model-specific figures on air-conditioner-installation rates and the pertinent charges. Only in the area of commercial vehicles are the data subject to major uncertainties.

The emission factors have been updated on the basis of the results of a study of the Federal Environment Agency (UBA) (Winfried Schwarz et al., 2012). In many application areas, the factors show a continuous development within the time series. Overall, the EF are considered to be accurate. In the study, the residual charges and recovery factors were determined for all areas of application of refrigeration and air-conditioning systems, in order to achieve conformance with the 2006 IPCC Guidelines.

The uncertainties for the entire sub-category of refrigeration and air conditioning systems have been quantified for the 2015 report.

4.7.1.4 Category-specific recalculations (2.F.1 all)

The unit-number figures for plug-in units and condensing units in the area of commercial refrigeration (sub-category 2.F.1.a), for retail businesses selling food, were recalculated, on the basis of figures of the Federal Statistical Office (Series 45341-0001), for the previous year. This led to changes in emissions from production and use of HFC-125, HFC-134a, HFC-143a and HFC-32 in the year 2019.

For central systems of small supermarkets (sub- source category 2.F.1.a), the final stocks of HFC-134a and R404A were updated for the year 2019. This led to changes in emissions from use of HFC-125, HFC-134a and HFC-143a in the year 2019.

For central systems of large supermarkets (sub- source category 2.F.1.a), charging-related consumption of R449A for the years 2017 through 2019; the final stocks of CO_2, HFC-134a and R448A in 2019; and the final stocks of R404A and R449A in the years 2017 through 2019 had to be updated. Also, for systems converted from R404A, the nominal quantities for disposal had to be updated for the years 2017 through 2019. This led to changes, in the years 2017 through 2019, in emissions from production of HFC-125, HFC-134a and HFC-32; in emissions from use of HFC-125, HFC-134a, HFC-143a and HFC-32; and in emissions from disposal of HFC-125, HFC-134a and HFC-143a.

In the area of low-temperature applications in commercial refrigeration and of systems converted from HCFC-22 (sub-category 2.F.1.a), data collected by the Federal Statistical Office, pursuant to the Environmental Statistics Act (UStatG, 2005), are used with regard to initial charges of systems converted to R413A, R508A, R508B, Isceon 89 and HFC-23, and with regard to initial charges of new systems using those refrigerants. The UStatG data on HFC, for each year in question, do not become available until December of the following year. As a result, the figures for the relevant previous year have to be recalculated annually. This leads to changes in emissions from production and use of PFC-116, PFC-218, HFC-125 and HFC-23 for the relevant previous year.

In the area of ice cream machines (sub- source category 2.F.1.b), the refrigerant fractions for appliances using the refrigerants HFC-134a and R290 had to be downwardly corrected, for the years 2015 through 2019, to take account of use of propane (R290), a natural refrigerant. This led to changes in emissions from use of HFC-125, HFC-134a and HFC-143a in the years 2015 through 2019.

In the area of industrial refrigeration (sub-category 2.F.1.c), data collected by the Federal Statistical Office, pursuant to the Environmental Statistics Act (UStatG, 2005), have been used with regard to initial charges of new systems, and to initial charges of systems converted to HFC-23 and HFC-227ea. On an annual basis, the numbers of new additions in the previous year have to be recalculated, since the relevant UStatG data, for each year in question, do not become available until December of the following year. This regularly leads to changes in emissions from production and use of HFC-227ea and HFC-23 for the relevant previous year. The applicable product quantities for fruit-juice and beer production were updated for the year 2019, on the basis of new statistics. In addition, the nominal quantities for disposal applying to systems converted from R404A and R407C in the years 2006 through 2019, and to systems converted from R422D in the years 2018 through 2019, had to be recalculated as the result of a model update. This led to changes in production-related and use-related emissions of HFC-125, HFC-134a, HFC-143a and HFC-32 in 2019, and to changes in disposal-related emissions of those substances in the years 2006 through 2019.

On the basis of new research findings, the refrigerant model for refrigerated containers (sub-source category 2.F.1.d) was adjusted with regard to refrigerant use. As a result, the refrigerant fractions of HFC-134a in the years 2015 through 2019, and of R404A in the years 2015 through 2018, had to be modified for new refrigerated containers. The refrigerant blends R452A and R513A, which have been used since 2018, were included in the model for the first time. Also, in an update for the period as of 2012, the following average charges were adjusted on the basis of information provided by leading manufacturers of refrigerated containers: for HFC-134a, from 6 kg to 5 kg, and for R404A, from 4 kg to 5 kg. In addition, the emission factor for use, for which previously a constant value of 10 % had been used, now decreases continuously as of 2012 and reaches a value of 5.6 % in 2019. The model adjustments led to changes in emissions from use of HFC-125, HFC-134a, HFC-143a and HFC-32 in the years 2012 through 2019.

For refrigerated vehicles (sub- source category 2.F.1.d), the average charges of the refrigerants HFC-134a, R404A, R410A and R452A were updated for the years 2018 and 2019. This led to changes in emissions from production and use of HFC-125, HFC-134a, HFC-143a and HFC-32 in the years 2018 and 2019.

In the area of automobiles and utility vehicles (sub- source category 2.F.1.e), the number of vehicles disposed of (both automobiles and N1 utility vehicles) annually has been taken from the waste statistics of the Federal Statistical Office. Since the data are published with a two-year time lag, the previous year's value has to be recalculated each year. This regularly leads to changes in emissions from disposal of HFC-134a for the relevant previous year.

For automobiles (sub- source category 2.F.1.e), the percentages of vehicles equipped with air conditioning systems, and the applicable average charges, were updated for domestically produced and newly registered vehicles for the years 2011 through 2019. This led to changes in emissions from production and use of HFC-134a in the years 2011 through 2019.

For utility vehicles (sub- source category 2.F.1.e), the number of domestically produced vehicles equipped with air-conditioning systems was updated for the year 2019. This led to higher charging-related emissions of HFC-134a in the year 2019.

For buses (sub- source category 2.F.1.e) – in particular, for vehicles newly registered in 2019 – the percentage of vehicles equipped with air conditioning systems, and the vehicles' average charge, were upwardly corrected, on the basis of new manufacturer data. The number and average charge of buses produced in Germany in 2019 were also updated. This led to changes in emissions from production and use of HFC-134a in 2019.

For railway vehicles (sub- source category 2.F.1.e), the quantities consumed for production had to be changed for the years 2014, 2018 and 2019. This led to changes in emissions from production and use of HFC-134a for the period as of 2014.

In the area of ships (sub- source category 2.F.1.e), the number of new inland-waterway cabin vessels was updated for the year 2019 on the basis of statistics of the Federal Waterways and Shipping Administration (WSV). The HFC-134a emissions from stocks in 2019 decreased as a result.

For heat pumps (sub- source category 2.F.1.f), the refrigerant model was adapted with regard to the use of refrigerants: as of 2019, the refrigerant HFC-32 is being used in brine/water-type heat pumps for heating. The applicable share for R407C decreased as a result in 2019, from 27% to 25%. This led to changes in emissions from production and use of HFC-125, HFC-134a and HFC-32 in the year 2019.

For heat-pump clothes dryers (sub- source category 2.F.1.f), the share of dryers sold with the refrigerant R407C was updated for the year 2019. This led to a change in the emissions from stocks of HFC-125, HFC-134a and HFC-32 in 2019.

The changes in the emissions of PFC-116, PFC-218, HFC-125, HFC-134a, HFC-143a, HFC-227ea, HFC-23 and HFC-32 in the sub-category refrigeration and air-conditioning systems (2.F.1), in the years 2006 through 2019, are shown in Table 205.

Table 205: Overview of the recalculation-related changes in emissions (EM) of PFC-116, PFC-218, HFC-125, HFC-134a, HFC-143a, HFC-227ea, HFC-23 and HFC-32 in the sub-category refrigeration and air-conditioning systems (2.F.1), in the years 2006 through 2019

	Units	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
EM HFC-125															
2022 Submission	t CO_2eq	1,526,648	1,598,515	1,670,450	1,742,221	1,897,420	2,045,657	2,178,785	2,180,119	2,211,906	2,223,271	2,258,185	2,272,571	2,252,195	2,146,963
2021 Submission	t CO_2eq	1,526,853	1,598,709	1,670,632	1,742,358	1,897,534	2,045,768	2,179,268	2,181,262	2,213,820	2,226,281	2,262,377	2,305,949	2,316,057	2,174,359
Difference	t CO_2eq	-205	-193	-182	-137	-114	-112	-483	-1,143	-1,914	-3,009	-4,192	-33,378	-63,862	-27,396
EM HFC-134a															
2022 Submission	t CO_2eq	4,095,900	4,040,656	4,231,513	4,655,546	4,656,934	4,845,135	4,995,464	5,088,559	5,170,081	5,240,383	5,188,984	4,999,080	4,822,681	4,564,614
2021 Submission	t CO_2eq	4,095,928	4,040,683	4,231,539	4,655,565	4,656,950	4,845,958	5,002,948	5,102,467	5,190,667	5,266,870	5,223,265	5,051,356	4,898,958	4,670,902
Difference	t CO_2eq	-28	-27	-25	-19	-16	-823	-7,485	-13,908	-20,586	-26,487	-34,281	-52,277	-76,277	-106,287
EM HFC-143a															
2022 Submission	t CO_2eq	1,609,568	1,729,006	1,839,567	1,937,960	2,022,436	2,096,833	2,137,066	2,099,105	2,095,956	2,032,647	1,937,130	1,827,008	1,637,116	1,450,985
2021 Submission	t CO_2eq	1,609,839	1,729,262	1,839,808	1,938,140	2,022,586	2,096,980	2,137,774	2,100,810	2,098,825	2,037,170	1,943,439	1,862,756	1,686,656	1,418,392
Difference	t CO_2eq	-271	-256	-241	-180	-150	-147	-708	-1,706	-2,869	-4,523	-6,309	-35,748	-49,540	32,593
EM HFC-32															
2022 Submission	t CO_2eq	39,106	47,355	55,991	63,536	72,420	82,658	94,401	106,018	118,388	132,526	148,062	164,621	179,929	193,290
2021 Submission	t CO_2eq	39,111	47,359	55,995	63,539	72,422	82,660	94,404	106,020	118,391	132,528	148,064	166,460	185,561	202,069
Difference	t CO_2eq	-5	-4	-4	-3	-3	-2	-2	-2	-2	-2	-2	-1,839	-5,633	-8,779
EM HFC-227ea															
2022 Submission	t CO_2eq														3,108
2021 Submission	t CO_2eq														3,140
Difference	t CO_2eq														-32
EM HFC-23															
2022 Submission	t CO_2eq														65,654
2021 Submission	t CO_2eq														67,503
Difference	t CO_2eq														-1,848
EM PFC-116															
2022 Submission	t CO_2eq														2,428
2021 Submission	t CO_2eq														2,351
Difference	t CO_2eq														76
EM PFC-218															
2022 Submission	t CO_2eq														1,874
2021 Submission	t CO_2eq														1,829
Difference	t CO_2eq														45

4.7.1.5 Planned improvements, category-specific (2.F.1 all)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.7.2 Foam blowing (2.F.2)

Since 1992, hydrofluorocarbons (HFCs) have also been used in foam blowing, as blowing agents substituting for ozone-depleting, climate-damaging CFCs and HCFCs.

A useful distinction can be made between open-cell and closed-cell foam products. In the case of open-cell foam products, the blowing-agent emissions occur only during the production process or immediately after it. The open-cell foam products that are produced and used in Germany include polyurethane integral foam, one-component polyurethane foam and extruded polystyrene hard foam (XPS) blown with HFC-152a. In the case of closed-cell foam products, emissions occur throughout products' entire lifetimes: in production, during use and upon disposal. The products in this category include rigid polyurethane foam, as well as extruded polystyrene hard foam (XPS) blown with HFC-134a or HFC-1234ze. Both types of closed-cell foam products are produced and used in Germany.

4.7.2.1 Closed-cell polyurethane hard foam products (2.F.2 PU hard foam)

4.7.2.1.1 Category description (2.F.2 PU hard foam)

Closed-cell polyurethane (PU) hard foam products are used in many different kinds of products, including household appliances, refrigerated vehicles, insulating boards with flexible laminates and sandwich elements with rigid laminates. HFC-134a was used as a blowing agent from 1998 to 2003. Since 2002, HFC-365mfc (with small quantities of added HFC-227ea) has also been used as a blowing agent, and HFC-245fa has also been used as such an agent since 2004. Use of HFC has been decreasing; it is being supplanted by hydrocarbons, such as pentane, and by CO_2 (in small amounts).

The time series, which does not begin until 1998, shows a small increase in emissions until 2003. A larger increase occurred in 2004. These results agree with the historical development of HFC use in this application area, an area which emerged only slowly, in keeping with the long period in which HCFCs were used. Emissions from PUR hard foam products decreased again from 2005 through 2009. A slight increase occurred in 2010, and since then the emissions have remained at a relatively constant level.

4.7.2.1.2 Methodological aspects (2.F.2 PU hard foam)

The production emissions are calculated, using Equation 1, by multiplying the quantity of HFC that is emitted no later than one year after the time of production (the first-year loss) by the $EF_{production}$. The emissions from stocks are calculated with Equation 2.

Given the products' average lifetime of up to 50 years (sandwich elements), disposal of PU hard foam products will not begin until a few years from now.

Emission factors

The emission factors used are shown in Table 204.

The emission factor for production with HFC-134a is 10 %. That figure is equivalent to the standard value given in the 2006 IPCC Guidelines (IPCC (2006a), Vol. 3, Table 7.6) for "polyurethane continuous panels."

The emission factors for all other HFCs have been approved by national experts and adjusted where necessary. For example, the emission factor for production of PU hard foam, with use of HFC-365mfc/HFC-227ea as of 2004, was increased from 10 % to 15 %, because that HFC mixture has been used increasingly in open on-site applications, especially in spray foams. The emission factor for production with HFC-245fa is also 15 %. These values lie within the standard-value range proposed by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.7) for "first-year losses" for the various PUR-hard-foam applications.

For PU hard foam blown with HFC-134a, the annual HFC emissions from the "stock" are estimated at 0.5 %. That figure is equivalent to the default value in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.6) for "polyurethane continuous panels." The products blown with HFC-365mfc/HFC-227ea and HFC-245fa emit 1 % annually, and thus lie within the default-value ranges given by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.7), for various PUR-hard-foam applications. The emission factor used for HFC-365mfc/HFC-227ea emissions from stocks was taken from an estimate based on test products.

Activity data

The figures for new domestic consumption, for each blowing agent and each product group, are based on the amounts of foam products produced in Germany. The data for products in service are based on the amounts of foam products used in Germany (sales in Germany) since the introduction of HFCs. Given a product lifetime of up to 50 years, removals from products in service do not yet play any significant role.

New domestic consumption and domestic sales of foam products are determined annually via surveys of manufacturers, users and blowing-agent suppliers; via information from the relevant industry association (IVPU[83]); and via the annual quantities used pursuant to the Environmental Statistics Act (UStatG, 2005).

4.7.2.2 Closed-cell and open-cell XPS hard foam (2.F.2 XPS)

4.7.2.2.1 Category description (2.F.2 XPS)

Extruded polystyrene hard foam (XPS) is used in insulating boards that need to be highly moisture-resistant. HFC consumption and emissions from production of XPS insulation boards have occurred only since 2001, since HCFCs or CO_2 / ethanol were used in this area prior to that time. Since 2001, both HFC-152a and HFC-134a have been used as blowing agents, either singly or in mixtures. Since 2012, HFC-1234ze has also been used as a blowing agent. The emissions behaviour of XPS insulating boards varies in keeping with the blowing agents used to produce them. When HFC-152a is used, HFC emissions occur only during production, and thus the resulting XPS insulating boards can be considered "open-cell" products. When HFC-134a or HFC-1234ze are used, closed-cell XPS hard foam products result that also release HFC emissions during use and disposal.

[83] IVPU – Industrieverband Polyurethan-Hartschaum e. V.

The relevant time series begins in 2001 and exhibits a slight initial emissions increase until 2002. As of 2003, the emissions decrease continuously; this is related to the increasing use of non-halogenated blowing agents in production of XPS hard foam products in Germany.

4.7.2.2.2 Methodological issues (2.F.2 XPS)

The production emissions are calculated by multiplying the production-related new HFC consumption by the $EF_{production}$, pursuant to Equation 1.

The use emissions are calculated, in keeping with Equation 2, from the domestic final HFC stocks in XPS insulating materials. Those stocks increase annually solely through new additions of insulating boards containing HFC-134a and HFC-1234ze. Given a product lifetime of 50 years, removals from products in service do not yet play any significant role. The new HFC additions are not equivalent to annual new consumption, minus production emissions. The reason for this is that, as a result of foreign trade, especially exports of XPS products with HFC-134a or HFC-1234ze, only 25 % (the complementary value for the export rate) of the HFC-134a or HFC-1234ze contained in products amounts to new additions to domestic HFC stocks.

Given that XPS insulating boards have an average lifetime of 50 years, disposal will not begin until 2051 at the earliest. Disposal emissions thus play no significant role to date.

HFC-1234ze is not subject to reporting obligations. Germany voluntarily reports emissions of this substance pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), under "additional greenhouse gases". For reasons of confidentiality, the HFC-1234yf emissions are aggregated with other emissions that are not subject to reporting obligations and are reported in Chapter4.9.3 under CRF 2.H.3.

Emission factors

The emission factors used are shown in Table 204.

The production emissions (HFC first-year losses) for HFC-152a are practically 100 % ($EF_{production}$ = 1), since the substance is used solely as a blowing agent in production. With HFC-134a, only part of consumption is emitted upon blowing; most of the substance enters into the product. The $EF_{production}$ for HFC-134a is determined empirically and communicated by the CEFIC[84] association or by its EXIBA[85] industry association. It is subject to confidentiality requirements. Until experimental measurements become available, the same $EF_{production}$ will be used for XPS insulating boards blown with HFC-1234ze that is used for insulating boards blown with HFC-134a.

Trials with HFC collection and recovery in the production process have been conducted, but to date no relevant systems have been implemented, for both technical and economic reasons.

The 2006 IPCC Guidelines (IPCC, 2006a) give the following default values, in Vol. 3, Table 7.6, for insulating boards blown with HFC-134a and HFC-152a: The "first year loss" is 25 % for HFC-134a and 50 % for HFC-152a. The corresponding values used in Germany, especially that for HFC-152a, differ widely from these figures. At the same time, they are considered to be representative, since they are based on information provided by industry experts.

A representative of the FPX extruded-polystyrene-foam association estimated the annual releases from enclosed HFC-134a cell gas as being less than 1 % in 2002. That figure is based, inter alia, on an internal study of BASF regarding the half-lives of various cell gases, including HFC-134a (Weilbacher, 1987). The EF_{use} from that laboratory study has been used for HFC-134a.

[84] CEFIC – The European Chemical Industry Council

[85] EXIBA – European Extruded Polystyrene Insulation Board Association

Fugitive emissions from boards depend on board thickness, and they can be given only as average values, or as values for specific board thicknesses. The value used, EF_{use} = 0.66 %, is based on a medium board thickness, and it lies below the value proposed in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Table 7.6), 0.75 %. The 2006 IPCC Guidelines do not provide any default values for insulating boards blown with HFC-1234ze. The same EF_{use} is used for such boards as is used for boards blown with HFC-134a.

Activity data

The data on new domestic consumption of HFC-134a and HFC-152a are obtained from data collected pursuant to the Environmental Statistics Act (Umweltstatistikgesetz; (UStatG, 2005)) and from surveys of manufacturers.

The data on new domestic consumption of HFC-1234ze are obtained from data collected via surveys pursuant to the Environmental Statistics Act (Umweltstatistikgesetz; (UStatG, 2005)) and via information provided by the pertinent propellant manufacturer.

All of the data required for emissions calculation, including new domestic consumption, loss rate in production and the foreign trade balance for insulation boards containing HFC-134a, are provided by the relevant European industry association (CEFIC or EXIBA).

4.7.2.3 Open-cell polyurethane integral foam (2.F.2 PU integral foam)

4.7.2.3.1 Category description (2.F.2 PU integral foam)

Open-cell polyurethane (PU) integral foams are foams with a porous core and a compact, tough skin. They are produced via reaction injection moulding. In that process, the reaction mixture, including the blowing agent, is injected in liquid form into a cold injection mould. All of the blowing agent is emitted during the foaming action that ensues. PU integral foams are used in the soles of athletic and leisure shoes, in car-body parts and in window profiles. HFCs have been used as blowing agents for production of PU integral foams since 1996.

Along with HFC-134a, which has been used since 1996, the blowing agents used in Germany also include HFC-365mfc (since 2002; and with minor additions of HFC-227ea) and HFC-245fa (since 2004).

The time series begins in 1996. From then until 2001, the emissions remained relatively constant. As of 2002, the emissions increase continuously. HCFCs were long used in production of PU integral foams in Germany, and this delayed the phasing-in of HFCs. An emissions reduction occurred in 2012. It was due to intensified use of hydrocarbons (such as pentane), as blowing agents, in place of HFCs. The emissions increased again through 2016, however. Then, beginning in 2017, they decreased again, ultimately reaching their level of 2010.

4.7.2.3.2 Methodological aspects (2.F.2 PU integral foam)

Pursuant to the 2006 IPCC-Guidelines (IPCC (2006a): page 7.34, equation 7.8), the emissions in this open application are considered to be the same as the HFC quantity used in production (new HFC consumption).

The production emissions are calculated by multiplying the production-related new HFC consumption by the $EF_{production}$, pursuant to Equation 1.

No use emissions or disposal emissions occur, since all of the blowing agent is emitted completely in production.

Emission factors

The emission factor used is shown in Table 204.

For PU integral foams blown with HFC-134a, HFC-245fa or HFC-365mfc (with additions of HFC-227ea), the 2006 IPCC Guidelines give a default value of 95 % for the first-year loss. The annual loss is given as 2.5 %, with the result that emissions occur over three years.

According to the in-country experts consulted, all of the blowing agent – except for small residual quantities – escapes during the blowing process. The small residual quantities are then emitted over a period of no longer than two years. For this reason, in a departure from the 2006 IPCC Guidelines, Germany considers an emission factor of 100 % to be appropriate for production.

Activity data

The figures for new domestic consumption, for each blowing agent and each product group, are based on the amounts of integral foam products produced in Germany.

New domestic consumption and domestic sales of foam products are determined annually via surveys of manufacturers, users and blowing-agent suppliers; via information from the relevant industry association (IVPU); and via the annual quantities used pursuant to the Environmental Statistics Act (UStatG, 2005).

4.7.2.4 Open-cell one-component polyurethane foam (2.F.2 one-component PU foam)

4.7.2.4.1 Category description (2.F.2 one-component PU foam)

The term "one-component foam" refers to open-cell polyurethane foam (PU foam) that is sprayed, on site, from pressurised containers (cans). Such foam is used, for example, in installation of windows and doorframes. The blowing agents now used for such foam, following the prohibition of HCFCs, include mixtures of HFCs and propane, butane or dimethyl ether (DME). At the same time, the HFC quantities in such cans have been continually reduced since 1996.

HFC-134a has been used in Germany since 1992, in production of PU one-component foam (in cans). HFC-152a was used from 2002 to 2004 in domestic production. Imported cans of one-component foam used in Germany contain HFC-134a (since 1992) or HFC-152a (since 1995).

The emissions of PU one-component foam increased sharply from 1992 through 1994; thereafter, they decreased continuously. Since 4 July 2008, a ban has been in force in the EU, with a few permitted exceptions, on sale of one-component-foam products filled with fluorinated greenhouse gases with a global warming potential (GWP) greater than 150. For that reason, future emissions can be expected to remain relatively constant, at low levels.

4.7.2.4.2 Methodological aspects (2.F.2 one-component PU foam)

The production emissions are calculated from the number of cans filled per year in Germany and the blowing-agent loss per can.

Pursuant to the 2006 IPCC-Guidelines (IPCC (2006a): p. 7.34, equation 7.8), in each case the emissions for this open use are considered the same as the HFC quantity sold with the can. Emissions from use are calculated, with Equation 2, via the HFC quantities sold in cans.

No disposal emissions occur, since all of the HFCs in cans of one-component foam are emitted when the cans are used.

Emission factors

The emission factors used are shown in Table 204.

The $EF_{production}$ was determined via surveys of experts and of manufacturers. From 1992 to 2002, it amounted to 1.5 g/can, while since 2003 it has been only 0.5 g/can, since the total fill quantities in cans have decreased.

The 2006 IPCC Guidelines (IPCC, 2006a), in Vol. 3, Table 7.6, give a first-year loss of 95 % and an annual loss of 2.5 % for one-component foams, with the result that the relevant emissions are distributed over a total of three years in each case. In contrast to the IPCC method, for the German inventory, it is assumed that all emissions occur in the year of sale (EF_{use} = 100 %), since use and disposal occur promptly. At the same time, used cans are not completely empty when they go to waste management; they still contain about 8 % of their original foam contents, including the relevant blowing agent. The majority of that blowing agent eventually also enters the atmosphere, after a certain delay.

Activity data

The data required for determination of losses from charging (production emissions) – the numbers of cans filled annually in Germany with HFC-134a or HFC-152a; the quantity of HFC per can, in grams; and the specific loss from charging – are obtained via surveys of experts and from information provided by manufacturers.

The data required for determination of the emissions from use – the numbers of cans sold annually in Germany with the propellants HFC-134a or HFC-152a, and the HFC quantity per can, in grams – are obtained from the manufacturers of spray cans with one-component-foam.

The pre-1995 data for foam sealants were obtained via discussion, in 2006, with leading foreign sellers of one-component foam products and from older publications.

4.7.2.5 Uncertainties and time-series consistency (2.F.2 all)

The uncertainties for the "foams" sub-category have been systematically quantified.

The emissions data for prior years, for PU foam products, are considered fairly accurate, since the quantities of HFCs used are rather small.

Because it includes only a small number of manufacturers, the German XPS market is not complex. Since the EF and AD were prepared in co-operation with manufacturers, they are considered sufficiently precise.

Since 2001, the relevant industry association has determined, via research, the input quantities of HFC-152a and HFC-134a in production of XPS hard foams. Since 2006, data collected pursuant to the Environmental Statistics Act (Umweltstatistikgesetz; (UStatG, 2005)) have also been available. Since only three manufacturers use HFC for XPS blowing, there is little reason to doubt the reliability of the activity data. This also applies to the export rate and the HFC production emissions determined for use of HFC-134a.

The production emissions in use of HFC-152a, 100 %, do not agree with the existing IPCC estimates. Nonetheless, the industry association considers them to be realistic.

The value for the emissions rate from current stocks, as determined by a laboratory study, will be used as long as no reliable measurements with insulation boards in actual service have been carried out; such measurements would be considered more conclusive than laboratory values.

4.7.2.6 Category-specific recalculations (2.F.2 all)

The values for the domestic consumption of HFC-134a, HFC-152a and HFC-1234ze, for the production of XPS hard foam, for the period as of 2007, have been taken from surveys pursuant to the Environmental Statistics Act (UStatG, 2005). The domestic consumption of the previous year has to be recalculated annually, since the relevant data collected pursuant to the UStatG, for each year in question, do not become available until December of the following year. This regularly leads to changes in emissions from production and use for the relevant previous year.

For polyurethane hard-foam products, and polyurethane integral foams, domestic-consumption figures for production with HFC-227ea were recalculated for the years 2005 through 2016, and 2018, on the basis of new findings. As a result, the emissions from production and use have changed for those years.

In the case of polyurethane hard-foam products and polyurethane integral foams, the domestic-consumption figures, for production with HFC-245fa and HFC-365mfc, have been updated for the year 2019, to take account of determination of the relevant propellants' applicable fractions via surveys pursuant to the Environmental Statistics Act (UStatG, 2005). For HFC-365mfc, the relevant value for 2013 was also corrected.

With regard to polyurethane integral foams, as of 2013 data on domestic consumption for production with HFC-134a are taken from surveys pursuant to the Environmental Statistics Act (Umweltstatistikgesetz) (UStatG, 2005). This made it necessary to recalculate the emissions from production for those years. With regard to one-component polyurethane foams, the HFC-134a and HFC-152a charges in domestically sold cans were updated for the years 2017 and 2018, on the basis of information provided by industry experts. This led to changes in the emissions from use for those two years.

The changes in the emissions of HFC-134a, HFC-152a, HFC-227ea, HFC-245fa and HFC-365mfc, in the sub-category foam blowing (2.F.2), in the years 2005 through 2019, are shown in Table 206.

Table 206: Overview of the recalculation-related changes in emissions (EM) of HFC-134a, HFC-152a, HFC-227ea, HFC-245fa and HFC-365mfc in the sub-category foam blowing (2.F.2), in the years 2005 through 2019

	Units	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
EM HFC-134a																
2022 Submission	t CO_2eq									465,686	495,259	513,399	485,041	483,634	295,415	59,917
2021 Submission	t CO_2eq									470,252	486,458	489,494	475,647	490,023	301,810	293,159
Difference	t CO_2eq									4,566	-8,800	-23,905	-9,394	6,389	6,395	233,242
EM HFC-152a																
2022 Submission	t CO_2eq													39,844	37,676	31,155
2021 Submission	t CO_2eq													39,367	37,228	37,479
Difference	t CO_2eq													-477	-449	6.324
EM HFC-227ea																
2022 Submission	t CO_2eq	12,383	9,664	27,825	24,439	30,920	28,722	31,744	29,743	28,293	24,907	47,339	57,315	75,095	17,044	18,462
2021 Submission	t CO_2eq	12,383	9,663	27,824	24,439	30,921	28,721	31,745	29,743	28,306	24,907	47,338	57,315	75,095	17,025	18,462
Difference	t CO_2eq	0.02	1	0.4	-0.1	-1	1	-1	0.3	-13	-0.4	0.4	0.2	-0.1	19	1
EM HFC-245fa																
2022 Submission	t CO_2eq															129,648
2021 Submission	t CO_2eq															131,321
Difference	t CO_2eq															-1,673
EM HFC-365mfc																
2022 Submission	t CO_2eq									86,999	95,375	169,136	175,827	185,600	90,205	165,755
2021 Submission	t CO_2eq									87,037	95,375	169,137	175,828	185,601	90.206	100,784
Difference	t CO_2eq									-38	-0.4	-0.4	-0.4	-0.4	-0.4	64.971

4.7.2.7 Planned improvements, category-specific (2.F.2 all)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.7.3 Fire extinguishers (2.F.3)

4.7.3.1 Category description (2.F.3)

Halons, which until 1991 were permitted fire extinguishing agents, have since been largely supplanted by ecologically safe substances – especially inert gases, such as nitrogen and argon, for systems for flooding rooms; and by powder, CO_2 and foams in handheld fire extinguishers.

In 1998, HFC-227ea was certified in Germany as a halon substitute. In 2001, HFC 236fa also received such certification. That substance is used solely in the military sector, however. HFC-23, while certified since 2002, did not begin to be used until 2005. While certification of fire extinguishing agents is no longer required, the list of fire extinguishing agents in use has nonetheless not grown, since all application areas can be covered with halogen-free agents and with the aforementioned HFCs (especially 227ea and 236fa).

HFC-based fire extinguishing agents are imported and filled into fire extinguishing systems in Germany. Virtually no foreign trade with charged systems takes place. The time series do not begin until 1998.

4.7.3.2 Methodological issues (2.F.3)

The annual new HFC additions in domestic systems are identical with the amounts added to new systems within the country (new HFC consumption).

Since activity data are available in Germany for HFC-227ea and HFC-236fa, a bottom-up approach is used. The approach used differs from the top-down approach given by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Chapter 7.6) in that emissions from charging have been taken into account.

Due to a lack of pertinent data, the installed quantities of HFC-23 are estimated by the Federal Environment Agency. As of report year 2016, it has been asssumed that, as a result of the provisions of Regulation (EU) No 517/2014 (F-GasV, 2014), no further new systems have been installed.

The average lifetime of fire extinguishing systems is estimated to be 20 years, a period on the same order as the duration range proposed by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Chapter 7.6.2.2), 15 to 20 years.

Disposal emissions occurred for the first time in 2018, at the end of the average lifetime for the category, 20 years.

Emission factors

The emission factors used are shown in Table 204.

The $EF_{production}$ are based on experts' assessments.

The EF_{use} for HFC-236fa and HFC-23 is 4 %. The 4 % figure conforms to the 2006 IPCC Guidelines. Specific installation and recharge quantities are available for HFC-227ea through report year 2007. Those quantities are extrapolated for the German market as a whole, on the basis of the market share estimated by the company. As of report year 2008, the emissions from use are calculated with an emission factor of 2.5%. We assume the actual emission factor is smaller than the EF= 4% assumed by the Guidelines. Our assumption is based on the considerably lower/smaller emissions / recharge quantities reported to date for the majority of the market, as well as on experience gained in implementing Regulation (EU) 517/2014 on fluorinated greenhouse gases.

For all HFCs, the emission factor for disposal is 1 %. Experts of the environmental research institution Öko-Recherche recommended this value, which differs from the value specified by the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Chapter 7.6.2.2), in light of the fact that, in practice, the gas cylinders used in such systems are normally reused (i.e. they are separated from the systems for recharging and reusing).

Activity data

The figures for HFC 227ea emissions are based on statistical surveys by one company, covering the aspects of input quantities, recharge quantities, accidental releases, releases in cases of fire, and flooding tests in Germany (by analogy to Tier 2). Up-scaling was carried out on the basis of the market shares estimated by the company. These data are available at this level of detail through report year 2007. As of report year 2008, two companies have been reporting the quantities they utilise. The two companies together have a market share of 90%, and the relevant input quantities are extrapolated to 100% of the market.

The data for HFC-236fa are based on company information provided on a voluntary basis. The figures for HFC-23 are based on estimates of the Federal Environment Agency.

4.7.3.3 Uncertainties and time-series consistency (2.F.3)

The uncertainties for the "fire extinguishing agents" sub-category have been systematically quantified.

4.7.3.4 Category-specific recalculations (2.F.3)

No recalculations were required.

4.7.3.5 Category-specific planned improvements (2.F.3)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.7.4 Aerosols (2.F.4)

This area includes metered-dose inhalers (MDI), which are used in medical applications, as well as general-purpose aerosols and so-called "novelty aerosols".

4.7.4.1 Metered-dose inhalers (2.F.4.a)

4.7.4.1.1 Category description (2.F.4.a)

Metered-dose inhalers are used in the medical sector, primarily for treatment of asthma. Metered-dose inhalers with an HFC propellant first reached the German market in 1996. They contained the propellant HFC-134a. Beginning 1999, metered dose inhalers with the propellant HFC-227ea were also sold. Since then, the number of available preparations has grown continually. Charging of inhalers with HFC-134a has taken place in Germany since 2001.

From 1996 through 2002, the time series shows a sharp emissions increase that correlates with increasing use of HFCs as CFC substitutes. A large change occurred in 2001. As of that year, CFCs were prohibited for the largest group of active ingredients, the short-acting betamimetics. Since 2003, the emissions have remained at a relatively constant high level.

4.7.4.1.2 Methodological issues (2.F.4.a)

Since 98 % of the contents of metered dose inhalers consist of propellant, their contents are considered to consist solely of HFCs.

The production emissions are calculated from the number of metered dose inhalers charged per year in Germany and the propellant loss per can. Part of the propellant emissions are collected with cold traps and then incinerated. Without such collection, the emissions would be higher.

Emissions from use are calculated, with Equation 2, via the HFC quantities sold in metered dose inhalers. The great majority of metered dose inhalers used in Germany are sold in pharmacies. An estimated 10 % are used by hospitals, for their own needs, while 3 % are free, "not-for-sale" medical samples that are for doctors and pharmaceutical representatives. These two shares are taken into account by adding 13 % to sales by pharmacies.

The time period between pharmacy sales and use is short. In a departure from the recommendation in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Equation 7.6), the reference figure for the emissions from use is thus not the sum of half the purchases (sales) of the previous year and half the purchases (sales) of the current year, but all purchases (sales) for the current year. The approach in the 2006 IPCC Guidelines would be a useful choice if the available data covered produced inhalers – rather than sold inhalers – since considerable time, for transport and storage, indeed can pass between production and use.

No disposal emissions occur, since all of the HFCs in metered dose inhalers are emitted when the cans are used.

Emission factors

The emission factors used are shown in Table 204.

The $EF_{production}$ on which production-emissions data are based is itself based on very precise determination of charging emissions, in actual operations, by the only German company that charges such inhalers. These amount to about 1.5 %, with respect to new consumption for charging. This translates to about 0.2 g per 10 ml inhaler.

In agreement with IPCC specifications (2006 IPCC Guidelines, Vol. 3, p. 7.28), a 100 % emissions level in use (EF_{use} = 1) is assumed. Inhaled HFCs are not broken down in bronchial passages; they are released into the atmosphere, without undergoing any changes, upon exhalation. In a departure from the Guidelines, Germany uses a lifetime of only one year for metered dose inhalers. The emission factor has thus been classified as "country-specific".

Activity data

The emissions data for the period until reporting years 2005 (production) and 2006 (use) are based on sales figures (sales in pharmacies) for metered-dose inhalers in Germany, as obtained via surveys of producers. The total unit numbers, the average fill quantity in ml and the propellant used have all entered into relevant calculations. As of reporting year 2006, the activity data for production are based on experts' estimates. As of reporting year 2007, the activity data for use are also based on such estimates. In the category "metered dose inhalers", the results of the Federal Statistical Office's annual surveys of certain climate-relevant substances (UStatG, 2005) normally do not become available on time for the corresponding current report year. Retroactive data cross-checking is carried out when necessary, however.

4.7.4.2 Other aerosols (2.F.4.b)

4.7.4.2.1 Category description (2.F.4.b)

In Germany, six types of general-purpose aerosols (includes neither medical metered dose inhalers nor novelties) containing HFC are sold:

- compressed-air sprays,
- cooling sprays,
- drain-opener sprays,
- lubricating sprays,
- insecticides, and
- self-defence sprays.

Production and use of general-purpose aerosols with HFC-134a began in 1992; production and use of such aerosols with HFC-152a began in 1995. Since 2013, HFC-1234ze has also been used as a propellant in cooling sprays and cleaning sprays. From 1992 through 1996, the time series shows a sharp emissions increase that correlates with increasing use of HFCs as CFC substitutes. The emissions remained at a constant level between 1996 and 2005. They made a large downward jump in 2009, and then increased again slightly. Since 2017, they have fallen to very low values.

Other aerosols include "novelty" aerosols (artificial snow, "silly string", etc.). Such products are not produced in Germany, however. Use of novelty sprays with HFC-134a began in 1995, while use of sprays with HFC-152a began in 2000. As of 2004, the emissions from such sprays decreased sharply. Since 2010, they have remained at a constant low level. That trend is the result of a EU ban, in force as of 4 July 2009, on sale of novelty aerosols filled with hydrofluorocarbons (HFCs) with a Global Warming Potential (GWP) greater than 150. Producers were quick to respond by choosing other propellants for their products.

As of 1 January 2018, sales of technical aerosols that use HFC with a GWP of more than 150 are prohibited in the EU (a few exceptions apply).

4.7.4.2.2 Methodological issues (2.F.4.b)

In the case of general-purpose aerosols, imports and exports are roughly in balance, and thus the domestic market can be considered equivalent to consumption for domestic filling. Domestic consumption refers to spray cans filled in Germany, regardless of where the cans are ultimately used. The production emissions are calculated, pursuant to Equation 1, from the HFC consumption for in-country filling of general-purpose aerosols and the propellant loss in production.

No novelty aerosols are produced in Germany. The basis for calculating the HFC quantities sold in novelty-aerosol cans consists of the German market's share of the EU market.

Emissions from use are calculated, using Equation 2, via the HFC quantities sold in "other aerosols".

Since the calculations are oriented to the numbers of aerosol cans sold – and not to the numbers produced – the average time period between the sale and use of such cans may be assumed to be very short. The reference figure for calculating the emissions from use – in contrast to the recommendation in the 2006 IPCC Guidelines (Vol. 3, Equation 7.6) – is thus not the sum of half the purchases (sales) of the previous year and half the purchases (sales) of the current year, but all purchases (sales) for the current year.

Since the HFCs contained in such aerosols are emitted completely when the aerosols are used, no disposal emissions have to be reported.

HFC-1234ze is not subject to reporting obligations. Germany voluntarily reports emissions of this substance pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), under "additional greenhouse gases". For reasons of confidentiality, the HFC-1234yf emissions are aggregated with other emissions that are not subject to reporting obligations and are reported in Chapter4.9.3 under CRF 2.H.3.

Emission factors

The emission factors used are shown in Table 204.

The $EF_{production}$ = 1.5 % on which production-emissions data for other aerosols are based is itself based on experts' assessments.

A 100 % emissions level in use of other aerosols (EF_{use} = 1) is assumed. This assumption is appropriate, and it accords with the IPCC specifications (IPCC (2006a), Vol. 3, p. 7.28). In a departure from the Guidelines' relevant proposal, it is assumed that all of the cans sold in Germany are used completely in the same year in which they are sold. The emission factor has thus been classified as "country-specific".

Activity data

The data for the period prior to 1995 are based on estimates of experts. In keeping with a bottom-up approach, all quantity data as of 1995 are provided directly by producers, fillers and operators, propellant manufacturers and the relevant industry association. Emissions data for general-purpose aerosols also include filling emissions (= production emissions). Estimates are based on EU-wide data.

4.7.4.3 Uncertainties and time-series consistency (2.F.4 all)

The uncertainties for the "aerosols" sub-category have been systematically quantified.

In the case of metered dose inhalers, the surcharge factor for hospitals and doctors' samples can vary, by ± 3 %, from the above-cited 13%.

In comparison to the emissions data for metered dose inhalers, the data for other aerosols are considered not as good, since the large number of products involved makes it difficult to obtain an overview of the market. Large quantities of imports, especially in the area of "novelties", also complicate the situation. The uncertainties are thus considerably higher (more than 20 %).

Since the shift from CFCs to chlorine-free propellants had already been completed by the beginning of the 1990s, the time series for the period 1995-2005 showed virtually no changes. Slight emissions decreases have been seen since 2006.

4.7.4.3.1 Category-specific recalculations (2.F.4 all)

No recalculations were required.

4.7.4.3.2 Planned improvements, category-specific (2.F.4 all)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.7.5 Solvents (2.F.5)

4.7.5.1 Category description (2.F.5)

Use of HFCs as solvents was banned in Germany until the year 2001 (2nd Ordinance on the Implementation of the Federal Immission Control Act – 2. BimSchV) and remains heavily restricted to this day. A separate permit has to be applied for for every surface-treatment facility that uses HFCs either in a pure form or in mixtures with trans-1,2-dichloroethene, and such permits are granted only in special cases. In addition to HFC-43-10mee, which has already been reported, the following substances are now also used, in very small quantities: HFC-365mfc (since 2013), HFC-245fa (since 2010) and C_6F_{14} (since 2006).

4.7.5.2 Methodological issues (2.F.5)

Emissions are calculated in keeping with Tier 2a as described in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Chapter 7.2). Emissions occur only during use.

Emission factors

In an objectively correct approach that is keeping with the IPCC specifications (IPCC (2006a): Vol. 3, Equation 7.5), emissions from a given solvent use are assumed to amount to 100 % within 2 years (EF_{Use} = 1).

Activity data

The consumption figures for HFC-43-10mee are based on the sales data of an authorised dealer. The quantities of HFC-245fa and of HFC-365mfc used are based on information provided by industry experts. The data on domestic consumption of C_6F_{14} was obtained from data collected pursuant to the Environmental Statistics Act (UStatG, 2005).

Since the data are confidential, they are reported under CRF 2.H.3.

4.7.5.3 Uncertainties and time-series consistency (2.F.5)

The uncertainties for the "solvents" sub-category have been systematically quantified. The figures on solvents consumption are obtained directly from the individual firms concerned. The uncertainties for the emissions (U_{min}/U_{max}) are thus very low. They are assumed to be 2 %. C_6F_{14} is an exception. According to expert judgements, the uncertainties for the emissions (U_{min}/U_{max}) of that substance amount to 20 %.

Prior to 2006, the emissions stayed at a constantly low level. Between 2006 and 2008, a sudden sharp emissions increase occurred, triggered in part by the onset of use of C_6F_{14}. Since 2009, the quantities used – and thus the emissions – have remained at a relatively constant low level.

4.7.5.4 Category-specific recalculations (2.F.5)

No recalculations were required.

4.7.5.5 Category-specific planned improvements (2.F.5)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.7.6 Other applications that use ODS substitutes (2.F.6)

Germany reports no emissions in this category.

4.7.7 Category-specific quality assurance / control and verification (2.F all)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The data for the 2003 report year, like the data for most of the previous years, were collected by an external expert working in the framework of a research project under commission to the Federal Environment Agency.

For the most part, quality assurance was carried out by an external expert. In addition, the data are checked by the relevant Federal Environment Agency specialists upon receipt.

In 2011, the entire sector of F-gas emissions was subjected to voluntary trilateral review. Experts from England, Germany and Austria reviewed "each other's" F-gas inventories. The aims of the review were to exchange information regarding country-specific methods for preparing F-gas inventories; to learn about the institutional and legal regulations for F-gas inventories in each country; to identify obstacles for the preparation of complete, precise inventories; and to discuss differences and similarities between the various methods used to prepare F-gas inventories. The meeting helped all three countries to review their methods for relevant emission calculation. In addition, the transparency, completeness and precision of the various inventories were assessed. That review had a positive outcome, namely that Germany has a good F-gas inventory. As a result, no recommendations were issued for improvements of the German F-gas inventory.

No other data sources, apart from the data provided by the Federal Statistical Office, the data collected by the research contractor and the data reported by the pertinent companies, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. Comparisons with other countries have revealed no requirements for improvements. The emission factors either are in keeping with the default emission factors given by the 2006 IPCC Guidelines or are of the same order as the values used by other countries.

4.8 Other product manufacture and use (2.G)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/T	**2 G, Other Product Manufacture and Use**		**N_2O**	**C**	**C**	**C**	**C**	**C**
L/T	**2 G, Other Product Manufacture and Use**		**SF_6**	**C**	**C**	**C**	**C**	**C**
-/-	2 G, Other Product Manufacture and Use		$C_{10}F_{18}$	C	C	C	C	C
-/-	2 G, Other Product Manufacture and Use		CH_4	4.5	0.0%	23.3	0.0%	415.2%
-/-	2 G, Other Product Manufacture and Use		HFC-134a	0.0	0.0%	0.2	0.0%	-
-/-	2 G, Other Product Manufacture and Use		HFC-245fa	0.0	0.0%	13.3	0.0%	-
-/-	2 G, Other Product Manufacture and Use		HFC-365mfc	0.0	0.0%	0.7	0.0%	-

Gas	Method used	Source for the activity data	Emission factors used
CO_2, CH_4, N_2O, SF_6, PFC, HFC	cf. Table 207	cf. Table 207	cf. Table 207

The category *Other product manufacture and use* is a key category for SF_6 emissions in terms of level and trend. For N_2O emissions, it is a key category only in terms of trend.

The category 2.G includes SF_6 from electrical equipments (2.G.1), SF_6 and PFC from other product use (2.G.2), use of N_2O (2.G.3), use of F gases in ORC systems (2.G.4 ORC systems) and in container fumigation (2.G.4 Container fumigation), and CO_2, CH_4, N_2O and particulate emissions from use of charcoal (2.G.4 Charcoal). With regard to use of cigarettes (2.G.4) and fireworks (2.G.4), emissions of particulates, precursor substances and heavy metals are reported. In the interest of more-precise data collection, these sub-categories are further divided, to some extent, in the following section.

The methods, emission factors and applicable lifetimes on which the emission calculation is based are listed in Table 207.

Table 207: Overview of the methods and emission factors used, for the current report year, in the categories 2.G.1 (Electrical equipments), 2.G.2 (SF_6 and PFC from other product use) and 2.G.4 (ORC systems, container fumigation and charcoal use)

	QG	Method	Gas			Lifetime	Emission factor (dimensionless)		
			SF_6	HFC	PFC	[years]	Production	Application	Waste management
Electrical equipments	**2.G.1**								
Switchgear and controlgear	2.G.1a	Tier 3	SF_6			40	0.02 (CS)	0.001 – 0.01 (CS)	0.015 (CS)
SF_6 and PFC from other product use	**2.G.2**								
AWACS	2.G.2a	CS					NO	1 (CS)	NO
Particle accelerators	2.G.2b	CS	SF_6				0.15 - 1 (CS)	0.006 – 0.003 (CS)	NO
Insulated glass windows	2.G.2c	Equ. 3.24 ff					0.33 (D)	0.01 (D)	1 (D)
Adiabatic behaviour	2.G.2d								
- Automobile tyres		Equ. 3.23	SF_6				NO	NO	1 (D)
- Athletic shoes		Equ. 3.23	SF_6		PFC		NO	NO	1 (D)
Other	2.G.2e								
- Trace gases		Equ. 3.22	SF_6				NO	1 (D)	NO
- Welding		CS	SF_6				NO	1 (CS)	NO
- Optical glass fibre		CS	SF_6				C	NO	NO
- Medicines and cosmetics		CS			PFC	-	NO	1 (D) 0.95 – 0.998 (CS)	NO
Use of N_2O	**2.G.3**								
Semiconductor manufacturing		D					C		
Narcotic applications		D	N_2O					1	
Explosives		D						0.1036 kg/t	
Spray cans		D						1	
Other	**2.G.4**								
ORC systems	2.G.4a	CS		HFC	PFC	20 – 30 (CS)	0.02 (CS)	0.04 (CS)	0.2 (CS)
Container fumigation	2.G.4a	CS	SO_2F_2			-	NO	1 (CS)	NO
Charcoal use	2.G.4b	Tier 1	CO_2-, CH_4-, N_2O- and particulates				C	C	

4.8.1 Electrical equipments (2.G.1)

This category consists primarily of use of electrical equipments (2.G.1), which is further sub-divided into high-voltage (HS – Hochspannungs-), medium-voltage (MS – Mittelspannungs-) and other electrical equipments.

4.8.1.1 Category description (2.G.1)

In electricity transmission and distribution, SF_6 is used primarily in switchgear and controlgear and equipment in high-voltage (52-380 kV) and, increasingly, medium-voltage (10-52 kV) networks. It serves as an arc-extinguishing and insulation gas. In addition, it is used in production of components installed in gas-insulated indoor switchgear and controlgear (instrument transformers, bushings) or supplied directly to operators (high-voltage instrument transformers for outdoor installations).

As a result of first-time inclusion, in report year 2002, of additional SF_6 applications, the time series shows a marked jump in emissions in 2002. In reporting year 2005, new companies were included in reporting, especially in the new category "Other electrical equipments." For reasons having to do with the economy as a whole, more systems were sold in 2005 and 2006. On the whole, the absolute emissions have been decreasing, primarily as a result of reductions of emissions from the high-voltage sector. Emissions from medium-voltage systems and other equipment have been increasing, partly as a result of the continually growing numbers of systems in service. . In 1996, industry, represented by producers' and operators' associations and the SF_6 producer, committed itself to reducing emissions in life cycles of switchgear and controlgear and to provide annual progress reports. In 2005, this voluntary commitment was extended, in co-operation with the Federal Environment Agency and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), to include additional energy-transmission and energy-distribution installations above the 1 kV level. In addition, specific reduction targets were added to the commitment. The scope of voluntary reporting was enlarged and refined accordingly. In subsequent years, producers, including the gas producer, have continued to invest in reduction measures. In some areas, substitutes for SF_6 foams are being used in bushings.

4.8.1.2 Methodological issues (2.G.1)

The emission factors used are shown in Table 207.

The emissions figures are based largely on a mass balance. Increasingly, they are also being combined with emission factors for sub-areas in which the technical measurement limits for mass-balancing have been reached or in which mass-balancing would necessitate unreasonably high costs.

The method used is based on the "Tier 3 Hybrid Life-Cycle Approach" described in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, Chapter 8.2.2).

Usage emissions

Ongoing emissions from stocks are based on the stocks of SF_6 that have accumulated since 1970, via annual additions of switchgear and controlgear, and that are in place as of the middle of a relevant year n.

The final stocks of SF_6 in all electrical equipments for a given year n change annually by the balance of new additions and removals. Some removals (high voltage) have been registered since 1997; large-scale removals of first-generation high-voltage switchgear and controlgear and equipment cannot be expected until after 2015, in light of the products' estimated service lifetime of at least 40 years.

Three special aspects must be taken into account in reporting relative to switchgear and controlgear:

- Calculation of the final stocks for a given year n is based on the final stocks for the previous year (n-1); this does not extend back to the first year of service, however. Such backward extension, an otherwise customary procedure, is not used for switchgear and controlgear, because operators/manufacturers estimated the SF_6 stocks in service for 1995. Their estimate was broken down into high-voltage and medium-voltage categories (770 t and 157.6 t, respectively).

- In the area of high-voltage switchgear and controlgear, stocks and emissions are determined via direct surveys of the some 100 operators. In such surveys, the operators are asked to provide data on their current stocks of SF_6 in electrical equipments (gas-insulated HV switchgear (GIS), circuit breakers, outdoor instrument transformers). Emission factors determined on the basis of reference systems are then applied to such stocks data.
- The group of operators of medium-voltage switchgear is very numerous and highly diverse. It is thus not feasible to conduct direct surveys. Manufacturers of medium-voltage switchgear have themselves taken responsibility for updating their domestic stocks data on the basis of their sales data. The emissions can be determined in that the systems are practically maintenance-free and, by definition (IEC 62271-1), require no refilling throughout their entire lifetimes. The emissions are minimal (usually, they occur only as a result of external influences), and they can be accounted for via a lump-sum emission factor (obtained via surveys of experts); the emissions rate has been set at a constant 0.1 % since 1998, since virtually all of the systems added to domestic stocks since the mid-1990s are systems that are "sealed for life" (hermetically sealed pressurised systems pursuant to IEC). In their voluntary commitment of 2005, the operators also promised to use only such systems. As a result, the impact of the few older systems that have emissions rates greater than 0.1 % has diminished. The stocks are calculated on the basis of the previous year's stocks, plus new deliveries and less decommissioned systems.

Disposal emissions

Because switchgear and controlgear have long service lifetimes (40 years), and because the first use of SF_6 dates from the late 1960s, disposal emissions were very low until 2004. For the period until 2004, therefore, the quantities of SF_6 (AD), in old switchgear and controlgear (high-voltage and medium-voltage), that were slated for disposal have been roughly estimated (at a constant 3 t/a). As of the 2005 report year, amounts for disposal from systems removal were determined precisely for the first time, by the relevant associations. This also applies to emissions from disposal, which prior to 2005 were estimated at 0.06 t.

Activity data

In the framework of the manufacturers' voluntary commitment, annual consumption by manufacturers of electrical equipments, and stocks of medium-voltage switchgear and controlgear, are reported to the Federal Environment Agency by the German Electrical and Electronic Manufacturers' Association (ZVEI), while stocks of high-voltage switchgear and controlgear, outdoor-mounted instrument transformers, gas-insulated lines and transformers are reported by the Forum network technology / network operation (FNN) in the Association for Electrical, Electronic & Information Technologies (VDE) and, since 2004, by the Association of the Energy and Power Generation Industry (VIK). Participants in the voluntary commitment jointly determine quantities of decommissioned units.

Table 208 shows the inventory data for the current year, broken down by sub-categories and with explanatory remarks. The sum total for electrical equipments for energy transmission and distribution agrees with the data in Table 2 (II)F, Sheet 2, category 2.G.1 in the CRF.

Table 208: 2020 inventory data for category 2.G.1, including relevant sub-categories

Category 2.G.1: Electrical equipments for energy transmission and distribution	Activity data			Emissions	
	Annual consumption, production	Stocks	Decommissioned	Production	Operation
			(tonnes of SF_6)		
Electrical equipments for energy transmission and distribution 2.G.1 (total), including:	**539**	**3075**	**11**	**3.3**	**5.9**
MV switchgear and controlgear *	181	1427	1.0	0.3	1.4
HV switchgear and controlgear **	287	1295	10	1.2	3.5
Other electrical equipments ***	71	353	0	1.8	1.0

IE= included in "HV switchgear and controlgear; marginal

Explanatory remarks:

* Hermetically sealed pressurised systems pursuant to IEC 62271-1 for the range 1kV through 52 kV; also known as "sealed for life" systems

** Sealed pressurised systems pursuant to IEC 62271-1 for the range above 52 kV

*** Gas-insulated transformers: marginal residual stocks in the network; (no production emissions) + high-voltage instrument transformers for outdoor installation (all emissions categories) + gas-insulated lines (GIL) (all emissions categories) + high-voltage bushings (only production emissions) + medium-voltage cast-resin instrument transformers (only production emissions) + testing of medium-voltage components (only production emissions) + 1000V capacitors (only production emissions)

4.8.1.3 Uncertainties and time-series consistency (2.G.1)

Since there are only about ten different manufacturers of electrical equipments (including bushings and instrument transformers), the consumption data, and the new-additions and decommissioned-units figures, are highly reliable. This holds all the more in that such data and figures are based on internal accounting, and that fill amounts are determined with great precision and then noted on devices' name plates. The pertinent uncertainty is in the area of ± 5 %.

Determination of emissions is more difficult, since the plants typically concerned have several different emissions sources, each quite small. Gas losses occur in filling of devices, in testing, in opening of products that fail to pass quality inspections, in product development, etc.. On the other hand, all domestic plants proceed in accordance with a standardised questionnaire that lists all possible emissions sources and that is checked for correctness during surveys. For this reason, and because there are few manufacturers (see above), the precision of data collection ultimately depends on the precision of the relevant measurements. The resulting figures lie within ±10 % of estimates.

Emissions from operations in the high-voltage sector are determined by selected operators, via monitoring of annual refilling of reference systems (refills are carried out when levels fall below 90 % of the desired charge, and the devices themselves normally display such fill requirements as soon as they occur). This method can be considered very reliable, i.e. the deviations from the actual value are about ±5 %. All surveys to date have produced similar results for emissions rates; all results are within a range from 0.55 to 0.88 %. The one-time emissions-rate peak for high-voltage switchgear and controlgear that occurred in 2004 is the result of special events. In the main, it was due to simultaneous refilling of old, older-model systems that were less well-sealed.

In the year 2000, a decrease with respect to the previous year occurred in high-voltage in-service stocks and, thus, in emissions, both of which had been increasing since 1995. For in-service stocks, the decrease amounted to over 25 t, while for emissions it amounted to 0.85 t. That decrease, which was due to trends in gas-insulated HV switchgear (GIS) (600 to 567 t), cannot be explained as the result of decommissioning removals, since the role of such removals is still insignificant. According to the association of network operators (VDN), which carried out the surveys at the time, the underlying problem is both statistical and organisational in nature. At the end of the 1990s, electricity-market liberalisation led to profound operator regrouping (through mergers and changes in ownership of various parts of companies). Along with those changes, personnel assignments relative to electrical equipments in service were repeatedly changed. As a result, it is possible that double-counting occurred in 1999, and that some operating equipment was not counted in 2000. In light of experience gained in recent years, the uncertainty today can be assumed to lie in the range of ± 5 % for high-voltage stocks.

Pursuant to the IEC, the emissions rate of 0.1 % in the medium-voltage sector is a normal rate for hermetically sealed pressurised systems.

4.8.1.4 Category-specific recalculations (2.G.1)

No recalculations were required.

4.8.1.5 Source-specific quality assurance / control and verification (2.G.1)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

As in previous years, the data for the current reporting year were reported to the Federal Environment Agency, in the framework of a voluntary agreement, by the relevant producer and operator associations and the pertinent SF_6 producer.

For the most part, quality assurance was carried out by the associations. In addition, the data are checked by the relevant Federal Environment Agency specialists upon receipt.

In 2011, the entire sector of F-gas emissions was subjected to voluntary trilateral review. Experts from England, Germany and Austria reviewed "each other's" F-gas inventories. The aims of the review were to exchange information regarding country-specific methods for preparing F-gas inventories; to learn about the institutional and legal regulations for F-gas inventories in each country; to identify obstacles for the preparation of complete, precise inventories; and to discuss differences and similarities between the various methods used to prepare F-gas inventories. The meeting helped all three countries to review their methods for relevant emission calculation. In addition, the transparency, completeness and precision of the various inventories were assessed. That review had a positive outcome, namely that Germany has a good F-gas inventory. As a result, no recommendations were issued for improvements of the German F-gas inventory.

No other data sources, apart from the data reported by the associations, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. Comparisons with other countries have revealed no requirements for improvements. The emission factors are of the same order of magnitude as the pertinent factors used in other countries.

4.8.1.6 Category-specific planned improvements (2.G.1)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.8.2 SF_6 and PFC from other product use (2.G.2)

This category comprises the applications *Military AWACS* (2.G.2.a), *Particle accelerators* (2.G.2.b), *Sound-proof glazing* (2.G.2.c), *Adiabatic properties: Automobile tyres* and *athletic shoes* (2.G.2.d), Other: *Trace gas, welding, optical glass fibres* and *medical and cosmetic applications* (2.G.2.e).

4.8.2.1 Military AWACS maintenance (2.G.2.a)

4.8.2.1.1 Category description (2.G.2.a)

SF_6 is used as an insulating medium for radar in Boeing E-3A (NAEWF; formerly, AWACS) aircraft, which are large military surveillance aircraft. It is used to prevent electrical arcing, towards the antenna, in waveguides with high voltages in excess of 135 kV. Ongoing emissions are relatively high, since SF_6 is released to equalize pressure as aircraft climb.

4.8.2.1.2 Methodological issues (2.G.2.a)

The emissions data for report years until 2001 are based on estimates that are themselves based on a survey from the year 1996. For this reason, the precision of the emissions data for the years 1997 to 2001 is lower than it is in subsequent years. For report year 2002, a new survey of consumed quantities was carried out. This showed a significant increase over relevant quantities in report year 2001. As of report year 2006, the quantities used are determined by the Federal Statistical Office (UStatG, 2005), via surveys.

For the SF_6 emissions of AWACS, an emission factor of 100 % of consumption is assumed.

The emissions decreased through 2016. Since then, they have been increasing again slightly. Data on AWACS maintenance are reported under CRF 2.H.3, since the data are confidential.

4.8.2.2 Particle accelerators (2.G.2.b)

4.8.2.2.1 Category description (2.G.2.b)

The insulating gas SF_6 is used to protect human safety and to safeguard equipment parts (to guard against burning of insulators). In relevant applications, high-voltage parts are insulated by being enveloped with the gas (which guards against electrical arc flashes between high-voltage parts and equipment walls).

In some cases, such protection can also be achieved by using other gases (such as nitrogen, nitrogen/CO_2 mixtures), by providing adequate physical distance (air insulation) or by enclosing equipment in concrete walls. The criteria entering into decisions for or against SF_6 as an insulating gas for equipment (either by itself or as an additive) include technical circumstances, design considerations and voltage levels. For this reason, the quantities of SF_6 that non-standardised equipment and components require will vary. The SF_6 charge in any given unit or system thus depends on the unit's/system's setup, and not on its size class (measured in MV, for example).

The SF_6-insulated particle accelerators in use differ in terms of size, design and function. High-voltage accelerator systems (0.3 to more than 23 MV) are used by university institutes, research groups and industry. In such high-voltage systems, the accelerator and the high-voltage source (Van de Graaff generator, or a more-compact high-voltage generator with cascaded diodes) sit within a tank that is insulated with SF_6 or an SF_6-containing mixture. In some cases, such tanks are also pressurised. Such tanks often have to be opened when equipment has to be adjusted or repaired. In such cases, the insulating gas is pumped into reserve tanks. SF_6 losses occur during such pumping, and they occur whenever overpressure valves of accelerator or reserve tanks are activated. Research accelerators, which are operated under varying conditions, have to be opened more frequently than industrially used electron accelerators do.

In industry, low-voltage devices with less than 0.3 MV are also used. In low-voltage systems, the depth to which electrons penetrate materials being processed is considerably lower than the depths occurring in connection with high-voltage systems. In industry, "electron-beam tools" are used for cross-linking of polymers, primarily polymers in cable and wire insulation. Low-voltage systems, with lower accelerator voltages, require less shielding (= smaller quantities of SF_6) than high-voltage systems do.

Yet another relevant category consists of radiation-therapy devices in medical facilities. In cancer treatments with electron or photon radiation, industrially pre-set particle accelerators are used. Such accelerators accelerate particles within waveguides that are filled with the insulating gas SF_6, which guards against electrical flashovers. Prior to 1996, CFCs were used in such equipment.

SF_6 is also used as an insulating gas in large electron microscopes (with accelerator voltages >100 kV) and in electron-beam lithography systems. Such devices, which are combined within the category "other equipment, have now been covered for the first time – for the year 2010.

In general, the following applies: The SF_6 consumption tied to initial charging and recharging of equipment, and to replacements of emission, depends on equipment size, pressure conditions and operating conditions.

4.8.2.2.2 Methodological issues (2.G.2.b)

In early 2004, Öko-Recherche, working under commission to the Federal Environment Agency, carried out a complete survey of particle accelerators within the country, with the aim of updating pertinent data, some of which date from 1996. In the process, both users and producers of the devices/systems were queried. The questions posed had to do with the quantities of SF_6 in their devices and with refills of SF_6 carried out during the last seven years.

The CSE assumes responsibility for structuring the survey. For all five relevant categories, it contains annual data on SF_6 stocks and on replacements to compensate for emissions. The emissions in question include both ongoing emissions and filling and disposal losses.

For the 2011 report year, another exhaustive survey was carried out out. For the first time, data on electron microscopes were gathered (Winfried Schwarz et al., 2012). Only small numbers of equipment changes – additions or removals, depending on the application – were seen. For this reason, constant levels of usage are assumed. Radiation therapy is an exception. In this area, the quantities used have been increasing slightly.

Table 209: SF_6 stocks in particle accelerators, in 5 application sectors, as of 1995, in t

User category	1995	2001	2003	2010	2015	2020
(1) University institutes	30.571	28.067	28.317	32.090	32.090	32.090
(2) Research institutions	19.555	19.305	19.555	13.531	13.531	13.531
(3) Industry (high-voltage)	13.750	24.422	24.422	26.575	26.575	26.575
(4) Industry (low-voltage)	1.600	1.600	1.600	1.425	1.425	1.425
(5) Institutions for radiation therapy	0.156	0.173	0.157	0.106	0.118	0.133
Total (1-5)	**65.632**	**73.817**	**73.801**	**73.727**	**73.739**	**73.755**

In most high-volume particle accelerators used for research or industrial purposes (the first three user categories), the recharge quantities, which serve as indicators of the ongoing emissions, amounted to 4.1-4.5 t per year in the years 1995 through 2003. The ongoing emissions were considerably lower in 2010. That decrease is more pronounced than is the decrease in the charges.

Table 210: SF_6 emissions from particle accelerators, broken down by five areas of application, as of 1995, in t

User category	1995	2001	2003	2010	2015	2020
(1) University institutes	1.853	1.508	1.558	1.582	1.582	1.582
(2) Research institutions	1.259	1.246	1.196	0.886	0.886	0.886
(3) Industry (high-voltage)	0.958	1.722	1.710	1.155	1.155	1.155
(4) Industry (low-voltage)	0.020	0.020	0.020	0.017	0.017	0.017
(5) Institutions for radiation therapy	0.345	0.384	0.395	0.491	0.503	0.519
Total	**4.435**	**4.880**	**4.879**	**4.131**	**4.143**	**4.159**

When tanks of high-volume high-voltage systems are opened, the SF_6 in the tanks is pumped out and then later returned to the tanks. This can entail considerable gas losses. The reported recharges also include compensations for emissions due to accidents. As a result, the emission factors in lines 1-3 fluctuate (Table 211).

Table 211: SF_6 emission factors of particle accelerators, in five areas of application, as of 1995, in % of SF_6 stocks

User category	1995	2001	2003	2010	2015	2020
(1) University institutes	6.1	5.4	5.5	4.9	4.9	4.9
(2) Research institutions	6.4	6.2	6.2	6.5	6.5	6.5
(3) Industry (high-voltage)	7.0	7.1	7.0	4.3	4.3	4.3
(4) Industry (low-voltage)	1.3	1.3	1.3	1.2	1.2	1.2
(5) Institutions for radiation therapy	222	222	252	463	426	387

According to information provided by producers, the emissions rate for small low-voltage systems in industry, in the years 1995-2003, was 1.3%. Producers also report that the emissions rate was 1.2 % in 2010, meaning that it had changed very little.

From 1995 through 2003, the radiation therapy units used in medical settings had annual emissions rates of 220 – 250 %. The high recharge requirements for such units result in that such units are opened an average of two to four times per year, for maintenance and repairs by producers, and the insulating gas escapes every times the units are opened. Service personnel regularly recharge the units in connection with maintenance and repairs. The differences in the emissions rates (annual losses per unit), for the three producers, form a factor-of-10 spread. The smaller the charge, the greater the recharge requirements – and, thus, the greater the emissions rate. For units of two of the three producers, the per-unit recharge rate remained constant between 2003 and 2010, while the rate decreased considerably for the third producer's units. In keeping with the fact that the share of small, highly emissive units, with respect to the overall unit pool, has increased markedly, the total loss rate for radiation therapy units increased considerably between 2003 and 2010, from about 250 % to about 460 %. One maker of radiation therapy units has reported having introduced a service tool, in 2006, for recycling SF_6 in the maker's units (for pumping SF_6 out of units, storing it temporarily and then re-adding it to units). According to that producer, this has considerably reduced SF_6 consumption. The emission factor has been decreasing continuously.

4.8.2.3 Sound-proof glazing (2.G.2.c)

4.8.2.3.1 Category description (2.G.2.c)

Since 1975, SF_6 has been used to enhance the soundproofing properties of multi-pane windows. In such use, the gas is inserted into the spaces between the panes. The disadvantages of such use are that it reduces windows' thermal-insulation performance and that SF6is a potent greenhouse gas. The higher priority given to thermal insulation – e.g. by the Thermal Insulation Ordinance (Wärmeschutzverordnung) – along with improved SF_6-less window technologies, have led to a reduction in use of SF6 in this application since the mid-1990s.

In Germany, sound-proof windows have been produced by numerous companies and filled with gas. Exports of assembled windows play no significant role.

Since 4 July 2007, a ban has been in force in the EU on sale of windows, for residential uses, that are filled with fluorinated greenhouse gases. As of 4 July 2008, that ban also applies to other windows. Current and future emissions in this category thus come primarily from open waste management of old windows, which is assumed to occur an average of 25 years after the windows were filled. For this reason, total emissions are expected to continue growing until the year 2020.

4.8.2.3.2 Methodological issues (2.G.2.c)

Emissions occur during filling of spaces between panes, as a result of overfilling (production emissions), during use (use emissions) and in disposal (disposal emissions). In keeping with equations 3.24 – 3.26 of IPCC-GPG (Penman et al., 2000), emissions are calculated on the basis of new domestic consumption, average annual stocks and the remaining stocks 25 years ago.

The time series for sound-proof glazing begin in 1975, since the filling quantities of the year 1975 are of relevance for emissions from stocks in 1995. These data, which were reconstructed with the help of industry experts in 1996, were published in 2004 for the first time.

Emission factors

According to expert-level information from manufacturers of windowpanes and gas-filling equipment, provided to industry experts and to a scientific institute, one-third of the SF_6 used in the process of pumping SF_6 into spaces between windowpanes escapes. The $EF_{production}$ is thus 33 %, with respect to new annual consumption.

This emission factor is obtained in the following manner: In use of both manual filling devices and automatic gas-filling presses, gas-swirling in the space between the panes cannot be avoided. As a result, the escaping gas consists not only of the air originally between the panes, it also includes an air-SF_6 mixture. More and more mixed gases escape as the filling process progresses. The gas loss, the "overfill", ranges from 20 to 60 % of the amount filled. The smaller the window concerned, the greater the overfill's relative importance. On average, i.e. throughout the entire spectrum of filled windows, of all shapes and sizes, the overcharge amounts to 50 % of the amount actually contained between the panes. This corresponds to one-third (33 %) of the relevant consumed amounts. This emission factor continues to be used, since neither filling technologies nor the range of window geometries have changed.

A DIN standard (DIN EN 1279-3, DIN 2003) specifies an upper limit of 10 per mil for annual losses of filled gas from panes' peripheral seals. This value also takes account of gas losses resulting from glass breakage in transport, installation and use, as well as from age-related increasing leakage from peripheral seals. The result is an emission factor EF_{use} of 1 % with respect to the average SF_6 stocks that have accumulated since 1975 and that are in place in year n.

Finally, disposal losses are incurred at the end of windows' service lifetimes (utilisation periods), or an average of 25 years after the windows were filled. For this reason, emissions from disposal do not have to be taken into account until the year 2000.

Since each year a window loses 1 % of its gas, with respect to the previous year's value, only part of a window's original quantity of gas is emitted when the window undergoes disposal. Since no gas collection upon disposal takes place, however, the emissions level is 100% ($EF_{disposal}$ = 1).

Activity data

The new annual consumption was determined via top-down survey (domestic sales by the gas industry).

Since the 2006 reporting year, the new-consumption data have been determined by the Federal Statistical Office via surveys of gas sellers with regard to SF_6-sales figures (UStatG, 2005).

4.8.2.4 Adiabatic behaviour – Automobile tyres (2.G.2.d)

4.8.2.4.1 Category description (2.G.2.d)

Beginning in 1984, automobile tyres were filled with SF_6 for reasons of image (the resulting improved pressure constancy is not relevant in practice). The peak consumption year was 1995. In that year, over 500 of the some 3,500 tyre-sales outlets in Germany had equipment for filling tyres with SF_6 gas. Because SF_6 is a powerfully acting greenhouse gas, many tyre dealers began filling tyres with nitrogen instead. This practice led to a considerable reduction in use of SF_6. Since 4 July 2007, a ban has been in force in the EU on sale of new automobile tyres filled with fluorinated greenhouse gases. No further emissions occur.

4.8.2.4.2 Methodological issues (2.G.2.d)

For the sake of simplicity, gas emissions during tyres' service lifetimes are not taken into account; as a result, emissions occur only when tyres are dismantled. Given an intended service lifetime of about 3 years, and the fact that there is no foreign trade with filled types, emissions follow domestic consumption for filling with a three-year time lag (Winfried Schwarz, 1996). The emissions are calculated using equation 8.19 of the 2006 IPCC Guidelines (Vol. 3).

Emission factors

The very small losses incurred in filling of tyres are not taken into account. Since SF_6 escapes completely when tyres are dismantled, $EF_{disposal} = 1$.

Activity data

Annual sales have been determined via surveys, carried out by the Federal Statistical Office (UStatG, 2005), of gas suppliers, regarding their domestic sales to tyre dealers and automobile service centres.

4.8.2.5 Adiabatic behaviour – Athletic shoes (2.G.2.d)

4.8.2.5.1 Category description (2.G.2.d)

SF_6 was inserted into the soles of sport shoes in order to enhance cushioning. 2003 was the last year in which this practice occurred anywhere in Europe. As of 2004, PFC-218 (C_3F_8) was used in this application. Use of that gas was then discontinued in 2006. Today, nitrogen is usually used for this purpose. The sale of footwear produced with fluorinated greenhouse gases has been prohibited in the EU since 4 July 2006. No further emissions occur.

4.8.2.5.2 Methodological issues (2.G.2.d)

The emissions were calculated using equation 8.9 of the IPCC Guidelines (2006). Production emissions occurred only in foreign countries. Current emissions were not determined. In keeping with a commitment to maintain confidentiality, data relative to athletic-shoe soles are reported under CRF 2.H.3.

Emission factors

Manufacturers have not reported production emissions.

It is assumed that no emissions occur during use.

In disposal, emissions may be equated with input quantities ($EF_{disposal}$ = 1). In addition, in a procedure similar to the IPCC method for automobile tyres, a time lag of three years is assumed (IPCC (2006a): Vol. 3, Equation 8.19).

Activity data

The filled quantities are based on manufacturers' European-wide sales figures. These figures are broken down, on the basis of Germany's population, to obtain figures for Germany. While such data have been available to the Federal Environment Agency since the 2001 report year, for reasons of confidentiality they are reported only in aggregate form, under CRF 2.H.3.

4.8.2.6 Other: Trace gas (2.G.2.e)

4.8.2.6.1 Category description (2.G.2.e)

SF_6, as a stable and readily detectable trace gas, even at extremely low concentrations, is used by research institutions to investigate a) ground-level and atmospheric airflows and gas dispersions and b) water currents. It is also used for the purpose of testing laboratory fume hoods.

As of report year 2007, use of SF_6 as a trace gas was reduced considerably with respect to earlier years.

4.8.2.6.2 Methodological issues (2.G.2.e)

The quantities used have been estimated by experts.

Emission factors

An "open use" is assumed, i.e. annual new inputs are completely emitted in the same year and are treated as consumption for production ($EF_{production}$ = 1). No recovery takes place.

Activity data

In 1996, total domestic use was estimated by experts of all relevant research institutions. Since then, use levels have been estimated by one expert at three-year intervals. These assessments indicate that the quantities used vary only slightly. The figures on use of SF_6 in the years 2007 through 2015 were upwardly corrected in 2017, to take account of first-time inclusion, in the inventory, of use of SF_6 for testing of laboratory fume hoods.

4.8.2.7 Other: Welding (2.G.2.e)

4.8.2.7.1 Category description (2.G.2.e)

According to gas suppliers, use of SF_6 in welding began in 2001. SF_6 is used as a protective gas in welding of metal. Since there is only one user in Germany, the pertinent data are subject to confidentiality protection.

4.8.2.7.2 Methodological issues (2.G.2.e)

Emissions occur only during use. Because they are confidential, data on consumption and emissions in connection with welding are reported under CRF 2.H.3.

Emission factors

No reliable data are available on SF_6 decomposition during use. Experts presume that the entire relevant input SF_6 quantities are emitted completely into the atmosphere during use. For this reason, consumption and emissions are considered equal for welding applications. The emission factor for welding is specified as EF_{use} = 1.

Activity data

The annual amounts consumed are determined via enquiry of the company that uses SF_6 for welding purposes.

4.8.2.8 Other: Optical glass fibre (2.G.2.e)

4.8.2.8.1 Category description (2.G.2.e)

Use of SF_6 in production of special optical glass fibre began in 2002. In such production, SF_6 is used for fluorine doping. Only a few production operations are in place in Germany.

4.8.2.8.2 Methodological issues (2.G.2.e)

Because the emission factor is based on confidential data, the emissions related to production of optical glass fibres are reported confidentially in CRF 2.H.3.

Emission factors

The 2006 IPCC-Guidelines (IPCC (2006a): Vol. 3) contain no information on use of SF_6 in production of optical glass fibre. To date, experts have estimated the emission factor to be 70 % ($EF_{production}$ = 0.7). Measurements have yielded a considerably lower emission factor, however. For this reason, the emission factor has been reduced considerably. It is confidential, however. In 2018, the time series for the emissions was recalculated retroactively, for all years.

Activity data

The annual consumption figures are obtained via surveys, carried out by the Federal Statistical Office (UStatG UStatG, 2005), of gas suppliers, with regard to their domestic sales. They have been increasing since 2001, with slight fluctuations.

4.8.2.9 Other: Medical and cosmetic applications (2.G.2.e)

4.8.2.9.1 Category description (2.G.2.e)

In Germany, fluorinated greenhouse gases, in addition to being used in medical metered dose inhalers (source category 2.F.4), are also used in various medical and cosmetic applications.

Since 2000, perfluorodecalin ($C_{10}F_{18}$, PFC-9-1-18) has been used, in pure form, in ophthamology and in research. In ophthamology, perfluorodecalin is used in retinal surgery within the eye, especially in treatment of retinal detachments, retinal tears, proliferative vitreoretinopathy, etc.. Perfluorodecalin is also used, in considerably smaller quantities, in research into organ preservation during transplants, as a contrast agent in diagnostic imaging techniques (magnetic resonance tomography, ultrasound) and as an oxygen carrier in cell cultivation.

Since 2012, perfluorodecalin has also been used as an ingredient in cosmetic products (skin care; nail care). In such products, it serves as a carrier or storage medium for oxygen. The perfluorodecalin concentrations used in such products, according to manufacturers, amount to 0.1 %.

In Germany, hydrofluoroethers (HFE) are the standard anaesthetic gases used for inhalative anaesthesia. They are used in some 9 million operations annually. Isoflurane, a halogenated ether (HCFE-235da2, CHF_2-O-CHCl-CF_3), has been used since 1985. Desflurane (HFE-236ea2, CHF_2-O-CHF-CF_3) and sevoflurane (HFE-347mmz1, CH_2F-O-$CH(CF_3)_2$, which have been used since 1995, currently have a combined market share of about 90 %. In relevant uses, the hydrofluoroethers are vaporized in special equipment. They are administered in concentrations of 1 % to 6 % in a carrier gas consisting of oxygen and nitrous oxide (N_2O). On average, 8.2 g of isoflurane, 32.6 g of desflurane or 11.4 g of sevoflurane are used per operation. The quantities of the various hydrofluoroethers that are used per operation vary, because the concentrations of narcotic gases – as provided through respirators, and along with carrier gases – needed to ensure proper anaesthetic effects differ widely.

As recommended by the 2006 IPCC Guidelines, medical and cosmetic applications of PFCs are placed in source category 2.G.2.

4.8.2.9.2 Methodological issues (2.G.2.e)

In ophthamological and research applications in which it is used in pure form, all of the perfluorodecalin used is emitted. The perfluorodecalin in cosmetic products is also emitted completely when the products are used (EF_{use} = 1).

Hydrofluoroethers used as inhalation anaesthetics are collected during operations and then vented into the atmosphere from central points. During operations, the various hydrofluoroethers that patients inhale are not exhaled in unchanged form; to some extent, and to varying degrees, they are metabolised in patients's bodies. In each case, the gas-specific emission factors amount to 100 % minus the applicable metabolisation rate.

No production emissions occur in the case of medical and cosmetic applications, since no relevant products are produced in Germany.

In the case of perfluorodecalin, the emissions from use are calculated, using Equation 2, via the quantities of perfluorodecalin sold in bulk and in cosmetic products. In a departure from the method proposed by the 2006 IPCC Guidelines for calculation of "prompt emissions" (equation 8.23), it is assumed that all of the quantities sold in a given year are emitted completely in the same year, i.e. the emissions are not calculated as the sum of half the purchases (sales) of the previous year and half the purchases (sales) of the current year. This approach is justified in that the time between sale and use tends to be very short.

Emissions from use of hydrofluoroethers used as anaesthetic gases are calculated with Equation 2, via the quantities used in Germany. The 2006 IPCC Guidelines provide no instructions for calculating such emissions.

Since the perfluorodecalin and the hydrofluoroethers are emitted completely when used, no disposal emissions have to be reported.

Because they are confidential, data on consumption and emissions in connection with perfluorodecalin are reported under CRF 2.H.3.

Emissions of hydrofluoroethers are not subject to reporting obligations. Germany voluntarily reports HFE emissions pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), under "additional greenhouse gases". Those emissions are aggregated with other emissions that are not subject to reporting obligations, and they are listed in Chapter 4.9.3 under CRF 2.H.3.

Emission factors

The emission factors used have been obtained from opinions provided by experts; they are listed in Table 207.

The EF_{use} for all medical and cosmetic applications of perfluorodecalin is 100 %.

With regard to the hydrofluoroethers used as inhalation anaesthetics, the EF_{use} for isoflurane and desflurane is 99.8 %, and for sevoflurane it is 95 %.

In agreement with the IPCC specifications (2006 IPCC Guidelines, p. 8.32), a 100 % emissions level for use of perfluorodecalin (EF_{use} = 100 %) is assumed. In a departure from the Guidelines, Germany applies a product lifetime of only one year in this area.

The 2006 IPCC Guidelines do not provide any instructions relative to the use of hydrofluoroethers as inhalation anaesthetics.

Activity data

The annual imports of $C_{10}F_{18}$ to Germany, for use in ophthamology and research, were disclosed by the manufacturer F2 Chemicals, UK, on a confidential basis.

The quantities of cosmetic products containing $C_{10}F_{18}$ that are imported to Germany were disclosed, on a confidential basis, by the trading enterprise P2 cosmetics, which sells the products in Germany.

The quantities of hydrofluoroethers that are used as inhalation anaesthetics were determined via surveys of industry experts (hospitals, manufacturers of anaesthesia equipment), and with the help of literature references, in the framework of a research project (Gschrey et al., 2015).

4.8.2.10 Uncertainties and time-series consistency (2.G.2 all)

The uncertainties for this source category have been systematically quantified.

In the case of sound-proof glazing, since 2006 data from the top-down survey of annual new consumption, carried out on the basis of commercial sales data, have been compared with data from the Federal Statistical Office's pertinent annual surveys (UStatG, 2005). This procedure, which may be considered reliable and complete, has increased data reliability. Due to the wide range of influencing factors, the $EF_{production}$ cannot be measured reliably. Estimates resulting from a survey of ten industry experts, conducted in 1996 and 1999 (the experts represented window manufacturers, suppliers of filling devices and one scientific institute), indicate that the mean filling loss ranges between 30 % and 40 %. A 1 % rate is considered realistic for ongoing gas losses.

With regard to athletic shoes, the filled-quantities breakdown, by Member States, is subject to considerable uncertainties, in spite of the good quality of the data for the EU.

In the case of medical applications, the data on the quantities of perfluorodecalin used are considered to be of good quality, since they were obtained directly from the manufacturer (F2 Chemicals Ltd, UK), and since that manufacturer is the sole exporter of perfluorodecalin to Germany. The uncertainties relative to cosmetic products are larger, since Germany's market for cosmetics is extremely dynamic, with the result that no reliable statistics for this purpose are available.

4.8.2.11 Category-specific quality assurance / control and verification (2.G.2 all)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The data for the current reporting year, like the data for most of the previous years, consist of data collected by an external expert working in the framework of a research project under commission to the Federal Environment Agency and of data collected in a survey of the Federal Statistical Office (UStatG, 2005).

For the most part, quality assurance was carried out by an external expert and by the Federal Statistical Office. In addition, the data are checked by the relevant Federal Environment Agency specialists upon receipt.

In 2011, the entire sector of F-gas emissions was subjected to voluntary trilateral review. Experts from England, Germany and Austria reviewed "each other's" F-gas inventories. The aims of the review were to exchange information regarding country-specific methods for preparing F-gas inventories; to learn about the institutional and legal regulations for F-gas inventories in each country; to identify obstacles for the preparation of complete, precise inventories; and to discuss differences and similarities between the various methods used to prepare F-gas inventories. The meeting helped all three countries to review their methods for relevant emission calculation. In addition, the transparency, completeness and precision of the various inventories were assessed. That review had a positive outcome, namely that Germany has a good F-gas inventory. As a result, no recommendations were issued for improvements of the German F-gas inventory.

No other data sources, apart from the data provided by the Federal Statistical Office, the data collected by the research contractor and the data reported by the pertinent companies, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. Comparisons with other countries have revealed no requirements for improvements. The emission factors either are in keeping with the default emission factors given by the 2006 IPCC Guidelines or are of the same order as the values used by other countries.

The methods and data relative to medical and cosmetic applications (sub-category 2.G.2.e) cannot be verified, since no countries other than Germany report emissions in this area.

4.8.2.12 Category-specific recalculations (2.G.2 all)

The data on domestic consumption of hydrofluoroethers used as anaesthetic gases are determined on the basis of national data on operations on people. Recalculations are required annually, since the pertinent national statistics become available, in each case, only after data collection for the inventory has concluded. This regularly leads to changes in emissions from use for the relevant previous year. Since hydrofluoroethers are among the substances that are reported on a voluntary basis, no further quantification is carried out.

4.8.2.13 Planned improvements, category-specific (2.G.2 all)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.8.3 Use of N_2O (2.G.3)

4.8.3.1 Category description (2.G.3)

The German nitrous oxide market is dominated by Air Liquide, Linde AG and Westfalen AG, all of which are leading producers as well as importers. No nitrous oxide emissions occur in nitrous oxide production and in filling of the gas into gas bottles. Emissions occur solely in use of the gas. Medical applications represent the most important N_2O-emissions source. Other emissions sources include use of laughing gas as a propellant in whipped-cream aerosol cans and use in the semiconductor industry. N_2O is also released, in small amounts, in blasting. Nitrous oxide emissions in anaesthesia, a predominant emissions source since 1990, have been decreasing sharply, due to increasing use of intravenously administered anaesthetics instead of nitrous oxide. This trend is expected to continue.

Medicine – anaesthesia

In medicine, nitrous oxide, a gas with analgesic properties, is used for anaesthetic purposes. In such applications, nitrous oxide is mixed with pure oxygen, to produce an active gas mixture consisting of 70 % nitrous oxide and 30 % oxygen. In modern anaesthesia, the effects of nitrous oxide are enhanced through addition of other anaesthetics. While medical use of N_2O is not prohibited, there is strong resistence – especially in the German medical sector – against widespread, general use of the substance. Medical use of laughing gas has thus been decreasing continuously since 1990.

Food industry – whipped-cream aerosol cans

In the food industry, nitrous oxide is used as an additive known as "E 942". Foods sold in pressurised containers are extracted from such containers with the help of propellants. As it exits such a container, a food takes on either a foamy or a creamy consistency, depending on what type of food it is. The foods with added N_2O include whipped cream (in aerosol cans), quark (curd) and various desserts, such as ready-made puddings (Die Verbraucher Initiative e.V. (2005); Linde Gas (2017)).

Semiconductor manufacturing

A wide range of different chemicals and gases is used in semiconductor production. Argon, ultra-pure oxygen, hydrogen, ultra-pure helium and nitrogen account for the lion's share of the gases used. Consumption of special process gases, such as nitrous oxide, ammonia and hexafluoroethane, is relatively low.

Explosives

Explosives are used in both military and industrial contexts. Civil and commercial explosives are used in mining, in construction in rocky terrain, in demolition, in geology and in fireworks.

Nitrous oxide emissions occur primarily in detonation of explosives that contain ammonium nitrate, such as ANFO (ammonium nitrate / fuel oil) and emulsion explosives. In general, commercial / civil explosives consist to some 60 to 80 % of ammonium nitrate (AN). By contrast, Andex, an ANFO explosive, contains up to 94 % ammonium nitrate.

In Germany, two companies produce explosives for civil use: Orica Mining (formerly Dynamit Nobel) and Westpreng GmbH (Wasag Chemie).

While no nitrous oxide emissions occur in manufacturing of explosives, nitrous oxide can form in thermal decomposition of explosives. The reason for this is that ammonium nitrate (AN) forms nitrous oxide (laughing gas) and water as it decomposes thermally.

Under careful warming to a temperature above the melting temperature, the reaction is as follows:

$$NH_4NO_3 \longrightarrow N_2O + 2H_2O$$

But in a fast, detonative reaction of an AN-containing explosive, the reaction occurs as follows:

$$NH_4NO_3 \longrightarrow 2H_2O + N_2 + 0{,}5O_2$$

This means that under high pressure and temperature AN primarily forms nitrogen, oxygen and water as it reacts. Only a small concentration of primarily formed N_2O remains intact in the detonation process. For example, detonation clouds of amatols[86], which contain some 80 % AN, have only 0.1 mole N_2O per mole of ammonium nitrate. From this figure, a theoretical maximum, for nitrous-oxide formation, of about 68 g (this figure was provided by an explosives expert; the stoichiometric value would be 44 g/mole amatol (80%-AN)) per kilogramme AN can be calculated ((Ornellas, 1982); Volk (1986): page 74). According to experts, this AN-content figure can be used as a basis for assumptions regarding N_2O emissions for other explosives.

[86] Amatol x/y : military explosives. pourable mixtures, generally consisting of x % TNT and y % ammonium nitrate

N_2O in automobile tuning

In automotive technology, nitrous oxide is used to improve combustion in gasoline / petrol engines, via so-called "laughing-gas injection". In the process, laughing gas is broken down into nitrogen and oxygen. The nitrogen cools the combustion process, and the oxygen increases the combustion power. This "tuning" tactic can quickly increase engine performance. To date, one company in Germany offers such tuning measures. Research has shown that the equipment used for such tuning is designed to consume the input laughing gas completely, without producing significant emissions.

4.8.3.2 Methodological issues (2.G.3)

Anaesthesia

The 1990 figure for N_2O emissions from medical applications is based on an extrapolation of a statistical plant survey conducted in 1990 in the territory of the former GDR. At the time, it was ascertained that one plant for the production of N_2O for anaesthetic purposes had existed in the former GDR. Also at the time in question, the plant had not yet been operational for long (it was constructed in 1988). The annual production capacity was approximately 1,200 t. Research indicated that there were no exports or imports of this substance, and thus it was assumed that all of the substance was used for domestic consumption. Via the per-capita emissions calculated from this for the former GDR, and assuming identical conditions, N_2 emissions of 6,200 t were estimated, as a rough approximation, for Germany in 1990. The N_2O figure for 2001 was obtained via a written memorandum, dating from 2002, of the Industriegaseverband e.V. (IGV) industrial-gas association. That figure was tied to a range of 3,000 ~ 3,500 t/a. The mean value from that range (3,250 t/a) was then used for generation of an N_2O-emissions time series.

Since 2005, the Industriegaseverband (IGV) industrial-gas association has carried out surveys of N_2O sales for all applications in Germany. In addition, the IGV has made the data from those surveys available to the Federal Environment Agency for reporting purposes. In 2010, the IGV entered into a voluntary agreement, with the Federal Ministry of Economics and Technology (BMWi), regarding annual provision of N_2O-sales data for purposes of emissions reporting.

The gaps in the data relative to uses in anaesthesia are closed via interpolation and extrapolation.

The pertinent emission factor is 100 %.

Whipped-cream aerosol cans

Use of N_2O in aerosol cans for whipped cream, in Germany, has to be carefully differentiated. In Germany, there is one maker of aerosol cans for whipped cream. That maker also fills the cans in Germany. In emissions calculations, it is assumed, on the basis of the above-described research, that that company accounts for a share of about 3 % of the laughing-gas sales of the IGV industrial-gas association. Most of the companies who deal with such aerosol cans have them filled abroad and then import them into Germany. The relevant sales of such companies are thus not included in the data of the IGV industrial-gas association. The MIV dairy-industry association has reported to the Federal Environment Agency the results of a one-time survey that showed that 50.2 million units of whipped-cream aerosol cans were sold in 2008. At the same time, the MIV association reported that the units involved vary in size, and that it is not possible to break the figures down by can sizes. Internet research showed that pressurized cartridges for this area are sold in Germany: cartridges with 8g of N_2O, for 0.5l (whipped-cream) cans, and cartridges with 16g of N_2O, for 1.0l cans. Comparison calculations have shown that 8g of N_2O is a safe approximation, for purposes of calculation, for the amount of laughing gas contained per sold unit (whipped-cream aerosol can). That, in turn, leads to an input figure of 401.6 t N_2O for whipped-cream aerosol cans in 2008 in Germany. Since no pertinent data are available for the years prior to 2008, that value is assumed to be constant.

The emission factor for whipped-cream aerosol cans is assumed to be 100 %.

Semiconductor manufacturing

On a one-time basis, the German Electrical and Electronic Manufacturers' Association (ZVEI) has provided information on quantities of laughing gas used (**activity data**) in the years 1990, 1995, 2000, 2001 and 2008. Values between those points are obtained via interpolation.

A wide range of different chemicals and gases is used in semiconductor production. Argon, ultra-pure oxygen, hydrogen, ultra-pure helium and nitrogen account for the lion's share of the gases used. Special process gases, such as nitrous oxide (dinitrogen monoxide) and ammonia, are used only in relatively small amounts, and the amounts involved have remained nearly constant over the past few years (AMD Saxony LLC&Co. KG, Dresden, Umweltbericht (environmental report) 2002/2003, (AMD, 2003): page 16).

Since 2020, the **emission factor** is no longer confidential. But since the pertinent N_2O emissions data are kept confidential, in order to ensure that data on emissions of dodecanedioic acid remain confidential, we are unable to provide details here.

In 2020, the German Electrical and Electronic Manufacturers' Association (ZVEI) retroactively reported the emissions data through 2015. That annual report has been made within the framework of an agreement aimed at assuring the long-term availability of the pertinent emissions data.

Explosives

In 2003, a total of 59 kt of explosives was produced in Germany. Of that figure, 13 kt were exported abroad, and 5.8 kt were imported into Germany[87]. Those figures, in turn, yield a figure of 51.8 kt for the amount of explosives used in Germany. Of that amount, ANFO accounts for a share of 60 %, emulsion explosives account for 25 % and dynamite explosives account for 15 %. ANFO explosives consist of 94 % ammonium nitrate and 6 % fuels. The corresponding relationship for emulsion explosives is 80 % to 20 %; for dynamite explosives, it is 50 % to 50 %.

At present, the quantities of nitrous oxide present in detonation clouds are not determined, while the pertinent quantities of NO and NO_2 are determined.

Normally, N_2O formation plays a significant role only in explosives that contain ammonium nitrate (AN). That said, no precise analyses of detonation clouds of ANFO explosives have been carried out. For this reason, it must be assumed that the N_2O concentrations formed upon detonation of ANFO are similar, with regard to AN content, to those formed upon detonation of amatols and ammonites[88], for which analyses have been carried out that support relevant estimates. The following result has been obtained: upon detonation, amatoles and ammonites form about 0.1 mole N_2O per mole of ammonium nitrate (AN).

According to the *Federal Office for Material Research and Testing* (BAM), levels of explosives use in Germany remained constant from 1990 to 2005.

[87] Personal communication: Federal Office for Material Research and Testing (BAM).

[88] Ammonite: Composition: 70-88 % ammonium nitrate, with 5-20 % nitroaromates, 1-6 % vegetable flour and, in some cases, 4 %
nitroglycerine, aluminium powder and potassium perchlorate

The emission factor for use of explosives is 0.1036 kg N_2O/t explosives. That emission factor was determined, via measurement, by the BAM in February 2010. As a result, the emission factor has been downwardly corrected, considerably, with respect to the 2010 submission.

For anaesthesia, whipped-cream aerosol cans and the semiconductor industry, the pertinent emissions are reported in aggregation with confidential emissions data from 1,12-dodecanedioic acid production (2.B.10).

4.8.3.3 Uncertainties and time-series consistency (2.G.3)

Since 2005, activity data for anaesthetic uses have been obtained from association information. For that reason, the uncertainty is estimated at 20 %. The data on consumption for whipped-cream aerosol cans and explosives are subject to a very high level of uncertainty (75 %), since the relevant calculations are based on several assumptions and since a definite figure is available only for one year. The uncertainty of the activity data for the semiconductor industry is estimated at 10 %, since the data have been obtained from facility operators themselves. For the uncertainties applying to the explosives, the IPCC default value of +/- 75 % is used.

The uncertainty in the emission factors for anaesthesia and whipped-cream aerosol cans is set as 0 %, since at present it is assumed that N_2O undergoes no transformation in use, and that the gas thus escapes completely into the atmosphere following its use. The emission factor for use in semiconductor manufacturing is estimated to have an uncertainty of 15 %, since the data have been obtained from facility operators themselves. The emission factor for explosives is estimated to have an uncertainty of 5 %, since the emission factor has been determined via an official measurement.

With these results, the time series can be considered to show a normal type of distribution.

4.8.3.4 Source-specific quality assurance / control and verification (2.G.3)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

With regard to use in anaesthesia, a comparison with other countries shows that most other countries use an emission factor of 1.0, as Germany does. That figure is equivalent to the default value in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 3, p. 8.36).

With regard to nitrous oxide emissions from use of explosives, no comparisons with other comparison or data sources are possible, since Germany is the only country that reports such emissions.

The quantities of nitrous oxide used cannot be verified via other data sources, since no other data are available that would support such verification. A special survey was carried out in order to obtain the data for the present report.

4.8.3.5 Category-specific recalculations (2.G.3)

No recalculations are required.

4.8.3.6 Planned improvements, category-specific (2.G.3)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.8.4 Other product manufacture and use: Other – ORC systems (2.G.4 ORC systems)

4.8.4.1 Category description (2.G.4 ORC systems)

Fluorinated greenhouse gases have been used in ORC systems in Germany since 2003. They are reported in category 2.G.4.

The Organic Rankine Cycle (ORC) is used for generating electricity from heat sources with temperatures and pressures that are too low for steam-powered generation . ORC systems are used especially in geothermal power generation and in harnessing of waste heat from combined heat and power (CHP) stations and biogas plants.

The working media used in the ORC cycle are certain organic substances, such as HFCs, PFCs, hydrocarbons and silicone oils, that evaporate at lower temperatures than water does. In ORC systems, such working media evaporate and drive turbines, just as steam drives turbines in conventional power stations. The largest fill quantities, far and away – up to 75 tonnes of fluorinated working media in each case – are used in geothermal applications. Considerably smaller fill quantities (0.2 to 0.6 tonnes) are used in systems that harness waste heat from biogas plants and in compact combined heat-and-power (CHP) generating systems.

In Germany, C_5F_{12} was first used as a working medium – in an ORC pilot system – in 2003. That system was decommissioned in 2010. HFC-134a was used for the first time in an ORC system in 2008. Use of HFC-245fa as a working medium began in 2010. Beginning 2011, several systems were commissioned that operate with HFC-245fa and with the working medium "Solkatherm", which consists of HFC-365mfc (65 %) and a perfluorinated polyether (PFPE) with the trade name "Galden" (35 %).

4.8.4.2 Methodological issues (2.G.4 ORC systems)

Emissions from ORC systems occur during filling, operation and disposal.

Production emissions are determined via new domestic consumption – the activity data – and calculated pursuant to Equation 1.

Emissions from use are determined on the basis of final quantities (i.e. in systems) of working media – the activity data – and via multiplication by the EF_{use}, in keeping with Equation 2.

Disposal emissions refer to new additions for the year that is x years (depends on product lifetime) prior to the current reporting year n. They are calculated pursuant to Equation 3.

Apart from one exception, disposal emissions have not begun playing any role yet, since most systems are new. Large ORC systems in geothermal applications are expected to have a useful lifetime of 30 years, while smaller systems are expected to have lifetimes of 20 years.

Emissions of the perfluorinated polyether "Galden" are not subject to reporting obligations. Germany voluntarily reports emissions of this substance pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), under "additional greenhouse gases." Those emissions are aggregated with other emissions that are not subject to reporting obligations, and they are listed in Chapter 4.9.3 under CRF 2.H.3.

Emission factors

The emission factors used have been obtained from opinions provided by experts; they are listed in Table 207.

The filling loss is 2 %. It is country-specific, since ORC systems are not covered by the 2006 IPCC Guidelines and thus no default factors are yet available.

The emissions from use are estimated to be 4 %. In this area as well, the 2006 IPCC Guidelines provide no specifications.

Under the current technological state of the art, the emission factor for disposal is 20 %. That value is also country-specific.

Activity data

ORC systems are a new area of application for fluorinated greenhouse gases, an area for which little data and technical information has been gathered to date. Almost all of the data used, therefore, are based on information provided by producers and operators of ORC systems. The data were determined through expert-level discussions (Gschrey et al., 2015).

4.8.4.3 Uncertainties and time-series consistency (2.G.4 ORC systems)

The uncertainties for the "ORC systems" sub-category have been systematically quantified.

The data on the quantities used are considered to be of good quality overall. Germany has only a small number (fewer than 10 companies) of manufacturers and sellers of ORC systems with florinated working media, and the country's market is relatively small. The data on the quantities of HFC-245fa and Solkatherm (HFC-365mfc and PFPE) that are used annually are of good quality, since the data come directly from the manufacturers of these working media (Honeywell und Solvay Solexis), and these companies are the only sellers who export to Germany.

The emission factors are subject to considerable uncertainties. Since sales of ORC systems in Germany began only a few years go, no pertient, solid empirical studies have been carried out to date. The values are based on estimates provided by operators of such systems.

4.8.4.4 Category-specific quality assurance / control and verification (2.G.4 ORC systems)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The data for the 2003 report year, like the data for most of the previous years, were collected by an external expert working in the framework of a research project under commission to the Federal Environment Agency.

For the most part, quality assurance was carried out by an external expert. In addition, the data are checked by the relevant Federal Environment Agency specialists upon receipt.

No other data sources, apart from the data collected by the research contractor, are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. No comparisons with other countries are possible, since no other countries report emissions from ORC systems. Neither can the emission factors be compared. The 2006 IPCC Guidelines provide no default emission factors, and thus no comparability is available in this area as well.

4.8.4.5 Category-specific recalculations (2.G.4 ORC systems)

The HFC-245fa-charge quantities for the years 2018 and 2019 were updated on the basis of information provided by producers. This led to the changes shown in Table 212 in emissions from production and use of HFC-245fa in those years.

Table 212: Overview of the recalculation-related changes in emissions (EM) of HFC-245fa in the sub-category ORC systems (2.G.4), in the years 2018 and 2019

	Units	2018	2019
EM HFC-245fa			
2022 Submission	t CO_2eq	10,373	10,818
2021 Submission	t CO_2eq	9.767	10,164
Difference	t CO_2eq	605	654

4.8.4.6 Planned improvements, category-specific (2.G.4 ORC systems)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.8.5 Other product manufacture and use: Other – Container fumigation (2.G.4 Container fumigation)

4.8.5.1 Category description (2.G.4 Container fumigation)

Since 2004, the fluorinated greenhouse gas sulphuryl difluoride (SO_2F_2) has been used in Germany for pest-control fumigation of containers with roundwood exports, and as a substitute for the ozone-depleting substance methyl bromide, the use of which has been prohibited for many years. In such applications, wood in containers is fumigated with the pesticide *ProFume®*, which contains sulphuryl difluoride as an active ingredient. All of the pesticide so used is released as an emission.

For many years, the utilized quantities and emissions of SO_2F_2 remained at a constant, high level. Recently, they have increased sharply, however, in keeping with growing roundwood exports tied to the nationwide droughts, and heavy bark-beetle infestation in spruce forests, that occurred in Germany in the years 2018 through 2020.

As a powerful greenhouse gas, sulphuryl difluoride has a high degree of environmental relevance. Because of this relevance, and because use of this substance has increased sharply, both domestically and globally, Germany is now reporting this substance voluntarily, as of reporting year 2020, in category 2.G.4.

4.8.5.2 Methodological issues (2.G.4 Container fumigation)

Emissions occur only during use of the substance, i.e. during fumigation of roundwoods in containers. They are determined by multiplying the new domestic consumption, the activity data, by the EF_{Use} pursuant to Equation 2.

Emissions of sulphuryl difluoride, which is not subject to reporting obligations, are reported voluntarily pursuant to the recommendations of the 2014 UNFCCC Reporting Guidelines (FCCC/CP/2013/10/Add.3, Decision 24/CP.19), under "additional greenhouse gases". Those emissions are aggregated with other emissions that are not subject to reporting obligations, and they are listed in Chapter 4.9.3 under CRF 2.H.3.

Emission factors

The emission factor used has been obtained via consultation with experts. It is listed in Table 207.

Under the current state of the art, the emission factor for use is 100 %, since no waste-gas scrubbing has been carried out to date in connection with this substance. This value is country-specific, since container fumigation is not listed in the 2006 IPCC Guidelines, meaning that no default factor is available.

Activity data

The utilized-quantity data are taken from annual statistics of the Federal Office of Consumer Protection and Food Safety (BVL) on sales of sulphuryl difluoride as an active ingredient for pesticides in Germany (BVL, 2022).

4.8.5.3 Uncertainties and time-series consistency (2.G.4 Container fumigation)

The uncertainties for the "container fumigation" sub-category have been systematically quantified.

The quality of the data on the quantities used are considered to be of good quality overall, since they are taken from official statistics of the BVL.

The emission factor is subject to considerable uncertainty. Since usage of SO_2F_2 began only a few years ago, no well-founded empirical studies have yet been carried out. For this reason, a conservative approach is used whereby emission of the substance is assumed to be complete.

4.8.5.4 Category-specific quality assurance / control and verification (2.G.4 Container fumigation)

For the most part, quality assurance was carried out by UBA experts.

No other data sources are available for review of the F-gas quantities determined for emissions reporting purposes, i.e. for review that would serve as a basis for verification. No comparisons with other countries are possible, since no other countries report emissions from container fumigation. Neither can the emission factors be compared. The 2006 IPCC Guidelines provide no default emission factors, and thus no comparability is available in this area as well.

4.8.5.5 Category-specific recalculations (2.G.4 Container fumigation)

No recalculations are required.

4.8.5.6 Planned improvements, category-specific (2.G.4 Container fumigation)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.8.6 Other product manufacture and use: Other, charcoal use (2.G.4 Charcoal)

4.8.6.1 Category description (2.G.4 Charcoal)

In this category, CO_2, CH_4, N_2O and particulate emissions from use of charcoal for barbecuing are reported.

Only small quantities of charcoal are produced in Germany – by one major charcoal-factory operator and in a number of demonstration charcoal kilns. The pertinent quantities are determined by the Federal Statistical Office (STBA) and are subject to confidentiality requirements. Use of charcoal is reported under 1.B.1b.

Apart from a downturn in 2008 that was tied to an economic slowdown, charcoal consumption increased continuously in the years 1990 through 2012. Since then, it has leveled off. The great majority of the charcoal used is imported. In 2020, charcoal consumption decreased by about 30% in comparison to previous years.

4.8.6.2 Methodological issues (2.G.4 Charcoal)

The calculation model is based on the assumption that all calculation method is consumed within a year of its purchase and is burned completely.

The CO_2, CH_4 and N_2 emissions are calculated via a Tier 1 method.

Activity data

The production-quantity data, and the data on the imported and exported quantities of charcoal, for the years as of 1996, were obtained from the Federal Statistical Office ((Statistisches Bundesamt, FS 4, R 3.1), Produzierendes Gewerbe, Produktion im Produzierenden Gewerbe sowie der Außenhandelsstatistik ("manufacturing industry; production in the manufacturing industry and foreign-trade statistics").

The quantities consumed are calculated in keeping with the formula Production + Imports – Exports.

For the years 1990 through 1995, the quantities consumed are calculated from the per-capita consumption, which has been derived from the data for the years 1996 through 2013. In the process, it is assumed that consumption also grew linearly in those (earlier) years.

Emission factors

Since import and export data are published, no exact emission factors for CO_2, CH_4 and N_2O may be given, for reasons of confidentiality. It may be disclosed, however, that the relevant emission factors are comparable to the emission factors that can be derived from the 2006 IPCC Guidelines.

Each emission factor is applied to the entire time series.

4.8.6.3 Uncertainties and time-series consistency (2.G.4 Charcoal)

A Tier 1 method, with emission factors similar to those provided by the 2006 IPCC Guidelines, has been used, and thus that source's relevant uncertainties for the activity data and emission factors apply (IPCC (2006a): Vol. 3, Ch. 5).

4.8.6.4 Category-specific quality assurance / control and verification (2.G.4 Charcoal)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

No other data, apart from the data provided by the Federal Statistical Office, are available for review of the relevant import, export and production quantities, for purposes of verification of the consumption-quantity data. The import and export figures were compared with the corresponding data of EUROSTAT. Its figures show good agreement with the figures the Federal Statistical Office has provided to EUROSTAT. It was not possible to compare production quantities, because EUROSTAT also lists them as confidential.

The emission factors were compared with the corresponding emission factors of other countries. For reasons of confidentiality, the result of that comparison can be documented only internally. The emission factors are comparable.

4.8.6.5 Category-specific recalculations (2.G.4 Charcoal)

The emissions had to be corrected for the year 2019, as a result of adjustments to foreign-trade statistics. The usage quantities – and, consequently, the emissions – increased by only 6 % as a result.

4.8.6.6 Planned improvements, category-specific (2.G.4 Charcoal)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.8.7 Other product manufacture and use: Other, nitrous oxide from explosives (2.G.4 Explosives)

4.8.7.1 Category description (2.G.4 Explosives)

The nitrous oxide emissions from use of explosives are reported in the CRF tables of category 2.G.4. A description of that category, in the NIR, is provided in Chapter 4.8.3- Use of N2O (2.G.3).

4.9 Other production (2.H)

The category *Other production* is not a key category.

In the CSE, process-related emissions from production of particle board and from pulp production are reported under 2.H.1 Pulp and paper.

Process-related emissions from production of alcoholic beverages, and from production of bread and other foods, are listed under 2.H.2 Food and drink.

Confidential data on emissions of fluorinated greenhouse gases are reported under 2.H.3. Data on F gases subject to voluntary reporting are reported in that section as well, in aggregated form.

4.9.1 Other production: Pulp and paper (2.H.1)

4.9.1.1 Category description (2.H.1)

Gas	Method used	Source for the activity data	Emission factors used
NO_X, SO_2, NMVOC			CS

The category *Other production – pulp and paper* is not a source of greenhouse-gas emissions and is thus not a key category.

All emissions of climate-relevant gases from the pulp and paper industry, and from particle-board production, in Germany result from combustion of fuels; for this reason, they are reported in Chapter 3.2 as energy-related emissions. The pulp and paper industry does not produce any process-related emissions of climate-relevant gases within the meaning of the *2006 IPCC Guidelines*.

Two of the six pulp plants in Germany carry out sulphate-process **pulp production** via caustification. For these plants, fuel-related CO_2 emissions in lime ovens are already taken into account, as energy-related emissions, via the pertinent fuel statistics. The remaining four plants use the sulphite process.

No attempt was made to take account of country-specific CO emission factors in energy-related emissions from pulp production, since that would have required conversion of product-based emission factors into fuel-based emission factors. Such conversion is an extremely involved process. Compared to the relevant CO emissions from paper mills, the CO emissions from the six pulp plants are of insignificant quantities.

The sulphate and sulphite pulp-production processes can both be a source of SO_2 emissions. In sulphate pulp production, NO_X, CO and NMVOC emissions are also released from recovery boilers, lime ovens, bark boilers and auxiliary boilers.

Particle board is produced from wood chips, with added binders, in a process that applies heat and pressure. The main source of NMVOC emissions in such production are the wood chips used, which release NMVOC during drying via heating. NMVOC can also be emitted from wood and binders during the pressing process.

Particle board is produced in a total of 20 plants in Germany. The particle-board industry tends to be dominated by larger companies.

4.9.1.2 Methodological issues (2.H.1)

The **pulp and paper industry** produces no process-related emissions of climate-relevant gases within the meaning of the *IPCC Good Practice Guidance* (Penman et al., 2000). Plant operators reported emission factors for the precursor substances nitrogen oxides, sulphur oxides and NMVOC.

Table 213: Emission factors for production of pulp. (German contribution to revision of the BAT reference (BREF) document for the pulp and paper industry, 2007 (Spörl, 2009))

in kg/t	NO_X	NMVOC	SO_2
Sulphate pulp	1.75	C	0.03
Sulphite pulp	2		1

According to the most recent figures, the following quantities were produced, in a total of 153 plants:

Table 214: Pulp and paper production, produced quantities

Product	Quantities produced in 2020	
Production of paper, cardboard and carton (PCC):	21.35	million t
Raw-material production:		
Paper pulp	1,466	kt
Wood pulp	684	kt
Recycled paper	14,486	kt
Quantity of recycled paper used for this purpose	(16,905 kt)	

Source: VDP (2020)

These figures, which the German Pulp and Paper Association (Die Papierindustrie e.V.; VDP) collects annually and publishes in a production report, are available back to 1990.

Particle board

Emission factors

The emission factors, amounting to 0.9 kg/t for NMVOC and 0.3 kg/t for dust, were determined via expert judgements.

Activity data

For use, the activity data, which were obtained from national statistics (W. Statistisches Bundesamt, 2021a), have to be converted from volume-based units into mass-based units.

Table 215: Converted activity data for the particle-board industry

Year	2015	2016	2017	2018	2019	2020
Particle-board production [in t]	4,402,000	4,560,000	4,703,000	4,322,168	4,489,681	4,430,611

Source: Statistisches Bundesamt, Melde-Nrn. (reporting numbers) through 2018: 1621 13 131; 1621 13 133; 1621 13 163; 1621 13 500; Meldenummern (reporting numbers) as of 2019: 162112001, 162112002, 162112003, 162113160, 162114190, 162114500, converted and summed in tonnes

4.9.1.3 Uncertainties and time-series consistency (2.H.1)

Pulp and paper

Germany's country-specific emission factors reflect the considerable modernisations that have been carried out in German sulphate pulp plants and that have sharply reduced their emissions. In sulphite pulp plants, continual improvements led to considerable SO_2-emissions reductions with respect to corresponding emissions levels in 1990.

The uncertainties in the activity data are estimated to amount to 5 %. The uncertainties for the emission factors are estimated at 20 %.

Particle board

The uncertainties for the activity data for the particle-board industry are ±5 % (expert assessment, carried out due to conversion of statistical data).

4.9.1.4 Source-specific quality assurance / control and verification (2.H.1)

Due to resources limitations, and to the area's minimal relevance, no QC/QA is carried out for reporting relative to precursors.

4.9.1.5 Category-specific recalculations (2.H.1)

Recalculations were required in 2021, since the association made slight corrections in the activity data for sulphate pulp for the year 2019. Since the emissions are not relevant as greenhouse gases, the corrections have not led to any changes in greenhouse-gas emissions.

4.9.1.6 Category-specific planned improvements (2.H.1)

No inventory improvements are currently planned for this category.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.9.2 Other production: Food and drink (2.H.2)

4.9.2.1 Category description (2.H.2)

Gas	Method used	Source for the activity data	Emission factors used
CO_2	NA	NA	NA
NMVOC	CS	NS	CS/D

The category *Other production – food and drink* is not a source of greenhouse-gas emissions and is thus not a key category.

The food and beverage industry's emissions of direct climate gases in Germany result from fuel combustion; for this reason, they are reported under CRF 1.A.2. The food and beverage industry's important process-related emissions include non-methane volatile organic compounds (NMVOC) (IPCC (2006a): Vol. 1 p. 7.13). Carbon dioxide emissions from food inputs that occur during certain production processes are not reported in CRF 2.H.2., since they result from use of biological carbon and do not contribute to net CO_2 emissions. The solvent emissions that occur in connection with extraction of oils & fats (soy, rapeseed, sunflower seeds, etc.) – i.e. from solvent use in connection with raw-material production – are reported in category 2.D.3. The CO_2 used in sugar production, which is obtained from burning of limestone, is bound during the production process. For this reason, this process is not emissions-relevant (p. Lechtenböhmer et al. (2006b); Lechtenböhmer et al. (2006a).

Emissions of the food and drink industry are reported, in summary form, in the inventory in "Table2(I)s2" of the sectoral report for industrial processes.

Pursuant to the IPCC Guidelines, emissions reporting for the category food and drink covers the following products:

Alcoholic beverages

- Wine
- Beer
- Spirits

Bread and other foods

- Meat, fish and poultry
- Sugar
- Margarine and solid and hardened fats
- Cake, cookies and breakfast cereals
- Bread
- Animal feedstuffs
- Coffee roasting
- The 2019 EMEP/EEA air pollutant emission inventory guidebook lists default emission factors for NMVOC emissions for these products (EMEP/EEA (2019), Chapter 2.H.2).

4.9.2.2 Methodological issues (2.H.2)

For emissions calculations, national emission factors were used where available. Otherwise, the emission factors recommended by EMEP / EEA were used. The basis for selection of emission factors consists of the research report "Emissions from the food industry" ("Emissionen aus der Nahrungsmittelindustrie") (Anderl et al., 2008; Theloke et al., 2008). The procedure is in keeping with that described in the NIR 2013.

Apart from just a few exceptions, the activity data are provided directly by the Federal Statistical Office, via data delivery. Also, queries can be submitted via the Federal Statistical Office's "Genesis-Online" Internet portal. Additional data have been used as follows: For wine production, data from the Federal Statistical Office's Fachserie 9 Reihe 3.2.2; for feed production, data from the Federal Ministry of Food and Agriculture's (BMEL's) Statistical yearbook on food, agriculture and forestry (Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten); for the wine and spirits industry, surveys of the Federal association of the German wine and spirits industry (BSI – Bundesverband der Deutschen Spirituosen-Industrie und Importeure). For purposes of international comparability, the Single National Entity aggregates all products in units of kilotonnes. Although the relevant overall figures can be read out from the CRF tables as activity data, they are the result of an estimation procedure.

For category 2.H.2, a total of 15.6 kt of NMVOC emissions result for 2020. Of those, 4.7 kt NMVOC are from bread production, 3.5 kt NMVOC are from sugar production and 3.5 kt NMVOC are from production of spirits. The changes with respect to the previous year lie within the customary fluctuation range. Considerable increases occurred only in the area of bread production, and decreases occurred in the area of beer production.

4.9.2.3 Uncertainties and time-series consistency (2.H.2)

The uncertainties in the activity data are estimated at 5-20 %. Further information about the relevant uncertainties is provided in the NIR 2013.

4.9.2.4 Source-specific quality assurance / control and verification (2.H.2)

Due to resources limitations, and to the area's minimal relevance, no QC/QA is carried out for reporting relative to precursors.

Other countries' reports contain very little information about 2.H.2, and thus no comparisons are possible at present. No comparison with ETS data is possible, since no emissions subject to emissions trading occur in 2.H.2.

4.9.2.5 Category-specific recalculations (2.H.2)

No recalculations were required.

4.9.2.6 Category-specific planned improvements (2.H.2)

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

4.9.3 Other sectors (2.H.3)

Gas	Method used	Source for the activity data	Emission factors used
HFC, PFC, SF6	Cf. Chapter 4.6.4: Table 204/ Table 207	Cf. Chapter 4.6.4 / 4.7.5 / 4.8.2	cf. Table 204/Table 207

SF_6 emissions from use in connection with *AWACS Maintenance* (2.G.2.a Military uses), with *Athletic shoes* (2.G.2.d. adiabatic properties – athletic shoes), with *Welding* (2.G.2.e Other – welding) and with production of *Optical glass fibres* (2.G.2.e Other – optical glass fibres) are reported, for reasons of confidentiality, in 2.H.3.

HFC emissions from use of the solvents HFC-43-10mee, HFC-245fa and HFC-365mfc are also reported under 2.H.3.

PFC emissions from uses as heat transfer fluids (2.E.4), as solvents (2.F.5), in athletic shoes (2.G.2.d Adiabatic properties – athletic shoes), and from use of perfluorodecalin in medical and cosmetic applications (2.G.2.e Other – medical and cosmetic applications), are also reported under 2.H.3. In keeping with the recommendations of the Expert Review Team, we note that all information on the emissions reported under 2.H.3, with respect to source category description, methodological issues, uncertainties & time-series consistency and category-specific recalculations & verification, and to planned improvements, is presented in the relevant category chapters.

In addition to reporting on greenhouse gases subject to reporting obligations, Germany has decided to report on the greenhouses gases shown in Table 216, which are not subject to reporting obligations. This reporting covers the applications of relevance in Germany, which are also listed as such in the table. For reasons of confidentiality, Table 217 shows the emissions of these greenhouse gases, which are not subject to reporting obligations, in aggregated form.

Table 216: Overview of voluntarily reported fluorinated greenhouse gases, their global warming potentials (GWP) and their areas of application

GHG	Formula	GWP	Area of application	QG
HFCKW-1233zd	$CHCl=CH-CF_3$ (E)	5[1]	Stationary air conditioning systems	2.F.1.f
HFC-1234yf	$CF_3-CF=CH_2$	4[1]	Commercial refrigeration Refrigerated transports Mobile air conditioning systems Stationary air conditioning systems	2.F.1.a 2.F.1.d 2.F.1.e 2.F.1.f
HFC-1234ze	$CF_3-CH=CHF$ (E)	7[1]	Commercial refrigeration Stationary air conditioning systems XPS foams General-purpose aerosols	2.F.1.a 2.F.1.f 2.F.2.a 2.F.4.b
HCFE-235da2 (isoflurane)	$CHF_2OCHClCF_3$	350	Inhaled anaesthetic	2.G.2.e

GHG	Formula	GWP	Area of application	QG
HFE-236ea2 (desflurane)	$CHF_2OCHFCF_3$	989	Inhaled anaesthetic	2.G.2.e
HFE-347mmz1 (sevoflurane)	$CH_2FOCH(CF_3)_2$	216[2]	Inhaled anaesthetic	2.G.2.e
PFPE/PFPMIE	$CF_3(OCF(CF_3)CF_2)_n(OCF_2)_mOCF_3$	10,300	ORC systems	2.G.4
Sulphuryl difluoride	SO_2F_2	4,090[2]	Container fumigation	2.G.4

Unless indicated otherwise, the GWP figures come from the 4th IPCC Assessment Report (IPCC 2007).

[1] GWP values pursuant to Regulation (EU) No 517/2014 (F-GasV, 2014).

[2] GWP value from the 5th IPCC Assessment Report.

Table 217: Aggregated emissions of the fluorinated greenhouse gases – which are not subject to reporting requirements – HCFC-1233zd, HFC-1234yf, HFC-1234ze, HCFE-235da2, HFE-236ea2, HFE-347mmz1, PFPE/PFPMIE and SO_2F_2

Year	Emissions, in t CO_2 equivalents
1990	3,038
1991	3,795
1992	4,619
1993	5,512
1994	6,474
1995	7,504
1996	13,874
1997	20,026
1998	26.671
1999	33,809
2000	41,439
2001	47,758
2002	54,433
2003	61,463
2004	69,871
2005	76,591
2006	316,265
2007	348,453
2008	295,501
2009	339,346
2010	310,419
2011	222,400
2012	257,553
2013	335,499
2014	307,038
2015	319,668
2016	291,922
2017	255,051
2018	347,861
2019	765,485
2020	971,157

5 Agriculture (CRF Sector 3)

5.1 Overview (CRF Sector 3)

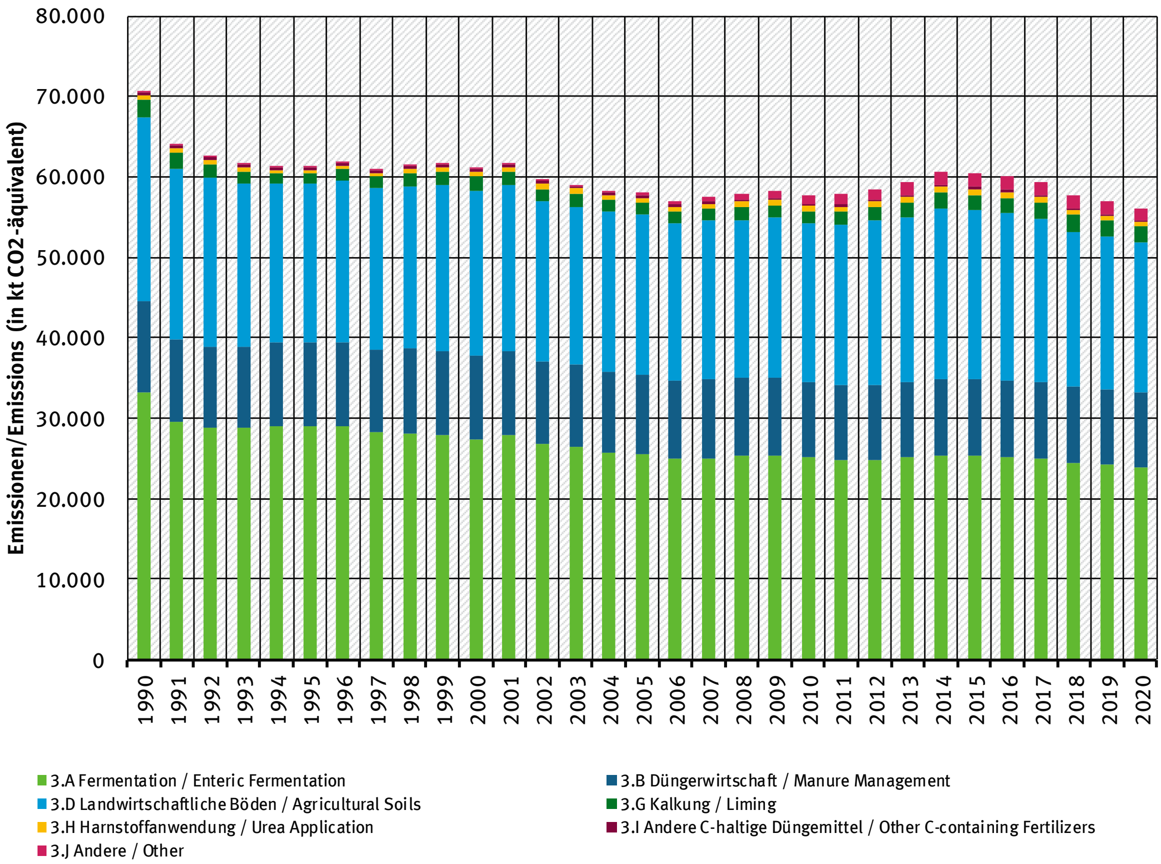
5.1.1 Categories and total emissions, 1990 - 2020

In category 3, "Agriculture", Germany reports on emissions from enteric fermentation (3.A), from manure management (including manure digestion and storage of digestates of manure) (3.B), from use of agricultural soils (3.D), from liming (3.G), from use of urea (3.H) and from use of other carbon-containing fertilisers (3.I). The NIR also reports on emissions occurring in connection with digestion of energy crops (3.J: Emissions from digestion of energy crops and from storage of digestates; 3.D: Emissions from application of digestates). Emissions from digestion and composting of other substances, such as food waste and green waste, are reported, along with the emissions from spreading of the resulting digestates, in waste sector 5.B.2 (cf. Chapter 7.3.2).

Emissions from rice cultivation (3.C) do not occur in Germany, while clearance of land by prescribed burning (3.E) is not practiced in Germany (NO). Field burning of agricultural residues (3.F) is prohibited in Germany by law (Federal Law Gazette (BGBl), 2004, and by preceding federal and federal state provisions; cf. Vos et al. (2022, Kap. 11.9)) (NO).

For the present 2022 NIR, Figure 43 provides an overview of the development of greenhouse-gas emissions, since 1990, in the areas 3.A, 3.B, 3.D, 3.G, 3.H and 3.J. The pertinent data have been calculated with the Py-GAS-EM inventory model (cf. Chapter 5.1.2).

Figure 43: Overview of greenhouse-gas emissions in CRF Sector 3



5.1.2 The Py-GAS-EM emissions-inventory model

5.1.2.1 Guidelines applied, and detailed report

The emissions-inventory model is based primarily on the relevant sets of guidelines (greenhouse gases: IPCC (2006a, Vol. 1 & 4)air pollutants, especially NH_3: EMEP/EEA (2019). The aforementioned guidelines present no methods for calculation of emissions from digestion of energy crops.

Over the past few years, many of the methods described in the guidelines have been refined for purposes of the Py-GAS-EM model. And a national method has been developed for calculation of emissions from digestion of energy crops. A comprehensive description of the Py-GAS-EM inventory model, including listings of relevant additional sources, is presented in the pertinent detailed report (Vos et al., 2022). The following remarks summarize that detailed report.

5.1.2.2 Basic structure of the Py-GAS-EM emissions-inventory model

Feed intake serves as the basis for emissions calculations in the animal husbandry sector. It is calculated as a function of basic and performance-related energy requirements, as Figure 44 shows with the example of dairy cows. That approach provides the CH_4 emissions from enteric fermentation (3.A), as well as the carbon and nitrogen excretions data needed to calculate emissions from management of manure and digested slurry (3.B). The latter, in turn, enter into calculations of nitrogen discharges into agricultural soils (3.D).

Figure 44: Logical structure behind national methods for calculating emissions from animal husbandry, illustrated with the example of dairy cows. ("Performance indicator" stands for the sum of basic and performance-related requirements.)

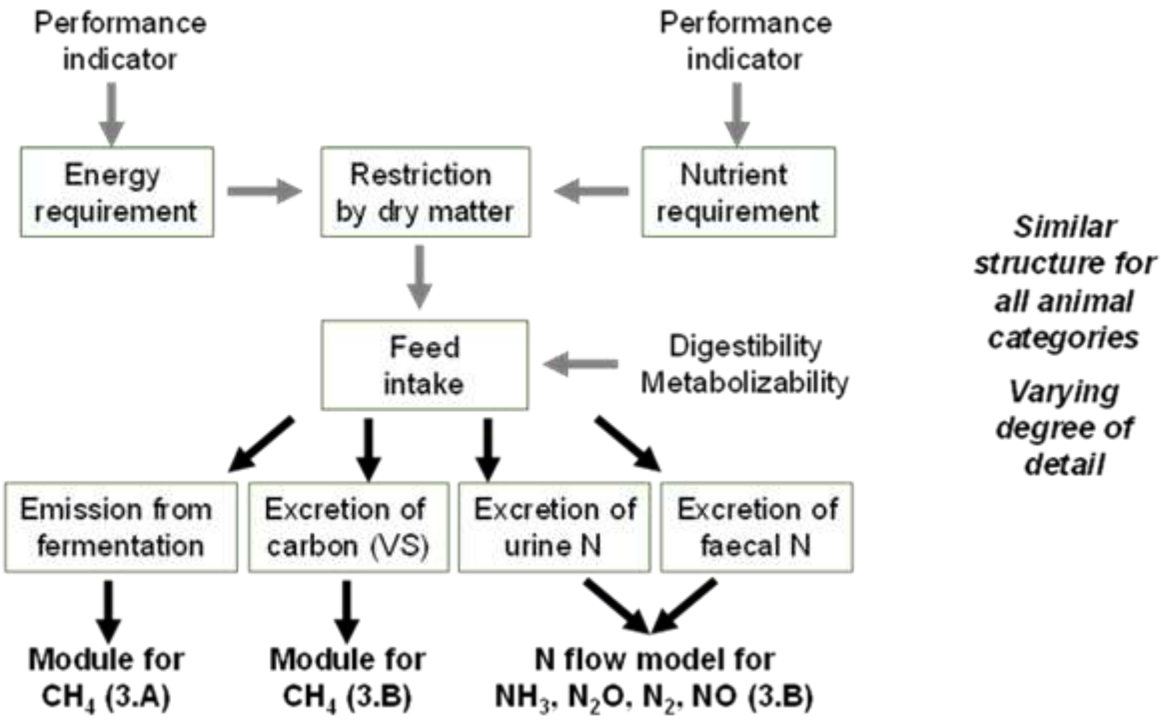
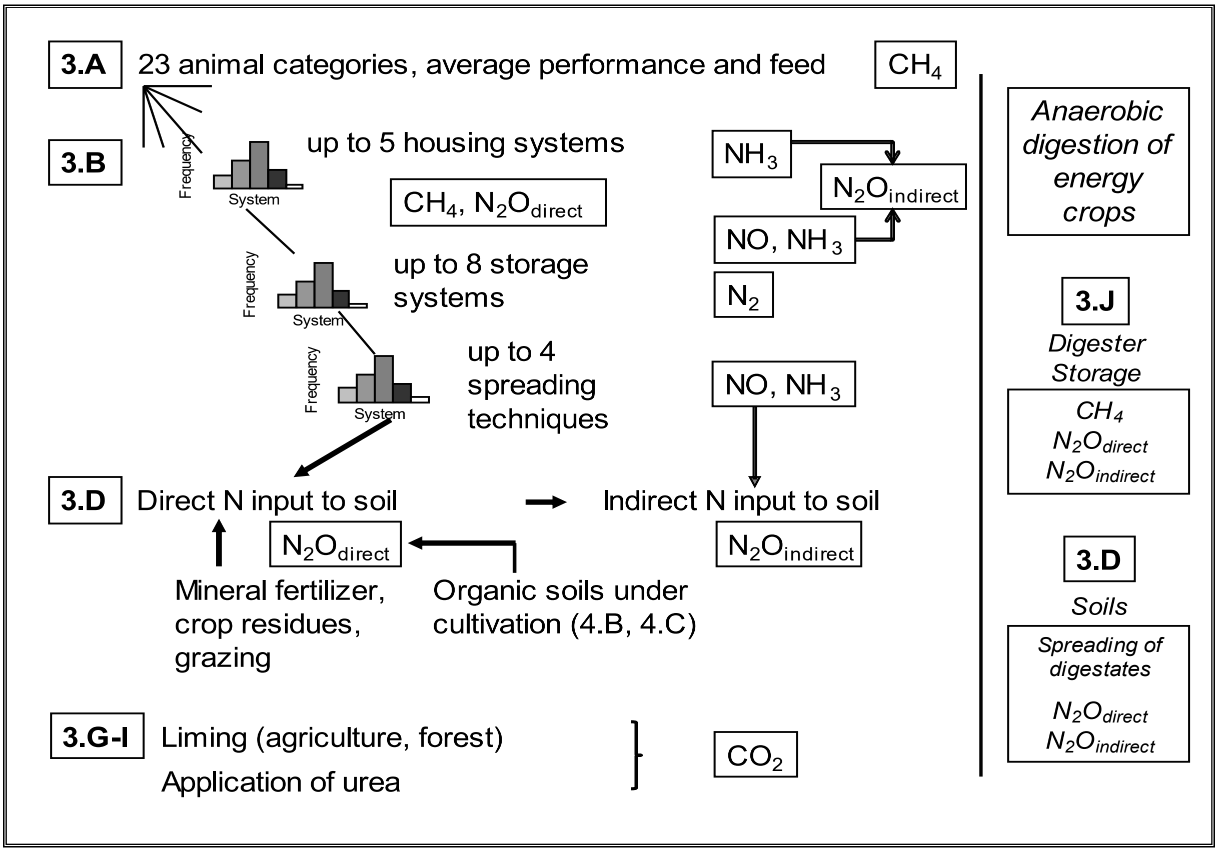


Figure 45 shows how the Py-GAS-EM model, for purposes of calculations in categories 3.A and 3.B, first differentiates between animal categories and sub-categories and then further subdivides those categories into housing systems, storage systems (with digestion as a separate storage system) and procedures for application of manure and digestates. CH_4 emissions are calculated separately for each animal sub-category in 3.A and 3.B. For categories 3.B and 3.D, N_2O

emissions are calculated on the basis of an N-flow concept (cf. Chapter 5.1.2.4). In categories 3.G-I, CO_2 emissions are calculated for liming and urea application. In line with the IPCC's guidelines, these calculations also include the area of liming of forests. Emissions from digestion of energy crops are calculated in two separate sections: Emissions from digesters and storage of digestates, in 3.J; and emissions from soils, as a result of application of digestates, in 3.D.

Figure 45: Concept and thematic content behind the Py-GAS-EM model



5.1.2.3 Treatment of CH_4 within the emissions inventory

The Py-GAS-EM inventory model is used to calculate CH_4 emissions from enteric fermentation and VS excretions of agricultural livestock (cf. Chapters 5.2 and 5.3.2), taking account of slurry-based and straw-based systems and their typical forms of storage. Anaerobic digestion of manure and energy crops, in biogas plants, is included in the calculations (cf. Chapters 5.1.3.6.5 and 5.1.4).

5.1.2.4 The nitrogen-flow concept (3.B, 3.D)

With the Py-GAS-EM model, N-species emissions are calculated on the basis of the N-flow concept (Dämmgen & Hutchings, 2005); cf. in this connection Chapter 3.3.4.3.1 in Vos et al. (2022).

To make it possible to apply the concept, the relevant animal N excretions have to be determined (cf. Chapter 5.1.3.4). For dairy cows, dairy heifers and female beef cattle, male beef cattle, swine, laying hens, pullets, broilers, ducks, and turkeys (males and hens), N excretions are calculated as the difference between the amount of N taken in with feed and basic and performance-based N requirements (animal weight, weight gain, annual milk yield or egg production (i.e. numbers of eggs) and, if relevant, numbers of young). The N intake with feed is determined on the basis of animal energy requirements and the energy and N content of the feed. For other animals, N-excretion data are taken from the pertinent German technical literature or derived.

In the case of N excretions, a distinction is made between the two fractions "organic N" and "TAN readily converted into NH_3" (TAN – "total ammoniacal nitrogen"). TAN is present in the urine of mammals; in the Py-GAS-EM model, in each case TAN is considered to be equivalent to the N content of urine. Poultry excrete "UAN" (uric acid nitrogen); in the inventory, UAN is treated as equivalent to TAN. As a result of the manner in which the relevant emission factors are defined, NH_3 emissions are calculated primarily in proportion to the available TAN quantity, while N_2O emissions, NO emissions and N_2 emissions are calculated in proportion to the available N quantity. For this reason, the calculations take account of two parallel N pools. These are (1) the entire N quantity available at the relevant stage being considered, i.e. the sum of organic N and TAN, and (2) TAN by itself.

The N excretions determined for a given animal category are divided into housing emissions and pasture emissions. This division is made in accordance with the percentages of time the relevant animals spend in housing and on pasture.

In the case of solid-manure systems, N inputs from bedding material are also taken into account, along with N excretions.

For each animal category, the amounts of N occurring in housing systems are divided in accordance with the relative shares of the animal-housing systems commonly used in Germany. N losses via NH_3 emissions are subtracted from the TAN pool and from the total N pool. The remaining N and TAN amounts for all stables are combined separately, for slurry-based systems and then for straw-based systems, and are transferred into the correspondent storage systems.

The inventory takes account of air-scrubbing systems in swine and poultry husbandry; cf. Chapters 3.3.4.3.3 and 3.4.5.2 in Vos et al. (2022). The N removed via air-scrubbing systems is treated as TAN, as if it were directly applied with manure (see below).

The total N and TAN amounts (for solid-manure systems, including the N inputs from straw bedding) accruing to the storage systems are divided, separately for the categories solid manure and slurry, among the different storage systems commonly used in Germany, in keeping with the applicable percentage shares. Anaerobic digestion of manure in biogas plants is included in the calculations (cf. Chapter 5.1.3.6.5). From storage, NH_3 emissions from the TAN pool and the total N pool occur. The N losses occurring via emissions of N_2O, NO and N_2 are calculated as a total, for housing systems and for storage systems, and then subtracted from the total N pool. At the same time, these N losses are subtracted from the TAN pool, using the ratio of the TAN quantity to the total-N quantity. The remaining N / TAN quantities are spread. The N removed via air-scrubbing systems is added to the TAN pool.

The amount of N applied is divided among the different application techniques commonly used in Germany, taking account of the different durations of manure incorporation commonly observed. This is carried out in accordance with the different application techniques' relative proportions of the total amount of manure applied, differentiated by animal category and by the categories of solid manure and liquid manure. The N_2O emissions released from agricultural soils as a result of application of manure, and of digestates of manure, are calculated in proportion to the N quantity applied.

The N_2O emissions from grazing are calculated from the total N quantity excreted during grazing. The N flows that occur in connection with digestion of energy crops, and with storage and application of the resulting digestates, are treated separately from the N flows for animal husbandry. The former are calculated on the basis of the N quantity in the digested energy crops (cf. Chapter 5.1.4.2), via a procedure analogous to that described above for animal N excretions.

In a procedure analogous to that used for manure application, the N_2O emissions from agricultural soils, resulting from application of mineral fertiliser, are calculated in proportion to the N quantity applied.

In a procedure analogous to that used for manure application, the direct and indirect N_2O emissions from agricultural soils, resulting from application of mineral fertiliser, are calculated in proportion to the N quantity applied.

5.1.3 Characterization of animal husbandry

5.1.3.1 Animal categories (3.A, 3.B)

For calculation of emissions from animal husbandry in German agriculture, animal stocks are divided into sub-categories, to permit description of sub-stocks that are homogeneous with regard to performance and to housing systems. Table 218 compares the animal categories to be reported on in the in CRF tables with the animal categories used in the German inventory.

The CRF categories "mules and asses" and "buffalo" are reported as "IE", since the numbers of animals in those categories are included in the figures for "horses" and "other cattle" (cf. Chapter 5.1.3.2.2).

The categories deer, rabbits, ostriches and fur-bearing animals are not reported in the CRF tables pursuant to IPCC (2006a, Vol. 4), because their contribution to the total emissions is less than 0.05 % of the overall inventory and less than 500 kt CO_{2eq} (pursuant to United Nations (2014 para 37)) and German statistical surveys do not record the respective animal numbers. The emissions contributions from those categories are estimated in Chapter 19.3.1. All those sources for which no emissions are reported ("NE" is entered) are listed in Chapter 21.

Table 218: CRF animal categories, and the subdivisions used for purposes of German emissions reporting (3.A, 3.B)

CRF animal categories		Animal categories in the German inventory
	Dairy cows	"Dairy cows" [a]
1	Other cattle	"Calves" (to 4 months old) [a] "Dairy heifers" [b] / "Female beef cattle" [b] (Young female cattle older than 4 months) [a] "Male beef cattle" (young male cattle older than 4 months) [a] "Suckler cows" [a] "Male cattle older than 2 years" [a]
2	Sheep	"Mature sheep" "Lambs"
3	Swine	"Sows" (incl. suckling piglets to 8 kg) "Weaners" "Fattening pigs" "Boars"

CRF animal categories		Animal categories in the German inventory
4	Buffalo	--- [a]
	Camels	--- [c]
	Deer	--- [d]
	Goats	"Goats"
	Horses	"Heavy horses" [e] "Light horses and ponies" [e]
	Mules and asses	--- [e]
	Poultry	"Laying hens" "Broilers" "Pullets" "Geese" "Ducks" "Turkeys, males" "Turkeys, females"
	Rabbits	--- [d]
	Reindeer	--- [c]
	Ostriches	--- [d]
	Fur-bearing animals	--- [d]

[a] In the years through 2012, the German inventory included buffalo with suckler cows; as of 2013, the official animal-population figures for the categories "other cattle" and "dairy cows" include buffalo. The buffalo data cannot be separated out from those figures. For details, cf. Chapter 4.1.1.2 in Vos et al. (2022).

[b] For definitions of dairy heifers and female beef cattle, cf. Vos et al. (2022), Chapter 4.5.

[c] These animals do not occur in Germany.

[d] These animals are not reported on, since their emissions contribution is insignificant; cf. Chapter 19.3.1.

[e] In the years through 2009, the German inventory included mules and asses with light horses and ponies; as of 2010, the official animal-population figures for horses include mules and asses. The data for those animals cannot be separated out from the horse figures.

5.1.3.2 Animal place data (3.A, 3.B)

The Py-GAS-EM inventory model calculates in chronological increments of one year. It cannot model interannual fluctuations, including fluctuations of animal populations. The German inventory thus is based on the assumption that the numbers of occupied and unoccupied animal places, as shown by official statistics as of a specified reference date (cf. Chapter 5.1.3.2.1), remain constant throughout the course of the relevant year It can be shown that, in the case of categories of animals with lifetimes of less than one year, this concept correctly takes account of the vacancies occurring between any two production cycles; cf. Chapter 3.1.2.2 in Vos et al. (2022).

For purposes of inventory calculations, the numbers of occupied animal places found as of the reference date are interpreted as the applicable numbers of animals. This approach is in keeping with the definition of AAP ("average annual population") given in IPCC (2006a Vol 4, Section 10.2.2): Vol. 4, Section 10.2.2., a definition that has also been adopted by EMEP (cf. EMEP/EEA (2019 3B-14)).

5.1.3.2.1 Surveys of the Federal and federal state statistical offices

The Federal Statistical Office and the statistical offices of the German federal states carry out agricultural-structure surveys[89] that, in addition to collecting other data, carry out censuses of

[89] https://www.destatis.de/Migration/DE/ZahlenFakten/Wirtschaftsbereiche/LandForstwirtschaftFischerei/Agrarstrukturerhebung2016/Agrarstrukturerhebung2016.html;jsessionid=EAB8F1AF6D6DD78AC06FA516B912A52D.internet741

cattle, swine, sheep, horses (as of 2010: equids) and poultry. In the periods 1990 – 1996 and 1999 – 2007, such agricultural structural surveys were carried out every other year. In 2010, they were carried out in the framework of the 2010 agricultural census (Landwirtschaftszählung 2010 – LZ 2010 (Statistikportal (Statistische Ämter des Bundes und der Länder), 2010), a more extensive census. Thereafter, they were carried out again in 2013 and 2016. The last agricultural census was carried out in 2020. It has now been taken into account in the inventory, for the first time, via any evaluations that the Federal Statistical Office provided on time for the present inventory. The 1990, 1992, 1994 and 1996 surveys were each carried out on 3 December, while the reference date for the surveys carried out in 1999 – 2007 was 3 May and that for the surveys carried out in 2010, 2013, 2016 and 2020 was 1 March.

In addition to the agricultural-structure surveys, annual livestock censuses are carried out (Statistisches Bundesamt, FS 3, R 4.1). Through 1998, such surveys were carried out semiannually for cattle and sheep (June, December), every four months for swine (April, August, December), and every two years, in even-numbered years (in December), for all animal species, i.e. also for horses and poultry. In each case, the reference date was the third calendar day of the pertinent month. Since 1999, the livestock census for cattle and swine has been carried out twice annually, as of the reference dates 3 May and 3 November. For the sheep census, the reference date was 3 May in the period 1999 through 2009. In 2010, it was 1 March. As of 2011, it has been 3 November.

Census data from official surveys are thus available for cattle, swine and sheep for all years since 1990. In the inventories through 1998, the December data were used (for sheep, the June data). Thereafter, through 2010, the May data were used (for sheep, in 2010: 1 March, since neither May nor November data were available). By agreement with the Federal Statistical Office, the November reference date is to be used as of 2011 (European Parliament and Council of the European Union, 2008 Article 4). These figures are in keeping with the figures the Federal Statistical Office has provided to EUROSTAT. The change in the reference date, to 3 November, does not significantly affect the population figures in the case of cattle and swine. Among the figures for sheep, livestock-population figures had to be corrected; cf. Chapter 5.1.3.2.2.

The numbers of goats in Germany were not surveyed between the years 1977 and 2010. Until 2004, the Federal Ministry of Food and Agriculture (BMEL) estimated goat populations at the national level. As of 2005, the pertinent time series was continued via estimation by the Federal Statistical Office. In 2010, the total number of goats (reference date: 1 March) was officially determined for the first time, in the framework of the 2010 agricultural census (Statistikportal (Statistische Ämter des Bundes und der Länder), 2010). The resulting figure is considerably lower than the estimates obtained in previous years. By agreement with the Federal Statistical Office, those estimates, which are also reported to EUROSTAT, continue to be used in the inventory. Official goat-population figures obtained by the Federal Statistical Office are available for 2013, 2016 and 2020 (reference date: 1 March).

For horses / equids, and for poultry, population figures are available only at intervals of two to three years, from agricultural-structure surveys (reference dates: through 1998, 3 December; for 1999 – 2007, 3 May; in 2010, 2013, 2016 and 2020, 1 March). By agreement with the Federal Statistical Office, the population figures have not been adjusted to take account for the variations in reference dates.

The 2013 poultry counts carried out by the Federal Statistical Office and the statistical offices of the federal states were tied to a revision of the relevant reporting groups. The revision was carried out because previous surveys (most recently, in 2010) had failed to take account of a number of large poultry flocks, due to the then-applicable rules for selection of the farms to be surveyed. The poultry counts obtained in 2013 are thus considerably higher than the surveys from prior years would have led one to expect. The Federal Statistical Office has not corrected the official poultry counts for earlier years until 2010. As a result, the counts used in the inventory for the period 2010 through 2013 show a marked increase. Due to the basic differences between the 2010 and 2013 livestock censuses, this trend does not reflect any real development in poultry counts. The rise in poultry counts that occurred from 2013 to 2016 is considerably flatter.

For purposes of inventory calculations, and in the interest of conformance with emissions-reporting requirements, a number of data gaps had to be closed, and some of the animal-place figures had to be adjusted. These changes, and the manner in which buffalo, mules and asses are taken into account, are discussed in Chapter 5.1.3.2.2.

5.1.3.2.2 Special aspects of animal-place figures in the inventory

Since 2008, cattle-population figures have been taken from the HIT database (StMELF, diverse Jahrgänge) of the Bavarian State Ministry for Food, Agriculture and Forestry (Bayerisches Staatsministerium für Ernährung, Landwirtschaft und Forsten – StMELF), in which all cattle are individually registered. Via the new survey method, systematically higher population figures result for years as of 2008 than result for earlier years in which not all animals were counted, due to the survey thresholds applied. A comparison carried out by the Federal Statistical Office for 2007 reveals that the population figures for cattle shown in HIT are 2.9 % higher than those resulting via the conventional survey method (for dairy cows alone, the population figures are 2.8 % higher). The Federal Statistical Office reports that the cattle time series for the period prior to 2008 will not be retroactively

adjusted. As a result, emissions from keeping of cattle are slightly underestimated for the years 1990 to 2007. The figures for dairy cows and male cattle > 2 years are taken directly from the statistics. Through 2007, the figures for suckler cows also include the figures for cows for fattening and for slaughter (thereafter, separate records have no longer been kept for that category). In the inventory, "calves" include only calves up to the age of 4 months. The relevant statistics keep records for calves up to the age of 8 months, however (prior to 2008, for calves up the age of 6 months). For this reason, the applicable numbers of animals have to be calculated out of the remaining categories in the official statistics, and this affects the numbers of male beef cattle, female beef cattle and dairy heifers (with regard to the definitions of dairy heifers and female beef cattle; cf. Chapter 4.5 in Vos et al. (2022)). The total number of other cattle in the inventory always corresponds to the total number of other cattle surveyed, however. For details, cf. Chapters 4.4.1.1, 4.5.1.1, 4.6.1.1 and 4.7.1.1 in Vos et al. (2022).

As of time-series year 2013, the cattle numbers reported by the Federal Statistical Office, by categories (calves, heifers, cows, etc.) also include a breakdown of the total number of cattle by breeds. That breakdown also includes a sum-total figure for bisons + buffalo. However, it is not possible to express this sum in a way, however, that would permit it to be broken down by the various relevant categories (calves, heifers, cows, etc.) (Spielmanns, 2020). As a result, it is not possible to calculate the applicable number of buffalo from the aforementioned figures for cattle. For this reason, as of the 2015 Submission, the inventory no longer lists buffalo as a separate category (included elsewhere, IE); their emissions are included in those of cattle. For such inclusion, however, buffalo counts had to be properly allocated to cattle counts for the years prior to 2013. While the Federal Statistical Office has not published any buffalo counts for that period, it proved possible to close the gap for the years 2000 through 2012 with figures provided by the German buffalo association; cf. Chapter 4.1.1.2 in Vos et al. (2022). In keeping with a recommendation in the final report for the "Initial Review under the Kyoto Protocol and Annual 2006 Review under the Convention," for the years prior to 2000 the time series for the buffalo population at the national level was completed via linear extrapolation from data for the years

2000 through 2012. (For the years 1990 through 1995, computationally negative buffalo counts result; they have been replaced with zeros.) Since no information on the structure of the buffalo population is available for all years through 2012, for that period all buffalo were assigned to the cattle category "suckler cows." Proof of the correctness of this approach is presented in Chapter 4.1.1.2. of Vos et al. (2022). Any errors that may have occurred via the above-described inclusion of buffalo in the cattle category are considered to be negligible, since the ratio of buffalo counts to cattle counts, for the entire time series as of 1990, ranges from zero to a figure smaller than 0.1 % (cf. Chapter 4.1.1.2 of Vos et al. (2022)).

For swine as well, several of the categories used in official surveys have been modified with a view to obtaining maximally homogeneous animal categories. The official numbers of animals for piglets weighing up to 20 kg animal^{-1}, and for young pigs and fattening pigs weighing at least 20 kg animal^{-1}, have been converted, using the procedure described in Haenel et al. (2011), into numbers of animals for the inventory categories "weaners" and "fattening pigs". This conversion has no impact on the total number of swine, however. For purposes of emission calculation, the number of piglets weighing up to 8 kg is deducted from that total number, however. This is done in keeping with an inventory concept whereby piglets weighing up to 8 kg are considered suckling piglets that, with regard to their emissions, are implicitly included in calculations for sows.

The official population numbers for sheep have been corrected for all years as of 2010; cf. Chapter 6.1.1.1 in Vos et al. (2022). This has been done to take account of the change in the relevant survey date from spring (until 2009, May / June) to 1 March (2010) and to 3 November (since 2011). The correction compensates for the apparent reduction in the number of lambs that this change entails (as well as the corresponding reduction in the total number of sheep).

The official goat-population figures for 2010, 2013, 2016 and 2020 were used as a basis for calculating, via linear interpolation, the (otherwise unavailable) goat counts for 2011, 2012, 2014, 2015 and 2017-2019.

In the inventory, population figures for horses are subdivided into the two categories "heavy horses" and "light horses and ponies", to take account of the differences in emissions behaviour between the two categories. In the 2010 agricultural census, and in the 2013, 2016 and 2020 censuses, "numbers of equids", rather than numbers of horses, were counted. The equid figures include the counts for mules and asses. The numbers for mules and asses cannot be separated out of the equid data (included elsewhere, IE). As of the 2015 submission, therefore, the inventory no longer includes "mules and asses" as a separate category. Until the year 2009, the count for mules and asses was added to the count for light horses and ponies. Using data of IGEM (Schmutz, 2009), the figure was estimated to be 8,500 mules and asses per year. Gaps within the time series for horses have been filled in via linear interpolation.

Until 2007, in contrast to actual housing practice (placement in stalling systems, as laying hens, as soon as they complete their 18th week of life – this is also the practice taken into account in the inventory) pullets were officially counted until they reached the age of 6 months. In the inventory, therefore, a fraction of the pullets was shifted into the laying-hen category, while the sum total for pullets and laying hens was not changed; cf. Chapters 8.3.1 and 8.5.1 in Vos et al. (2022). The next poultry count, after 2007, took place in 2010. As of that count, shifting of figures between the pullet and laying-hen categories is no longer required, since the relevant populations have been counted in keeping with actual housing practice.

For all poultry categories, gaps in the animal-number time series have been closed via linear interpolation; cf. (Vos et al., 2022).

In the inventory, the official census data for turkeys were broken down by the categories "turkeys, males" and "turkeys, females", for all years since 1990, to take account of the pertinent differences in growth.

5.1.3.2.3 Animal place data used in the inventory (3.A, 3.B)

Table 219 presents a compilation of the animal-place figures on which German reporting is based. The years listed correspond to the years that are used, in the following chapters, in time series. The complete time series for the animal-population data is provided in Chapter 3.4.2.2 of Vos et al. (2022). The sharp decrease in the numbers of animals at the beginning of the 1990s is a direct result of structural change in the German agricultural sector following German reunification. In eastern Germany in particular, large herds were trimmed. Since 2017, the numbers of dairy cows and other cattle have decreased considerably. As a result of this development, and following several years with higher figures, the numbers of dairy cows are now at record-low levels. For other cattle, the decrease continues the trend of the previous years. In the swine category as well, a noticeable decrease has occurred since 2017. It follows a period of years with no consistent trend. The reason for the decrease cannot be unambiguously determined. Examples of possible reasons for this include a lack of feed, resulting from the extreme drought that prevailed in Germany in 2018 and 2019, and a reaction, on the part of farmers, to the tighter regulations introduced by the new Fertiliser Ordinance (DüV, 2017). Sheep counts since 2014 have exhibited a slightly decreasing trend, and that trend continued in the last time-series year. Goat counts have exhibited a slightly increasing trend, throughout the entire time series, while horse counts have been increasing slightly since 2016. Poultry counts have remained at about the same level since 2016.

With regard to the uncertainties in the animal counts, cf. Table 263 in Chapter 5.1.6.

Table 219: Animal-place figures used in German reporting (3.A, 3.B), in thousands

[in thousands]	Dairy cows	Other cattle	Swine	Sheep	Goats	Horses	Poultry
1990	6,355	13,133	26,502	3,266	90	499	113,879
1995	5,229	10,661	20,387	2,991	100	634	111,228
2000	4,570	9,969	21,768	2,743	140	500	120,180
2005	4,236	8,800	22,743	2,643	170	508	120,560
2010	4,183	8,629	22,244	2,245	150	462	128,900
2011	4,190	8,340	22,788	1,980	143	462	145,044
2012	4,190	8,319	23,648	1,966	137	461	161,189
2013	4,268	8,418	23,391	1,877	130	461	177,333
2014	4,296	8,447	23,667	1,892	133	455	176,080
2015	4,285	8,351	22,979	1,867	136	448	174,827
2016	4,218	8,249	22,761	1,851	139	442	173,574
2017	4,199	8,082	22,921	1,863	143	445	173,468
2018	4,101	7,848	22,019	1,846	147	448	173,361
2019	4,012	7,628	21,596	1,814	151	451	173,255
2020	3,921	7,380	21,622	1,780	155	454	173,148

5.1.3.2.4 Comparison with livestock-population figures of the FAO (3.A, 3.B)

The United Nations Food and Agriculture Organization (FAO) publishes global livestock-census data in its FAOSTAT Internet database (FAO, 2021). In general, the German figures in FAOSTAT come from the German Federal Statistical Office, which is also the data source for the German inventory. Nonetheless, numerous discrepancies result, for cattle, swine, sheep, goats, horses and poultry, when the data of FAOSTAT (as of 3 August 2021: time series through 2019, for horses and poultry only through 2017) and the data used in the 2022 submission are compared: From 1990 through 2019, only about 14 % of the FAOSTAT figures agree with the corresponding German data (even when the figures rounded to whole 100s of animals are taken into account).

The main reasons for the differences – large, in part – between the FAOSTAT data and the German data are that FAOSTAT has assigned a number of entries to the wrong years, and that it is inconsistent in its choice of methods for closing data gaps.

In the following section, the most important results of the data comparison are listed.

Cattle (including buffalo): The FAOSTAT animal-population data agree with the official German data only for the years 2014 – 2019. Prior to the year 2000, the FAOSTAT figures are shifted by a year with respect to the German figures. For example, the cattle-population figure that Germany listed for 1998 is listed by FAOSTAT for 1999. In the years 2011 – 2013, FAOSTAT uses the data from the May census, while the German inventory – in keeping with an EU provision (cf. Chapter 5.1.3.2.1) – uses the data from the November census.

Swine: In general, the swine-census figures listed by FAOSTAT cannot be compared with the corresponding inventory figures, since the inventory, for methodological reasons, deducts the numbers of piglets that weigh less than 8 kg (cf. Chapter 5.1.3.2.2). A comparison of a) the FAOSTAT swine-population figures and b) the swine-population figures of the Federal Statistical Office without deduction of suckling piglets shows that the FAOSTAT figures, like the FAOSTAT cattle-census figures for the period prior to 2000, are shifted – erroneously – by one year. With the exception of the years 2011 – 2013, in which the FAOSTAT figures agree with those of the May census, while the German inventory, in keeping with an EU provision (cf. Chapter 5.1.3.2.1), calculates using the data of the November census, the animal-number time series are largely similar. The figures actually agree (taking account of the rounding to whole 100s of animal places) only for the years 2001 – 2003 and 2007 – 2009, however.

Sheep: In the periods 1991, 1993 – 2000 and 2005 – 2009, the FAOSTAT figures are very similar to the data of the Federal Statistical Office. They actually agree (taking account of rounding to 100s of animal places) only for the years 2007 – 2009, however. In the years 1990, 1992, 1993 and 2001 – 2004, there are discrepancies – some of them large – that cannot be explained with the available information. As of 2010, the two time series cannot be compared, since the official sheep-population figures are corrected in the inventory (cf. Chapter 5.1.3.2.2).

Goats: For the years prior to the period 1991 through 2002, the FAOSTAT goat counts are shifted by one year with respect to the corresponding German figures. For example, FAOSTAT's goat count for 1991 is the same as the German goat count for 1990. For the years 1990, 2003, 2005, 2007, 2008, 2013 and 2016, the FAOSTAT figures agree with the corresponding German figures. For those years, in between the above years, in which Germany neither collected nor estimated data in this category, FAOSTAT lists data that must be the result of estimations, although FAOSTAT states that those data are official data. The pertinent estimates are implausible especially for the period as of 2011, since they contradict the trends obtained via linear interpolation between the supporting years.

Horses (including mules and asses): The FAOSTAT figures for the period prior to 2010 list horse-only counts, i.e. do not include mules and asses. When the added mules and asses are deducted from the inventory figures (cf. Chapter 5.1.3.2.2), for purposes of comparison, the FAOSTAT figures show a one-year lag behind the German figures until the year 2004. In this context, it should be noted that the livestock-population figures given by FAOSTAT often differ from those listed in official German statistics. As of 2005, the FAOSTAT data and the German data agree only for the years 2013 and 2016. In those years between 2005 and 2016 in which Germany collected no data in this category, the FAOSTAT estimates – like those for goats – show an implausible chronological progression.

Poultry: The poultry counts largely agree for nearly all years with animal censuses (1994, 1999, 2003, 2005, 2007, 2010, 2013 and 2016). In FAOSTAT, the results of the censuses of the years 1990, 1996 and 2001 have been erroneously entered in the following year in each case. In addition, FAOSTAT's closures of data gaps for the period as of 2010 are similarly implausible to its closures of data gaps for goats and horses. The resulting chronological progression for the period as of 2010 is erratic.

5.1.3.3 Performance, energy and feed data (3.A, 3.B)

To calculate emissions in accordance with a Tier 2 method, one requires data on animal performance (animal weight, weight gain, milk yield, milk protein content, milk fat content, numbers of births, grazing data (if applicable), numbers of eggs and weights of eggs) and on the relevant feed (phase feeding, feed components, protein and energy content, energy metabolizability and digestibility of organic matter). To divide the total numbers of turkeys, as reported by the Federal Statistical Office, into cocks and hens, one must know the applicable sex ratio. For the most part, such data are not available from official statistics. In the present case, such data were obtained from the open literature, from association publications, from regulations for agricultural consulting in Germany and via surveys of experts.

As a result of quality-assurance measures and the availability of updated input data, numerous changes have been carried out, with respect to the 2021 submission, that have affected the input data, including the data on performance, energy requirements and feed intake. The most important changes, in terms of their impacts, are listed in the overview below. (For a complete list of the changes, cf. Chapter 3.5.2 in Vos et al. (2022)).

- 2020 agricultural census: For the present 2022 submission, and for the first time, some already available input data from the 2020 agricultural census were used, such as data on applicable shares for animal-housing systems, storage and application procedures for manure, and grazing. This has resulted in changes – in some cases, considerable ones – in the calculated emissions, in comparison to the previous year's submission, throughout the period back to 2000.
- Dairy cows: The 2019 milk yield and slaughter weight have been slightly corrected, for all German federal states, in the official statistics.
- Suckler cows: For suckler cows, the energy-requirements and feed-intake models have been completely updated, and adjusted in keeping with the dairy-cow model (2021 submission).
- Heifers: Minor changes in the nutrient content of some feed ingredients (concentrates and rapeseed expeller).
- Male beef cattle: For some years, the age at slaughter and weights at slaughter were updated in the HIT database (cf. Chapter 5.1.3.2.2).
- Sows: For Bavaria, a correction has slightly reduced the number of piglets per sow and year in 2019.
- Fattening pigs: The following feed parameters have been adjusted, on the basis of information provided by professional associations, for the entire time series: raw protein content, ash content, digestibility of organic matter, energy digestibility, metabolizable energy, and energy content (Emthaus et al., 2021b). For Bavaria, a slight correction was made in the initial- and final-weight figures for 2019.
- Broilers: The parameters for the crude protein content in feed, and the feed conversion, were adjusted for the entire time series, on the basis of information provided by professional associations (Emthaus et al., 2021a).
- Turkeys: The input data for the years 2017-2019 were updated – this affected the data on weight at slaughter and weight gain, and the feed conversion coefficients.

- Geese: The existing value for N excretions was adjusted, to take account of a more-recent, and more-plausible, source relative to the N excretions of geese. In addition, an N input from bedding material is now also being taken into account for geese.
- Laying hens: New interpolation of the starting and final weights, in all years of the time series.
- Pullets: New interpolation of the final weight, in all years of the time series.

Table 220 shows the mean animal weights for dairy cows, other cattle, swine and poultry. The mean animal weight for dairy cows is obtained from the pertinent starting and final weights (averaged over the German federal states, and weighted with the animal numbers at the federal state level); cf. Chapter 4.3.1.2 in Vos et al. (2022). With regard to calculation of the mean animal weights for other cattle, swine and poultry, cf. Chapter 4.9.2.1, 5.7.2 and 8.9.1.2 in Vos et al. (2022).

Table 220: Average animal weights (3.A, 3.B)

[kg animal-1]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	566.9	581.9	591.1	592.3	592.6	592.3	589.0	586.5	585.0	587.7	584.4	587.3	588.4	595.5	601.3
Other cattle	318.5	333.1	343.9	340.8	342.9	340.1	339.0	340.0	339.4	340.9	341.2	341.8	343.4	346.3	348.1
Swine	66.7	69.0	67.3	67.0	65.3	64.1	63.7	63.6	63.7	63.3	63.3	63.2	63.6	63.2	63.1
Poultry	1.61	1.60	1.67	1.78	1.79	1.75	1.73	1.70	1.70	1.70	1.70	1.70	1.69	1.69	1.68

The animal weights for sheep, goats and horses do not enter into the emissions calculations, but they have been estimated for CRF-3.B: Sheep, 50 kg animal^{-1}; goats, 40 kg animal^{-1}; and horses, 490 kg animal^{-1}; cf. Chapters 6.5.1, 6.6.1 and 7.5.1 in Vos et al. (2022).

Table 221 shows daily milk yield from dairy cows, expressed as an average for Germany as a whole; it is obtained by dividing the annual milk yield by 365 days. The slight discrepancy in the year 2019, with respect to the 2021 NIR, is a result of the above-described updating of milk-yield data.

Table 221: Mean daily milk yield for dairy cows (3.A)

[kg d-1]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
milk yield	12.88	14.78	16.60	18.40	19.41	19.84	20.06	20.12	20.66	20.90	21.22	21.27	22.10	22.59	23.17

For dairy cows, dairy heifers and female beef cattle, male beef cattle, suckler cows, sows, weaners and fattening pigs, the gross energy (GE) intake is calculated as a function of performance. Cf. in this regard the following chapters in Vos et al. (2022): dairy cows, 4.3.3; dairy heifers and female beef cattle, 4.5.3; male beef cattle, 4.6.3; suckler cows, 4.5.3; sows, 5.3.3; weaners, 5.4.3; fattening pigs, 5.5.3. Such calculations are based on the IPCC concept (IPCC (2006a Vol 4, Chapter 10.2.2)) to the effect that feeding precisely meets animals' energy requirements. The energy requirements for dairy cows are given in terms of the "net energy for lactation (NEL)" (cf. Kirchgessner et al. (2008)), while the term "metabolizable energy (ME)" is used for other animals for which the German inventory includes energy-requirements calculations (for example, cf. Gesellschaft für Ernährungsphysiologie (2006)).

The NEL and ME requirements figures comprise all relevant sub-requirements categories (maintenance, growth, production of young and products, grazing) that are relevant for the applicable animal category in each case. The quantity of feed, of a given composition, required to meet NEL and ME energy requirements is calculated on the basis of the energy requirements and the mean NEL and ME energy content of the feed . The GE intake for a given animal is calculated on the basis of the feed quantity ingested and the mean GE content of the feed.

The GE-intake figure for boars is a standard value. For calves, and male cattle older than 2 years, GE intake is derived from standard values for ME intake. Cf. in this regard the following chapters in Vos et al. (2022): calves, 4.4.2; male cattle older than 2 years, 4.8.2; boars, 5.6.3. No GE intake figures are determined for the remaining animal categories (sheep, goats, horses, poultry).

Table 222 shows the daily GE intake for dairy cows, other cattle and swine. The discrepancies with respect to Table 230 in the 2021 NIR are the result of the described changes in the calculation of animal performance and feeding.

Table 222: Mean daily GE intake (3.A)

[MJ place^{-1} d^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	241.3	264.0	283.0	298.8	307.5	310.5	312.5	312.0	316.0	318.9	322.3	322.5	329.4	336.7	342.6
Other cattle	100.1	104.0	106.9	106.6	108.1	107.7	107.6	107.8	107.6	108.2	108.2	108.6	109.0	110.0	110.9
Swine	30.9	32.5	33.4	33.5	34.0	34.3	34.5	34.8	35.1	35.2	35.5	35.7	36.0	36.1	36.4

Table 224 through Table 226 show, for dairy cows, other cattle and swine, the input data for the VS calculation on which the calculation of CH_4 emissions from manure management is based (cf. Chapter 5.3.2.2.1). The data include dry-matter (DM) intake, digestibility of organic matter and ash content of feed. For details on DM intake, we refer to the animal-specific chapters in Vos et al. (2022); cf. Table 223. No DM intake figures are determined for sheep, goats, horses and geese, because no pertinent data on feeding are available. Neither are any standard values available. For this reason, the VS-excretion figures are obtained by other methods; cf. Chapter 5.1.3.5. Discrepancies with respect to the 2021 submission are a result of the aforementioned changes in performance and feed-related data.

Table 223: Description of DM intake in Vos et al. (2022)

Animal category	Chapter	Animal category	Chapter
Dairy cows	4.3.3	Mature sheep	---
Calves	4.4.2	Lambs	---
Dairy heifers and female beef cattle	4.5.3	Goats	---
Male beef cattle	4.6.3	Heavy horses	---
Suckler cows	4.7.3	Light horses / ponies	---
Male cattle > 2 years	4.8.2	Laying hens	8.3.4
Sows	5.3.3	Broilers	8.4.3
Weaners	5.4.3	Pullets	8.5.4
Fattening pigs	5.5.3	Geese	---
Boars	5.6.3	Ducks	8.7.4
		Turkeys	8.8.2.3

Table 224: Daily DM intake

[kg^{-1} place^{-1} d^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	13.20	14.44	15.47	16.32	16.75	16.90	17.00	16.97	17.17	17.33	17.51	17.52	17.89	18.29	18.55
Other cattle	5.47	5.69	5.85	5.84	5.91	5.89	5.88	5.89	5.88	5.91	5.91	5.93	5.96	6.01	6.06
Swine	1.84	1.94	1.98	2.00	2.05	2.06	2.08	2.09	2.11	2.14	2.16	2.18	2.19	2.20	2.21

The mean digestibility and the mean ash content of feed have been determined largely on the basis of German standard values for the various feed components (DLG, 2005, 2014), in combination with information provided by experts (Spiekers, 2019). Lacking data have been estimated on the basis of other sources (including Beyer et al. (2004) and information provided by producers). Discrepancies between a) the values given in Table 225 and Table 226 and b) the corresponding table values in the 2021 NIR result from the aforementioned changes in performance and feed data.

Table 225: Digestibility of organic matter in feed (3.A)

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	75.6	75.5	75.6	75.9	75.8	75.8	75.8	75.8	75.8	75.8	75.8	75.8	75.9	76.0	76.0
Other cattle	74.5	74.3	74.1	74.2	74.1	74.1	74.1	74.1	74.1	74.0	74.1	74.1	74.0	74.0	74.0
Swine	82.8	82.8	82.8	83.5	84.2	84.2	84.2	84.3	84.3	84.3	84.3	84.3	84.3	84.3	84.3

Table 226: Ash content of feed

[kg kg⁻¹]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	0.084	0.084	0.083	0.082	0.078	0.077	0.077	0.076	0.075	0.075	0.075	0.075	0.075	0.075	0.075
Other cattle	0.089	0.090	0.090	0.090	0.089	0.089	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.088	0.087
Swine	0.060	0.060	0.051	0.049	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048

The following chapters present further information related to animal husbandry – for example, excretion data (N, VS).

None of the animal models used call for mean percentages of pregnant animals as input figures. For cattle, they are reported in CRF Table 3.A, however, in the interest of completeness.

5.1.3.4 N excretions (3.B)

The manner in which N excretions are determined is described in the animal-specific chapters in Haenel et al. (2020a); (Vos et al., 2022); cf. Table 227.

Table 227: Description of N excretions in Vos et al. (2022)

Animal category	Chapter	Animal category	Chapter
Dairy cows	4.3.7.1	Mature sheep	6.3.5
Calves	4.4.6.1	Lambs	6.4.5
Dairy heifers and female beef cattle	4.5.7.1	Goats	6.6.5
Male beef cattle	4.6.7.1	Heavy horses	7.3.5
Suckler cows	4.7.7.1	Light horses / ponies	7.4.5
Male cattle > 2 years	4.8.6.1	Laying hens	8.3.8.1
Sows	5.3.7.1	Broilers	8.4.7.1
Weaners	5.4.7.1	Pullets	8.5.8.1
Fattening pigs	5.5.7.1	Geese	8.6.6
Boars	5.6.7.1	Ducks	8.7.8.1
		Turkeys	8.8.6.1

For dairy cows, dairy heifers and female beef cattle, male beef cattle, suckler cows, swine (except for boars), laying hens, pullets, broilers, ducks and turkey cocks and turkey hens, N excretions are calculated as a function of performance. For other animals, the N-excretion values are taken or derived from the relevant German technical literature.

Calculation of N excretions as a function of performance is based on the assumption that feeding precisely meets energy requirements (cf. Chapter 5.1.3.3). The N quantity ingested by an animal is obtained from the ingested quantity of feed and the mean N quantity of the feed ration that conforms to relevant national feeding recommendations. Growth-related N retention, N output via products (milk/eggs) and N losses via pregnancy/offspring are all deducted from the ingested N quantity. The remaining N quantity is the N-excretion figure.

The following parameters enter into calculation of N excretions:

- Dairy cows: milk yield, milk-protein content, milk-fat content, animal weight, weight gain, numbers of births per year, feed characteristics
- Suckler cows: milk yield, animal weight, weight gain, numbers of births per year (constant values in each case), feed characteristics (these vary, because grazing periods vary)
- Dairy heifers, female beef cattle and male beef cattle: weight gain, final weight and feed characteristics;
- Swine: animal weight; for sows, also number of piglets per year; for weaners and fattening pigs, also weight gain and feed characteristics;
- Laying hens, pullets, ducks, turkeys: weight gain, final weight, and feed characteristics; for laying hens, also egg production and egg weights;
- Broilers: Gross meat quantities at slaughter, feed characteristics.

For animal categories with grazing, calculated N excretions per animal place and year are broken down into in-pasture and in-housing excretions, since only in-housing excretions can enter into calculation of N_2O emissions in 3.B. Calculation of N_2O emissions in 3.D takes account of N excretions in pasture. N excretions are divided into in-housing and in-pasture categories in keeping with the relative time proportions for time in housing and time on pasture (cf. Chapter 19.3.2, Table 569).

Table 228 shows the time series for N excretions. The N excretions for goats, which are not listed, are constant over time (11.0 kg place^{-1} a^{-1}). For other cattle, the N excretions are somewhat lower than the corresponding figure in the 2021 NIR, as a result of adjustments, as mentioned in Chapter 5.1.3.3, to bring the suckler-cow model in line with German standard recommendations. The N excretions of swine have changed slightly, throughout the entire time series, as a result of updating of feed parameters for fattening pigs, as described in Chapter 5.1.3.3. The N excretions for poultry are lower than as given in the 2021 NIR. This is due especially to a change in the feed parameters for broilers.

Table 228: N excretions per animal place and year (3.B(b))

[kg place^{-1} a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	92.0	97.9	103.8	108.9	110.3	110.9	111.1	110.5	111.5	112.8	114.2	113.9	116.4	119.5	121.8
Other cattle	37.9	39.9	41.3	41.2	42.1	42.0	42.0	42.1	42.2	42.5	42.5	42.7	42.9	43.3	43.7
Swine	13.0	13.4	13.2	13.0	12.8	12.8	12.8	12.8	12.8	13.0	13.1	13.1	13.1	13.0	13.0
Sheep	7.7	7.7	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
Horses	48.2	48.1	49.0	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8	48.8
Poultry	0.68	0.65	0.66	0.72	0.74	0.71	0.69	0.65	0.66	0.67	0.68	0.68	0.68	0.67	0.66

Table 229 shows the annual N excretions for the four manure management systems "slurry-based (without digestion)," "straw-based (without deep bedding and without digestion)," "deep bedding (without digestion)" and "digestion"; as well as for "grazing". The changes in comparison to the 2021 submission are due, for the most part, to use of new data from the 2020 agricultural census; cf. Chapter 5.1.3.3.

Table 229: Annual N excretions, broken down by manure management systems (3.B(b)) and grazing systems (3.D)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	1555.1	1336.2	1301.0	1253.9	1246.6	1249.5	1267.5	1280.7	1294.6	1293.0	1283.9	1277.9	1257.0	1245.8	1234.2
Slurry-based [a]	870.5	820.1	803.4	742.3	630.3	612.7	616.9	606.0	612.0	612.1	614.1	613.8	608.0	610.0	610.3
Straw-based [b]	423.1	292.7	283.5	279.6	287.9	281.0	277.8	272.9	266.6	257.7	247.4	238.4	229.0	219.9	208.4
Deep bedding [a]	48.4	49.9	53.5	61.3	63.2	65.5	70.1	75.7	80.8	84.2	88.1	91.2	93.7	96.8	99.2
Digestion	0.04	0.56	4.8	32.4	132.6	161.6	175.3	198.1	206.9	210.8	208.2	210.2	204.8	199.3	199.1
Grazing	213.1	172.9	155.7	138.3	132.7	128.8	127.4	127.8	128.3	128.2	126.1	124.3	121.6	119.9	117.3

[a] Without digestion

[b] Without deep bedding and without digestion

5.1.3.5 VS excretions (3.B)

The VS excretions for dairy cows, other cattle, swine and poultry (exception: geese) are calculated with the national procedure of Dämmgen et al. (2011); cf. Chapter 3.3.3.1 in Vos et al. (2022).

Equation 5: Calculation of VS excretions

$$VS_{\mathrm{i}} = m_{\mathrm{feed,\ DM,\ i}} \cdot (1 - X_{\mathrm{DOM,i}}) \cdot (1 - x_{\mathrm{ash,\ feed}})$$

VS_{i}	VS excretions for animal category i (in kg place^{-1} d^{-1})
$m_{\mathrm{feed,\ DM,\ i}}$	Dry-matter intake, animal category i (in kg place^{-1} d^{-1})
$X_{\mathrm{DOM,\ i}}$	Digestibility of organic matter, animal category i (in kg kg^{-1})

$X_{ash,i}$ Ash content of feed, animal category i (in kg kg^{-1})

The VS excretions for geese are estimated on the basis of the VS excretions for ducks; cf. Chapter 8.6.4 in Vos et al. (2022): 0.023 kg pl^{-1} d^{-1}.

The input data for the VS calculation include: dry-matter intake, digestibility of organic matter and ash content of feed; for a pertinent overview for dairy cows, other cattle and swine, cf. Chapter 5.1.3.3.

The VS excretions, calculated with national input data, for dairy cows, other cattle, swine and poultry are shown in Table 230. For other cattle, the VS excretions differ slightly from the figures given in the 2021 NIR, as a result of the adjustments in the suckler-cow model that are mentioned in Chapter 5.1.3.3. The changes in the broiler model that are described in the same chapter lead to only very slight changes in the VS excretions of poultry. The changes in the feed parameters for fattening pigs that are mentioned in that chapter lead to a considerable increase in the VS excretions for swine overall.

Table 230: Daily VS excretions, for dairy cows, other cattle, swine and poultry (without geese) (3.B(a))

[kg place^{-1} d^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	2.95	3.24	3.46	3.62	3.73	3.77	3.80	3.80	3.85	3.88	3.91	3.92	3.99	4.06	4.12
Other cattle	1.27	1.33	1.38	1.37	1.39	1.39	1.39	1.39	1.39	1.40	1.40	1.40	1.41	1.42	1.44
Swine	0.30	0.31	0.32	0.31	0.31	0.31	0.31	0.31	0.32	0.32	0.32	0.33	0.33	0.33	0.33
Poultry	0.022	0.022	0.023	0.026	0.027	0.026	0.025	0.024	0.025	0.025	0.025	0.025	0.025	0.025	0.025

Table 231 shows the daily VS excretions for sheep, goats and horses. Cf. in this regard Vos et al. (2022), chapters 6.3.3, 6.4.3, 6.6.3, 7.3.3 and 7.4.3. Because the applicable population fractions for small and large animals vary from year to year, the mean VS excretions for sheep and horses do not remain constant over time. The annual variations are very small, however.

Table 231: Daily VS excretions for sheep, goats and horses (3.B(a))

[kg place^{-1} d^{-1}]	*VS*	Mean value, 2020
Mature sheep	0.53	0.41
Lambs	0.21	
Goats	0.30	0.30
Heavy horses	2.59	2.39
Light horses and ponies	1.73	

5.1.3.6 Housing systems, storage systems and application procedures (CRF 3.B, 3.D)

5.1.3.6.1 Frequency distributions (3.B, 3.D)

The German inventory uses annual frequency distributions, broken down by animal sub-categories, for the various husbandry systems (proportions for pasture grazing / stable housing; proportions for different housing systems), manure-storage systems and manure-application techniques, and time allotted to pasture grazing. The data for manure digestion and storage of digestates are discussed in Chapter 5.1.3.6.5 . Data collection and processing for the inventory, at the level of the German federal states, is described in detail in Chapter 3.4.3 in Vos et al. (2022). With regard to description of the frequency distributions at the level of Germany as a whole, we refer to Chapter 19.3.2 in the present NIR.

The following tables show, for the important animal categories "dairy cows," "other cattle," "swine," and "poultry," how the pertinent animal populations break down, in terms of percent of excreted VS, with respect to the various categories of manure management systems. Thanks to the 2020 agricultural census, new data became available, for the first time since 2010, on the frequencies of the various animal-housing systems; cf. Chapter 5.1.3.3. For this reason,

considerable discrepancies are seen for the period after 2010, in all animal categories, in comparison with last year's inventory.
Other changes with respect to the 2021 NIR are the result of updating of input data for manure digestion.

Table 232: Slurry-based systems without digestion, in % of excreted VS (3.B(a))

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	53.1	69.5	72.2	70.1	58.9	56.3	55.7	54.2	54.1	54.6	55.6	55.8	56.7	57.9	58.5
Other cattle	58.0	55.1	51.4	45.0	35.2	33.9	33.6	33.0	32.7	32.8	32.9	32.8	33.1	33.3	33.3
Swine	81.5	87.7	89.6	88.8	82.9	81.6	81.3	79.9	79.7	79.3	79.7	79.9	80.2	80.8	81.1

Table 233: Straw-based systems without digestion, in % of excreted VS (3.B(a))

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	26.8	15.1	14.7	15.3	15.5	14.6	13.9	13.1	12.3	11.6	10.8	10.0	9.2	8.5	7.7
Other cattle	19.8	18.4	19.0	20.6	23.9	22.6	21.3	20.1	19.0	18.1	16.9	15.8	14.7	13.6	12.5
Swine	16.3	10.3	8.4	7.4	6.3	5.8	5.3	5.0	4.7	4.4	4.1	3.8	3.6	3.3	3.0
Poultry	100.0	99.9	99.6	96.7	89.8	88.6	88.2	86.5	86.2	85.5	85.7	85.9	86.3	86.3	86.1

Table 234: Deep bedding systems without digestion, in % of excreted VS (3.B(a))

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	0.1	0.2	0.2	0.2	0.1	0.5	0.9	1.2	1.6	1.9	2.3	2.7	3.0	3.4	3.8
Other cattle	7.3	9.6	10.9	14.0	14.9	15.6	16.5	17.3	18.1	18.7	19.5	20.3	21.1	21.9	22.6
Swine	2.2	1.9	1.6	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3

Table 235: Digestion systems, in % of excreted VS (3.B(a))

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	0.003	0.053	0.52	3.3	15.3	18.6	20.0	22.1	22.9	23.0	22.8	23.3	23.1	22.5	22.6
Other cattle	0.003	0.034	0.28	2.0	7.1	8.8	9.5	10.4	10.7	10.6	10.6	10.9	10.6	10.4	10.5
Swine	0.002	0.040	0.32	2.4	9.5	11.3	12.1	13.8	14.3	15.0	14.9	15.0	14.9	14.6	14.6
Poultry	0.004	0.057	0.45	3.3	10.2	11.4	11.8	13.5	13.8	14.5	14.3	14.1	13.7	13.7	13.9

Table 236: Grazing, in % of excreted VS (3.B(a))

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	20.0	15.2	12.5	11.1	10.1	9.9	9.6	9.4	9.1	8.8	8.5	8.2	7.9	7.6	7.3
Other cattle	14.9	16.9	18.4	18.5	18.9	19.0	19.1	19.3	19.6	19.9	20.1	20.3	20.5	20.8	21.0

5.1.3.6.2 Bedding material in solid-manure systems

In solid-manure systems, additional nitrogen enters the system via the bedding material. In the inventory, this nitrogen is taken into account in calculation of N_2O and NO emissions from manure management. Table 569 in Chapter 19.3.2 lists the applicable bedding-material quantities, as fresh matter, for the various different animal-housing procedures. With a dry-matter content of 86 %, and an N quantity of 0.58 % in dry matter (cf. Chapter 3.3.4.3.2 in Vos et al. (2022)), the bedding-material N quantities listed in Table 237, for the various animal categories, result.

Discrepancies with respect to the 2021 NIR occur in all animal categories. For other cattle, the present submission reports higher N inputs via bedding material, because the share for housing with deep bedding has increased considerably, pursuant to the data of the 2020 agricultural census, and larger straw inputs are assumed for that housing system. For dairy cows and swine, on the other hand, the share for housing in slurry-based systems has increased, with the result that straw inputs have decreased in recent years.

Table 237: Annual totals for N inputs via bedding material, in straw-based systems

[kt a⁻¹]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**52.6**	**40.5**	**38.6**	**38.1**	**39.2**	**38.7**	**39.0**	**39.6**	**40.0**	**39.8**	**39.5**	**39.2**	**38.6**	**38.1**	**37.5**
Dairy cows	17.2	7.6	7.1	6.7	6.8	6.7	6.6	6.7	6.7	6.6	6.3	6.2	6.0	5.8	5.6
Other cattle	24.0	21.1	21.4	21.2	22.9	22.5	22.8	23.4	23.9	24.0	24.1	23.9	23.6	23.3	22.9
Swine	3.18	1.78	1.57	1.40	1.18	1.15	1.13	1.08	1.06	0.98	0.95	0.92	0.86	0.80	0.78
Sheep	0.83	0.75	0.70	0.68	0.58	0.51	0.50	0.48	0.48	0.47	0.47	0.47	0.47	0.46	0.45
Goats	0.04	0.05	0.07	0.08	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Horses	6.54	8.30	6.65	6.75	6.12	6.12	6.12	6.12	6.03	5.95	5.86	5.90	5.94	5.98	6.02
Poultry	0.82	0.93	1.11	1.28	1.52	1.63	1.74	1.84	1.80	1.75	1.71	1.70	1.68	1.67	1.66

5.1.3.6.3 Maximum methane-producing capacity B_o (3.B(b))

For calculation of emissions (cf. Chapter 5.3.2.2.1), the methane formation related to manure storage is characterized via the animal-specific maximum methane-producing capacity B_o and the storage-specific methane conversion factor *MCF*. With regard to the *MCF,* cf. Chapter 5.1.3.6.4.

Table 238 *shows the* B_o values used and the origins of the relevant data. For cattle and swine, the data are national data. For other animals (apart from pullets and geese), IPCC default values have been used. No IPCC default values are available for pullets and geese. For pullets, in a conservative approach, the default value (IPCC (2006a): Vol. 4) for laying hens was used. For the B_o for geese, a value of 0.36 m^3 kg^{-1} has been adopted, in keeping with Chapter 8.6.4 in Vos et al. (2022). Owing to variations in the population fractions for the various poultry categories, *the mean* B_o for poultry is not a constant, as Table 239 illustrates.

Table 238: Maximum methane-producing capacity B_o (3.B(b))

[m^3 kg^{-1}]	B_o	Source
Cattle	0.23	(Dämmgen et al., 2012a)
Swine	0.30	(Dämmgen et al., 2012a)
Sheep	0.19	(IPCC, 2006a Vol 4, 10.82)
Goats	0.18	(IPCC, 2006a Vol 4, 10.82)
Horses	0.30	(IPCC, 2006a Vol 4, 10.82)
Laying hens	0.39	(IPCC, 2006a Vol 4, 10.82)
Broilers	0.36	(IPCC, 2006a Vol 4, 10.82)
Ducks	0.36	(IPCC, 2006a Vol 4, 10.82)
Turkeys	0.36	(IPCC, 2006a Vol 4, 10.82)
Pullets	0.39	Assumption (see text)
Geese	0.36	Chapter 8.6.4 in Vos et al. (2022)

Table 239: Maximum methane-producing capacity B_o for poultry (3.B(b))

[m^3 kg^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Poultry	0.380	0.377	0.374	0.372	0.370	0.370	0.371	0.371	0.371	0.372	0.372	0.372	0.372	0.372	0.373

5.1.3.6.4 Methane conversion factors MCF (3.B)

In CRF 3.B(a), the MCF values for the various national manure management categories are to be reported under "Additional Information." In Germany, the pertinent categories are "slurry-based without digestion", "straw-based without digestion" (heap), "deep bedding without digestion", "digestion" and "pasture". The values are weighted average values, over all animal categories, based on the MCF values described below. The category "slurry-based without digestion" includes all animals housed in slurry-based systems with no digestion of the animals' manure. The categories "straw-based without digestion (solid-manure-storage systems)" and "deep bedding without digestion" should be understood in the same way. The "digestion" category includes all animals whose manure is digested.

Table 240 shows the MCF values for cattle, broken down by the storage systems commonly used in Germany. The national values proposed by Dämmgen et al. (2012a) are in boldface type. In a conservative approach, chosen due to a lack of IPCC default values or national values, the MCF applying to "liquid manure without natural crust" was used for "liquid manure with solid cover" (including tent structures), "liquid manure with floating chopped-straw cover" and "liquid manure with floating cover foil." The values for deep bedding and pasture were taken from IPCC (2006a Vol 4, 10.44).

Table 240: Methane conversion factors *MCF* (in percent of B_o) for cattle (3.B(a))

		MCF [%]
Liquid manure	Open tank, without natural crust	**17**
	Solid cover	17
	Natural crust	**10**
	Floating cover (chopped straw)	17
	Floating cover (cover foil)	17
	Below slatted floor > 1 month	**17**
Solid manure	Deep bedding	17
	Heap	**2**
Pasture		1

Table 241 lists the methane conversion factors MCF for manure storage in swine husbandry. As is the case for the cattle data, the values consist of national values (Dämmgen et al., 2012a), default values from IPCC (2006a Vol 4, 10.44) IPCC (2006a) or conservative assumptions in cases in which no MCF is known. For cattle, the MCF for "deep bedding" is the same as that for liquid manure without natural crust, and thus the same relationship has been assumed to hold for swine. Free-range management of swine ("pasture") plays a very insignificant role in Germany and is thus not taken into account in the inventory. Any excretions on pasture are included in the other housing systems (included elsewhere, IE).

Table 241: M*ethane-conversion factors* MCF *(in percent of* B_o) for swine (3.B(a))

		MCF [%]
Liquid manure	Open tank, without natural crust	**25**
	Solid cover	25
	Natural crust	**15**
	Floating cover (chopped straw)	25
	Floating cover (cover foil)	25
	Below slatted floor > 1 month	**25**
Solid manure	Deep bedding	25
	Heap	**3**

The average methane conversion factors for slurry-based systems without digestion, for dairy cows, other cattle and swine, depend on the frequencies of the various applicable housing systems and thus are not constant, as Table 242 shows.

Table 242: Average *methane conversion factors* MCF *(in percent of* B_o) for slurry-based systems without digestion (3.B(a))

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	14.3	14.0	14.0	14.3	14.9	14.9	14.9	14.9	14.9	14.8	14.8	14.7	14.7	14.6	14.6
Other cattle	14.6	14.4	14.6	14.8	15.1	15.1	15.0	15.0	15.0	14.9	14.9	14.9	14.8	14.8	14.7
Swine	24.7	23.7	23.6	22.8	22.2	22.3	22.4	22.5	22.6	22.7	22.7	22.8	22.9	23.0	23.1

For storage of manure from other animals (goats, sheep, horses and poultry), default values from IPCC (2006a Vol 4, 10.44) are used (cf. Table 243).

Table 243: Methane conversion factors MCF (in percent of B_o) for goats, sheep, horses and poultry (3.B(a))

MCF [%] [a]	
Heap	2
Poultry manure	1.5
Pasture	1

For systems in which manure is digested, a variable MCF results, when the various contributions from pre-storage systems, digesters and systems for storage of digestates are taken into account (cf. Chapter 5.1.3.6.5).

5.1.3.6.5 Manure digestion and storage of digestates (3.B)

Pursuant to IPCC (2006a, Vol. 4, Tab. 10.17), anaerobic digestion of manure, with storage of the resulting digestates, is considered to be a separate storage-system type. In keeping with the German situation, that storage type is taken into account for cattle, swine and poultry (Haenel and Wulf (2016); chapters 3.3.4.4 and 3.4.4 in Vos et al. (2022)). The time series for the activity data have been provided by Grebe et al. (unveröffentlicht). They are based primarily on data of the Deutsches Biomasseforschungszentrum (DBFZ), but they also take account of the animal N excretions calculated for the inventory.

Equation 6, using the example of slurry, describes the concept used by Grebe et al. (unveröffentlicht) to determine the relevant relative fractions of manure that undergo digestion. Equation 6 is used in a similar manner for solid manure (including the N from the bedding material). The aggregation into "manure, total" is carried out on the basis of numbers of animals and of animal-specific manure production.

Equation 6: Concept for calculation of the percentage shares of digested manure with respect to total manure production

$$pct_{\mathrm{SL,dig,i}}(y) = 100 \cdot \frac{SL_{\mathrm{dig,i}}(y)}{SL_{\mathrm{total,i}}(y)} = 100 \cdot \frac{W_{\mathrm{el,dig}}(y) \cdot s_{\mathrm{i}}}{SL_{\mathrm{total,i}}(y)}$$

Where

$pct_{\mathrm{SL, dig, i}}$	Quantity of digestates, as a fraction of the total slurry production of animal category i (in %)
i	Index of the pertinent animal category
y	Year (1990, 1991, …)
$SL_{\mathrm{dig, i}}$	Quantity of nitrogen in digestates of animal category i (in kg a^{-1})
$SL_{\mathrm{total, i}}$	Total slurry production (nitrogen quantity) of animal category i (in kg a^{-1})
$W_{\mathrm{el, dig}}$	Annual electrical work of German biogas plants (in GWh_{el} a^{-1})
s_{i}	Work-specific substrate input (nitrogen quantity) of animal category i (in kg GWh_{el}^{-1})

Grebe et al. (unveröffentlicht) derived the applicable annual electrical work $W_{\mathrm{el, dig}}$, differentiated by German federal states and plant-performance classes, from data of the registry of biogas plants (Biogasanlagenregister). In the process, consideration of the factor "equivalent electrical work" makes it possible to take account also of those biogas plants that solely feed biomethane into the gas network, i.e. without producing any electricity. The work-specific substrate input s_{i} was calculated separately for cattle slurry, cattle manure, swine slurry and poultry manure, using data from 1,664 biogas plants. The nitrogen quantities $SL_{\mathrm{total, i}}$ were derived from the numbers of animals and from the animal-specific slurry and solid-manure production (including bedding material). The time series have been updated with respect to the 2021 submission.

Table 244 shows the resulting updated fractions for digestion of cattle slurry, cattle solid manure, swine slurry and poultry manure, as well as the resulting updated digested fractions of the total manure quantity from animal husbandry, expressed as percentages of the N quantities entering into storage systems. For solid swine manure, no digestion is taken into account, since the relevant data are of uncertain reliability, due to the small quantities of solid manure involved. In general, the discrepancies with respect to Table 252 in the 2021 NIR result from the changes in the N excretions calculated for the inventory.

Table 244: Relative shares of manure undergoing digestion (in % of the N quantities entering storage), for the various animal categories with manure undergoing digestion, along with pertinent weighted averages for all animal husbandry overall

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**0.003**	**0.048**	**0.42**	**2.9**	**11.9**	**14.4**	**15.4**	**17.2**	**17.7**	**18.1**	**18.0**	**18.2**	**18.0**	**17.7**	**17.8**
Cattle slurry	0.005	0.066	0.60	4.1	18.4	22.5	24.1	26.5	27.3	27.6	27.3	27.8	27.0	26.0	**26.1**
Cattle solid manure	0.001	0.015	0.13	0.9	3.1	4.0	4.4	4.8	5.0	5.2	5.2	5.4	5.4	5.4	**5.6**
Swine slurry	0.003	0.045	0.36	2.6	10.3	12.2	13.0	14.9	15.2	16.0	15.9	15.9	15.8	15.5	**15.4**
Poultry manure	0.004	0.057	0.44	3.3	10.2	11.4	11.8	13.5	13.8	14.5	14.4	14.1	13.7	13.7	**14.0**

The data in Table 244 are also used to calculate the share of stored VS quantities that undergoes digestion.

The total MCF for digestion of manure and slurry in biogas plants, including pre-storage systems and systems for storage of digestates, is calculated in accordance with a national method; cf. Equation 7. For derivation of this equation, cf. Chapter 3.3.4.4.1 in Vos et al. (2022).

Equation 7: Calculation of total MCF for digestion of manure and slurry in biogas plants, including pre-storage of substrate and storage of digestates

$$MCF\% = MCF\%_{ps} + (100\,\% - MCF\%_{ps}) \cdot \left((1-\mu_{rg}) \cdot L_{dig} \; + \; \mu_{rg} \cdot \frac{MCF\%_{residues}}{100\,\%} \right)$$

Where

$MCF\%$	Total MCF for the system "pre-storage system + digester + system for storage of digestates" (in %)
$MCF\%_{ps}$	MCF for the pre-storage system (in %)
μ_{rg}	Potential for residual gas production, with respect to B_o (with $0 \le \mu_{rg} \le 1$ m³ m⁻³)
L_{dig}	Relative leakage rate of the digester, with respect to the quantity of CH_4 produced in the digester (with $0 \le L_{dig} \le 1$ m^3 m^{-3})
$MCF\%_{residues}$	MCF for the system for storage of digestates (in %)

Table 245 shows the methane conversion factors $MCF\%_{ps}$ for pre-storage systems. For derivation of this equation, cf. Chapter 3.4.4.2.2 in Vos et al. (2022).

Table 245: Methane conversion factors for pre-storage systems (in percent of B_o)

$MCF\%_{ps}$ [%]	
Cattle slurry	1.7
Cattle solid manure	0.2
Swine slurry	2.5
Poultry manure	0.15

On the basis of (Grebe et al., unveröffentlicht), the potential CH_4 residual gas potential μ_{rg} with respect to B_o has been set at 4.6 % (or 0.046 m^3 m^{-3}); cf. Chapter 3.4.4.2.2 in Vos et al. (2022).

In keeping with the figures given in Bachmaier and Gronauer (2007), Börjesson and Berglund (2007), Gärtner et al. (2008) and Roth et al. (2011), the leakage rate of digester L_{dig} is set at 1 %, or 0.01 m^3 m^{-3} (Grebe et al., unveröffentlicht). In a 2016 study, UBA also applied a leakage rate of of 1 %, from Fehrenbach et al. (2016, p. 113).

A leakage rate is assumed even for a gas-tight system for storage of residues from manure digestion; that leakage rate is assumed to be the same as that of the digester. Taking account of the relative share of gas-tight storage systems, with respect to all storage of digestates, one obtains Equation 8.

Equation 8: Calculation of *MCF* for systems for storage of digestates

$$MCF\%_{\text{residues}} = x_{\text{gts}} \cdot (100 \cdot L_{\text{sto,gt}}) + (1 - x_{\text{gts}}) \cdot MCF\%_{\text{ngts}}$$

Where

$MCF\%_{residues}$	MCF for the system for storage of digestates (in %)
x_{gts}	Relative share of gas-tight storage of digestates (in kg kg^{-1})
$L_{sto,gt}$	Relative leakage rate for gas-tight storage of digestates ($L_{sto,gt} = L_{dig}$)
$MCF\%_{ngts}$	MCF for non-gas-tight systems for storage of digestates (in %)

In general, digestates are in a liquid state. For non-gas-tight storage of digestates, it is assumed that a natural floating crust forms, as a result of co-digestion of energy crops, which increases the dry-matter content in the digestates. This type of storage is thus similar to open storage of undigested cattle slurry with a natural floating crust. For this reason, the relevant MCF for undigested cattle slurry is used for $MCF\%_{ngts}$: 10 % (cf. Chapter 5.1.3.6.4).

Table 246 shows the fraction of gas-tight storage of manure digestates, as a percentage share of all storage of manure digestates, and in percent of N inputs. The data were derived by Grebe et al. (unveröffentlicht) from the pertinent input quantities of digestion substrates, broken down by German federal states and by plant-performance classes, as well as by the percentage shares of biogas plants with gas-tight, covered storage of digestates, with respect to the performance classes prevailing in Germany. The sharp increase, from 2011 to 2012, in the use of gas-tight storage of digestates is attributed to the 2012 German act on electricity feed-in (Energieeinspeisegesetz, EEG), which mandates gas-tight covers for all digestate-storage systems that went into operation on or after 1 January 2012. The percentage values for gas-tight covers in 2019 have been updated with respect to the 2021 submission. This has led to an increase of about 0.6 percentage points in the distribution share for gas-tight covers. For 2020, the values for 2019 have been carried forward, due to a lack of new data.

Table 246: Percentage shares for storage of digestates in gas-tight and non-gas-tight storage systems (in percent of the N inputs in biogas plants)

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
gas-tight	0.0	4.5	9.1	15.2	40.6	45.6	57.0	59.1	60.9	61.6	61.9	61.8	62.2	62.8	62.8
non- gas-tight	100.0	95.5	90.9	84.8	59.4	54.4	43.0	40.9	39.1	38.4	38.1	38.2	37.8	37.2	37.2

The total MCF values resulting from Equation 7, for the systems "pre-storage systems + digester + system for storage of digestates", for dairy cows, other cattle, swine and poultry, are listed in the following table.

Table 247: Average methane conversion factors *MCF* (in percent of B_o) for manure management systems with digestion (3.B(a))

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	2.99	3.01	3.00	2.97	2.87	2.85	2.81	2.80	2.79	2.79	2.79	2.79	2.79	2.79	2.79
Other cattle	2.98	2.89	2.85	2.79	2.67	2.64	2.59	2.58	2.57	2.56	2.56	2.56	2.55	2.55	2.54
Swine	3.88	3.86	3.84	3.82	3.71	3.69	3.65	3.64	3.63	3.63	3.63	3.63	3.63	3.62	3.62
Poultry	1.56	1.54	1.53	1.50	1.40	1.38	1.33	1.33	1.32	1.31	1.31	1.31	1.31	1.31	1.31

The reduction of CH_4 emissions from manure management that is related to digestion depends on the fraction of manure that is digested, as well as on the relative frequency of gas-tight systems for storage of digestates. The pertinent reductions resulting in Germany are given in Chapter 5.3.2.2.3.

Table 248 lists the N_2O emissions that the inventory takes account of for the various relevant sub-systems and manure types. For details, cf. Chapter 3.3.4.4.2 in Vos et al. (2022).

N_2O and NO emissions from agricultural soils, resulting from application of digestates, are described in Chapter 5.5.

Table 248: Calculation of N_2O emissions from anaerobic digestion

		Slurry	Solid manure / poultry manure
Pre-storage systems		0	Equation 9
Digester		0	0
System for storage of digestates	gas-tight	0	0
	non- gas-tight	Equation 10	Equation 10

Equation 9: Calculation of N_2O emissions from systems for pre-storage of solid manure and poultry manure

$$E_{\mathrm{N2O\text{-}N,dig,ps}} = (N_{\mathrm{excr,dig}} + N_{\mathrm{straw,dig}}) \cdot EF_{\mathrm{N2O\text{-}N,dig,ps}}$$

Where

$E_{\mathrm{N2O\text{-}N,\,dig,\,ps}}$	N losses via N_2O emissions from pre-storage of solid manure or poultry manure (in kg N_2O-N a^{-1})
$N_{\mathrm{excr,\,dig}}$	Fraction of annual in-stable N excretions that goes to digestion (in kg a^{-1})
$N_{\mathrm{straw,\,dig}}$	Fraction of annual N inputs from bedding material that goes to digestion (in kg a^{-1})
$EF_{\mathrm{N2O\text{-}N,\,dig,\,ps}}$	N_2O-N emission factor for pre-storage of solid manure or poultry manure (in kg N_2O-N per kg N)

Equation 10: Calculation of N_2O emissions from non-gas-tight storage of digestates

$$E_{\mathrm{N2O\text{-}N,dig,ngts}} = (1 - x_{\mathrm{gts}}) \cdot N_{\mathrm{tot,dig,ferm}} \cdot EF_{\mathrm{N2O\text{-}N,dig,ngts}}$$

Where

$E_{\mathrm{N2O\text{-}N,\,dig,\,ngts}}$	N losses via N_2O emissions from non-gas-tight storage of digestates (in kg N_2O-N a^{-1})
x_{gts}	Relative share of gas-tight storage of digestates (in kg kg^{-1})
$N_{\mathrm{tot,\,dig,\,ferm}}$	Total N quantity from digestates that leaves the digester (in kg a^{-1})
$EF_{\mathrm{N2O\text{-}N,\,dig,\,ngts}}$	N_2O-N emission factor for non-gas-tight storage of digestates (in kg N_2O-N per kg N)

The N_2O emission factors used in the inventory are listed in Table 249. For the derivation of these factors, we refer to Chapter 3.4.4.2.3 in Vos et al. (2022).

Table 249: N_2O-N emission factors for manure pre-storage and for storage of digestates

	[kg kg^{-1}]	Solid manure	Poultry manure
Pre-storage systems	$EF_{\mathrm{N2O\text{-}N,\,dig,\,ps}}$	0.001	0.0001
Systems for storage of digestates, non-gas-tight	$EF_{\mathrm{N2O\text{-}N,\,dig,\,ngts}}$	0.005	0.005

The N quantity in digestates at the beginning of storage ($N_{\mathrm{tot,\,dig,\,ferm}}$) is calculated with inclusion of the N losses from pre-storage. It is assumed that no N losses from digesters occur.

The procedure for calculating NO emissions occurring in connection with manure digestion is similar to that for calculating N_2O emissions. As is customary in the German inventory's sections on manure management (cf. Chapter 3.3.4.3.5 in Vos et al. (2022 eq. 3.56), the NO-N emission factor is assumed to be one-tenth of the N_2O-N emission factor.

To calculate the indirect N_2O emissions from agricultural soils that are related to deposition of reactive nitrogen (cf. Chapter 5.5.2.1.2), one must also calculate the NH_3 emissions that occur in connection with digestion of manure. NH_3 emissions are calculated for pre-storage of solid manure and poultry manure, for non-gas-tight storage of digestates and for application of digestates. On the other hand, for pre-storage of slurry, for digesters and for gas-tight storage of digestates, it is assumed that NH_3 emissions either do not occur or are negligible. For details on the extensive subject of NH_3-calculation methods, see Chapters 3.3.4.4.3 and 3.4.4.2.4 in Vos et al. (2022).

5.1.4 Digestion of energy crops: Concept and activity data

5.1.4.1 The concept, and its consideration in the CRF tables

The inventory covers the six energy-crop categories that are the most important in Germany in terms of quantities: maize silage, grass silage, whole-plant silage, wheat grain, rye grain and Corn Cob Mix (CCM). They differ only slightly in terms of their key characteristics (N and VS content in dry matter, maximum methane formation potential B_o; cf. (Grebe et al., unveröffentlicht). This makes it possible to treat the total dry matter for all included energy crops as a single energy-crop category. The procedure for calculating the pertinent emissions is similar to that for calculating emissions from digestion of solid manure (cf. Chapter 5.1.3.6.5), with the exception that no pre-storage is included.

In practice, manure and energy crops are normally digested together. Nonetheless, the emissions occurring in connection with digestion of these two substrate categories are calculated separately, with a view to highlighting the contribution that energy-crop digestion makes to the greenhouse-gas balance.

For further details on emission calculation in connection with digestion of energy crops, see Chapters 3.3.5, 3.4.4.1 and, especially, Chapter 10 in Vos et al. (2022).

The following emissions are calculated that result, directly or indirectly, from digestion of energy crops, as well as from storage and application of digestates:

Digester (in 3.J)

- CH_4 (via leakage)

Storage (in 3.J)

- CH_4 (via leakage)
- Direct N_2O
- N_2O resulting indirectly from deposition of NH_3 and NO from storage
- NO

Application (in 3.D)

- Direct N_2O
- N_2O resulting indirectly from deposition of NH_3 and NO via application
- N_2O resulting indirectly from leaching / surface runoff of the nitrogen applied via spreading of digestates
- NO

The emissions from digesters and systems for storage of digestates (CH_4, N_2O, indirect N_2O from deposition of NH_3 and NO from storage) are described in Chapter 5.9 and reported under 3.J in CRF Table 3s2. The direct and indirect N_2O emissions occurring as a result of spreading of digestates are described in Chapter 5.5 and reported under 3.D (CRF 3.D: a.2.c, b.1 and b.2). The NO emissions resulting from application of digestates are also reported under 3.D, as NO_x emissions.

5.1.4.2 Activity data and parameters

The activity data used in calculation of the pertinent emissions consist of the total quantities of energy-crop dry matter that are input into digestion; cf. Table 250. The applicable substrate quantities were derived and provided in connection with calculations related to manure digestion (cf. Chapter 5.1.3.6.5). The data for 2019 have been updated, with respect to the 2021 NIR, by (Grebe et al., unveröffentlicht). The results show a very slight increase in 2019. The values from 2019 have been carried forward, due to a lack of data for 2020.

Table 250: Total dry matter in the energy crops input into biogas plants

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	3.4	43.9	380.8	3.216	11.619	14.492	15.870	19.194	20.089	20.865	20.750	20.410	20.111	20.120	20.120

A weighted average B_o value of 0.36 m^3 kg^{-1} was derived from the B_o values for the six energy-crop categories (cf. Chapter 5.1.4.1), using the IPCC default value for the density of methane (0.67 kg m^{-3}). The following weighted averages for the VS and N content resulted (with respect to dry matter): VS content, 0.947 kg kg^{-1}; N content, 0.0148 kg kg^{-1}.

The VS quantity required for calculation of the CH_4 emissions is obtained by multiplying the dry matter by the average VS content; cf. Table 251.

Table 251: Total VS quantity in the energy crops input into biogas plants

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	3.2	41.6	360.6	3.045	11.003	13.724	15.029	18.176	19.025	19.759	19.650	19.329	19.045	19.053	19.053

The N quantities required for calculation of the N emissions are obtained with the help of the relevant N content; cf. Table 252.

Table 252: Total N quantity in the energy crops input into biogas plants

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	0.05	0.65	5.6	47.6	172.0	214.5	234.9	284.1	297.3	308.8	307.1	302.1	297.6	297.8	297.8

In keeping with Grebe et al. (unveröffentlicht), the leakage rates for digesters and gas-tight systems for storage of digestates are considered to be the same as those used in connection with manure digestion (cf. Chapter 5.1.3.6.5).

Table 253 shows the fractions of gas-tight storage of residues of energy-crop digestion, as percentages of the pertinent input fresh matter (Grebe et al., unveröffentlicht). The data for 2019 have been updated with respect to the 2021 submission. Since no data on frequencies of use of gas-tight storage were available for 2020, the relevant figures for 2019 were retained for that year. The sharp increase, from 2011 to 2012, in the use of gas-tight storage of digestates is attributed to the 2012 German act on electricity feed-in (Energieeinspeisegesetz, EEG), which mandates gas-tight covers for all digestate-storage systems that went into operation on or after 1 January 2012. The data differ somewhat from those for storage of manure digestates (cf. Table 246). This is due to the fact that the total fraction of energy crops, with respect to the manure / energy-crop substrate mix, increases with plant (i.e. facility) size (a relationship that also holds for the covered-system fraction of systems for storage of digestates).

Table 253: Percentage shares for systems for gas-tight and non-gas-tight storage of digestates of energy crops (in percent of the fresh matter inputs into digestion)

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
gas-tight	0.0	4.7	9.4	15.8	42.2	47.5	59.4	61.9	63.9	64.6	64.8	64.5	64.8	65.5	65.5
non- gas-tight	100.0	95.3	90.6	84.2	57.8	52.5	40.6	38.1	36.1	35.4	35.2	35.5	35.2	34.5	34.5

A range of different application methods, and different incorporation periods for cropland and grassland, are used. The NH_3 emission factors for the different combinations involved vary. For calculation of direct N_2O emissions from application of digestates, only the N quantity applied needs to be taken into account. The indirect N_2O emissions from application-related deposition of reactive nitrogen, on the other hand, depend on total NH_3 emissions from application of digestates – and, thus, on the relative frequencies of the various application methods and incorporation periods used. The relative-frequency figures used were obtained from surveys carried out by the Federal Statistical Office in 2011 (for the year 2010), 2016 (for the year 2015) and 2020; cf. Chapter 19.3.2, Table 571.

5.1.5 Concept and activity data for emissions from agricultural soils and crops

5.1.5.1 N_2O emissions from agricultural soils (3.D)

5.1.5.1.1 Concept for calculation of direct emissions from agricultural soils

In the present 2022 submission, Tier 2 emission factors are being used for the first time for a) direct N_2O emissions from application of mineral fertiliser, manure, sewage sludge and digestates and b) N_2O emissions from crop residues. The Tier 2 emission factors, which differ by region at the NUTS-3 level, have been derived by Mathivanan et al. (2021). Details on division of N quantities at the NUTS-3 level are presented in Chapter 5.1.5.1.2, while the derivation of the emission factors is described in Chapter 5.5.2.1.1. Tier 1 emission factors from IPCC (2006a) continue to be used for N_2O emissions from mineralisation of organic substances in mineral soils and from grazing. For mineralisation in organic soils, Tier 2 emission factors from Tiemeyer et al. (2020a) are used.

5.1.5.1.2 The N quantities behind direct N_2O emissions (3.D)

Table 254 shows the N quantities, from various sources, that have been used as a basis for calculating direct N_2O emissions (cf. Chapter 5.5.2.1.1).

Table 254: N quantities on which calculation of direct N_2O emissions from agricultural soils are based (3.D)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Mineral fertiliser	2195.5	1723.0	1921.7	1796.7	1635.4	1665.3	1691.9	1654.8	1715.6	1736.2	1730.7	1622.0	1499.3	1403.7	1362.2
Manure, including digestates from manure digestion	1119.5	972.3	953.8	923.8	927.8	933.5	949.3	960.8	972.4	971.5	965.6	961.5	947.3	939.8	932.4
Digestates of energy crops	0.0	0.6	5.4	45.8	167.4	209.3	230.5	279.1	292.4	303.8	302.2	297.2	292.9	293.1	293.1
Sewage sludge	27.4	35.3	33.0	27.4	26.0	25.1	25.0	21.5	21.3	18.7	18.7	14.1	12.5	14.3	14.3
Grazing	213.1	172.9	155.7	138.3	132.7	128.8	127.4	127.8	128.3	128.2	126.1	124.3	121.6	119.9	117.3
Crop residues	485.3	498.3	560.4	587.1	572.7	560.3	604.9	604.8	689.1	606.0	588.7	620.7	499.2	558.9	574.5
Mineralisation	2.5	2.4	2.4	2.3	2.1	2.0	2.0	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.8

Since no data on mineral-fertiliser application are collected, the inventory considers the N quantities from mineral-fertiliser application to be the same as the N quantities given by official statistics on sales of mineral fertilisers. The delay in the relevant surveys amounts to half a year. For purposes of the inventory, all of the mineral fertiliser sold in the second half of year j-1, and all of the mineral fertiliser sold in the first half of year j, is assigned to year j. Since the 2021 submission, multiple-year averaging of mineral-fertiliser data has been carried out in order to approximate storage effects, for purposes of the inventory (this has included use of the following averages: for the period 1990 through 2019, a moving, centered three-year average; for 2020, a weighted average of 2019 (with weighting of 1/3) and 2020 (with weighting of 2/3)). This approach is in keeping with the examples of Austria (with an average over two years) and France (average over three years) (UNFCCC, 2021b).

The N quantity in the total quantity of applied manure is calculated with the help of the N-flow concept (cf. Chapter 3.3.4.3.1 in Vos et al. (2022)). As shown in Table 255, the N quantity applied with manure and digestates from manure digestion is equivalent to the sum of a) the N quantity excreted in housing systems and b) the N quantity introduced to solid-manute systems via bedding material, minus the losses via N emissions from housing and storage (manure: Chapter 1.5.2.4; digestates from manure digestion: Chapter 5.1.3.6.5). Emissions from application of digested and composted other substances – for example, from food waste and green waste – are reported in waste sector 5.B.2 (cf. Chapter 7.3.2).

Changes with respect to the 2021 NIR are the result of updating of input data and animal models; cf. Chapters 5.1.3.2.3, 5.1.3.3 and 5.1.3.6.5.

To calculate direct N_2O emissions from soils, one requires N-input data for the NUTS-3 regions. In the inventory model, the distribution of manure and digestates is calculated from activity data at the NUTS-3 level. It is assumed that manure is applied in the same NUTS-3 region in which it is produced. For the German federal states (NUTS-1 regions), data on the N quantity in sewage sludge are available; they are provided by the Federal Statistical Office on an annual basis. The data are apportioned to the NUTS-3 regions in keeping with their populations.

The quantities of mineral fertiliser applied in the NUTS-3 regions have been modelled, for the average of the years 2014-2016, with the help of the regionalised agricultural and environmental information system (RAUMIS, (Henrichsmeyer et al., 1996)); cf. (Mathivanan et al., 2021) for a detailed description. With regard to the synthetic-fertiliser N inputs for the various time-series years, it has been assumed each NUTS-3 region's N-quantity share of the nationally sold N quantity in synthetic fertilisers is as high, in all years, as it was in the year 2015, for which the breakdown modelled with RAUMIS is available. The NUTS-3 regions' shares of the national total-N quantity in synthetic fertilisers are shown in the map in Figure 46 (Mathivanan et al., 2021).

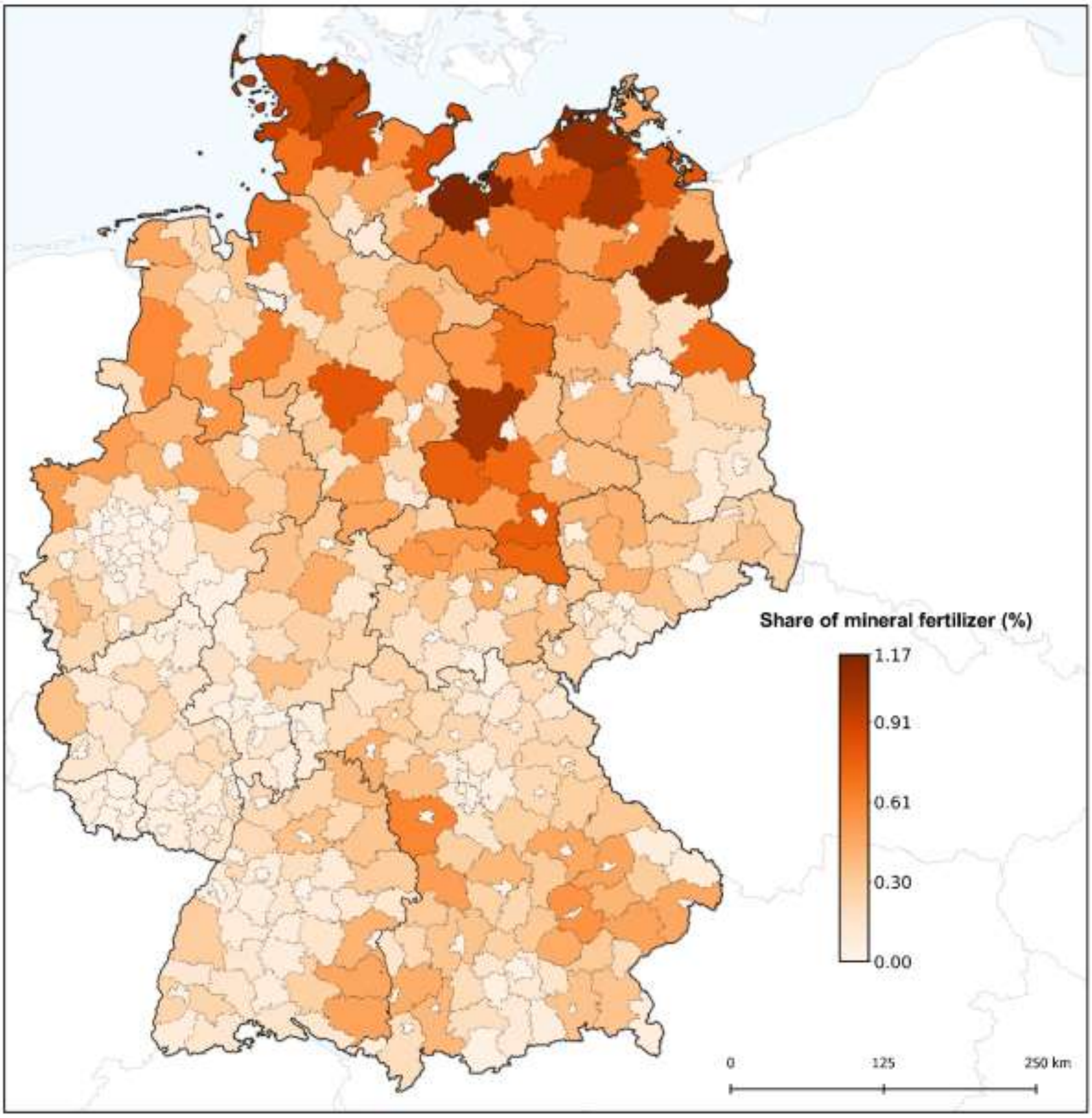


Figure 46: NUTS-3 regions' shares of national mineral-fertiliser quantities, as averages for the years 2014-2016.

Table 255: Calculation of the N quantities in the total sum of manure applied (including digestates of manure) (3.D)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
N excretions [a]	1342.0	1163.3	1145.3	1115.6	1114.0	1120.8	1140.1	1152.8	1166.3	1164.8	1157.8	1153.6	1135.4	1125.9	1116.9
+ bedding material N [b]	52.6	40.5	38.6	38.1	39.2	38.7	39.0	39.6	40.0	39.8	39.5	39.2	38.6	38.1	37.5
- (NH_3-N + NO-N) [c]	-254.1	-212.6	-211.6	-211.6	-207.2	-208.2	-212.3	-214.2	-216.3	-215.6	-214.2	-214.1	-209.8	-207.5	-205.6
- N_2O-N [d]	-5.3	-4.7	-4.6	-4.6	-4.5	-4.4	-4.4	-4.4	-4.4	-4.4	-4.3	-4.3	-4.2	-4.2	-4.2
- N_2 [e]	-15.8	-14.2	-13.8	-13.7	-13.6	-13.3	-13.1	-13.1	-13.2	-13.1	-13.0	-12.9	-12.7	-12.6	-12.5
Result	**1119.5**	**972.3**	**953.8**	**923.8**	**927.8**	**933.5**	**949.3**	**960.8**	**972.4**	**971.5**	**965.6**	**961.5**	**947.3**	**939.8**	**932.2**

[a] Total N excretions after deduction of excretions during grazing; cf. Table 229 in the present NIR (corresponds to the sum of line 38 in CRF Table 3.B(b))

[b] cf. Table 237 in the present NIR

[c] cf. cell O37 in CRF Table 3.B(b)

[d] cf. Table 296 in the present NIR (corresponds to cell T40 in CRF Table 3.B(b), multiplied by the molar ratio 28/44)

[e] N_2 emissions from manure management are calculated as three times the N_2O-N emissions (cf. Vos et al. (2022), Chapter 3.3.4.3.5, equation (3.58))

The N quantity that is applied with digestates from digestion of energy crops is obtained as the N quantity in the energy crops input into digestion, minus the N losses via emissions from the system for storage of digestates.

For each federal state in Germany, N quantities from sewage-sludge application are taken from data of the Federal Environment Agency (Section III 3.3) and (since 2009) of the Federal Statistical Office (Section G 202). Since no data were available for 2020, the relevant figure for 2019 was carried forward for that year.

The direct N_2O emissions from N excretions during grazing are calculated in proportion to the N quantity excreted on pasture (cf. Chapter 5.1.3.4).

The quantities of N remaining in the soil in crop residues are obtained from the relevant areas under cultivation, yields and crop-specific N content data. Data on areas under cultivation and fresh-matter yields are reported in (Statistisches Bundesamt, FS 3, R 3a). The data are converted into dry-matter yields with the help of dry-matter-content data given by the Fertiliser Ordinance (DüV, 2017). The relative N quantities contained in crop residues are taken from the Fertiliser Ordinance (DüV, 2007, 2017) and from a list prepared by the Institute of Vegetable and Ornamental Crops (Feller et al., 2011). The N quantities removed from relevant areas, for bedding material in animal husbandry, are deducted. For the pertinent input data and calculation methods, cf. Chapter 11.7 in Vos et al. (2022).

In the present NIR, the method for determining N mineralisation in mineral cropland soils is described in Chapter 6 (cf. Chapters 6.1.2.7, 6.1.2.8 and 6.5.2.3.2).

Changes with respect to the 2021 submission result for the following input data and N quantities on which calculation of direct N_2O emissions is based:

- **2020 agricultural census:** For the present 2022 submission, some already available input data from the 2020 agricultural census were used, such as data on applicable shares for animal-housing systems, for application procedures for manure, and for grazing. This has resulted in changes – in some cases, considerable ones – in the calculated applied nitrogen quantities, throughout the period back to 2000. Figure 47 shows, by way of example, the change in the application procedures for slurry between 2015 and 2020.

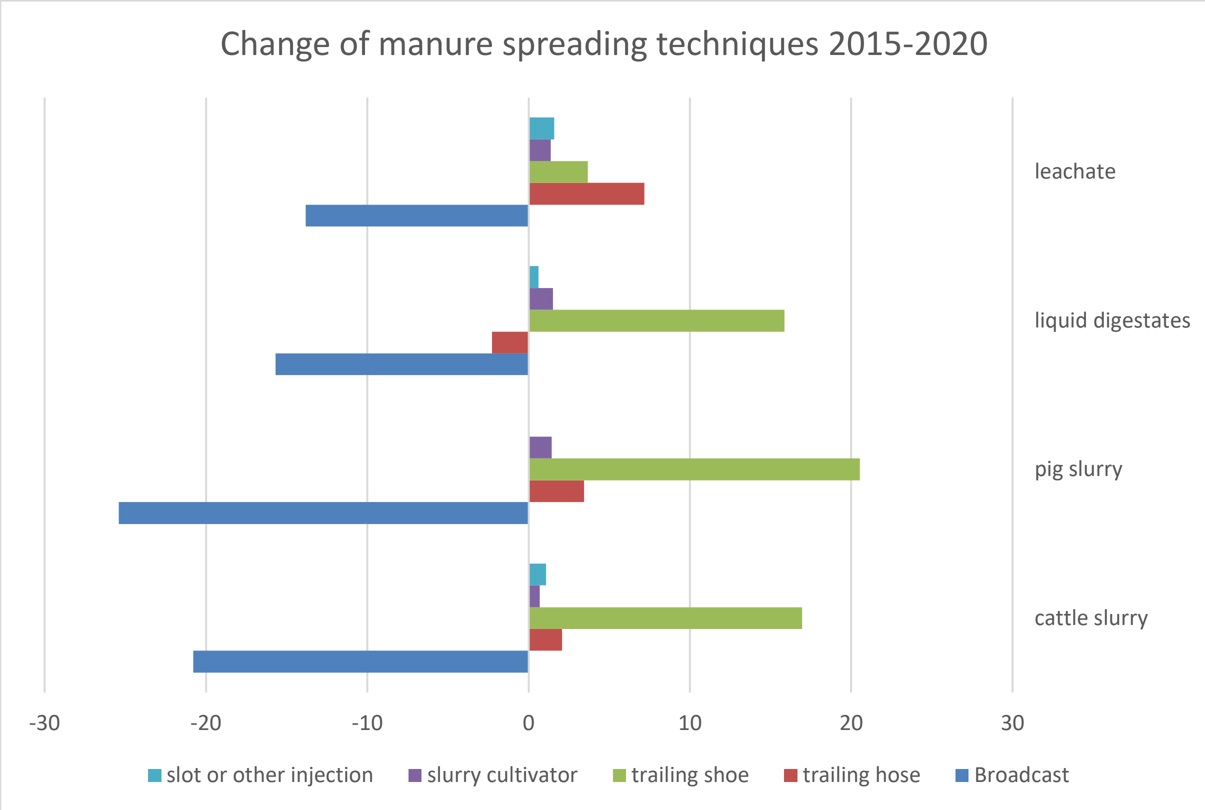


Figure 47: Changes in manure application procedures between 2015 and 2020

- **Digestates of energy crops:** The total mass of digested energy crops has been updated, with respect to the 2021 NIR, for the year 2019; cf. Chapter 5.1.4.2. This has led to a slight increase.
- **Sewage sludge:** The sewage sludge quantity extrapolated for the year 2019, in the 2021 NIR, has been replaced with the corresponding values from official statistics.
- **Grazing:** The N quantities are lower, for all years, than the corresponding quantities reported in the 2021 NIR. This results from a) the new figures, from the 2020 agricultural census, for grazing, and b) updating of the suckler-cow model.
- **Crop residues:** A reduction of the N quantity occurred in all years as of 2000. The main reason for this is the increase in removals of straw that is tied to the increase – resulting from first-time use of data from the 2020 agricultural census – in the shares for animal housing with deep bedding.
- N mineralisation in mineral soils: The data for N mineralisation have been obtained via the procedures used for calculation in connection with mineralisation processes and carbon accounting for the LULUCF sector. The data are updated annually. The updated values are at about the same level as the corresponding values in the 2021 submission.

The time series for N quantities from crop residues shows the following two interesting features: a) a sharp increase from 2013 to 2014, and b) in 2015, a decrease to the level seen in 2013. These features result directly from the excellent harvest obtained in 2014. A significant reduction in the N quantities of crop residues and mineral fertiliser is seen from 2017 to 2018. For now, this is being attributed to the difficult cultivation conditions and, in many cases, very small harvests, that resulted from the extremely hot, dry weather that prevailed in 2018. The very wet conditions that prevailed in some regions of Germany at the end of the year in 2017 – i.e. at the sowing time for winter crops – are seen as another factor. The year 2019 was also hot and, in a number of regions, dry. Nonetheless, the average harvests in that year were better than those of 2018. At the same time, a further decrease in the N quantity from mineral fertiliser occurred. With regard to mineral fertiliser, it is unclear to what extent the factors a) weather conditions and b) changes in applicable laws each contributed to the decrease.

5.1.5.1.3 Area of organic soils under cultivation (3.D)

Table 256 shows the applicable areas of organic soils under cultivation, broken down by cropland and grassland (in the strict sense). The data have been provided by the LULUCF sector, and they correspond to the pertinent areas identified in the LULUCF sector (cf. Chapter 6.1.2.2.2). As of the 2021 submission, Grassland areas include all sub-areas, regardless of the distance to the groundwater level. As of the 2021 submission, the fact that no N_2O is emitted in areas in which the distance to the groundwater level is very small is reflected in the implied emission factors (IEF); cf. Chapter 5.5.2.1.1. For all time-series years, the total area of cultivated organic soils is about the same as the corresponding values in the 2021 NIR.

Table 256: Areas of organic soils under cultivation (3.D)

[1,000s of ha]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**1313.9**	**1315.8**	**1317.6**	**1316.1**	**1305.5**	**1303.6**	**1301.7**	**1299.7**	**1297.8**	**1295.9**	**1293.3**	**1290.7**	**1288.1**	**1285.5**	**1283.0**
$Cropland_{annual}$	335.6	328.9	322.2	333.6	335.6	338.8	342.1	345.3	348.6	351.8	347.7	343.6	339.4	335.3	331.2
Grassland	978.4	986.9	995.4	982.5	969.9	964.7	959.6	954.4	949.2	944.1	945.6	947.2	948.7	950.2	951.8

5.1.5.1.4 Deposition of reactive nitrogen (3.B, 3.D, 3.J)

Deposition of reactive nitrogen is derived from the NH_3 and NO emissions from the German agricultural sector, as calculated in the inventory. This is carried out for the NH_3 and NO sources "housing and storage" (3.B), "storage of digestates of energy crops" (3.J) and "application and grazing" (3.D). In addition to application of manure and digestates from manure digestion, "application" also includes application of mineral fertiliser and digestates of energy crops.

Table 257 shows, for categories 3.B and 3.J, the quantities of reactive nitrogen on which the calculations of indirect N_2O from N deposition are based. Similar data for the sector 3.D are provided in Table 258. The differences in the two tables, with respect to the 2021 Submission, result from the updating of input data described above, in connection with Table 254. The sharp reduction seen in 2020 results from the described reduction of the NH_3 emission factor for urea fertiliser as of that year; cf. Chapter 5.5.2.1.

Table 257: Sectors 3.B and 3.J: Quantities of reactive nitrogen from deposition of NH_3 and NO

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
3.B, Manure, including digestates from manure digestion	254.1	212.6	211.6	211.6	207.2	208.2	212.3	214.2	216.3	215.6	214.2	214.1	209.8	207.5	205.6
3.J, Digestates of energy crops	0.0	0.0	0.1	1.0	2.6	2.9	2.5	2.8	2.8	2.8	2.8	2.7	2.7	2.6	2.6

Table 258: Sector 3.D: Quantities of reactive nitrogen from deposition of NH_3 and NO

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
3.D, Total	**355.6**	**293.2**	**296.7**	**284.6**	**302.4**	**307.8**	**311.5**	**316.3**	**323.1**	**324.0**	**321.6**	**306.9**	**289.2**	**275.1**	**246.7**
3.D, Manure, digestates from manure digestion, mineral fertiliser, grazing	355.5	293.1	295.6	275.7	269.7	266.8	268.6	266.6	273.0	273.9	272.5	259.3	243.0	229.6	201.9
3.D, Digestates of energy crops	0.0	0.1	1.1	8.9	32.7	41.0	43.0	49.7	50.1	50.1	49.1	47.6	46.2	45.5	44.8

5.1.5.1.5 Leaching and surface runoff (3.D)

For calculation of N_2O emissions from leaching and surface runoff, and in accordance with IPCC (2006a): Vol. 4, the total activity data used consists of the sum of the nitrogen in applied quantities of mineral fertiliser, manure, digestates (including digestates of energy crops) and sewage sludge, plus the N quantities in crop residues, from mineralisation and from grazing. For details, cf. Chapter 12.2 in Vos et al. (2022).

Only part of the available N quantity is leached. The ratio of that quantity to the available N quantity is given by $Frac_{LEACH}$ (cf. IPCC (2006a Vol 4, 11.21)). For $Frac_{LEACH}$, Germany uses the IPCC default value 0.30 kg kg^{-1} (IPCC (2006a Vol 4, 11.21)). The criterion for use of this default value is that the soil's water-retention capacity is exceeded; cf. IPCC (2006a Vol 4, 11.21). This criterion must be assumed to be fulfilled, on a yearly average, throughout all Germany, since new groundwater formation takes place everywhere in Germany (Neumann & Wycisk, 2002). The calculated quantities of leached nitrogen are shown in Table 259. The differences, with respect to the 2021 Submission, result from the updating of input data described in Chapter 5.1.5.1.2, in connection with Table 254.

Table 259: Leached N quantity (including surface runoff) (3.D)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	1213.0	1021.4	1089.7	1056.4	1039.2	1057.3	1089.3	1095.3	1146.3	1129.9	1120.2	1092.5	1012.4	999.4	988.6

5.1.5.2 CO_2 emissions from liming and urea application (3.G-I)

The report differentiates between dolomite and limestone, in order to take account of how the two groups differ in carbonate carbon content, as well as in their CO_2 emission factors. With regard to limestone, application of calcium ammonium nitrate is considered as a separate case. The CO_2 emissions from such application are reported under CRF 3.I ("Other carbon-containing fertilisers"). Otherwise, CO_2 emissions from application of limestone and dolomite are reported under CRF 3.G. In keeping with the IPCC requirements (IPCC (2006a Vol 4, Chapter 11.3)), the reported CO_2 emissions include both the pertinent emissions from the agricultural sector and those from liming in the forestry sector IPCC (2006a).

No data on applied quantities of lime fertiliser are available. For this reason, the applied quantities are considered to be equal to the product quantities sold, and statistically recorded (Statistisches Bundesamt, FS 4, R 8.2), within the country. The delay in the relevant surveys amounts to half a year. For purposes of the inventory, it is assumed that all of the lime fertiliser sold in the second half of year j-1, and all of the lime fertiliser sold in the first half of year j, is applied (spread) in year j. Then, in a procedure similar to that used for mineral fertiliser (cf. Chapter 5.1.5.1.2), multiple-year averages are obtained.

Calcium carbonate, compound lime, carbolic lime ("Carbokalk"), residual lime and calcium ammonium nitrate are all taken into account. For purposes of emissions calculations, product quantities reported in units of CaO or N are converted into units of $CaCO_3$, for limestone, and of $CaMg(CO_3)_2$, for dolomite.

Dolomite's share of the total quantity of fertiliser lime is not recorded statistically. For purposes of the inventory, that share has been calculated on the basis of an expert judgement (Müller, 2016), according to which the lime fertiliser used in the forestry sector consists of one-third $MgCO_3$, and the use of dolomite in the agricultural sector is negligible.

Table 260 shows the lime-fertiliser quantities, for the agriculture and forestry sectors taken together, on which the emissions calculations are based; cf. Chapter 11.10 in Vos et al. (2022). The discrepancies in the data for 2019, with respect to the 2021 submission, result from inclusion of the data for 2020 within the overarching average.

Table 260: Lime-fertiliser quantities (3.G & 3.I)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Limestone [in $CaCO_3$]	4204.1	2435.3	3468.0	3018.4	3325.0	3431.3	3644.6	3944.8	4159.2	4156.4	4126.2	4269.1	4528.3	4525.0	4370.2
Dolomite [in $CaMg(CO_3)_2$]	735.8	437.5	356.3	211.5	180.4	175.1	185.6	186.3	182.9	161.5	139.0	124.2	115.3	100.3	84.7
Calcium ammonium nitrate [in $CaCO_3$]	1160.1	885.2	833.2	698.9	584.6	600.2	577.1	546.1	536.9	524.3	513.0	484.2	460.7	441.4	431.1

The CO_2 emissions from urea application are calculated in proportion to the quantities of applied urea listed in Table 261 (including applied urea ammonium nitrate solution). These values have been derived stoichiometrically (via multiplication by the molar ratio 60/28) from the urea-N quantities reported in official statistics, and they have been included in the moving temporal average mentioned above in the context of liming.

Table 261: Applied quantities of urea, including urea ammonium nitrate solution (3.H)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	656.0	625.3	808.8	874.2	969.2	891.9	940.8	917.1	1022.3	1079.3	1111.6	981.2	825.3	678.7	622.7

5.1.5.3 NMVOC emissions from agricultural crops

Table 262 shows, by way of example for the first time-series year and the last, the input data calculated for the NMVOC-emission calculation for agricultural crops pursuant to EMEP/EEA (2019 -3D-16) and EMEP/EEA (2019 -3D-30) (cf. Chapter 5.5.2.1.5). Data on areas under cultivation and fresh-matter yields are reported in (Statistisches Bundesamt, FS 3, R 3a). The data are converted into dry-matter yields on the basis of DM-content data given by the Fertiliser Ordinance (DüV, 2007, 2017). The relative emission durations for wheat, rye, rape and grass have been taken from EMEP/EEA (2019 -3D-16)) and applied, analogously, to the other crops involved.

Table 262: Input data for calculation of NMVOC emissions from agricultural crops (overview)

Crop	Area under cultivation [1,000s of ha]		Fresh matter yields [Mg ha^{-1}]		DM content [kg kg^{-1}]	Relative emission duration [a a^{-1}]
	1990	2020	1990	2020		
Wheat	2419.9	2801.5	6.3	7.8	0.86	0.3
Rye	1067.1	636.0	3.8	5.5	0.86	0.3
Barley	2612.5	1667.3	5.4	6.5	0.86	0.3
Oats	533.5	165.745	4.4	4.5	0.86	0.3
Triticale	77.3	341.296	5.1	6.0	0.86	0.3
Grain for whole-plant harvest	0.0	125.623	0.0	24.9	0.35	0.3
Grain maize	228.4	419.297	6.8	9.6	0.86	0.3
Silage maize	1365.4	2299.741	40.4	42.4	0.28	0.3
Rape	557.5	954.351	3.0	3.7	0.91	0.3
Root crops	1249.6	659.5	40.6	61.2	0.22	0.3
Grass clover ley, alfalfa, forage grass	856.6	647.5	34.0	35.3	0.20	0.5
Legumes	121.2	223.9	3.4	3.8	0.86	0.3
Pastures and meadows	5417.2	4505.44	31.6	29.3	0.20	0.5

5.1.6 Total uncertainty of all GHG emissions in Sector 3

Along with calculation of emissions, the total uncertainty for all GHG emissions in Sector 3 was calculated. This was done in accordance with the "Approach 1" procedure described in IPCC (2006a Vol 1, Chapter 3), a procedure based on Gaussian error propagation calculation. By way of convention, it is ignored that such error propagation calculations assume a normal distribution. Some of the activity data and emission factors that enter into the calculation either do not fulfill this assumption or cannot be checked in this regard. For the present greenhouse-gas inventory for the agricultural sector, the standard version of the "Approach 1" procedure described in IPCC (2006a Vol 1, Chapter 3) has been used as a basis: The emission factors of the various time-series years are assumed to be correlated, but the activity data are assumed not to be correlated from year to year. For asymmetric distributions, the larger of the two intervals [2.5 percentile; average] and [average; 97.5 percentile] was used, as required by IPCC (2006a Vol 1, Chapter 3) for the "Approach 1" procedure. (For the Federal Environment Agency's uncertainties calculation, using the "Approach 2" procedure, for the greenhouse-gas report as a whole, the upper and lower bound of the 95 % confidence interval, and the type of distribution involved, were provided in the CSE for all uncertainties of agricultural figures.) Further details on uncertainties calculation for the German inventory are presented in Chapter 14 in Vos et al. (2022).

Table 263 shows, for the last time-series year, the total uncertainty, as calculated with the "Approach 1" procedure, for all emissions of the "agriculture" sector (Sector 3), including emissions from digestion of energy crops and from storage and application of digestates of energy crops. Table 263 also shows the uncertainty for the overall trend since 1990. All emissions values are given in CO_2 equivalents that were obtained using the relevant greenhouse warming potential (GWP) conversion factors pursuant to IPCC (2006a Vol 4) – 25 kg kg^{-1} for CH_4 and 298 kg kg^{-1} for N_2O.

In the interest of clarity, the presentation in Table 263 uses the collective animal categories "other cattle," "swine," "horses" and "poultry." The activity-data and emission-factor uncertainties given for these collective categories were derived, via error-propagation calculation, from the uncertainties in the animal sub-categories used in the Py-GAS-EM model. A presentation similar to that shown in Table 263, but with all individual animal sub-categories included, is provided in Chapter 14.6 in Vos et al. (2022).

The activity-data and emission-factor uncertainties for the various mineral-fertiliser categories were also aggregated via error propagation calculations. The aggregated uncertainties for application of manure and manure digestates given in Table 263 were aggregated using error propagation calculations, and taking account of the uncertainties for the application contributions of the various individual animal categories.

With regard to the uncertainty values used, cf. Chapters 5.2.3, 5.3.2.3, 5.3.4.3, 5.3.5.3, 5.5.4, 5.8.4 and 5.9.7. The uncertainties for the emission factors clearly tend to be considerably higher than those for the activity data, and thus they predominate in the combined uncertainty in the column "Combined uncertainty as % of total national emissions."

The total uncertainty for the emissions in source sector 3 (animal husbandry, cultivation of agricultural soils, digestion of energy crops) is 25.9 % (valid for the year 2020). The reduction of the total uncertainty, with respect to the value of 29.0 % given in the 2021 NIR, results primarily from the new Tier 2 N_2O emission factors used for application of mineral fertiliser, manure, sewage sludge and digestates, and for emissions from crop residues, pursuant to (Mathivanan et al., 2021). These emission factors are smaller than the values used in the 2021 NIR, and they have much smaller uncertainties. The uncertainty for the trend for the period 1990 – 2020 is 11.8 %.

Table 263: Total-uncertainties calculation for emissions from Sector 3 (animal husbandry, agricultural soils), including digestion of energy crops

Source category EntFer = Enteric Fermentation MM = Manure Management DEC = Digestion of Energy Crops	Gas	Base year emissions, in CO_2 equivalents (GWP$_{CH4}$ = 25, GWP$_{N2O}$ = 298)	Year 2020 emissions, in CO_2 equivalents	Activity data uncertainty (half the 95 % confidence interval)	Emission factor uncertainty (half the 95 % confidence interval)	Combined uncertainty (half the 95 % confidence interval)	Auxiliary calculations [A]	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Square of "Uncertainty introduced into the trend in total national emissions" [B]
		kt a^{-1}	kt a^{-1}	%	%	%		%	%	%	%	
EntFer, dairy cows	CH_4	17,718.2	13,802.7	4	20	20.4	25.2	0.00	0.20	0.08	1.11	1.23
EntFer, other cattle	CH_4	14,017. 0	8,938.4	2.2	10.9	11.1	3.1	0.03	0.13	0.34	0.39	0.27
EntFer, swine	CH_4	692.4	635.6	3.0	15.0	15.3	0.0	0.00	0.01	0.02	0.04	0.00
EntFer, sheep	CH_4	518.2	283.2	10	30	31.6	0.0	0.00	0.00	0.05	0.06	0.01
EntFer, goats	CH_4	11.3	19.4	20	30	36.1	0.0	0.00	0.00	0.00	0.01	0.00
EntFer, horses	CH_4	204.6	188.1	10	30	31.6	0.0	0.00	0.00	0.01	0.04	0.00
MM, dairy cows	CH_4	2,195.7	2,278.1	4	20	20.4	0.7	0.01	0.03	0.15	0.18	0.06
MM, other cattle	CH_4	2,396.2	1,414.0	2.2	11.3	11.5	0.1	0.01	0.02	0.08	0.06	0.01
MM, swine	CH_4	3,059.4	2,583.3	3.0	16.4	16.7	0.6	0.00	0.04	0.04	0.15	0.02
MM, sheep	CH_4	22.5	12.3	10	30	31.6	0.0	0.00	0.00	0.00	0.00	0.00
MM, goats	CH_4	0.5	0.8	20	30	36.1	0.0	0.00	0.00	0.00	0.00	0.00
MM, horses	CH_4	38.8	35.7	10	30	31.6	0.0	0.00	0.00	0.00	0.01	0.00
MM, poultry	CH_4	89.1	146.5	6.2	10.0	11.8	0.0	0.00	0.00	0.01	0.02	0.00
MM, direct N_2O, dairy cows	N_2O	955.8	721.0	4	100	100.1	1.7	0.00	0.01	0.05	0.06	0.01
MM, direct N_2O, other cattle	N_2O	982.9	721.2	2.2	52.0	52.1	0.4	0.00	0.01	0.04	0.03	0.00
MM, direct N_2O, pigs	N_2O	400.8	367.8	3.0	78.5	78.6	0.3	0.00	0.01	0.05	0.02	0.00
MM, direct N_2O, sheep	N_2O	28.5	15.5	10	100	100.5	0.0	0.00	0.00	0.01	0.00	0.00
MM, direct N_2O, goats	N_2O	1.6	2.8	20	100	102.0	0.0	0.00	0.00	0.00	0.00	0.00
MM, direct N_2O, horses	N_2O	60.1	55.3	10	100	100.5	0.0	0.00	0.00	0.01	0.01	0.00
MM, direct N_2O, poultry	N_2O	36.7	62.0	6.2	52.8	53.2	0.0	0.00	0.00	0.02	0.01	0.00
MM, indirect N_2O, all animals	N_2O	1,189.7	962.9	40	400	402.0	47.6	0.00	0.01	0.10	0.77	0.61
Soils, mineral fertilisers	N_2O	6,240.4	3,871.7	0.5	20.3	20.3	2.0	0.02	0.05	0.31	0.04	0.10
Soils, spreading of manure	N_2O	3,441.3	2,877.7	9.6	19.2	21.4	1.2	0.00	0.04	0.04	0.55	0.31
Soils, sewage sludge	N_2O	80.8	37.8	20	40	44.7	0.0	0.00	0.00	0.01	0.02	0.00
Soils, crop residues	N_2O	1,373.8	1,622.8	50	40	64.0	3.4	0.01	0.02	0.30	1.63	2.73
Soils, organic soils	N_2O	3,789.5	3,704.2	0.13	245	245.0	261.7	0.01	0.05	2.40	0.01	5.77
Soils, mineralization	N_2O	11.5	8.4	13.6	200	200.5	0.0	0.00	0.00	0.00	0.00	0.00
Soils, grazing	N_2O	1,905.7	1,038.5	20	200	201.0	13.8	0.01	0.01	1.35	0.42	1.99
Soils, indirect N_2O (deposition)	N_2O	1,665.0	945.6	50	400	403.1	46.2	0.01	0.01	2.14	0.95	5.48
Soils, indirect N_2O (leaching, runoff)	N_2O	4,260.2	3,163.4	170	230	286.0	260.1	0.00	0.04	0.72	10.78	116.63

Source category EntFer = Enteric Fermentation MM = Manure Management DEC = Digestion of Energy Crops	Gas	Base year emissions, in CO_2 equivalents (GWP$_{CH4}$ = 25, GWP$_{N2O}$ = 298)	Year 2020 emissions, in CO_2 equivalents	Activity data uncertainty (half the 95 % confidence interval)	Emission factor uncertainty (half the 95 % confidence interval)	Combined uncertainty (half the 95 % confidence interval)	Auxiliary calculations [A]	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Square of "Uncertainty introduced into the trend in total national emissions" [B]
		kt a^{-1}	kt a^{-1}	%	%	%		%	%	%	%	
DEC, digester and storage	CH_4	0.3	1,312.9	10	20	22.4	0.3	0.02	0.02	0.37	0.26	0.21
DEC, storage, direct N_2O	N_2O	0.1	240.4	10	100	100.5	0.2	0.00	0.00	0.34	0.05	0.12
DEC, storage, indirect N_2O (deposition)	N_2O	0.0	12.4	10	400	400.1	0.0	0.00	0.00	0.07	0.00	0.00
DEC, soils, direct N_2O	N_2O	0.2	884.6	10	30	31.6	0.2	0.01	0.01	0.38	0.18	0.17
DEC, soils, indirect N_2O (deposition)	N_2O	0.0	209.7	10	400	400.1	2.2	0.00	0.00	1.19	0.04	1.41
DEC, soils, indirect N_2O (leaching, runoff)	N_2O	0.1	308.8	10	230	230.2	1.6	0.00	0.00	1.01	0.06	1.02
Liming, without dolomite	CO_2	1,849.8	1,922.9	3	3	4.2	0.0	0.01	0.03	0.02	0.12	0.01
Liming, dolomite	CO_2	350.7	40.4	100	3	100.0	0.0	0.00	0.00	0.01	0.08	0.01
Liming, calcium ammonium nitrate	CO_2	510.4	189.7	3	3	4.2	0.0	0.00	0.00	0.01	0.01	0.00
Application of urea	CO_2	481.0	456.6	1	1	1.4	0.0	0.00	0.01	0.00	0.01	0.00
Total		70,581.0	56,095.1									
					Percentage uncertainty in total inventory:		25.9			Trend uncertainty (percentage):		11.8

[A] The data in this column describe auxiliary data needed to derive the percentage uncertainty in total inventory in the bottommost cell of this column. The data have been calculated with the procedure provided in IPCC (2006a Vol 1, 3.31, Table 3.2, column H). Note, however, that the column heading as prescribed by IPCC (2006a Vol 1, 3.31, Table 3.2, column H) ("Contribution to Variance by Category") does not correctly describe the data in column H. Hence the column heading has been modified.

[B] The heading for this column, as prescribed by IPCC (2006a Vol 1, 3.31, Table 3.2, column M) ("Uncertainty introduced into the trend in total national emissions"), has been modified, in order to match the formula provided by IPCC (2006a Vol 1), and applied in the table above to calculate the data in this column.

5.1.7 Quality assurance and control

General quality control (QC) and, additionally for 3.D, G & J category-specific quality control, and quality assurance (QA), have been carried out, in conformance with the requirements of the QSE manual and its associated applicable documents, by the relevant involved experts and the Single National Entity (SNE).

5.1.7.1 The Thünen Institute's quality management for emissions inventories

The Thünen Institute's quality management for emissions-inventory preparation has been developed in conformance with the IPCC guidelines and the QSE (Chapter 1.6.1). The framework for the quality management, and the process for carrying it out, are described in detail in the relevant concept (BMELV, 2016) and in the provisions for the implementation of the concept (TI, 2016). Documents of importance for quality control are added to the inventory description that is archived by the Single National Entity. The requirements and procedures set forth by the provisions for implementation of the concept were fully complied with. The following sections discuss important aspects of the quality control for the present submission.

5.1.7.2 Input data, calculation procedures and emissions results

Checking of the emissions calculations and of the NIR has included checking for the following:

- In the framework of inventory improvement, and in the run-up to emissions reporting for 2022, the following changes were made (cf. Chapter 3.5.2 in Vos et al. (2022)):
    - Use of Tier 2 emission factors, pursuant to (Mathivanan et al., 2021), for application of mineral fertiliser, manure, digestates, sewage sludge and emissions from crop residues
    - Updating of the modelling of energy requirements and feeding, with regard to suckler cows, on the basis of German standard values
    - Use of temporally variable input data for the feed parameters for broilers and fattening pigs
    - Updating of the coefficients for N- and VS excretions, and for straw inputs for geese
    - Mineral fertiliser, liming, urea application: Multiple-year averaging of the activity data (for the period 1990 through 2018, a moving, centered, three-year average has been used; for 2019, the average of 2019 (weighted as 1/3) and 2020 (weighted as 2/3) has been used)).
- The other calculation procedures agree formally with those used for the 2021 emissions report.
- The activity data have been checked for plausibility and consistency and updated, as necessary, on the basis of newer data.
- It has been ensured that the areas of the organic soils used for cropland or as managed grassland are consistent across the LULUC (Chapter 4.B, 4.C) and Agriculture (3.D) sections.
- Every single time series of the emissions results for the 2022 Submission was checked for consistency with the corresponding time series in the 2021 Submission. All discrepancies can be explained as the result of updating of input data and/or calculation procedures.
- The fluctuations and trends in the time series can be explained, and the most important of these are described in the NIR.

- The activity data and emissions results were compared with corresponding data of central European countries that are either direct neighbors of Germany or that have comparable agricultural practices. In most cases, the German data fall within the middle range, or are at the level found in one or more of the countries being compared, or are at the level of an IPCC (2006a) standard value. Any important departures from these criteria discrepancies can be justified, in each individual case.
- The input data and calculation results for all relevant emission sources in agricultural-sector emissions reporting are provided, as background for the results presented in the NIR 2022 and the CRF tables, in an EXCEL file that is available as a supplement to Vos et al. (2022) (cf. Chapter 2.4 in Vos et al. (2022)).
- The data in the NIR text have been checked for consistency, via comparison with the calculation results.
- To ensure that the activity data and emission factors (IEF) were correctly entered into the Central System of Emissions (CSE) database, on which the CRF tables are based, the emissions as calculated with the CSE were compared with the emissions as calculated with the Py-GAS-EM inventory model.

5.1.7.3 Verification

The national emissions results calculated with the Py-GAS-EM inventory model cannot be compared with other pertinent data from Germany, since no such data are available. Instead, (cf. Chapter 5.1.7.2) the input data and emissions results have been compared with corresponding data of other countries and with IPCC (2006a) default values. That process is discussed in the present NIR, in the relevant sub-chapters.

In the framework of a verification project for the 2014 NIR, an external expert (Zsolt Lengyel, Verico SCE) reviewed the German emissions calculations. That review found that the input data are consistent, and that the calculations are consistent and have been carried out in keeping with the methodological requirements set forth in the IPCC Guidelines.

Furthermore, the Py-GAS-EM model is continuously validated and verified, in the framework of the European Agricultural Gaseous Emission inventory Research network (EAGER) group, and via review of modules, by KTBL.

5.1.7.4 Reviews and reports

The ERT recommendations from the reviews, up to and including that of the 2016 submission, were implemented through the 2018 submission and thus are not detailed here.

The ERT for the review of the 2018 submission recommended[90] that transparency be improved in the NIR, or in supporting documentation, regarding

- the derivation of the German N_2O-EF for drained grassland,
- the methods used to take account of buffalo, and
- the methods and input data used to determine the energy requirements, feed intake and excretions of heifers and suckler cows.

With regard to the N_2O-EF for drained grassland, a pertinent additional explanation was included in the 2019 NIR. In the two other cases (buffalo; heifers and suckler cows), extensive details were added to the supplementary documentation for the 2020 NIR (Haenel et al., 2020b); in the NIR, cf. Chapters 4.1.1.2, 4.5.2, 4.7.2, 4.7.6.1. The heifer model was updated for the 2021 submission. It now includes estimation of energy requirements and feed intake on the basis of

[90] Cf. the Review Report, https://unfccc.int/sites/default/files/resource/arr2018_DEU.pdf

key data from industry-association publications. The suckler-cow model has been similarly updated, and it is being used for the first time in the present 2022 submission.

No review was carried out for the 2019 submission. The 2019 submission was reviewed in spring 2019, however, pursuant to Article 19(2) of EU Regulation 525/2013, in the framework of an EU review. The result was that no changes in the inventory methods or input data were called for (EEA, 2019). A similar result was returned by the EU review of the 2020 submission, which was carried out in spring 2020 (EEA, 2020).

A national quality audit carried out by the firm of Verico SCE (auditor for the agricultural sector: Markus Helm), in April 2016, confirmed that the reporting system's Quality System for Emission Inventories (QSE) – and thus its emissions reporting for the agricultural sector – are in conformance with the requirements of the IPCC (2006a) Guidelines (Betzenbichler et al., 2016a).

5.2 Enteric fermentation (3.A)

5.2.1 Category description (3.A)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**3 A, Enteric Fermentation**	**Dairy cows**	**CH_4**	**17,718.2**	**1.4%**	**13,802.7**	**1.9%**	**-22.1%**
L/T	**3 A, Enteric Fermentation**	**non-dairy cattle**	**CH_4**	**14,017.0**	**1.1%**	**8,938.4**	**1.2%**	**-36.2%**
-/-	3 A, Enteric Fermentation	other animals	CH_4	1,426.5	0.1%	1,126.3	0.2%	-21.0%

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier1/Tier2/Tier3	M/Q/AS/RS/NS	CS/D

The category *Dairy cows* is the most important emissions source within the source category *Enteric fermentation*. For methane, it is a key category in terms of emissions level and trend. This is due to the large numbers of animals and the high performance involved. The source category *Other cattle* is also a key category, but only in terms of emissions level.

CH_4 from enteric fermentation occurs via microbial conversions in animals' digestive tracts. The quantities released per animal and unit of time depend on the animal species in question, individual-animal performance and feed composition.

Germany reports CH_4 emissions from enteric fermentation of dairy cows, other cattle (calves, dairy heifers, female beef cattle, male beef cattle, suckler cows, male cattle older than 2 years), swine (sows, including suckling piglets weighing up to 8 kg per animal, weaner piglets, fattening pigs and boars), sheep, goats and horses.

The CH_4-emissions trend is shaped by decreasing animal populations – for cattle especially, throughout the entire period, and for all animal categories in the early 1990s – and by improved feed digestibility, which is partly offset by increasing GE intake levels in connection with increases in milk yield and animal weights.

Table 264 shows the changes of CH_4 emissions from enteric fermentation, for the entire livestock population since 1990, as well as the percentage shares of these emissions with respect to the total emissions from the German agricultural sector, broken down by CH_4 and greenhouse gases (GHG, in CO_2 equivalents). The percentage shares of the total emissions differ, since the GHG also include the N_2O and CO_2 emissions.

Table 264: CH_4 emissions from enteric fermentation, in the entire animal husbandry sector (3.A): Changes since 1990, and shares of total emissions from the German agricultural sector (broken down by CH_4 and GHG (CO_2)) (3.A)

[%]	Change since 1990	Share of total agricultural emissions (CH_4 and GHG) 1990	2020
CH_4	-28.0	81.0	75.4
GHG (CO_{2eq})		47.0	42.5

5.2.2 Methodological issues (3.A)

5.2.2.1 Methods (3.A)

The CH_4 emissions from enteric fermentation of dairy cows are calculated with a national procedure (Tier 3). For other cattle and swine, the calculation is carried out using a Tier 2 procedure (IPCC, 2006a Vol 4, 10.24). Figures for sheep, goats and horses are calculated using a Tier 1 method that employs default emission factors (cf. Chapter 5.2.2.2).

In the national method for calculation of CH_4 emissions from enteric fermentation of dairy cows (Dämmgen et al., 2012b), the emission factor is calculated, pursuant to Kirchgessner et al. (1994), as a function of intake of raw fibre, N-free extracts, raw protein and fat:

Equation 11: Calculation of the CH_4 emission factor for dairy cows (national method)

$$EF_{\text{CH4,ent}} = a \cdot M_{\text{XFi}} + b \cdot M_{\text{NFE}} + c \cdot M_{\text{XP}} + d \cdot M_{\text{XF}} + e$$

Where

$EF_{\text{CH4, ent}}$	Emission factor for CH_4 from enteric fermentation (in kg place^{-1} a^{-1} CH_4)
a	Coefficient (a = 0.079 kg kg^{-1})
M_{XFi}	Raw-fibre intake (in kg place^{-1} a^{-1})
b	Coefficient (b = 0.010 kg kg-1)
M_{NFE}	Intake of N-free extracts (in kg place^{-1} a^{-1})
c	Coefficient (c = 0.026 kg kg^{-1})
M_{XP}	Intake of raw protein (in kg place^{-1} a^{-1})
d	Coefficient (d = - 0.212 kg kg^{-1})
M_{XF}	Intake of fat (in kg place^{-1} a^{-1})
e	Constant (e = 365 · 0.063 kg place^{-1} a^{-1})

The intake of raw fibre, N-free extracts, raw protein and fat is determined from the basic feed-composition data and from the pertinent quantities of ingested feed (cf. Chapter 5.1.3.3).

The methane conversion factor is calculated from those figures, with the help of the GE intake (cf. Chapter 5.1.3.3):

Equation 12:

$$x_{\text{CH4,GE}} = \frac{\eta_{\text{CH4}} \cdot EF_{\text{CH4,ent}}}{GE}$$

Where

$x_{\text{CH4, GE}}$	Methane-conversion factor for dairy cows (in MJ MJ^{-1})
η_{CH4}	Energy content of methane (η_{CH4} = 55.65 MJ (kg CH_4)$^{-1}$)
$EF_{\text{CH4, ent}}$	Emission factor for CH_4 from enteric fermentation (in kg place^{-1} a^{-1} CH_4)
GE	Gross energy intake (in MJ place^{-1} a^{-1} GE)

As a result of increasing milk yields, the feed intake and, thus, the GE intake, for dairy cows increase over the years, with the relative fraction of more easily digestible concentrated feed, i.e. as a share of the total ration, growing and thereby supplanting basic feed; cf. Chapter 4.3. 3 in Vos et al. (2022). As a result of this shifting within feed rations, the increase in the CH_4 emissions from enteric fermentation, as calculated with Equation 11, is smaller than the increase in the GE intake. This results, in turn, in a decreasing trend in the methane conversion factor over the years, which is tied to the trend in milk yield; cf. Table 265 and Chapter 5.2.2.3.

Table 265: Dairy cows: Milk yield, GE intake, enteric-fermentation related CH_4 emissions and methane conversion factor (3.A)

	1990	2020
Average daily milk yield [kg animal place^{-1} d^{-1}]	12.9	23.2
Annual GE intake [GJ animal place^{-1} a^{-1}]	88.1	125.1
Annual CH_4 emissions from enteric fermentation [kg animal place^{-1} a^{-1}]	111.5	140.8
Methane conversion factor [MJ MJ^{-1}]	0.071	0.063

For suckler cows, use of the new model (cf. Chapter 5.1.3.3) yields variable methane conversion factors between 0.086 and 0.084 MJ MJ^{-1}.

The Tier 2 method that is used for other cattle and swine calculates the emission factor from the GE intake (cf. Chapter 5.1.3.3) and the methane conversion factor, in accordance with the following formula:

Equation 13: Calculation of the CH_4 emission factor (Tier 2 method, IPCC (2006a Vol 4, 10.31))

$$EF_{\mathrm{CH4,ent}} = GE \cdot \frac{x_{\mathrm{CH4,GE}}}{\eta_{\mathrm{CH4}}}$$

Where

$EF_{\mathrm{CH4,\,ent}}$	Emission factor for CH_4 from enteric fermentation (in kg place^{-1} a^{-1} CH_4)
GE	Gross energy intake (in MJ place^{-1} a^{-1} GE)
$x_{\mathrm{CH4,\,GE}}$	Methane-conversion factor (in MJ MJ^{-1})
η_{CH4}	Energy content of methane (η_{CH4} = 55.65 MJ (kg CH_4)$^{-1}$)

The category-specific methane conversion factors for the various sub-categories of the other cattle are given in Table 266. Due to changes in the composition of the overall population, the weighted average value for all other cattle varies slightly over the years. Table 266 shows the average value for all other cattle for the first and last year of the time series.

Table 266: Methane conversion factors for other cattle (3.A)

	MJ MJ^{-1}	Source
dairy heifers and female beef cattle, male beef cattle, mature males > 2 years	0.065	IPCC (2006a Vol 4, Table 10.12)
Suckler cows	0.086 - 0.084	Vos et al. (2022)
Calves	0.043	Vos et al. (2022)
Average value for all other cattle, 1990	0.0650	Calculation
Average value for all other cattle, 2020	0.0666	Calculation

Table 267 shows the national category-specific methane conversion factors for the various swine categories (Dämmgen et al., 2012c), along with the weighted average values for all swine in the first and last year of the time series. The average values differ as a result of the changes in the composition of the overall swine population.

Table 267: Methane conversion factors for swine (Dämmgen et al., 2012c) (3.A)

	MJ MJ^{-1}
Sows	0.0071
Weaners	0.0044
Fattening pigs	0.0046
Boars	0.0071
Average values for all swine, 1990	0.0052
Average values for all swine, 2020	0.0049

With regard to the emission factors calculated with Equation 13, cf. Chapter 5.2.2.2.

A general description of calculation of CH_4 emissions from enteric fermentation is provided in Chapter 3.3.2 in Vos et al. (2022). Animal-specific details are also provided in Vos et al. (2022), in the chapters referred to in Table 268.

Table 268: Description of calculation of CH_4 emissions from enteric fermentation, in Vos et al. (2022)

Animal category	Chapter	Animal category	Chapter
Dairy cows	4.3.4	Mature sheep	6.3.2
Calves	4.4.3	Lambs	6.4.2
Dairy heifers and female beef cattle	4.5.4	Goats	6.6.2
Male beef cattle	4.6.4	Heavy horses	7.3.2
Suckler cows	4.7.4	Light horses / ponies	7.4.2
Male cattle > 2 years	4.8.3	Laying hens	---
Sows	5.3.4	Broilers	---
Weaners	5.4.4	Pullets	---
Fattening pigs	5.5.4	Geese	---
Boars	5.6.4	Ducks	---
		Turkeys	---

5.2.2.2 Emission factors (3.A)

Table 269 shows the CH_4 emission factors calculated per animal place for enteric fermentation of dairy cows, other cattle and swine.

Table 269: Animal-place-based CH_4 emission factors, enteric fermentation (3.A)

[kg^{-1} place^{-1} a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	111.5	120.2	126.5	131.3	131.7	132.2	132.4	131.9	132.8	133.7	134.8	134.9	136.9	139.1	140.8
Other cattle	42.7	45.2	46.9	46.8	47.4	47.1	47.0	47.1	47.0	47.3	47.2	47.4	47.6	48.1	48.4
Swine	1.05	1.10	1.12	1.12	1.12	1.13	1.13	1.14	1.14	1.15	1.15	1.16	1.17	1.17	1.18

The changes with respect to the 2021 submission result from the changes made, as mentioned in Chapter 5.1.3.3, in modelling of energy requirements and feeding of suckler cows and fattening pigs, as well as from use of new grazing data from the 2020 agricultural census.

Table 270 shows the inventory's Tier 1 emission factors for sheep, goats and horses. The values shown have been used for the entire time series. The emission factor for goats has been taken from IPCC (2006a Vol 4, Table 10.10). The emission factors given in IPCC (2006a Vol 4, Table 10.10) for sheep and horses have been used for adult sheep and heavy horses; cf. Chapters 6.3.2 and 7.3.2 in Vos et al. (2022). The emission factors for lambs and light horses / ponies have been derived from the Tier 1 emission factors for adult sheep and heavy horses, respectively; cf. Chapters 6.4.2 and 7.4.2 in Vos et al. (2022). Because the compositions of the small-animal / large-animal populations do not remain constant, the emission factors reported in the CRF tables vary slightly, from year to year, for sheep overall and for horses overall. Table 270 shows the average value for the last time-series year.

Table 270: Tier 1 emission factors for CH_4 from enteric fermentation of sheep, goats and horses (3.A)

[kg place^{-1} a^{-1}]	EF	Average value for 2020
Mature sheep	8.0	6.4
Lambs	3.6	
Goats	5.0	5.0
Heavy horses	18.0	16.6
Light horses / ponies	12.0	

5.2.2.3 Emissions (3.A)

The calculated CH_4 emissions from enteric fermentation, for all German animal husbandry, are listed in Table 271.

Table 271: CH_4 emissions from enteric fermentation (3.A)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**1326.5**	**1162.4**	**1096.4**	**1019.6**	**1007.2**	**993.5**	**993.5**	**1005.9**	**1014.6**	**1014.1**	**1004.1**	**996.2**	**980.8**	**969.5**	**954.7**
in % of 1990	**100.0**	**87.6**	**82.7**	**76.9**	**75.9**	**74.9**	**74.9**	**75.8**	**76.5**	**76.5**	**75.7**	**75.1**	**73.9**	**73.1**	**72.0**
Dairy cows	708.7	628.4	578.1	556.2	550.9	553.9	554.7	562.8	570.4	572.9	568.3	566.4	561.4	557.9	552.1
Other cattle	560.7	481.8	467.5	411.9	408.7	392.9	391.3	396.4	396.9	394.8	389.6	383.3	373.8	366.6	357.5
Swine	27.7	22.4	24.3	25.4	25.0	25.7	26.7	26.6	27.1	26.4	26.3	26.6	25.8	25.3	25.4
Sheep	20.7	18.9	17.6	16.9	14.3	12.6	12.5	11.9	12.0	11.9	11.8	11.9	11.7	11.5	11.3
Goats and horses	8.6	10.9	9.0	9.3	8.4	8.4	8.3	8.3	8.2	8.1	8.0	8.1	8.2	8.2	8.3

In the main, the emissions trend since 1990 and, in particular, the decrease seen as of 2015, have been shaped by the following factors:

- the trend in numbers of animals (cf. Chapter 5.1.3.2.3), especially with regard to cattle, which make an especially significant contribution to emissions from enteric fermentation (the dairy-cow population in 2020 was about 38 % lower than it was in 1990; the corresponding figure for other cattle is about 44 % lower than the figure in 1990);
- continual increases in performance (milk yield, animal weights, weight gains); cf. Chapter 5.1.3.3;
- a considerable decrease, over the years, in the methane conversion factor for dairy cows (cf. Chapter 5.2.2.1).

5.2.3 Uncertainties and time-series consistency (3.A)

Table 263 in Chapter 5.1.6 shows the uncertainties in activity data and emission factors that have been used in estimating the total uncertainty of the German GHG inventory.

The uncertainties for the emission factors for CH_4 from enteric fermentation are default value taken from IPCC (2006a Vol 4, 10.33). With regard to the uncertainty of the activity data (animal-population data), cf. Chapters 4.1.2, 5.1.2, 6.1.2, 7.1.2 and 8.1.2 in Vos et al. (2022).

The emissions time series are consistent, since they were calculated with the same method for all years of the report period, and since the input data are also consistent and complete.

5.2.4 Category-specific quality assurance / control and verification (3.A)

With regard to quality control and quality assurance, we refer to Chapter 5.1.7.

As part of verification, the German animal husbandry data for dairy cows, other cattle and swine were compared with the corresponding IPCC default values and with relevant data of neighboring countries, including data of the UK (cf. Table 272 and Table 273). At the time the German 2022 emissions report was being prepared, the results of the other countries' 2022 emission reporting were not yet known. For this reason, data from 2021 reports are being used for those countries, while the German data have been taken from the current 2022 report. The international comparison is being carried out for 2019 (the last time-series year in the 2021 report).

Table 272 shows, for dairy cows, the national mean figure for animal-place-related emission factor (implied emission factor, IEF), GE intake and milk yield (which is the key factor affecting emissions levels). The CH_4-conversion factor is also included. It is used to calculate the fraction of GE intake that is converted into methane energy that is lost with emitted methane (cf. the method description in Chapter 5.2.2.1).

Of the ten countries compared with Germany, Denmark has the highest IEF, while Poland has the lowest. Germany's IEF is slightly above the average value. This also applies to its GE-intake and milk yield figures. With regard to methane conversion factors, three countries (Austria, Czech Republic and Poland) have used the IPCC default value of 6.5 %. The value used by Switzerland is considerably higher than the IPCC default value. The methane conversion factors used by Belgium, Denmark, France, Germany, the Netherlands and the UK are lower than the IPCC default value, with the UK's value coming closest to the IPCC default value.

Table 272: Methane emissions from enteric fermentation of dairy cows, in various countries – a comparison of Implied Emission Factors (IEF) for the time-series year 2019

	IEF_{CH4} [kg place^{-1} a^{-1}]	CH_4-conversion factor Y_m [MJ MJ^{-1}]	GE intake [MJ place^{-1} d^{-1}]	milk yield [kg place^{-1} d^{-1}]
Austria	136.56	0.0650	320.31	19.67
Belgium	127.16	0.0610	317.83	23.38
Czech Republic	156.36	0.0650	366.76	23.86
Denmark	162.39	0.0600	412.65	28.56
France	124.40	0.0613	309.56	19.68
Germany	**139.06**	**0.0631**	**336.75**	**22.59**
Netherlands	135.31	0.0573	278.67	NA
Poland	118.80	0.0650	278.67	16.38
Switzerland	137.38	0.0690	303.56	22.86
UK	125.44	0.0642	297.66	22.26
IPCC (2006a Vol 4, 10.15 bis 10.31, 10.72)	117	0.065	Equation 10.3-10.16	16.44

Source: Germany: 2022 Submission; other countries: UNFCCC (2021b)

NE, NA, n/a: no data available

a Calculated from the annual milk yield assumed by IPCC (2006a Vol 4):

6,000 kg place^{-1} a^{-1}

Table 273 shows the IEF and the GE intakes for the group of other cattle and for all swine combined.

For other cattle, the IEF values range from 34.6 kg place^{-1} a^{-1} (Netherlands) to 59.1 kg place^{-1} a^{-1} (Austria). The latter value is only slightly higher than the IPCC default value of 57 kg place^{-1} a^{-1}. Germany's IEF and GE-intake values lie somewhat below the median.

For swine, all of the countries involved, except for Denmark, Germany, France and Switzerland, use the IPCC default value for the IEF. The four countries that calculate the IEF obtain results that are lower than the IPCC default value. This could indicate that the IPCC default value is too high for the circumstances prevailing in central Europe. France's IEF, in the context of an international comparison, seems unrealistically low. Germany's IEF is of the same order of magnitude as the values of Denmark and Switzerland. GE intake is reported only by Denmark, Germany and Switzerland. Germany's value is close to Denmark's value.

Table 273: Methane emissions from enteric fermentation of other cattle and swine, in various countries – a comparison of Implied Emission Factors (IEF) for the time-series year 2019

	Other cattle		Swine	
	IEF_{CH4} [kg place^{-1} a^{-1}]	GE intake [MJ place^{-1} d^{-1}]	IEF_{CH4} [kg place^{-1} a^{-1}]	GE intake [MJ place^{-1} d^{-1}]
Austria	59.08	138.58	1.50	NA
Belgium	46.57	122.12	1.50	NE
Czech Republic	58.82	147.85	1.50	NA
Denmark	41.10	129.94	1.07	38.04
France	53.22	125.53	0.74	NE
Germany	**48.06**	**110.05**	**1.17**	**36.08**
Netherlands [a]	34.64	90.09	1.50	NA
Poland	50.49	118.44	1.50	n/a
Switzerland [a]	46.71	118.52	1.03	26.26
UK [b]	54.71	103.73	1.50	NE
IPCC (2006a)	57	Equation 10.3-10.16	1.5	Equation 10.3-10.16

Source: Germany: 2021 submission; other countries: UNFCCC (2021b)

NE, NA, n/a: no data available

[a] Other cattle: calculated from CRF data

[b] UK, other cattle: Cattle, not including dairy cows, and not including dairy replacements (with calves)

5.2.5 Source-specific recalculations (3.A)

Table 274 shows, for dairy cows, other cattle and swine, GE intake in comparison to the corresponding data in the 2021 submission. The differences for other cattle and swine are due mainly to the changes, described in Chapter 5.1.3.3, made in modelling of the energy requirements and feed composition for suckler cows and in modelling of feed composition in pig fattening. GE intake does not enter into the emissions calculations for the other relevant mammals, i.e. for sheep, goats and horses. For this reason, those animals are not included in Table 274.

Table 274: Comparison of mean daily GE intakes, for dairy cows, other cattle and swine (3.A), as reported in the 2021 and 2022 submissions

[MJ/animal]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dairy cows, 2022	241.3	264.0	283.0	298.8	307.5	310.5	312.5	312.0	316.0	318.9	322.3	322.5	329.4	336.7
Dairy cows, 2021	241.3	264.0	283.0	298.8	307.5	310.5	312.5	312.0	315.9	318.8	322.3	322.5	329.4	337.0
Other cattle, 2022	100.1	104.0	106.9	106.6	108.1	107.7	107.6	107.8	107.6	108.2	108.2	108.6	109.0	110.0
Other cattle, 2011	99.7	103.1	105.7	105.5	107.0	106.6	106.5	106.7	106.6	107.2	107.1	107.6	108.0	109.0
Swine, 2022	30.9	32.5	33.4	33.5	34.0	34.3	34.5	34.8	35.1	35.2	35.5	35.7	36.0	36.1
Swine, 2011	30.2	31.8	32.6	33.0	33.8	34.0	34.3	34.5	34.8	35.0	35.2	35.5	35.8	35.8

Table 275: Comparison of the CH_4 emission factors (enteric fermentation) for dairy cows, other cattle and swine (3.A), referenced to animal place, as reported in the 2021 and 2022 submissions

[MJ/animal]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dairy cows, 2022	111.5	120.2	126.5	131.3	131.7	132.2	132.4	131.9	132.8	133.7	134.8	134.9	136.9	139.1
Dairy cows, 2021	111.5	120.2	126.5	131.3	131.7	132.1	132.3	131.7	132.5	133.4	134.4	134.5	136.4	138.6
Other cattle, 2022	42.7	45.2	46.9	46.8	47.4	47.1	47.0	47.1	47.0	47.3	47.2	47.4	47.6	48.1
Other cattle, 2021	41.7	43.1	44.2	44.1	44.7	44.5	44.5	44.6	44.6	44.8	44.8	45.0	45.2	45.6
Swine, 2022	1.05	1.10	1.12	1.12	1.12	1.13	1.13	1.14	1.14	1.15	1.15	1.16	1.17	1.17
Swine, 2021	1.02	1.07	1.09	1.10	1.12	1.12	1.12	1.13	1.14	1.14	1.15	1.15	1.16	1.16

The discrepancies with respect to the 2021 submission that are seen in Table 275 (emission factors) and Table 276 (emissions) are also due to the reasons mentioned in connection with

Table 274. In addition, the changes in grazing resulting from inclusion of the results of the 2020 agricultural census also have an effect as of 2010.

Table 276: Comparison of the CH_4 emissions (enteric fermentation) for all mammals, and for dairy cows, other cattle and swine (3.A), as reported in the 2021 and 2022 submissions

[Tg a^{-1} CH_4]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Mammals, 2022	1.326	1.162	1.096	1.020	1.007	0.993	0.994	1.006	1.015	1.014	1.004	0.996	0.981	0.970
Mammals, 2021	1.313	1.140	1.069	0.995	0.985	0.972	0.972	0.984	0.993	0.992	0.982	0.975	0.959	0.948
Dairy cows, 2022	0.709	0.628	0.578	0.556	0.551	0.554	0.555	0.563	0.570	0.573	0.568	0.566	0.561	0.558
Dairy cows, 2021	0.709	0.628	0.578	0.556	0.551	0.554	0.554	0.562	0.569	0.572	0.567	0.565	0.559	0.556
Other cattle, 2022	0.561	0.482	0.468	0.412	0.409	0.393	0.391	0.396	0.397	0.395	0.390	0.383	0.374	0.367
Other cattle, 2021	0.547	0.460	0.441	0.388	0.386	0.372	0.370	0.376	0.376	0.374	0.370	0.364	0.355	0.348
Swine, 2022	0.0277	0.0224	0.0243	0.0254	0.0250	0.0257	0.0267	0.0266	0.0271	0.0264	0.0263	0.0266	0.0258	0.0253
Swine, 2021	0.0271	0.0219	0.0238	0.0250	0.0248	0.0255	0.0265	0.0264	0.0269	0.0262	0.0261	0.0264	0.0256	0.0252

5.2.6 Planned improvements (3.A)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

5.3 Manure management (3.B)

5.3.1 Category description (3.B)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**3 B, Manure Management**	**Dairy cows**	**CH_4**	**2,195.7**	**0.2%**	**2,278.1**	**0.3%**	**3.8%**
-/-/T2	**3 B, Manure Management**	**Dairy cows**	**N_2O**	**955.8**	**0.1%**	**721.0**	**0.1%**	**-24.6%**
-/-	3 B, Manure Management	non-dairy cattle	CH_4	2,396.2	0.2%	1,414.0	0.2%	-41.0%
-/-	3 B, Manure Management	non-dairy cattle	N_2O	982.9	0.1%	721.2	0.1%	-26.6%
L/T	**3 B, Manure Management**	**swine**	**CH_4**	**3,059.4**	**0.2%**	**2,583.3**	**0.4%**	**-15.6%**
-/-	3 B, Manure Management	swine	N_2O	400.8	0.0%	367.8	0.1%	-8.2%
-/-	3 B, Manure Management	other animals	CH_4	150.9	0.0%	195.3	0.0%	29.4%
-/-	3 B, Manure Management	other animals	N_2O	126.9	0.0%	135.7	0.0%	6.9%
-/-/T2	**3 B, Manure Management**	**deposition**	**N_2O**	**1,189.7**	**0.1%**	**962.9**	**0.1%**	**-19.1%**

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	M/Q/AS/RS/NS	CS/D
N_2O direct	Tier 2	M/Q/AS/RS/NS	CS/D
N_2O indirect	Tier 1	M/Q/AS/RS/NS	D
NO_X	Tier 2	M/Q/AS/RS/NS	CS
NMVOC	Tier 2 / Tier 1	RS/NS	D

For CH_4 emissions from swine, manure management is a key category in terms of emissions level and trend. The 3.B. category manure management for dairy cows is a key category for CH_4 in terms of emissions level and trend, and a key category for N_2O in terms of emissions level (Approach 2 analysis). Indirect N_2O from deposition has also been identified as a key category, in terms of both emissions level and trend (both via Approach 2 analysis).

In sector 3.B, Germany reports on CH_4, N_2O, NO and NMVOC from manure management.

CH_4 occurs when methanogenic bacteria break down organic substances in anaerobic environments. Direct N_2O emissions are produced by nitrification and denitrification processes that take place during storage of manure and of digestates. NO is produced via nitrification in surface layers of manure storage facilities. NMVOC emissions are released from silage fodder and from manure storage facilities.

Reporting on manure management also covers indirect N_2O emissions. Such emissions can occur in connection with decomposition processes in the soil, and they are generated from reactive nitrogen originating via deposition of NH_3 and NO from management of manure and of digestates, as well as via nitrogen leaching and surface runoff from management of manure and of digestates. For reasons of water protection, seeping/leachage and uncontrolled above-ground runoff from management of manure and of digestates are to be prevented (Council of the European Union, 1991). For this reason, no indirect N_2O emissions from leachage / surface runoff have been calculated. This procedure has been followed for all years as of 1990. With regard to total N_2O emissions from the German agricultural sector, this amounts to a conservative assumption, since the nitrogen that is not lost via N_2O from leaching / surface runoff is applied to fields, thereby computationally causing higher N_2O emissions as a result.

The relevant emissions are calculated in relation to a range of factors, including animal category; animal excretions (which, in turn, are a function of animal performance and diet); the amounts of time spent by relevant animals in various defined areas (pastures, stables); the types of stables used; nitrogen inputs from bedding material (straw); and the type of manure storage involved.

Table 277 shows the changes over time in emissions from all manure management since 1990. In addition, for the initial and end years of the time series, it shows these emissions' shares of relevant total emissions from the German agricultural sector. With regard to the absolute emissions levels, cf. Chapters 5.3.2.2.3, 5.3.3.2.3 and 5.3.4.2.3. The emissions decrease seen since 1990 is due primarily to changes in livestock populations. Decreases of CH_4 and N_2O emissions have also occurred via reliance on manure digestion. The even-greater percentage decrease seen in NMVOC since 1990 is due almost exclusively to reductions in cattle populations.

Table 277: Percentage changes of emissions from manure management (index: MM) since 1990, and such emissions' percentage shares of total agricultural emissions of CH_4, N_2O, GHG and NMVOC

[%]	Change since 1990	Share of total agricultural emissions (CH_4, N_2O, GHG, NMVOC) 1990	2020
CH_4, MM	-17.1	19.0	20.4
N_2O_{MM}, direct	-21.1	9.3	8.9
N_2O_{MM}, indirect	-19.1	4.5	4.4
$CH_{4,\ MM}$ + N_2O_{MM} (as GHG in CO_{2eq})	-18.1	16.2	16.7
$NMVOC_{MM}$	-25.9	98.1	96.9

5.3.2 Methane emissions from manure management (3.B, CH_4)

5.3.2.1 Category description (3.B, CH_4)

Cf. Chapter 5.3.1.

5.3.2.2 Methodological issues (3.B, CH_4)

5.3.2.2.1 Methods (3.B, CH_4)

For all animal categories, CH_4 emissions are calculated in accordance with the Tier 2 method:

Equation 14: Calculation of total CH_4 emissions from manure management

$$E_{\mathrm{CH4,MM}} = \sum_{\mathrm{i,j}} n_{\mathrm{i}} \cdot EF_{\mathrm{i,j}} = \sum_{\mathrm{i,j}} n_{\mathrm{i}} \cdot \alpha \cdot \rho_{\mathrm{CH4}} \cdot VS_{\mathrm{i}} \cdot B_{\mathrm{o,i}} \cdot MS_{\mathrm{i,j}} \cdot MCF_{\mathrm{i,j}}$$

Where

$E_{CH4, MM}$	Total methane emissions from manure management (in kg a^{-1} CH_4)
n_i	Number of animal places of animal category i (in places)
$EF_{i, j}$	Methane emission factor for animal category i in manure management system j (in kg $place^{-1}$ a^{-1} CH_4)
α	Factor for conversion of time units (α = 365 d a^{-1})
ρ_{CH4}	Density of methane (ρ_{CH4} = 0.67 kg m^{-3})
VS_i	VS excretions for animal category i (in kg $place^{-1}$ d^{-1})
$B_{o, i}$	Maximum methane-producing capacity for animal category i (in m^3 kg^{-1} CH_4)
$MS_{i, j}$	Relative proportion of housing places, for animal category i, whose excrement occurs in manure management system j (in place $place^{-1}$)
$MCF_{i, j}$	Methane-conversion factor for manure management system j (in m^3 m^{-3})[91]

With regard to the number of animal places n_i, the reader's attention is called to Chapter 5.3.2.2.1. The VS excretions are described in Chapter 5.1.3.5. With regard to the relative percentages of storage systems for solid manure, slurry and digestates, and to time allotted to grazing, cf. Chapters 5.1.3.6.1 and 19.3.2. The methane-producing capacity B_o and the methane conversion factors *MCF* are discussed in Chapters 5.1.3.6.3 and 5.1.3.6.4. According to the IPCC, manure digestion, including storage of manure digestates, is a separate storage type. The B_o and *MCF* values for it are covered in Chapter 5.1.3.6.5.

5.3.2.2.2 Emission factors (3.B, CH_4)

Table 278 shows the time series for the emission factors referenced to animal place. They have been calculated using Equation 14 in Chapter 5.3.2.2.1. The emission factors include the emissions reduction effects resulting via manure digestion.

Table 278: Animal-place-based CH_4 emission factors; manure management (3.B(a))

[kg $place^{-1}$ a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	13.8	18.6	20.5	21.5	20.2	19.9	20.0	19.8	20.1	20.5	21.0	21.2	21.9	22.7	23.2
Other cattle	7.3	7.5	7.7	7.4	6.8	6.7	6.8	6.9	6.9	7.0	7.1	7.2	7.3	7.5	7.7
Swine	4.6	5.0	5.2	4.8	4.3	4.3	4.4	4.4	4.4	4.5	4.5	4.6	4.7	4.7	4.8
Sheep	0.28	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Goats	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Horses	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
Poultry	0.031	0.030	0.032	0.035	0.037	0.035	0.034	0.032	0.033	0.033	0.034	0.034	0.034	0.034	0.034

5.3.2.2.3 Emissions (CRF 3.B, CH_4)

Table 279 shows the calculated total CH_4 emissions from manure management, in both absolute values and relative percentage values referenced to 1990.

Table 279: CH_4 emissions from manure management (3.B(a))

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
[kt a^{-1}]	312.09	285.19	289.42	273.12	246.92	245.84	251.28	251.68	256.53	256.72	258.33	260.19	257.77	257.85	258.83
[% of 1990]	100.0	91.4	92.7	87.5	79.1	78.8	80.5	80.6	82.2	82.3	82.8	83.4	82.6	82.6	82.9

The progression over time is due largely to the development in the sizes of animal populations (cf. Chapter 5.1.3.2), with the effects of such trends modified by emissions-increasing performance growth (cf. Chapter 5.1.3.3).

[91] The IPCC gives *MCF* in percent (of B_o); in the German inventory, the units m^3 m^{-3}, which are clearer in their reference, are used.

Table 280 shows the emissions contributions of dairy cows, other cattle and swine, along with these three animal categories' (taken together, as a group) percentage shares of the total emissions for all animals. The ratios between the emissions of cattle and those of swine have been added as supplementary information.

Table 280: CH_4 from manure management (dairy cows, other cattle, swine); percentage contributions to total CH_4 emissions from manure management; and the ratio between the emissions of cattle and those of swine

[kt a-1]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows	87.8	97.3	93.8	91.0	84.6	83.6	83.8	84.3	86.3	87.8	88.6	88.9	89.6	90.9	91.1
Other cattle	95.8	80.4	76.6	65.6	58.9	56.3	56.5	57.7	58.3	58.5	58.7	58.2	57.7	57.4	56.6
Swine	122.4	101.3	112.8	110.0	96.6	98.9	103.5	101.9	104.2	102.7	103.3	105.3	102.6	101.7	103.3
Total	306.1	279.0	283.2	266.5	240.1	238.7	243.8	243.9	248.7	248.9	250.5	252.4	249.9	250.0	251.0
% share	98.1	97.8	97.8	97.6	97.2	97.1	97.0	96.9	97.0	97.0	97.0	97.0	96.9	96.9	97.0
Cattle : Swine	1.5	1.8	1.5	1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.4

The CH_4-emissions reductions achieved via manure digestion are shown in Table 281. Without digestion, the so-saved emissions would have been emitted in addition to the quantities shown in Table 279. The percentage reductions refer to the emissions that would have occurred without digestion.

Table 281: Absolute and percentage changes in CH_4 emissions achieved as a result of manure digestion, in comparison to a situation with no digestion and no storage of digestates (negative sign: Emissions reduction)

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
[kt a-1]	-0.01	-0.08	-0.7	-6.6	-26.8	-33.1	-36.6	-41.6	-43.9	-44.7	-44.4	-45.6	-44.6	-43.4	-43.6
[%]	-0.003	-0.03	-0.2	-2.4	-9.8	-11.9	-12.7	-14.2	-14.6	-14.8	-14.7	-14.9	-14.7	-14.4	-14.4

5.3.2.3 Uncertainties and time-series consistency (3.B, CH_4)

Table 263 in Chapter 5.1.6 shows the uncertainties in activity data and emission factors that have been used in estimating the total uncertainty of the German GHG inventory.

The uncertainties for the CH_4 emission factors for manure management are default values from IPCC (2006a Vol 4, Table 10.48). With regard to the uncertainty of the activity data (animal-population data), cf. Chapters 4.1.2, 5.1.2, 6.1.2, 7.1.2 and 8.1.2 in Vos et al. (2022).

The emissions time series are consistent, since they were calculated with the same method for all years of the report period, and since the input data are also consistent and complete.

5.3.2.4 Source-specific quality assurance / control and verification (3.B, CH_4)

With regard to quality control and quality assurance, we refer to Chapter 5.1.7.

In the framework of verification, and in an approach similar to that used in Chapter 5.2.4, the results and input data obtained for 2019 were compared with those (for 2019) of neighbouring countries and of the UK (2021 Submission for 2019, UNFCCC (2021b)).

Table 282 shows, for dairy cows, the IEF for CH_4 from manure management, and a number of important influencing factors. In keeping with the CRF requirements, the percentage shares for slurry systems, and the corresponding MCF values, refer only to slurry systems whose slurry is not digested in biogas plants.

The spread in the IEF values of the countries compared is relatively wide. The median (22.6 kg place^{-1} a^{-1}) lies within the IPCC's default-value range for the IEF, as does the German IEF. The daily VS excretions calculated for Germany lie at the lower end of the scale (and are just about the same as France's value). The German MCF for slurry systems amounts to 86 % of the median for the countries being compared, while the degree of use of slurry systems in Germany is about the same as the median.

Table 282: CH_4 emissions from storage of manure from dairy cows, in various countries – a comparison of Implied Emission Factors (IEF) and important emissions-relevant parameters for the time-series year 2019

	IEF_{CH4}	VS excretions	Slurry systems (without digestion)	
			Frequency	Mean MCF
	[kg place^{-1} a^{-1}]	[kg place^{-1} d^{-1}]	[%]	[%]
Austria	17.21	5.04	54.30	8.77
Belgium	26.07	4.55	47.70	19.00
Czech Republic	13.03	6.77	10.70	17.00
Denmark	47.67	7.12	63.37	12.32
France	10.54	4.22	16.67	17.57
Germany	**22.67**	**4.06**	**57.91**	**14.62**
Netherlands	38.99	4.88	84.15	17.00
Poland	7.73	4.81	10.53	17.00
Switzerland	22.57	4.82	53.21	13.50
UK	41.12	5.67	59.88	17.00
IPCC (2006a), Western Europe, cool region 10°C/11°C	21 to 23	5.1	35.7	17 to 19

Source: Germany: 2022 submission; other countries: UNFCCC (2021b)

Table 283 shows, for other cattle, the IEF for CH_4 from manure management, and a number of important influencing factors. The German IEF lies slightly above the median. The primary reason for the large fluctuation range seen in the IEF values – apart from differences in VS excretions and MCF values – is that the frequency of use of liquid-manure systems differs very widely. In this area, Germany lies at the midpoint between the median and the third quartile. As was the case for dairy cows, Germany's VS excretions value is lower than the median. It lies between the VS excretions values of Belgium and the Netherlands.

As Table 284 indicates, Germany's IEF for CH_4 from manure management also lies in the middle of the range in the case of swine; it is slightly higher than the median.

Table 283: CH_4 emissions from storage of manure from other cattle, in various countries – a comparison of Implied Emission Factors (*IEF*) and important emissions-relevant parameters for the year 2019

	IEF_{CH4}	VS excretions	Slurry systems (without digestion)	
	[kg place^{-1} a^{-1} CH_4]	[kg place^{-1} d^{-1}]	Frequency [%]	Mean MCF [%]
Austria	6.18	2.13	34.86	8.26
Belgium	2.82	1.49	15.83	19.00
Czech Republic	3.56	2.95	6.60	17.00
Denmark	14.59	3.25	31.66	12.32
France	3.19	1.91	2.58	18.94
Germany	**7.52**	**1.42**	**31.91**	**14.77**
Netherlands [a]	7.89	1.18	69.72	17.00
Poland	1.73	1.79	5.06	17.00
Switzerland [a]	6.19	2.49	30.67	13.50
UK [b]	7.00	1.96	18.04	17.00
IPCC (2006a): Vol. 4, 10.38, 10.77, Western Europe, cool region 10°C/11°C	6 to 7	2.6	25.2	17 to 19

Source: Germany: 2022 submission; other countries: UNFCCC (2021b)

[a] Calculated from CRF data

[b] UK: Cattle, not including dairy cows, and not including dairy replacements (with calves)

Table 284: CH_4 emissions from storage of manure from swine, in various countries – a comparison of Implied Emission Factors (IEF) and important emissions-relevant parameters for the year 2019

	IEF_{CH4}	VS excretions	Slurry systems (without digestion)	
	[kg place^{-1} a^{-1} CH_4]	[kg place^{-1} d^{-1}]	Frequency [%]	Mean MCF [%]
Austria	1.15	0.30	86.10	3.39
Belgium	4.46	0.22	96.89	19.00
Czech Republic	6.26	NA	28.10	NO
Denmark	3.41	0.18	82.38	13.33
France	4.17	0.19	86.19	21.95
Germany	**4.71**	**0.33**	**79.10**	**22.66**
Netherlands	5.73	0.42	49.46	36.00
Poland	1.38	0.31	24.90	17.00
Switzerland	4.00	0.31	81.73	13.50
UK	4.07	0.25	35.95	17.00
IPCC (2006a Vol 4, 10.80, 10.81), Western Europe, cool region 10°C/11°C	Sows, boars: 9 to 10 Other: 6	Sows, boars: 0.46 Other: 0.30		17 to 19

Source: Germany: 2022 submission; other countries: UNFCCC (2021b)

Table 285 shows, for poultry, the average IEF, the average VS excretions and the average animal weight, the last of which serves as an indicator of energy requirements and, thus, feed intake and excretions. With regard to IEFs, if one neglects the comparatively very high value of the Czech Republic, a range of 0.017 to 0.034 kg place^{-1}a^{-1} results. The highest IEF in this category is reported by Germany. The reason for this is that Germany's VS excretions value is higher than those of other countries (at least of those seven countries that report VS excretions). While the German VS excretions figure marks the upper bound of the scale, Germany is part of a group, along with Denmark, France and the Netherlands, that have VS excretions figures that are higher, by factors of 2 to 2.5, than the lower bound of the IPCC default range. Average poultry weights are reported only by Belgium, the Czech Republic, Denmark and Germany. These values are all of a comparable magnitude; Germany's average poultry weight is closest to Belgium's value.

Table 285: CH_4 emissions from storage of manure from poultry, in various countries – a comparison of Implied Emission Factors (IEF) and important emissions-relevant parameters for the year 2019

	IEF_{CH4} [kg place^{-1} a^{-1}]	VS excretions [kg place^{-1} d^{-1}]	Mean animal weight [kg animal^{-1}]
Austria	0.024	0.02	NA
Belgium	0.023	NE	1.54
Czech Republic	0.100	NA	1.32
Denmark	0.025	0.017	2.00
France	0.025	0.019	NE
Germany	**0.034**	**0.025**	**1.69**
Netherlands	0.031	0.023	NA
Poland	0.028	NA	NA
Switzerland	0.017	0.013	NA
UK	0.012	0.013	NE
IPCC (2006a Vol4, 10.82), W-Europe, cool region, developed countries	0.02 to 0.09 [a]	0.01 to 0.07 [a]	0.9 to 6.8 [a]

Source: Germany: 2022 submission; other countries: UNFCCC (2021b)

[a] low value: laying hens; high value: turkeys

5.3.2.5 Source-specific recalculations (3.B, CH_4)

Table 286 through Table 288 show, for dairy cows, other cattle, swine and poultry, a comparison of figures for VS excretions, emission factors and emissions as reported in the current submission and the previous year's submission.

The two submissions differ slightly with regard to the VS excretions of dairy cows and other cattle. The differences are a direct result of a) the changes made for suckler cows, in the areas of energy requirements and feed composition, and b) use of new grazing data from the 2020 agricultural census; cf. Chapter 5.1.3.3. The differences for swine and poultry are due to the changes, mentioned in Chapter 5.1.3.3 and Chapter 5.1.3.2.3, made in feeding data for fattening pigs and broilers. Use of new data, from the 2020 agricultural census, on the applicable shares of housing systems and manure-storage systems, also has a strong influence on the changes in the emission factors and emissions; cf. Chapter 5.1.3.3.

Table 286: Comparison of VS excretions as reported in the 2022 and 2021 submissions (3.B(a))

[kg place^{-1} d^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dairy cows, 2022	2.95	3.24	3.46	3.62	3.73	3.77	3.80	3.80	3.85	3.88	3.91	3.92	3.99	4.06
Dairy cows, 2021	2.95	3.24	3.46	3.62	3.73	3.77	3.79	3.79	3.84	3.87	3.90	3.90	3.97	4.04
Other cattle, 2022	1.27	1.33	1.38	1.37	1.39	1.39	1.39	1.39	1.39	1.40	1.40	1.40	1.41	1.42
Other cattle, 2021	1.26	1.31	1.36	1.35	1.38	1.37	1.37	1.37	1.38	1.38	1.38	1.39	1.40	1.41
Swine, 2022	0.298	0.314	0.324	0.315	0.308	0.310	0.312	0.314	0.316	0.321	0.324	0.326	0.329	0.329
Swine, 2021	0.264	0.278	0.284	0.287	0.294	0.295	0.297	0.299	0.302	0.302	0.305	0.307	0.309	0.310
Poultry, 2022	0.0225	0.0219	0.0234	0.0256	0.0271	0.0262	0.0253	0.0241	0.0246	0.0250	0.0252	0.0254	0.0255	0.0255
Poultry, 2021	0.0225	0.0218	0.0234	0.0255	0.0271	0.0263	0.0254	0.0242	0.0248	0.0252	0.0254	0.0255	0.0258	0.0257

Table 287: Comparison of the animal-place-based CH_4 emission factors, as reported in the 2021 and 2022 Submissions, for manure management (3.B(a))

[kg place^{-1} a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dairy cows, 2022	13.8	18.6	20.5	21.5	20.2	19.9	20.0	19.8	20.1	20.5	21.0	21.2	21.9	22.7
Dairy cows, 2021	13.8	18.6	20.5	21.6	20.5	20.0	19.8	19.3	19.4	19.6	19.8	19.8	20.2	20.6
Other cattle, 2022	7.30	7.54	7.68	7.45	6.82	6.75	6.80	6.85	6.90	7.01	7.11	7.20	7.35	7.52
Other cattle, 2021	7.26	7.44	7.60	7.58	7.11	6.93	6.88	6.84	6.79	6.80	6.82	6.82	6.88	6.93
Swine, 2022	4.62	4.97	5.18	4.84	4.34	4.34	4.38	4.36	4.40	4.47	4.54	4.59	4.66	4.71
Swine, 2021	4.05	4.38	4.52	4.39	4.12	4.09	4.10	4.06	4.08	4.06	4.10	4.13	4.17	4.17
Poultry, 2022	0.0313	0.0304	0.0322	0.0349	0.0365	0.0353	0.0339	0.0324	0.0330	0.0334	0.0338	0.0340	0.0342	0.0342
Poultry, 2021	0.0314	0.0302	0.0321	0.0348	0.0366	0.0354	0.0341	0.0325	0.0332	0.0337	0.0340	0.0342	0.0346	0.0345

Table 288: Comparison of CH_4 emissions from manure management as reported in the 2021 and 2022 Submissions (3.B(a))

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
All animals, 2022	**312.1**	**285.2**	**289.4**	**273.1**	**246.9**	**245.8**	**251.3**	**251.7**	**256.5**	**256.7**	**258.3**	**260.2**	**257.8**	**257.9**
All animals, 2021	**296.6**	**272.1**	**274.3**	**264.8**	**245.7**	**241.9**	**244.7**	**242.9**	**245.1**	**241.8**	**241.2**	**240.8**	**236.6**	**233.3**
Dairy cows, 2022	87.8	97.3	93.8	91.0	84.6	83.6	83.8	84.3	86.3	87.8	88.6	88.9	89.6	90.9
Dairy cows, 2021	87.8	97.3	93.8	91.5	85.8	83.7	82.9	82.5	83.4	83.8	83.7	83.1	82.9	82.6
Other cattle, 2022	95.8	80.4	76.6	65.6	58.9	56.3	56.5	57.7	58.3	58.5	58.7	58.2	57.7	57.4
Other cattle, 2021	95.4	79.3	75.8	66.7	61.3	57.8	57.2	57.5	57.3	56.8	56.2	55.1	54.0	52.9
Swine, 2022	122.4	101.3	112.8	110.0	96.6	98.9	103.5	101.9	104.2	102.7	103.3	105.3	102.6	101.7
Swine, 2021	107.4	89.3	98.4	99.9	91.7	93.3	97.0	95.0	96.6	93.4	93.4	94.7	91.7	90.0
Poultry, 2022	3.57	3.38	3.86	4.21	4.71	5.12	5.47	5.74	5.81	5.85	5.86	5.90	5.93	5.92
Poultry, 2021	3.58	3.36	3.86	4.20	4.71	5.13	5.49	5.77	5.84	5.89	5.91	5.96	6.06	6.06

5.3.2.6 Planned improvements (3.B, CH_4)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

5.3.3 NMVOC emissions from manure management

5.3.3.1 Category description (NMVOC)

Cf. Chapter 5.3.1.

5.3.3.2 Methodological aspects (NMVOC)

5.3.3.2.1 Methods (NMVOC)

IPCC (2006a) does not provide any method for calculating NMVOC emissions from manure management. EMEP/EEA (2019) provides methods and the relevant parameters. Germany calculates NMVOC emissions separately for each animal category. In the process, it uses the Tier 2 method for dairy cows and other cattle (EMEP/EEA, 2019-3B-28), and the Tier 1 method for other animals (EMEP/EEA, 2019 -3B-18). With the simple Tier 1 method, the number of animals in each case is multiplied by an emission factor that is referenced to animal place. The Tier 2 method calculates animal-specific NMVOC emissions as the sum of emissions a) from silage storage, b) from feeding with silage, c) in housing, d) from manure management, e) from manure application and f) from grazing. To determine how these sub-fractions of emissions relate to one another, the method relies on ratios between corresponding fractions of NH_3 emissions. In the German Py-GAS-EM inventory model, and for purposes of reporting under the CLRTAP (United Nations Economic Comission for Europe, 1979), these NH_3 emissions are calculated in a manner consistent with the way greenhouse-gas emissions are calculated.

For further details of the NMVOC-emissions calculations, cf. Vos et al. (2022), Chapter 3.3.4.2. With regard to the equation set used in the Tier 2 method, we refer to EMEP/EEA (2019-3B-29).

5.3.3.2.2 Emission factors (NMVOC)

For the Tier 1 method, EMEP/EEA (2019 -3B-18) provides different emission factors for feeding with and without silage. For horses, the German inventory applies the relevant emission factors for feeding with silage; for other animals, for which a Tier 1 calculation is carried out, it uses the factors for feeding without silage. Table 289 presents a list of the emission factors used in the inventory. In addition, the following approach has been taken – because some emission factors are lacking and some do not fit with the inventory animal categories – for weaners, boars, sheep, horses and pullets (cf. Chapter 3.3.4.2.1 in Vos et al. (2022)):

- In a conservative approach, the emission factor for sows is used for boars, and the factor for fattening pigs is used for weaners.
- The emission factor for sheep listed in EMEP/EEA (2019) has been interpreted as applying to mature sheep. The emission factor for lambs is set at 40 % of the emission factor for mature sheep.
- The emission factor for horses listed in EMEP/EEA (2019) has been interpreted as applying to heavy horses. For light horses and ponies, the emission factor given in EMEP/EEA (2019) for mules and asses has been used.
- Due to the similarity in the applicable housing systems, the emission factor for broilers has been used for pullets.

Table 289: NMVOC: Tier 1 emission factors pursuant to EMEP/EEA (2019) that are used in the inventory

[kg place^{-1} a^{-1}]	Tier-1-EF_{NMVOC}
Sows, boars	1.704
Fattening pigs, weaners	0.551
Mature sheep	0.169
Lambs	0.068
Goats	0.542
Heavy horses	7.781
Light horses and ponies	3.018
Laying hens	0.165
Broilers, pullets	0.108
Geese, ducks and turkeys	0.489

Table 290 shows, for selected years, the calculated Tier 2 implied emission factors (IEF) for dairy cows and other cattle.

Table 290: NMVOC: Tier 2 emission factors (IEF) calculated in the inventory

[kg place^{-1} a^{-1}]	1990	2005	2019
Dairy cows	30.94	36.71	40.80
Other cattle	11.74	11.72	11.57

The increasing trend in the IEF for dairy cows since 1990 results directly from performance increases. In the calculation, it is taken into account via GE intake. The temporal development of the IEF for other cattle reflects the impacts of performance growth in fattening animals and the temporal variance in the composition of the population (since the IEF for the various sub-categories of other cattle differ from one another).

Major differences are apparent between the Tier 2 and Tier 1 emission factors for dairy cows and other cattle (with silage feeding). The latter factors, pursuant to EMEP/EEA (2019 -3B-18), are 17.937 kg pl^{-1} a^{-1} (dairy cows) and 8.902 kg pl^{-1} a^{-1} (other cattle). These large differences can only be explained as the result of inconsistency between the two methods.

5.3.3.2.3 Emissions (NMVOC)

Table 291 lists the NMVOC emissions from manure management that are to be reported under CRF 3s1.

Table 291: NMVOC emissions from manure management

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**391.2**	**332.9**	**318.9**	**298.3**	**297.2**	**297.4**	**299.4**	**304.6**	**306.9**	**305.7**	**302.7**	**300.0**	**296.2**	**293.5**	**289.8**
in % of 1990	**100.0**	**85.1**	**81.5**	**76.2**	**76.0**	**76.0**	**76.5**	**77.8**	**78.5**	**78.1**	**77.4**	**76.7**	**75.7**	**75.0**	**74.1**
Dairy cows	196.6	171.0	162.1	155.5	155.8	157.6	157.7	159.9	162.8	163.5	162.6	161.8	161.3	161.0	160.0
Other cattle	154.2	125.0	118.2	103.1	101.6	97.5	96.8	97.8	97.5	96.3	94.7	92.7	90.1	88.0	85.4
Swine	18.4	14.2	15.0	15.5	14.9	15.1	15.5	15.3	15.4	15.0	14.8	14.9	14.3	14.0	13.9
Sheep	0.43	0.39	0.36	0.35	0.30	0.26	0.26	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.23
Goats	0.05	0.05	0.08	0.09	0.08	0.08	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08
Horses	3.2	4.1	3.3	3.4	3.1	3.1	3.1	3.1	3.0	3.0	2.9	3.0	3.0	3.0	3.0
Poultry	18.3	18.1	19.8	20.3	21.6	23.8	26.0	28.2	27.9	27.7	27.4	27.3	27.3	27.2	27.2

As Table 292 shows, cattle husbandry is responsible for great majority of the emissions. The reduction in NMVOC emissions seen since 1990, therefore, is due almost exclusively to decreases in numbers of cattle (R^2 = 94.8 %). The relative emissions contribution from poultry husbandry has increased sharply, with respect to 1990, as a result of increases in numbers of poultry. At the end of the time series, that contribution is considerably greater than the total contribution from other animals.

Table 292: Percentage contributions to NMVOC emissions, from manure management

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Cattle	89.7	88.9	87.9	86.7	86.6	85.8	85.0	84.6	84.8	85.0	85.0	84.8	84.9	84.8	84.7
Poultry	4.7	5.4	6.2	6.8	7.3	8.0	8.7	9.3	9.1	9.0	9.0	9.1	9.2	9.3	9.4
Other animals	5.7	5.6	5.9	6.5	6.2	6.2	6.3	6.1	6.1	6.0	6.0	6.0	5.9	5.9	5.9

5.3.3.3 Uncertainties and time-series consistency (NMVOC)

EMEP/EEA (2019-3B-37) highlights the very large uncertainty of the emission factors, but it does not provide any pertinent quantitative information. The German inventory assumes a 95 % confidence interval of [-79 %, +200 %]; cf. in this regard Chapter 3.3.4.2.3 in Vos et al. (2022). With regard to the uncertainty of the activity data (animal-population data), cf. Chapters 4.1.2, 5.1.2, 6.1.2, 7.1.2 and 8.1.2 in Vos et al. (2022).

The emissions time series are consistent, since they were calculated with the same method for all years of the report period, and since the input data are also consistent and complete.

5.3.3.4 Source-specific quality assurance / control and verification (NMVOC)

With regard to quality control and quality assurance, we refer to Chapter 5.1.7.

5.3.3.5 Source-specific recalculations (NMVOC)

For cattle, the NMVOC emission factors – and, thus, the NMVOC emissions – differ from the figures reported in the 2021 NIR, while for the other animal categories the NMVOC emissions agree with the corresponding figures in the 2021 NIR. Table 293 shows the different emissions data reported in the 2022 and 2021 submissions. The different emission factors are not included, since the emissions are directly proportional to the emission factors. For the most part, the differences shown in Table 293 between the two submissions result from use of new animal husbandry data from the 2020 agricultural census, which has a retroactive impact back to the year 2000.

Table 293: Comparison of NMVOC emissions, as reported in the 2022 NIR and the 2021 NIR, for dairy cows and other cattle

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dairy cows, 2022	196.6	171.0	162.1	155.5	155.8	157.6	157.7	159.9	162.8	163.5	162.6	161.8	161.3	161.0
Dairy cows, 2021	196.6	171.0	162.1	155.5	155.8	157.5	157.4	159.4	162.0	162.4	161.8	161.2	160.8	160.8
Other cattle, 2022	154.2	125.0	118.2	103.1	101.6	97.5	96.8	97.8	97.5	96.3	94.7	92.7	90.1	88.0
Other cattle, 2021	153.7	124.3	117.3	102.5	101.1	97.4	96.9	98.1	98.0	97.0	95.8	94.2	91.9	90.1

5.3.3.6 Planned improvements (NMVOC)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

5.3.4 Direct N_2O and NO emissions from manure management (3.B, N_2O & NO)

5.3.4.1 Category description (3.B, N_2O_{direct} & NO)

Cf. Chapter 5.3.1.

5.3.4.2 Methodological issues (3.B, N_2O_{direct} & NO)

5.3.4.2.1 Methods (3.B, N_2O_{direct} & NO)

N_2O emissions from manure management are calculated separately for all animal categories, taking account of the management systems in use (and including manure digestion; cf. Chapter 5.1.3.6.5):

Equation 15: Calculation of N_2O emissions from manure management

$$E_{\mathrm{N2O\text{-}N}} = \sum_{\mathrm{i,j}} [(N_{\mathrm{excr,\ i}} + N_{\mathrm{straw,i,\ j}}) \cdot MS_{\mathrm{i,\ j}}] \cdot EF_{\mathrm{N2O\text{-}N,\ j}}$$

Where:

E_{N2O-N}	Total N_2O-N emissions from manure management (kg a^{-1} N_2O-N)
$N_{excr,i}$	Total N excretions of animal category i (kg a^{-1} N)
$N_{straw,i,j}$	N input via bedding material, for animal category i and manure management system j (kg a^{-1} N)
$MS_{i,j}$	Relative share of manure management system j of animal category i (place place^{-1})
$EF_{N2O-N,j}$	N_2O-N emission factor for manure management system j (kg kg^{-1} N_2O-N)

With regard to total N excretions and total N inputs via bedding material, cf. Chapters 5.1.3.4 and 5.1.3.6.2. With regard to the relative frequencies of manure management systems, cf. Chapters 5.1.3.6.1 and 19.3.2.

NO emissions from manure management are calculated using a method similar to that used to calculate the relevant N_2O emissions.

N_2O and NO emissions from manure application and grazing are reported under 3.D.

5.3.4.2.2 Emission factors (3.B, N_2O_{direct} & NO)

For slurry storage, the default emission factors available in IPCC (2006a) are used: Outdoor storage facilities without natural crust cover (equivalent to "open tank, without natural crust" in Table 294); outdoor storage facilities with natural crust cover; storage below slatted floor. In a conservative approach, for slurry storage with solid cover, or with artificial floating cover (chaff) – both of which are not mentioned in IPCC (2006a Vol 4) – the emission factor for outdoor storage with natural crust is used. For slurry storage under a foil cover, which is also not mentioned in IPCC (2006a Vol 4), it is assumed that the emission factor for outdoor storage without natural crust can be used.

Systems for storage of solid manure are broken down into the categories tied systems / pens allowing free movement (with storage in heaps) and deep bedding. With regard to housing with use of deep bedding, German agricultural techniques do not include active mixing of the bedding (expert judgement, Brigitte Eurich-Menden et al. cf. Chapters 4.2.2.2 and 5.2.2.2 in Vos et al. (2022)). For deep bedding, therefore, the IPCC (2006a) default value of 0.010 kg N_2ON (kg N)$^{-1}$ is used IPCC (2006a Vol 4, 10.63). For storage of solid manure from tied systems / pens allowing free movement, and for storage of poultry manure, the respective IPCC (2006a) default values of 0.005 and 0.001 kg N_2ON (kg N)$^{-1}$ are used IPCC (2006a Vol 4, 10.63).

IPCC (2006a Vol 4, 10.63) treats manure digestion, including storage of digestates, as a separate type of storage, one that produces no N_2O emissions (EF = 0 kg kg^{-1}). This IPCC default approach does not take account of the fact that open systems for storage of digestates emit N_2O. The German inventory thus reports non-zero N_2O emissions from manure digestion, broken down by different types of manure and digestates storage; cf. Chapter 5.1.3.6.5.

Table 294 shows the N_2O-N emission factors used in the 2022 submission.

Table 294: Emission factors for emissions of N_2O-N from manure management, not including digestion (in relation to total excreted N and straw-bedding N) (3.B(b))

Manure		Emission factor [kg kg^{-1}]
Slurry	Open tank, without natural crust [a]	0.000
	Solid cover [b]	0.005
	Natural crust cover [a]	0.005
	Floating cover (chaff) [b]	0.005
	Floating cover (plastic film) [c]	0.000
	Below slatted floor [a]	0.002
Leachate[d]	Solid cover	0.005
Solid manure		0.005
Deep bedding[a]		0.010
Poultry manure with or without litter[a]		0.001

[a] Source: IPCC (2006a Vol 4)

[b] Worst-case assumption: Like natural crust, since no information is available.

[c] Assumption: With floating plastic film covers, no N_2O formation occurs.

[d] Assumption: Comparable to storage of liquid manure under a solid cover

IPCC (2006a Vol 4) does not give any emission factors for NO. The Tier 1 emission factors given in EMEP/EEA (2019-3B-17) refer to animal places. They cannot be used in the Py-GAS-EM inventory model, since Py-GAS-EM, in the context of the N-flow concept (cf. Chapter 5.1.2.4), requires emission factors that refer to emissions-relevant N quantities. Comparative calculations have shown, however that the German total NO emissions from Sector 3.B, as calculated with the Tier 1 emission factors, can be reproduced with the Py-GAS-EM N-flow concept if the NO-N emission factor oriented to N is smaller than the N_2O-N emission factor by an order of magnitude. For this reason, in the inventory, the NO-N emission factor has been set at a level of 10 % of the N_2O-N emission factor. This approach yields NO emissions that are directly proportional to the relevant N_2O emissions.

Neither IPCC nor EMEP gives emission factors for N_2 (which must also be taken into account in the N-flow concept; cf. Chapter 5.1.2.4). Jarvis and Pain (1994) obtained 3:1 as the ratio of N_2 emissions to N_2O-N emissions. Therefore, for purposes of the inventory, it has been assumed that N_2 emission factor is three times as large as the N_2O-N emission factor.

Table 295 shows the time series for the average N_2O-N emission factors for the four overarching categories of manure management systems of relevance for reporting. These categories are "slurry-based (without digestion)", "straw-based (without deep bedding and without digestion)", "deep bedding (without digestion)" and "digestion" (of manure). In the interest of clarity, we have used the units g kg^{-1}, instead of the common units for emission factors (kg kg^{-1}; cf. Table 294). These emission factors are defined as the ratio of total N_2O-N emissions from a management system to the sum of animal N excretions in the same management system. Under this perspective, the total N_2O emissions of categories with bedding also include emissions fractions tied to bedding-N. For this reason, the resulting emission factor for deep bedding that is listed in Table 295 is higher than the factor given in Table 294. The same holds, in principle, for straw-based systems without deep bedding and without digestion, although the effect is not perceived, because the relevant values in Table 295 also include the considerably lower emission factor for poultry (cf. Table 294). The N_2O-N emission factors for straw-based systems and systems with digestion show, throughout the entire time series, a pronounced negative trend. For straw-based systems, this results from decreases in N_2O contributions from solid-manure systems in cattle and swine husbandry. Those decreases, in turn, result from changes in numbers of animals in the various housing systems. For digestion systems, the negative trend in the emission factors is due primarily to increasing use of gas-tight storage of digestates (cf. Chapter 5.1.3.6.5). The discrepancies between the data in Table 295 and the data in the corresponding table in the 2021 NIR result from changes made, between the 2021 submission and the present 2022 submission, in models and activity data.

Table 295: Average N_2O-N emission factors, by manure management systems (3.B(b))

[g kg^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Slurry-based [a]	3.05	3.42	3.38	3.37	3.38	3.34	3.30	3.27	3.24	3.21	3.18	3.14	3.12	3.09	3.06
Straw-based [b]	4.89	4.61	4.45	4.42	4.28	4.11	3.99	3.86	3.82	3.76	3.71	3.63	3.56	3.49	3.45
Deep bedding [a]	11.28	11.41	11.40	11.36	11.35	11.38	11.41	11.45	11.47	11.49	11.51	11.54	11.56	11.57	11.59
Digestion	5.44	5.10	4.86	4.57	3.33	3.06	2.48	2.37	2.27	2.23	2.20	2.20	2.17	2.13	2.12

[a] Without digestion

[b] Without deep bedding and without digestion

5.3.4.2.3 Emissions (3.B, N_2O_{direct} & NO)

Table 296 shows the direct total N_2O emissions from manure management (including storage of digested manure) and breaks them down by system categories. The sharp emissions decrease in the first half of the 1990s is due primarily to reductions of livestock populations following German reunification. Additional influencing factors include shifts, over time, in the distributions of management systems (cf. Chapters 5.1.3.6.1 and 19.3.2), and gradually (over the years) increasing emissions reductions achieved via manure digestion (cf. Chapter 5.1.3.6.5).

Table 296: Direct N_2O emissions from manure management (MM), total and by system categories (3.B(b))

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
MM total	8.28	7.43	7.25	7.20	7.11	6.98	6.88	6.87	6.91	6.87	6.82	6.77	6.66	6.60	6.53
in % of 1990	100.0	89.8	87.6	87.0	85.9	84.4	83.1	83.1	83.5	83.0	82.5	81.9	80.5	79.7	78.9
Slurry-based [a]	4.17	4.41	4.27	3.93	3.35	3.22	3.20	3.12	3.12	3.09	3.07	3.03	2.98	2.96	2.93
Straw-based [b]	3.25	2.12	1.98	1.94	1.94	1.81	1.74	1.66	1.60	1.52	1.44	1.36	1.28	1.21	1.13
Deep bedding [a]	0.86	0.90	0.96	1.10	1.13	1.17	1.26	1.36	1.46	1.52	1.59	1.65	1.70	1.76	1.81
Digestion	0.00	0.00	0.04	0.23	0.69	0.78	0.68	0.74	0.74	0.74	0.72	0.73	0.70	0.67	0.66

[a] Without digestion

[b] Without deep bedding and without digestion

Table 297 shows the absolute and percentage reductions in N_2O emissions achieved via manure digestion, in comparison to a situation with no digestion and storage of digestates. Positive values denote an emissions increase. The primary reason for the increase is that storage of digestates, if it is not gas-tight, generates higher N_2O emissions than does conventional storage of manure. Furthermore, storage of digested poultry manure generally produces higher N_2O emissions than does storage of undigested poultry manure. The fraction of storage systems with gas-tight storage has increased significantly over the years (cf. Chapter 5.1.3.6.5). Only in the period as of 2006/2007 has this trend led to reductions in N_2O emissions for total manure digestion, however.

Table 297: Absolute and percentage changes in direct N_2O emissions as a result of manure digestion, in comparison to a situation with no digestion and storage of digestates (negative values: Emissions reduction)

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
[kt a^{-1}]	0.0001	0.0008	0.006	0.04	-0.12	-0.21	-0.37	-0.43	-0.47	-0.48	-0.47	-0.47	-0.46	-0.45	-0.44
[%]	0.001	0.011	0.08	0.6	-1.7	-2.9	-5.1	-5.9	-6.4	-6.5	-6.4	-6.5	-6.4	-6.3	-6.3

Table 298 shows the total NO emissions in source category 3.B. Because the NO and N_2O emission factors are proportional to each other, the trends for NO are identical to those for N_2O.

Table 298: NO emissions from manure management

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	1.129	1.013	0.989	0.981	0.970	0.952	0.938	0.937	0.942	0.937	0.931	0.924	0.908	0.899	0.890

5.3.4.3 Uncertainties and time-series consistency (3.B, N_2O_{direct} & NO)

Table 263 in Chapter 5.1.6 shows the uncertainties in activity data and emission factors that have been used in estimating the total uncertainty of the German GHG inventory.

The estimate of the uncertainty of the N_2O emission factors (95 % confidence interval) is based on the default values in IPCC (2006a Vol 4, Table 10.21). See also in this regard Chapters 4.2.2.4 and 14.4.1 in Vos et al. (2022). With regard to the uncertainty of the activity data (animal-population data), cf. Chapters 4.1.2, 5.1.2, 6.1.2, 7.1.2 and 8.1.2 in Vos et al. (2022).

Due to a lack of data on the uncertainty of the NO emission factor, the uncertainty of the N_2O emission factor is used as that uncertainty.

The emissions time series are consistent, since they were calculated with the same method for all years of the report period, and since the input data are also consistent and complete.

5.3.4.4 Source-specific quality assurance / control and verification (3.B, N_2O_{direct} & NO)

With regard to quality control and quality assurance, we refer to Chapter 5.1.7.

In the framework of verification, and in an approach similar to that used in Chapter 5.2.4, the 2019 N-excretions and N_2O-emissions figures for manure management in Germany were compared with the corresponding figures of neighboring countries and the UK; cf. Table 299 and Table 300.

Germany's value for N excretions of dairy cows is about 6 % higher than the median, and in plausible proximity to the values of other countries. The German value for N excretions of other cattle is about at the level of the median. The German N-excretions value for swine is the second-highest. These results bring up the question of how to define the average value for the entire swine population. Germany calculates the average value in conformance with the rules for an AAP place that is occupied 365 days of the year – cf. Chapter 3.1.2.2 in Vos et al. (2022). The lower N-excretions values given by the other countries may be due in part to non-AAP-consistent inclusion of vacancy periods.

With regard to poultry, Germany lies at the upper end of the value range. A lack of data on the compositions of the total populations in the various countries hampers direct comparisons, since the various types of poultry have widely differing excretion levels (cf. the range pursuant to EMEP/EEA (2019-3B-31)).

Table 299: N excretions per animal place, for dairy cows, other cattle, swine and poultry of various countries, for the time-series year 2019

	Dairy cows [kg place^{-1} a^{-1}]	Other cattle [kg place^{-1} a^{-1}]	Swine [kg place^{-1} a^{-1}]	Poultry [kg place^{-1} a^{-1}]
Austria	107.11	45.48	9.33	0.55
Belgium	121.41	53.84	8.83	0.56
Czech Republic	109.20	58.71	11.80	0.51
Denmark	156.20	42.82	7.57	0.46
France	115.58	59.97	9.47	0.48
Germany	**119.47**	**43.32**	**13.04**	**0.67**
Netherlands [a]	83.80	39.48	14.06	0.59
Poland	112.90	51.08	10.88	0.65
Switzerland [a]	111.65	39.63	9.34	0.47
UK [b]	112.90	44.35	10.17	0.57
IPCC (2006a Vol 4, 10.59, 10.72, 10.78, 10.80-10.82):	105.1 [c]	50.6 [c]	9.3 / 30.4 [c,d]	0.53 [c, e]
EMEP/EEA (2019-3B-31)	105	41	12.1 / 34.5 [d]	0.36 to 1.64

Source: Germany: 2022 submission; other countries: UNFCCC (2021b)

a Netherlands and Switzerland, other cattle: calculated from CRF data

b UK: Cattle data differentiate between dairy cows (dairy cows and dairy replacements, including calves selected to be dairy cows) and the remaining "other cattle"

c IPCC weights: calculated pursuant to IPCC (2006a Vol 4), with the IPCC's standard values for weight and N excretions and, in the case of poultry, with the German animal counts in the various poultry sub-categories (2022 submission)

d IPCC (2006a Vol 4) Sows and boars: 30.4, other: 9.3; EMEP/EEA (2019): Sows: 34.5, fattening pigs: 12.1

e Poultry: Assumptions for lacking values: Weight of geese = 1/2 standard weight of turkeys IPCC (2006a Vol 4); N excretions of geese = standard N excretions of turkeys IPCC (2006a Vol 4); weight of pullets = 1/2 standard weight of laying hens IPCC (2006a Vol 4); N excretions of pullets = standard N excretions of laying hens IPCC (2006a Vol 4)

Table 300 shows a comparison of the IEFs for direct N_2O emissions from manure management for dairy cows, other cattle, swine and poultry. The data sets reported by the various countries all exhibit very wide ranges. The fluctuation ranges cannot be explained on the basis of the available data. Germany's value for dairy cows is slightly above the median, while its value for other cattle is slightly below the median. With regard to swine, Germany's value is about 15% above the median and, as a result, approximately at the level of the values reported by the Czech Republic and Denmark. For poultry, Germany has the third-highest value. As a result, its value is considerably higher than the values of the majority of its neighbours. Germany's high value for poultry can be explained in that the German poultry IEF also includes N_2O emissions from digestion of poultry manure, and from related storage of digestates; the effective emission factor for such digestion and storage is considerably higher than the emission factor for conventional storage of poultry manure.

Table 300: IEFs of various countries for direct N_2O emissions from manure management for dairy cows, other cattle, swine and poultry, in 2019

	Dairy cows [kg place^{-1} a^{-1}]	Other cattle [kg place^{-1} a^{-1}]	Swine [kg place^{-1} a^{-1}]	Poultry [kg place^{-1} a^{-1}]
Austria	0.668	0.380	0.046	0.00079
Belgium	0.713	0.552	0.030	0.00088
Czech Republic	0.579	0.317	0.055	0.00387
Denmark	0.945	0.370	0.058	0.00071
France	0.402	0.182	0.004	0.00069
Germany	**0.604**	**0.323**	**0.058**	**0.00122**
Netherlands [a]	0.408	0.233	0.027	0.00094
Poland	0.796	0.353	0.085	0.00103
Switzerland [a]	0.330	0.142	0.024	0.00071
UK [b]	0.516	0.578	0.169	0.00492

Source: Germany: 2022 Submission; other countries: UNFCCC (2021b)

a Netherlands and Switzerland, other cattle: calculated from CRF data

b UK: Cattle data differentiate between dairy cows (dairy cows and dairy replacements, including calves selected to be dairy cows) and the remaining "other cattle"

5.3.4.5 Source-specific recalculations (3.B, N_2O_{direct} & NO)

Table 301 shows the direct N_2O emissions from manure management in comparison to the corresponding results in the 2021 submission. The underlying N-excretions data are shown in Table 302.

With regard to the N excretions, clear differences between the two submissions are apparent. The differences are a direct result of a) the changes made for suckler cows, fattening pigs and broilers, in the areas of energy requirements and feed composition, and b) use of new grazing data from the 2020 agricultural census; cf. Chapter 5.1.3.3. The differences in N excretions lead to differences in the N_2O emissions. In addition, the N_2O emissions differ as a result of use of new animal husbandry data, from the 2020 agricultural census, which has a retroactive effect back to the year 2000.

Table 301: Comparison of direct total N_2O emissions from manure management, as calculated in the 2021 and 2022 submissions

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2022	8.276	7.431	7.251	7.197	7.111	6.982	6.882	6.874	6.908	6.870	6.824	6.774	6.660	6.596
2021	8.225	7.419	7.286	7.336	7.314	7.182	7.080	7.056	7.086	7.006	6.957	6.904	6.782	6.701

Table 302: Comparison of total N excretions as calculated in the 2022 and 2021 submissions (cf. Chapter 5.1.3.4)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2022	1555.1	1336.2	1301.0	1253.9	1246.6	1249.5	1267.5	1280.7	1294.6	1293.0	1283.9	1277.9	1257.0	1245.8
2021	1534.9	1328.1	1298.8	1256.1	1255.3	1259.9	1279.4	1294.3	1310.1	1305.3	1297.6	1293.2	1275.1	1265.1

The NO emissions, because they are directly proportional to N_2O emissions (cf. Chapter 5.3.4.2.2), have changed in the same manner that the N_2O emissions have changed; cf. Table 303

Table 303: Comparison of total NO emissions from manure management, as calculated in the 2021 and 2022 Submissions

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2022	1.129	1.013	0.989	0.981	0.970	0.952	0.938	0.937	0.942	0.937	0.931	0.924	0.908	0.899
2021	1.122	1.012	0.993	1.000	0.997	0.979	0.965	0.962	0.966	0.955	0.949	0.941	0.925	0.914

5.3.4.6 Planned improvements (3.B, N_2O_{direct} & NO)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

5.3.5 Indirect N_2O emissions as a result of manure management (3.B)

5.3.5.1 Category description (3.B, $N_2O_{indirect}$)

Cf. Chapter 5.3.1.

5.3.5.2 Methodological issues (3.B, $N_2O_{indirect}$)

5.3.5.2.1 Methods (3.B, $N_2O_{indirect}$)

Indirect N_2O emissions via leaching from manure management are not reported for Germany; cf. Chapter 5.3.1.

The indirect N_2O emissions resulting from deposition of NH_3 and NO from manure management (including storage of digestates of manure; not including application) are calculated, in keeping with IPCC (2006a Vol 4, 11.21), in proportion to the deposited N quantity:

Equation 16: Indirect N_2O emissions from manure management

$$E_{\text{N2Oindirect,MM}} = \frac{44}{28} \cdot (E_{\text{NH3-N,MM}} + E_{\text{NO-N,MM}}) \cdot EF_4$$

Where:

$E_{\text{N2O, indirect,-MM}}$	Indirect N_2O emissions from deposition of NH_3-N and NO-N from manure management (kg a^{-1})
$E_{\text{NH3-N, MM}}$	Total NH_3-N emissions from manure management (kg a^{-1})
$E_{\text{NO-N, MM}}$	Total NO-N emissions from manure management (kg a^{-1})
EF_4	N_2O-N emission factor; cf. Chapter 5.3.5.2.2

A general description of the method used to calculate NH_3 and NO emissions from housing systems and manure storage is provided in Chapter 3.3.4.3 in Vos et al. (2022). Details are provided in the relevant animal-specific chapters in Vos et al. (2022); cf. Table 304.

Table 304: Animal-specific details in Vos et al. (2022) on NH_3 and NO emissions from housing systems and from manure storage

Animal category	Chapter	Animal category	Chapter
Dairy cows	4.3.7	Mature sheep	6.3.5
Calves	4.4.6	Lambs	6.4.5
Dairy heifers and female beef cattle	4.5.7	Goats	6.6.5
Male beef cattle	4.6.7	Heavy horses	7.3.5
Suckler cows	4.7.7	Light horses / ponies	7.4.5
Male cattle > 2 years	4.8.6	Laying hens	8.3.8
Sows	5.3.7	Broilers	8.4.7
Weaners	5.4.7	Pullets	8.5.8
Fattening pigs	5.5.7	Geese	8.6.6
Boars	5.6.7	Ducks	8.7.8
		Turkeys	8.8.6

5.3.5.2.2 Emission factor (3.B, $N_2O_{indirect}$)

The emission factor EF_4 for indirect N_2O emissions resulting from deposition of NH_3 and NO via manure management and management of digestates (not including application) amounts to 0.01 kg N_2O-N (kg N)$^{-1}$ (IPCC, 2006a Vol 4, 11.24, Table 11.3).

5.3.5.2.3 Emissions (3.B, $N_2O_{indirect}$)

Table 305 shows the indirect N_2O emissions resulting from deposition of reactive nitrogen via NH_3 and NO emissions from manure management – as reported in the present submission and, in anticipation of Chapter 5.3.5.5, as reported in last year's submission. The emissions for the entire time series were calculated with the same method used for last year's submission.

In general, the trend for deposition-related indirect N_2O emissions from manure management follows the trend for direct N_2O emissions; cf. Chapter 5.3.4.2.3. The pertinent reasons for the differences, between the 2021 submission and the 2022 submission, are largely the same as those for the differences between the two submissions' data on direct N_2O emissions from manure management; cf. Chapter 5.3.4.5.

Table 305: Indirect N_2O emissions as a result of deposition of NH_3 and NO from manure management (2022 and 2021 submissions)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2022	3.992	3.341	3.325	3.326	3.257	3.272	3.336	3.366	3.399	3.388	3.367	3.365	3.297	3.260	3.231
2021	3.933	3.321	3.332	3.337	3.280	3.283	3.336	3.351	3.372	3.325	3.291	3.279	3.206	3.155	

5.3.5.3 Uncertainties and time-series consistency (3.B, $N_2O_{indirect}$)

Table 263 in Chapter 5.1.6 shows the uncertainties in the activity data and the emission factor that have been used in estimating the total uncertainty of the German GHG inventory.

The emission-factor uncertainty (95 % confidence interval) from the calculation of deposition-related indirect N_2O emissions from agricultural soils (cf. Vos et al. (2022), Chapter 3.3.4.3.6) has been used here as well. With regard to estimation of the uncertainty of the activity data (available quantity of reactive nitrogen), cf. Chapter 3.3.4.3.6 in Vos et al. (2022).

The emissions time series are consistent, since they were calculated with the same method for all years of the report period, and since the input data are also consistent and complete.

5.3.5.4 Source-specific quality assurance / control and verification (3.B, $N_2O_{indirect}$)

With regard to quality control and quality assurance, we refer to Chapter 5.1.7.

5.3.5.5 Source-specific recalculations (3.B, $N_2O_{indirect}$)

With regard to the source-specific recalculations, cf. Chapter 5.3.5.2.3.

5.3.5.6 Planned improvements (3.B, $N_2O_{indirect}$)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

5.4 Rice cultivation (3.C)

No rice is cultivated in Germany (not occurring – NO).

5.5 Agricultural soils (3.D)

5.5.1 Category description (3.D)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	3 D, Agricultural Soils		N_2O	22,768.5	1.8%	18,673.2	2.6%	-18.0%

Gas	Method used	Source for the activity data	Emission factors used
N_2O	Tier 1 / Tier 2	M/AS/RS/NS	D, CS
NO_X	Tier 1	RS/NS	D
NMVOC	Tier 1	RS/NS	D

The source category *agricultural soils* is a key category for *N_2O emissions*, in terms of both emissions level and trend.

Microbial transformations of N compounds (nitrification and denitrification) lead to emissions of N_2O from soils. A distinction is made between direct and indirect N_2O emissions. The reported direct emissions in sector 3.D include N_2O emissions resulting from:

- application of mineral fertiliser
- application of manure (including manure digestates)
- application of digestates of energy crops
- application of sewage sludge
- grazing
- crop residues
- mineralisation
- cultivation of organic soils

Emissions resulting from spreading of compost, and of residues from digestion of biowaste other than manure and energy crops, are calculated and reported in the sector "Biowaste treatment" (5.B); cf. Chapters 7.3.1.2 and 7.3.2.2.

The indirect N_2O emissions in Sector 3.D result from deposition of reactive nitrogen and from leaching and surface runoff.

Table 306 shows the changes, over time, in emissions from use of agricultural soils since 1990. In addition, it shows, for the initial and final years of the time series, the emissions' shares of the relevant total emissions in the German agricultural sector.

Table 306: Percentage change in emissions from use of agricultural soils since 1990, and percentage shares of total agricultural sector emissions of N_2O and GHG

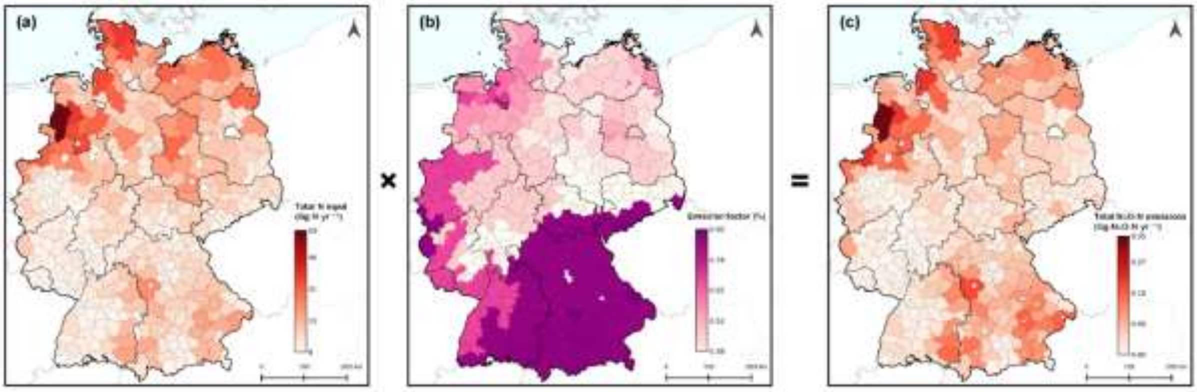
[%]	Change Since 1990	Share of total agricultural emissions (N_2O, GHG, NMVOC) 1990	2020
N_2O_{soils}, direct	-16.6	63.7	64.3
N_2O_{soils}, indirect	-21.9	22.4	21.2
Total of N_2O_{soils}	-18.0	86.2	85.5
ditto, as GHG (in CO_2 eq.)	-18.0	32.3	33.3
$NMVOC_{soils}$	19.0	1.9	3.1

5.5.2 Methodological aspects, and emissions (3.D)

5.5.2.1 Methods and emission factors (3.D)

5.5.2.1.1 Direct N_2O emissions (3.D.a)

Direct N_2O emissions resulting from application of N-containing substrates, and from crop residues, are calculated with a Tier 2 method at the NUTS-3 level, and with emission factors pursuant to Mathivanan et al. (2021) (cf. Chapter 5.1.5.1.1). The Tier 2 emission factors used for this purpose were derived via a meta-analysis. The database for the analysis came from 71 studies, carried out in Germany, comprising a total of 676 field measurements of N_2O emissions carried out at 43 sites in Germany, over a period of at least 150 days. The emission factors were derived with the help of generalised Bayesian mixed linear models.



Relevant graphic: Figure 3 in Mathivanan et al. (2021). a) N inputs via mineral fertiliser, manure, digestates, sewage sludge and crop residues, in Gg N yr^{-1}. b) district-level N_2O emission factors in %. c) district-level annual direct N_2O emissions from application of N-containing substrates and from crop residues

Figure 48: Description of district-level calculation of direct N_2O emissions from agricultural soils.

Separate emission factors for organic and mineral soils were determined. For classification as organic soil, the criterion used consisted of the threshold of at least 90 g kg^{-1} SOC, which is also used in the German LULUCF inventory. Emission factors for mineral soils were determined for four regions, in Germany, that were derived from the ecological zones pursuant to Metzger et al. (2005). For organic soils, it was only possible to derive an emission factor for Germany as a whole. Pursuant to Mathivanan et al. (2021), the breakdown by synthetic fertilisers and other nitrogen inputs called for in the IPCC 2019 Refinement (IPCC, 2019a Table 11.1) is not significant for Germany. The derived Tier 2 emission factors, therefore, do not depend on the type of N inputs involved.

For purposes of inventory calculation, emission factors for all German NUTS-3 regions (districts) were calculated (cf.Figure 48). This was done by producing average emission factors for mineral and organic soils that are weighted, in each case, in keeping with the soil's relevant share of the agricultural area within the pertinent NUTS-3 region. The area data of the LULUCF inventory were used for this purpose.

The emission factors for N inputs on mineral soils are listed in Table 307. (Mathivanan et al., 2021; Metzger et al., 2005).

Table 307: N_2O-N emission factors for N inputs on soils, pursuant to (Mathivanan et al., 2021)

Soil	Region	Emission factor	Confidence interval
Mineral soils	Northwest Germany	0.0049	0.0026 – 0.0078
	Northeast Germany	0.0039	0.0017 – 0.0066
	Southwest Germany	0.0072	0.0037 – 0.0108
	Southeast Germany	0.0088	0.0038 – 0.0143
Organic soils	Germany	0.0101	0.0039 – 0.0165

The combined emission factors for the NUTS-3 regions (as weighted averages for mineral and organic soils) lie between 0.0038 and 0.0092 kg N_2O-N per kg of applied nitrogen. The emission factors in NUTS-3 regions in southern Germany are generally higher than those in northern Germany. This is ascribed to the relevant differences in climate and soil characteristics (Dechow & Freibauer, 2011). With regard to the N-input quantities, the situation is about reversed, because the agricultural area's share of the NUTS-3 region tends to be higher, in general, in northern Germany, and because agriculture tends to be more intensive in northern Germany. The resulting N_2O emissions differ widely throughout Germany. In general, they are highest in areas in which the share for organic soils is high and large quantities of nitrogen are applied. The lowest N_2O emissions occur in urban regions in western Germany, where N inputs are small.

Pursuant to IPCC (2006a Vol 4, 11.7), emissions from N excretions during grazing are calculated in proportion to the N quantity excreted on pasture (cf. Chapter 5.1.5.1). The relevant emission factor for cattle is EF = 0.02 kg N_2O-N per kg of excreted nitrogen. For sheep, goats and horses, the N_2O-N emission factor is 0.01 kg kg^{-1}. For swine, free-range management plays a negligible role in Germany (IE; cf. Chapter 5.1.3.6.4).

Direct N_2O emissions from mineralisation of organic soil substance in mineral agricultural soils are calculated, using a Tier 1 procedure pursuant to IPCC (2006a Vol 4, 11.7), in proportion to the relevant released N quantities (cf. Chapter 5.1.5.1). Pursuant to IPCC (2006a), the relevant emission factor is 0.01 kg N_2O-N per kg of mineralised nitrogen.

Direct N_2O emissions from mineralisation of organic soil substance on cultivated organic soils are calculated by multiplying the relevant area by an emission factor. This is done separately for cropland and grassland. With regard to the areas, cf. Chapter 5.1.5.1.3. A Germany-wide study, (Tiemeyer et al., 2020a), has derived current N_2O-N emission factors for Germany: 11.1 kg ha^{-1} a^{-1} for cropland and 4.6 kg ha^{-1} a^{-1} for grassland. The data on which the previous emission factors were based have been re-evaluated by Tiemeyer et al. (2020a) and supplemented with more-recent data: Overall, the updated emission factors for cropland and grassland are based on 206 year-round measurements for 25 different moorland areas in Germany. In the LULUCF sector, the updated emission factors were used to calculate the total N_2O emissions for cropland and grassland on organic soils, with those calculations taking account of the fact that sub-areas with a depth to water table < 10 cm do not emit any N_2O. Division of these emissions by the total areas given in Chapter 5.1.5.1.3 yields the implied emission factors (IEF): about 11.0 kg ha^{-1} a^{-1} for cropland and about 4.5 kg ha^{-1} a^{-1} for grassland. Table 308 shows the area-weighted average value derived from these factors. Because the ratio of cropland to grassland areas is not constant, that average value varies over time.

Table 308: Average N_2O-N emission factors for agricultural soils

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Application of mineral fertiliser [kg kg^{-1}]	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061	0.0061
Application of manure [kg kg^{-1}]	0.0066	0.0067	0.0067	0.0067	0.0067	0.0066	0.0066	0.0066	0.0066	0.0066	0.0066	0.0066	0.0066	0.0066	0.0066
Application of digestates [kg kg^{-1}]	0.0067	0.0067	0.0067	0.0066	0.0066	0.0066	0.0065	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064
Application of sewage sludge [kg kg^{-1}]	0.0063	0.0063	0.0062	0.0059	0.0058	0.0058	0.0058	0.0058	0.0058	0.0057	0.0058	0.0057	0.0057	0.0057	0.0057
Crop residues [kg kg^{-1}]	0.0060	0.0059	0.0060	0.0060	0.0059	0.0061	0.0060	0.0059	0.0060	0.0059	0.0060	0.0060	0.0061	0.0061	0.0060
Grazing [kg kg^{-1}]	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Mineralisation [kg kg^{-1}]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cultivated organic soils [kg ha^{-1}]	6.16	6.12	6.09	6.14	6.16	6.18	6.20	6.22	6.23	6.25	6.24	6.22	6.20	6.19	6.17

5.5.2.1.2 Indirect N_2O emissions resulting from deposition of reactive nitrogen via use of agricultural soils (3.D)

Indirect N_2O emissions resulting from deposition of reactive nitrogen are calculated, pursuant to IPCC (2006a Vol 4, 11.21), in proportion to the N quantity deposited. The method used is basically in keeping with the approach described in Chapter 5.3.5.2.1. With regard to the emission factor, cf. Chapter 5.3.5.2.2 (0.01 kg N_2O-N (kg N)$^{-1}$). The total deposited N quantity of relevance for the calculations in Sector 3.D comprises the N quantities of the NH_3 and NO emissions (cf. Chapter 5.1.5.1.4) from:

- application of mineral fertiliser,
- application of manure (including manure digestates),
- application of digestates of energy crops,
- application of sewage sludge,
- grazing.

A description of the calculation of indirect N_2O emissions resulting from deposition of NH_3-N and NO-N is provided in Chapter 12.1 in Vos et al. (2022). The German inventory does not use the IPCC default values for $Frac_{GASM}$ and $Frac_{GASF}$. Instead, it calculates the NH_3 and NO emissions that lead to deposition of reactive nitrogen by multiplying the relevant applied N quantity / N excretions on pasture by the pertinent emission factors:

With regard to application of the various types of mineral fertiliser, cf. Chapter 11.1.2 in Vos et al. (2022). Calculation of NH_3 and NO emissions from manure application (including application of manure digestates) and from grazing is described in the chapters in Vos et al. (2022) that are listed in Table 304 in Chapter 5.3.5.2.1. With regard to application of digestates of energy crops, and of sewage sludges, we refer to Chapters 10.2 and 11.4.2 in Vos et al. (2022). As of time-series year 2020, new legal requirements apply to the application of urea fertilisers: "As of 1 February 2020, urea may be applied, as a fertiliser, only if a urease inhibitor is added to it, or if it is worked into the soil without delay, no later than four hours following its application." (DüV, 2017 §6, Absatz 2). As of time-series year 2020, therefore, an emission factor reduced by 70% is used for NH_3 from urea (Bittman et al., 2014, Chapter 8, Table 15). Consequently, the indirect N_2O emissions drop considerably as of that year.

5.5.2.1.3 Indirect N_2O emissions resulting from leaching and surface runoff (3.D)

The indirect N_2O emissions resulting from leaching and surface runoff are calculated, with the Tier 1 method pursuant to IPCC (2006a Vol 4, 11.21), as the product of the N_2O-N conversion factor 44/28, the leached N quantity, and the emission factor (0.0075 kg N_2O-N (kg N)$^{-1}$; cf. IPCC (2006a Vol 4, 11.24, Table 11.3). The leached N quantity amounts to 30 % of the total consisting of the applied N quantity and the N quantity from crop residues and mineralisation; cf. Chapter 5.1.5.1.5).

A detailed description of the calculation of indirect N_2O emissions resulting from leaching and surface runoff is provided in Chapter 12.2 in Vos et al. (2022).

5.5.2.1.4 NO emissions

The method for calculating NO emissions is similar to that for calculating N_2O emissions (cf. Chapter 5.5.2.1.2). EMEP/EEA (2019-3D, Table 3.1) provides, for application of mineral fertiliser and manure, and for animal excretions on pasture, a unified NO emission factor of 0.04 kg NO_2 per kg of applied nitrogen (cf. in this regard also EMEP/EEA (2019-3D-13)). This emission factor has been rounded to two decimal places, and it is based on the emission factor of Stehfest and Bouwman (2006), which amounts to 0.012 kg kg^{-1} in NO-N units. The inventory uses the original emission factor of Stehfest and Bouwman (2006) and, within the meaning of EMEP/EEA (2019-3D, Table 3.1, p.13, Supplement A2.3), also uses it for N excretions on pasture and from application of sewage sludge.

5.5.2.1.5 NMVOC emissions

IPCC (2006a) does not provide any method for calculating NMVOC emissions from agricultural crops. Germany calculates the pertinent NMVOC emissions separately for each crop, using a Tier 2 method pursuant to EMEP/EEA (2019)-3D-30 ff:

Equation 17: Calculation of annual NMVOC emissions from agricultural crops pursuant to EMEP/EEA (2019)

$$E_{\mathrm{NMVOC,\,cult,i}} = A_{\mathrm{i}} \cdot m_{\mathrm{FM,i}} \cdot x_{\mathrm{DM,i}} \cdot t_{\mathrm{i}} \cdot EF_{\mathrm{NMVOC,\,cult,i}}$$

Where

$E_{\mathrm{NMVOC,\,cult,\,i}}$	NMVOC emissions from agricultural crop i (in kg a^{-1})
A_{i}	Area under cultivation with crop i (in ha)
$m_{\mathrm{FM,\,i}}$	Average fresh matter yield from crop i (in kg ha^{-1} a^{-1})
$x_{\mathrm{DM,\,i}}$	Dry-matter content of crop i (in kg kg^{-1})
t_{i}	Fraction of the year during which crop i emits NMVOCs (in a a^{-1})
$EF_{\mathrm{NMVOC,\,cult,\,i}}$	NMVOC emission factor for crop i (in kg kg^{-1})

With regard to areas under cultivation, fresh-matter yields, dry-matter content and relative duration of emissions, cf. Chapter 5.1.5.3. The emission factors for wheat, rye, rape and grass were obtained from EMEP/EEA (2019 3D Table 3.3); cf. Table 309. For the crop categories "grass clover ley, alfalfa, forage grass" and "pastures and meadows", the EMEP emission factor for grass has been used. For the remaining crops, the EMEP emission factor for wheat has been used.

Table 309: NMVOC emission factors for agricultural crops

Crop	Emission factor [kg kg^{-1} h^{-1}]
Wheat	$2.60 \cdot 10^{-8}$
Rye	$1.41 \cdot 10^{-7}$
Rape	$2.02 \cdot 10^{-7}$
Grass (15 °C)	$1.03 \cdot 10^{-8}$

5.5.2.2 *Frac* values (3.D)

Germany reports on $Frac_{GASF}$, $Frac_{GASM}$ and $Frac_{leach.}$

In the German inventory, $Frac_{LEACH}$ is an input value. It shows the relative fraction of N inputs into the soil that is lost via leaching and surface runoff. The German inventory uses the IPCC default value $Frac_{LEACH}$ = 0.30 kg kg^{-1} (IPCC, 2006a Vol 4, 11.24, Table 11.3); cf. Chapter 5.1.5.1.5.

The quantities $Frac_{GASF}$ and $Frac_{GASM}$, on the other hand, are not used in the inventory. For reporting purposes, however, they are determined retroactively from the input and output data for the completed emission calculation.

Pursuant to IPCC (2006a Vol 4, 11.21, eq.11.9), $Frac_{GASF}$ denotes the fraction of the N quantity applied via mineral fertiliser that is emitted as NH_3-N and NO-N; cf. Table 310. In such emissions, NH_3 is the predominant influencing factor. Because different NH_3 emission factors are used for different mineral fertiliser types, the $Frac_{GASF}$ value depends on the mineral-fertiliser mix prevailing in the year in question. Because urea has a relatively high emission factor (EMEP/EEA, 2019), until 2019 $Frac_{GASF}$ correlates very well with the ratio of urea-N to total-mineral-fertilizer-N; cf. (Vos et al., 2022). In 2020, the $Frac_{GASF}$ value is considerably lower than it was in previous years, since the calculation is being carried out with an NH_3 emission factor for urea that has been reduced by 70 % (cf. Chapter 5.5.2.1.2).

Table 310: $Frac_{GASF}$ time series and weighted average throughout the entire time series (3.D)

[kg kg^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
FracGASF	0.042	0.045	0.049	0.052	0.057	0.054	0.055	0.055	0.057	0.058	0.059	0.057	0.054	0.051	0.034	0.050

Pursuant to IPCC (2006a Vol 4, 11.21, eq.11.9), FracGASM denotes the fraction of the N quantity applied via manure (including manure digestates), energy-crop digestates, sewage sludge and grazing that is emitted as NH_3-N and NO-N; cf. Table 311. (The $Frac_{GASM}$ definition in CRF Table 3.D does not conform to this definition.)

Table 311: $Frac_{GASM}$ time series and weighted average throughout the entire time series (3.D)

[kg kg^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Mean
$Frac_{GASM}$	0.194	0.182	0.177	0.169	0.167	0.169	0.164	0.162	0.159	0.157	0.155	0.153	0.151	0.149	0.147	0.170

5.5.2.3 Emissions (3.D)

Table 312 presents an overview of the contributions of the various individual sub-sources to overall N_2O emissions from agricultural soils. The indirect emissions also include the contributions resulting from application of digestates of energy crops.

Table 312: Overview of N_2O emissions from agricultural soils (3.D)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total emissions	**76.4**	**66.2**	**68.8**	**66.8**	**66.2**	**67.1**	**68.5**	**68.8**	**71.2**	**70.5**	**70.0**	**68.5**	**64.7**	**63.7**	**62.7**
Total direct emissions	**56.5**	**49.5**	**51.3**	**49.9**	**49.2**	**49.8**	**50.8**	**50.9**	**52.6**	**52.1**	**51.7**	**50.8**	**48.2**	**47.6**	**47.1**
Total indirect emissions	**19.9**	**16.6**	**17.5**	**16.9**	**17.0**	**17.3**	**17.7**	**17.9**	**18.6**	**18.4**	**18.3**	**17.7**	**16.5**	**16.1**	**15.5**
Mineral fertiliser	20.9	16.4	18.3	17.1	15.6	15.9	16.1	15.8	16.4	16.6	16.5	15.5	14.3	13.4	13.0
Manure	11.5	10.2	10.0	9.7	9.7	9.7	9.9	10.0	10.1	10.1	10.0	10.0	9.8	9.7	9.7
Digestates of energy crops	0.0	0.0	0.1	0.5	1.7	2.2	2.4	2.8	2.9	3.0	3.0	3.0	3.0	3.0	3.0
Sewage sludge	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Grazing	6.4	5.1	4.6	4.1	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.7	3.6	3.6	3.5
Crop residues	4.6	4.7	5.3	5.5	5.4	5.3	5.7	5.6	6.5	5.6	5.5	5.9	4.8	5.3	5.4
Mineralisation	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Organic soils	12.7	12.7	12.6	12.7	12.6	12.7	12.7	12.7	12.7	12.7	12.7	12.6	12.6	12.5	12.4
Indirect, deposition, not including EC [a]	5.6	4.6	4.6	4.3	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.1	3.8	3.6	3.2
Indirect, deposition, EC [a]	0.0	0.0	0.0	0.1	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
Indirect, leaching, not including EC [a]	14.3	12.0	12.8	12.3	11.7	11.7	12.0	11.9	12.5	12.2	12.1	11.8	10.9	10.7	10.6
Indirect, leaching, EC [a]	0.0	0.0	0.0	0.2	0.6	0.7	0.8	1.0	1.0	1.1	1.1	1.1	1.0	1.0	1.0

[a] EC: Digestates of energy crops

The total N_2O emissions decreased in the first half of the 1990s. In subsequent years, through 2013, no clear trend emerges. A marked increase occurred from 2013 to 2014. In the years thereafter, the emissions decreased again markedly, however; in 2020, they are 12.0 % lower than they were in 2014.

In spite of the multiple-year averaging of mineral-fertiliser quantities (cf. Chapter 5.1.5.1.2) that has been carried out, mineral-fertiliser application continues to account for most of the annual fluctuations in total emissions. The factors that contribute to the marked increase in total N_2O emissions that occurred from 2013 to 2014 include an increase of N_2O emissions from crop residues, tied to the unusually large harvests of 2014 (cf. Table 254 in Chapter 5.1.5.1.2). The reduction of total emissions seen in subsequent years is due primarily to reductions in mineral-fertiliser application. In addition, a change from 2017 to 2018 occurred in that the harvest of 2018 was smaller than that of 2017, with the result that harvest residues in 2018 were smaller than they were in 2017 (cf. Chapter 5.1.5.1.2). The emission-reducing effects of the livestock-population reductions that have occurred in recent years have been partly offset by the emissions-increasing effects of performance increases. Since 2005, application of increasing quantities of manure digestates and energy-crop digestates has an impact.

Table 313 presents, for the first and last years of the time series, the percentage contributions of the various individual sub-sources to the total N_2O emissions from agricultural soils.

Table 313: N_2O from agricultural soils: Percentage shares of sub-sources

[%]	1990	2020
Mineral fertiliser	27.4	20.7
Manure (including digestates from manure digestion)	15.1	15.4
Digestates of energy crops	0.0	4.7
Sewage sludge	0.4	0.2
Grazing	8.4	5.6
Crop residues	6.0	8.7
Mineralisation	0.05	0.04
Organic soils	16.6	19.84
Total indirect N_2O	26.0	24.8

The results of the NO-emissions calculations are shown in Table 314. With regard to the sources, cf. Chapter 5.5.2.1.2. Table 314 shows the emissions from application of energy-crop digestates separately, in order to highlight their relative importance. The trend for the total emissions largely follows that for the N_2O emissions. (For purposes of reporting in CRF 3s2, the NO values are converted into NO_2, via multiplication by the molar ratio 46/30.)

Table 314: NO emissions from agricultural soils

[kt a⁻¹]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**91.4**	**74.7**	**78.9**	**75.4**	**74.3**	**76.2**	**77.8**	**78.3**	**80.5**	**81.2**	**80.8**	**77.6**	**73.9**	**71.2**	**69.9**
Digestates of energy crops	0.0	0.0	0.1	1.2	4.3	5.4	5.9	7.2	7.5	7.8	7.8	7.6	7.5	7.5	7.5
Other sources	91.4	74.7	78.8	74.2	70.0	70.8	71.8	71.1	73.0	73.4	73.1	70.0	66.4	63.7	62.4

Table 315 shows the development of NMVOC emissions over time. The annual changes – and, thus, the increasing trend that continued until 2014 – are primarily tied to variations in harvest yields. The yields of 2014 were the largest seen to date.

Table 315: NMVOC emissions from agricultural crops

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
[kt a⁻¹]	7.69	8.19	8.79	9.17	9.53	9.03	10.05	10.36	11.40	9.91	9.69	9.74	7.82	8.56	9.16
in % of 1990	100.0	106.5	114.2	119.2	123.9	117.3	130.7	134.7	148.2	128.9	126.0	126.7	101.7	111.3	119.0

5.5.3 Category-specific quality assurance / control and verification (3.D)

With regard to quality control and quality assurance, we refer to Chapter 5.1.7.

For purposes of verification, Table 316 and Table 317, in an approach similar to that used in Chapter 5.2.4, compare the German inventory's N_2O-N emission factors and Frac values $Frac_{GASF}$, $Frac_{GASM}$ and $Frac_{LEACH}$ with the corresponding data of countries that are neighbouring countries or whose agricultural practice in this regard is similar to that of Germany. For the reasons given in Chapter 5.2.4, the year chosen for the comparison is the time-series year 2019.

Table 316: Comparison of the N_2O-N emission factors used in the German inventory with those of neighboring countries, for the time-series year 2019

N_2O-N	Mineral fertiliser	Manure	Crop residues	Mineralisation	Organic soils	Grazing	Deposition	Leaching
	[kg kg⁻¹]	[kg kg⁻¹]	[kg kg⁻¹]	[kg kg⁻¹]	[kg ha⁻¹]	[kg kg⁻¹]	[kg kg⁻¹]	[kg kg⁻¹]
Austria	0.0100	0.0100	0.0100	0.0100	8.2000	0.0167	0.010	0.0075
Belgium	0.0100	0.0100	0.0100	0.0100	8.0000	0.0195	0.010	0.0075
Czech Republic	0.0100	0.0100	0.0100	0.0100	NO	0.0190	0.010	0.0023
Denmark	0.0100	0.0100	0.0100	0.0100	7.4724	0.0177	0.010	0.0048
France	0.0100	0.0100	0.0100	NO	8.0183	0.0191	0.010	0.0075
Germany	**0.0061**	**0.0066**	**0.0053**	0.0100	**6.1864**	**0.0189**	**0.010**	**0.0075**
Netherlands	0.0106	0.0082	0.0139	NO	4.4459	0.0314	0.012	0.0075
Poland	0.0100	0.0100	0.0100	0.0100	8.0000	0.0194	0.010	0.0075
Switzerland	0.0096	0.0100	0.0100	0.0100	8.0000	0.0189	0.026	0.0075
UK	0.0072	0.0052	0.0100	0.0100	9.5235	0.0037	0.010	0.0075
IPCC (2006a Vol 4, 11.11, 11.24), IPCC (2014) [a]	0.0100	0.0100	0.0100	0.0100	8.00 (13 / 4.3 / 8.2 / 1.6) [a]	0.02 (cattle, swine, poultry); 0.01 (other animals)	0.0100	0.0075

Source: Germany: 2022 submission; other countries: UNFCCC (2021b)

[a] IPCC (2014) Wetlands Supplement, Table 2.5 (cropland, drained / grassland, drained, nutrient-poor / grassland, deep-drained, nutrient-rich / grassland, shallow-drained, nutrient-rich)

As of the present 2022 submission, for application of mineral fertiliser, manure, digestates and sewage sludge, and for crop residues, Germany is using the regionalised emission factors derived by (Mathivanan et al., 2021), which are considerably lower than the IPCC (2006) default emission factor of 0.01 kg kg⁻¹. For application of mineral fertiliser, the average German emission factor is lower than the values of Switzerland, the Netherlands and the UK, which also use Tier 2 emission factors. For manure application, the average German value is lower than the value of the Netherlands and higher than that of the UK. For crop residues, the Netherlands are the only other country, in addition to Germany, to use a Tier 2 emission factor. Their emission factor is considerably higher than both the German value and the default emission factor.

For N_2O-N from organic soils, four countries use the IPCC (2006a) default emission factor of 8 kg ha^{-1}. Two countries' values are greater than this default value, while one country's value is somewhat lower. The German value, which is based on national emission factors for cropland and grassland (cf. Chapter 5.5.2.1.1), is considerably lower than the IPCC (2006a) default emission factor. At the same time, it lies in about the middle of the range between the emission factor of the Netherlands and the IPCC default value.

Clearly enough, most of the emission factors for N_2O-N resulting from grazing are based on a combination of the two default values of IPCC (2006a). The effects of the share for "other animals," which has the lower emission factor, vary from country to country. The German value is close to the default value for cattle, swine and poultry. This fact makes it clear that the population fractions for the other animals are relatively small.

For indirect N_2O-N emissions from deposition of reactive nitrogen, and from leaching and surface runoff, Germany, like most of the other countries, uses the relevant IPCC (2006a) default values.

Table 317: Comparison of Germany's Frac values with those of neighboring countries, for the time-series year 2019

[kg kg^{-1}]	$Frac_{GASF}$	$Frac_{GASM}$	$Frac_{LEACH}$
Austria	0.05	0.16	0.15
Belgium	0.07	0.17	0.30
Czech Republic	0.10	0.20	0.30
Denmark	0.06	0.08	0.25
France	0.06	0.11	0.25
Germany	**0.05**	**0.15**	**0.30**
Netherlands	0.05	NA	0.13
Poland	0.10	0.20	0.30
Switzerland	0.07	0.23	0.18
UK	0.04	0.04	0.20
IPCC (2006a Vol 4, 11.24)	0.10	0.20	0.30

Source: Germany: 2022 Submission; other countries: UNFCCC (2021b)

The scattering seen in the $Frac_{GASF}$ data can be attributed to the variation, among the neighboring countries, seen in the relative shares of different fertiliser types (with their different NH_3 emission factors). The German value lies somewhat below the median (IPCC, 2006a). This also applies to $Frac_{GASM}$. For $Frac_{LEACH}$, Germany, like a number of other countries, uses the default value given in IPCC (2006a).

5.5.4 Uncertainties and time-series consistency (3.D)

The activity-data and emission-factor uncertainties, for direct and indirect N_2O emissions, that enter into the estimate of the total uncertainty of the German GHG inventory are listed in Table 263 in Chapter 5.1.6.

The emission-factor uncertainties for direct N_2O from mineral fertiliser, organic fertiliser (manure, digestates, sewage sludge), and crop residues are uncertainties that (Mathivanan et al., 2021) has calculated for the pertinent emission factors. The emission factors for grazing are default values from IPCC (2006a Vol 4, 11.11, Table 11.1). With regard to the uncertainty of the activity data (N quantities), cf. Chapters 11.1.1, 11.2.1, 11.3.1, 11.4.1, 11.5.1 and 11.7.1.6 in Vos et al. (2022).

The activity-data and emission-factor uncertainties for direct N_2O emissions from drained organic soils have been derived from national data; cf. Chapters 11.6.1 and 11.6.2 in Vos et al. (2022). The same applies to mineralisation of organic soil substance; cf. Chapters 11.8.1 and 11.8.2 in Vos et al. (2022).

For NO from application of mineral fertiliser, manure, digestates and sewage sludge, and from N excretions on pasture, the German inventory uses a 95 % confidence interval of -95 % to +400 %; cf. Vos et al. (2022), Chapters 11.1.2.4, 11.2.2, 11.4.2.3 and 11.5.2. With regard to the uncertainties for the activity data (N quantities) Vos et al. (2022), we refer to the discussion on N_2O emissions above.

With regard to the uncertainties in connection with the indirect N_2O emissions, cf. Chapters 12.1 and 12.2 in Vos et al. (2022).

EMEP/EEA (2019) does not provide any uncertainty information with regard to the Tier 2 NMVOC emission factors. If one adopts the upper value-range boundary given in EMEP/EEA (2019-3D, Table 3.1) for the Tier 1 emission factor, and then fits a log-normal distribution, a 95 % confidence interval of -89 % to +300 % results (Vos et al., 2022, Kap. 11.12.2). No information on the uncertainty of the activity data is available.

The emissions time series are consistent, since they were calculated with the same method for all years of the report period, and since the input data are also consistent and complete.

5.5.5 Source-specific recalculations (3.D)

Table 318 compares the N_2O emissions from agricultural soils as reported in the present submission and in last year's submission.

Table 318: Total N_2O from agricultural soils, in the 2020 and 2021 submissions (3.D)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2022	76.4	66.2	68.8	66.8	66.2	67.1	68.5	68.8	71.2	70.5	70.0	68.5	64.7	63.7
2021	98.9	85.1	89.4	86.9	86.1	87.4	89.6	90.1	93.6	92.6	91.9	89.9	84.5	83.8

Table 319 shows the changes in N_2O emissions with respect to the figures given in last year's submission.

Table 319: Change, between the 2021 submission and the 2022 submission, in total N_2O emissions (direct + indirect) from use of agricultural soils (negative values: reduction from the 2021 submission to the 2022 submission)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	**-22.465**	**-18.948**	**-20.565**	**-20.157**	**-19.907**	**-20.263**	**-21.068**	**-21.319**	**-22.428**	**-22.118**	**-21.961**	**-21.442**	**-19.848**	**-20.033**
Mineral fertiliser	-13.55994883	-10.64159288	-11.868518	-11.097	-10.100485	-10.285337	-10.449589	-10.220665	-10.59613184	-10.72333711	-10.68946676	-10.018026	-9.259727183	-8.918
Manure	-5.772	-4.897	-4.874	-4.796	-4.936	-5.026	-5.156	-5.264	-5.355	-5.321	-5.295	-5.295	-5.240	-5.223
Application of digestates of EC [a]	0.000	-0.003	-0.028	-0.248	-0.902	-1.129	-1.262	-1.569	-1.654	-1.724	-1.718	-1.672	-1.638	-1.633
Sewage sludge	-0.159518911	-0.20518241	-0.197904362	-0.1767376	-0.1724038	-0.165965	-0.1663027	-0.1428824	-0.140958938	-0.125181195	-0.124755175	-0.09583806	-0.092146404	-0.076
Grazing	-0.033	-0.055	-0.066	-0.062	-0.053	-0.075	-0.100	-0.127	-0.155	-0.192	-0.216	-0.243	-0.268	-0.298
Crop residues	-3.017	-3.172	-3.528	-3.748	-3.673	-3.500	-3.843	-3.895	-4.416	-3.928	-3.767	-3.924	-3.107	-3.524
Mineralisation	-0.000137043	-0.000179199	-0.000190094	3.3884E-05	0.00011857	-1.608E-05	-5.273E-05	-6.624E-05	-5.03766E-05	-7.93078E-05	-0.000111568	-0.00019691	-0.000290912	-0.0004
Organic soils	-0.004	-0.005	-0.005	-0.005	-0.007	-0.007	-0.006	-0.006	-0.006	-0.007	-0.004	0.000	0.007	0.016
Indirect: Deposition, not including EC [a]	0.024	0.007	-0.006	-0.021	-0.040	-0.042	-0.044	-0.045	-0.046	-0.040	-0.069	-0.097	-0.128	-0.188
Indirect: deposition, EC [a]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.012	-0.025	-0.036	-0.047
Indirect: leaching, not including EC [a]	0.058	0.024	0.009	-0.004	-0.024	-0.032	-0.041	-0.050	-0.059	-0.056	-0.064	-0.072	-0.085	-0.142
Indirect: leaching, EC [a]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001

[a] EC: Digestates of energy crops

[b] Leaching: Leaching and surface runoff of digestates of energy crops

The emissions reported in the 2022 submission are considerably lower, in all years, than the corresponding emissions in the 2021 submission. The most noticeable, and quantitatively largest, changes with respect to the 2021 submission are seen in the areas of mineral fertilisers, manure, digestates, sewage sludge and crop residues. The values in all of these areas are now considerably lower. This is a result of first-time use of the Tier 2 emission factors of (Mathivanan et al., 2021), which are 38% lower, on average, than the Tier 1 default emission factors that were previously used. The additional changes seen in Table 319, with respect to the 2021 submission, have resulted from updating of input data.

Table 320 compares the total NO emissions with the corresponding data from last year's submission. In Table 321, the differences between the two submissions are broken down by sub-sources. Here as well, the numeral "0" means that no changes have occurred. Since the NO emissions are generally calculated on the basis of their being proportional to the available N quantity, the non-zero differences reflect the updating of the N quantities as described in Chapter 5.1.5.1.2. The changes that result for 2019, for mineral fertiliser, result from multiple-year averaging.

Table 320: Comparison of total NO emissions from agricultural soils (3.D)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2022	91.4	74.7	78.9	75.4	74.3	76.2	77.8	78.3	80.5	81.2	80.8	77.6	73.9	71.2
2021	91.0	74.5	78.9	75.4	74.4	76.4	78.0	78.6	80.8	81.6	81.2	78.1	74.4	72.2

Table 321: Changes, between the 2021 submission and the 2022 submission, in NO emissions from use of agricultural soils (negative values: reduction from the 2021 submission to the 2022 submission)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Total	**0.419**	**0.177**	**0.074**	**-0.004**	**-0.128**	**-0.185**	**-0.240**	**-0.298**	**-0.361**	**-0.334**	**-0.386**	**-0.435**	**-0.520**	**-0.925**
Mineral fertiliser	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.406
Manure	0.447	0.222	0.128	0.047	-0.085	-0.123	-0.158	-0.194	-0.234	-0.177	-0.209	-0.238	-0.291	-0.318
Application of digestates of EC [a]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
Sewage sludge	0.000	-0.000	-0.000	0	0.000	0.000	0	0	0	0.000	0.000	0.000	0.000	0.034
Grazing	-0.027	-0.045	-0.054	-0.050	-0.043	-0.062	-0.082	-0.104	-0.127	-0.157	-0.176	-0.197	-0.217	-0.240

[a] EC: Digestates of energy crops

The NMVOC emissions have changed only slightly with respect to last year's submission. They are due to updating of activity data, and they are not visible in the number format chosen.

Table 322: Comparison of NMVOC emissions from use of agricultural soils (3.D)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2022	7.692	8.190	8.788	9.171	9.530	9.025	10.053	10.361	11.402	9.913	9.694	9.744	7.820	8.559
2021	7.692	8.190	8.788	9.171	9.530	9.025	10.053	10.361	11.402	9.913	9.694	9.744	7.820	8.559

5.5.6 Planned improvements (3.D)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

5.6 Prescribed burning of savannas (clearance of land by prescribed burning) (3.E)

Land clearance by prescribed burning is not practiced in Germany (NO).

5.7 Field burning of agricultural residues (3.F)

Field burning of agricultural residues was already prohibited in Germany in 1990, at the beginning of the emissions-reporting period. Approvals for such burning are issued only in exceptional cases (for example, in cases of insect infestation), and only at the municipal level. Since no official data on such cases are available, Germany reports no emissions (NO) under 3.F. For details, cf. Chapter 11.9 in Vos et al. (2022).

5.8 CO_2 emissions from liming and urea application (3.G-I)

5.8.1 Category description (3.G-I)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/T	3 G, Liming		CO_2	2.200.5	0.2%	1.963.3	0.3%	-10.8%
-/-	3 H, Urea Application		CO_2	481.0	0.0%	456.6	0.1%	-5.1%
-/-	3 I, Other carbon-containing fertilisers		CO_2	510.4	0.0%	189.7	0.0%	-62.8%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1	NS	D

The source category *CO_2 from liming* is a key category for CO_2 emissions in terms of the emissions trend.

Liming, i.e. addition of carbonates to the soil, reduces the soil's acidity. It enhances plant growth, releasing CO_2 in the process. Lime fertilisers include all carbonates of calcium and magnesium, either as pure substances or as additives. The reports differentiate between dolomite and limestone, in order to take account of how the two groups differ in carbonate carbon content, as well as in their CO_2 emission factors. With regard to the latter group, application of calcium ammonium nitrate is considered separately. The resulting CO_2 emissions are reported under CRF 3.I ("Other carbon-containing fertilisers"), while the CO_2 emissions from application of limestone and dolomite are reported under CRF 3.G. In keeping with the requirement in IPCC (2006a Vol 4, 11.3 & CRF Table 3.G-I), the reported CO_2 emissions include both the pertinent emissions from the agricultural sector and those from liming in the forestry sector.

Nitrogen fertilisation with urea leads to CO_2 emissions via reactions involving urease and water. Germany reports such CO_2 emissions in Sector 3.H, without deducting CO_2 bound via industrial production of urea fertiliser.

The CO_2 emissions from liming and urea application that are reported in this chapter represent 100 % of the CO_2 emissions of the agricultural sector. Table 323, which complements the above table, shows the change over time in the sum of these CO_2 emissions since 1990, as well as, for the initial and final years of the time series, the emissions' percentage shares of total GHG emissions from the German agricultural sector.

Table 323: Percentage change in the sum of CO_2 emissions from liming and urea application since 1990, and percentage shares of total GHG emissions from the German agricultural sector

[%]	Change Since 1990	Share of total agricultural GHG emissions 1990	2020
Total CO_2 from liming and urea application	-18.2	4.5	4.7

5.8.2 Methods and emissions (3.G-I)

The Tier 2 approach given in IPCC (2006a Vol 4, 11.27) is based on use of the Tier 1 equation (equation 11.12 in IPCC (2006a Vol 4, 11.27)), which calls for multiplication of the fertiliser quantity with the emission factor. With regard to the fertiliser quantities, cf. Chapter 5.1.5.2. No specific German emission factors are available for dolomite and limestone; for this reason, the default emission factors given in IPCC (2006a Vol 4, 11.27) are used: 0.13 kg CO_2-C per kg dolomite ($CaMg(CO_3)_2$) and 0.12 kg CO_2-C per kg limestone ($CaCO_3$). In the case of calcium ammonium nitrate, CO_2 is produced from the $CaCO_3$ fraction, a process for which the limestone emission factor of 0.12 kg CO_2-C per kg $CaCO_3$ has been used. On that basis, an emission factor of 0.02748 kg CO_2-C per kg with respect to the total applicable mass of calcium ammonium nitrate can be derived; cf. Chapter 11.10.2 in Vos et al. (2022).

For purposes of entry into the CRF tables, the so-calculated CO_2-C emissions are converted into CO_2 units via multiplication by the molar ratio 44/12 (IPCC (2006a Vol 4, 11.27)). These CO_2 emissions may be seen as the highest emissions possible, since the aforementioned emission factors are based on the conservative assumption that all of the carbon contained in the fertilisers is converted into CO_2.

Table 324 shows the CO_2 emissions from liming over time, both as a sum total and broken down in accordance with the three reported lime fertiliser categories.

Table 324: CO_2 emissions from liming (3.G, 3.I)

[kt a⁻¹]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**2711.0**	**1669.6**	**2062.4**	**1736.4**	**1806.2**	**1857.4**	**1946.0**	**2064.8**	**2153.5**	**2136.5**	**2107.5**	**2150.7**	**2250.1**	**2233.1**	**2153.0**
in % of 1990	**100.0**	**61.6**	**76.1**	**64.1**	**66.6**	**68.5**	**71.8**	**76.2**	**79.4**	**78.8**	**77.7**	**79.3**	**83.0**	**82.4**	**79.4**
Limestone	1849.8	1071.5	1525.9	1328.1	1463.0	1509.8	1603.6	1735.7	1830.1	1828.8	1815.5	1878.4	1992.5	1991.0	1922.9
Dolomite	350.7	208.5	169.8	100.8	86.0	83.5	88.5	88.8	87.2	77.0	66.3	59.2	55.0	47.8	40.4
Calcium ammonium nitrate	510.4	389.5	366.6	307.5	257.2	264.1	253.9	240.3	236.2	230.7	225.7	213.0	202.7	194.2	189.7

The Tier 1 method for CO_2-C emissions from urea application (IPCC, 2006a Vol 4, 11.32) calculates the emissions in proportion to the quantity of urea applied (cf. Chapter 5.1.5.2). The proportionality factor used in the procedure is the CO_2-C emission factor, which is to be derived stoichiometrically and is given as 0.2 kg CO_2-C per kg of urea (IPCC, 2006a Vol 4, 11.32). Conversion into units of CO_2, as required for the CRF tables, is analogous to the conversion for CO_2 from liming; see above. Table 325 shows the resulting time series.

Table 325: CO_2 emissions from urea application (3.H)

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
[kt a⁻¹]	481.0	458.5	593.1	641.1	710.8	654.0	689.9	672.6	749.7	791.5	815.1	719.6	605.3	497.7	456.6
in % of 1990	100.0	95.3	123.3	133.3	147.8	136.0	143.4	139.8	155.8	164.5	169.5	149.6	125.8	103.5	94.9

5.8.3 Category-specific quality assurance / control and verification (3.G-I)

With regard to quality control and quality assurance, we refer to Chapter 5.1.7.

In the framework of verification, and in an approach similar to that used in Chapter 5.2.4, the 2019 CO_2 emissions from liming and urea application in Germany (current 2022 Submission) were compared with those of neighboring countries and the UK (2021 Submission, UNFCCC (2021b)); cf. Table 326.

Table 326: Comparison of the CO_2 IEF values used in the German inventory with those of neighboring countries, for the time-series year 2019

[kg CO_2-C per kg of fertiliser]	Limestone [kg kg^{-1}]	Dolomite [kg kg^{-1}]	Other carbon-containing fertilisers [kg kg^{-1}]	Urea application [kg ha^{-1}]
Austria	0.12	0.13	0.12500	0.20
Belgium	0.12	0.13	NO	0.20
Czech Republic	0.12	0.13	NO	0.20
Denmark	0.12	IE	0.03000	0.20
France	0.12	0.13	0.12500	0.20
Germany	**0.12**	**0.13**	**0.02748**	**0.20**
Netherlands	0.12	0.13	NO	0.20
Poland	0.12	0.13	0.12000	0.20
Switzerland	0.12	0.13	NO	0.20
UK	0.12	0.13	NO	0.20
IPCC (2006a): Vol. 4, 11.27	0.12	0.13		0.20

Source: Germany: 2022 Submission; other countries: UNFCCC (2021b)

IE, NO, n/a: No data available

It appears that all countries that report CO_2 emissions from liming with limestone use the default emission factors given by IPCC (2006a): Vol. 4. With the exception of Denmark, this also applies in the case of dolomite use. Use of other lime-containing fertilisers is reported only by a few countries. If the German IEF were rounded to two decimal places, it would be equivalent to the Danish value. All compared countries report CO_2 emissions from urea application, and all use the default emission factor given in IPCC (2006a).

5.8.4 Uncertainties and time-series consistency (3.G-I)

Table 263 in Chapter 5.1.6 shows the activity-data and emission-factor uncertainties, for CO_2 from liming and urea application, that have been used in estimating the total uncertainty of the German GHG inventory. For derivation of the uncertainties, cf. Chapters 11.10.1 and 11.10.2 in Vos et al. (2022).

The uncertainty of the activity data does not include the uncertainty that results because a) normally, not all of the carbon applied is converted into CO_2, and b) the pertinent conversion rate cannot be quantified. The calculated emissions thus represent the maximum possible emissions in the framework of the uncertainties listed in Table 263 in Chapter 5.1.6.

The emissions time series are consistent, since they were calculated with the same method for all years of the report period, and since the input data are also consistent and complete.

5.8.5 Source-specific recalculations (3.G-I)

Only in time-series year 2019 do the emissions differ from those reported in the 2021 submission. This is a direct result of multiple-year averaging of activity data; cf. Chapter 5.1.5.2.

Table 327: CO_2 emissions from liming and urea application (3.G-I)

[kt a⁻¹]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2022, total	2711.0	1669.6	2062.4	1736.4	1806.2	1857.4	1946.0	2064.8	2153.5	2136.5	2107.5	2150.7	2250.1	2233.1	2153.0
2021, total	2711.0	1669.6	2062.4	1736.4	1806.2	1857.4	1946.0	2064.8	2153.5	2136.5	2107.5	2150.7	2250.1	2297.6	
2022 - 2021	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-64.5	2153.0
2022 - 2021, in %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.8	

5.8.6 Planned improvements (3.G-I)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

5.9 CH_4 and N_2O from digestion of energy crops (digesters and systems for storage of digestates) (3.J)

5.9.1 Category description (3.J)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-e.)	(fraction)	Trend 1990-2020
-/T	**3 J, Other**		**CH_4**	**0.3**	**0.0%**	**1,312.9**	**0.2%**	**475758.2%**
-/-	3 J, Other		N_2O	0.1	0.0%	252.8	0.0%	202928.7%

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	Q/RS/NS	CS/D
N_2O direct	Tier 2	Q/RS/NS	CS/D
N_2O indirect	Tier 1	Q/RS/NS	D
NO_X	Tier 2	Q/RS/NS	CS

The source category "CH_4 and N_2O from digestion of energy crops (digesters and systems for storage of digestates)" is a key category in terms of trend.

Digestion of energy crops is carried out primarily for purposes of energy generation. The emissions occurring during digestion itself (digester) and through storage of digestates (CH_4, N_2O and NO; cf. Chapter 5.1.4.1) are reported as a separate source category (CRF 3s2/J). The emissions resulting via use of digestates as fertiliser are reported in conjunction with reporting on emissions from application of other fertilisers, under 3.D.2.c.

In a procedure analogous to that used for manure, the indirect N_2O emissions connected to storage of digestates of energy crops are calculated as a result of deposition of reactive nitrogen. In addition, it is assumed, as in the case of manure, that no indirect N_2O emissions result from leaching / surface runoff from storage systems.

Table 328, which complements the table above, shows, for the first and last years of the time series, the percentage shares of emissions of CH_4, N_2O and GHG from digestion of energy crops (digesters and systems for storage of digestates) with respect to total agricultural emissions of CH_4, N_2O and GHG. Table 328 does not show percentage changes in emissions since 1990; because of the low prevalence of energy-crop digestion in 1990, such data are of limited use, as the table above shows. The emissions increase over time is a direct result of the growth in quantities of substrate.

Table 328: Percentage shares of emissions from digestion of energy crops (digester + system for storage of digestates; Index: EC) with respect to total agricultural emissions of CH_4, N_2O and GHG

[%]	Share of total agricultural emissions (CH_4, N_2O, GHG)	
	1990	2020
$CH_{4,EC}$	0.0	4.1
N_2O_{EC}	0.0	1.2
$CH_{4,EC}$ + N_2O_{EC} as GHG (in CO_{2eq})	0.0	2.8

5.9.2 Methodological issues (3.J)

The procedure for calculating CH_4 emissions and direct N_2O emissions is analogous to that for calculation of emissions from solid-manure digestion (cf. Chapter 5.1.3.6.5), with the exception that it does not take pre-storage into account.

As for manure (cf. Chapter 5.3.5), indirect N_2O emissions from storage of digestates of energy crops are calculated as a result of deposition of reactive nitrogen. In the case of energy crops, such nitrogen originates in NH_3 and NO emissions from systems for storage of digestates of energy crops. Like NO emissions from manure, NO emissions from systems for storage of digestates are calculated via a procedure similar to that for calculation of N_2O emissions (cf. Chapter 5.3.4.2). With regard to calculation of NH_3 emissions from systems for storage of residues from digestion of energy crops, we refer to Chapter 10 in Vos et al. (2022).

5.9.3 CH_4 emission factor and emissions (3.J, CH_4)

Table 329 shows the temporal development for the CH_4 emission factor for digestion of energy crops (digesters and systems for storage of digestates), related to the dry-matter quantities that are input into the digestion process along with energy crops (cf. Chapter 5.1.4.2). In the interest of clarity, we have used the units g kg^{-1}, instead of the kg kg^{-1}, the common units for emission factors. The decrease in the emission factor over time results from increasing use of gas-tight storage for digestates (cf. Chapter 5.1.4.2). For such storage, only the CH_4 leakage rate has to be taken into account, instead of the higher emission factor for open storage.

Table 329: CH_4 emission factor for digestion of energy crops (digesters and systems for storage of digestates), related to the dry-matter quantities input into digestion along with energy crops

[g kg^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	3.23	3.19	3.14	3.08	2.83	2.78	2.67	2.64	2.63	2.62	2.62	2.62	2.62	2.61	2.61

The CH_4 emissions from digestion of energy crops (digesters and systems for storage of digestates) are shown in Table 330. The increasing trend results from strong increases in the quantities of energy crops being digested, especially since 2005. It has been slowed by the increasing use of gas-tight storage of digestates. For details, cf. Chapter 5.1.4.2.

Table 330: CH_4 emissions from digestion of energy crops (digesters and systems for storage of digestates)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	0.01	0.14	1.20	9.91	32.89	40.31	42.35	50.74	52.74	54.64	54.29	53.46	52.62	52.52	52.52

5.9.4 N_2O emission factors and emissions (3.J, N_2O)

The emission factors for direct N_2O emissions from digestion of energy crops (systems for storage of digestates) are shown in Table 331. These data represent the average values for gas-tight and open storage. In their decreasing trend, they represent the increasing use that has occurred, over the years, of gas-tight storage, which emits no N_2O. In the interest of clarity, we have used the units g kg^{-1}, instead of the kg kg^{-1}, the common units for emission factors. The emission factors in Table 331 are to be applied to the N quantities that are input, along with energy crops, into the digestion process (cf. Chapter 5.1.4.2).

Table 331: Implied N_2O-N emission factor for direct N_2O emissions from digestion of energy crops (systems for storage of digestates), related to the N quantities input via energy crops

[g kg^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	5.00	4.77	4.53	4.21	2.89	2.63	2.03	1.90	1.80	1.77	1.76	1.77	1.76	1.72	1.72

The emission factor for indirect N_2O emissions as a result of deposition of NH_3 and NO from storage of digestates of energy crops, like that for the comparable process in connection with manure, is set at EF = 0.01 kg kg^{-1} (IPCC (2006a Vol 4, 11.24, Table 11.3). To obtain the relevant emissions, this emission factor has to be multiplied by the N quantities that are deposited – which are given in Chapter 5.1.5.1.4.

The calculated direct and indirect N_2O emissions are presented in Table 332. The trend reflects the sharp increase that has occurred – especially since 2005 – in the digested quantities of energy crops (cf. Chapter 5.1.4). The marked emissions decrease seen from 2011 to 2012 results from a disproportional increase in use of gas-tight storage; cf. Chapter 5.1.4.2.

Table 332: N_2O emissions from storage of digestates of energy crops

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**0.000**	**0.005**	**0.042**	**0.331**	**0.821**	**0.931**	**0.788**	**0.893**	**0.886**	**0.902**	**0.891**	**0.884**	**0.864**	**0.848**	**0.848**
N_2O_{direct}	0.000	0.005	0.040	0.315	0.781	0.886	0.750	0.849	0.843	0.858	0.847	0.841	0.822	0.807	0.807
$N_2O_{indirect}$	0.000	0.000	0.002	0.016	0.040	0.046	0.039	0.044	0.043	0.044	0.044	0.043	0.042	0.041	0.041

5.9.5 NO emission factors and emissions (3.J, NO)

As for the case of manure (cf. Chapter 5.3.4.2.2), the relevant NO emissions are calculated in proportion to the direct N_2O emissions, via use of the NO-N emission factor, which is to be applied to the input N quantity; that factor is set to 10 % of the N_2O-N emission factor.

Table 333 shows the trend in NO emissions from digestion of energy crops (systems for storage of digestates).

Table 333: NO emissions from storage of digestates of energy crops

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
	0.000	0.001	0.005	0.043	0.107	0.121	0.102	0.116	0.115	0.117	0.116	0.115	0.112	0.110	0.110

5.9.6 Category-specific quality assurance / control and verification (3.J)

With regard to quality control and quality assurance, we refer to Chapter 5.1.7.

Verification cannot be carried out, due to a lack of other German data sources. Neither can an international comparison be carried out, as a substitute, since other countries do not have comparable levels of use of digestion of energy crops.

5.9.7 Uncertainties and time-series consistency (3.J)

Table 263 in Chapter 5.1.6 shows the activity-data and emission-factor uncertainties, in connection with digestion of energy crops, that have been used in estimating the total uncertainty of the German GHG inventory. For derivation of the uncertainties, cf. Chapters 10.1 and 10.2.2 in Vos et al. (2022).

The emissions time series are consistent, since they were calculated with the same method for all years of the report period, and since the input data are also consistent and complete.

5.9.8 Source-specific recalculations (3.J)

The entire time series for CH_4 emissions and N_2O emissions (cf. Chapters 5.9.3 and 5.9.4) have been recalculated, with the same calculation method used in the 2020 submission. Table 334 compares the results of the present submission with those of last year's submission. Discrepancies are seen only for the year 2019. They result from updating of activity data for that year; cf. Chapter 5.1.4.2.

Table 334: Comparison of GHG emissions from digestion of energy crops (digesters and systems for storage of digestates), as reported in the 2021 and 2022 Submissions (3.J)

CO_2eq	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
2022 [kt]	0.40	5.02	42.5	346.3	1067.1	1285.2	1293.7	1534.6	1582.5	1634.9	1622.7	1599.8	1573.1	1565.7
2021 [kt]	0.40	5.02	42.5	346.3	1067.1	1285.2	1293.7	1534.6	1582.5	1634.9	1622.7	1599.8	1573.1	1573.1
2022-2021 [kt]	0	0	0	0	0	0	0	0	0	0	0	0	0	-7.37289521
2022-2021 [%]	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.46869726

5.9.9 Planned improvements (3.J)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

6 Land Use, Land Use Change and Forestry (CRF Sector 4)

6.1 Overview (CRF Sector 4)

6.1.1 Categories and total emissions and sinks, 1990 - 2020

In the sub-category "Forestry and other land use" within the LULUCF sector (Common Reporting Framework Sector 4), Germany reports on positive (source) and negative (sink) CO_2 emissions from the carbon pools[92]

- above-ground and below-ground biomass
- dead wood, litter,
- organic and mineral soils,
- and harvested wood products (4.G),

for the land-use categories

- Forest Land (4.A.1)
- Cropland (4.B.1)
- Grassland (4.C.1)
- Wetlands (4.D.1)
- Settlements (4.E.1)

as well as the relevant land-use changes between these categories (CRF 4.A.2 - 4.E.2). In the category Other Land (4.F), no anthropogenic emissions occur, since the relevant land areas are not used. No land-use changes to Other Land occur, since, by definition, land cannot be reassigned to the category "unused land" once it is in use.

The following are also inventoried:

- CO_2 emissions from
  - industrial peat extraction (4.D.1)
  - peat fires (4(V))
- N_2O emissions from
  - organic soils in land-use categories 4.A, 4.C (only woody grassland), 4.D, 4.E (emissions from the categories 4.B Cropland and 4.C Grassland are reported under Agriculture in CRF 3.D.a.6)
  - direct (CRF 4(III)) and indirect (CRF 4(IV)) emissions from humus mineralisation in mineral soils as a result of land-use changes and / or land management (emissions in category 4.B.1 are reported under Agriculture CRF 3.D.a.5)
  - industrial peat extraction (4(II))
  - wildfires (4(V))
- CH_4 emissions from
  - organic soils (4(II))
  - drainage ditches of organic-soil areas (4(II))
  - industrial peat extraction (4(II))
  - wildfires (4(V))
  - peat fires (4(V))

In reporting on emissions/removals of greenhouse gases in each land-use category, a distinction is made between areas which, during the reporting period,

[92] CO_2 emissions from wildfires are taken into account implicitly, via carbon-stock changes in Forest Land.

- undergo no land-use changes, and thus remain, in unchanged form, in the land-use category they are in (remaining categories 4.A.1 - 4.F.1)
- undergo land-use changes: From the time of conversion onward, these areas are reported in the category to which they were converted. Within those land-use categories, the converted areas are then reported in transition categories (4.A.2 - 4.F.2) for a total of 20 years. After 20 years in a transition category, the areas are reported under the relevant remaining categories. In cases in which land-use changes resume, prior to the end of the transition period, the relevant areas are assigned – with immediate effect as of the time of the land-use change – to the pertinent new transition category. A new 20-year period (the effective transition period) then begins for those areas.

Figure 49, Figure 50 and Figure 51 provide an overview, for the present 2022 Submission, of the development over time of greenhouse-gas emissions (sum of CO_2, CH_4 and N_2O emissions, as CO_2 equivalents) in categories 4.A-4.E, differentiated by sub-categories, pools and greenhouse gases. The x-axis consists of all the years covered by the report, while the y-axis consists of a scale for emissions (positive values) and removals (negative values), expressed in kilotonnes of CO_2 equivalents (kt CO_2-eq.).

The considerable emissions changes seen in the years 1990, 2002 and 2008 result from use of forest-biomass emission factors that have been highly modified to account for wood use. During the inventory period 1991 through 2001, wood use decreased sharply with respect to its level in 1990 (the harvest was increased in 1990 in connection with work to address storm damage). From 2002 – 2008, wood use increased again, and then a slight decrease occurred in 2008 (cf. Chapter 6.4.2.2.1). The reduced sink function of forest biomass between 2017 and 2020 is the result of forest damage tied to the severe drought that occurred in these report years. The time series reflect the changes in forest biomass and the trends in land-use changes (cf. Chapter 6.3.5). The land-use changes have been determined on the basis of data sets for the reference years 1990, 2000, 2005, 2010, 2015 and 2020 (cf. Chapter 6.3). Between the reference years, the land-use changes have been linearly interpolated. As a result, constant, average land-use changes emerge for the periods between reference years (cf. Table 360).

The course of net emissions shows that the sector functioned as a sink in most of the years in the period 1990 through 2020. The main factor behind this trend was the land-use category Forest Land. The pools forest biomass and forest soils contribute significantly to the sink. Harvested wood products, via their function as carbon stocks, also contributed to the sink function. The sink is offset primarily by emissions from agriculturally used areas in the land-use categories Cropland and Grassland. These two categories **exhibit continuingly high emissions, over the years,** from drained organic soils**.** The land-use category Wetlands contributes to GHG emissions primarily via industrial peat extraction. In the years 1990, 1990, 2002, 2003, 2004, 2005 and 2007, the LULUCF sector was a source of greenhouse gases, primarily as a result of intensified wood harvesting that was linked primarily to clean-up of forest damage caused by various disasters.

The predominant GHG is carbon dioxide (CO_2), which functions as a significant net sink. Emissions of methane (CH_4) and nitrous oxide (N_2O), by contrast, are relatively small. Detailed descriptions of the pertinent emissions and their time series are presented in the relevant chapters for the land-use categories (Chapter 6.4.1, Chapter 6.5.1, Chapter 6.6.1, Chapter 6.7.1, Chapter 6.8.1 and Chapter 6.10.1).

Figure 49: Time series for GHG emissions and removals (sum of CO_2, CH_4 and N_2O) [kt CO_2-eq.] in the LULUCF sector since 1990, by sub-categories

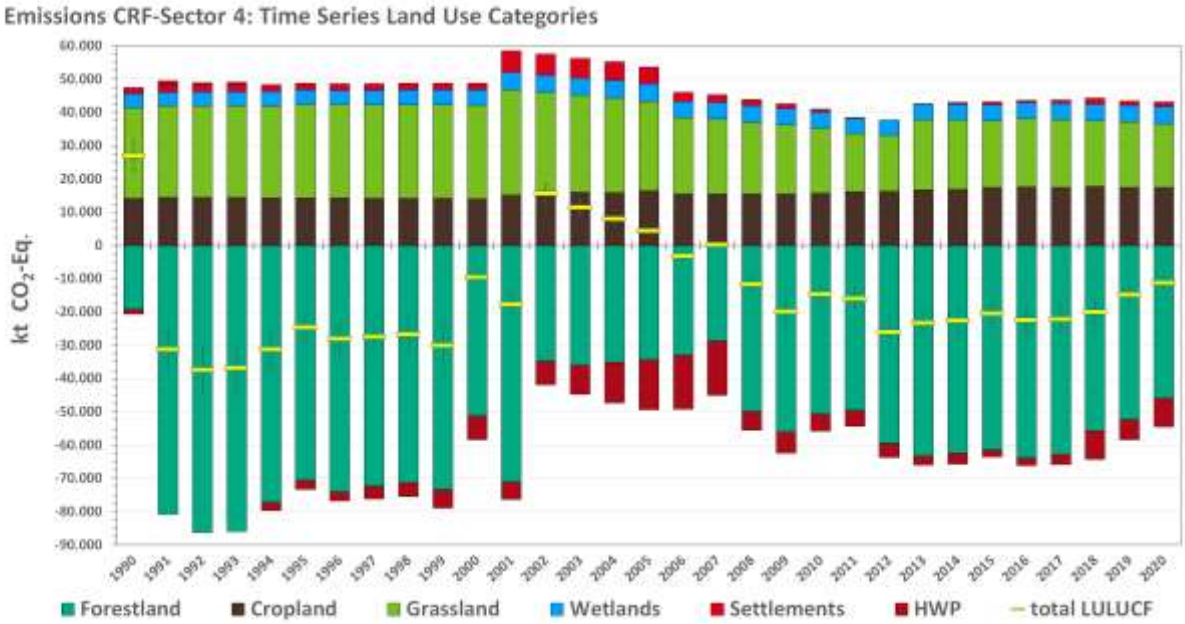


Figure 50: Time series for GHG emissions and removals (sum of CO_2, CH_4 and N_2O) [kt CO_2-eq.] in the LULUCF sector since 1990, by pools

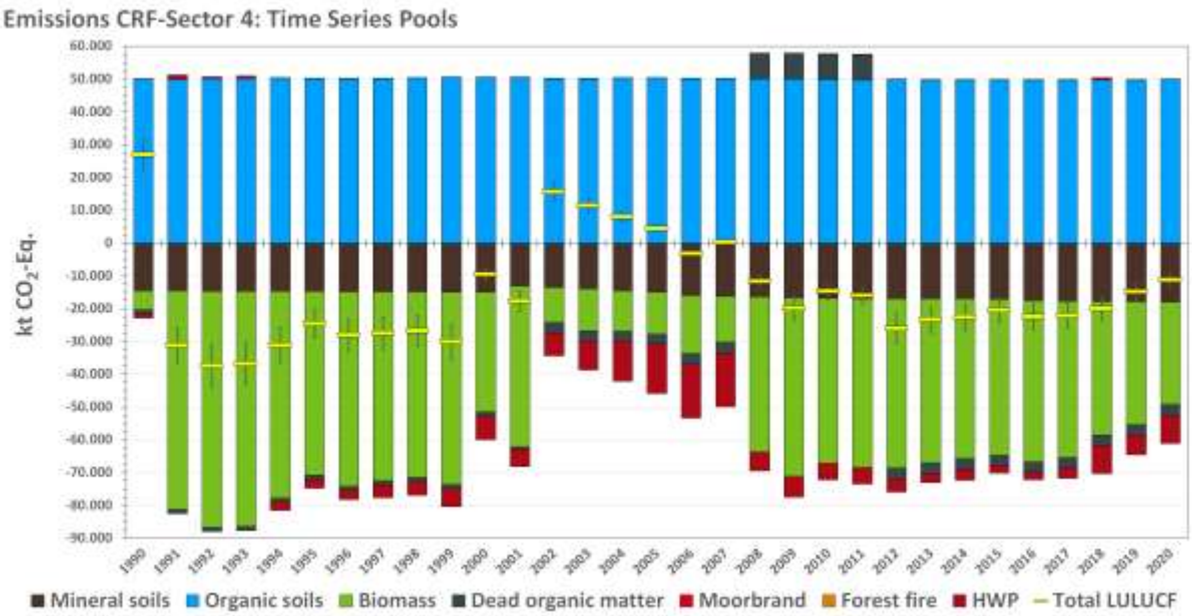
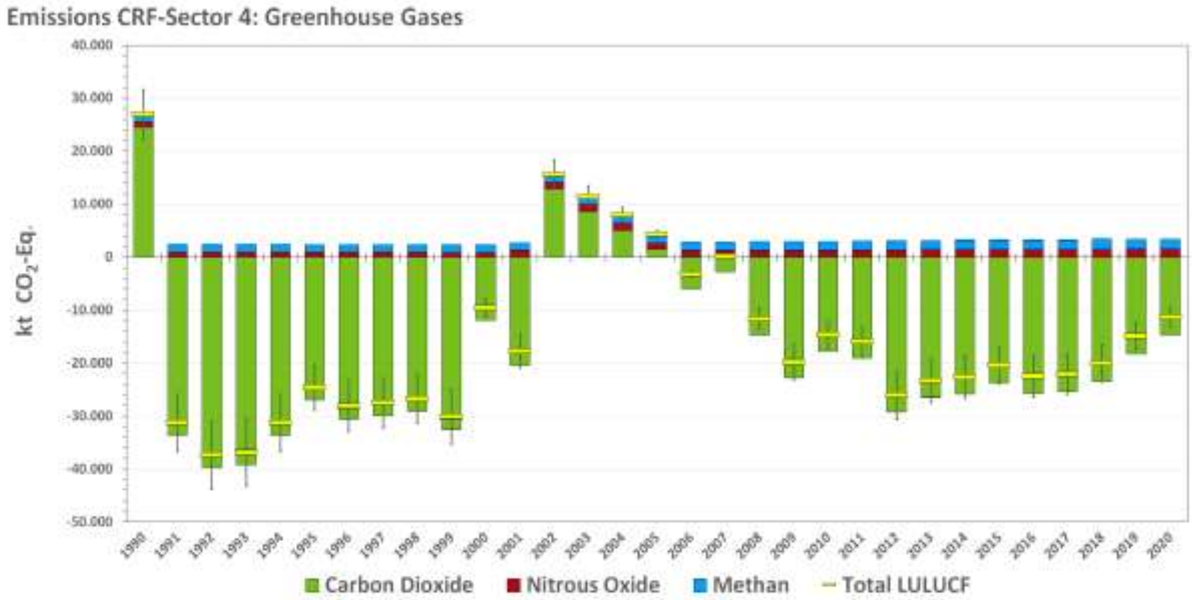


Figure 51: Time series for GHG emissions and removals (sum of CO_2, CH_4 and N_2O) [kt CO_2-eq.] in the LULUCF sector since 1990, by greenhouse gases (GHG)



The pertinent calculation shows that the total uncertainty of the German LULUCF inventory (not including harvested wood products) is 17.4 %. The pertinent details are presented in the relevant chapters for the individual land-use categories and in Chapter 6.1.2.1.

6.1.2 Methodological issues

Germany has adopted the land-use-classification scheme that the 2006 IPCC Guidelines require for CRF Sector 4. The implementation is outlined in Table 335, while precise relevant definitions and descriptions are provided in Chapter 6.2 (cf. also Chapter 6.3).

Table 335: Correlation of the German reporting categories with the IPCC land-use categories

IPCC category	German LULUCF categories	
4.A Forest Land	Forest Land	
4.B Cropland	Cropland with annual crops	
	Cropland with perennial crops	Hops
		Vineyards
		Orchards
		Short-rotation plantations
		Tree nurseries
		Christmas tree plantations
4.C Grassland	Grassland (in the strict sense)	
	Woody Grassland	
4.D Wetlands	Terrestrial Wetlands	
	Waters	
	Peat extraction	
4.E Settlements	Settlements	
4.F Other Land	Other Land	
4.G Harvested Wood Products	Harvested wood products	

Basic elements of the LULUCF inventory, and the steps required to prepare it

1. **Land-use matrix$_{annual}$** *[Area_ann]*: Annual calculation of the total areas for the sub-categories "'land use remaining" and "land-use change," in each of the categories Forest Land, Cropland$_{annual}$, Hops, Vineyards, Orchards, Tree nurseries, Christmas tree plantations, Short-rotation plantations, Grassland (in the strict sense), Woody Grassland, Terrestrial Wetlands, Waters, Peat extraction, Settlements and Other Land, and differentiated, by mineral and organic soils, for all time series. The relevant land uses, and the specific areas assigned to them, were explicitly determined for the years 1990, 2000, 2005, 2010, 2015 and 2020. The areas applying to the periods between those years were obtained by linearly interpolating the calculated areas, in keeping with the IPCC Guidelines (2006 IPCC Guidelines IPCC (2006b), Vol. 4 Ch. 3 Fig. 3.1) (cf. Chapter 6.3)**.**
2. **Emission factors for carbon stocks, and nitrous oxide and methane emissions, in the year of a land-use change** *[EF_ann]*: The emission factors for the various pools are calculated individually for each survey point, and separately for each land-use category (Chapter 6.1.2 ff). The carbon stocks, nitrous oxide emissions and methane emissions per area unit are not constant over time.
3. **Carbon-stock changes for annual land-use changes** *[E_ann]* are calculated using the equation **E_ann [e.g. t C] = EF_ann [e.g. t C/ha]* Area_ann [ha]**, under the assumption that the entire carbon-stock change occurs in the year of the land-use change.
4. **Introduction of a transition period lasting no more than twenty years,** *[Area_20y]*: The land-use-matrix calculation is referenced to the year 1970, to make it possible to determine land-use-change areas for years prior to the actual reporting period (cf. Chapter 6.3.4). Identified conversion areas are assigned to the relevant land-use-change category, in the year in which the land-use change takes place, and they remain in that category for a maximum of 20 years. At the end of the 20-year period, the areas are assigned to the remaining category within the final use category. Consequently, as of the second reporting year, the areas in the remaining categories are smaller, and those in the transition categories larger, than the corresponding areas in an annual land-use matrix. The relevant areas are shown in the CRF tables Table 358 and Table 359. When areas undergoing a 20-year transition period again undergo land-use changes, within that period, the areas are assigned – with immediate effect as of the time of the land-use change – to the pertinent new transition category, and they enter a new 20-year transition period.
5. **Emission factors** *[EF]* **and implied emission factors** *[IEF]* **for the twenty-year transition period** *[IEF_20y]*: These factors are listed in the CRF tables. Annual emission factors are converted into emission factors, and implied emission factors, that are appropriate for the land-use-matrix areas with 20-year transition periods. Conversion of *EF_ann* to *IEF_20y*, following inclusion of the mineral-soil and organic-soil areas for emissions from pools, yields adjusted EFs, i.e. implied emission factors (IEFs). Even though the absolute emissions remain unchanged, the IEF are affected by the areas' annual net changes, and by the various ***IEF_20y*** of the mineral soils in the transition categories, as a result of new land-use changes within the 20-year transition period. In the process, the following equations are used:
   - **Mineral soils**: The entire carbon-stock change as a result of a land-use change is linearly distributed over the 20-year transition period, using the equation *IEF_20y = EF_ann / 20*; i.e. only one twentieth of the total emissions are added

annually. As a result of the introduction of the "effective transition period," the carbon stocks in mineral soils have to be rechecked at every survey point, and recorded, since those stocks, in combination with the relevant new final value, serve as the basis for calculating the new ***EF_ann*** in the case of new land-use changes within the 20-year transition period (cf. Chapter 6.1.2.1.1)

- **Organic soils I**: In the land-use categories Forest Land and Woody Grassland, the same quantities of CO_2, CH_4 and N_2O are emitted each year; this applies both to the transition categories and, in each case, to the remaining category for the new land use. A similar relationship holds for the N_2O emissions of all other land-use categories; *IEF_20y = EF_ann*.
- **Organic soils II**: For organic soils areas under Cropland (including all sub-categories), Grassland (in the strict sense), Wetlands (including all sub-categories) and Settlements, CO_2 and CH_4 emissions are calculated annually, via response functions and as a function of the groundwater level.
- **Net carbon-stock changes, and carbon-stock increases and decreases, in the biomass of annual herbaceous plants and dead organic matter (Cropland$_{annual}$, Hops, Grassland (in the strict sense), Waters, Peat extraction)**: All emissions are completely accounted for in the year of the land-use change, in line with the equation ***IEF_20y = E_ann / [Area_20y***].
- **Net carbon-stock changes, and carbon-stock increases, in biomass and dead organic matter, and in connection with land-use changes to Forest Land; Vineyards and Orchards; Christmas tree plantations, tree nurseries, and short-rotation plantations; Woody Grassland; Wetlands; and Settlements**: The entire carbon-stock change resulting from a land-use change is determined with the equation ***IEF_20y = EF_ann***; i.e., the relevant carbon removal by sink is allocated to the entire land-use-change area each year.
- **N_2O from loss of organic matter in mineral soils, as a result of land-use changes to Cropland**: The method used is the same as the one used for calculation of carbon-stock losses in mineral soils. The entire carbon-stock change as a result of a land-use change is linearly distributed over the 20-year transition period, in keeping with the equation *IEF_20y = E_ann / Area_20y*; i.e. only one twentieth of the total emissions are added each year. The same procedure is used in the case of new land-use changes within the 20-year period.

6. For purposes of the UN Framework Convention on Climate Change, **total carbon-stock changes for areas with twenty-year transition periods** are calculated in accordance with the following formula: *E_20y [kt C] = IEF_20y [t C/ha]* Area_20y [kha]*.
7. **Calculation of CO_2 emissions** on the basis of the carbon-stocks values for the NIR, via multiplication of carbon-stock changes by the factor -44/12.
8. **Calculation of N_2O emissions from nitrogen values, via multiplication of the nitrogen-stock changes by the factor -44/28; the N_2O values are converted into CO_2 equivalents using the factor 298 (GWP 100 pursuant to** Decision **24/CP.1 (Annex III)).**
9. **The CH_4 emissions are** converted into CO_2 equivalents using the factor 25 (GWP 100 **pursuant to** D**ecision 24/CP.1 (Annex III))**.

The 2022 Submission was compiled in accordance with the following provisions:

- 2006 IPCC Guidelines (IPCC, 2006b)

- 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC et al., 2014a)
- 2013 Supplement to the IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC et al., 2014b)

The key inventory-improvement measures that were carried out for the present submission and that led to recalculations:

- Updating of the map bases for determination of activity data with regard to designation of land uses and land-use changes, and adjustment of the land-use matrix over time (cf. Chapter 6.3.1 ff) Implementation of models for calculation and tracing of carbon stocks in the biomass of perennial plants outside of Forest land, as a function of species and age, and of management aspects (such as rotation periods, cutting, new establishment), at every survey point, and on an annual basis (cf. Chapter 6.1.2.2ff)
  - Adjustment of the emission factors for above-ground and below-ground forest biomass (cf. Chapter 6.1.2.3.4ff and Chapter 6.4.2.2)
  - Adjustment of the emission factors for dead wood (cf. Chapter 6.4.2.3)
  - Adjustment of the emission factors for biomass in connection with land-use changes from Woody Grassland to Forest Land (cf. also Chapter 6.1.2.3.6)
  - Correction of the value for carbon and nitrogen stocks of mineral soils, in the category Settlements remaining Settlements (cf. Chapter 6.1.2.1.6 and Chapter 6.8.2.4).
  - Modification of the emission factor for nitrous oxide emissions from organic soils under Settlements (Chapter 6.8.2.4)
  - Correction of the algorithm for calculation of methane emissions in the sub-category Waters (Chapter 6.7.2.4)

Apart from these changes, the methods, data sources and emission factors used in the previous submission were again used. The calculations for determination of all emissions and inventory-relevant values for Germany's LULUCF sector are carried out completely automatically, via a program system, in the framework of a combined geoinformation/database system.

6.1.2.1 Carbon emissions from mineral soils (4.A to 4.F)

6.1.2.1.1 Overview of methods used

The area of the mineral soils was calculated as the difference between the national total areas and the areas covered by organic soils (Chapter 6.1.2.2).

Changes in carbon and nitrogen stocks in mineral soils are calculated, pursuant to Equation 2.25 in the 2006 IPCC Guidelines (IPCC, 2006b), as the difference between the stocks prior to relevant land-use changes and the stocks after the changes. The emission factors have been derived on a country-specific basis. The values for forest soils (CRF 4.A) were obtained from the Forest Soil Inventories (cf. Chapter 6.4.2.5.3). In the framework of the Forest Soil Inventories, an annual carbon-stock change of 0.41 ± 0.11 t C ha^{-1} a^{-1} was determined for category 4.A.1, Forest Land remaining Forest Land (cf. Chapter 6.4.2.5.4). This quantity is added to the previous year's stocks, on an annual basis, and is reported as a removal.

The country-specific, representative carbon stocks for the land-use categories 4.B ($Cropland_{annual}$, Hops, Orchards, Vineyards, Christmas tree plantations, tree nurseries, short-rotation plantations), 4.C (Grassland (in the strict sense), Woody Grassland) and 4.D.1 (Terrestrial Wetlands) were determined on the basis of a complete-coverage inventory of agricultural soils (Agricultural Soil Inventory Jacobs et al. (2018)). For the Other Land land-use categories, representative carbon stocks, weighted by area, were determined for mineral soils with depths to 30 cm, from usage-differentiated profile data available in Germany.

For the Settlements category, country-specific carbon stocks, based on the results of the Forest Soil and Agricultural Soil inventories, were derived as a function of the direction of the pertinent land-use change, the previous use and the degree of soil sealing on the areas concerned (Chapter 6.1.2.1.6). Thus, the reporting on mineral soils applies a Tier 2 approach.

For mineral soils with no use or name change, in land-use categories 4.B, 4.C, 4.D, 4.E and 4.F, it is assumed that the pertinent carbon inputs into the soil and carbon extractions from the soil are equal in size, so that the systems are in equilibrium. The reasons for this assumption are described in Chapters 6.5.2.3 and 6.6.2.3. In the CRF tables, the pertinent spaces are marked with "NA" (in keeping with the requirements of the ERT 2021).

In the category Wetlands (4.D), mineral soils occur only in the sub-categories Terrestrial Wetlands and waters. For land-use changes leading to Waters, no carbon-stock changes are applied; in the case of land-use changes from Waters to other land-use forms, the difference between the previous use as Waters and the final use is applied, if it is known. If it is not known, no changes are assumed.

For each transition category, the carbon-stock changes in mineral soils resulting from land-use changes are calculated as the difference between the carbon stocks of the final land-use category and the carbon stocks of the initial land-use category. Since the carbon stocks in forest soils (4.A) change annually, the inventory calculations are based on the actual annual values for the years in question. Pursuant to the IPCC default (IPCC, 2006b), the total changes are linearly distributed over a period of 20 years. The sum of all carbon-stock changes from land-use changes in Germany's mineral soils is calculated, for a 20-year period, as follows:

$$\Delta C = C_{final} - C_{initial}$$

ΔC: Change in carbon stocks as a result of land-use changes in mineral soils of a transition category [t C $(20*a)^{-1}$]

C_{final}: Mineral-soil carbon stocks [t C] in the final category

$C_{initial}$: Mineral-soil carbon stocks [t C] in the initial category

Land-use changes leading to Settlements are an exception in this regard. In such cases, in a one-time step, and only in the year of the use change, 11 % of the carbon stocks in the mineral soils of the previous use are applied as an emission (Chapter 6.1.2.1.6). The carbon stocks of mineral soils in the various land-use categories, and the carbon-stock changes derived from those stocks and used as emission factors, are shown for 2020 in Table 336; the pertinent derivations are described in the following chapters.

Table 336: Mean carbon stocks in Germany's mineral soils, by land use [t C ha^{-1}], and therefrom-derived carbon-stock differences following land-use changes, for the year 2020

Mean carbon stocks in Germany's mineral soils in 2020	Forest Land	Cropland$_{annual}$	Hops	Vineyards	Orchards	Tree nurseries	Christmas tree plantations	Short-rotation plantations	Grassland (in the strict sense)	Woody Grassland	Terrestrial Wetlands	Waters	Peat extraction	Settlements#	Other Land
[t C ha^{-1}]	*67.54*	61.18	62.89	49.30	71.69	62.89	62.89	62.89	89.41	62.89	109.31			36.81	55.60

Carbon-stock change in 20 years [t C ha^{-1} (20 a)$^{-1}$] Initial\Final	Forest Land	Cropland$_{annual}$	Hops	Vineyards	Orchards	Tree nurseries	Christmas tree plantations	Short-rotation plantations	Grassland (in the strict sense)	Woody Grassland	Terrestrial Wetlands	Waters	Peat extraction	Settlements	Other Land
Forest Land		*-6.36*	*-4.65*	*-18.24*	*4.15*	*-4.65*	*-4.65*	*-4.65*	*21.87*	*-4.65*	*41.77*	0	NO	*-30.73*	NO
Cropland$_{annual}$	*6.36*		1.71	-11.88	10.51	1.71	1.71	1.71	28.23	1.71	48.13	0	NO	-6.73	NO
Hops	*4.65*	-1.71		-13.59	8.8	0	0	0	26.52	0	46.42	0	NO	-6.92	NO
Vineyards	*18.24*	11.88	13.59		22.39	13.59	13.59	13.59	40.11	13.59	60.01	0	NO	-5.42	NO
Orchards	*-4.15*	-10.51	-8.8	-22.39		-8.8	-8.8	-8.8	17.72	-8.8	37.62	0	NO	-7.89	NO
Short-rotation plantations	*4.65*	-1.71	0	-13.59	8.8		0	0	26.52	0	46.42	0	NO	-6.92	NO
Tree nurseries	*4.65*	-1.71	0	-13.59	8.8	0		0	26.52	0	46.42	0	NO	-6.92	NO
Christmas-tree plantations	*4.65*	-1.71	0	-13.59	8.8	0	0		26.52	0	46.42	0	NO	-6.92	NO
Grassland (in the strict sense)	*-21.87*	-28.23	-26.52	-40.11	-17.72	-26.52	-26.52	-26.52		-26.52	19.9	0	NO	-9.84	NO
Woody Grassland	*4.65*	-1.71	0	-13.59	8.8	0	0	0	26.52		46.42	0	NO	-6.92	NO
Terrestrial Wetlands	*-41.77*	-48.13	-46.42	-60.01	-37.62	-46.42	-46.42	-46.42	-19.9	-46.42		0	NO	-12.02	NO
Waters	0	0	0	0	0	0	0	0	0	0	0		NO	0	NO
Peat extraction	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO		NO	NO
Settlements	*30.73*	24.37	26.08	12.49	34.88	26.08	26.08	26.08	52.6	26.08	72.5	0	NO		NO
Other Land	*11.94*	5.58	7.29	-6.3	16.09	7.29	7.29	7.29	33.81	7.29	53.71	0	NO	-6.12	

Values in italics: Changing from year to year

Negative: Carbon losses; positive: Carbon sequestration; NO: not occurring

#: only once, in the year of the land-use change

To take account of the 20-year transition period, the total stock change for each transition category in question (EF_ann, cf. Table 336) is divided by 20. This yields the implied emission factors for the transition categories for land-use changes leading out of a remaining category (IEF_20y; cf. Table 337). In the case of land-use changes to and from Forest Land, and because carbon stocks in mineral forest soils change from year to year, an implied emission factor (IEF) has to be derived for each reported year. These IEF, which vary from year to year, are derived for each transition category from the change in mineral-soil carbon stocks, ΔC_i. The derivation is as follows:

$$\Delta C_i = \begin{cases} \frac{(C_{final,i} - C_{initial,i})}{20}, i = 0 \\ \frac{(C_{final,i} + 0{,}41t - C_{initial,i})}{(20 - i)}, i > 0 \end{cases}$$

ΔC_i: Change in mineral-soils carbon stocks in year i following a land-use change [t C a-1]

$C_{final,i}$: Final soil organic carbon stocks in the final category in year i following the land-use change [t C]

$C_{initial,i}$: Current soil organic carbon stocks in the initial category [t C] in year i following the land-use change

i: Year following the land-use change (0 - 19)

The new soil organic carbon stocks, in each case, are then obtained as the sum of a) the current soil organic carbon stocks applying to the initial use and b) and the calculated stock change ($\Delta C_i + C_{initial, i}$). Since the carbon stocks in mineral soils of Forest Land currently show an annual rate of change of 0.41 t C ha^{-1} a^{-1}, that quantity has to be added to the final stocks on an annual basis.

Areas affected by land uses remain for at least 20 years within a transition category. At that point, they have attained the final category's carbon-stocks level, and they are assigned to the relevant remaining category. As a result of the introduction of the "effective transition time" concept, an area affected by a land-use change is assigned to its relevant new transition category right at the time of the pertinent use change, regardless of how long it has already been listed in a transition category. Since the carbon-stock changes pursuant to the above equation depend, in each case, on the initial and final stocks involved, the carbon stocks of mineral soils have to be monitored and recorded for all grid points and for all relevant times. While final stocks (C_{final}) are predetermined – and, with the exception of those for forest soils (as defined by this model), have fixed values – initial stocks are variable. In each case, they represent the value achieved, until the time of the next land-use change, in the previous transition category. Carbon-stock changes for areas undergoing early removal from transition categories are also calculated using the above algorithms, although $C_{initial}$ then represents the current mineral-soil carbon stocks attained in the previous transition category, up to the time of the next land-use change, as measured at the relevant detection point. The so-calculated carbon-stock changes are distributed over 20 years: ΔC / 20 thus yields the annual rate of change that is added to the current initial soil organic carbon stocks until the time of the next land-use change or until the area transitions into the relevant remaining category. Ultimately, each implied emission factor is the mean of all IEF_20y for a transition category in a given reported year. Table 337 shows the pertinent values for the year 2020. Logically enough, the values it presents are not the same as the quotients obtained by dividing the soil-carbon-stocks differences shown in Table 336 by 20.

Table 337: Implied emission factors [t C ha^{-1} a^{-1}] for determination of annual carbon-stock changes in Germany's mineral soils, following land-use changes, for the year 2020

Initial\Final	Emission factors$_{mineral\ soils}$ [t C ha^{-1} a^{-1}] for the year 2020														
	Forest Land	Cropland$_{annual}$	Hops	Vineyards	Orchards	Tree nurseries	Christmas tree plantations	Short-rotation plantations	Grassland (in the strict sense)	Woody Grassland	Terrestrial Wetlands	Waters	Peat extraction	Settlements	Other Land
Forest Land	0.41	0	0	0	0	0	0	0	0	0	2.361	0	NO	-0.385	NO
Cropland$_{annual}$	0.391		0.001	-0.56	0.46	0.035	0.032	0.28	1.325	0.050	2.324	0	NO	-0.198	NO
Hops	0.376	-0.089		0	0.395	0	0	0	1.303	0	0	0	NO	-0.402	NO
Vineyards	1.055	0.533	0.679		0.936	0.615	0.679	0.679	1.944	0.649	0	0	NO	-0.197	NO
Orchards	-0.064	-0.445	-0.415	-1.072		-0.352	-0.411	-0.369	0.898	-0.415	0	0	NO	-0.205	NO
Tree nurseries	0.376	-0.093	0	-0.679	0.437		0	0	1.302	-0.036	0	0	NO	-0.583	NO
Christmas tree plantations	0.376	-0.087	0.010	-0.676	0.425	0		0	1.289	-0.010	0	0	NO	-0.629	NO
Short-rotation plantations	0	-0.113	0	0	0.432	0	0		1.135	-0.032	0	0	NO	-0.748	NO
Grassland (in the strict sense)	-0.469	-1.163	-0.901	-1.350	-0.575	-0.991	-1.046	-1.035		-1.052	1.063	0	NO	-0.431	NO
Woody Grassland	0.346	-0.097	-0.009	-0.556	0.365	0	-0.077	-0.063	1.263		1.940	0	NO	-0.474	NO
Terrestrial Wetlands	-1.862	-1.54	0	-1.436	-1.881	-2.241	0	0	-0.746	-1.985		0	NO	-0.754	NO
Waters	0	-0.076	0	-0.679	-0.089	-0.41	0	0	0.257	-0.021	0.266		NO	0	NO
Peat	NO	NO	NO	NO	NO	NO	0	0	NO	NO	NO	NO		NO	NO
Settlements	1.586	1.182	1.210	0.735	1.718	1.249	1.299	1.255	2.498	1.216	3.405	0	NO		NO
Other Land	0.726	0.279	0	-0.315	0	0	0	0	1.69	0.365	2.686	0	NO	0	

Negative: Carbon losses; positive: Carbon sequestration; NO: not occurring

6.1.2.1.2 Database and procedure

The basis for the determination of the nationwide, representative mean carbon stocks in mineral soils, as a function of land use, consists of the following data sources:

- Soil map (Bodenübersichtskarte; BÜK), scaled to 1:1,000,000 (BÜK 1000; BGR 1995 & 1997, Düwel et al. (2007))
- Soil profiles from BÜK 1000 no. 2.3; FISBo BGR (BGR (2011))
- "Gehalte an organischer Substanz in Oberböden Deutschlands – Bericht über länderübergreifende Auswertung von Punktinformationen im FISBo BGR" ("Stocks of organic matter in Germany's topsoils – report on inter-Länder evaluation of point data in the FISBo BGR") (Düwel et al., 2007)
- Results of the Forest Soil Inventories I and II (BZE I and BZE II; Wellbrock et al. (2016))
- Results of the Inventory of Agricultural Soils in Germany (Agricultural Soil Inventory; Bodenzustandserhebung auf landwirtschaftlichen Böden in Deutschland) (BZE-LW; Jacobs et al. (2018))
- Data sets of the Basic Digital Landscape Model (Basis-Digitales Landschaftsmodell; B-DLM) of the Official topographic-cartographic information system (Amtliches Topographisch- Kartographisches InformationsSystem (ATKIS®), for the years 2000, 2005, 2010, 2015 and 2020 (AdV 2000; 2005; 2010; 2015; 2020)
- IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use (IPCC, 2006b)

The emission factors for the various land-use categories were determined with the help of a fallback system. This means that

- where specifically collected soil data are available for a given land-use category (BZE II data or BZE-LW data), they are used for determination of the soil organic carbon stocks in the relevant categories.
- Where such data are not available, determination is based on estimates from the BÜK 1000.

In keeping with the different data situations for the various land-use categories, the area-weighted, use-specific and soil-specific mineral-soil carbon stocks were determined separately for the various categories. The values for Forest Land were taken from the Forest Soil Inventories (BZE I and BZE II; Wellbrock et al. (2016)), while those for Cropland$_{annual}$, Hops, Orchards, Vineyards, Christmas tree plantations, tree nurseries, and short-rotation plantations, and for the categories Grassland, Woody Grassland and Terrestrial Wetlands, were taken from the Agricultural Soil Inventory (Jacobs et al., 2018). The mineral-soil carbon stocks for Settlement soils have been derived from the results of these soil inventories (Chapter 6.1.2.1.6). Only the carbon stocks in mineral soils of the land-use category Other Land had to be derived from the Soil map for the Federal Republic of Germany 1:1,000,000 (BGR, 1997).

The BÜK 1000 soil map divides Germany's soils into 71 scientifically characterised soil categories / legend units. Those units, known as "dominant soil associations" (DSA), comprise dominant and secondary soil types. They are characterised on the basis of dominant soil types that are representative for the areas in question and that have been assigned selected soil profiles. Along with descriptive parameters, the profile descriptions include information about key soil characteristics, such as humus and nitrogen content and physical soil parameters. The data set on which the present calculations are based includes, inter alia, derived central tendencies for carbon (C_t), inorganic carbon (C_i), nitrogen (N_t), rock content and bulk density$_{dry}$, along with the ranges for the values, in the form of class information pursuant to KA 4 (Finnern, 1994).

The mean carbon stocks of a dominant soil association can be calculated from these data by multiplying the carbon content by soil mass and correcting for skeleton and carbonate content. For determination of the mean carbon stocks in mineral soils of the category Other Land, the BÜK 1000 was merged with the Basis-DLM (Chapter 6.3.2.1). The land-use-specific area data and soil-characteristics data of the BÜK 1000 (bulk density, skeleton content) were combined with the organic-carbon data produced by the BGR study "Gehalte organischer Substanz in Oberböden Deutschlands: Länderübergreifende Auswertung von Punktinformationen im FISBo BGR" ("Concentrations of organic matter in Germany's topsoils – report on Länder-overarching evaluation of point data in the FISBo BGR") (Düwel et al., 2007).

Düwel et al. (2007) list typical concentrations of organic matter (C_{org}) and humus in Germany's topsoils, for a total of 15 groups of soil parent material and 4 climate zones. Those listings are based on complete-coverage evaluation of data for ca. 14,000 profiles, broken down by land use (Cropland, Grassland and Forest Land) and by climate region.

In addition, that study assigns the 71 legend units of the BÜK, on the basis of their pedo-lithological characteristics, to those 15 groups of soil parent material (Düwel et al., 2007), with the result that those groups link to the legend units of the BÜK 1000.

6.1.2.1.3 Forest Land

The mean carbon stock value for mineral soils of up to 30 cm depth, as determined in the Forest Soil Inventories, was assigned to all areas that fall under the definition of "forest land" according to the National Forest Inventory (based on the Federal Forest Act) or, respectively, under the forest definition according to the IPCC, as selected by Germany.

Upon the completion of this work, it was possible to base the LULUCF inventory calculations, as of the 2013 submission, on the results of the Forest Soil Inventories (BZE) with regard to soil organic carbon stocks and their rates of change. The so-derived mean carbon stocks for mineral soils, to a depth of 30 cm, are 61.8 ± 3.7 t ha^{-1} for the year 2006. The mean annual change rate determined for the period between the inventories amounts to 0.41 ± 0.11 t ha^{-1} a^{-1} (cf. Chapter 6.4.2.5). To determine the carbon stocks of forest mineral soils for the various reporting years, the mean change rate was added to / deducted from the 2006 average soil organic carbon stocks of all German mineral forest soils. This yielded the following time series for the report period beginning in 1990 (Table 338):

Table 338: Mean carbon stocks [to 30 cm soil depth, in t C ha^{-1} ± 1.96 * standard error] in mineral forest soils

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
$C_{stocks\_}$ Forest soils [tC ha-1]	55.24 ± 6.44	57.29 ± 6.68	59.34 ± 6.92	61.39 ± 7.16	63.44 ± 7.40	65.49 ± 7.64	65.90 ± 7.69	66.31 ± 7.73	66.72 ± 7.78	67.13 ± 7.83	67.54 ± 7.88

These values form the basis for all relevant calculations within this inventory, for the respective years.

6.1.2.1.4 Cropland

The carbon stocks of mineral soils on cropland with annual crops, on areas used for cultivation of hops, vineyards and orchards, and on areas used for tree nurseries, Christmas tree plantations and short-rotation plantations, were derived from the results of the Agricultural Soil Inventory (Jacobs et al., 2018). The Agricultural Soil Inventory (Bodenzustandserhebung Landwirtschaft) is a sample survey with systematic sample distribution. In it, all of Germany's agricultural soils were systematically described, sampled and analyzed, to a soil depth of 1 m, throughout a complete-coverage grid array of 8 x 8 km cells. The results of the Agricultural Soil Inventory are representative with regard to both a) the distribution of soil characteristics and soil parameters and b) current agricultural land use in Germany. The mean carbon-stocks values for mineral soils in the various individual cropland sub-categories are shown in Table 339.

Table 339: Mean area-based mineral-soil carbon stocks to a soil depth of 30 cm [t C ha^{-1} $30cm^{-1}$], and pertinent uncertainties (upper and lower bounds in %) for croplands with annual crops

Mineral soils	Carbon stocks [t C ha^{-1}]	Uncertainty [%]
$Cropland_{annual}$	61.18	1.23
Hops	62.89	7.84
Vineyards	49.30	11.36
Orchards	71.69	8.87
Tree nurseries	62.89	7.84
Christmas tree plantations	62.89	7.84
Short-rotation plantations	62.89	7.84

In the Agricultural Soil Inventory (BZE-LW), the number of soil profiles studied on sites with hops, tree nurseries, Christmas tree plantations and short-rotation plantations was too small to permit any derivation of specific average mineral-soil carbon stocks for these crops. Consequently, no statistically significant differences can be given for these sub-categories. For this reason, the average value applying to all of Germany's special-crop areas is assumed to apply to these areas. Nonetheless, the areas with hops, tree nurseries, Christmas tree plantations and short-rotation plantations are listed separately.

Specific mineral-soil carbon stocks, differing significantly from those for all other special crops and differing from each other, can be given for a) vineyards and b) for orchards, however, due to the high prevalence of such areas. Germany has two major fruit-growing regions: one in northern Germany (near Hamburg; the "Altes Land" region), and one in the southernmost part of the country (the Lake Constance region). While they lie in different climate zones, no significant, climate-related differences between the two regions' carbon stocks have been found. Consequently, the same carbon-stocks value is used, nationwide, for orchards. Germany's vineyards all lie within the same climate zone. For this reason, their soils do not need to be stratified in terms of climatic influences.

6.1.2.1.5 Grassland

The land-use category "Grassland" comprises the sub-categories "Grassland in the strict sense" and "Woody Grassland" (cf. Chapter 6.2.3). The values for its mean carbon stocks were obtained from the Agricultural Soil Inventory (Jacobs et al., 2018). For grassland soils, the mean for all surveyed and listed permanent grassland sites is used as a basis. For the Woody Grassland sub-category, the mean for all perennial crops is used. The relevant values are shown in Table 340.

Table 340: Mean area-related carbon stocks [t C ha^{-1} 30 cm^{-1}], and their uncertainties (%), for Grassland and Woody Grassland areas, to a soil depth of 30 cm

Mineral soils	Carbon stocks [t C ha^{-1}]	Uncertainty [%]
Grassland in the strict sense	89.41	2.20
Woody Grassland	62.89	7.84

6.1.2.1.6 Settlements

Emissions resulting from active construction measures

In the case of land-use changes leading to Settlements, the humus-rich topsoil layer (30 cm soil depth), which is relevant for reporting purposes, is completely removed on the affected area. German law mandates special protection for topsoil (Section 202 German Building Code (BauGB (2015))), requiring topsoil to be stored, preserved and protected in unmixed form in the case of construction activities. In cases involving sealing, the topsoil must be laid down laterally, must not be contaminated and must not be mixed (German soil protection act (Bundesministeriums der Justiz und für Verbraucherschutz, 1998; KrWG, 2012); and 16 pertinent Länder construction codes). Normally, topsoil sections of sealed areas are applied to unsealed areas (if possible, on the building site involved or on neighboring land), with the result that little or no carbon is lost. Only lateral translocation occurs. The overall balance with respect to the carbon remains nearly the same. The IPCC Guidelines 2006 explicitly refer to such cases. Pursuant to the Guidelines, good practice in them calls for reducing potential carbon losses by the amount of carbon contained in laterally translocated soil (IPCC (2006b), Chapter 8.3.3.1). When such measures are carried out, the soil on the affected areas is disturbed, however (it is excavated, transported away, and reapplied; in some cases, it may be appropriately stockpiled), The measures disrupt the soil structure, and subject the soil to intensive aeration – at least for short periods of time. Such measures normally initiate intensified decomposition, via micro-organisms, of organic soil substances. The so-released quantities of CO_2 have to be determined and included in the balance sheet. Such carbon losses are quantified on the basis of the assumptions outlined below.

- No specifically collected scientific data are available on the carbon losses, from organic topsoil substance, resulting from construction measures; for this reason, such losses have to be estimated. The losses are estimated with the help of response functions that describe the carbon losses, from organic substance in mineral soils, resulting from conversion of Grassland or Forest Land into Cropland (Poeplau et al., 2011). Such land-use changes result in enormous, lasting disruptions of the topsoil, including intensified aeration of the topsoil.

Response functions (Poeplau et al., 2011) (cf. Figure 52)

Grassland converted to Cropland: $\Delta\ C_{SOC}$_Ini_prev = 36.11*[1-exp(-t/2,74)]

Forest Land converted to Cropland: $\Delta\ C_{SOC}$_Ini_prev = 32.19*[1-exp(-t/5,15)]

$\Delta\ C_{SOC}$_Ini_prev: Relative carbon-stock change [%]

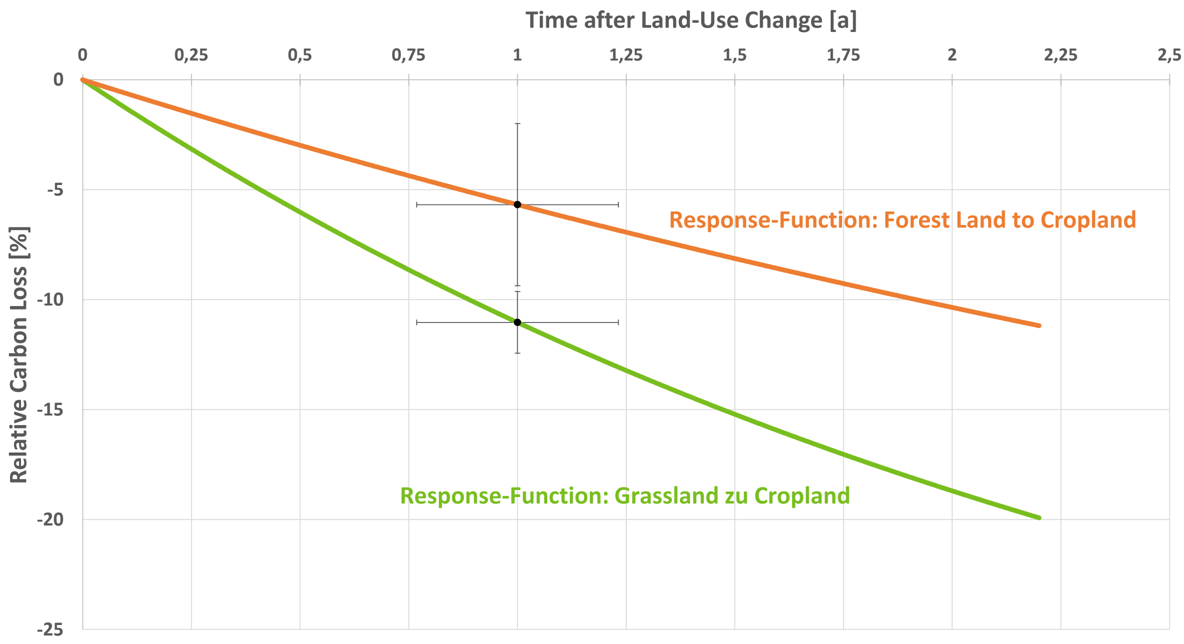
t: Time following the disruption [a]

- Construction projects in Germany normally take from 6 – 25 months, depending on the project involved (Schulz, 2012). With the help of statistical data – the mean values of the time series for the numbers of relevant completed construction projects since 2010 (Statistisches Bundesamt, 2020) – it was possible to calculate a weighted mean for the length of construction periods in Germany. The value obtained is 11.9 months. In a conservative approach, a period of 12 months is assumed (t = 1 in the response functions).

If one inserts the so-calculated mean construction period in the response functions, one obtains the following relative carbon losses with respect to the initial stocks:

- Grassland converted to Cropland: -11.0 %
- Forest Land converted to Cropland: -5.7 %

Figure 52: Relative carbon loss ([%]; uncertainties: 95 % confidence interval [%]) from humus-rich topsoil as a result of construction-related disruptions, derived from response functions for Grassland / Forest Land converted to Cropland (Poeplau et al., 2011), and assuming an average construction period of 12 months



In a conservative approach, in light of the fact that land-use changes from Grassland to Settlements take place 4-5 times as frequently as land-use changes from Forest Land to Settlements, the carbon losses from humus-rich topsoil layers as a result of construction-related disruptions are estimated using the response function for land converted from Grassland to Cropland. For an average construction period of 12 months, the calculation yields carbon losses of -11 ± 1.4 % C ($uncertainty_{relative}$: 12.7 %) (cf. Figure 52) from the current mineral-soil carbon stocks of affected areas at the time of the land-use change. In the inventory, the so-determined carbon losses are applied only once, and only in the year of the land-use change.

Carbon stocks in settlement soils

Facts and assumptions

Unsealed soils within cities can exhibit carbon stocks comparable to those found in forest and grassland soils outside of settlement areas (Klingenfuß et al. (2020); Cambou et al. (2018); Edelmann (2013); Raciti et al. (2012); Pouyat et al. (2009)). In particular, residential gardens, parks and green areas, allotment gardens (such as those cultivated in the German "Kleingarten" tradition) and other areas with trees and shrubs have topsoils with carbon stocks that can considerably exceed those of comparable soils outside of settlement areas, regardless of how such soils are used (Klingenfuß et al. (2020); Cambou et al. (2018); Edmondson et al. (2012); Edelmann (2013); Pouyat et al. (2009)). The reasons for this include the fact that inner-city green areas are often enriched with additional humus-rich soil, and are often intensively cultivated (inputs, irrigation) (Edmondson et al., 2014); Pouyat et al. (2009)). At the same time, many agricultural soils are now in states of gradual degradation (Edmondson et al., 2014). Vasenev et al. (2013) found that urban soils of the greater Moscow region conformed to this pattern for inner-city soils, with regard to carbon concentrations in topsoil layers and – especially – in subsoil layers. They refer to such layers as "cultural layers," meaning layers that have been reshaped by human activities. Such carbon-stock differences between a) inner-city soils and b) neighbouring soils outside of cities were quantified in all of the aforementioned studies. Nonetheless, such data do not support derivation of generally valid relative rates of change that would make it possible to estimate the carbon stocks in unsealed settlement soils (i.e. following land-use changes), on the basis of the soil carbon stocks during the previous uses, since

- the differences between the two sets of carbon stocks cover an extremely wide range, with variation that depends on site characteristics, land use and cultivation: Edmondson et al. (2014) found, for soils of urban green areas in the city of Leicester (England), 21 – 89 % higher carbon stocks than in neighbouring agriculturally used grassland soils (86 t ha^{-1} 21 cm^{-1}; cropland: 73 t ha^{-1} 21 cm^{-1}). For the city of Paris, Cambou et al. (2018) found that the carbon-stock differences between a) urban soils and b) comparable soils throughout the region (forest land > agricultural areas) varied by 30 – 110 %, depending on how the former soils were used (parks > gardens ≥ areas with trees and shrubs).
- the various forms of use exhibit no consistent trends (Klingenfuß et al., 2020)

For these reasons, we assume, in a conservative approach, that unsealed, urban soils have carbon stocks similar to those of the soils from which they develop following a land-use change.

In addition, we assume that any land on which buildings are located has undergone deep excavation during construction and thus contains either no carbon or completely negligible quantities of carbon. During construction, and in keeping with applicable laws, the humus-rich topsoils on such land are shifted laterally on the building site or onto neighbouring parcels. Consequently, losses of soil carbon stocks via construction-related topsoil disruptions are completely offset on unsealed land. Ultimately, for each point in question, they are equivalent to the SOC stocks of mineral soils in their previous use – as documented for the point at the time of the land-use change ($SOCI_{ni\_prev}$).

Cambou et al. (2018) Edmondson et al. (2012), Wei et al. (2014), Edelmann (2013) and Raciti et al. (2012) show that considerable quantities of soil organic carbon are present under sealed areas on which no buildings are located. Nonetheless, the authors find that so-sealed areas have lower soil carbon stocks than unsealed neighbouring areas do; depending on the study, the stocks are 54 % - 74 % (with uncertainties of 15 - 83 %) lower, with an average value of -65 % (and an uncertainty of 93 %) and a median of -66 %. On the basis of these studies, and in a conservative approach, we assume, for purposes of the German inventory, that the carbon stocks under sealed areas on which no buildings are located – as a rule, such areas are transport-infrastructure areas – have carbon stocks amounting to 1/3 of the initial stocks on the relevant areas (SOC_{Ini_prev}).

Estimation of emissions from mineral soils in connection with land-use changes leading to settlements

The procedure is carried out in keeping with the assumptions and explanations set forth in the aforementioned sections of the chapter:

- From SOC_{Ini_prev}, a lump-sum quantity of 11 % of the carbon stocks is deducted. That quantity is then listed as a one-time emission in the year of the land-use change: $Emission_{LUC\_settlement} = SOC_{Ini\_prev} * -0.11$
- SOC_{Ini_prev} is also the starting value for estimating the mineral-soil carbon stocks on the area affected by the land-use change. The calculation is carried out in keeping with Equation 18, which takes account of the above-described assumptions.

Equation 18:

$$SOC_{min\_set} = SOC_{Ini\_prev} * (AF_{unsealed} * CF_{unsealed} + AF_{transport} * CF_{transport} + AF_{buildings} * CF_{buildings})$$

SOC_{min_set}: Organic mineral-soil carbon stocks of a settlement area, following a land-use change [t C ha^{-1} 30 cm^{-1}]
SOC_{Ini_prev}: Organic carbon stocks of the mineral soil during the previous use, at the time of the land-use change [t C ha^{-1} 30 cm^{-1}]
$AF_{unsealed}$: Area factor = 0.5; 50 % unsealed area
$CF_{unsealed}$: Carbon factor for the unsealed area = 1; 100 % SOC_{Ini_prev}
$AF_{transport}$: Area factor = 0.175; 17.5 % of transport-infrastructure areas are sealed
$CF_{transport}$: Carbon factor for sealed transport-infrastructure areas = 0.333; 33.3 % SOC_{Ini_prev}
$AF_{buildings}$: Area factor = 0.325; 32.5 % of built-up areas are sealed
$CF_{buildings}$: Carbon factor for sealed built-up areas = 0; 0 % SOC_{Ini_prev}

The so-determined stocks are used as a basis for all other calculations with urban soils at the relevant point. Those stocks are assigned directly to the point, in the year of the land-use change, and with no transition period. Apart from the emissions caused by the disruption via the construction, no further losses from mineral soils occur, since the excavated soil is laterally shifted and spread.

For all settlement areas whose previous use is not known (this group consists of all areas that, both prior to and after the year 1990, are listed in the remaining category), average carbon stocks, weighted by area and the previous use in each case, are assumed for mineral soils. To this end, for each transition category, the average value of the category's share of the total land-use changes leading to settlements was determined for the period 1990 – 2018. For the relevant land-use category in each case, that share was then multiplied by the typical soil organic carbon stocks for that category. The sum of the resulting values yields SOC_{Ini_prev} for mineral soils on settlement areas; it amounts to 69.6 t C ha^{-1} 30 cm^{-1}(± 3.9 %) (Table 341). The actual area-related stocks are estimated using Equation 18. The uncertainty for the area-allocation estimations is assumed to be 10 %. As a result, carbon stocks of 38.8 t C ha^{-1} 30 cm^{-1} (± 13.7 %) are obtained for settlement areas whose previous use is not known (Table 341). The so-determined stocks are used as a basis for all other calculations with urban soils at the relevant point. This value has changed by 5.5 % with respect to the previous year. As a result of a wrong assumption with regard to the area, the values for the carbon and nitrogen stocks in mineral soils, in the category Settlements remaining Settlements, had to be corrected with respect to the previous year's submission: from 36.8 t C ha^{-1} to 38.8 t C ha^{-1}, and from 3.3 t N ha^{-1} to 3.4 t N ha^{-1}.

Table 341: Mean area-related carbon [t C ha^{-1} 30 cm^{-1}] and nitrogen stocks [t N ha^{-1} 30 cm^{-1}] of mineral soils on settlement areas without ($SOC_{Ini\_prev\_1990}$ and $N_{Ini\_prev\_1990}$) and with correction for sealing ($SOC_{min\_set\_1990}$ and $N_{min\_set\_1990}$), and the pertinent uncertainties [%]

Mineral soils	Soil organic carbon stocks [t C ha^{-1} 30 cm^{-1}]	Uncertainty [%]
$SOC_{Ini\_prev\_1990}$	69.6	3.9
SOC_{min_set_1990}	38.8	13.7
Mineral soils	**Nitrogen stocks** [t N ha^{-1} 30 cm^{-1}]	**Uncertainty** [%]
$N_{Ini\_prev\_1990}$	6.2	3.7
$N_{min\_set\_1990}$	3.4	13.7

Estimation of emissions from mineral soils in connection with land-use changes from Settlements

The procedure used in the case of land-use changes from Settlement areas to other land-use categories is in keeping with the relevant general method (Chapter 6.1.2.1). The starting point for the calculation, in each case, consists of the currently recorded SOC stocks for the relevant land point. An effective transition period of no more than 20 years is assumed.

6.1.2.1.7 Terrestrial Wetlands and Other Land

The mean carbon stocks for mineral soils in Terrestrial Wetlands (no soil carbon stocks are listed for water bodies; peat-extraction areas are found only on organic soils) were derived from the Basic Digital Landscape Model (Digitales Basis-Landschaftsmodell (B-DLM; ATKIS®), the soil map (Bodenübersichtskarte) scaled to 1:1,000,000 (BÜK 1000; BGR (1995);BGR (1997)) and the results of the Agricultural Soil Inventory (BZE-LW; Jacobs et al. (2018)). In the process, those wet areas shown in the B-DLM (with a depth to water table < 10 cm) that contain no organic soils were intersected with the dominant soil associations shown in the BÜK 1000 (cf. Chapter 6.1.2.1.2). The wet-soil area sections identified, in this manner, for the various dominant soil associations were then assigned the Grassland soil carbon stocks that the Agricultural Soil Inventory (BZE-LW) determined for such areas. As a result, it was possible to derive specific carbon stocks, for wet mineral soils, for each relevant dominant soil association. Then, from the so-derived carbon stocks, area-weighted mean soil organic carbon stocks were calculated for mineral soils in Germany's Terrestrial Wetlands (Table 342).

Table 342: Mean area-related carbon stocks [t C ha^{-1}], and their uncertainties (%), in mineral soils of Terrestrial Wetlands, to a soil depth of 30 cm

Mineral soils	Carbon stocks [t C ha^{-1}]	Uncertainty [%]
Terrestrial Wetlands	109.31	8.50

No soil inventories were available for determination of the mean carbon stocks of mineral soils on Other Land. The carbon stocks values were derived from the sole complete-coverage soil map available for Germany – the BÜK 1000 (BGR 1997), from the map of Germany's soil parent material (Karte der Bodenausgangsgesteine Deutschlands (BAG 5000 BGR (2008)), and from a study of the Federal Institute for Geosciences and Natural Resources (BGR), "Organic material content in Germany's topsoils: Cross-Länder analysis of point data in the BGR's soil information system" ("Gehalte organischer Substanz in Oberböden Deutschlands: Länderübergreifende Auswertung von Punktinformationen im FISBo BGR" (Düwel et al., 2007), and from the soil parameters given in these resources (Chapter 6.1.2.1.2).

The database on which the BÜK 1000 is based lists no dominant profiles for soils on Other Land. Such profiles are listed only for Forest Land, Cropland and Grassland locations. Even for such locations, profiles are not available for all dominant soil associations, however. Therefore, the profiles for Grassland locations were used as substitute dominant profiles for soils in Other-Land locations. For dominant soil associations without dominant grassland profiles and key pedological data, the horizons seen in forest-soil profiles were assumed. This was because soils in Other Land areas are often in an initial stage, and because the A horizons in such soils' topsoils tend to be not as deeply developed as those of agriculturally managed grasslands or croplands. For a total of 42 of the 71 dominant soil profiles, this approach led to changes – mostly reductions – in carbon stocks in comparison with Grassland. In addition, the spatial distribution of Other Land in the soil landscape has a considerable impact on the mean carbon stocks of mineral soils, with the result that the so-determined values for Other Land differ considerably from those for Grassland and Forest Land. The mean carbon-stocks values are listed in Table 343.

Table 343: Mean area-based carbon stocks [t C ha^{-1}], and pertinent uncertainties (upper and lower uncertainty bounds in %]), in mineral soils of Other Land, to a soil depth of 30 cm

Mineral soils	Soil organic carbon stocks [t C ha^{-1}]	Uncertainty bounds	
		lower [%]	upper [%]
Other Land	55.60	5.08	5.08

The emission factor derived from these mean carbon stocks, which are weighted by climate region, land use and areas, is listed in Table 336 and Table 337 in Chapter 6.1.2.1. The emission factors with statistical indicators, for the description of uncertainties, are listed in Table 430 in Chapter 6.7.3.

6.1.2.1.8 Uncertainties

The uncertainties for the carbon stocks of mineral soils of forest land, and for the changes in those stocks over time, were statistically calculated from the measurements of the Forest Soil Inventory (Wellbrock et al. (2016); cf. Chapter 6.4.3.3); the uncertainties for the land-use categories Cropland$_{annual}$; Hops; Vineyards; Orchards; Tree nurseries, Christmas tree plantations and short-rotation plantations; Grassland; Woody Grassland; and Terrestrial Wetlands were calculated from the measurements of the Agricultural Soil Inventory (Jacobs et al.).

Except where a different value is explicitly listed, half of the 95% confidence interval is always used as the uncertainty.

The uncertainties for the mineral soils in the land-use category Other Land were derived from a study, carried out by the Federal Institute for Geosciences and Raw Materials (BGR) (Düwel et al., 2007), of the BÜK 1000 soil map (BGR 1997) and KA4 capillary rise data (Finnern, 1994).

The carbon-stock data from the BGR study are supported by descriptive statistics. The values for the 25th and 75th percentiles, i.e. the upper and lower threshold values for the carbon stocks, were derived from those statistics. The values for bulk density, skeleton content and carbon stocks of horizons without available values from the topsoil study of the BGR (Düwel et al., 2007) were derived via KA4 capillary rise data, using the dominant-profile descriptions in the BÜK 1000 and pertinent class information. Individual profiles (dominant profiles from the BÜK 1000) do not support conclusions relative to the heterogeneity of soil parameters within the legend units. Therefore, the potential range of carbon and nitrogen stocks in dominant soil associations (DSA) of the BÜK 1000 and associated uncertainties were estimated through the construction of extreme constellations of the respective class values:

- DSA carbon stocks$_{maximum}$: C_{org} content$_{maximum}$, bulk density$_{maximum}$, skeleton content$_{minimum}$
- DSA carbon stocks$_{minimum}$: C_{org} content$_{minimum}$, bulk density$_{minimum}$, skeleton content$_{maximum}$

The so-determined minimum and maximum soil organic carbon stocks form the relevant upper and lower bounds and, in combination with the central tendency, show the steep-left distribution that is typical for such data.

6.1.2.1.9 Planned improvements

For this submission, regionalisation of mineral-soil carbon stocks data, as a function of site-specific parameters, had been planned. For technical reasons, it has not yet been possible to carry out this effort. Plans now call for the regionalisation to be carried out in the near future, however. With that move, Germany will implement a pertinent ERT recommendation from the 2020 review process (ARR 2020: L.8, Table 5).

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

6.1.2.2 Emissions from organic soils (3.D; 4.A through 4.F; CRF Table 4(II))

CO_2, N_2O and CH_4 emissions from organic soils are reported in the land-use categories Forest Land, Cropland, Grassland (in the strict sense), Woody Grassland, Terrestrial Wetlands (industrial peat extraction) and Settlements (N_2O from drained organic soils is reported under Cropland and Grassland in CRF Sector 3.D.a.6). Reporting also covers methane emissions from drainage ditches, as well as carbon losses in connection with dissolved organic carbon (DOC). In Germany, the majority of organic soil areas is drained.

Emissions are calculated by multiplying the peatland areas per sub-category by pertinent use-specific emission factors. For land-use changes, the emission factor for the final category is used right away:

$$E_{orgsoil} = \sum_{i=1}^{n} (A_i * EF_i)$$

$E_{orgsoil}$: CO_2, N_2O and CH_4 emissions from organic soils of a land-use category [kt C]

A_i: Peatland area subject to a certain land use [kha]

EF_i: Land-use-specific emission factor [t C ha^{-1} a^{-1}]

i: transition categories or remaining categories

n: Number of conversion and remaining categories

The present inventory is based on highly detailed maps showing the locations and drainage of organic soils in Germany (Chapter 6.1.2.2.1). In addition, this submission makes use of extensive measurement data on GHG emissions from organic soils in Germany that have been obtained, using standardised measurement protocols, in the "Organic Soils" ("Organische Böden") project, a collaborative research project of the Johann Heinrich von Thünen Institute[93] (Federal Research Institute for Rural Areas, Forestry and Fisheries), as well as in predecessor projects (a small quantity of the data was obtained from the relevant national literature).

With respect to the previous year's submission, the procedure for calculating emissions from organic soils has again been modified and improved. For every one of the 1,822,109 detection points on organic soils, the calculations are now carried out as a function of the depth to the water table. The depth-to-water-table data are taken from a digital, dynamic groundwater map that is updated annually (cf. Chapter 6.1.2.2.2). The pertinent CO_2 and CH_4 emissions are calculated with response functions, as a function of the depth to the water table. They are calculated individually for each survey point (cf. Chapter 6.1.2.2.2). The response functions are used for all land-use categories, except for Forest Land and Woody Grassland. The database for the activity data and emission factors, and the relevant derivations, meet the criteria for an IPCC Tier 3 method. To ensure transparency and consistency with other activity data, with N_2O emissions estimates and with other pools (DOC, drainage ditches), however, a national Tier 2 method was developed for the inventory from those inputs (Tiemeyer et al., 2020b).

Implementation of these systems fulfills an EU-Commission recommendation calling for development of systems, with regard to emissions from organic soils in Germany, with which changes in soil carbon stocks, resulting from management measures to reduce emissions or to promote carbon sequestration, in the remaining categories 4.B and 4.C – for cropland management (CM) and grazing land management (GM) – can in future be recorded and reported

[93] www.organische-boeden.de

("Member State recommendations on reporting systems for cropland & grazing land management emissions & removals" (Ecofys & Environment Agency Austria, 2017), pursuant to EU Regulation (EU) 2018/841. In addition, the system is to support binding reporting, as the EU Regulation requires for the period as of 2026, on emissions from "managed wetlands".

6.1.2.2.1 Activity data

On behalf of the Thünen Institute, until 2013 an "Organic Soils Map" ("Karte organischer Böden") (Parametrized area data on the organic soils in Germany) was developed that is fully in line with the IPCC definition of organic soils (Roßkopf et al., 2015):

- Spatial resolution / scale: heterogenous, for process-related reasons, ~1:10,000 – 1:200,000; grid width 25 m.
- Temporal resolution: Regionally varying, depending on the database involved (from the beginning of the 20th century to the present).
- Data records: In close cooperation with government agencies of the German Länder, the existing soil data, peatland cadastres and data sets available from geological, silvicultural and agricultural maps were harmonised, and then incorporated in the inventory process, as completely as possible and at the highest level of resolution possible.
- Data selection (minimal criterion): In keeping with the "Bodenkundliche Kartieranleitung" (soil mapping instructions; KA 5, Sponagel (2005), 2005)) and the IPCC (2006b) Guidelines for reporting on organic soils, the organic soil classes were identified that primarily describe soils with a 9 % minimum content of organic carbon (15 % organic soil matter) in a mixed sample of the upper 20 cm.

The new organic-soils area encompasses a total of 1.824 million ha. The new organic soils map supplants the previously used soil map of Germany (BÜK 1000), which was drawn to a coarse scale of 1:1,000,000 (BGR 1995), and which did not include any shallow peat soils or peats mixed with mineral soils (old total area: 1.725 million ha). Because the area allocations in the new organic soils map are much more precise than those in the old map, the area fractions for the various land-use categories have changed with respect to the NIR submissions prior to 2015. Grassland in the strict sense is now far and away the predominant use. Thanks to considerable densification of the point grid, effective as of the 2020 submission (cf. Chapter 6.3), small-scale structures can now be recorded, and a highly precise time series of land use and land-use changes on organic soils can be reported.

Table 344 shows the areas of organic soils, broken down by land-use categories. The regional distribution of the water levels in organic soils, which serves as a basis for emissions calculation, is derived pursuant to (Bechtold et al., 2014), and it is based, in part, on the organic soils map (Roßkopf et al., 2015) and on many years of measurements of water levels in organic soils.

The area for organic soils under agricultural use, as reported in the agricultural sector (CRF Table 3.D.a.6), does not differ from that area as reported in the LULUCF sector. The cropland-soil areas under cultivation are the same in both sectors subject to reporting obligations. In the LULUCF sector, the areas of the sub-categories "Grassland (in the strict sense)" and "Woody Grassland" are subsumed under Grassland. Woody Grassland areas are not agricultural land in the strict sense. For this reason, they are not listed in 3.D.a.6. All the same, in the interest of obtaining a consistent description of the entire German area, they have to be included in the LULUCF sector.

To determine CH_4 emissions from drainage ditches, the ditches' areas and the land uses on the areas bordering them must be determined. To that end, buffer zones were formed around those linear elements of the ATKIS Basic Digital Landscape Model (Basis-DLM) that represent drainage ditches, as indicated by the relevant legend information. This made it possible, with the help of the map of organic soils (Roßkopf et al., 2015) and the ATKIS Basis-DLM, to determine the entire area of all ditches for drainage of organic soils, for all land-use categories (Table 344).

Table 344: Areas of organic soils and drainage ditches, by land-use categories, for the year 2020

	Area of organic soils [ha]	Area of drainage ditches [ha]
Forest Land	278,000	3,164
Cropland	331,168	3,152
Grassland (in the strict sense)	951,783	14,887
Woody Grassland	21,941	437
Terrestrial Wetlands	108,626	713
Waters	22,432	76
Peat extraction	17,720	66
Settlements	90,408	1,257
Other Land	31	0
∑	**1,822,109**	**23,755**

6.1.2.2.2 Emissions calculation

The emission factors have been developed in keeping with the 2013 IPCC Wetlands Supplement (IPCC et al., 2014b). CO_2 from the soil (CO_2-C on-site) and CH_4 from the soil (CH_{4_land}) were calculated for all land-use categories, except Forest Land, using empirical models (Tier 3). For forest soils, the necessary emission factors were taken from the 2013 IPCC Wetlands Supplement (IPCC et al., 2014b). For N_2O, emission factors were developed from national annual measurements (Tier 2). For CO_2 from dissolved organic carbon (CO_2-C_{DOC}) and CH_4 from drainage ditches (CH_{4_Ditch}), the default from the 2013 IPCC Wetlands Supplement (IPCC et al., 2014b) were used.

CO_2 from soils (CO_2-$C_{on\text{-}site}$):

The database consists of representatively surveyed, quality-checked, national annual measurements (261 measurement years, 118 sites, 17 different peatland areas). From these data, Tiemeyer et al. (2020b) derived an empirical (non-linear) response function for emissions as a function of the groundwater level. That function was then used in order to calculate the emissions for every point on organic soils, for the years 2000, 2005, 2010, 2015 and 2020. Linear interpolation was carried out for the periods between those years; for the period prior to 2000, the emissions of the year 2000 were adopted, since the input data for those years are not available. The required water-level data were calculated, using the machine-learning model in (Bechtold et al., 2014), separately for the relevant years. Since the model predicts transformed water levels, the "law of the unconscious statistician" was used in order to calculate expected values for water levels and emissions on a pointwise basis. The model uncertainties were determined via bootstrapping.

The response function from Tiemeyer et al. (2020b) is based on only a few, uncertain measurements from forest land areas. For this reason, the standard emission factor given in the 2013 IPCC Wetlands Supplement (IPCC et al., 2014b) was used for points under Forest Land. The same factor was also used for the sub-category Woody Grassland.

CH_4 from soil (CH_{4_land}):

The database consists of representatively surveyed, quality-checked, national annual measurements (296 measurement years, 137 sites, 17 different peatland areas). The emissions were calculated via a procedure similar to that used for CO_2, on the basis of Tiemeyer et al. (2020b) and Bechtold et al. (2014). Since the response function for Forest Land is based on a very small number of data points, and is predominantly influenced by just two measurements, the standard emission factor given by the 2013 IPCC Wetlands Supplement (IPCC et al., 2014b) was used for points under Forest Land and for the category Woody Grassland.

N_2O:

The database consists of representatively surveyed, quality-checked, national measurements that cover at least one year (320 sites, 21 different peatland areas). Since it was not possible to identify any functional relationships, the average measurement values for the various land-use categories were used as the emission factors (Tiemeyer et al., 2020b).

6.1.2.2.3 Implied emission factors (IEF)

In the framework of inventory preparation, the emissions from organic soils are calculated with implied emission factors – including specific factors for each GHG and for each land-use category. The emission factors given by the 2013 IPCC Wetlands Supplement (IPCC et al., 2014b) are valid for specific conditions of organic soils. In determination of emissions from a given land-use category, non-drained, wet areas also have to be taken into account, along with the carbon discharge with the soil water, in the form of dissolved organic carbon (DOC), and the methane emissions from ditches draining organic soils. This procedure yields the implied emission factors (IEF) given in Table 345 for CO_2, CH_4 and N_2O emissions from Germany's organic soils, for the year 2020.

Table 345: Implied emission factors (IEF) and their uncertainties (95% percentile) for CO_2-onsite + DOC, CH_{4_land} + CH_{4_ditch} and N_2O-onsite from Germany's organic soils (4.A - 4.E; 4(II)), for the year 2020

Land use	EF	CO_2-onsite + DOC 95% percentile	IEF	CH_{4_land} + CH_{4_ditch} 95% percentile	IEF	N_2O-onsite 95% percentile
		t CO_2-C ha^{-1} a^{-1}		kg CH_4 ha^{-1} a^{-1}		kg N_2O-N ha^{-1} a^{-1} CH_4
Forest Land	2.65	(2.1 - 3.3)	4.91	(1.26 - 10.32)	4.33	(-0.88 - 9.43)
$Cropland_{annual}$	9.43	(5.35 - 11.28)	12.94	(5.55 - 24.75)	17.31	(2.81 - 63.17)
Hops	8.74	(4.96 - 10.46)	24.73	(10.61 - 47.31)	17.17	(2.78 - 62.64)
Vineyards	8.56	(4.86 - 10.24)	8.53	(3.66 - 16.31)	17.44	(2.83 - 63.64)
Orchards	8.86	(5.03 - 10.6)	20.08	(8.62 - 38.42)	17.25	(2.8 - 62.93)
Tree nurseries	9.49	(5.39 - 11.35)	12.59	(5.4 - 24.09)	17.32	(2.81 - 63.18)
Christmas tree plantations	9.42	(5.35 - 11.27)	9.06	(3.89 - 17.34)	17.38	(2.82 - 63.41)
Short-rotation plantations	0.00	(0 - 0)	0.00	(0 - 0)	0.00	(0 - 0)
Grassland (in the strict sense)	7.54	(0.82 - 10.67)	39.63	(15.9 - 214.83)	7.05	(0.46 - 34)
Woody Grassland	2.64	(2.09 - 3.28)	6.25	(1.95 - 12.88)	4.29	(-0.87 - 9.35)
Terrestrial Wetlands	5.22	(0.29 - 10.65)	164.60	(3.49 - 373.84)	1.09	(-0.19 - 4.52)
Peat extraction	1.38	(1.25 - 1.54)	5.69	(1.22 - 12.11)	1.41	(0.52 - 2.3)
Settlements	7.28	(3.44 - 9.19)	26.98	(11.23 - 51.83)	6.04	(0.39 - 29.15)

6.1.2.3 Carbon emissions from biomass (4.A through 4.F)

6.1.2.3.1 General information

In the framework of the German GHG inventory, emissions from the above-ground and below-ground biomass pools are listed for

- the remaining categories Forest Land, Hops, Vineyards, Orchards, Tree nurseries, Christmas tree plantations, Short-rotation plantations, Woody Grassland, Terrestrial Wetlands, Settlements
- all transition categories

For the remaining catetories $Cropland_{annual}$ and Grassland (in the strict sense), and for unchanging crop types (annual or perennial), no carbon-stocks changes are listed, since, pursuant to the IPCC Guidelines (2006 IPCC Guidelines, IPCC (2006b)), in these sub-categories an equilibrium condition is assumed for the carbon fluxes of the annual biomass pools. With the gain-loss method, therefore, ΔC = 0 (Equation 2.7 in the 2006 IPCC Guidelines, IPCC (2006b)). "NA" is entered in the pertinent spaces in the CRF tables. For the remaining categories Waters and Other Land, no emissions from plant biomass occur, since such sites are free of vegetation.

At present, the existing system for assessing land-use changes does not allow for a spatially explicit and complete verification of changes in annual crops, broken down by crop type. As a result, a mean carbon-stocks value, weighted by crop type and area under cultivation – a mixed value for the biomass of all annual crops – has to be derived from official statistics (Statistisches Bundesamt, FS 3, R 3.2.1) (cf. Chapter 6.1.2.3.3). The official statistics are the only consistent (with regard to both content and chronological coverage) data source that supports nearly complete-coverage (subject to the limitations of official statistics, such as exclusion limits) derivation, weighted by yields and areas, of representative carbon stocks for herbaceous plants from agricultural production in Germany. In the case of land-use changes to and from annual Cropland, such carbon stocks serve as the basis for calculations of emissions from biomass.

In the present submission, and for the first time, emissions from biomass are being listed in the year in which they occur. To this end, a new method has been introduced that, in particular, takes account of the specific composition and development of the plant biomass in the various individual land-use categories. With this approach, the plant-biomass carbon stocks (divided into various compartments), and their changes during their life and cultivation cycles, are continuously modelled and recorded (cf. Chapter 6.1.3.2).

This approach implements relevant recommendations/requirements from the UNFCCC reviews (ARR 2021: KL.12, KL.13, KL.17, L.12, L.14, L.15, Table 5; ARR 2020: KL.5, Kl.6, Table 3; ARR 2018: KL.10, KL.11). In its "Member State recommendations on reporting systems for cropland & grazing land management emissions & removals" (Ecofys & Environment Agency Austria, 2017), the EU Commission recommended that a system be implemented for georeferenced inventorying of perennial Woody Grassland areas within the Cropland category, as well as of their area changes, and that the system be capable of recording the emissions in real time. This recommendation has been adopted and implemented.

6.1.2.3.2 General calculation methods

The carbon-stock changes resulting from land-use changes are determined, and reported, for both annual and perennial biomass. The biomass-stocks changes are calculated in keeping with the gain-loss method (2006 IPCC Guidelines). In the process, removals and emissions of CO_2 are determined via the relevant carbon-stock changes, and separately for above-ground and below-ground biomass, on the basis of national data.

The carbon-stock changes in biomass are estimated by subtracting the complete biomass carbon stocks directly prior to the land-use conversion from the stocks that grow in the first year following the conversion, with reference to the area affected by the change (in keeping with Equation 2.16, 2006 IPCC Guidelines, IPCC (2006b)):

$$\Delta C_{Bio} = \sum_{i=1}^{n} \left(A_i * EF_{final} - A_i * EF_{initial} \right)$$

ΔC_{Bio}:	Change in the biomass carbon stock for a given land-use category, in the year of the use change [t]
A_i:	Area on which the land-use change has occurred [ha]
EF_{final}:	Plant-specific biomass carbon stock in the first year following the use change [t ha^{-1}]
$EF_{initial}$:	Plant-specific biomass carbon stock prior to the land-use change [t ha^{-1}]
n:	Number of transition categories
i:	transition categories

6.1.2.3.3 Annual crops and Grassland: Calculation methods and emission factors

For $Cropland_{annual}$ and Grassland, the calculation method set forth in Chapter 6.1.2.3.2 means the following:

- following land-use changes from/to these categories, the entire biomass carbon stocks are credited in the year of the land-use change; also, in the case of land-use changes to these categories, an equilibrium condition is assumed as of the second year
- in the remaining categories, an equilibrium is assumed for the plant biomass of the relevant crops; consequently, no emissions are reported (and "NA" in entered into the pertinent spaces in the CRF tables)

The carbon stocks for the above-ground and below-ground biomass of plants of annual Cropland and horticultural crops, and of Grassland (in the strict sense), are derived annually on the basis of harvest surveys of the Federal Statistical Office; in the process, the same data sources and algorithms are used as are used for calculation of crop residues in CRF sector 3.D. The official statistics are the only Germany-wide, consistent (in terms of both content and chronology) data source that supports derivation, on a complete-coverage basis, of representative emission factors for herbaceous plants from agricultural production in Germany (cf. Chapter 6.1.2.3.1).

The mean carbon stocks of cropland and horticultural crops are determined on the basis of harvest data and area under cultivation for a total of 65 field crops. These include:

- Winter wheat, spring wheat, rye, triticale, maslin, winter barley, spring barley, oats, mixed grains other than maslin, grain maize;
- Field peas, broad beans;
- Potatoes, sugar beets, fodder beets;
- Winter oilseed rape;
- Clover, alfalfa, grass, silage maize;
- Cauliflower, broccoli, Chinese cabbage, kale, kohlrabi, Brussels sprouts, red cabbage, white cabbage, savoy, oak-leaf lettuce, iceberg lettuce, endive, lamb's lettuce, head lettuce, lollo lettuce, radicchio, romaine lettuce, arrugula, other lettuce types, spinach, rhubarb, asparagus, celery, fennel, celeriac, horseradish, carrots, radishes, (larger) radishes, red beets, pickling cucumbers, slicing cucumbers, edible pumpkins, zucchini, sweet corn, bush beans, broad beans, runner beans, split peas, peas, bunching onions, onions, parsley, leeks and chives.

For Grassland (in the strict sense), the data consists of harvest and cultivation-area data for all statistically recorded

- meadows
- mowed pastures
- pastures
- mountain pastures and rough pastures

The dry biomass of individual plant parts is derived from harvest data, pursuant to Rösemann et al. (2015), using relevant ratios and water-content data from various sources. The data and methods used are consistent with those used to calculate nitrogen in crop residues (CRF 3.D.a.4).

For calculation of biomass carbon stocks, an average carbon content of 45 % by weight was assumed – and used instead of the IPCC default value (50 % by weight) – since Osowski et al. (2004) list carbon contents of 44 to 48 % by weight for plants in central Europe and since Pöpken (2011), in her studies of cultivated trees (carried out for the German inventory), also found average values of 45 to 46 % by weight.

With the help of all these data, mean carbon stocks are calculated with respect to area. For each specific crop, this is done by multiplying the relevant areas under cultivation ([ha]) by the pertinent yields ([t biomass ha-1]). The resulting products (on a by-crop basis; absolute harvested quantities of individual herbaceous plants or parts thereof [t]) are converted to dry matter and carbon content, summed and then divided by the relevant area sum [ha]. This approach yields area-weighted, yield-weighted averages, for herbaceous plants from agricultural production [t C ha-1], that are representative for Germany. These area-based mean carbon stocks [t C ha-1] in the above-ground and below-ground biomass of field crops and grasses are used as emission factors. This approach is in keeping with the methods set forth in the 2006 IPCC Guidelines.

The results for annual crops of Cropland and horticultural areas are shown in Table 346, while those for Grassland (in the strict sense) are shown in Table 347.

As Table 346 shows, the values for biomass of annual Cropland and horticultural crops show a positive, significant trend over time. For this reason, the calculations of carbon-stock changes due to land-use changes are always based on the current pertinent value for the year in question.

Table 346: Area-based carbon stocks [t C ha-1 ± half of the 95 % confidence interval] of the biomass of annual crops on Cropland and horticultural land

Year	Cropland$_{annual}$ Carbon stocks [t C ha^{-1}]		
	Biomass$_{total}$	Biomass$_{above-ground}$	Biomass$_{below-ground}$
1990	5.17 ± 0.61	3.72 ± 0.51	1.45 ± 0.33
1995	5.54 ± 0.65	4.12 ± 0.57	1.42 ± 0.32
2000	5.89 ± 0.69	4.40 ± 0.60	1.49 ± 0.33
2005	6.08 ± 0.71	4.58 ± 0.63	1.50 ± 0.34
2010	5.96 ± 0.70	4.51 ± 0.62	1.45 ± 0.32
2011	6.09 ± 0.71	4.55 ± 0.62	1.54 ± 0.35
2012	6.43 ± 0.75	4.84 ± 0.66	1.59 ± 0.36
2013	6.32 ± 0.74	4.81 ± 0.66	1.51 ± 0.34
2014	7.21 ± 0.84	5.45 ± 0.75	1.76 ± 0.40
2015	6.48 ± 0.76	4.95 ± 0.68	1.53 ± 0.34
2016	6.36 ± 0.75	4.81 ± 0.66	1.55 ± 0.35
2017	6.64 ± 0.78	4.96 ± 0.68	1.68 ± 0.38
2018	5.50 ± 0.64	4.12 ± 0.56	1.39 ± 0.31
2019	6.12 ± 0.72	4.58 ± 0.63	1.54 ± 0.34
2020	6.41 ± 0.75	4.80 ± 0.66	1.61 ± 0.36

For Grassland (in the strict sense), the carbon stocks of plant biomass show no significant trend in the time series, and the annual changes are considerably smaller than the uncertainties. For this reason, mean carbon stocks for the biomass of Grassland (in the strict sense) are estimated and, in a consistent manner, used as a basis for the calculations for all the years concerned (cf. Table 347). The mean carbon stocks over time were determined via bootstrapping. Bootstrapping is a resampling procedure in which statistical indexes are calculated on the basis of samples (in the present case, the mean carbon stocks of the above-ground and below-ground biomass of herbaceous grassland plants for the years 1990 – 2015). This procedure is especially useful in cases in which the theoretical distribution of the statistics is not known, and one parameter (in the present case, the mean) of the population (i.e. not the sample) and its average divergence from the true parameter, have to be estimated. The so-calculated values for herbaceous plants of Grassland (in the strict sense) are shown in Table 347. They serve as a basis for all relevant calculations in the inventory. The standard error of the calculated means for the population is 2.3 % (half of the 95 % confidence interval).

Table 347: Area-related carbon stocks [t C ha-1] of Grassland (in the strict sense) (± half of the 95 % confidence interval)

Grassland (in the strict sense)	Carbon stocks [t C ha^{-1}]		
	$Biomass_{total}$	$Biomass_{above}$	$Biomass_{below}$
Grassland (in the strict sense)	6.81 ± 2.06	3.78 ± 1.37	3.03 ± 1.54

6.1.2.3.4 Perennial crops: Calculation methods and emission factors

For perennial plant biomass outside of Forest Land, and for the first time in reports such as the present one, anthropogenic CO_2 emissions resulting from carbon-stock changes are now being listed at the time at which they occur. To make this possible, the complete growth cycles of the various Woody Grassland plants and understory vegetation have to be determined and then modelled over time, as a function of rotation cycles and operational duration. The carbon stocks of plant biomass consist of various different compartments, depending on the land use and crop involved. The relevant land-use categories and perennial crops, the assumed composition of the plant biomass and the biomass's rotation cycles are shown in Table 348.

Table 348: Woody Grassland land-use categories with perennial woody crops outside of forest land, and their compartments and rotation cycles [a]

Land-use category	Abbreviation	Compartments (weighting factor)	Rotation cycle [a]	Rotation cycle+
Orchards	croo	Fruit trees (1), grassland (0.75)	20	Next cycle
Vineyards	crow	Vines (1), grassland (0.75)	30	Next cycle
Tree nurseries	crot	Forest trees (0.33), ornamental trees and shrubs (0.33), grassland (0.33)	10	Equilibrium
Christmas tree plantations	crox	Coniferous trees (1), grassland (0.75)	10	Next cycle
Short-rotation plantations	cros	Deciduous trees (1)	10	Next cycle
Hedges / field shrubs	gra2	Hedge shrubs / deciduous trees (1)	12	Next cycle
Terrestrial Wetlands	wet1	Hedge shrubs / deciduous trees (0.33); grassland (0.66)	12	Equilibrium
Settlements	set1	Hedge shrubs / deciduous trees (0.25); grassland (0.25)	12	Equilibrium

During rotation periods, the compartments are treated in different ways. A site's current biomass carbon stocks in a specific year are obtained as the sum of the current stocks of the compartments involved. The calculation method is also based on the following additional assumptions:

- The biomass stocks of perennial crops outside of forest land are determined at every sample point; this is required for annual determination of the change in the absolute stocks.
- The biomass stocks of the various different perennial crops depend on the crops' rotation cycles. The system-relevant maximum stocks are attained in the last year of the cycle.
- At the end of a rotation period, a new growth cycle begins, regardless of whether the crop is in a transition category or a remaining category.
- Regardless of the rotation cycles involved, the transition period lasts no longer than 20 years (the "effective transition time" concept (Kapitel 6.1.2)); at the end of the transition period, the crop is transferred into the remaining category that corresponds to the relevant transition category, and it remains within its current rotation cycle. Only the allocation of the current stocks and emissions changes.
- In the case of land-use changes from one land-use category with perennial crops to any other land-use category, the current carbon stocks of all compartments are recorded, completely, as emissions in the year of the land-use change.

- Each point that showed perennial crops for the year 1990 was assigned some stage within the relevant crop-specific rotation period, with the help of a random generator.
- Also with the help of a random generator, each point that previously fell within the collective category "Other perennial crops" has been assigned to one of the new categories Tree nurseries, Christmas tree plantations, and Short-rotation plantations, as a function of the relevant percentage share arising from the official statistical data for the pertinent survey times. Data on short-rotation plantations have been explicitly collected only since 2010.

The annual emissions calculation is carried out pursuant to Equation 2.7 IPCC 2006, Vol. 4:

Equation 19

$$Emission\left[t\,CO_2\,ha^{-1}a^{-1}\right] = \left(C_{curr\,year} - C_{prev\,year}\right) * {}^{-44}/_{12}$$

$C_{curr\,year}$: Carbon stocks in the current year [t C ha^{-1} a^{-1}]

$C_{prev\,year}$: Carbon stocks of the previous year [t C ha^{-1} a^{-1}]

The carbon stocks are determined specifically, for the various crops, as follows:

Equation 20

$$C_{cultspec} = C_{cultspec\_abo} + C_{cultspec\_bel}$$

$C_{cultspec}$: Crop-specific biomass carbon stocks [t C ha^{-1} a^{-1}]

$C_{cultspec\_abo}$: Above-ground crop-specific biomass carbon stocks [t C ha^{-1} a^{-1}]

$C_{cultspec\_bel}$: Below-ground crop-specific biomass carbon stocks [t C ha^{-1} a^{-1}]

The carbon stocks in above-ground and below-ground plant biomass are calculated as follows: the carbon stocks of the pertinent subcompartments (which are required for this purpose) are multiplied by a specific weighting factor that depends, in each case, on the reference value (such as area, above-ground biomass) being used for the relevant subcompartment. The terms for pruning and for herbaceous plants (gra1) are optional, depending on the crop involved:

Equation 21

$$C_{abo} = C_{stem,branch} * GF + C_{cut} * GF + C_{gra1_{abo}} * GF$$

C_{abo}: Above-ground biomass carbon stocks [t C ha^{-1} a^{-1}]

$C_{stem,branch}$: Above-ground carbon stocks of woody plants (stem, branches) [t C ha^{-1} a^{-1}]

GF: Crop-specific weighting $factor_{reference\ value}$

C_{cut}: Carbon stocks of pruned material [t C ha^{-1} a^{-1}]

$C_{gra1\ abo}$: Above-ground carbon stocks of herbaceous biomass [t C ha^{-1} a^{-1}]

Equation 22

$$C_{bel} = C_{roots} * GF + C_{gra1_{bel}} * GF$$

C_{bel}: Below-ground biomass carbon stocks [t C ha^{-1} a^{-1}]

C_{roots}: Below-ground carbon stocks of woody plants (roots) [t C ha^{-1} a^{-1}]

$C_{gra1\ bel}$: Below-ground carbon stocks of herbaceous biomass [t C ha^{-1} a^{-1}]

GF: Crop-specific weighting $factor_{reference\ value}$

6.1.2.3.5 Derivation of emission factors for perennial woody crops

In the framework of the research project "Development of methods for determining the biomass of perennial woody plants, outside of forests" ("Methodenentwicklung zur Erfassung der

Biomasse mehrjährig verholzter Pflanzen außerhalb von Waldflächen"), country-specific carbon-stock data were collected for above-ground and below-ground biomass of orchards, vineyards and Christmas-tree plantations in Germany. The mean carbon stocks of the plants in tree nurseries were then estimated on the basis of these data and of results of the National Forest Inventory. The mean tree-biomass values for short-rotation plantations and hops plantations were derived country-specifically, from literature and research-project data.

6.1.2.3.5.1 Fruit trees

In the framework of the aforementioned research project, with trees taken from Germany's two main fruit-growing regions (Altes Land ("Old country"): northern Germany, and Lake Constance region: southern Germany), a total of 100 fruit trees (91 apple trees, 6 cherry trees and 3 plum trees), of differing ages and types, were destructively tested. In addition, the following data were collected from 210 living apple trees:

- Diameter at stem base
- Diameter at breast height
- Height

Only commercial fruit cultivation was considered in this context. With the entirety of the data collected in the research project, and the results of official statistics (fruit-tree-cultivation surveys[94] Statistisches Bundesamt (FS 3, R 3.1.4)), it proved possible to determine the total carbon stocks in the above-ground and below-ground biomass of the various fruit trees and shrubs, for various age classes and for all years of the fruit-cultivation surveys (Statistisches Bundesamt, FS 3, R 3.1.4) (2002, 2007, 2012, 2017). In the process, the values derived for apple trees were also assigned to pear trees, while those derived for cherry and plum trees were also assigned to prune, mirabelle and greengage trees.

For purposes of the inventory, orchards are georeferenced only generally; they cannot be differentiated by fruit-tree types. For this reason, a longtime area-weighted figure for the average carbon stocks in the above-ground phytomass of fruit trees and shrubs was derived from the data. This was done by dividing the sum of the total carbon stocks of each partition within an age class by the relevant area under cultivation. This procedure did not lend itself to the below-ground plant biomass, since the original data obtained in the research project varied widely, for sampling-related reasons, and no significant dependence on the above-ground biomass could be derived. For this reason, the below-ground plant biomass was derived from the above-ground biomass using the pertinent equation of MOKANY et al. (2006)[95].

From the so-derived values, it was then possible to derive, via regression, a sigmoid function for the above-ground biomass that describes, in a highly significant manner, the ratio of carbon stocks in fruit trees to the trees' age:

[94] The fruit-tree-cultivation surveys involved are representative statistical surveys of Germany's commercial fruit-cultivation sector. They are carried out every 5 years. For the present submission, the results of the fruit-cultivation surveys of 2002, 2007, 2012 and 2017 were used. In the surveys, the Federal Statistical Office determines the sector's total numbers of apple, pear, sweet-cherry, sour-cherry, plum, prune, mirabelle and greengage trees, in different age classes, as well as the areas under cultivation with trees in the various age classes. The fruit-tree-cultivation surveys are exhaustive surveys.

[95] $Phytomass_{below\text{-}ground} = 0.489 * (Phytomass_{above\text{-}ground}\ Trees)^{0.890}$ – In their survey project, MOKANY et al. (2006) derived, for numerous types of vegetation, root / shoot ratios as a function of biomass, climatic parameters and local site parameters. Their results were then adopted as default values in the 2006 IPCC Guidelines (IPCC 2006).

Equation 23

$$C_{croo_{stem,branch}} = -1.9798 + \frac{16.9435}{(1 + e^{-\frac{a-13.0365}{6.1938}})}$$

$C_{croo\ stem,branch}$: Carbon stocks in stems and branches of fruit trees [t C ha^{-1}]

a: Number of years following initial planting (1, 2, 3 - 20) after stock renewal

All of the inventory calculations relative to fruit trees on based on this formula (Mokany et al.), and on the values for below-ground biomass derived with it.

Other assumptions include:

- The annual quantity pruned amounts to 20 % of above-ground biomass (PÖPKEN 2011)
- 75 % of orchards' areas have a herbaceous-plant / grass cover.
- The rotation period for orchards is assumed to be 20 years (figures range between 12 – 25 years; calculated from the tree-biomass distributions in the various age classes as given by the Federal Statistical Office: 18.3 years); after this time, a complete stock renewal is carried out (not with grass)

The above-ground plant biomass stocks for orchards are calculated via

Equation 24

$$C_{croo_{abo}} = C_{croo_{stem,branch}} + C_{croo_{cut}} + C_{gra1_{abo}} * 0.75$$

$C_{croo\ stem,branch}$: Carbon stocks in stems and branches of fruit trees [t C ha^{-1}]

$C_{croo\ cut}$: Carbon stocks of annually pruned material [t C ha^{-1}]

$C_{gra1\ abo}$: Carbon stocks in the above-ground biomass of Grassland (in the strict sense) [3.78 t C ha^{-1}]

The below-ground plant biomass stocks for orchards are calculated via:

Equation 25

$$C_{croo_{roots}} = 0.489 * C_{croo_{abo}}{}^{0.89}$$

$C_{croo\ roots}$: Carbon stocks of below-ground biomass of fruit trees [t C ha^{-1}]

$C_{croo\ abo}$: Carbon stocks of above-ground biomass of fruit trees [t C ha^{-1}]

Equation 26

$$C_{croo_{bel}} = C_{croo_{roots}} + C_{gra1_{bel}} * 0.75$$

$C_{croo\ bel}$: Carbon stocks of below-ground biomass of fruit trees [t C ha^{-1}]

$C_{croo\ roots}$: Carbon stocks of root biomass of fruit trees [t C ha^{-1}]

$C_{gra1\ bel}$: Carbon stocks in the below-ground biomass of Grassland (in the strict sense) [3.03 t C ha^{-1}]

The total carbon stocks in the plant biomass of orchards, and the resulting emissions to be taken into account, are calculated using the methods described in Chapter 6.1.2.3.2 and Chapter 6.1.2.3.3. The development of orchards' carbon stocks, over the course of multiple rotation cycles, and the pertinent emissions, are shown in Figure 53.

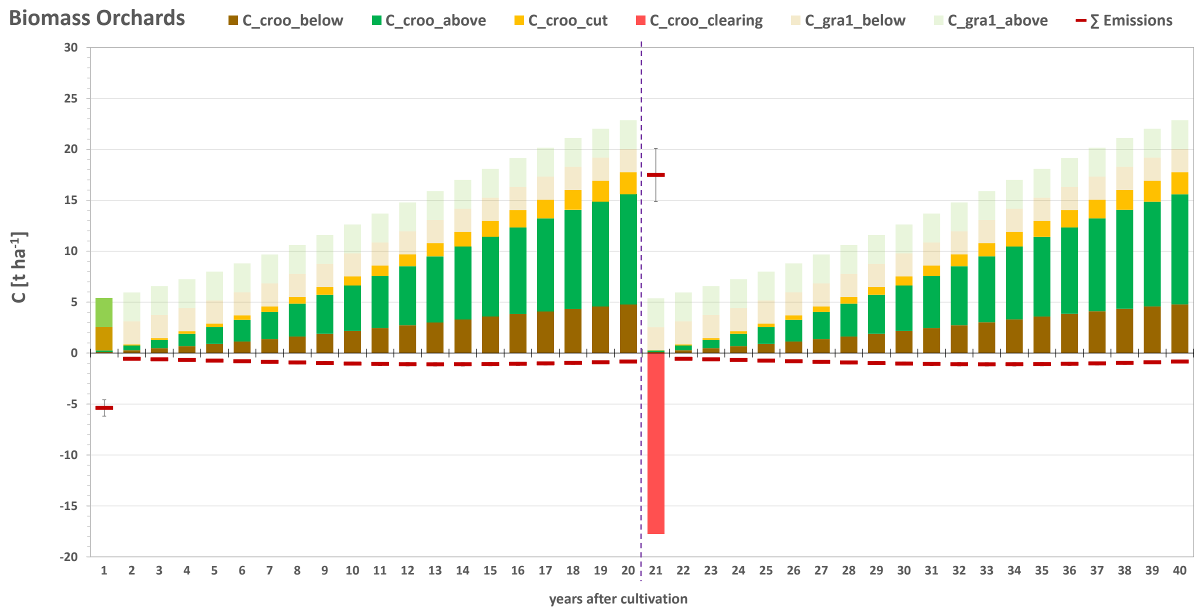


Figure 53: Development of carbon stocks [t C ha^{-1}] in compartments of plant biomass of orchards, and the resulting emissions [t C ha^{-1}], in successive rotation cycles (|). Transparent bars are emissions-relevant only in the case of land-use changes

6.1.2.3.5.2 Vineyards

In the project "Development of methods for determining the biomass of perennial woody plants, outside of forests" ("Methodenentwicklung zur Erfassung der Biomasse mehrjährig verholzter Pflanzen außerhalb von Waldflächen") (Pöpken, 2011), a total of 74 grapevines were destructively sampled for the purpose of determining a country-specific value for carbon stocks of grapevines. The ages of the vines were 15 and 25 years. In the analysis, the vines' weights, and the water and carbon content of the above-ground and below-ground plant parts, were determined (Pöpken, 2011). From these data it proved possible, using nonlinear regression, to determine a highly significant relationship between the ages and carbon stocks of the above-ground and below-ground biomass of grapevines. Since vineyards in Germany contain an average of 4,000 grapevines per ha (Pöpken, 2011), the carbon stocks per area unit (ha) were calculated by multiplying the carbon stocks of individual plant compartments / total plants by 4,000. The above-ground and below-ground plant biomass is calculated using the following equations:

Equation 27: Calculation of above-ground biomass of grapevines

$$C_{crow_{vine}} = (-0.004 * a^2 + 0.0234 * a) * \frac{4000}{1000}$$

$C_{crow\ vine}$: Carbon stocks of grapevine [t C ha^{-1}]

a: Number of years following initial planting (1 – 30)

Equation 28: Calculation of below-ground biomass of grapevines

$$C_{crow_{roots}} = (0.0001 * a^2 + 0.0096 * a) * \frac{4000}{1000}$$

$C_{crow\ roots}$: Carbon stocks of grapevine roots [t C ha^{-1}]

a: Number of years following initial planting (1 – 30)

In vineyards in Germany, grassland plants are normally cultivated on the strips of land between grapevine rows. The reasons for this include erosion protection. In vineyards, as in orchards, grassland plants are assumed to account for 75 % of the area under cultivation in each case. In other studies, it was found that the amount of material pruned annually is equivalent to about 0.81 t C ha^{-1}. Grass fractions and pruned material are taken into account only in the cases of first-time initial planting and of use changes from vineyards to a different land-use category. The operational duration is the same as the rotation period, in this context, and it amounts to 30 years. For vineyards, therefore, the carbon stocks in biomass are calculated with the following formulae:

Equation 29: Sum of above-ground biomass of vineyards [t C ha^{-1}]

$$C_{crow_{abo}} = C_{crow_{vine}} + C_{crow_{cut}} + C_{gra1_{abo}} * 0.75$$

$C_{crow\ abo}$: Carbon stocks of above-ground biomass of vineyards [t C ha^{-1}]

$C_{crow\ vine}$: Carbon stocks of above-ground biomass of grapevines [t C ha^{-1}]

$C_{crow\ cut}$: Carbon stocks of material annually pruned from grapevines [t C ha^{-1}]

$C_{gra1\ abo}$: Carbon stocks of above-ground biomass of grassland between plant rows [t C ha^{-1}]

Equation 30: Sum of below-ground biomass of vineyards [t C ha^{-1}]

$$C_{crow_{bel}} = C_{crow_{roots}} + C_{gra1_{bel}} * 0.75$$

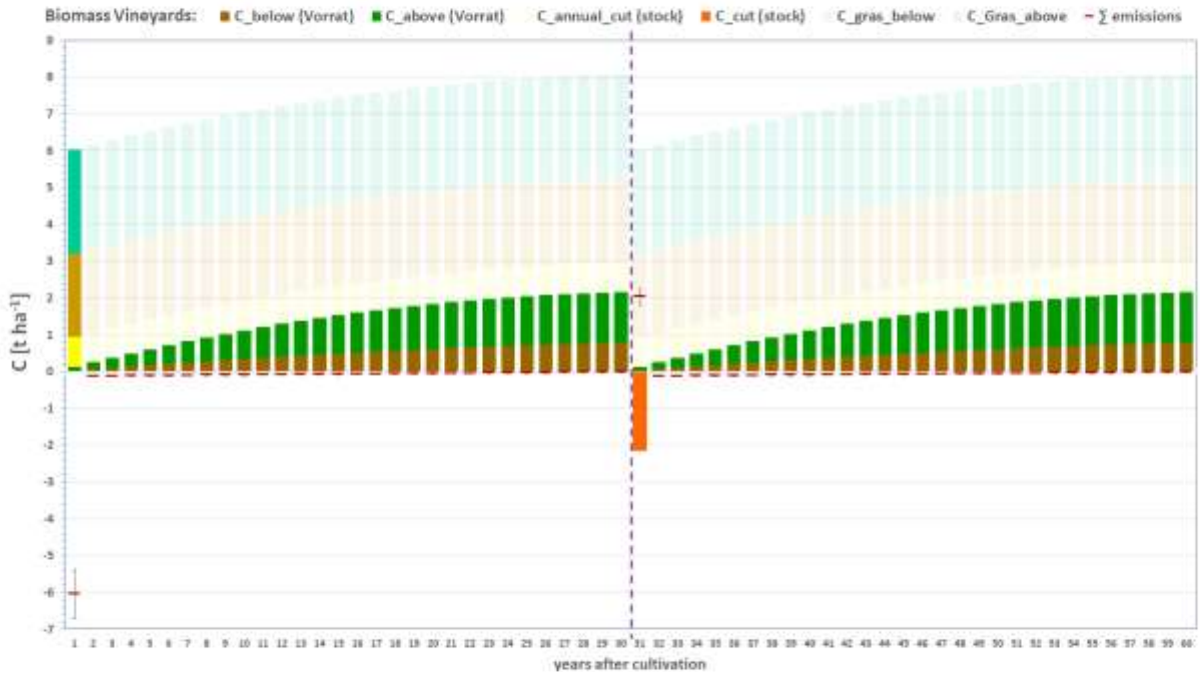
$C_{crow\ bel}$: Carbon stocks of below-ground biomass of vineyards [t C ha^{-1}]

$C_{crow\ roots}$: Carbon stocks of below-ground biomass of grapevines [t C ha^{-1}]

$C_{gra1\ bel}$: Carbon stocks of below-ground biomass of grassland between plant rows [t C ha^{-1}]

The total carbon stocks in the plant biomass of vineyards, and the resulting emissions to be taken into account, are calculated using the methods described in Chapter 6.1.2.3.2 and Chapter 6.1.2.3.3. The development of vineyards' carbon stocks, over time, and the pertinent emissions, are shown in Figure 54.

Figure 54: Development of carbon stocks [t C ha-1] in compartments of plant biomass of vineyards, and the resulting emissions [t C ha-1], in successive rotation cycles (|). Transparent bars are emissions-relevant only in the case of land-use changes



6.1.2.3.5.3 Tree nurseries

An exhaustive tree-nursery survey carried out at 4-year intervals by Statistisches Bundesamt (FS 3, R 3.1.7) provides information about the tree species cultivated in tree nurseries (crot). The 2017 survey showed that German tree nurseries cultivate primarily ornamental plants and other trees and shrubs (about 80 %); only 20 % of their area was used for cultivation of forest plants (Statistisches Bundesamt (FS 3, R 3.1.7)). Since no studies have been carried out of the average biomass stocks in trees and shrubs cultivated in tree nurseries in Germany, the average carbon stocks per unit of tree-nursery area were derived from country-specific biomass-stock values for trees and shrubs. To this end, the following assumptions were made:

- The plants cultivated in tree nurseries consist of 2/3 ornamental trees and shrubs and 1/3 forest trees (actually, the latter are cultivated on only about 20 % of the nurseries' available space; but since tree nurseries also cultivate coniferous trees for the Christmas season and for use as ornamental trees, as well as "forest trees" such as oak and beech, the relevant percentage was increased to 33 %).
- Tree-nursery plants remain within the nursery for a maximum of 10 years.
- The age classes within the various tree/shrub groups are evenly distributed.
- Nurseries have 6,000 plants per ha (this is equivalent to an average distance between plants of about 120/130 cm).
- In addition, 1/3 of nurseries' areas are covered with herbaceous plants / grass; this is taken into account once, in the year of initial planting; after that, it is taken into account only in the case of use changes from crot to a different LUC.
- Rotation period: 10 years; it is assumed that the tree/shrub system reaches an equilibrium, 10 years after the initial planting, in which removals and additions are in balance. For this reason, as of the 10th year the average of the tree/shrub biomass produced in 10 years is assumed to represent the equilibrium value. As of the 11th year, no further emissions are reported.

The fruit-tree carbon stocks derived from the results of the project "Development of methods for determining the biomass of perennial woody plants, outside of forests" (Pöpken) were also applied to ornamental trees and shrubs, in a representative approach. For half of the larger trees and shrubs, the carbon stocks determined for cherry and plum trees were applied; for half of the smaller trees and shrubs, the stocks determined for apple trees were used (cf. Chapter 6.1.2.3.5.1). For the calculation of the biomass of forest trees, the methods developed by (Kändler & Bösch) for calculating forest biomass were applied. Those methods are described in Chapter 6.4.2.2. The below-ground biomass of the various tree groups was estimated using the formula of Mokany et al. (2006b) (cf. Chapter 6.1.2.3.5.1).

From the carbon stocks of the various tree groups, age-dependent average values were obtained that represent the carbon stocks in the plant biomass of tree nurseries' trees and shrubs. These carbon stocks were set in relation to the plants' ages. This made it possible to obtain highly significant regression equations, for both above-ground and below-ground biomass, that serve as a basis for all relevant calculations:

Equation 31: Above-ground biomass for tree nurseries [t C ha^{-1}]

$$C_{crot_{abo}} = 0.2673 * a^2 - 0.0744 * a + \frac{C_{gra1_{abo}}}{3}$$

$C_{crot\ abo}$: Carbon stocks of above-ground biomass of tree nurseries [t C ha^{-1}]

a: Number of years following initial planting (1 – 10)

$C_{gra1\ abo}$: Carbon stocks in the above-ground biomass of Grassland (in the strict sense) [3.78 t C ha-^{1}]

Equation 32: Below-ground biomass of tree nurseries [t C ha^{-1}]

$$C_{crot_{bel}} = 0.0599 * a^2 + 0.1562 * a + \frac{C_{gra1_{bel}}}{3}$$

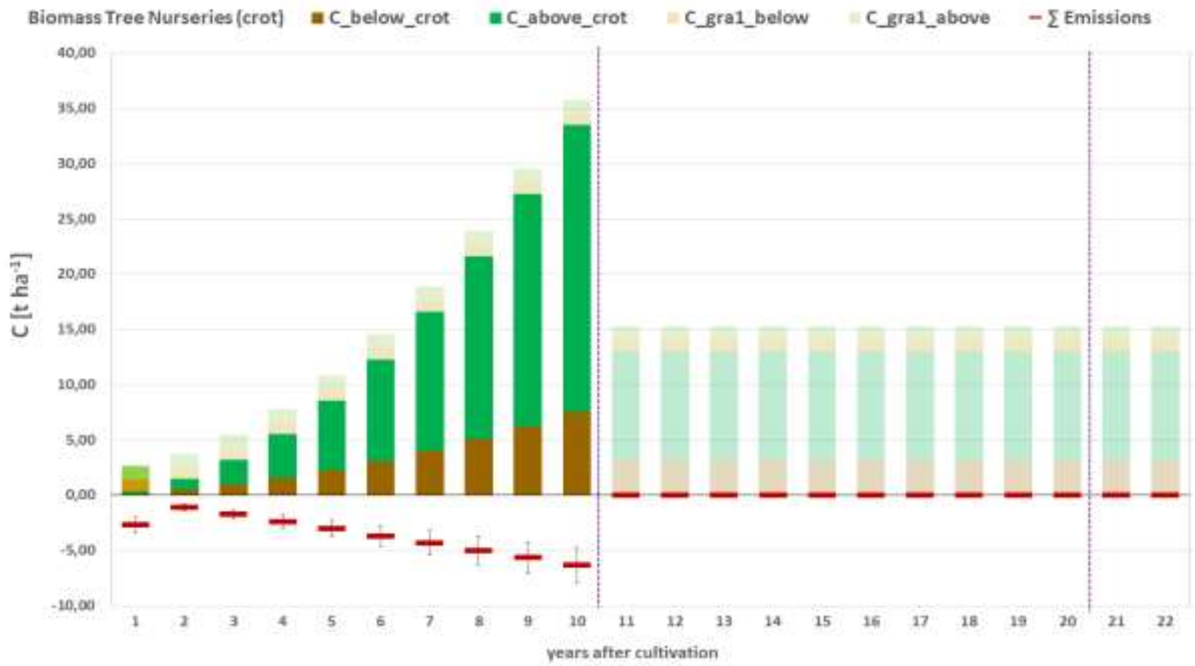
$C_{crot\ bel}$: Carbon stocks of above-ground biomass of tree nurseries [t C ha^{-1}]

a: Number of years following initial planting (1 – 10)

$C_{gra1\ bel}$: Carbon stocks in the below-ground biomass of Grassland (in the strict sense) [3.03 t C ha^{-1}]

Apart from the aforementioned deviations, the total carbon stocks in the plant biomass of tree nurseries, and the resulting emissions and their allocation, are calculated using the methods described in Chapter 6.1.2.3.2 and Chapter 6.1.2.3.3. Figure 55 shows the development of carbon stocks in tree nurseries during successive rotation cycles, along with the resulting emissions.

Figure 55: Development of carbon stocks [t C ha^{-1}] in compartments of plant biomass of tree nurseries (SOC), and the resulting emissions [t C ha^{-1}], in successive rotation cycles (|). Transparent bars are emissions-relevant only in the case of land-use changes and of the end of an operational period



6.1.2.3.5.4 Christmas tree plantations

Areas for cultivation of Christmas trees (crox) normally contain both coniferous trees and herbaceous plants. The area share for the latter is assumed to be 75 %, and the carbon stocks in herbaceous biomass are calculated using the relevant value for Grassland (in the strict sense) as a proxy. Virtually no data are available on plant biomass of Christmas trees. PÖPKEN (2011) cites studies of the University of Copenhagen that obtained a value of 50 t biomass ha^{-1}, for rotation periods of 8 – 12 years. For this reason, the duration of an average rotation cycle was assumed to be 10 years. In keeping with the fact that the aforementioned 50 t biomass ha^{-1}, which corresponds to 22.5 t C ha^{-1}, refer to the total biomass, the below-ground fraction of that biomass was determined to be 5.95 t C ha^{-1}, using the formula of MOKANY et al. (2006). Consequently, a value of 16.56 t C $^{-1}$ results for the above-ground biomass of Christmas trees. For determination of the annual carbon-stocks changes in the above-ground biomass of Christmas trees, that value was distributed linearly among the years of the pertinent rotation cycle. As a result, the above-ground carbon stocks are calculated with:

Equation 33: Above-ground biomass of Christmas tree plantations

$$C_{crox_{abo}} = a * 1.656 + C_{gra1_{abo}} * 0.75$$

$C_{crox\ abo}$: Carbon stocks in the biomass of Christmas tree plantations [t C ha^{-1}]

$C_{gra1\ abo}$: Carbon stocks in the above-ground biomass of herbaceous, annual plants [3.78 t C ha^{-1}]

a: Number of years following initial planting (with a rotation cycle of 10 years)

The plantations' below-ground biomass is calculated by combining the below-ground biomass for the trees, as determined with the equation of MOKANY et al. (2006), with the below-ground biomass of the herbaceous plants:

Equation 34: Below-ground biomass of Christmas tree plantations

$$C_{crox_{bel}} = 0.489 * x^{0.89} + C_{gra1_{bel}} * 0.75$$

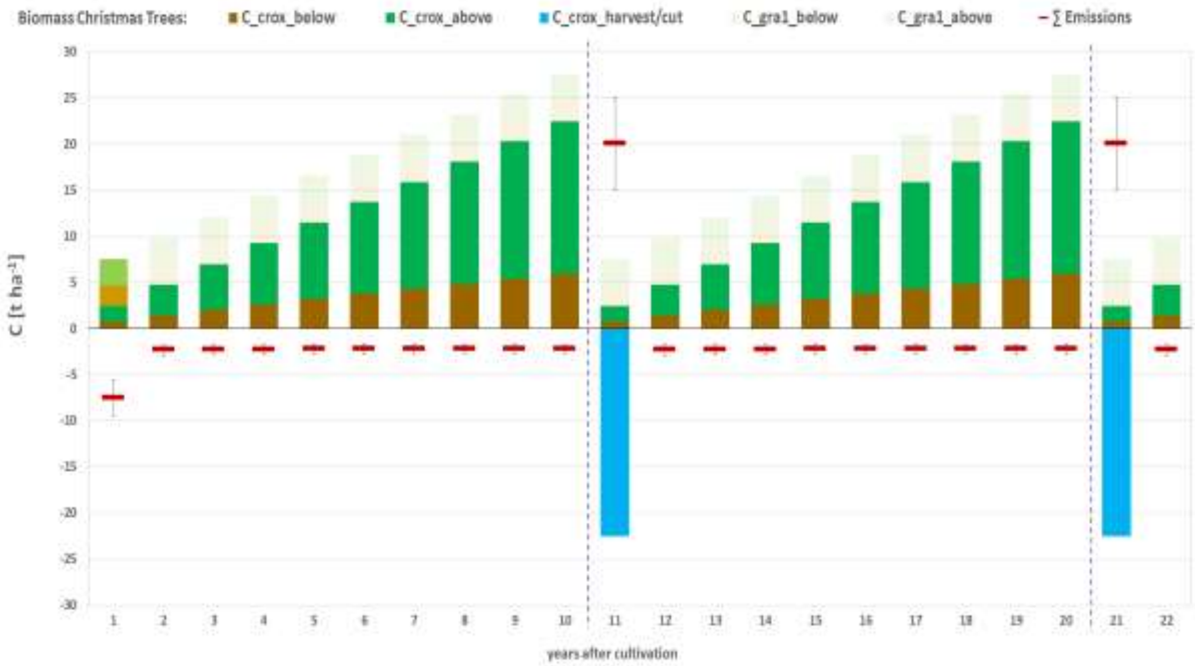
$C_{crox\ bel}$: Carbon stocks in the below-ground biomass of Christmas tree plantations [t C ha^{-1}]

x: Carbon stocks in the above-ground biomass $C_{crox\ abo}$

$C_{gra1\ bel}$: Carbon stocks in the below-ground biomass of herbaceous, annual plants [3.03 t C ha^{-1}]

It is assumed that, at the end of a rotation cycle, the woody biomass in Christmas tree plantations is completely replaced; in other cases, the methods described in Chapter 6.1.2.3.2 and Chapter 6.1.2.3.3 are used. Under this approach, the development of carbon stocks in Christmas tree plantations, during successive rotation cycles, and the related emissions, are as shown in Figure 56.

Figure 56: Development of carbon stocks [t C ha^{-1}] in compartments of plant biomass of Christmas tree plantations (crox), and the resulting emissions [t C ha^{-1}], in successive rotation cycles (|). Transparent bars are emissions-relevant only in the case of land-use changes



6.1.2.3.5.5 Short-rotation plantations

In Germany, pursuant to Article 2 of the Federal Forest Act (BWaldG) (2015), short-rotation plantations are not considered forest land, and are therefore reported solely in the land-use category Cropland. Since short-rotation plantations are also listed as cropland in the framework of the National Forest Inventory, there is no risk of double-counting in this area. Since the biomass of short-rotation plantations in Germany is used exclusively for energy purposes (cf. category 1.A, Chapter 3.2), the emissions tied to such plantations are not reported under "harvested wood products" (HWP) (cf. Chapter 6.10.1).

To obtain country-specific, mean carbon stocks for the biomass of short-rotation plantations, data were derived from the relevant literature. Fundamental data were obtained especially from the overviews Walter et al. (2015), Horn (2013), Gurgel (2011), Kern et al. (2010), Biertümpfel et al. (2009), Boelcke (2007), Stolzenburg (2006) and Maier and Vetter (2004). This work includes the results obtained on 23 experimental short-rotation plantation sites, which are distributed throughout Germany (Bavaria, Baden-Württemberg, Thuringia, Saxony, Brandenburg, Mecklenburg – West Pomerania and Lower Saxony). As a group, the sites cover all the country's relevant climate zones (precipitation: 550 – 1550 mm), average annual temperatures 6.8 – 10.1°C), soil types (light to heavy soils) and geographic regions (lowlands to mid-elevation mountains). Short-rotation plantations were established on a total of 62 test areas, with main species including poplars (58 %) and willow (34 %), although birch (3 %), alder, black locust (robinia) and foxglove tree (paulownia) (5%) were also planted. The rotation periods ranged from one to ten years, and averaged 4.2 years. Since these studies cover all relevant operational aspects of short-rotation plantations in Germany, including spatial distribution, site conditions, vegetation and management practices[96], they are representative.

From the results of these studies, an average annual dry yield of 9.05 (-6.0 % / +9.9 %) t ha^{-1} a^{-1} of above-ground biomass was derived for short-rotation plantations in Germany. In light of the circumstances prevailing in Germany, an average operational duration of 20 years and an average rotation cycle of 10 years were assumed. At the end of the rotation period, all the plants in the plantation are cut back radically (to a height of 10-20 cm), while the below-ground biomass remains intact. As a result, the entirety of the above-ground biomass is credited as an emission. Subsequent emissions occur only through growth of above-ground biomass. At the end of the operational period, the above-ground and below-ground phytomass is completely removed, and the plantation is replanted. For derivation of the growth curves of the above-ground biomass, the average annual dry harvest is converted into carbon, using a factor of 0.45, and then multiplied by the number of years in the operational period.

Equation 35: Above-ground biomass of short-rotation plantations

$$C_{cros_{abo}} = a * 9.05 * 0.45$$

$C_{cros\ abo}$: above-ground biomass of short-rotation plantations [t ha^{-1}]

9.05: Average dry harvest of above-ground biomass in short-rotation plantations [t ha^{-1}]

0.45: Carbon fraction in dry plant biomass

a: Number of years following initial planting

The below-ground biomass was determined via the above-ground carbon stocks, using the formula of (Mokany et al.).

Equation 36: Below-ground biomass of short-rotation plantations

$$C_{cros_{bel}} = 0.489 * x^{0.89}$$

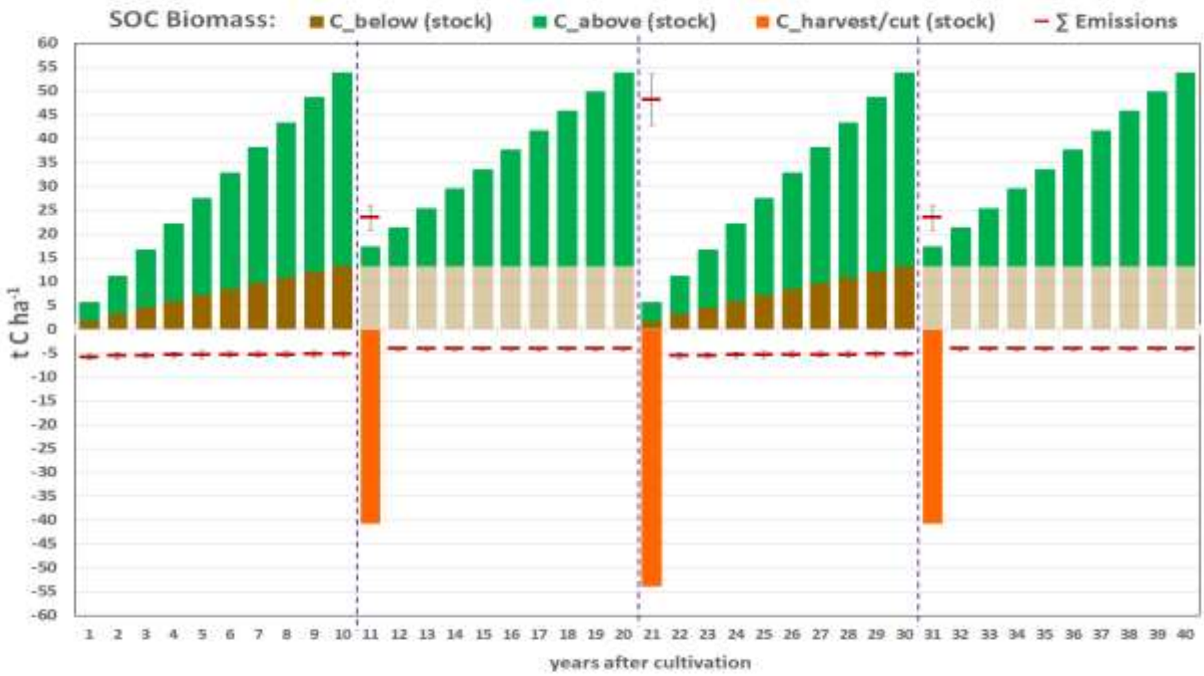
$C_{cros\ bel}$: below-ground biomass of short-rotation plantations [t ha-1]

x: Carbon stocks in the above-ground biomass $C_{cros\ abo}$

The total carbon stocks in the plant biomass of short-rotation plantations, and the resulting emissions and their allocation, are calculated using the methods described in Chapter 6.1.2.3.2 and Chapter 6.1.2.3.3. Figure 57 shows the development of carbon stocks in short-rotation plantations during successive rotation cycles, along with the resulting emissions.

[96] Implementation of findings ARR 2021, KL.12, Table 5; 2020, KL.5+6, Table; 2018, KL.10+11; for better transparency: Throughout Germany, no data are collected on management/fertilisation of agricultural areas. As a result, no concrete information can be provided here about fertilisation of short-rotation plantations. In general, relevant studies and cultivation recommendations indicate that fertilisation is required only in very exceptional cases, however, since such plantations normally receive adequate supplies of key nutrients by natural means ({DBU 2010}; p. 19) and: "Overall, average input rates of ≥ 10 kg N ha^{-1} a^{-1} can be assumed for short-rotation plantations, with the result that annual inputs from atmospheric deposition alone suffice to compensate for harvesting-related N removals" ({DBU 2010}; p. 20)

Figure 57: Development of carbon stocks [t C ha^{-1}] in compartments of plant biomass of short-rotation plantations (SOC), and the resulting emissions [t C ha^{-1}], in successive rotation cycles (|). Transparent bars are emissions-relevant only in the case of land-use changes and of the end of an operational period



6.1.2.3.5.6 Hops

The values for the biomass of hops have been obtained from research work and from publications of the hops-research centre of the Bavarian state research centre for agriculture (Bayerische Landesanstalt für Landwirtschaft). Portner et al. (2019) quantitatively determined the total above-ground biomass of hops, and of catch crops, grown at two sites in the Hallertau area. Graf et al. (2014); Graf (2016) and Sobotik et al. (2018) estimated that the quantity of below-ground biomass found in hops amount to 50 % of the plant's above-ground biomass. With these data, the carbon stocks shown in Table 349 result for the various biomass compartments of hops. The values listed under "Hops" serve as the basis for all emissions calculations in connection with hops. The stock changes in the phytomass of hops plants, resulting from use and land-use changes, are calculated – and the relevant emissions credited – with the methods set forth in Chapter 6.1.2.3.2 and Chapter 6.1.2.3.3.

Table 349: Area-based carbon stocks [t C ha^{-1}] (± half of the 95 % confidence interval) of the biomass of hops plantations, and of catch crops, and their sum totals, broken down by Portner et al. (2019)

Crop	Carbon stocks [t C ha^{-1}]		
	$Phytomass_{total}$	$Phytomass_{above}$	$Phytomass_{below}$
Hops	4.77 ± 0.84	3.18 ± 0.32	1.59 ± 0.80
Catch crop	0.61 ± 0.3	0.45 ± 0.18	0.15 ± 0.08
Hops-cultivation area	**5.38 ± 0.89**	**3.64 ± 0.39**	**1.74 ± 0.80**

6.1.2.3.6 Calculation methods, and determination of emission factors, for hedges and field copses

In order to determine carbon stocks in hedges, Pöpken (2011) studied 50 hedges, in the framework of the research project "Methodenentwicklung zur Erfassung der Biomasse mehrjährig verholzter Pflanzen außerhalb von Waldflächen" ("Development of methods for determining the biomass of perennial woody plants, outside of forests") . The hedges studied varied widely in terms of:

1. **Age**
   - About 4 – 20 years old
2. **Size**
   - Height, about 2 - 9 m
   - Depth, about 1 – 6 m
   - Length, about 100 – 500 m
3. **Species composition**
   - Typical hedge plants, such as dog rose (Rosa canina), blackthorn / sloe (Prunus spinosa), common hazel (Corylus avellana), elder (Sambuccus spec.), hawthorn (Crataegus spec.), honeysuckle (Lonicera spec.) and willow (Salix spec.)
   - Trees, such as field maple (Acer campestre), common hornbeam (Carpinus betulus), willow (Salix spec.), beech (Fagus sylvatica), linden (Tilia spec.) and elm (Ulmus spec.)

As a result, the study has included a representative spectrum of relevant field trees and shrubs. Laboratory analysis of tree/shrub samples taken of the various species in question included measurement of weight, water content and carbon content. Those measurements, in connection with relevant field sizes, made it possible to determine absolute and area-related carbon stocks. Via regression, carried out on the basis of these data, a highly significant correlation was found between a) the average carbon stocks of the biomass of hedges and b) hedges' ages.

Equation 37: Above-ground biomass of hedges and field copses

$$\boldsymbol{C_{gra2_{abo}} = 1,5506 * x^{1,6015}}$$

$C_{gra2\ abo}$: Average carbon stocks of above-ground biomass in hedges / field copses [t C ha^{-1}]

x: Age of hedges / field copses from time of planting [a]

For nature conservation reasons, the study of Pöpken (2011) was able to survey only above-ground biomass. For this reason, the below-ground biomass was estimated, using the formula of (Mokany et al.).

Equation 21: Below-ground biomass of hedges and field copses

$$C_{gra2_{bel}} = 0{,}489 * {C_{gra2_{abo}}}^{0{,}89}$$

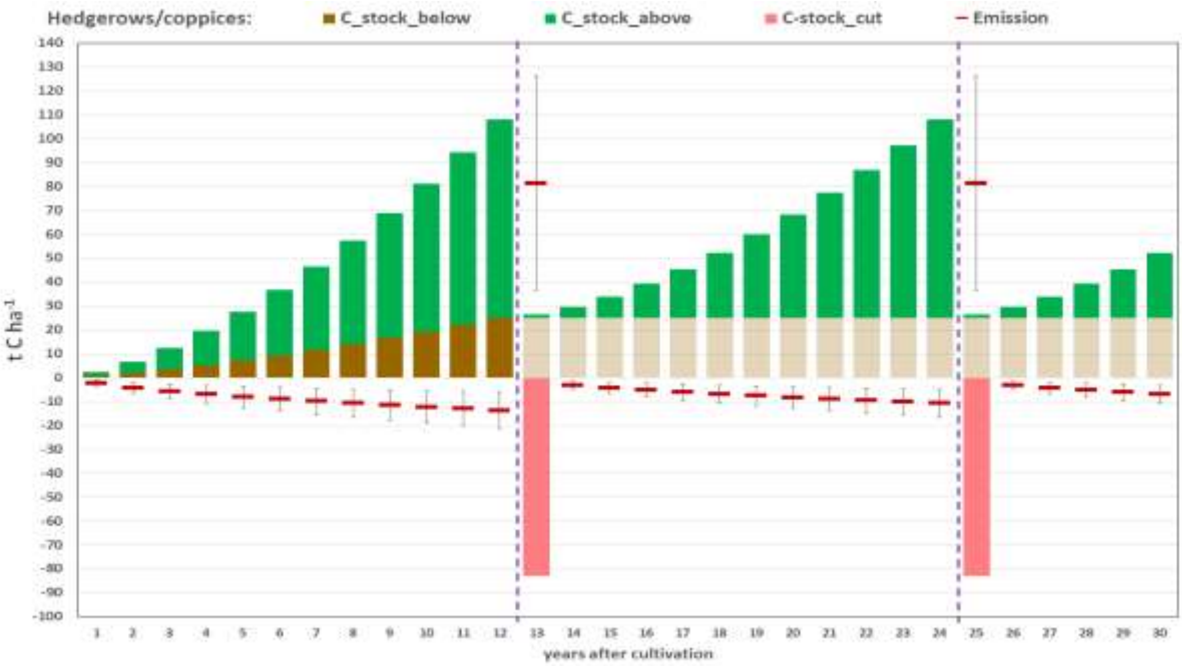
$C_{gra2\ bel}$: Average carbon stocks of above-ground biomass in hedges / field copses [t C ha^{-1}]

The total stocks per age class are obtained from the sum of all compartments. A rotation cycle of 12 years is assumed. This is in keeping with the average rotation cycle for hedges in Germany, i.e., the period after which the hedge is cut back hard for rejuvenation purposes. Since the below-ground biomass remains intact, this means that as of the 13th year emissions arise only via growth and cutting of above-ground biomass. The development of carbon stocks in the plant biomass of hedges / field copses is shown in Figure 58.

In the case of land-use changes from hedges / field copses to other land-use categories, the sum of the current carbon stocks of all compartments of the biomass of hedges / field copses is normally balanced with the biomass stocks of the follow-on use that grows in the first year (cf.

Chapter 6.1.2.3.2 and Chapter 6.1.2.3.3). Land-use changes from hedges / field copses to Forest Land are an exception to this rule. In such cases, only half of the current biomass in the hedges / field copses is taken into account as an emission. This correction has been introduced for the reason that a relevant evaluation of National Forest Inventory data found that in about 50 % of the cases of such land-use changes biomass of the category hedges / field copses enters completely into the biomass of the Forest Land.

Figure 58: Development of carbon stocks [t C ha^{-1}] in compartments of plant biomass of hedges / field copses, and the resulting emissions [t C ha^{-1}], in successive rotation cycles (|); transparent bars are emissions-relevant only in the case of land-use changes



6.1.2.3.7 Terrestrial Wetlands and Settlements

Terrestrial Wetlands (wet1)

As a rule, Terrestrial Wetlands are covered with trees and shrubs (throughout a spectrum ranging from scattered bushes to actual forests), mosses and grasses, with mosses and grasses predominating. Accordingly, the inventory uses the following assumption relative to the area-related distribution of carbon stocks in biomass: 1/3 trees and shrubs and 2/3 mosses and grasses. Since no specific biomass surveys of such lands have been carried out in Germany, the relevant values for hedges / field copses (Chapter 6.1.2.3.6) and Grassland (in a strict sense) (Chapter 6.1.2.3.3) are used as approximations. The carbon stocks of Terrestrial Wetlands, including below-ground and above-ground biomass, are calculated as follows:

Equation 38: Biomass of Terrestrial Wetlands

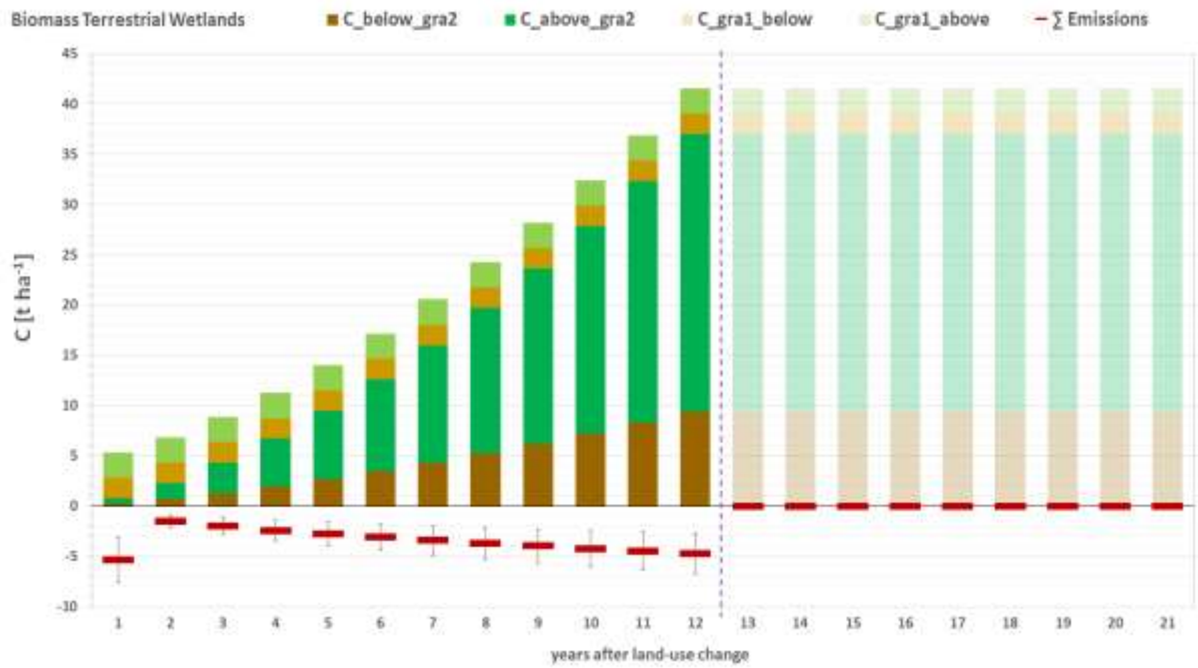
$$C_{wet1} = \frac{1}{3} C_{gra2} + \frac{2}{3} C_{gra1}$$

C_{gra2}: Carbon stocks of the above-ground / below-ground biomass of hedges / field copses in year x following initial planting [t C ha^{-1}] (Chapter 6.1.2.3.6)

C_{gra1}: Carbon stocks of the above-ground / below-ground plant biomass of Grassland (in the strict sense) [t C ha^{-1}] (Chapter 6.1.2.3.3)

The total carbon stocks in the plant biomass of Terrestrial Wetlands, and the resulting emissions to be taken into account, are calculated using the methods described in Chapter 6.1.2.3.6 and Chapter 6.1.2.3.3. In a departure from this procedure, it is assumed that after 12 years carbon stocks reach an equilibrium state. Consequently, as of the 13th year, no further emissions are reported for each relevant survey point. The following figure shows the resulting development of carbon stocks over time.

Figure 59: Development of carbon stocks [t C ha^{-1}] in compartments of plant biomass of Terrestrial Wetlands (wet1), and the resulting emissions [t C ha^{-1}], in successive rotation cycles (|). Transparent bars are emissions-relevant only in the case of land-use changes



Settlements (set1)

Settlement and transport areas include significant portions of unsealed land that is covered with vegetation. Representative-sample studies of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), an institute sited within the Federal Office for Building and Regional Planning (BBR), have shown that built-over and sealed areas account for 40–50 % of designated settlement and transport areas (Einig et al., 2009). In the German inventory, areas covered with vegetation are thus assumed to account for an average of 50 % of settlement areas.

No data have been collected specifically for biomass and carbon stocks on such areas within Germany's settlement and transport areas. In lieu of such data, the following assumption is made: half of all areas covered with vegetation consist of woody grassland, and half consist of meadow/grass green areas. That assumption is approximately in keeping with the corresponding basic figures used in Switzerland. Via remote sensing, it was determined there that trees and shrubs account for 47.4 % of plant cover, with trees accounting for 32.1 % and shrubs accounting for 15.3 % (FOEN, 2010). Settlement and transport areas contain a great variety of different types of trees and shrubs – from garden-plot shrubbery to hedges of all kinds and to roadside and forest trees. In this land-use category, the biomass of such trees and shrubs has been determined with the same method that was used to determine the biomass of hedges / field copses (gra2; Chapter 6.1.2.3.6), while the biomass of meadows/grass has been determined with the method used for Grassland (in the strict sense) (gra1; Chapter 6.1.2.3.3). The carbon stocks in the biomass of settlement areas can then be calculated pursuant to:

Equation 39: Biomass of Settlement areas

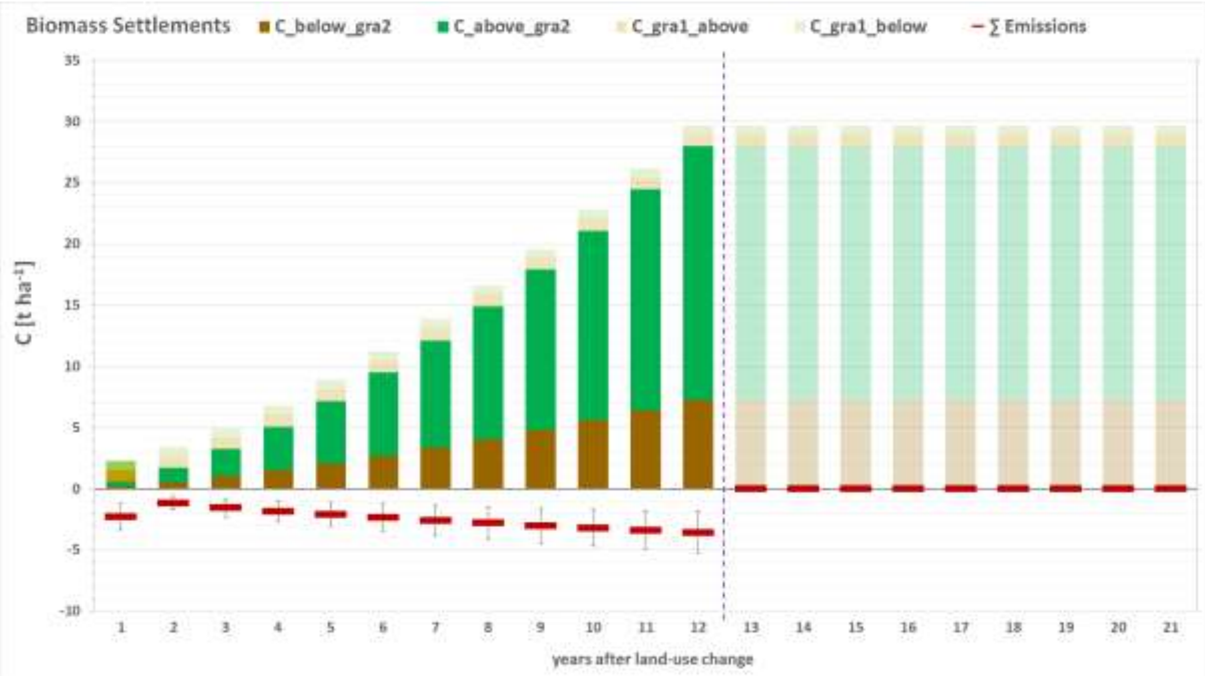
$$C_{set1} = \frac{\frac{1}{2}C_{gra2} + \frac{1}{2}C_{gra1}}{2}$$

C_{gra2}: Carbon stocks of the above-ground / below-ground biomass of hedges / field copses in year x following initial planting [t C ha^{-1}] (Chapter 6.1.2.3.6)

C_{gra1}: Carbon stocks of the above-ground / below-ground plant biomass of Grassland (in the strict sense) [t C ha^{-1}] (Chapter 6.1.2.3.3)

The total carbon stocks in the plant biomass of Settlement areas, and the resulting emissions to be taken into account, are calculated using the methods described in Chapter 6.1.2.3.6 and Chapter 6.1.2.3.3. In a departure from this procedure, it is assumed that after 12 years carbon stocks reach an equilibrium state. Consequently, as of the 13th year, no further emissions are reported for each relevant survey point. The following figure shows the resulting development of carbon stocks over time.

Figure 60: Development of carbon stocks [t C ha^{-1}] in compartments of plant biomass of Settlement areas (set1), and the resulting emissions [t C ha^{-1}], in successive rotation cycles (|). Transparent bars are emissions-relevant only in the case of land-use changes



6.1.2.3.8 Forest Land

The carbon-stock changes of plant biomass on Forest Land, resulting from land use and land-use changes, are calculated using the methods set forth in Chapter 6.1.2.3.1 ff. Further information about the methods and emission-factor derivation used for Forest biomass are provided in Chapter 6.4.2.2ff. In calculation of stocks in the conversion of Forest Land into other land uses (deforestation), average values determined for deforestation areas in Germany, in the National Forest Inventories of 2002 and 2012, and in the 2017 Carbon Inventory (AFZ 2019, (Schwitzgebel & Riedel, 2019)), were used as a basis for the relevant reported years. With regard to methods and value derivation, cf. Chapter 6.4.2.2ff. The values are shown in Table 350. The annual carbon-stocks changes in forest biomass, following afforestation, are shown in Table 364 in Chapter 6.4.2.2.2).

Table 350: Time series for mean carbon stocks (± half of the 95 % confidence interval) of biomass of deforestation areas [t C ha^{-1}]

Year	Biomass – carbon [t C ha^{-1} (EF 1)				
	Bio_{total}	Bio_{above}	Bio_{below}	Dead wood	Litter
1990	28.93 ± 7.86	24.53 ± 7.47	4.39 ± 1.47	1.88 ± 0.98	19.00 ± 0.60
1995	28.93 ± 7.86	24.53 ± 7.47	4.39 ± 1.47	1.88 ± 0.98	18.94 ± 0.60
2000	28.93 ± 7.86	24.53 ± 7.47	4.39 ± 1.47	1.88 ± 0.98	18.88 ± 0.59
2005	36.27 ± 9.86	31.52 ± 9.60	4.75 ± 1.59	1.82 ± 0.95	18.81 ± 0.59
2010	39.48 ± 10.73	34.88 ± 10.63	4.60 ± 1.54	1.48 ± 0.77	18.75 ± 0.59
2015	40.88 ± 11.11	36.06 ± 10.99	4.82 ± 1.62	1.97 ± 1.03	18.69 ± 0.59
2016	40.88 ± 11.11	36.06 ± 10.99	4.82 ± 1.62	1.97 ± 1.03	18.68 ± 0.59
2017	40.88 ± 11.11	36.06 ± 10.99	4.82 ± 1.62	1.97 ± 1.03	18.66 ± 0.59
2018	40.88 ± 11.11	36.06 ± 10.99	4.82 ± 1.62	1.97 ± 1.03	18.65 ± 0.59
2019	40.88 ± 11.11	36.06 ± 10.99	4.82 ± 1.62	1.97 ± 1.03	18.65 ± 0.59
2020	40.88 ± 11.11	36.06 ± 10.99	4.82 ± 1.62	1.97 ± 1.03	18.65 ± 0.59

6.1.2.4 Carbon emissions from dead organic matter (4.A to 4.F)

Emissions from dead organic matter are reported only for the land-use category Forest Land and for land-use changes from Forest Land to one of the other land-use categories in 4.B – 4.E. For such reporting, dead organic matter is subdivided into the two pools dead wood and litter. Descriptions of the method used for this, and of the pertinent results, are presented in Chapter 6.4.2.3, for dead wood, and Chapter 6.4.2.4, for litter (in both cases, within the land-use category Forest Land).

In the land-use-change categories 4.B – 4.E, emissions from dead organic matter are included with emissions from living biomass, since estimates of emissions from living biomass are always based on entire plants. To prevent double-counting in these transition categories, emissions from dead organic matter are marked IE (included elsewhere) in the CRF tables. In category 4.F, NO (not occurring) is used, since, by definition, the areas in this category have no vegetation cover.

6.1.2.5 Direct N_2O emissions from nitrogen fertilisation of forest land and other land areas (4(I))

No nitrogen fertilisation in Forest Land, Wetlands and Settlements is carried out in Germany. In CRF Table 4(I), therefore, NO (not occurring) is entered for all such activities.

6.1.2.6 Emissions from drainage of organic and mineral soils

Emissions from drainage or from other soil-management measures in Germany occur only on organic soils. No emissions occur on mineral soils. For this reason, NO (not occurring) is entered in CRF Table 4(II) for mineral soils, for all land-use categories.

Rewetting of organic soils was also not considered; accordingly, NO (not occurring) has been entered in the CRF Table. As a result, emissions occur solely through drainage of organic soils.

Carbon emissions from organic soils are included in CRF tables 4.A through 4.F. In CRF Table 4(II), and for organic soils, the values for N_2O and CH_4 are entered. IE (included elsewhere) has been entered for CO_2.

A description of the method for derivation of activity data and emission factors for organic soils is presented in Chapter 6.1.2.2 Emissions from organic soils.

6.1.2.7 Direct nitrous oxide (N_2O) emissions from nitrogen mineralisation (CRF Table 4(III))

The direct (CRF Table 4 (III)) N_2O emissions tied to losses of organic soil substance resulting from land-use changes and land-management measures have been determined in keeping with the 2006 IPCC Guidelines. To that end, the carbon-stock changes determined for the individual land-use-change areas were divided by the mean C/N ratios for the pertinent soils; this yielded the absolute changes in soil nitrogen stocks (Equation 11.8 in the 2006 IPCC Guidelines IPCC (2006b)). The C/N ratios for forest soils were obtained from the Forest Soil Inventory (BZE-Wald) (Wellbrock et al., 2016), while those for Cropland soils, Grassland (in the strict sense), Woody Grassland, Terrestrial Wetlands and Settlements were obtained from the Agricultural Soil Inventory (BZE-Landwirtschaft) (Jacobs et al., 2018). The C/N ratios for Settlement soils and mineral soils in the category Other Land were derived from the soil-profile estimation data in the Soil map for the Federal Republic of Germany 1:1,000,000 (BÜK 1000) n 2.3 (BGR 2011).

For determination of the direct emissions, the absolute nitrogen-stock differences were multiplied by the IPCC default value of 0.01 kg N_2O-N $(kg\ N)^{-1}$, in keeping with Equation 11.1 in the 2006 IPCC Guidelines (IPCC, 2006b). The so-determined N_2O emissions are listed in CRF Table 4 (III); the relevant emission factors are listed in Table 351; and the uncertainties are presented in the uncertainties chapters for the individual land-use categories (cf. Chapters 6.4.3, 6.5.3, 6.6.3, 6.7.3 and 6.8.3).

The nitrous oxide emissions are also subject to transition-time considerations; like the carbon-stock changes, they are distributed over 20 years. The methods to be used for carbon also apply with regard to the effective transition time. In addition, the remarks made with regard to carbon (cf. Chapter 6.1.2.1.1) apply with regard to derivation of the implied nitrogen emission factors for Forest Land.

Pursuant to the 2006 IPCC Guidelines, direct nitrous oxide emissions from decomposition of organic matter in the remaining category Cropland[97] are reported in the agriculture sector, under 3.D.a.5.

[97] Sum of emissions from the remaining categories and transition categories among the land-use categories $Cropland_{annual}$, Hops, Orchards, Vineyards, Tree nurseries, Christmas tree plantations and Short-rotation plantations

Table 351: Implied emission factors for direct nitrous oxide emissions [kg N_2O ha^{-1} a^{-1}] caused by losses of organic matter from mineral soils, following land-use changes, for the year 2020

Implied emission factors$_{mineral\ soils}$ [kg N_2O ha^{-1} a^{-1}] for the year 2020														
Initial\Final	**Forest Land**	**Cropland$_{annual}$**	**Hops**	**Vineyards**	**Orchards**	**Tree nurseries**	**Christmas tree plantations**	**Short-rotation plantations**	**Grassland (in the strict sense)**	**Woody Grassland**	**Terrestrial Wetlands**	**Waters**	**Peat**	**Settlements**	**Other Land**
Forest Land		0.08	0	0	0	0	0	0	0	0.073	0	0	NO	0.356	NO
Cropland$_{annual}$	0.060		*0.091*	*0.806*	*0.019*	*0.057*	*0.067*	*0.085*	0	0.062	0	0	NO	0.283	NO
Hops	0	*0.13*		*0*	*0*	*0*	*0*	*0*	0	0	0	0	NO	0.584	NO
Vineyards	0	*0.007*	0		0	*0.004*	*0*	*0*	0	0.015	0	0	NO	0.300	NO
Orchards	0.93	*0.661*	*0.601*	*1.552*		*0.512*	*0.596*	*0.536*	0	0.614	0	0	NO	0.299	NO
Tree nurseries	0	*0.135*	0	*0.988*	*0.003*		0	0	0	0.052	0	0	NO	0.297	NO
Christmas-tree plantations	0	*0.128*	0	*0.983*	*0.008*	0		0	0	0.044	0	0	NO	0.847	NO
Short-rotation plantations	0	*0.174*	0	0	0	0	0		0	0.097	0	0	NO	0.914	NO
Grassland (in the strict sense)	0.767	0	1.281	1.921	0.866	1.420	1.490	1.471		1.525	0	0	NO	0.612	NO
Woody Grassland	0.074	0.148	0.015	0.810	0.030	0	0.122	0.098	0		0	0	NO	0.689	NO
Terrestrial Wetlands	2.240	1.886	0	0	2.26	2.693	0	0	0.959	2.386		0	NO	0.906	NO
Waters	0	0	0	1.726	0	0	0	0	0	0	0		NO	0	NO
Peat	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO		NO	NO
Settlements	0	0	0	0.002	0	0	0	0	0	0	0	0	NO		NO
Other Land	0	0	0	0	0	0	0	0	0	0	0	0	NO	0	

Values in italics: Reported in the Agriculture sector (3.D.a.5)

Positive: Nitrous oxide emissions

6.1.2.8 Indirect nitrous oxide (N_2O) emissions from cultivated soils (CRF Table 4(IV))

The indirect N_2O emissions tied to losses of organic soil substance resulting from land-use changes and land-management measures have been determined in keeping with the 2006 IPCC Guidelines IPCC (2006b) and listed in CRF Table 4 (IV). Indirect N_2O emissions from atmospheric deposition are reported in the agriculture sector (CRF 3.B.2.5). In CRF Table 4(IV), therefore, the pertinent columns are labelled with the notation key IE. For determination of indirect nitrous oxide emissions, the carbon-stock changes determined for the individual land-use-change areas were divided by the mean, area-weighted C/N ratios for the pertinent soils; this yielded the absolute changes in soil nitrogen stocks (Equation 11.8 in the 2006 IPCC Guidelines IPCC (2006b)). The C/N ratios for forest soils were obtained from the Forest Soil Inventory (BZE-Wald) (Wellbrock et al., 2016), while those for Cropland soils, Grassland (in the strict sense), Woody Grassland and Terrestrial Wetlands were obtained from the Agricultural Soil Inventory (BZE-Landwirtschaft) (Jacobs et al., 2018). The C/N ratios for Settlement soils and mineral soils in the category Other Land were derived from the soil-profile estimation data in the Soil map for the Federal Republic of Germany 1:1,000,000 (BÜK 1000 N 2.3) (BGR 2011) (cf. Chapter 6.1.2.1.2).

For estimation of the indirect nitrous oxide emissions, the N-stock differences pursuant to Equation 11.10 of the 2006 IPCC Guidelines were multiplied by the standard factors $Frac_{Leach-(H)}$ (0.3 kg N_2O-N (kg N)$^{-1}$) and EF_5 (0.0075 kg N_2O-N (kg N)$^{-1}$) (IPCC, 2006b). The emission factors for the indirect nitrous oxide emissions, for the year 2020, are listed in Table 352. The pertinent uncertainties are listed in the uncertainties chapters for the respective land-use categories (cf. Chapters 6.4.3, 6.5.3, 6.6.3, 6.7.3 and 6.8.3). The results are entered in CRF Table 4(IV).

The nitrous oxide emissions are also subject to transition-time considerations; like the carbon-stock changes, they are distributed over 20 years. The methods to be used for carbon also apply with regard to the effective transition time. In addition, the remarks made with regard to carbon (cf. Chapter 6.1.2.1.1) apply with regard to derivation of the implied nitrogen emission factors for Forest Land.

Pursuant to the 2006 IPCC Guidelines, direct nitrous oxide emissions from decomposition of organic matter in the remaining category Cropland[98] are reported in the agriculture sector, under 3.D.a.5.

Table 352: Implied emission factors for indirect nitrous oxide emissions [kg N_2O ha^{-1} a^{-1}] caused by losses of organic matter from mineral soils, following land-use changes, for the year 2020

Implied emission factors$_{mineral\ soils}$ [kg N_2O ha^{-1} a^{-1}] for the year 2020															
Initial\Final	**Forest Land**	**Cropland$_{annual}$**	**Hops**	**Vineyards**	**Orchards**	**Tree nurseries**	**Christmas tree plantations**	**Short-rotation plantations**	**Grassland (in the strict sense)**	**Woody Grassland**	**Terrestrial Wetlands**	**Waters**	**Peat**	**Settlements**	**Other Land**
Forest Land		0	0	0	0	0	0	0	0	0	0	0	NO	0.080	NO
Cropland$_{annual}$	0.013		*0.020*	*0.181*	*0.004*	*0.013*	*0.015*	*0.019*	0	0.014	0	0	NO	0.063	NO
Hops	0	*0.029*		*0*	*0*	*0*	*0*	*0*	0	0	0	0	NO	0.131	NO
Vineyards	0	*0.002*	*0*		*0*	*0*	*0*	*0*	0	0.003	0	0	NO	0.067	NO
Orchards	0.021	*0.15*	*0.135*	*0.349*		*0.115*	*0.134*	*0.121*	0	0.138	0	0	NO	0.067	NO
Tree nurseries	0	*0.031*	*0*	*0.222*	*0.001*		*0*	*0*	0	0.012	0	0	NO	0.191	NO
Christmas-tree plantations	0	*0.029*	*0*	*0.221*	*0.002*	*0*		*0*	0	0.010	0	0	NO	0.206	NO
Short-rotation plantations	0	*0.039*	*0*	*0*	*0*	*0*	*0*		0	0.022	0	0	NO	0.245	NO
Grassland (in the strict sense)	0.173	0	0.288	0.432	0.195	0.319	0.335	0.331		0.343	0	0	NO	0.138	NO
Woody Grassland	0.017	0.033	0.003	0.182	0.007	0.029	0.028	0.22	0		0	0	NO	0.155	NO
Terrestrial Wetlands	0.504	0.424	0	0.388	0.509	0.606	0	0	0.216	0.537		0	NO	0.204	NO
Waters	0	0	0	0	0	0	0	0	0	0	0		NO	0	NO
Peat	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO		NO	NO
Settlements	0	0	0	0	0	0	0	0	0	0	0	0	NO		NO
Other Land	0	0	0	0	0	0	0	0	0	0	0	0	NO	0.022	

Values in italics: Reported in the Agriculture sector (3.D.a.5)

Positive: Nitrous oxide emissions

6.1.2.9 Burning of Biomass (CRF Table 4(V))

In Germany, combustion of biomass takes place solely via forest fires. The resulting emissions are entered in CRF Table 4(V). A description of the method used for estimating forest fire emissions is presented in Chapter 6.4.2.7.5 (wildfires) in the land-use category Forest Land.

No emissions from burning of biomass occur in the land-use categories Cropland, Grassland, Wetlands and Other Land. For all categories, a distinction is made between controlled burning and wildfires, however. Wildfires seldom occur in these land-use categories in Germany and thus are not recorded as such. The relevant greenhouse-gas emissions are negligible. In CRF Table 4(V), NO (not occurring) is entered for that category.

No large anthropogenic wildfires, such as the peat fire of 2018, were recorded in 2020.

[98] Sum of emissions from the remaining categories and conversion categories among the land-use categories Cropland$_{annual}$, Hops, Orchards, Vineyards, Tree nurseries, Christmas tree plantations and Short-rotation plantations

Controlled burning (on-site burning of biomass) is prohibited by law in Germany (Article 3 German Ordinance on direct payments (DirektZahlVerpflV); Bundesgesetzblatt (2004)) and thus does not occur in Germany. This applies to all land-use categories. In CRF Table 4(V), NO (not occurring) is entered for that category.

6.1.2.10 Uncertainties

Uncertainties in the LULUCF section of the German GHG inventory are determined in accordance with the 2006 IPCC Guidelines and the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). The uncertainty statistics commonly given for a normal distribution include the 95 % confidence interval, ± half of the 95 % confidence interval or 1.96 x the standard error, in % of the mean. In the case of non-symmetric distributions – such as triangular or log-normal distributions – the uncertainties are expressed as percentages of the position scale, and as upper and lower bounds. As a rule, they are determined via the quantiles (p = 0.025 and p = 0.975). In keeping with above guidelines, the propagation of uncertainties was calculated via a conservative estimation in which the distance between the extreme value of the sloping axis section and the position scale is defined as half of the 95 % confidence interval. Due to a lack of uncertainty estimates for the relevant emission factors, it was not possible to calculate uncertainties for harvested wood products (cf. also Chapter 11.3.1.5.3).

The total uncertainty of the LULUCF section of the German GHG inventory thus amounts to 17.4 % with respect to the level of emissions. The largest contribution to the total uncertainty comes from the CO_2 emissions (97.2 %). The total-uncertainty contributions from emissions of methane (2.4 %) and nitrous oxide emissions (0.3 %) are marginal – in fact, they are hardly noticeable.

With respect to pools, organic soils make far and away the largest contribution (82.6 %) to the total uncertainty of the LULUCF inventory. Their largest component contributions occur in the categories Grassland (96.2 %); the contributions of all other categories are < 1 % for this pool. The mineral soils pool also contributes significantly to the total uncertainty (13.6 %); its contributions to the biomass (2.4 %) and dead organic matter (1.4 %) are slight, however.

All in all, the land-use categories Grassland (in the strict sense) (79.8 %), Forest Land (16.3 %) and $Cropland_{annual}$ (2.7 %) account for 98.9 % of the total uncertainty of the German LULUCF inventory.

6.1.3 Quality assurance and control

General quality control (QC) and, additionally for 4.A through 4.G and total land area, category-specific quality control, and quality assurance (QA), have been carried out, in conformance with the requirements of the QSE manual and its associated applicable documents, by the relevant involved experts and the Single National Entity (SNE).

For QA, detailed checklists were used, and individual checks carried out, for review and documentation of the results in keeping with the quality management guidelines of the Thünen Institute (TI 2016). The Single National Entity archives the Thünen checklists, as well as other documents of importance for quality control. All these documents are thus also available for purposes of external review.

6.1.3.1 The Thünen Institute's quality management for emissions inventories

The Thünen Institute's quality management for emissions-inventory preparation has been developed in conformance with the IPCC Guidelines and the QSE manual (Chapter 1.3.3). The framework for the quality management, and the process for carrying it out, are described in detail in the relevant concept (BMELV, 2016) and in the provisions for the implementation of the concept (TI, 2016). All pertinent documents and data are added to the inventory description that is archived by the SNE. The requirements and procedures set forth by the provisions for implementation of the concept were fully complied with. The following section describes the special additional quality controls carried out for the present submission.

6.1.3.2 Input data, calculation procedures and emissions results

In a first step, the land-use matrix was checked for quality and then approved for emissions calculation. Quality checks covered the decision trees and the results of the annual land-use matrix and of the 20-year transition period. The following section lists key test criteria, for the land-use matrix, that were applied in this year's tests. These criteria exceed the requirements set forth by the provisions for implementation of the concept. They apply for the entire land-use matrix and for the two sub-matrixes for mineral and organic soils:

- The national area is constant.
- The national area is the same as that used in the previous year.
- The areas of the land-use categories are the same, or almost the same, as the corresponding areas used in the previous year; if there are any discrepancies, they can be explained.
- The areas and area trends are consistent with the relevant statistical data; if and where they are not consistent, the discrepancies can be explained.
- The sums of the total areas, consisting of remaining areas and areas with land-use changes, are correct.
- Other Land areas have remained the same or have decreased; no land-use changes to the category Other Land have occurred.
- Peat-extraction areas have been listed separately.
- Consistency between the LULUCF reporting and KP-LULUCF reporting is assured with regard to forest-land areas and afforestation/reforestation/deforestation (ARD) areas.

The emissions calculations have been carried out using the quality-assured land-use matrix. The calculations of emissions for annual land-use changes and the transition period were implemented step-by-step, in tabular form, on the basis of the area data and emission factors / implied emission factors (IEF). The tables have been reviewed with regard to:

1. Correctness of the calculations,
2. Consistency of the time series,
3. Consistency with the calculations of the previous year.

The following test criteria have also been applied:

Emission factors:

- The calculations of the emission factors and implied emission factors (IEF) are correct.
- The time series for the emission factors is consistent; any changes from year to year can be explained.
- The emission factors are the same as those of the previous year, except in cases in which data and methods have changed; any new emission factors are plausible. Any differences with respect to those of the previous year can be explained and have been completely documented.
- Uncertainties have been correctly reported and are consistent with those of the previous year.

- Data consistency between the Convention (LULUCF) and Kyoto-Protocol-reporting (KP-LULUCF) frameworks is assured.

Calculations:

- The basic calculations and the calculations for the annual land-use changes and the transition period are correct.
- The overview tables, which serve as the basis for the CRF tables and the text, are correct.
- The emissions results are consistent with those of the previous year; any discrepancies can be explained as the result of use of new data and methods.
- The consistency of the calculations, between the Convention (LULUCF) and Kyoto-Protocol-reporting (KP-LULUCF) frameworks, is assured.

Results of quality controls:

1. All calculations are correct.
2. The time series are consistent. Any major year-to-year changes result solely from the periodicity of data and from linear interpolation between pertinent periods.
3. No unexplainable outliers were found in the relative differences with regard to the emissions of the previous year. All changes with respect to the previous year have been correctly documented and are included in the National Inventory Report.

After the relevant activity data and implied emission factors (IEF) were entered into the Central System of Emissions (CSE) database, the emissions as calculated in the CSE were compared, for quality control purposes, with emissions results obtained via calculations made outside of the database environment. All quality control steps and their results are fully recorded in the inventory description that is also archived by the Single National Entity.

6.1.3.3 Verification

The inventory in the LULUCF sector is prepared primarily with data from inventories and surveys that are unique to Germany. This means that no comparable data are available that could be used to verify it. The inventories and surveys that are used include the National Forest Inventory (NFI), the Forest Soil Inventory and the Agricultural Soil Inventory (Soil Inventory – BZE), the data from the ATKIS® official topographic-cartographic information system, forest-fire statistics, etc. These sources serve as sources of primary statistics. In the interest of data quality, inventories such as the NFI and the BZE carry out their own extensive quality assurance and controls (cf. also Chapter 6.4.4). All of the results used include error information that enters into the uncertainties calculation for the LULUCF inventory.

The results and implied emission factors (IEF), differentiated by carbon pools and land-use categories, have been compared with those of neighbouring countries. Details on such comparison are provided in the "Category-specific quality assurance / control and verification" chapters for the various land-use categories.

6.1.3.4 Reviews and reports

In 2020, the German LULUCF inventory was reviewed by an expert panel of the Climate Secretariat. In addition, the inventory's CM and GM reporting was reviewed by an EU committee of experts. The following recommendations of the reviewers have been implemented:

11. Stratification of perennial woody plants cultivated on Cropland

- Perennial woody plants cultivated on cropland have now been further subdivided, into the sub-categories Orchards, Vineyards, Hops, Tree nurseries, Christmas tree plantations and Short-rotation plantations. For each of these sub-categories, stratified separate data, on the relevant areas and emissions, are also included in the CRF tables (Chapter 6.1ff, Chapter 6.3ff and Chapter 6.5ff).

12. Carbon-stock changes in the biomass of perennial crops

- Implementation of a new method for a) determination of all annual carbon-stock changes in the biomass of perennial crops outside of Forest Land, broken down by type, age and management method (including aspects such as rotation periods, pruning, new planting); and b) for tracing of annual carbon stocks at each survey point, via modelling of plant-stock development on areas with perennial trees and shrubs outside of Forest Land, and covering all stages of development. The pertinent models are based solely on country-specific activity data and emission factors, and the relevant calculation is completely computerized. The method makes it possible to determine emissions at the time of their occurrence, as requested by the ERT, and to do so even with georeferencing (Chapter 6.1.2.3.4).

The ERT also requested listing of soil carbon stocks for the various individual perennial Cropland sub-categories, broken down by climate, soil type and use. In light of the available data, this request cannot be fulfilled. The soil carbon stocks under perennial crops have been determined on the basis of the results of a soil inventory (Jacobs et al.). Consequently, the soils' so-measured physical characteristics represent the result of the impacts of all site factors, environmental influences and management measures, throughout recent years, at the relevant survey points. For some sub-categories (Orchards and Vineyards), the resulting data show significant differences in soil organic carbon stocks, which is why the data are broken down for listing purposes. Within the individual sub-categories, no statistically significant differences were found, however (for example: Orchards: The main fruit-growing regions ("Altes Land" in northern Germany, and the Lake Constance region, in southern Germany) lie in different climate zones and different soil-parent-material regions; nonetheless, no significant differences in soil organic carbon stocks have been found. For this reason, no regionalized values can be provided within the individual sub-categories.

The ERT requested regionalisation of the soil organic carbon stocks and nitrogen stocks, with a breakdown by soil characteristics and site factors, for all other land-use categories. This has not yet been completed, due to the considerable time and effort required for derivation and validation of such data, and for implementation of the data within the inventory model.

6.1.4 Planned improvements

Plans call for the introduction of regionalised emission factors for mineral soils, broken down by site-specific parameters, and computerized management of such factors (ERT request: ARR 2020: L.8, Table 5); an effort is being made to complete this in the short term.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

6.2 Land-use definitions and land-use classification systems, and their reflection in the LULUCF categories

6.2.1 Forests

The definition of forest used in the German inventory conforms with that given in the 2006 IPCC Guidelines (IPCC (2006a): Vol. 4, Ch. 2.2). The manner in which national land-use systems are allocated to this category is shown in Table 354 in Chapter 6.3.2.1.

The basis for reporting consists of the definition of forest used by the National Forest Inventory (NFI); (Polley, 2001):

"Forest" within the meaning of the NFI is any area of ground covered by forest vegetation, irrespective of the information in the relevant cadastral survey or similar records. The term "forest" also refers to clear-cut or thinned areas, forest tracks, dividing strips in forests, firebreaks, openings and clearings, forest glades, feeding grounds for game, timber yards / lumberyards, forest aisles for conduction, further areas linked to and serving the forest including areas with recreation facilities, overgrown heaths and peatland, overgrown former pastures, alpine pastures and rough pastures, as well as areas with dwarf pines and green alders. Heaths, peatland, pastures, alpine pastures and rough pastures are considered to be overgrown if the naturally regenerated forest cover has reached an average age of five years and if at least 50 % of the area is covered by forest. Forested areas of less than 1,000 m^2 located in farmland or in developed regions, narrow thickets less than 10 m wide, Christmas tree and decorative brushwood cultivations and parkland belonging to residential areas do not constitute forest within the meaning of the NFI. Watercourses with widths of up to 5 m do not break the continuity of a forest area.

At the same time, in a departure from the NFI definition of "forest", areas that the NFI counts as forest, but places in the forest category "non-forest ground", i.e. because they are not wooded, were taken into account as "non-forest" in calculation of carbon stocks and carbon-stock changes. While short-rotation plantations are recorded separately in the NFI, they are not forest within the meaning of the NFI, the Federal Forest Act and the present inventory. They are thus reported under Cropland.

Pursuant to the 2006 IPCC Guidelines, Land converted to Forest Land remains in that transition category for at least 20 years and is only then included in Forest Land remaining Forest Land. For afforestation areas, data for the period as of 1970 are taken into account.

6.2.2 Cropland

The definition of Cropland used in the German inventory conforms with the 2006 IPCC Guidelines (IPCC (2006a): Vol. 4, Ch. 3.2). The manner in which national land-use systems are allocated to this category is shown in Table 354 in Chapter 6.3.2.1. As of the 2021 submission, the land-use category Cropland is divided into seven sub-categories: $Cropland_{annual}$, Hops, Orchards, Vineyards, Tree nurseries, Christmas tree plantations and Short-rotation plantations.

In CRF 4.B, these sub-categories are listed separately, with regard to remaining categories and all transition categories. Conversions among the Cropland sub-categories are treated like land-use changes. In the tables, they are reported separately (CRF 4.B.1).

For purposes of emissions calculations, such land-use systems are stratified by specific pools:

- Calculation of biomass stocks: Annually variable stratification by 65 annual crops (Chapter 6.1.2.3.3) and permanent crops: Hops (Chapter 6.1.2.3.5.6), Orchards (Chapter 6.1.2.3.5.1), Vineyards (Chapter 6.1.2.3.5.2), Tree nurseries (Chapter 6.1.2.3.5.3), Christmas tree plantations (Chapter 6.1.2.3.5.4) and Short-rotation plantations (Chapter 6.1.2.3.5.5). Permanent crops accounted for 2.05 % of the total Cropland area in 2020.
- Calculation of emissions from soils: Constant stratification over time, broken down into organic soils and mineral soils; further differentiation by use (cf. Chapters 6.1.2.1 and 6.1.2.2).
- The total area of open drainage ditches is determined in addition to the area of organic soils under Cropland.
- Calculation of emissions from land-use changes: Annually updated stratification by the categories Cropland remaining Cropland and Land converted to Cropland. The relevant data are taken annually from the pertinent land-use information (Chapter 6.2; Chapter 6.3).

6.2.3 Grassland

Grassland as defined in the German inventory is in keeping with the definition given in the 2006 IPCC Guidelines ((IPCC, 2006): Vol. 4, Chapter 3.2). The manner in which national land-use systems are allocated to this category is shown in Table 354 in Chapter 6.3.2.1.

Grassland is divided into two sub-categories: a) areas covered with grasses and herbs (Grünland im engeren Sinn / Grassland in the strict sense) and b) areas that are covered with trees and shrubs (Gehölze / Woody Grassland) but do not fall under the definition of "forest". It also includes object type 4106 "swamp, reeds" from the Basic Digital Landscape Model (Digitales Basis-Landschaftsmodell; Basis-DLM) (Chapter 6.3.2.1), which consists of undrained organic soils under grassland. In the following, such areas are also referred to as "wet grassland." In 2020, Grassland (in the strict sense) accounted for 93.5 % of the total grassland area (mineral soils: 79.4 %; organic soils: 14.1 %) while Woody Grassland accounted for 6.5 % of the total area (mineral soils: 6.2 %; organic soils: 0.3 %).

The sub-categories in this area include the following types of land use and plants:

- Meadows, pastures, alpine pastures, rough pastures, heath areas, natural-condition grassland, recreational areas and swamp/reeds are grouped under "Grassland (in the strict sense)".
- Hedges, field copses and shrubbery make up the sub-category "Woody Grassland".

Conversions and changes between these two sub-categories are treated like land-use changes.

For purposes of emissions calculation, the two grassland sub-categories are stratified by pools. To that end, area-weighted mean carbon stocks are determined, and the resulting figures are used in the inventory:

Calculation of biomass stocks: Stratification within the sub-categories, by crop types. For grassland (in a strict sense), the stratifications include above-ground and below-ground biomass of grasses and herbaceous plants (Chapter 6.6.2.2). For woody grassland, a model for calculation of biomass of hedge plants and field copses has been developed that is stratified by age, rotation cycles, growth density and growth height (Chapter 6.1.2.3.6).

- Calculation of emissions from soils: Constant stratification over time, broken down into organic soils and mineral soils; further differentiation by use.

  - Emissions from organic soils are reported as a function of depth to water table. (cf. Chapter 6.1.2.2). In addition, the total area of drainage ditches has been estimated.
- Calculation of emissions from land-use changes: Annually updated stratification, by the categories Grassland (in the strict sense) remaining Grassland (i.t.s.s.), Woody Grassland remaining Woody Grassland and Land converted to Grassland. The relevant data are taken annually from the pertinent land-use information (Chapter 6.2; Chapter 6.3).

6.2.4 Wetlands

Pursuant to the 2006 IPCC Guidelines, the "Wetlands" land-use category must subsume all those land areas where soils are intermittently or constantly waterlogged, or covered with water, and that do not fall within the land-use categories 4.A, 4.B, 4.C and 4.E. In the German inventory, these areas are combined in the sub-categories Terrestrial Wetlands (IPCC: Other Wetlands) and Waters (IPCC: Flooded Land). In addition, all areas that are related to peat extraction are combined within an additional sub-category under the land-use category Wetlands (IPCC: Peat Extraction; cf. the 2006 IPCC Guidelines, IPCC (2006a)). These peat-extraction areas, and their changes over time, are recorded and listed in a spatially explicit manner.

In Germany, the majority **(>90%)** of these former wetland areas have been drained and either are being used agriculturally or silviculturally or are located in Settlement areas. In 2020 these areas amounted to 1,673 kha ≙ 91.8 % **of the total area of organic soils**. In keeping with the 2006 IPCC Guidelines, these areas are reported in the relevant land-use categories (CRF 4.A - 4.C and 4.E). The sub-category Terrestrial Wetlands thus only includes Germany's few remaining hardly drained, semi-natural (i.e. subject to very little anthropogenic influence) peatlands, along with certain other wetlands on mineral soils and peat-extraction areas. In the sub-category Waters, a distinction is also made in terms of the degree of anthropogenic influence – between a) flooded land[99] and b) "non-regulated" and "regulated" natural water bodies (the latter of which are not covered by reporting obligations). Table 353 shows how Germany's wetlands areas have been classified, for the year 2020, in accordance with these provisions.

Table 353: Breakdown of the land-use category Wetlands pursuant to the 2006 IPCC Guidelines, and allocation of water-body and terrestrial-wetlands areas [ha] to the relevant sub-categories for 2020

<table>
<tr><th colspan="8">4.D Wetlands
[741,863ha]</th></tr>
<tr><th colspan="4">Terrestrial Wetlands
[128,428 ha]</th><th colspan="2">Peat extraction
[17,720 ha]</th><th colspan="2">Waters
[595,715 ha]</th></tr>
<tr><td colspan="2">Mineral soils
[19,802 ha]</td><td colspan="2">Organic soils
[108,626 ha]</td><td colspan="2">Organic soils
[17,720 ha]</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td colspan="2">undrained
[19,802 ha]</td><td colspan="2">drained [96,569 ha] /
undrained [12,057 ha]</td><td colspan="2">drained
[17,720 ha]</td></tr>
<tr><td>Remaining
[19,340 ha]</td><td>Changed
[462 ha]</td><td>Remaining, including all undrained
[104,835 ha]</td><td>Converted (drained)
[2,477 ha]</td><td>Remaining
[17,287ha]</td><td>Converted
[433 ha]</td><td>Remaining
[591,821 ha]</td><td>Changed
[3,894 ha]</td></tr>
<tr><td colspan="2">Natural and semi-natural wetlands (such as swamps, rivers and streams)</td><td>Natural and semi-natural peatlands (such as peat areas, fens)</td><td>Semi-natural peatlands</td><td colspan="2">Peat-extraction areas</td><td colspan="2">Natural and artificial water bodies, including both standing and flowing water bodies</td></tr>
<tr><td>No emissions</td><td>Emissions from mineral</td><td>Emissions from organic soils, biomass</td><td>Emissions from organic</td><td colspan="2">Emissions from on-site, off-site</td><td>No emissions</td><td>Emissions from biomass</td></tr>
</table>

[99] Water bodies that are regulated via human activities and that exhibit wide fluctuations in water level and/or changes in the area they cover (dammed reservoirs, etc.) (2006 IPCC Guidelines)

4.D Wetlands [741,863ha]						
Terrestrial Wetlands [128,428 ha]				Peat extraction [17,720 ha]	Waters [595,715 ha]	
	soils, biomass		soils, biomass			

The sub-categories "Peat extraction", "Terrestrial Wetlands" and "Waters" differ in terms of their emissions behaviour. For this reason, they are listed as separate sub-categories and reported separately in the CRF tables (4.D and 4(II)) (for details, cf. Chapter 6.3). For the land-use category Wetlands, land areas are calculated with the help of annually updated stratification by Terrestrial Wetlands, Waters, and Peat-extraction areas. The relevant data are taken annually from the pertinent land-use information (Chapter 6.3). Conversions between the sub-categories are treated as land-use changes originating in other land-use categories.

For purposes of emissions calculation, the sub-categories Peat Extraction, Terrestrial Wetlands and Waters are stratified by pools. To that end, area-weighted mean carbon stocks are determined, and the resulting figures are used in the inventory:

Remaining category:

- Calculation of biomass stocks: No biomass occurs in the sub-categories Waters and Peat Extraction. The biomass of the sub-category Terrestrial Wetlands has been derived from the relevant figures for Grassland (in the strict sense) and Woody Grassland (Chapter 6.1.2.3.7).
- Calculation of emissions from mineral soils: No soil carbon stocks are listed for water areas; peat-extraction areas are found only on organic soils. In the tables, the emissions are listed as not occurring (NO). For the sub-category Terrestrial Wetlands, emissions from mineral soils are derived from the relevant figures for Grassland (in the strict sense) (Chapter 6.1.2.1.7).
- Calculation of emissions from organic soils: For peat-extraction areas, both on-site and off-site emissions are calculated (Chapter 6.7.2), in keeping with the 2006 IPCC Guidelines and the 2013 IPCC Supplement on Wetlands. The sub-category Terrestrial Wetlands is divided into wet (depth to water table < 0.1 m) and drained areas (depth to water table > 0.1 m) (cf. Chapter 6.1.2.2); on-site emissions are reported; but no emissions are reported for the sub-category Waters.

Transition categories:

- Calculation of biomass stocks: In the case of land-use changes to Waters, the biomass stocks are set to "zero". The biomass of the sub-category Terrestrial Wetlands has been derived from the relevant figures for Grassland (in the strict sense) and Woody Grassland (Chapter 6.1.2.3.7).
- Calculation of emissions from soils: No emissions occur in the sub-category Waters. The sub-category Terrestrial Wetlands is divided, in a constant manner over time, into "organic soils" and "mineral soils." For organic soils, on-site emissions are reported as a function of water level (Chapter 6.1.2.2). Emissions from mineral soils occur only in the sub-category Terrestrial Wetlands, since peat-extraction areas, by definition, contain no mineral soils.

6.2.5 Settlements

The description of the categories used by national land-use systems in connection with settlements and transport, and the manner in which they are allocated to the IPCC category Settlements, are shown in 6.3.2.1. The definition of settlements used in the German inventory conforms with the 2006 IPCC Guidelines (IPCC (2006a): Vol. 4, Ch. 2.2). All settlement areas have been combined within a single category.

Settlement areas contain significant portions of unsealed land that is covered with vegetation. Spot surveys have revealed that built-over, sealed areas account for 40–50 % of Germany's listed settlement and transport areas (BKG, 2015; Einig et al., 2009). In the German inventory, unsealed areas – which are normally covered with vegetation – are thus assumed to account for an average of 50 % of settlement areas.

Other surveys have shown that traffic routes normally account for 30 – 40 % of sealed areas; consequently, 60 – 70 % of sealed areas are covered with buildings or other structures (BKG, 2015; Statistisches Bundesamt, FS 3, R 5.1). This applies for all German Länder, with the exception of the city-states; in the city-states, transport infrastructure areas account for only about 22 % of sealed areas. The corresponding nationwide figure, in 2018, was 35 % (Statistisches Bundesamt, FS 3, R 5.1). In light of these findings, the following land coverage is assumed, in the German inventory, for Settlement areas:

- 50 % unsealed areas (such as parks, residential gardens/yards, allotment gardens (Kleingärten), recreational areas, roadside vegetation, etc.)
- 17.5 % transport infrastructure areas (such as roads, pathways, public squares, parking areas, etc.)
- 32.5 % areas with structures (such as residential and commercial buildings, industrial buildings, production facilities, warehouses, etc.)

For purposes of emissions calculations, the land-use category is stratified by specific pools. To that end, area-weighted mean carbon stocks are determined, and the resulting figures are used in the inventory:

- Calculation of biomass stocks: The biomass of the category Settlements has been derived from the relevant figures for Grassland (in the strict sense) and Woody Grassland (Chapter 6.1.2.3.7).
- Calculation of emissions from soils: Constant differentiation over time by organic soils and mineral soils. The carbon stocks in mineral soils are derived a) as a function of land use, b) from the data of the Forest Soil and Agricultural Soil Inventories (BZE Wald und Landwirtschaft), and c) taking account of the different degrees of soil sealing involved (cf. Chapter 6.1.2.1). For organic soils, the values for Grassland (in the strict sense) are used as proxies (Chapter 6.1.2.2).
- Calculation of emissions from land-use changes: Annually updated stratification by the categories Settlements remaining Settlements and Land converted to Settlements. The relevant data are taken annually from the pertinent land-use information (Chapter 6.2; Chapter 6.3).

6.2.6 Other Land

Within the German reporting system, and in keeping with the 2006 IPCC Guidelines, the following object types defined in ATKIS® are assigned to the category Other Land: "Area without vegetation" (AAA_Ob.-No. 43007) and "area currently undefined" (AAA_Ob.-No. 43008). The relevant areas are described and allocated in keeping with Table 354 in Chapter 6.3.2.1 and the algorithms described in that section.

6.3 Information on approaches used for determining relevant land areas and on the sources of land-use data used

6.3.1 Introduction

The method for determining land-use changes in the LULUCF sector takes account of all land uses and land-use changes in a chronologically and spatially consistent manner, and separately for organic and mineral soils. A sample-based system is used. The method used is based on spatially explicit observations and thus, pursuant to the 2006 IPCC Guidelines (IPCC (2006a): Vol. 4 Chapter 3.3.1), can be classified as an "approach 3." The reasons why this sample-based system was chosen are given in Freibauer et al. (2017).

As of the 2020 submission, the sampling system employs a regular, 100 m x 100 m grid of sample points laid over Germany's total area. The grid chosen is based on the Basic Digital Landscape Model (Basis-Digitales Landschaftsmodell; Basis-DLM), whose most-precise data set for Germany includes areas as small as 1 ha. A total of 35,790,122 sample plots result. In comparison to the grid used for earlier submissions (528,223 sample plots), this procedure considerably improves precision in the identification of land uses and land-use changes on organic and mineral soils, in all land-use categories.

6.3.2 Database and data processing

The land-use matrix (LUM) has been derived from the Basis-DLM. Where necessary, it has been supplemented with additional data sets (cf. Chapter 6.3.2.1). For a data source to be usable, its land-use classes – as assigned via interpretation or modelling – must lend themselves to translation into the IPCC land-use categories. Not every data set has to show all land-use classes; it suffices if at least one of the six main land-use categories can be identified. The land-use information in the various data sets is correlated with the sample points, via geographic location. As a result, chronologically distributed data are then available for each sample point.

The aim of this flexible survey system is not to record land-use changes as often as possible, but rather

- to identify the most reliable land-use information, from the overall available information,
- to filter out and detect land-use changes, and
- to eliminate any possible uncertainties and sources of error.

6.3.2.1 Data sources

The following data sources / sets been used:

- The Basic Digital Landscape Model (Basis-Digitales Landschaftsmodell; Basis-DLM) for the years 2000, 2005, 2010, 2015 and 2020,
- Map of Germany's organic soils
- The OpenStreetMap dating from 2013 (©OpenStreetMap co-authors)
- Corine Land Cover (CLC) 1990, 2000
- The digital land cover model (Digitales Landbedeckungsmodell; LBM-DE) for the year 2012 (LBM12)

The majority of the land-use information has been taken from the Basis-DLM. This can be illustrated with the example of the information provided in 2018: 98.5 % from the Basis-DLM and 1.5 % from the OpenStreetMap. Information relative to a total area of 106 ha (0.0003 % of the points involved) was taken from the LBM12.

The Basic Digital Landscape Model (Basis-DLM)

The Basic Digital Landscape Model (Basis-Digitales Landschaftsmodell; Basis-DLM) is the basis for Germany's Official Topographical-Cartographical Information System (Amtliches Topographisch-Kartographischen Informationssystem; ATKIS®), which is managed by the Working Committee of the Surveying Authorities of the Länder of the Federal Republic of Germany (AdV). The ATKIS® system describes Germany's topography in terms of digital landscape and terrain models:

"The Basis-DLM uses a vector format to describe topographic objects of the landscapes and the relief of the earth's surface. Each object is assigned to a specific object type and defined in terms of its spatial position, geometric type, descriptive attributes and relations to other objects. Each object has an identification number (identifier) that is unique throughout all objects for Germany. In the Basis-DLM, spatial position is given true to scale, and independently of any representations, within the coordinate system used for land surveying. The object types contained in the DLM, and the manner in which the objects are to be formed, are defined in the ATKIS® object-type catalogue (ATKIS®-OK)" (AdV). The informational spectrum of the Basis-DLM is oriented to the contents of standard 1:25,000 topographic maps. At the same time, the Basis-DLM features greater precision of position (± 3m) for the most important point-shaped and line-shaped objects. Data of the Basis-DLM systems of the Länder are adopted by the Federal Agency for Cartography and Geodesy (BKG) and then checked, harmonised, georeferenced and processed, without any overlapping, for use within a nationally standardised Basis-DLM. The BKG also manages the data, within a special database, for purposes of provision to federal authorities and other agencies.

The purpose of ATKIS® is to provide a landscape model (land-cover model that is maximally up-to-date and has the highest resolution possible) of Germany, with regularly updated and expanded geometries and content. The surveying administrations of the Länder collect the pertinent data on an ongoing basis, and not on a national basis as of a given key date. As a result, new surveying results are continuously transmitted to the Federal Agency for Cartography and Geodesy (BKG) and integrated within ATKIS®. While five years is given as time period within which a complete revision should be accomplished, that specification is applied very differently from state to state (states = German Länder). In practice, the data for areas with vegetation cover are between one and seven years old. For areas of very high current interest, especially with regard to area changes – such as settlement and transport areas – a period of three to twelve months is prescribed for transfer into ATKIS®. The Basis-DLM version maintained and managed by the BKG is always the latest version. No pertinent history data are recorded, nor are old versions archived.

For the reporting by the Thünen Institute, this means:

- Basis-DLMs are obtained on an annual basis; the Basis-DLM for a given reporting year is obtained in September of that year;
- In each case, the version for the current year is archived within the institute.

Basis-DLM data sets have been available on an annual basis to the Thünen Institute only since 2005. One data set is available for the year 2000. No ATKIS® data exist for years prior to 2000. Due to the multi-year revision cycles involved, Basis-DLM data records are used at five-year intervals, to prevent the regional artifacts that can occur via seemingly sudden massing of land-use changes in updating years.

In 2009, the Basis-DLM was adapted to a new data model. Somewhat later, the system began to be referred to as "Basis-DLM (as of 2013)". In the years 2009 through 2012, some German Länder provided data in the old model and some provided data in the new model. As of 2013, the Basis-DLM (as of 2013) is being used for all of Germany.

Each data set in the Basis-DLM (through 2012) comprises some 800 individual layers, with the layers differing in their degree of detail. For example, polygons with relatively low resolution (such as those showing settlement areas) are found on the lowest level, while polygons with very high resolution and rich detail (such as those showing residential areas) are found on the highest level. A single record thus will contain numerous superimposed polygons that, in terms of content, can be assigned to the same LULUCF categories. All such related content, with all overlays, is put into the calculation system as a whole. As a result, data gaps occur only where the entire pertinent Basis-DLM data record contains no data. In a subsequent step, the various areas are merged with the points of the GHG sampling grid. Where a point touches several stacked areas, only a single value is chosen, with the help of a priority list. Where the same priorities overlap (for example, vegetation with vegetation), then that area with the lower ATKIS® identification value is selected. This procedure was carried out for the Basis-DLM (through 2012) from the years 2000, 2005 and 2010. The Basis-DLM categories (through 2012) are assigned to the LULUCF categories with the help of a translation table (cf. Table 354).

The new data model (Basis-DLM (as of 2013)) includes a layer designated "actual use" ("Tatsächliche Nutzung"). "All object types within this object-type area are included in the unbroken, overlap-free and complete-coverage description of the earth's surface (ground areas)." As a result, virtually no areas overlap. In general, the quality of the data has improved considerably: After use of all areas in the Basis-DLM (through 2012), about 0.05 % of points cannot be assigned any information from the Basis-DLM. With the Basis-DLM (as of 2013), the corresponding figure has decreased to only 0.0003 %. The Basis-DLM categories (as of 2013) are assigned to the LULUCF categories with the help of a translation table (cf. Table 354).

Map of Germany's organic soils

The map of Germany's organic soils is a 1:25,000 scale map that has been prepared by Humboldt-Universität (Berlin). It shows organic soils within the meaning of the pertinent IPCC definition, along with their carbon stocks (Roßkopf et al., 2015). In identification of land uses, it is used for the purpose of differentiating mineral soils from organic soils.

OpenStreetMap® (OSM)

Area information relative to the German road network cannot be derived from the Basis-DLM. For this reason, such information was extracted from OpenStreetMap, a free map of the world. Initially, the OpenStreetMap project aimed solely at producing a road map. Since then, OpenStreetMap has grown to become the world's largest free geodatabase (cf. also www.openstreetmap.org). The line elements in the road network have been fitted with suitably wide buffers, in keeping with the road categories used. This has generated a layer with transport infrastructure areas, and that layer has been intersected with the point grid.

CORINE Land Cover (CLC) data

CORINE Land Cover (CLC) is a European remote-sensing project for standardising classification of land use and land-use changes. It was initiated by the EU Commission in the mid-1980s. In the CLC framework, digital satellite images of European countries are collected, via standardised procedures, and analysed with regard to land-use changes. Image data recorded in four different years, 1990, 2000, 2006 and 2012, are currently available. The CORINE classes have been allocated to the LULUCF categories with the help of a translation table (cf. also Table 354). CLC is the only source used for deriving land use in 1990, since no other Germany-wide data are available for the period prior to 2000.

The LBM land-cover model

The Landbedeckungsmodell (LBM) is a land-cover model that is published by the Federal Agency for Cartography and Geodesy (BKG). It was developed for the purpose of deriving Corine Land Cover for Germany from the Basis-DLM. The geometries of the Basis-DLM are checked and updated with the help of satellite photos. This produces a land-cover database that is complete, of high-quality, and highly current. The first LBM dates from 2012 and appeared in the spring of 2016. The LBM 2015 appeared in early 2019. The LBM is only partly comparable to the Basis-DLM, for two reasons: 1) the Basis-DLM takes account of land use, while the LBM takes account of land cover; 2) the Basis-DLM is updated on an ongoing basis, and reflects changes over multiple years, while the LBM is a snapshot of a given year in each case.

Key for correlation of data-source and IPCC categories

The various land-use definitions used in the underlying data sources have been correlated with the various LULUCF reporting categories (Table 354).

In the B-DLM, the catalogue of object types changed with the introduction of the new AAA model. For this reason, a new correlation table is being used for the submissions as of 2013. The six IPCC land-use categories are directly correlated with the object types used in the Basis-DLM (AAA levels) of ATKIS® (Table 354).

In preparation of the land-use matrix, the grid-point allocation is computerized; it is carried out fully automatically via dedicated programmes. In support of that purpose, the allocation keys for these classification systems are included in digital form, with the result that any given grid point can always be unambiguously allocated to an object type key number and, thus, to a specific land-use category, regardless of the data source being used. The scripts for these programmes are maintained in the inventory description.

Table 354: Allocation of main object type index numbers and attributes in ATKIS® to IPCC land-use categories

		ATKIS Object-type catalog			CORINE LAND COVER
Object number, AAA levels	**Attribute, AAA levels**	**Object number, levels**	**Object type**	**Description / attributes pursuant to ATKIS object-type catalog**	**Nomenclature code**
IPCC category: Forest Land					
43002	VEG, all	4107	Forest Land	Deciduous, coniferous and mixed forest	311; 312; 313; 324
IPCC category: Cropland					
43001	VEG 1010	4101	Agriculture: Cropland	Area for cultivation of field crops (such as grain, legumes, root crops) and berries (such as strawberries) Cropland also includes rotational set-asides, permanent set-asides and areas set aside to achieve eligibility for EU compensation payments.	211; 212
43001	VEG 1012	4109	Agriculture: Hops	"Hops" refers to agricultural areas that are equipped with special fixtures for hops cultivation.	No allocation
43001	VEG 1030	4103	Agriculture: Horticultural land	Horticultural land is land for cultivation of vegetables, fruit and flowers, and for growing of cultivated plants.	242
43001	VEG 1031	4109	Agriculture: Tree nursery	"Tree nurseries" are areas on which woody plants are grown from seeds, shoots and cuttings, and are transplanted multiple times in the process.	No allocation
43001	VEG 1031	4109	Agriculture: Christmas tree plantations	"Christmas tree plantations" are agricultural areas that are planted primarily with Christmas trees.	No allocation
43001	VEG 1031	4109	Agriculture: Short-rotation plantations	"Short-rotation plantations" are areas on which tree species are planted with the aim of producing a wood harvest in the near term; stocks in such plantations have rotation periods no longer than 20 years.	No allocation
43001	VEG 1040	4109	Agriculture: Vineyard	Vineyard	221
43001	VEG 1050	4109	Agriculture: Orchards	Orchards	222
IPCC category: Grassland					
43001	VEG 1020	4102	Agriculture: Grassland	Grassland is a grassy area that is mowed or grazed.	231; 321;421
43004		4104	Heath	A heath area is a sandy area (typically) with certain typical shrubs and grasses, and with sparse, scrub tree cover.	322
43006		4106	Marsh Grassland (in the strict sense)	A marsh area is a waterlogged area that is covered with water for part of the year. Areas that are wet for brief periods, after rainfall, are not considered marsh areas.	411
43007	FKT 1300		Wasteland and vegetation-free areas: Semi-natural area	A semi-natural area is an area that is not used for crop cultivation and that is covered with grass, wild herbs and other plants.	No allocation
43003		4108	Woody plants	Area covered with individual trees, groups of trees, bushes, hedges and shrubs.	243
43007	FKT 1200		Wasteland and vegetation-free areas: Succession area	A succession area is an area that has been permanently set aside from agricultural or other existing use and that is allowed to revert to its original condition – for example, as Woody Grassland, a peatland or a heath.	No allocation

ATKIS Object-type catalog						CORINE LAND COVER
Object number, AAA levels	Attribute, AAA levels	Object number, levels	Object type		Description / attributes pursuant to ATKIS object-type catalog	Nomenclature code
IPCC category: Wetlands						
43005		4105	Peatland	Terrestrial Wetlands	Uncultivated area whose top layer consists of peaty or decomposed plant remains.	412
41005	AGT 4010	2301	Open-pit mine: Peat extraction			No allocation
44001 to 44007		5101 - 5203, 3402	Waters		For example, dammed reservoirs, rivers at least 12 m wide, canals, storage basins, shifting shorelines and banks. 3402 refers to harbour basins – and, thus, to Waters and not Settlements (in AAA 44005).	511; 512; 423; 521; 522; 523
IPCC category: Settlements						
41001 to 41010		2101-2352	Settlements		Settlements refer to areas, either with or without buildings and structures, that have been shaped by human occupation or that support human occupation.	111; 112; 121; 131; 132; 133; 141; 142
42001 to 42016		3101-3543	Transport		Transport areas consist of areas, either with or without buildings and structures, that serve and support transports.	122; 123; 124
43007	FKT 1100		Wasteland and vegetation-free areas: Area accompanying a water body		An area accompanying a water body is an area, either with or without buildings and structures, that is allocated to a watercourse.	122; 123; 124
IPCC category: Other Land						
43007	FKT 1000	4120	Wasteland and vegetation-free areas: Areas without vegetation		Areas without significant vegetation cover, as a result of special soil characteristics such as unprotruding rocks, sand or ice areas.	331; 332; 333; 334; 335
43008		4199	Area currently undefined		Areas whose characteristics cannot currently be determined, in terms of allocation to object types.	No allocation

6.3.2.2 Derivation of LULUCF information

The GHG sampling grid is merged with the above-described maps, and each grid point is assigned all relevant information from the maps. Then, each point is taken through a decision-tree process in which, as a rule, data from the Basis-DLM is used for the period as of 2000. Data are taken from other maps only in cases in which no data are available in the Basis-DLM.

The results for Forest Land are compared with the corresponding data from the National Forest Inventory (NFI). The Basis-DLM includes tree-covered areas that do not necessarily conform to the NFI's definition of "Forest Land," which is used in reporting. Nonetheless, the two data sets normally showed excellent agreement with regard to their Forest Land areas. Discrepancies amounted to less than 1 %, meaning that the areas result may be considered consistent with the "Forest Land" definition used in reporting.

The Basis-DLM (through 2012) was expanded, in a series of steps, through 2008. As a result, the available surveys for the period prior to 2008 are less extensive than later surveys are. This has impacts on two categories: The peat-extraction areas are incomplete for the period before 2008 (i.e. the total area is too small), and the breakdown of the special crops, into the categories hops, grapevines, fruit trees and tree nurseries, is inadequate for the period before 2008. With regard to peat extraction, survey data prior to 2008 were set as equivalent to the corresponding data in the Basis-DLM 2008. Consequently, all those points to which peat extraction was assigned in the Basis-DLM 2008 were also assigned that land use for 2005, 2000 and 1990. A similar approach was taken with the special crops: All points that, prior to 2008, were included as "special crops" have now been assigned a specific special- crop category, i.e. hops, grapevines, fruit trees or tree nurseries. In most cases in which a point was in the special crops category prior to 2008, and was no longer in that category after 2008, the point was assigned to the category with the largest biomass (tree nurseries), in the interest of a conservative calculation approach. In the German Länder Rhineland-Palatinate and Hesse, which cultivate large quantities of wine grapes, such points were assigned to the "grapevines" special-crops category.

In general, derivation of land uses and land-use changes for the period 1990 to 2000 is problematic. Since no Basis-DLM data are available for the period prior to 2000, Corine Land Cover (CLC) data have to be used for 1990, and this imposes a change of database between 1990 and 2000 (CLC to Basis-DLM). The 2006 IPCC-Guidelines (IPCC (2006a): Vol. 1 Chapter 5.3.3) recommend that the "overlap approach" be used in such cases. In keeping with this recommendation, overlapping was used in order to harmonize the older data series (CLC) with the newer one (Basis-DLM). This procedure amounted to a backward extrapolation of the Basis-DLM data for 2000, with the help of the trends in the CLC data for 1990 and 2000.

In keeping with the provisions of the 2006 IPCC Guidelines, reporting under the UNFCCC takes account of land-use changes that took place as early as 1970. As a result, the transition categories are already being filled with area data in a manner that enables them, as of 1990, to reach a stable dynamic state comprising additions of new change areas and transfers of areas into relevant remaining categories. At present, the earliest georeferenced data available for Germany date from the NFI 1987; and, in general, no complete and – more importantly – internally consistent national data sets are available for the period prior to 1990. Consequently, the changes in all land-use categories in the period 1990 – 2000 were extrapolated retroactively to 1970. That approach is in keeping with that used, for example, by the Czech Republic and by Austria for the land-use matrix.

6.3.3 Errors

The various sources of error involved in the sampling method employed include

- the sampling error,
- inconsistencies between definitions,
- discrepancies between Minimum Mapping Units, and
- errors occurring in georeferencing of data sets.

The error sources a) inconsistencies between definitions, b) discrepancies between Minimum Mapping Units and c) imprecise georeferencing cannot be quantified. Only the sampling error is included in the analysis of uncertainties.

6.3.4 Step-by-step implementation

Complete implementation of the above-described system for time-based surveys of land uses and land-use changes throughout Germany calls for extensive preliminary work and continuous supporting efforts. This includes the following:

- The various data sets, for different points in time, have to be acquired,
- Geometric corrections (of erroneous geometries, etc.) and checks have to be carried out,
- Conversion functions have to be written for converting the original classifications into the categorisation used here,
- The sample points have to be merged with the maps,
- The decision tree has to be programmed and adjusted as necessary, in keeping with data quality and availability, and
- The transition-time procedures have to be programmed and adjusted as necessary, in keeping with data quality and availability.

The decision to use this flexible, sample-based system was made in spring 2011, in consultation with the Single National Entity (Federal Environment Agency – UBA) and the Federal Ministry of Food and Agriculture (BMEL), which is responsible for the forest inventories.

The decision trees for the classification years (one per year), and the "transition-time" procedures, were programmed in keeping with the current data structure.

6.3.4.1 Derivation of land uses

At each sample point, data are available (cf. Chapter 6.3.2) that make it possible to assign the sample point to a land-use category for the years in question (2000, 2005, 2010, 2015 and 2020). The basic table (cf. Table 355) is structured as follows (the table is shown here with three sampling points provided by way of the example):

Table 355: Basic table for derivation of land uses

Point ID	LBM 2012	OSM	Org. Soil	DLM 2000	DLM 2005	DLM 2010	DLM 2015	DLM 2020	CORINE 1990	CORINE 2000	CORINE 2006	Point ID	LBM 2012
1	sett	0	0	crop	crop	crop	sett	sett	gra1	gra1	gra1	1	sett
1000	gra1	1	0	gra1	gra1	gra1	gra1	gra1	gra1	gra1	gra1	1000	gra1
2000	crop	0	0	crop	gra1	crop	crop	crop	gra1	crop	crop	2000	crop

The following land-use-class codes are used in the data sets:

Table 356: Codes in the basic table

Code	Category	Sub-category
crop	$\text{Cropland}_{\text{annual}}$	$\text{Cropland}_{\text{annual}}$
croh	Special crop	Hops
crow	Special crop	Vineyards
croo	Special crop	Orchards
cros	Special crop	Short-rotation plantations
crot	Special crop	Tree nurseries
crox	Special crop	Christmas tree plantations
gra1	Grassland	Grassland (in the strict sense)
gra2	Grassland	Woody Grassland
forl	Forest Land	Forest Land
wet1	Wetlands	Terrestrial Wetlands
wet2	Wetlands	Waters
wet3	Wetlands	Peat extraction
sett	Settlements	Settlements
othl	Other Land	Other Land
dlm0	No information[100]	

The decision trees were applied to this basic table for the respective years, 1990, 2000, 2005, 2010, 2015 and 2020. The Basis-DLM is always used, except in cases in which the Basis-DLM provides no information for a given point. In those cases, gradations are relied on – from a chronologically near Basis-DLM to the LBM2012 and to a chronologically near Corine Land Cover data set. Land use for 1990 (LU 1990) is decided via the Overlap Approach (OA), and not via the decision tree.

Use of the decision trees yields a further table (cf. Table 357) with, in each case, the most likely land uses per sample point and year (1990, 2000, 2005, 2010, 2015, and 2020) and the best data source.

100 No land-use information at this point in the Basis-DLM data

Table 357: Most probable land use (LU) and pertinent data sources (DB)

Point ID	LU 1990	LU 2000	LU 2005	LU 2010	LU 2015	LU 2019	DB 1990	DB 2000	DB 2005	DB 2010	DB 2015	DB 2020
1	crop	crop	crop	crop	sett	sett	dlm(OA)	dlm	dlm	dlm	dlm	dlm
1000	sett	sett	sett	sett	sett	sett	osm	osm	osm	osm	osm	osm
2000	gra1	crop	gra1	crop	crop	crop	clc	dlm	dlm	dlm	dlm	dlm

(For abbreviations, see Table 356)

Use of the Overlap Approach (OA) is illustrated with the example of the point with point ID 1. For the year 2000, the Corine database shows a different land use than the Basis-DLM does. In addition, the Corine database shows no land-use changes from 1990 to 2000. The Basis-DLM database, which is better and newer than Corine, is used for the year 2000. The data for 1990 are obtained via backward extrapolation from the Basis-DLM's data for 2000, within the meaning of "no changes" with regard to 1990.

6.3.4.2 Derivation of annual land-use changes

Following the land-use-identification process, the relevant land-use-change categories were derived for each change period (1990-2000, 2001-2005, 2006-2010, 2011-2015, 2016-2020) and each sample point. A function was programmed to that end; it is documented in the inventory description.

The process of developing a land-use matrix that takes account of the required 20-year transition period following a land-use change takes place in several sub-steps:

- All land-use changes that occur within a transition period covered by the included observations (1990-2020) are first analyzed point-specifically. At the same time, the land-use changes are spatially correlated with the individual observation points.
- Land-use-change areas that emerged prior to that period (1970-1990) are back-extrapolated from observations carried out during the first measurement period (1990-2000). Spatial correlation with the observation points is carried out by distributing the area sums among the points.
- The observation period is divided into transition periods of different lengths (1990-2000, 2001-2005, 2006-2010, 2011-2015, 2016-2020), and the annual changes in those change periods are calculated on a proportional basis, via linear interpolation.

As of the 2020 submission, all effective land-use changes are being followed with point-by-point precision. In addition, the inventory now takes account of land-use changes occurring before the end of the assumed 20-year transition period. However, each point (or corresponding area) that undergoes a land-use change is reported for exactly 20 years within its last land-use-change category. Example: The point with ID 2000 undergoes land-use changes in 1995, 2002, and 2006. In keeping with the types of changes involved, that 1 ha of land is reported for the period 1995 through 2001 in the change category Grassland to Cropland, for the period 2002 through 2005 in the change category Cropland to Grassland and for the period as of 2006 in the change category Grassland to Cropland. If it undergoes no further land-use changes, it remains in that final change category until 2025. As of 2026, it then is transferred into the category Cropland remaining Cropland.

6.3.5 Land-use changes pursuant to the Convention and the KP

The method described here for determining land-use changes, and the resulting land-use matrix (cf. Table 358), including a 20-year "transition time" beginning in 1970, are compliant with reporting requirements pursuant to the UNFCCC, as set forth in the 2006 IPCC Guidelines. Table 359 shows the complete detailed land-use matrix for 2020, by way of example.

For determination of land-use changes pursuant to the Kyoto Protocol, the same set of annual data is used (cf. Table 360), but only land-use changes since 1990 are taken into account and, in the transition categories of afforestation and deforestation, they are accumulated for more than 20 years (cf. Table 484 in Chapter 11.2.2).

Table 358: Areas of the various land-use categories, and their transitions, including a 20-year transition time pursuant to reporting rules for the Convention

Year	4.A.1 Forest Land remaining Forest Land [ha]	4.A.2 ... LUC to Forest Land [ha]	4.B.1 Cropland remaining Cropland [ha]	4.A.2 ... LUC to Cropland [ha]	4.C.1 Grassland remaining Grassland [ha]	4.A.2 ... LUC to Grassland [ha]	4.D.1 Wetlands remaining Wetlands [ha]	4.A.2 ... LUC to Wetlands [ha]	4.E.1 Settlements remaining Settlements [ha]	4.A.2 ... LUC to Settlements [ha]	4.F.1 Other Land remaining Other Land [ha]	4.F.2 ... LUC to Other Land [ha]
1990	10,603,849	234,560	13,087,052	502,120	6,440,662	365,570	617,555	30,596	3,602,566	238,000	67,592	0
1991	10,614,144	234,605	13,091,228	500,795	6,427,790	362,636	617,993	30,493	3,606,478	237,411	66,549	0
1992	10,624,440	234,654	13,095,278	499,600	6,414,498	360,140	618,396	30,403	3,610,299	236,915	65,499	0
1993	10,634,733	234,702	13,099,229	498,504	6,400,842	357,996	618,812	30,328	3,614,105	236,420	64,451	0
1994	10,645,034	234,747	13,103,041	497,546	6,386,851	356,190	619,203	30,261	3,617,825	236,018	63,406	0
1995	10,655,325	234,788	13,106,651	496,785	6,372,775	354,486	619,566	30,217	3,621,496	235,671	62,362	0
1996	10,665,623	234,825	13,110,116	496,171	6,358,239	353,221	619,937	30,177	3,625,030	235,463	61,320	0
1997	10,675,921	234,858	13,113,465	495,673	6,343,417	352,259	620,285	30,151	3,628,556	235,259	60,278	0
1998	10,686,213	234,901	13,116,586	495,399	6,328,314	351,575	620,598	30,176	3,631,999	235,132	59,229	0
1999	10,696,506	234,942	13,119,613	495,236	6,312,954	351,136	620,861	30,240	3,635,317	235,135	58,182	0
2000	10,706,800	234,990	13,122,548	495,140	6,297,280	350,993	621,165	30,283	3,638,608	235,176	57,139	0
2001	10,709,914	232,518	12,994,384	547,088	6,197,948	473,495	616,216	40,254	3,621,145	302,241	54,919	0
2002	10,713,031	230,048	12,865,679	599,584	6,098,076	596,551	611,230	50,243	3,603,278	369,704	52,698	0
2003	10,716,163	227,561	12,736,212	652,837	5,997,247	720,563	606,224	60,246	3,585,267	437,315	50,487	0
2004	10,719,275	225,096	12,606,246	706,612	5,895,588	845,394	601,170	70,287	3,567,017	505,164	48,273	0
2005	10,722,398	222,629	12,475,684	760,960	5,793,154	970,985	596,085	80,384	3,548,525	573,255	46,063	0
2006	10,728,690	220,337	12,403,205	778,909	5,748,922	1,027,958	594,815	87,790	3,544,242	610,165	45,089	0
2007	10,734,965	218,024	12,330,261	797,349	5,704,136	1,085,478	593,567	95,186	3,539,786	647,252	44,118	0
2008	10,741,245	215,722	12,256,850	816,258	5,658,944	1,143,401	592,334	102,565	3,535,192	684,460	43,151	0
2009	10,747,526	213,419	12,183,154	835,438	5,613,292	1,201,783	591,008	110,049	3,530,618	721,649	42,186	0
2010	10,753,808	211,114	12,109,157	854,922	5,567,043	1,260,750	589,731	117,468	3,526,063	758,847	41,219	0
2011	10,761,436	205,818	12,004,174	916,736	5,497,334	1,324,694	589,864	121,548	3,529,093	798,719	40,706	0
2012	10,769,069	200,515	11,898,369	979,400	5,427,036	1,389,231	589,997	125,624	3,532,018	838,670	40,193	0
2013	10,776,698	195,201	11,792,099	1,042,530	5,356,323	1,454,172	590,126	129,729	3,534,739	878,818	39,687	0
2014	10,784,326	189,903	11,685,376	1,106,091	5,285,102	1,519,638	590,250	133,818	3,537,331	919,116	39,171	0

Year	4.A.1 Forest Land remaining Forest Land [ha]	4.A.2 ... LUC to Forest Land [ha]	4.B.1 Cropland remaining Cropland [ha]	4.A.2 ... LUC to Cropland [ha]	4.C.1 Grassland remaining Grassland [ha]	4.A.2 ... LUC to Grassland [ha]	4.D.1 Wetlands remaining Wetlands [ha]	4.A.2 ... LUC to Wetlands [ha]	4.E.1 Settlements remaining Settlements [ha]	4.A.2 ... LUC to Settlements [ha]	4.F.1 Other Land remaining Other Land [ha]	4.F.2 ... LUC to Other Land [ha]
2015	10,791,942	184,604	11,578,168	1,170,151	5,213,639	1,585,323	590,305	137,990	3,539,742	959,599	38,659	0
2016	10,797,934	186,964	11,522,203	1,195,214	5,168,322	1,625,078	589,936	141,054	3,541,110	984,151	38,156	0
2017	10,803,927	189,323	11,465,263	1,221,246	5,122,399	1,665,430	589,533	144,151	3,542,310	1,008,885	37,655	0
2018	10,809,927	191,677	11,408,187	1,247,418	5,076,123	1,706,115	589,107	147,305	3,543,562	1,033,543	37,158	0
2019	10,815,925	194,029	11,350,312	1,274,401	5,029,548	1,747,071	588,734	150,413	3,544,634	1,058,397	36,658	0
2020	10,821,924	196,383	11,292,118	1,301,692	4,982,617	1,788,409	588,308	153,555	3,545,593	1,083,362	36,161	0

Table 359: Land-use matrix for 2020. In each case, the boldface number on the diagonal shows the area remaining in the same category for the column in question. The other table cells show the relevant land-use changes (including 20-year transition times)

Land-use matrix for 2020: Areas [ha]																	
Initial*Final*	*Forest Land*	*Cropland annual*	*Hops*	*Vineyards*	*Orchards*	Tree nurseries	Christmas tree plantations	Short-rotation plantations	*Grassland (in the strict sense)*	*Woody Grassland*	*Terrestrial Wetlands*	*Waters*	*Peat extraction*	*Settlements*	*Other Land*	**Σ reductions**	**Σ additions - Σ reductions**
Forest Land	10,821,924	0	0	0	0	0	0	0	0	0	10,321	7,838	64	95,828	0	114,051	82,332
Cropland annual	1,061	11,006,628	4,683	3,070	12,291	7,380	4,535	1,116	1,485,685	55,734	1,306	13,773	434	514,899	0	2,105,967	-777,373
Hops	95	2,956	15,047	0	113	0	0	3	243	0	0	2	0	106	0	3,518	1,736
Vineyards	186	3,240	2	107,339	215	26	4	2	4,815	3,249	0	16	0	2,297	0	14,052	-8,012
Orchards	1,208	31,933	128	491	54,769	239	223	92	16,587	1,670	2	103	0	4,816	0	57,492	-38,504
Tree nurseries	0	758	0	0	54	13,931	0	473	225	62	0	2	0	137	0	1,711	7,319
Christmas tree plantations	1,808	8,138	8	13	605	0	7,107	0	1,408	299	0	3	0	788	0	13,070	647
Short-rotation plantations	1,535	3,544	7	19	936	0	0	0	1,714	389	3	11	38	878	0	9,074	-1,708
Grassland (in the strict sense)	48,620	1,158,273	376	1,607	3,951	952	3,287	274	4,459,904	175,445	23,683	30,987	2,003	410,188	0	1,859,646	10,324
Woody Grassland	113,190	54,130	36	611	461	0	5,565	5,381	182,900	164,368	2,068	2,960	31	42,093	0	409,426	-132,642
Terrestrial Wetlands	6,784	1,051	0	1	5	8	1	0	9,201	1,322	76,671	1,234	899	1,177	0	21,683	30,074
Waters	7,225	2,866	1	1	14	3	1	0	18,070	2,609	1,027	490,599	16	6,936	0	38,769	66,347
Peat extraction	51	1,864	0	0	0	0	0	0	937	59	3,422	395	14,045	167	0	6,895	-3,220
Settlements	11,702	58,879	13	224	343	422	101	25	141,155	33,776	9,922	46,702	190	3,545,593	0	303,454	779,908
Other Land	2,918	962	0	3	0	0	0	0	7,030	2,170	3	1,090	0	3,052	36,161	17,228	-17,228
Σ additions	196,383	1,328,594	5,254	6,040	18,988	9,030	13,717	7,366	1,869,970	276,784	51,757	105,116	3,675	1,083,362	0		
Σ Land-use category	11,018,307	12,335,222	20,301	113,379	73,757	22,961	20,824	7,366	6,329,874	441,152	128,428	595,715	17,720	4,628,955	36,161		
Total area of Germany									35,790,122								

Table 360: Annual areas of land-use changes used as a basis for inventory calculations in reporting for the UNFCCC (20-year transition period) and under the Kyoto Protocol (cumulative area changes).

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**
… to Forest Land					
$Cropland_{annual}$ to Forest Land	0	190	12	5	5
Hops to Forest Land	0	0	19	0	0
Vineyards to Forest Land	0	0	37	0	0
Orchards to Forest Land	0	0	242	0	0
Tree nurseries to Forest Land	0	0	0	0	0
Christmas tree plantations to Forest Land	0	0	362	0	0
Short-rotation plantations to Forest Land	0	0	307	0	0
Grassland (in the strict sense) to Forest Land	6,120	1,725	2,526	1,200	4,273
Woody Grassland to Forest Land	2,828	4,816	4,632	4,438	8,752
Terrestrial Wetlands to Forest Land	40	697	345	95	220
Wetlands to Forest Land	343	635	269	219	321
Peat extraction to Forest Land	0	0	2	3	6
Settlements to Forest Land	2,081	864	568	458	451
Other Land to Forest Land	354	329	105	53	97
… to $Cropland_{annual}$					
Forest Land to $Cropland_{annual}$	0	0	0	0	0
Hops to $Cropland_{annual}$	0	0	89	341	221
Vineyards to $Cropland_{annual}$	12	272	309	130	159
Orchards to $Cropland_{annual}$	2,682	3,165	2,312	844	1,191
Tree nurseries to $Cropland_{annual}$	0	0	0	99	79
Christmas tree plantations to $Cropland_{annual}$	0	0	431	918	546
Short-rotation plantations to $Cropland_{annual}$	0	0	128	330	408
Grassland (in the strict sense) to $Cropland_{annual}$	16,471	80,182	50,880	92,681	54,797
Woody Grassland to $Cropland_{annual}$	4,242	5,359	2,620	2,457	3,212
Terrestrial Wetlands to $Cropland_{annual}$	18	59	37	53	102
Waters to $Cropland_{annual}$	335	303	122	175	242
Peat extraction to $Cropland_{annual}$	0	0	78	157	164
Settlements to $Cropland_{annual}$	3,663	9,570	4,907	2,566	3,601
Other Land to $Cropland_{annual}$	133	186	26	1	19

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**
... to Hops					
Forest Land to Hops	0	0	0	0	0
$Cropland_{annual}$ to Hops	0	0	65	347	550
Vineyards to Hops	0	0	0	0	0
Orchards to Hops	0	0	20	7	4
Tree nurseries to Hops	0	0	0	0	0
Christmas tree plantations to Hops	0	0	0	1	0
Short-rotation plantations to Hops	0	0	0	0	1
Grassland (in the strict sense) to Hops	0	0	6	40	34
Woody Grassland to Hops	0	0	0	2	5
Terrestrial Wetlands to Hops	0	0	0	0	0
Waters to Hops	0	0	0	0	0
Peat extraction to Hops	0	0	0	0	0
Settlements to Hops	0	0	0	1	1
Other Land to Hops	0	0	0	0	0
... to Vineyards					
Forest Land to Vineyards	0	0	0	0	0
$Cropland_{annual}$ to Vineyards	8	103	87	244	317
Hops to Vineyards	0	0	0	0	0
Orchards to Vineyards	0	0	19	44	53
Tree nurseries to Vineyards	0	0	0	0	0
Christmas tree plantations to Vineyards	0	0	3	0	0
Short-rotation plantations to Vineyards	0	0	0	2	1
Grassland (in the strict sense) to Vineyards	3	33	45	135	177
Woody Grassland to Vineyards	1	6	12	47	75
Terrestrial Wetlands to Vineyards	0	0	0	0	0
Waters to Vineyards	0	0	0	0	0
Peat extraction to Vineyards	0	0	0	0	0
Settlements to Vineyards	0	5	8	23	22
Other Land to Vineyards	0	1	0	0	0

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**
... to Orchards					
Forest Land to Orchards	0	0	0	0	0
$Cropland_{annual}$ to Orchards	331	956	552	1,004	1,354
Hops to Orchards	0	0	2	3	19
Vineyards to Orchards	0	0	9	21	23
Tree nurseries to Orchards	0	0	0	13	6
Christmas tree plantations to Orchards	0	0	36	56	49
Short-rotation plantations to Orchards	0	0	84	67	50
Grassland (in the strict sense) to Orchards	146	130	80	301	514
Woody Grassland to Orchards	57	42	7	37	61
Terrestrial Wetlands to Orchards	0	0	0	0	1
Waters to Orchards	4	0	0	1	2
Peat extraction to Orchards	0	0	0	0	0
Settlements to Orchards	79	49	15	30	41
Other Land to Orchards	0	0	0	0	0
... to Tree nurseries					
Forest Land to Tree nurseries	0	0	0	0	0
$Cropland_{annual}$ to Tree nurseries	0	0	340	0	0
Hops to Tree nurseries	0	0	1	0	0
Vineyards to Tree nurseries	0	0	6	0	0
Orchards to Tree nurseries	0	0	32	0	0
to Tree nurseries	0	0	184	0	0
to Tree nurseries	0	0	0	0	0
Grassland (in the strict sense) to Tree nurseries	0	0	82	0	0
Woody Grassland to Tree nurseries	0	0	51	630	432
Terrestrial Wetlands to Tree nurseries	0	0	0	0	0
Waters to Tree nurseries	0	0	0	0	0
Peat extraction to Tree nurseries	0	0	0	0	0
Settlements to Tree nurseries	0	0	12	0	0
Other Land to Tree nurseries	0	0	0	0	0
... to Christmas tree plantations					
Forest Land to Christmas tree plantations	0	0	0	0	0
$Cropland_{annual}$ to Christmas tree plantations	0	1	0	0	1,476
Hops to Christmas tree plantations	0	0	0	0	0
Vineyards to Christmas tree plantations	0	0	0	0	5
Orchards to Christmas tree plantations	0	0	0	0	48
Tree nurseries to Christmas tree plantations	0	0	0	0	0

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**
Short-rotation plantations to Christmas tree plantations	0	0	0	0	0
Grassland (in the strict sense) to Christmas tree plantations	0	0	0	221	0
Woody Grassland to Christmas tree plantations	0	0	0	0	0
Terrestrial Wetlands to Christmas tree plantations	0	0	0	0	2
Waters to Christmas tree plantations	0	0	0	0	1
Peat extraction to Christmas tree plantations	0	0	0	0	0
Settlements to Christmas tree plantations	0	0	0	0	84
Other Land to Christmas tree plantations	0	0	0	0	0
… to Short-rotation plantations					
Forest Land to Short-rotation plantations	0	0	0	0	0
$Cropland_{annual}$ to Short-rotation plantations	0	0	0	1,168	0
Hops to Short-rotation plantations	0	0	0	0	0
Vineyards to Short-rotation plantations	0	0	0	2	0
Orchards to Short-rotation plantations	0	0	0	53	0
Tree nurseries to Short-rotation plantations	0	0	0	0	0
Christmas tree plantations to Short-rotation plantations	0	0	0	0	0
Grassland (in the strict sense) to Short-rotation plantations	0	0	0	196	496
Woody Grassland to Short-rotation plantations	0	0	0	672	497
Terrestrial Wetlands to Short-rotation plantations	0	0	0	1	0
Waters to Short-rotation plantations	0	0	0	1	0
Peat extraction to Short-rotation plantations	0	0	0	0	0
Settlements to Short-rotation plantations	0	0	0	27	0
Other Land to Short-rotation plantations	0	0	0	0	0

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**
... to Grassland (in the strict sense)					
Forest Land to Grassland (in the strict sense)	0	0	0	0	0
$Cropland_{annual}$ to Grassland (in the strict sense)	13,706	119,406	78,414	107,683	73,932
Hops to Grassland (in the strict sense)	0	0	10	20	30
Vineyards to Grassland (in the strict sense)	6	349	659	207	309
Orchards to Grassland (in the strict sense)	725	774	694	1,642	885
Tree nurseries to Grassland (in the strict sense)	0	0	0	20	31
Christmas tree plantations to Grassland (in the strict sense)	0	0	47	125	161
Short-rotation plantations to Grassland (in the strict sense)	0	0	52	132	193
Woody Grassland to Grassland (in the strict sense)	3,382	18,111	8,877	7,933	11,960
Terrestrial Wetlands to Grassland (in the strict sense)	21	1,093	419	260	475
Waters to Grassland (in the strict sense)	295	1,779	1,193	911	999
Peat extraction to Grassland (in the strict sense)	0	0	42	76	132
Settlements to Grassland (in the strict sense)	2,202	15,658	11,443	7,044	10,287
Other Land to Grassland (in the strict sense)	382	872	639	141	181
... to Woody Grassland					
Forest Land to Woody Grassland	0	0	0	0	0
$Cropland_{annual}$ to Woody Grassland	599	5,134	3,863	3,037	3,384
Hops to Woody Grassland	0	0	0	0	0
Vineyards to Woody Grassland	0	164	330	125	170
Orchards to Woody Grassland	41	171	176	111	100
Tree nurseries to Woody Grassland	0	0	0	6	9
Christmas tree plantations to Woody Grassland	0	0	89	34	34
Short-rotation plantations to Woody Grassland	0	0	51	27	53
Grassland (in the strict sense) to Woody Grassland	679	12,216	12,773	10,096	12,418
Terrestrial Wetlands to Woody Grassland	1	261	38	60	87
Waters to Woody Grassland	33	209	146	167	197
Peat extraction to Woody Grassland	0	0	0	7	7
Settlements to Woody Grassland	279	3,383	2,168	1,648	2,560
Other Land to Woody Grassland	48	214	69	208	87

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**
… to Terrestrial Wetlands					
Forest Land to Terrestrial Wetlands	7	1,280	362	136	368
$Cropland_{annual}$ to Terrestrial Wetlands	16	243	65	31	33
Hops to Terrestrial Wetlands	0	0	0	0	0
Vineyards to Terrestrial Wetlands	0	0	0	0	0
Orchards to Terrestrial Wetlands	0	0	2	0	0
Tree nurseries to Terrestrial Wetlands	0	0	0	0	0
Christmas tree plantations to Terrestrial Wetlands	0	0	0	0	0
Short-rotation plantations to Terrestrial Wetlands	0	0	0	0	0
Grassland (in the strict sense) to Terrestrial Wetlands	44	1,936	1,071	731	1,685
Woody Grassland to Terrestrial Wetlands	5	205	86	53	133
Waters to Terrestrial Wetlands	7	59	27	29	111
Peat extraction to Terrestrial Wetlands	0	0	90	173	442
Settlements to Terrestrial Wetlands	7	1,385	855	8	24
Other Land to Terrestrial Wetlands	2	1	0	0	0
… to Waters					
Forest Land to Waters	240	685	351	257	347
$Cropland_{annual}$ to Waters	509	1,048	1,119	623	603
Hops to Waters	0	0	0	0	0
Vineyards to Waters	0	2	1	1	0
Orchards to Waters	15	7	6	8	5
Tree nurseries to Waters	0	0	0	0	0
Christmas tree plantations to Waters	0	0	0	1	0
Short-rotation plantations to Waters	0	0	0	1	1
Grassland (in the strict sense) to Waters	299	2,490	1,822	1,339	1,686
Woody Grassland to Waters	70	179	174	135	180
Terrestrial Wetlands to Waters	0	62	109	63	68
Peat extraction to Waters	0	0	3	29	60
Settlements to Waters	318	2,283	3,743	3,172	851
Other Land to Waters	31	66	45	43	82

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**
… to Peat extraction					
Forest Land to Peat extraction	0	0	2	7	6
$Cropland_{annual}$ to Peat extraction	0	0	10	47	48
Hops to Peat extraction	0	0	0	0	0
Vineyards to Peat extraction	0	0	0	0	0
Orchards to Peat extraction	0	0	0	0	0
Tree nurseries to Waters	0	0	0	0	0
Christmas tree plantations to Waters	0	0	0	0	0
Short-rotation plantations to Waters	0	0	0	1	6
Grassland (in the strict sense) to Peat extraction	0	1	22	185	216
Woody Grassland to Peat extraction	0	0	3	2	2
Terrestrial Wetlands to Peat extraction	0	0	3	75	122
Waters to Peat extraction	0	0	0	0	3
Settlements to Peat extraction	0	2	1	7	31
Other Land to Peat extraction	0	0	0	0	0
… to Settlements					
Forest Land to Settlements	1,184	6,643	4,732	3,746	5,052
$Cropland_{annual}$ to Settlements	6,411	44,009	26,404	29,290	15,110
Hops to Settlements	0	0	3	14	7
Vineyards to Settlements	4	173	143	96	82
Orchards to Settlements	265	462	332	154	125
Tree nurseries to Settlements	0	0	0	19	14
Christmas tree plantations to Settlements	0	0	25	76	67
Short-rotation plantations to Settlements	0	0	28	73	85
Grassland (in the strict sense) to Settlements	3,437	27,495	21,798	21,423	19,739
Woody Grassland to Settlements	410	1,696	1,898	2,529	2,922
Terrestrial Wetlands to Settlements	11	122	21	25	136
Waters to Settlements	133	1,651	876	354	476
Peat extraction to Settlements	0	0	4	6	29
Other Land to Settlements	94	547	84	66	33

6.3.6 Verification

For the inventory, the land-use categories were selected so as to be in accordance with the relevant definitions pursuant to the UNFCCC, the Kyoto Protocol and the IPCC. In addition to the basic digital landscape model (B-DLM; Basis-Digitales Landschaftsmodell) of AKTIS®, which serves as the database for the German inventory, there are other, independent systems for surveying land areas (unfortunately, it is not possible to use the German InVeKoS data (IACS) in the present context). There is no system, however, that shows land-use changes in a georeferenced format. As a result, verification always has to be carried out by comparing area sums for land-use categories. Data sets used for comparison:

- Area survey based on the type of actual use involved (survey on the basis of the automatic real estate cadastre and the B-DLM database of ATKIS®, with various post-processing steps (such as conversion of linear elements into areas); official statistics Statistisches Bundesamt (FS 3, R 3.1.2))
- Agricultural-structure survey (ASE; questionnaire-based survey; agricultural statistics) (Statistisches Bundesamt, FS 3, R 3.1.2)
- Sampling grid of the Agricultural Soil Inventory (Bodenzustandserhebung Landwirtschaft) (Jacobs et al., 2018)

These data sources can be used only to a very limited degree for verification purposes, since

- different export formats are involved: statistical data vs. a map with high spatial resolution. As a result, comparison is restricted to area sums. Land-use changes cannot be derived from the data available in statistics.
- They have differing definitions for important land-use categories – especially for agricultural areas, settlements and other land
- They differ widely in their data collection methods – for example, they exhibit
  - differences of survey scope
  - differences in their spatial resolution
  - differences in their approach: statistical approach vs. wall-to-wall approach (in surveying, remote sensing)
  - differences of focus: Land cover, land use or a mixed form thereof
  - exclusion limits and criteria
  - differences in the ways linear elements are recorded and displayed
  - differences in the periodicity of their surveys, etc.

As a result, the various survey systems differ – widely, in some cases – in their area data for the same land-use categories. While such inconsistencies can exceed 10 %, and are well-known, they have been retained with a view to achieving consistent time series in all data sets. Without being manipulated, the results yielded by the different survey systems hardly lend themselves to comparison, on an absolute basis. For this reason, an additional criterion was used for comparison across survey systems: the development of area sums in individual land-use categories since 2000, in the various survey systems, and the pertinent trends. Comparisons with this criterion showed excellent agreement between the results of the area surveys and the corresponding values in the B-DLM. Consequently, area surveys based on the type of actual use involved may be considered consistent with the corresponding data in the inventory.

The three surveys can be compared only with respect to the total agricultural area involved. All three show the applicable trend very accurately. A comparison of individual aspects of the agricultural area, between the agricultural statistics (ASE) and the corresponding values in the land-use matrix (from the B-DLM in AKTIS®) on which the inventory is based, shows a considerably more diffuse picture, at both the national and state (Land) levels. Along with outstanding agreement in the trend, sharp discrepancies in the curve progressions are also apparent. Such discrepancies are clearly seen to depend on the numbers of areas that are subject to exclusion criteria in the relevant reference areas in the official statistics.

This has been confirmed by an additional test. In it, data of the B-DLM were compared with data of the Agricultural Soil Inventory (Bodenzustandserhebung-LW) (Jacobs et al., 2018) and with data of the Agricultural Structural Survey (Agrarstrukturerhebung; ASE) (Statistisches Bundesamt, FS 3, R 3.1.2). The BZE-LW used a nationwide, systematic, complete-coverage sampling grid (8 x 8 km) to survey soil quality on agriculturally used land. The land uses involved were verified on site, for all points of the grid. Differences between the BZE and the B-DLM arise solely through the survey methods used. Whereas the BZE explicitly lists areas with grassland crop rotation as such and then, in post-processing, assigns such areas completely to Cropland (in the ASE, such areas are mapped as Cropland), the B-DLM records the current use – i.e. either Grassland or Cropland – at the time of the survey. When the Grassland values / Cropland values of the B-DLM are adjusted to the relevant values in the BZE, with suitable area offsets in the pertinent other category, the two survey systems' results show excellent agreement, while the Agricultural Structure Survey tends to underestimate the agricultural area, especially with regard to Cropland (as a result of exclusion criteria)(Table 361). With regard to the small difference between the total area represented in the BZE and that represented in the B-DLM, we noted that statistical survey systems with relatively coarse resolution often overestimate the sizes of small areas (cf. Jacobs et al. (2018)).

Table 361: Percentage distribution of agriculturally used land areas, pursuant to the Agricultural Soil Inventory (BZE), the Basic Digital Landscape Model of ATKIS® (B-DLM) and the Agricultural Structural Survey (ASE)[101].

	BZE	B-DLM_GL_an	B-DLM_AL_an	ASE
		[%]		
Cropland	71.9	71.0	71.9	59.6
Grassland	26.4	26.4	25.5	23.5
Special crops	1.6	1.3	1.3	1.0
Total area represented	100.0	98.8	98.8	84.1

6.4 Forest Land (4.A)

6.4.1 Category description (4.A)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**4 A , Forest Land**		**CO_2**	**-19,707.1**	**-1.5%**	**-46,252.0**	**-6.4%**	**134.7%**
-/-	4 A , Forest Land		N_2O	465.0	0.0%	375.4	0.1%	-19.3%
-/-	4 A , Forest Land		CH_4	39.5	0.0%	35.9	0.0%	-9.1%

* The category-specific indirect N_2O emissions are not included and shown as such in the CRF tables; they are included, however, in the sum, for all sub-categories, presented in CRF Table 4.(IV).2

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS/Tier 2	RS/NS	CS/D
CH_4	Tier 2	RS/NS	CS/D
N_2O	Tier 2	RS/NS	CS/D

The categories Forest Land remaining Forest Land (4.A.1) und *Land converted to Forest Land* (4.A.2) are key sources for CO_2 emissions and removals in terms of emissions level, trend and Tier 2 analysis.

[101] The reference area is the total area covered by the BZE. For purposes of correction of areas with grassland crop rotation, the areas shown in the B-DLM were adjusted to the Grassland (B-DLM_GL_an) and Cropland (B-DLM_AL_an) areas shown in the BZE.

In the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a), and in the official Common Reporting Format (CRF) tables for GHG inventories submitted to the UNFCCC Secretariat, the category "Forest Land" is subdivided into "Forest Land remaining Forest Land" and "Land converted to Forest Land". Land converted to Forest Land occurs as a result of succession, reforestation and afforestation, on land previously used for other purposes. Pursuant to the 2006 IPCC Guidelines, when such land-use changes occur, calculations must take a 20-year transition period into account, on the basis of data as of the year 1970 (cf. Chapter 6.3). Consequently, before it can be placed in the category Forest Land remaining Forest Land, Land converted to Forest Land has to remain in the relevant transition category for 20 years. Forest Land remaining Forest Land refers to a) areas that, in the year for which the inventory is being prepared, remain Forest Land, and b) areas that, at the end of a 20-year transition period, are removed from the relevant transition category (Land converted to Forest Land (4.A.2)) and added to the category Forest Land remaining Forest Land.

Reporting in the category *Forest Land* covers CO_2 emissions / removals from mineral and organic soils, above-ground and below-ground biomass, litter, dead wood and wildfires. It also covers nitrous oxide emissions from wildfires, from drainage of organic soils and from mineralisation in mineral soils, and it covers methane emissions from wildfires and from drainage of organic soils.

In 2020, the total emissions from forests amounted to -45,841 kt CO_2 equivalents. Table 362 lists the emissions for the category Forest Land, by pools and GHG, and with the pertinent uncertainties included.

Table 362: Emissions in the category Forest Land for the year 2020

Source category	Gas	Emission	2.5 % percentile	97.5 % percentile	2.5 % percentile	97.5 % percentile
		[kt CO_2-eq.]			%	
Forest Land$_{total}$ [102]		-45,840.7	-38,064.2	-53,621.6	16.96	16.97
Mineral soils	CO_2 [103]	-16,018.0	-7,748.6	-24,287.4	51.63	51.63
	$N_2O_{indirect}$ [104]	2.9	0.4	9.1	86.92	216.72
	N_2O_{direct} [105]	12.7	5.9	31.9	53.33	151.24
Organic soils	CO_2 [103]	2,705.7	2,186.3	3,311.5	19.20	22.39
	CH_4 [106]	34.1	10.6	68.8	68.93	101.98
	N_2O [106]	358.6	-40.6	749.6	111.32	109.01
Biomass	CO_2 [103]	-29,333.6	-26,723.4	-31,944.2	8.90	8.90
Litter	CO_2 [103]	160.3	-330.0	650.6	305.84	305.84
Dead wood	CO_2 [103]	-3.,766.4	-2,834.0	-4,698.9	24.76	24.76
Wildfires	CO_2 [107]	IE	IE	IE	IE	IE
	CH_4 [107]	1.8	0.3	3.3	82.26	82.26
	N_2O [107]	1.2	0.5	1.9	57.21	57.21

In the category Forest Land (2020), the most important factors for removals are the pools biomass (56.02 %), mineral soils (30.56 %) and dead wood (7.19 %). Sources occur via litter, drainage, mineralisation and wildfires. Such sources account for only a very small share – 6.23 % – of the greenhouse-gas balance for forests, however.

[102] Sum of the emissions from CRF tables 4.A, 4(II).A, 4(III).A, 4(IV).2, 4(V).A

[103] CRF table 4.A

[104] The category-specific indirect N_2O emissions are not included and shown as such in the CRF tables; they are included, however, in the sum, for all sub-categories, presented in CRF Table 4.(IV).2

[105] CRF table 4(III).A

[106] CRF table 4(II).A

[107] CRF table 4(V).A

Figure 61: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq.] as a result of land use and land-use changes in forests, 1990 – 2020, by sub-categories

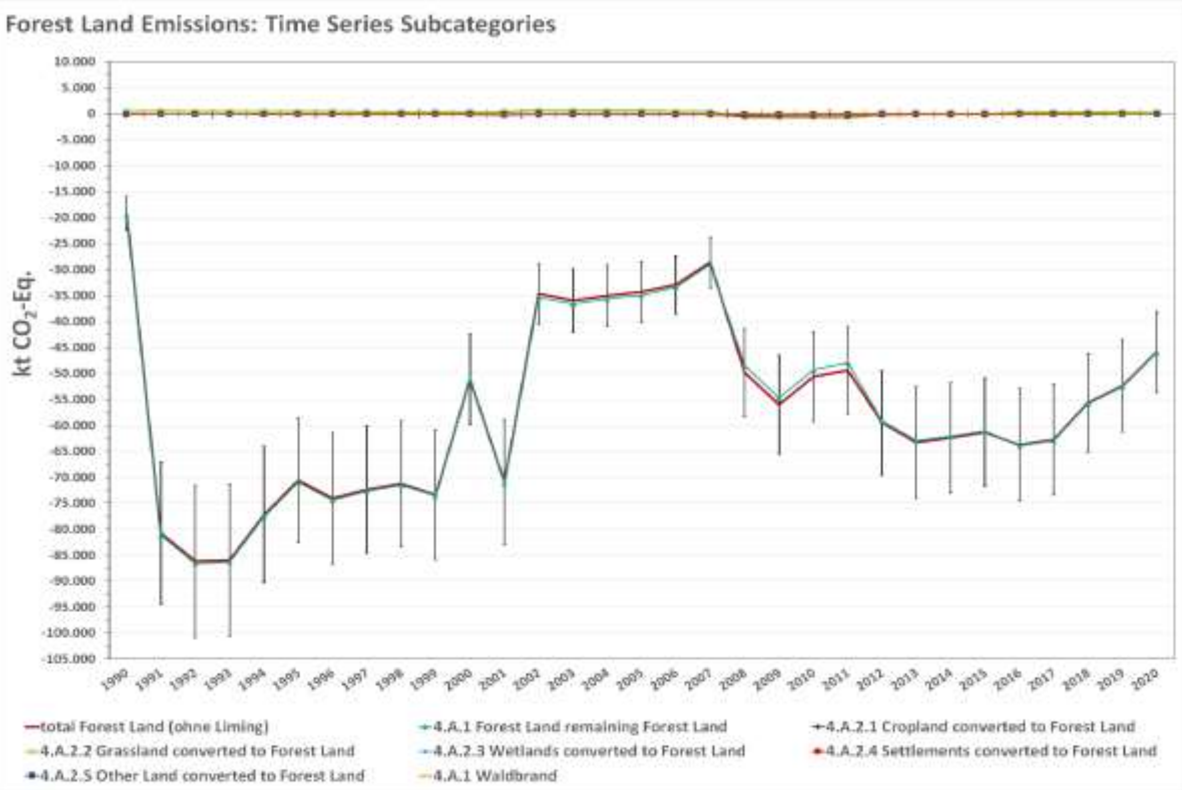
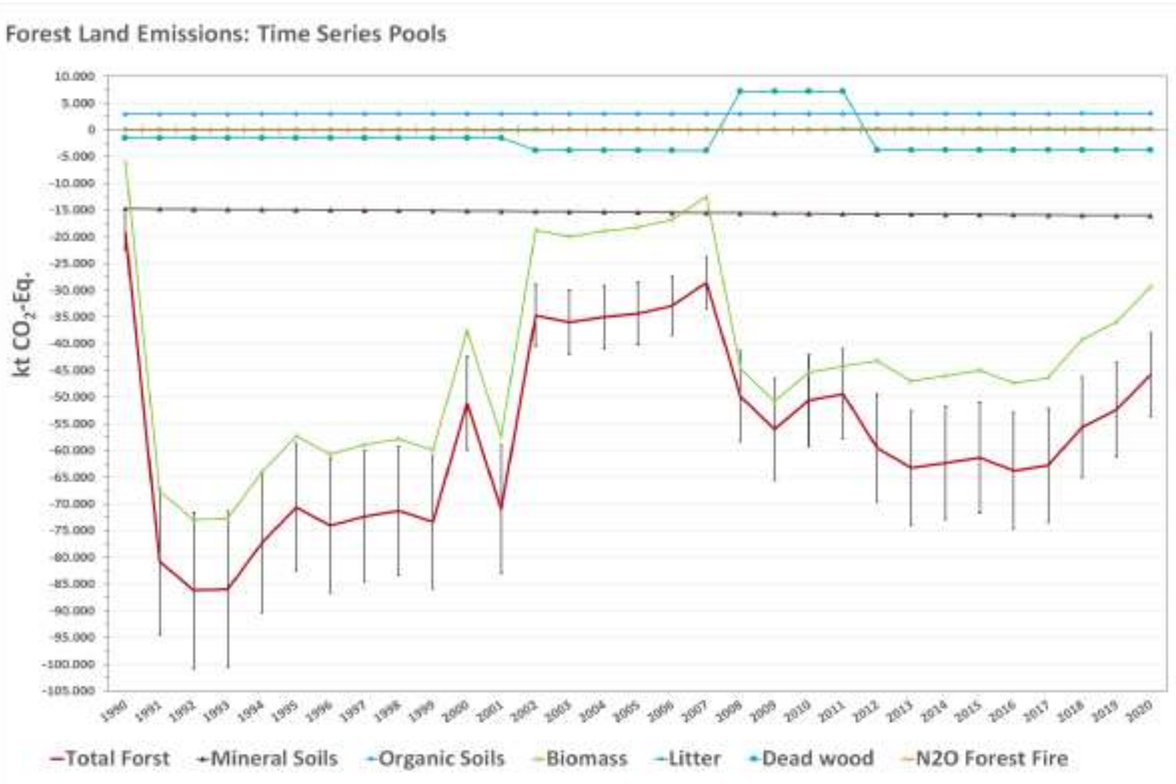


Figure 62: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq.] as a result of land use and land-use changes in forests, 1990 – 2020, by pools



6.4.2 Methodological issues (4.A)

6.4.2.1 Data sources

The following data sources were used for determination of forest areas and of land-use changes that have occurred; for estimation of the relevant emission factors for soil, biomass, litter and dead wood; for calculation of carbon stocks and stock changes at various times and over various periods; and for calculation of emissions from wildfires, drainage and mineralisation:

- National Forest Inventory 1987 (NFI 1987)
- National Forest Inventory 1987 (NFI 1987)
- National Forest Inventory 2002 (NFI 2002)
- National Forest Inventory 2012 (NFI 2012)
- Inventory Study 2008 (Inventurstudie; IS08)
- Carbon Inventory 2017 (CI 2017)
- Datenspeicher Waldfonds (DSW)
- Logging statistics of the Thünen Institute of Wood Research (also used for HWP)
- Forest Soil Inventory I (Bodenzustandserhebung im Wald I; BZE I)
- Forest Soil Inventory II (Bodenzustandserhebung im Wald II; BZE II)
- Official topographic-cartographic information system (Amtliches Topographisch-Kartographisches Informationssystem; ATKIS®)
- CORINE Land Cover (CLC)
- Soil map for the Federal Republic of Germany 1:1,000,000 (Bodenübersichtskarte der Bundesrepublik Deutschland; BÜK 1000)
- Map of Germany's organic soils (Roßkopf et al., 2015)
- Forest-fire statistics of the Federal Republic of Germany

6.4.2.1.1 National Forest Inventory and intermediary inventories, Datenspeicher Waldfonds and logging data

The National Forest Inventory surveys the state of forests, and of forest production potential, on a large scale throughout Germany, using a standardised sampling procedure. The National Forest Inventory is a terrestrial sampling inventory that uses permanently marked sample points in a 4 km x 4 km basic grid whose resolution, at the request of the Länder, has been increased on a regional basis[108]. The first National Forest Inventory (NFI 1987) covered only the territory of the Federal Republic of Germany, in its pre-1990 borders, and West Berlin. It was carried out in the period 1986 to 1989 (sample year 1987). The second National Forest Inventory (NFI 2002) was carried out in the period 2001 to 2003 (sample year 2002), as a repeat inventory in the old German Länder and as a first inventory in the new German Länder (Polley, 2001; Schmitz et al., 2005). The surveys of the third National Forest Inventory (NFI 2012) were carried out from 2011 through 2012 (sample year 2012), as a repeat inventory, and throughout the entire national territory. The NFI 2012 provides data, as of the beginning of the Kyoto Protocol's second commitment period, on the condition of forests and the ways they are changing.

In addition to being collected in the National Forest Inventories (NFI), forest-condition data were collected in the years 2008 and 2017 on a sub-sample of the NFI that consisted of an 8 by 8 km grid. For the most part, the Inventory Study 2008 (Inventurstudie; IS08) and the Carbon Inventory 2017 (CI 2017) use the same methods that are used in the National Forest Inventory (Bundesministerium für Verbraucherschutz, 2010; Riedel et al., 2019; Schwitzgebel et al., 2009).

The Datenspeicher Waldfonds (DSWF) database contains complete-coverage forestry-management data for the territory of the former GDR through 1993. Those data were collected at

[108] For further information: http://www.bundeswaldinventur.de

periodic intervals, annually updated with the help of growth models and updated in keeping with completion and change reports of that country's forest operations (Bundesministerium für Verbraucherschutz, 1994).

The logging data are derived from the national logging statistics (Statistisches Bundesamt, FS 3, R 3.3.1) – which underestimate the annual raw-wood harvest by about 30 % – and are calibrated with forest inventory data on removals of raw wood from forests (Rüter) (cf. also Chapter 6.10.2.1).

6.4.2.1.2 Forest Soil Inventory (Bodenzustandserhebung im Wald – BZE)

Carbon emissions from forest soils were estimated via the stock-change method (IPCC, 2006a). To that end, data from the soil surveys BZE I and BZE II were used. The Forest Soil Inventory I (BZE I) was carried out from 1987 to 1992, while the Forest Soil Inventory II (BZE II) was carried out from 2006 to 2008. In both inventories, samples were taken of the total organic layer, hereafter "litter", pursuant to the 2006 IPCC Guidelines, as well as of mineral soils. The data for the inventories were collected by the German Länder.

In the BZE I (Wolff & Riek, 1997) and BZE II (Wellbrock et al., 2006), forest soils throughout Germany were sampled in accordance with an 8 km x 8 km grid. In the sampling procedure, at each grid point, eight satellite samples were taken, within a 10 m radius around a central excavation with an exposed soil profile. For the BZE I, there were 1800 grid points; for the BZE II, there were 2000. The primary reason for the increase in the number of grid sample points, from one inventory to the next, is that for the second it became possible to access areas which had been closed for the first (for which no access permits were available; for example, various former military exercise grounds were opened up).

For the most part, corresponding grid points for the two inventories lay within a 30-m radius. For some 400 points, a systematic grid shift with respect to the BZE I occurred.

For the BZE I, a database is available that contains about 1,800 points for which carbon stocks in litter and mineral soils (0-30 cm depth) have been calculated (Wolff & Riek, 1997). For the BZE II, the German Länder transmitted some 2,000 points to a common national database. Carbon-stocks data are available for about 1,800 of the 2,000 sample points available from the BZE II[109].

6.4.2.2 Biomass (CRF Table 4.A)

6.4.2.2.1 Forest Land remaining Forest Land

The changes in biomass carbon stocks are calculated with the stock-difference method, following a Tier 2 approach (Equation 2.8, 2006 IPCC Guidelines). In the process, only those forest areas are taken into account that were forest land at both points in time (Forest Land remaining Forest Land). Afforested and deforested areas (Land to Forest Land and Forest Land to Land) are not taken into account; the figures for those areas are calculated separately in each case, using the stock-difference method. With that method, one obtains an average country-specific implied emission factor (EF) for the time periods between the relevant inventories. Each such emission factor is calibrated on the basis of the annual quantity of logged wood. For each year, this procedure produces an EF that is adjusted to the pertinent quantity of logged wood. A description of the method is provided by Röhling et al. (2016).

Figure 63 shows the carbon stocks and changes for the various inventory time points and periods. These values highlight the increase in forest biomass carbon stocks as well, even though they include only carbon stocks in the category Forest Land remaining Forest Land (not

[109] cf.: https://www.thuenen.de/de/wo/arbeitsbereiche/waldmonitoring/bodenzustandserhebung/

including Land converted to Forest Land). The carbon-stock-change values are the EF for the relevant period. Overall, the forests of the Federal Republic of Germany thus act as a net sink for carbon.

Figure 63: Soil organic carbon stocks and carbon-stock changes in below-ground and above-ground phytomass, in forests, for the years 1987/1993, 2002, 2008, 2012 and 2017

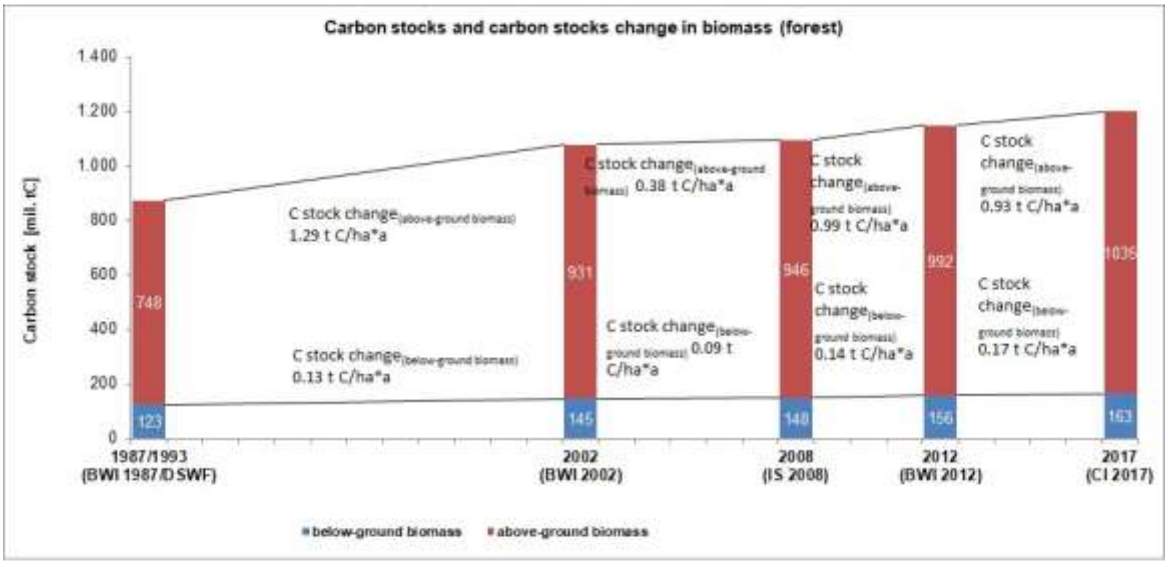


Figure 64 shows the relevant logging statistics for Germany. The method used to derive these statistics is described in Chapter 6.10.2.1 and in (Rüter). The annual EF, which are shown in Table 363, have been derived from the logging recalculation.

Figure 64: Quantities of wood logged in Germany

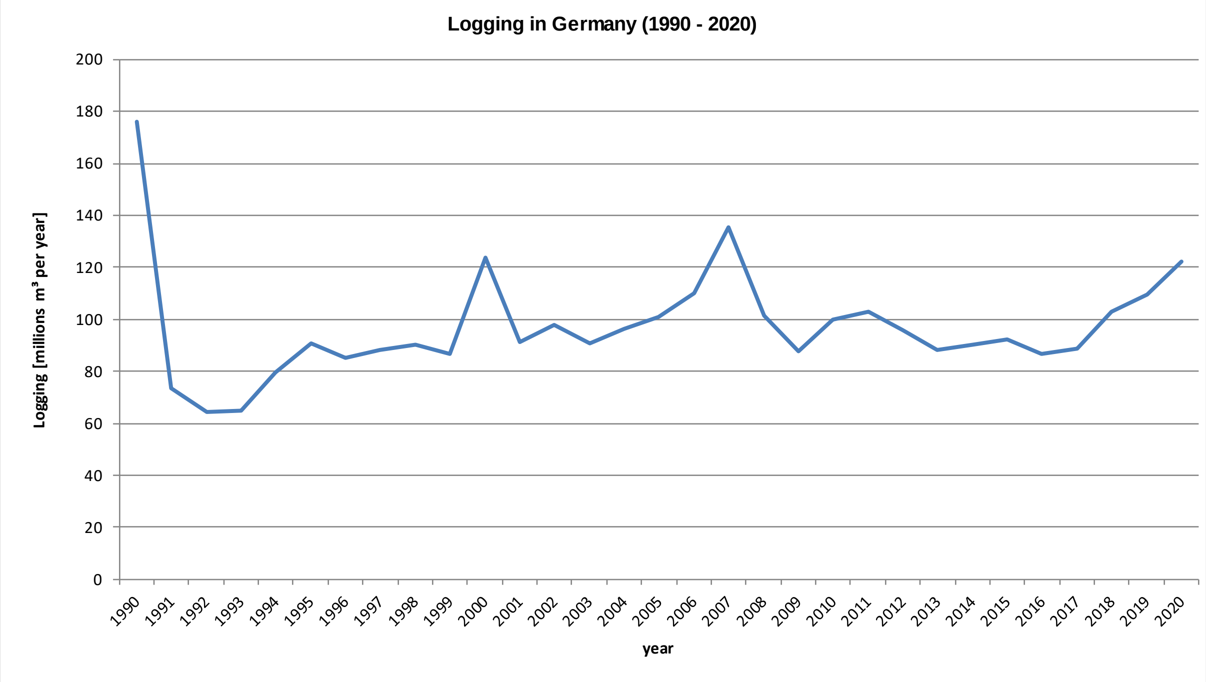


Table 363: Emission factors for above-ground and below-ground biomass on Forest Land remaining Forest Land

Year	EF above-ground biomass [t C*ha]	EF below-ground biomass [t C*ha]
1990	0.14	0.01
1995	1.34	0.13
2000	0.87	0.08
2005	0.38	0.10
2010	0.99	0.14
2015	0.96	0.17
2016	1.02	0.18
2017	1.00	0.18
2018	0.85	0.15
2019	0.78	0.14
2020	0.64	0.11

The very low emission factors in the years 1990 and 2007 stand out. They correlate with the large quantities of timber cut in those years, as a result of storm events that damaged very large numbers of trees. In 1990, Germany was hit by a series of hurricanes that damaged about 70 million m^3 of timber. In 2007, hurricane "Kyrill" struck, leaving behind about 37 million m^3 of damaged timber. At present, as a result of drought and related beetle infestations in the period 2018 through mid-2020, timber damage is estimated to have reached about 178 million m^3 (BMEL, 2020). The figures reported for the years 2018 through 2020 do not yet reflect the full extent of all of this timber damage. The logging statistics only take account of wood that has actually been harvested and moved into wood processing or storage; they do not take account of damaged timber that remains in forests. No reliable estimates of the quantities of such remaining damaged timber are yet available.

Another aspect to be considered is that the relevant damaged timber has to be shifted from the biomass pool into the dead wood pool; in the balance on which reporting is based, the size of the latter pool will then be of an order of magnitude similar to that of the timber damage. It will not be possible estimate the size of that pool reliably, however, until reliable pertinent data become available, via the results of the next National Forest Inventory.

6.4.2.2.2 Land converted to Forest Land

The changes in biomass carbon stocks on Land converted to Forest Land are calculated following the Tier 2 method given by Equation 2.16 of the *2006 IPCC Guidelines*. In that method, the stock changes are determined as the difference between the biomass stocks prior to the conversion and after the conversion (cf. also Chapter 6.1.2.3). In each case in the CRF tables, the biomass stocks from the previous use that are lost are entered under "losses," while the biomass increase on Land converted to Forest Land is entered under "gains."

The National Forest Inventory (BWI) differentiates between forest land that has been afforested (Land to Forest Land), forest land that was already forest (Forest Land remaining Forest Land) and forest land that has been deforested (Forest Land to Land). The pertinent change calculation is carried out separately for the categories afforestation, Forest Land remaining Forest Land and deforestation. The stock changes calculated in this context (using the stock-difference method) refer only to afforestation areas.

For the category Land converted to Forest Land, an individual-tree calculation was carried out on the basis of the NFI 1987, the NFI 2002, the IS2008, the NFI 2012 and the CI 2017. For the period through 2002, only trees in the old German Länder were taken into account, since the NFI 1987 inventory was carried out only there. As of the year 2002, calculations were carried out on a nationwide basis. The biomass carbon stocks were calculated for each area on which conversion from a given land use to Forest Land took place, and then all the resulting stocks were aggregated within the category "Land converted to Forest Land". The stocks of initial land-use categories were deducted – and thus taken into account.

For the new German Länder in the period 1990 through 2002, it was not possible to derive timber stocks for Land converted to Forest Land directly from comparison of two inventories. Thus, the relevant values for the old German Länder were used for that period.

It must be remembered that afforested areas remain in this land-use category for 20 years. On the areas added each year, the carbon-stock losses from initial land uses must be taken into account in the year in which conversion takes place; those losses are immediately accounted for as emissions.

Table 364 shows the EF for the annual increase in the above-ground and below-ground biomass on afforestation areas, without reference to previous uses.

Table 364: EF for above-ground and below-ground biomass on Land converted to Forest Land

Period	1990-2001	2002-2007	2008-2011	2012-2020
EF above-ground biomass [t C*ha]	-0.70	-0.22	-1.94	-0.86
EF below-ground biomass [t C*ha]	-0.14	-0.06	-0.34	-0.18

6.4.2.2.3 Derivation of individual-tree biomass

The above-ground biomass is estimated by means of biomass functions derived from the data of the BWI. Additional information is presented in Kändler and Bösch (2013) and in Chapter 6.4.2.2.4. The below-ground biomass is also derived via allometric equations. The equations being used for this purpose are representative of national circumstances (cf. Chapter 6.4.2.2.5).

Soil organic carbon stocks in the old German Länder as of 1987 were calculated on the basis of data from the NFI 1987 (some 230,000 measured trees). For the new German Länder, data on forest-management plans through 1993 are available in an aggregated form, in the Datenspeicher Waldfonds database, which can be used for calculations of carbon stocks. The NFI

2002 survey, in which some 377,000 trees were measured, provides the database for the 2002 sampling year. The data of the NFI 2012, covering some 537,000 trees, are now also available. The NFI data are supplemented with data from the Inventory Study 2008 (repeat surveys of some 83,000 trees) and the Carbon Inventory 2017 (repeat surveys of some 96,000 trees). These data sources provide such a good basis for calculation of the estimated carbon-stock changes that it was possible to use the stock-difference method (IPCC (2006a)) instead of the gain-loss method (IPCC (2006a)).

6.4.2.2.4 Conversion into above-ground individual-tree biomass

The some 1,600 trees covered by the study of Kändler and Bösch (2013) included only the species spruce, pine, beech and oak. All other tree species, except for soft hardwoods species, were included in those four species groups. If the study had also included the soft hardwoods in the beech group, and then applied the pertinent functions and coefficients, it would have considerably overestimated the biomass of that group. For this reason, for soft hardwoods a more suitable allometric equation of the same type was used that was adapted with the help of "pseudo-observations" based on the tables in Grundner and Schwappach (1952).

The biomass allometric equations based on the tree-species groups are divided into three parts:

- Trees >= 10 cm diameter at breast height (DBH)
- Trees >= 1.3 m height and < 10 cm DBH, and
- Trees < 1.3 m height

Trees that are less than 1.3 m in height (and for which no DBH can be measured) cannot be reasonably differentiated in accordance with the five aforementioned tree-species groups. For this reason, such trees are differentiated only in terms of whether they are coniferous or broadleaf trees. In conversion areas, the functions have been smoothed with the help of statistical procedures. This prevented any jumps between the functions that might otherwise have occurred.

The following section presents the equations used for deriving above-ground biomass from the BWI data, as well as the equations' coefficients, broken down by tree-species groups.

Trees with at least 10 cm DBH

Equation 40:

$$Y_{BIOM_0} = b_0 e^{b_1 \frac{BHD}{BHD+k_1}} e^{b_2 \frac{D03}{D03+k_2}} H^{b_3}$$

Where Y_{BIOM_0} = Above-ground biomass in kg per individual tree,

$b_{0,1,2,3}$ and $k_{1,2}$ = Coefficients of the Marklund function,

DBH = Diameter at breast height in cm,

D03 = Diameter in cm at 30% of tree height,

H = Tree height in m.

Table 365: Coefficients of biomass function for trees >= 10 cm DBH

Tree species	b_0	b_1	b_2	b_3	k_1	k_2	RMSE%
Spruce	0.75285	2.84985	6.03036	0.62188	42.0	24.0	11.2
Pine	0.33778	2.84055	6.34964	0.62755	18.0	23.0	15.6
Beech	0.16787	6.25452	6.64752	0.80745	11.0	135.0	18.8
Oak	0.09428	10.26998	8.13894	0.55845	400.0	8.0	12.1
Soft hardwoods	0.27278	4.19240	5.96298	0.81031	13.7	66.8	50.0[110]

Trees > 1.3 m height and < 10 cm DBH

Equation 41:

$$Y_{BIOM_0} = b_0 + \left(\frac{b_s - b_0}{d_s^2} + b_3(BHD - d_s)\right) BHD^2$$

Y_{BIOM_0} = Above-ground biomass in kg per individual tree,

$b_{0,s,3}$ = Coefficients of the function,

DBH = Diameter at breast height in cm,

d_s = Diameter-validity boundary for this function = 10 cm.

Table 366: Coefficients of biomass function for trees >= 1.3 m height and < 10 cm DBH

Tree species	b_0	b_s	b_3
Spruce	0.41080	26.63122	0.01370
Pine	0.41080	19.99943	0.00916
Beech	0.09644	33.22328	0.01162
Oak	0.09644	28.94782	0.01501
Soft hardwoods	0.09644	16.86101	-0.00551

Trees < 1.3 m height

Equation 42:

$$Y_{BIOM_0} = b_0 \, H_1^b$$

Y_{BIOM_0} = Above-ground biomass in kg per individual tree,

$b_{0,1}$ = Coefficients of the function,

H = Tree height in m.

In the NFI, heights of trees smaller than 1.3 m are recorded only in terms of two basic classes: 20 – 50 cm and 50 – 130 cm, and thus the mid-range values of these classes, 35 cm and 90 cm, have been used in the function as standard values.

Table 367: Coefficients of biomass function for trees < 1.3 m height

Tree species	b_0	b_1
Spruce	0.23059	2.20101
Beech	0.04940	2.54946

No inventory data were available for the new German Länder for the year 1990. The only available data source is the Datenspeicher Waldfonds of 1993, which surveyed the stocks and the forested areas in the new German Länder via a consistent method. For this reason, the raw-wood stocks have been converted into biomass, using the methods described in Burschel et al. (1993). In a first step of the relevant process, the raw-wood volume is multiplied by the applicable root percentage; this yields the pertinent below-ground volume. Then the raw-wood volume and the below-ground volume are multiplied by a volume-expansion factor. The product of that

110 For this function, no figure for RMSE% is available. Therefore, the IPCC default value of 50% has been used.

multiplication is then the applicable total tree-wood volume. The branch volume is obtained by subtracting the raw-wood volume and the below-ground volume from the tree-wood volume. Then, the various volumes are multiplied by the bulk density, using specific-bulk-density figures, pursuant to Pistorius et al. (2007), for the branch volume. All relevant values are listed in the following tables.

Table 368: Root percentages and bulk densities for conversion of Datenspeicher Waldfonds data

Tree species	Root percentage (up to 20 years old)	Root percentage (> 20 years)	RMSE%	Bulk density (roundwood and roots)	Bulk density (branch wood)	RMSE%
Spruce	100	30	50	0.38	0.49	18.8
Fir	100	25	50	0.36	0.49	22.7
Douglas fir	100	25	50	0.41	0.49	20.7
Pine	100	25	50	0.43	0.49	27.2
Larch	100	25	50	0.49	0.49	18.2
Beech	100	25	50	0.56	0.54	13.7
Oak	100	25	50	0.57	0.57	19.8
Hard hardwoods	100	25	50	0.56	0.57	15.0
Soft hardwoods	100	25	50	0.46	0.54	8.7

Table 369: Volume-expansion factors for conversion of raw-wood volume and below-ground volume into the tree-wood volumes of the Datenspeicher Waldfonds data

Tree species	0 through 20 years	21 through 40 years	41 through 60 years	61 through 80 years	81 through 100 years	101 through 120 years	121 through 140 years	141 through 160 years	> 160 years	RMSE%
Spruce	4	1.65	1.51	1.45	1.45	1.45	1.46	1.47	1.48	50
Fir	4	1.52	1.44	1.44	1.38	1.41	1.41	1.42	1.41	50
Douglas fir	4	1.65	1.51	1.45	1.45	1.45	1.46	1.47	1.48	50
Pine	4	1.51	1.42	1.40	1.36	1.34	1.34	1.34	1.33	50
Larch	4	1.51	1.42	1.40	1.36	1.34	1.34	1.34	1.33	50
Beech	4	1.69	1.47	1.41	1.38	1.39	1.39	1.38	1.39	50
Oak	4	1.58	1.41	1.39	1.37	1.35	1.34	1.35	1.34	50
Hard hardwoods	4	1.69	1.47	1.41	1.38	1.39	1.39	1.38	1.39	50
Soft hardwoods	4	1.69	1.47	1.41	1.38	1.39	1.39	1.38	1.39	50

No uncertainties are known for the root percentage and for the volume-expansion factor. For this reason, the IPCC default value of 50 % has been used.

6.4.2.2.5 Conversion into below-ground biomass

As of the 2015 Submission, allometric equations based on peer-reviewed articles are used. This addresses the need for consistency between the method used to derive above-ground biomass and that used to derive below-ground biomass, as well as the need for overall clarity and transparency. The Thünen Institut has developed a separate biomass function for derivation of below-ground biomass for pine. All biomass functions chosen are of the form of Equation 43.

Equation 43:

$$Y_{BIOM_u} = b_0\ BHD^{(b_1)}$$

Y_{BIOM_u} = Below-ground biomass, in kg per individual tree

$b_{0,1}$ = Coefficients of the below-ground biomass function.

DBH = Diameter at breast height in cm

Table 370: Coefficients, parameters, uncertainties and sources for the biomass functions used, by tree species

Tree species	b_0	Parameter	b_1	RMSE%	Region	Source
Spruce	0.003720	DBH [cm]	2.792465	34.6	Solling	(Bolte et al., 2003)
Pine	0.006089	DBH [cm]	2.739073	26.3	Barnim	(Neubauer & Demant, 2016)
Beech	0.018256	DBH [cm]	2.321997	49.0	Solling	(Bolte et al., 2003)
Oak	0.028000	DBH [cm]	2.440000	50.0[111]	Northeast France	(Drexhage & Colin, 2001) in (Bolte et al., 2003)
Soft hardwoods (root biomass)	0.000010	DBH [mm]	2.529000	9.6	South Sweden	(Johansson & Hjelm, 2012)
Soft hardwoods (root-stump biomass)[112]	0.000116	DBH [mm]	2.290300	15.9	South Sweden	(Johansson & Hjelm, 2012)

The log functions available in the literature (cf. Figure 65) were intentionally not used. "Back transformation" of log error values, for further use in the error budget, either was unfeasible or, in cases in which the original measurements were available, yielded values as high as they were in the original scale units.

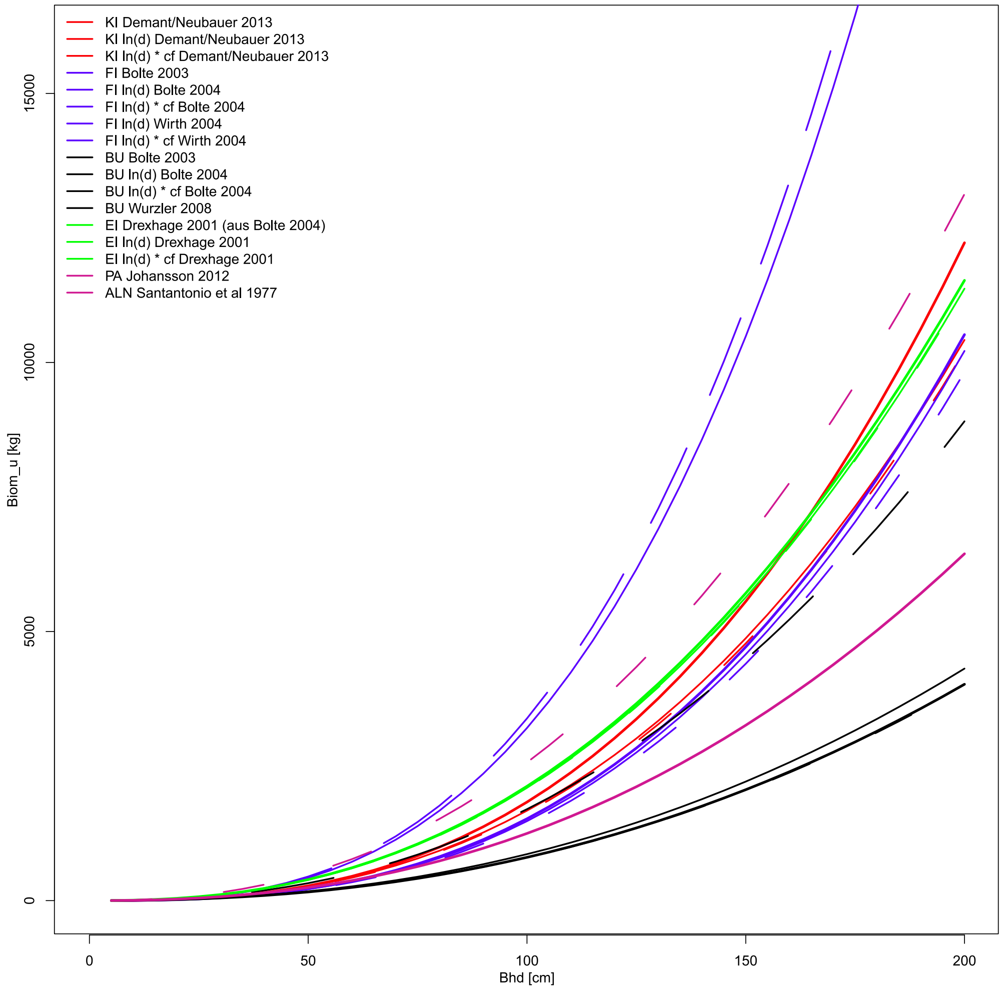
Both the Thünen institute's own pine function (Neubauer & Demant, 2016) and the oak function of Drexhage and Colin (2001), in Bolte et al. (2003), are unique in Europe. The selected functions for beech and spruce cover a considerably broader area of DBH distribution, especially for larger diameters, than do the comparable studies of Wutzler et al. (2008) and Wirth et al. (2004). The functions thus have a considerably smaller extrapolation region, which prevents upward "drifting" of biomass values (cf. Figure 65).

At the same time, the chosen functions for spruce and beech were derived from data of a small region, the "Solling" region. On the other hand, the functions of Wutzler et al. (2008) and Wirth et al. (2004) make use of data from various, and geographically different, studies.

This comparison of the chosen functions for spruce, beech and soft hardwoods (in each case, the unbroken line in Figure 65) with functions from other publications shows that the chosen functions always produce conservative estimates of biomass stocks. The rates of change between two states are thus also small compared to the corresponding figures produced by other functions. Since carbon accumulates in the category of below-ground biomass, throughout the entire period covered by the report, the estimates of the sequestration rate may be considered conservative.

111 For this function, no figure for RMSE% is available. Therefore, the IPCC default value of 50% has been used.
112 The mean RMSE% for both functions (root-stump biomass + root biomass) is 24.2%.

Figure 65: Comparison of different functions for derivation of below-ground biomass



6.4.2.2.6 Conversion of individual-tree biomass to carbon

A value of 0.5 has been applied for conversion of biomass to carbon stocks. Wirth et al. (2004) report that the differences between compartments within a given tree species are larger than the differences between tree species. They obtain a range of 0.50 to 0.56 g C g^{-1} in conifers. The relative standard error for carbon content in wood is given by Burschel et al. (1993) as 1 to 2 %; Weiss et al. (2000) use 2 %. Overall, therefore, 0.5 g C g^{-1}, with a relative standard error of ±2 %, seems appropriate as a good assumption for mean carbon content.

6.4.2.2.7 State estimator for 1987, 2002, 2008, 2012 and 2017

Some German Länder use sampling grids smaller than 4 by 4 km. In addition, some Länder have increased the density of their sampling grids between the inventories. For this reason, extrapolation to the level of the national territory must be done in a stratified manner, using sampling strata with grids of homogeneous densities. This section presents the procedures for scaling up the values "raw-wood stocks", "biomass" and "carbon", in the framework of the stratified sampling plan, for given time periods. The relevant states for the years 1987, 2002, 2008, 2012 and 2017 have been calculated. The up-scaling procedures for different domains (all of Germany, various regions (old/new Länder) and different LULUCF/ARD categories) are identical.

The NFI is designed as a cluster sample. The cluster, with four cluster points (sample points), is the smallest sampling unit. Along the boundaries of the inventory area, or of sampling strata, incomplete clusters, of varying sizes, will be found, i.e. the number of sample points (cluster points in forest and non-forest) within such clusters can vary between 1 and 4. For each cluster c located within a stratum *l*, the local sampling density (*Y*) must be calculated first:

Equation 44:

$$Y_{lc} = \frac{\sum_{m=1}^{M} I_{l,c,m} Y_{l,c,m}}{M_{l,c}}$$

Y = local sampling density

l = stratum

c =cluster

m =sample point

M = number of sample points

The estimator of means for stratum *l*, with respect to the sampling density for both Forest Land and non- Forest Land, is thus obtained as follows:

Equation 45:

$$\hat{\hat{Y}}_l = \frac{\sum_{c_l=1}^{C_l} M_{l,c} Y_{lc}}{\sum_{c_l=1}^{C_l} M_l}$$

$\hat{\hat{Y}}$= Weighted average of the local sampling density

l = stratum
c = cluster
C = number of clusters
M = number of sample points
Y = local sampling density

The estimator of means for a given value, throughout all sampling strata, is the mean of the individual stratum estimators, weighted with the area proportions for the various strata:

Equation 46:

$$\hat{\hat{Y}}_{st} = \sum_{l=1}^{L} \hat{\hat{Y}}_l \frac{\lambda(U_{l)}}{\lambda(U)}$$

$\hat{\hat{Y}}_{st}$= estimator of the total

l = stratum
U = area
λ= estimated value

The estimator of the total is obtained by multiplying the estimator of means throughout all strata by the total area *λ(U)*.

Equation 47:

$$\hat{Y}_{st} = \hat{\hat{Y}}_{st} \lambda(U)$$

$\hat{Y}_{st}$= estimator of the total

st = state
U = area
λ = estimated value

The (forest-) area-related mean value is defined as the quotient or ratio estimator; it is obtained as follows:

Equation 48:

$$\hat{R}_{st} = \frac{\hat{Y}_{st}}{\lambda(U_{Wald})}$$

$\hat{R}_{st}$ = Ratio estimator
$\hat{Y}_{st}$= Total state estimator
U_{Wald} = Forest area
λ = Estimate

6.4.2.2.8 Estimator for stock changes pursuant to the stock-difference method

For calculation of the changes between two time points (as in the periods 1987-2002, 2002-2008, 2008-2012 and 2012-2017), the "continuous forest inventory" (CFI) method was used, i.e. for up-scaling only those cluster points were used that were included at both times. The change estimate is thus based on the difference between the two estimators of the total. At the stratum level, the total change is estimated as follows:

Equation 49:

$$\hat{G}_l = \hat{Y}_l^{(t_2)} - \hat{Y}_l^{(t_1)}$$

$\hat{G}_l$= total change in stratum
l = stratum
t = time
$\hat{Y}$= estimator of the total

The total change throughout all strata for a given domain is estimated in the manner described in Equation 49. The estimated total change is calculated by means of Equation 50. The change in the area-related mean estimator is determined via:

Equation 50:

$$\hat{G}_{R\,st} = \hat{R}_{st}^{(t_2)} - \hat{R}_{st}^{(t_1)}$$

$\hat{G}_{R_{st}}$= total change over all strata
t = time
$(\hat{R}_{st})$= estimator of ratio

6.4.2.2.9 Derivation of the annual change estimates

Since the National Forest Inventory is a periodically recurring inventory, only average EF can be determined for the years in the periods. To allow for variability in the periods, the logging factor method was used (Röhling et al., 2016). The carbon losses caused by the wood harvest influence the carbon-stocks change. The higher the quantity of harvested wood in a given year is, in comparison to the periodic average, and the higher the resulting carbon losses are, the more the EF is adjusted to the wood harvest. For the logging factor method (LFM), the following equations are used:

Equation 51:

$$EF_{LFM} = EF * (1 + F_1)$$

EF_{LFM} = Annual emission factor corrected to the quantity of logged wood (tC/ha*a)
EF = Average emission factor for the inventory period (tC/ha*a)
F_1 = Correction factor

Equation 52:

$$F_1 = \frac{(L_{fp} - L_{fa})}{L_{fp}}$$

F_1 = Correction factor
L_{fa} = Annual quantity of logged wood (m^3)
L_{fp} = Periodic quantity of logged wood (m^3)

6.4.2.3 Dead wood (CRF Table 4.A)

6.4.2.3.1 Forest Land remaining Forest Land

The changes in dead-wood carbon stocks are calculated with the stock-difference method, a Tier 2 approach (Equation 2.25, IPCC (2006a)).

The carbon stocks in dead wood were calculated with data of the NFI 2002 (Schmitz et al., 2005), the 2008 Inventory Study, the NFI 2012 and the Carbon Inventory 2017. The NFI 1987 did not include any surveys of dead wood, and thus no dead-wood data for that time are available. The terrestrial survey used for the NFI 2002 included only fallen dead wood with a thicker-end diameter of at least 20 cm, standing dead wood with a diameter of at least 20 cm at breast height (DBH), and trunks with either a height of at least 50 cm or a cut-surface diameter of at least 60 cm (Polley, 2001). In the 2008 Inventory Study, the NFI 2012 Inventory Study and the CI 2017, the survey threshold for dead-wood objects was reduced to a diameter of at least 10 cm at the thicker end, in keeping with requirements for climate reporting (BMELF, 2010). In all three forest inventories, trees were sub-divided into three main tree-species groups: conifers, deciduous trees (except for oaks) and oaks. The degree of decomposition of dead wood was divided into four classes (BMELF, 2010) (Polley, 2001).

For purposes of reporting pursuant to the 2006 IPCC Guidelines, the applicable dead-wood-stock relationship between the 10 cm and 20 cm survey limits was determined from the data collected in the Inventory Study 2008. Under the assumption that this relationship was the same at the time of the NFI 2002, the dead-wood stocks from the 10 cm survey limit upward were estimated for the year 2002. The biomass of the dead-wood stocks from the NFI 2002, the 2008 Inventory Study, the NFI 2017 and the CI 2017, for the various relevant decomposition classes, was determined with the wood density figures pursuant to Fraver et al. (2002) for conifers, and pursuant to Müller-Using and Bartsch (2009) for deciduous trees. To calculate the bulk density of deciduous wood, the dead-wood objects in the deciduous (other than oak) and oak tree-species groups were combined. An overview of the biomass-expansion factors used, and their errors, by tree-species classes and degrees of decomposition, is presented in Table 371.

Table 371: Biomass-expansion factors (BEF) and their errors (RMSE%) for the various tree-species classes and degrees of decomposition (NDH = conifers (Nadelbäume), LBH = deciduous trees (Laubbäume), EI = oak (Eiche))

Type of dead wood	Degree of decomposition		BEF	RMSE%	Source
NDH	1	Just died	0,372	17.2	(Fraver et al.)
NDH	2	Onset of decomposition	0,308	27.9	(Fraver et al.)
NDH	3	Advanced decomposition	0,141	35.5	(Fraver et al.)
NDH	4	Heavily rotted	0,123	25.2	(Fraver et al.)
LBH	1	Just died	0.58	12.1	(Müller-Using & Bartsch)
LBH	2	Onset of decomposition	0.37	43.2	(Müller-Using & Bartsch)
LBH	3	Advanced decomposition	0.21	33.3	(Müller-Using & Bartsch)
LBH	4	Heavily rotted	0.26	65.4	(Müller-Using & Bartsch)
EI	1	Just died	0.58	12.1	(Müller-Using & Bartsch)
EI	2	Onset of decomposition	0.37	43.2	(Müller-Using & Bartsch)
EI	3	Advanced decomposition	0.21	33.3	(Müller-Using & Bartsch)
EI	4	Heavily rotted	0.26	65.4	(Müller-Using & Bartsch)

The annual carbon stock change in dead wood was calculated using Equation 53 (Equation 2.19, IPCC (2006a)). The EF for dead wood on Forest Land remaining Forest Land are shown in Table 372.

Equation 53:

$$\Delta C_{FF_{DW}} = \frac{A * \left(B_{t_2} - B_{t_1}\right)}{T} CF$$

Where:

ΔC_{FFDW} = Annual change in carbon stocks in dead wood, on Forest Land remaining Forest Land [t C ha^{-1}]

A = Area of Forest Land remaining Forest Land [ha]

B_{t1} = Dead-wood stocks at time t_1 (beginning of the period) for Forest Land remaining Forest Land

B_{t2} = Dead-wood stocks at time t_2 (end of the period) for Forest Land remaining Forest Land [t C ha^{-1}]

$T=(t_2-t_1)$ = Time period between the two estimates [a]

CF = Carbon conversion factor (IPCC default value = 0.5)

Table 372: Dead-wood EF for Forest Land remaining Forest Land

Period	1990-2001	2002-2007	2008-2011	2012-2020
EF, dead wood [t C*ha]	0.037	0.097	-0.188	0.095

6.4.2.3.2 Land converted to Forest Land

The annual carbon-stocks change in dead wood on Land converted to Forest Land has been calculated in keeping with Equation 2.19 of the 2006 IPCC Guidelines (IPCC, 2006a). That equation is identical with the equation for calculating changes in dead-wood carbon stocks on Forest Land remaining Forest Land (cf. Equation 53). The data of the NFI 2002, NFI 2012 and CI 2017 were available for determination of dead-wood carbon stocks on Land converted to Forest Land. The 2008 Inventory Study did not collect data on Land converted to Forest Land, and the NFI 1987 did not collect data on dead wood. The EF for dead wood on Land converted to Forest Land are shown in Table 373.

Table 373: Dead-wood EF for Land converted to Forest Land

Period	1990-2007	2008-2011	2012-2020
EF, dead wood [t C*ha]	-0.034	-0.229	-0.003

6.4.2.4 Litter (CRF Table 4.A)

6.4.2.4.1 Forest Land remaining Forest Land

The changes in carbon stocks in litter are calculated with the stock-difference method, following the Tier 2 approach (Equation 2.19, 2006 IPCC Guidelines).

The calculation of carbon-stocks changes in the soil and in litter is based on data from national forest-soil inventories (BZE I and BZE II; cf. Chapter 6.4.2.1.2 and Grüneberg et al. (2014)). A slight decrease in carbon stocks in litter, amounting to a source of -0.02 t C ha^{-1} a^{-1}, occurred in the period from 1990 (BZE I) to 2006 (BZE II) (Grüneberg et al., 2014). That trend is assumed to be valid as well for the period 2007 to 2020. A detailed description of the method used to determine the carbon-stock change in litter is presented in Chapter 6.4.2.4.4.

The third Forest Soil Inventory (BZE III) is currently being prepared. Relevant field measurements will be carried out beginning in 2022. When the results of BZE III become available, recalculations will be carried out for the period as of 2007.

6.4.2.4.2 Land converted to Forest Land

The carbon-stock changes were calculated in keeping with the Tier 2 methodology (Equation 2.23, 2006 IPCC Guidelines, IPCC (2006a)). This methodology requires derivation of the annual rate of carbon-stock change. That rate is calculated from the average litter stocks in forests, under equilibrium conditions, and the transition period that is required for litter stocks to develop following afforestation.

Calculations relative to the litter ground cover were carried out with the status data of the BZE I and BZE II Forest Soil Inventories. According to those calculations, the mean carbon stocks in litter, referenced to 1990 (BZE I), were 19.0 t C ha^{-1}, and, referenced to 2006 (BZE II), 18.8 t C ha^{-1}. This shows that the average carbon stocks in litter in forests also exhibited a slight trend. The average litter carbon stocks are being adjusted in keeping with that trend. For the period 1991 to 2005, the mean carbon stocks in litter are obtained via interpolation; for the period as of 2007 they are obtained via extrapolation and used as a basis for calculating afforestation areas (cf. Table 374). A description of the method used to derive carbon stocks in litter is presented in Chapter 6.4.2.4.3.

Table 374: Implied emission factors (IEF) (carbon) for litter in the land-use categories Land converted to Forest Land

Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
IEF [t C ha^{-1}]	0.4747	0.4732	0.4716	0.4698	0.4684	0.4669	0.4666	0.4662	0.4662	0.4662	0.4662

Regarding the transition period, it was assumed that the resulting average carbon stocks take 40 years to form in litter. That figure is confirmed by standard values for carbon storage in litter, and by standard values for the time periods required for a new balance to form pursuant to {PAUL et al. (2009)} and the 2003 IPCC Good Practice Guidance, Table 3.2.1 (IPCC, 2003). In IPCC Table 3.2.1, the warm, temperate climate zone is assumed to be moist in Germany, and an applicable average is obtained from the values for deciduous and coniferous forests. The annual carbon-stock increase in litter is obtained by dividing the mean carbon stocks for the year in question by the number of years required for those mean carbon stocks to accumulate.

The afforestation areas were not further subdivided into the classes "natural regeneration" and "human induced" (cf. Chapter 11.4.1).

6.4.2.4.3 Derivation of carbon stocks in litter

Litter was sampled at the BZE sample points. This was accomplished by taking mixed samples at satellite plots, using sampling frames of various sizes (Grüneberg et al., 2014). In keeping with the 2006 IPCC Guidelines, litter was considered to include the entire dead organic top soil layer, including the L, Of and Oh horizons (IPCC, 2006a). Organic carbon concentrations in the litter were measured via similar methods. It is assumed that total carbon (C_{ges}) is equal to organic carbon (C_{org}) ($[C_{ges}]=[C_{org}]$). In each case, the carbon stocks in litter are calculated from the area of the sampling frame, and from the weight and organic carbon concentration in the litter. A description of the methods used for sampling and analysis is presented in Wellbrock et al. (2006) and König et al. (2005).

All points available from the BZE I and BZE II surveys, along with information on the respective forest types, entered into calculation of litter carbon stocks. All values that were either smaller or larger than twice the standard deviation ($x \pm 2\sigma$) were considered to be outliers and were deleted. The values of the remaining sample points for the BZE I (n = 1629) and BZE II (n = 1542) enabled the calculation of carbon stocks separately for deciduous, coniferous and mixed forest (cf. Table 375). The mean carbon stocks given by the two inventories were calculated as a weighted mean from the carbon stocks for the three forest types concerned. The applicable weights were obtained from the forest types' area shares of the total forest area, as given by CORINE Land-Cover data for 1990 and 2006, and from the regional densities of the sample grid. The mean carbon stocks in the samples were 19.0 ± 0.3 t C ha^{-1}, for BZE I, and 18.8 ± 0.3 t C ha^{-1}, for BZE II (Grüneberg et al., 2014). These values serve as the basis for calculating CO_2 emissions from litter in connection with deforestation (cf. Chapter 11.3.1.4) and carbon sequestration in litter in connection with afforestation (cf. Chapter 6.4.2.4.2).

Table 375: Soil organic carbon stocks in litter in German forests, as determined in the BZE I and BZE II inventories, along with the pertinent standard error (Grüneberg et al., 2014)

Forest type	Carbon stocks (BZE I) [t C ha^{-1}]	Carbon stocks (BZE II) [t C ha^{-1}]
Deciduous forest	8.35 ± 0.37	6.78 ± 0.30
Mixed forest	17.94 ± 0.63	14.99 ± 0.70
Coniferous forest	23.75 ± 0.44	25.23 ± 0.49
Total forest	**19.04 ± 0.30**	**18.83 ± 0.32**

6.4.2.4.4 Derivation of carbon-stock changes in litter in the period from 1990 (BZE I) to 2006 (BZE II)

The sample points included in the calculation of carbon stocks were analysed as unpaired samples. With a two-sided t-test for unpaired samples, it was tested whether the carbon stocks (which had been logarithmised) at the two inventory times differed. Each sample plot was assigned a weight consisting of the area percentage for the relevant stratum and the regional sample grid density. The average difference was -0.02 ± 0.02 tC ha^{-1} a^{-1} (Grüneberg et al., 2014). The value does not deviate significantly from zero.

For Land converted to Forest Land, annually decreasing factors for litter accumulation were calculated from the carbon stocks given by BZE I / BZE II and the average difference (cf. Chapter 6.4.2.4.2 and Table 374).

6.4.2.5 Mineral soils (CRF Table 4.A)

6.4.2.5.1 Forest Land remaining Forest Land

The changes in carbon stocks in mineral soils are calculated following the Tier 2 methodology of the 2006 IPCC Guidelines (Equation 2.25, IPCC (2006a)).

Carbon stocks, and carbon-stock changes, in mineral soils were up-scaled on the basis of the BZE I and BZE II (cf. Chapter 6.4.2.1.2), in accordance with Grüneberg et al. (2014). With the available data, the changes in mineral soils were calculated, with respect to both inventories. The relevant methods are described in detail in the following Chapters 6.4.2.5.3 and 6.4.2.5.4 . The resulting extrapolation for the entire national territory yielded a mean annual increase in carbon stocks in mineral soils of 0.41 ± 0.11 t C ha^{-1}. It has been assumed that this trend also continued in the period 2007 to 2020.

The third Forest Soil Inventory (BZE III) is currently being prepared. Relevant field measurements will be carried out beginning in 2022. When the results of BZE III become available, recalculations will be carried out for the period as of 2007.

6.4.2.5.2 Land converted to Forest Land

For Land converted to Forest Land, as for Forest Land remaining Forest Land, the carbon-stock change in mineral soils is calculated following the Tier 2 methodology (Equation 2.25, IPCC (2006a)).

For Land converted to Forest Land, the carbon-stock changes in mineral soils were calculated in keeping with the procedure in Chapter 6.1.2.1. The calculated mean emission factors (implied emission factors) for the year 2017, which are summarised in Table 336 in Chapter 6.1.2.1.1, are oriented to annual carbon-stock changes in mineral soils in connection with land-use conversions to Forest Land (Land converted to Forest Land), over a change period of 20 years.

6.4.2.5.3 Derivation of carbon stocks and carbon-stock changes

The carbon stocks and their changes were derived on the basis of inventory data (cf. Chapter 6.4.2.1.2 and Grüneberg et al. (2014)). Mineral soil was sampled at depths of relevance for the national inventory report; at most BZE plots, this involved depth ranges of 0-5 cm, 5-10 cm and 10-30 cm. In a few cases, samples were taken on a horizon basis.

As part of sampling, the fine-soil bulk density (TRD_{fb}), the coarse-fragment content (GBA) and the organic-carbon concentration (C_{org}) were determined using similar methods (König et al., 2005). The fine-soil bulk density was determined via volume-adapted sampling, for different depth ranges; to some extent, values estimated on the basis of soil profiles were used (Wolff and Riek (1997), Wellbrock et al. (2006)). Where fine-soil bulk-density data is lacking, existing relevant values from other inventories have been used. That procedure has also been applied to obtain coarse-fragment-content values, which are needed for calculation of the TRD_{fb} and fine-soil stocks.

In carbonate-containing soils, the organic-carbon concentration (C_{org}) in fine soils was measured with respect to the inorganic-carbon concentration (C_{inorg}) ($[C_{org}] = [C_{total}] - [C_{inorg}]$). In non-carbonate-containing soils, the relationship $[C_{org}] = [C_{total}]$ applies.

The total carbon stocks per plot were calculated from the stocks of the individual depth layers. To that end, it was necessary first to translate horizon-based data into depth-layer sections. This was accomplished, in each case, by calculating the carbon stocks in a given depth layer, with stocks weighted in accordance with the thicknesses of overlapping sections and their carbon stocks.

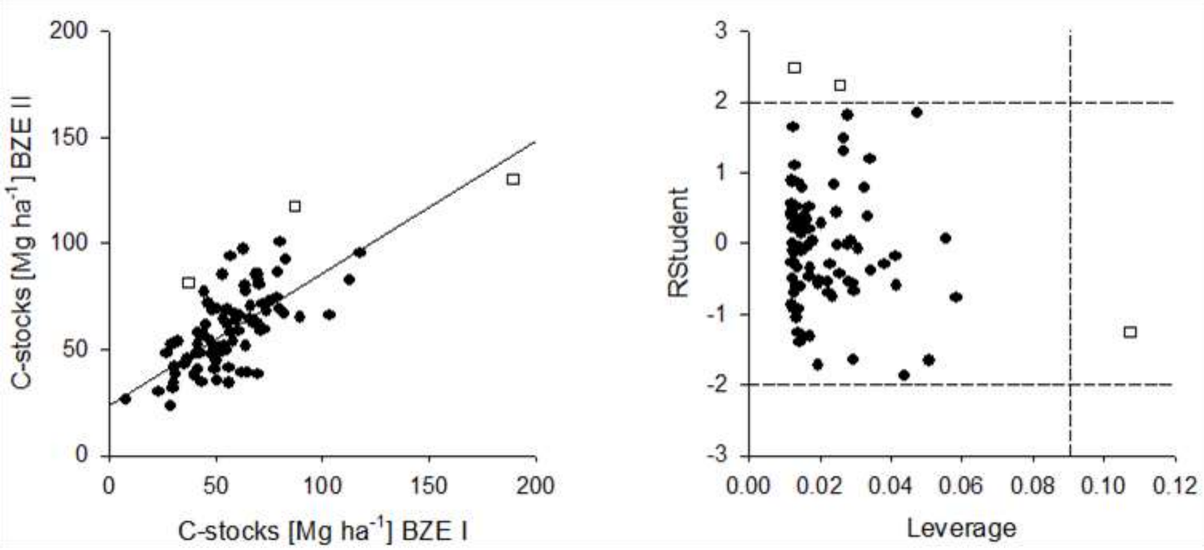
An area-referenced approach, with strata formation, was used for calculation of carbon stocks and of their changes between the two inventory time points. The basis for formation of area-relevant strata consisted of the 72 legend units used in the soil map for Germany "Bodenübersichtskarte der Bundesrepublik Deutschland 1:1.000.000" (BÜK 1000). That source describes the dominant soil types, and parent material for soil formation, pursuant to the German soil system (Arbeitsgruppe Boden, 1994) and FAO (International Soil Reference Information Centre, 1990). Since the classes concerned differed in the number of sample points they contained, the various dominant soil units were aggregated into new dominant soil units. This increased the population size for each class, thereby increasing the pertinent statistical significance. The groups formed were oriented to similar soil types, to substrate type and parent material and to texture and lime content. Overall, 16 new dominant soil units, with their pertinent parent material, were then available for area-referenced evaluation (cf. Table 376). The sample points were allocated to the dominant soil units on the basis of data, collected in the inventories, relative to the parent material and any layering of that material, to soil type, to horizon sequences and to soil texture.

Table 376: Combined legend units on the basis of the BÜK 1000 soil map

Abb.	Dominant soil groups, by substrate type, soil texture and lime content
1	Nutrient-poor soils from dry, nutrient-poor sands
2	Various soils from sandy to loamy terrace or riverine deposits
3	Various soils from partly calcareous, loamy-clayey terrace or riverine deposits
4	Pseudo-gleyed soils from sandy to loamy sediments overlying boulder clay
5	Various soils from sandy sediments overlying boulder clay
6	Brown earths from nutrient-rich sands
7	Soils of loess areas
8	Various soils from scree overlying calcareous, marl and dolomite rock, alternating with terra fusca from silty-clayey redeposited products of limestone weathering
9	Brown earth and terra fusca from redeposited products of weathering of calcareous, marl and dolomite rock, and rendzina from limestone
10	Pelosol – brown earth / pelosol-pseudogley from weathering products of marl and clay rocks and calcareous layers
11	Brown earth from alkiline and intermediary magmatic rock
12	Brown earth from acidic magmatic and metamorphic rock
13	Brown-earth / podzolic soils from hard clayey and silty slates with fractions of greywacke, sandstone, siltstone, quarzite and phyllite
14	Podzols / brown earths from low-alkilinity quarzites, sandstones and conglomerates
15	Various soils alternating tightly with greywacke, clay slate, limestone, sandy, silty and clayey stones and loess-loam overlying various rocks
16	High-mountain soils from limestone, dolomite rock and silicate rock

For purposes of analysis, carbon-stocks data was available from a total of 1,865 plots from the BZE I inventory, and from 1,813 plots from the BZE II inventory Grüneberg et al. (2014). Except for the data from two German Länder, the data were available mainly as paired samples, i.e. samples in which it was possible to correlate each BZE I plot with exactly one BZE II plot. The number of points that entered into the final calculation was lower than the number suggested by the above figures, however. This was because some organic-soil areas were excluded, because a) it proved impossible to assign the relevant points to a dominant soil unit or b) because their stocks were seen to be implausible, on the basis of outlier analysis, and thus were rejected. For the analysis, the total sample, broken down by German Länder, was divided into a paired sample subset and an unpaired sample subset. In the paired sample subset, it proved possible to identify outliers via residual analysis. To that end, the carbon stocks for each dominant soil unit, at the various inventory time points, were compared through plotting a linear regression. A relevant example is presented in Figure 66 (on the left). Studentised residuals were used to eliminate outliers that seemed inconsistent with the rest of the data (cf. Figure 66 (on the right)). In addition, a "hat matrix" was generated, for identification of "leverage" points[113] that represent outliers within the independent variable (cf. Figure 66 (right); (Weisberg, 2005)).

Figure 66: Regression between carbon stocks (0-30cm) as shown by BZE II data and the BZE I data (left), and outliers identified via residuals analysis with studentised residuals (middle) and "high-leverage" points (right), illustrated with the example of a dominant soil group



Since two Länder have shifted the grid between the BZE I and BZE II inventories, the points for which assignment to a dominant soil group was possible are available as unpaired samples. Soil organic carbon stocks for those plots were calculated via formation of mean values for each dominant soil group. Outliers for each class were detected via double standard deviation (x ± 2 σ) and then removed. In addition, organic soils were excluded. Then, the mean carbon stocks for each dominant soil group were correlated with the relevant annual differences. After elimination of the outliers, via outlier analysis, a total of 1,577 points from the BZE I inventory, and 1,539 points from the BZE II inventory, remained. Of those, a total of 1,075 points were available as paired samples.

To permit area-weighted calculation of carbon-stock changes, the forest areas in the dominant soil units were determined as percentage shares of Germany's total forest area. To that end, the CORINE Land Cover data were combined with the BÜK 1000, within a Geographic Information System (GIS). In each case, it proved possible to correlate a forest area with the mean carbon-stock change for a dominant soil group. That, in turn, enabled the calculation of the average annual change in organic carbon for Germany, taking account of the selected dominant soil units' shares of the total area.

6.4.2.5.4 Results of derivation of carbon stocks and carbon-stock changes

Based on the area-weighted approach, the carbon stocks in Germany's mineral soil, to a depth of 30 cm, amounted to 55.6 ± 3.4 t C ha^{-1} at the time of the BZE I inventory, and to 61.8 ± 3.7 t C ha^{-1} at the time of the BZE II inventories. Those figures translated into annual increases of 0.41 ± 0.11 t C ha^{-1} (Grüneberg et al., 2014). A variance analysis (type III - ANOVA) showed that the differences between the two inventories were significant ($p<0.001$). Both the rate of change and the total stocks lie within a range that other authors have already estimated for central Europe.

[113] Leverage is a dimensionless statistical indicator that shows how strongly a given individual value is influencing a given statistical regression model.

Estimates of annual carbon sequestration in the root zone range from 0.1 t C ha^{-1} a^{-1} (Nabuurs & Schelhaas, 2002) to 0.9 t C ha^{-1} a^{-1} (Schulze et al., 2000). Most of the values given in the literature are based on model-based up-scaling, and they take the soil's entire root zone into account (Liski et al. (2002); De Vries et al. (2006)). In comparison to those studies, the present effort was able to draw on considerably more measurement plots, arrayed within a finer grid. Those data represent a more valid sample, one that supports conclusions for Germany that are more reliable and that have a nationwide focus.

For nearly all dominant soil units, carbon stocks, broken down by classes, were estimated to be higher at the time of the BZE II inventory than they were at the time of the BZE I inventory (cf. Table 377). In addition, carbon stocks were higher in soils with high clay content than they were in soils with high sand content. Reasons for this are discussed in Six et al. (2002) and Baritz et al. (2010), for example. An assessment of the time series between the BZE I and BZE II shows greater annual changes in carbon stocks especially in sandy dominant soil units of the North German lowlands. For example, the annual relevant rate of change for the dominant soil units 1, 5 and 6 was greater than 0.6 MgC ha^{-1} a^{-1} (Grüneberg et al., 2014). On the other hand, Prietzel et al. (2006) put carbon sequestration, in the upper 30 cm, at 0.2 t C ha^{-1} a^{-1} on sandy sites and at 0.4 t C ha^{-1} a^{-1} on loamy sites. Smaller positive changes in carbon stocks, ranging between 0.1 and 0.6 t C ha^{-1} a^{-1}, were found in over half of all classes formed. A marked decrease in carbon stocks, between the two inventory times, was seen in class 9.

Table 377: Carbon stocks at the time of the BZE I, and at the time of the BZE II, in the newly formed dominant soil units (Grüneberg et al., 2014)

		Carbon stocks (BZE I) [t C ha^{-1}]			Carbon stocks (BZE II) [t C ha^{-1}]	
DSU	n	MV	SE	n	MV	SE
1	201	52.8	1.6	187	65.5	6.8
2	56	60.5	2.6	62	65.0	4.9
3	20	67.3	3.2	25	68.1	2.4
4	105	66.4	1.8	87	64.1	4.5
5	77	33.4	1.6	75	52.8	2.2
6	34	24.6	1.6	34	43.7	1.8
7	126	55.8	1.5	109	63.0	2.2
8	110	76.3	2.4	106	79.1	0.8
9	36	77.1	4.9	43	68.3	1.0
10	55	56.7	2.1	63	60.8	0.8
11	39	51.3	3.2	39	54.6	0.9
12	187	59.5	1.7	163	62.5	2.2
13	222	54.7	1.4	233	60.1	4.1
14	245	50.5	1.2	257	55.3	3.2
15	30	51.8	2.9	30	49.0	0.9
16	34	84.4	6.2	26	104.5	0.5

(DSU = dominant soil units, n = number of soil samples, MV = mean value, SE = standard error)

6.4.2.6 Organic soils (CRF Table 4.A)

This chapter solely discusses CO_2 emissions from organic soils. Those emissions are entered in CRF Table 4.A, under "organic soils." The methods applied for N_2O and CH_4 emissions are described in Chapter 6.1.2.2. Those emissions are reported in CRF Table 4(II).

6.4.2.6.1 Forest Land remaining Forest Land

The areas covered by organic soils were determined via a georeferencing procedure, with overlaying of the map of organic soils ("Karte organischer Böden") and ATKIS® data. In the process, drained and non-drained organic soils are differentiated. For Forest Land remaining Forest Land, the organic soils area for the year 2020 is 256,804 ha. A detailed description of the method used to derive organic-soil areas, and the drained fractions of those areas, is presented in Chapter 6.1.2.2.1.

The method used to derive the emission factor is described in Chapter 6.1.2.2.2, while the method used to derive the implied emission factor (IEF) is described in Chapter 6.1.2.2. Table 378 summarizes the implied emission factors for organic forest soils.

Table 378: Implied emission factors (IEF) (carbon) for organic soils

Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
IEF [t CO_2 ha^{-1}]	9.7384	9.7287	9.6992	9.7120	9.7615	9.7588	9.7587	9.7588	9.7555	9.7469	9.7378

6.4.2.6.2 Land converted to Forest Land

For Land converted to Forest Land, the organic soils area for the year 2020 is 21,191 ha (cf. Chapter 6.1.2.2.1). The emission factors presented in Table 378 are also used for organic soils on Land converted to Forest Land. Those annual emissions are being reported for all years since the relevant conversions. The manner in which GHG emissions from organic soils are derived, for all land-use categories, is described in Chapter 6.1.2.2.

6.4.2.7 Other GHG emissions from forests

6.4.2.7.1 Nitrous oxide emissions from nitrogen fertilisation (CRF Table 4(I))

No nitrogen fertilisation in forests takes place in Germany. Therefore, CRF Table 4(I) reports this activity as NO (not occurring; cf. also Chapter 6.1.2.5).

6.4.2.7.2 Drainage and rewetting of organic and mineral soils (CRF Table 4(II))

The derivation of GHG emissions, from organic and mineral soils, related to drainage and rewetting is described, for all land-use categories, in Chapter 6.1.2.6. The CO_2 emissions for forests are entered in CRF Table 4.A and, in CRF Table 4(II), are marked IE (included elsewhere; cf. also Chapter 6.4.2.6). The pertinent CH_4 and N_2O emissions, on the other hand, are presented in CRF Table 4(II). Table 379 summarizes the implied emission factors for organic forest soils.

No rewetting of mineral soils in forests occurs; in CRF Table 4(II), that source is marked NO (not occurring).

Table 379: Implied emission factors (IEF) (methane and nitrogen) for organic soils

Year	Methane [kg CH_4 ha-1]	Nitrogen [kg N_2O ha-1]
1990	4.9102	4.3285
1995	4.9135	4.3285
2000	4.9121	4.3286
2005	4.9271	4.3297
2010	4.9227	4.3308
2011	4.9210	4.3314
2012	4.9243	4.3317
2013	4.9217	4.3315
2014	4.9200	4.3307

Year	Methane [kg CH_4 ha-1]	Nitrogen [kg N_2O ha-1]
2015	4.9183	4.3285
2016	4.9191	4.3295
2017	4.9132	4.3301
2018	4.9123	4.3304
2019	4.9073	4.3305
2020	4.9117	4.3299

6.4.2.7.3 Direct nitrous oxide emissions related to nitrogen mineralisation and immobilisation (CRF Table 4(III))

The manner in which direct N_2O emissions from mineralisation and immobilisation of mineral soils are determined is described in Chapter 6.1.2.7. The pertinent N_2O emissions are listed in CRF Table 4(III).

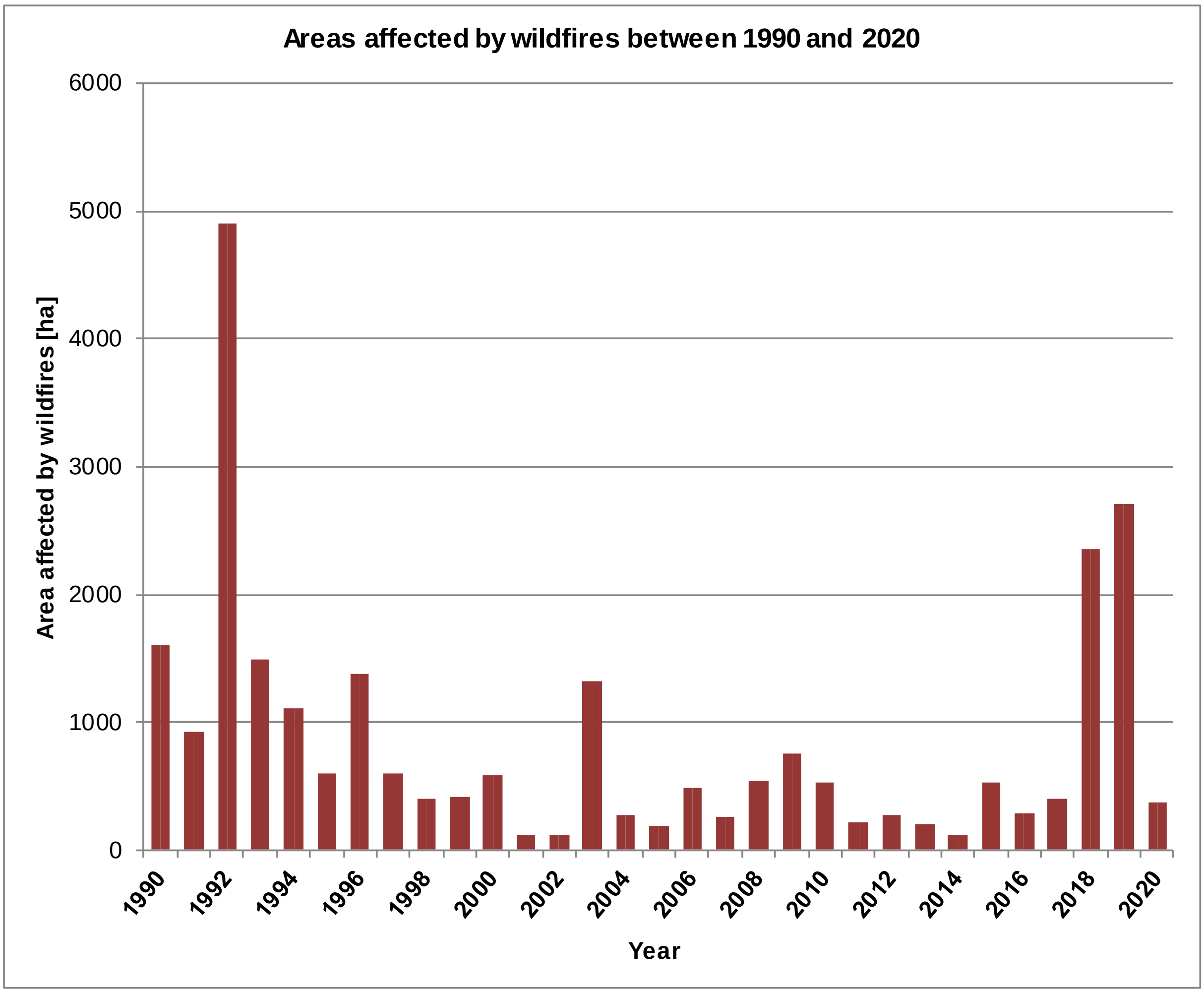
6.4.2.7.4 Indirect nitrous oxide emissions from cultivated soils (CRF Table 4(IV))

The manner in which indirect N_2O emissions related to losses of organic soil substance resulting from land-use changes and cultivation measures are determined is described, in summary form for all land-use categories, in Chapter 6.1.2.8. The pertinent N_2O emissions are listed in CRF Table 4(IV).

6.4.2.7.5 Wildfires (CRF Table 4(V))

While in other countries "prescribed burning" is an accepted method for clearing land or for managing ecosystems, no prescribed/controlled burning of biomass is carried out in Germany's managed forests. In CRF-Table 4 (V), therefore, NO is entered in the category "Controlled Burning." In keeping with Germany's climatic situation, and with measures taken in Germany to prevent wildfires, such fires tend to be rather seldom. This conclusion is confirmed by relevant wildfire statistics (BLE (2020)) and their data on areas affected by wildfires (cf. Figure 67). The mean forest area affected annually by wildfires, in the period 1990 – 2020, was 839 ha. In some years, unseasonably high summer temperatures have resulted in larger burned areas. This was the case, for example, in 1996, 2003, 2018 and 2019. An unusually large burned area, about 4,908 ha, was measured in 1992, which had an extremely warm summer.

Figure 67: Areas affected by wildfires between 1990 and 2020 (pursuant to BLE, 2021)



Along with CO_2, wildfires emit a range of other greenhouse gases (CO, CH_4, N_2O, NO_x and NMVOC). The CO_2 emissions resulting from biomass combustion have already been taken into account as part of changes of biomass stocks (CRF Sector 4.A.1 Forest Land remaining Forest Land), via the stock-difference method. For this reason, they are listed as IE (included elsewhere). The emissions of other greenhouse gases were calculated using Equation 54 (Equation 2.27, IPCC (2006a)).

Equation 54:

$$L_{fire} = A * B * C * D * 10^{-6}$$

- L_{fire} = Quantity of GHG [t] emitted via fire
- A = Wildfire burned area [ha]
- B = Mass of fuel present on the relevant site (biomass) [$kg_{dry\ matter}$ ha^{-1}]
- C = Combustion efficiency
- D = Emission factor [$g(kg_{drymatter})^{-1}$]

The NMVOC emissions were calculated with the pertinent equation pursuant to the 2016 EMEP/EEA Emission Inventory Guidebook (EMEP, 2019).

Equation 55:

$$M(C) = 0.45 * A * B * \alpha * \beta$$

0.45 = Average fraction of carbon in fuel wood

A = Area burnt [m²];

B = Average total biomass of fuel material per unit area [kg m⁻²];

α = Fraction of average above-ground biomass, relative to the total average biomass B;

β = Burning efficiency (fraction burnt) of the above-ground biomass.

The data on areas affected by wildfires in the period 1990 to 2020 have been taken from the wildfire statistics maintained by the Federal Agency for Agriculture and Food (BLE; Waldbrandstatistik – BLE 2021). In determination of the relevant areas, no distinction is made between Land converted to Forest Land and Forest Land remaining Forest Land. For this reason, the emissions from Land converted to Forest Land are reported within the section for the category Forest Land remaining Forest Land and listed as "IE" in CRF Table 4(V). The data available for determination of biomass include the data for 1990 from the NFI 1987 and DSWF; the data for 2002 from the NFI 2002; the data for 2008 from the IS08; the data for 2012 from the NFI 2012; and the data for 2017 from the CI 2017. The mean above-ground biomass for each year was derived via linear interpolation between 1990, 2002, 2008, 2012 and 2017, and via extrapolation for the years as of 2018. Pursuant to the expert judgement carried out by König (2007), 80 % of the wildfires in Germany remain on the ground surface and 20 % rise into tree crowns. In accordance with Table 2.6 (IPCC, 2006a), a combustion efficiency (mass loss via direct combustion) of 0.15 was used for fires remaining on the surface, and an efficiency of 0.45 was used for fires rising to tree crowns. The emission factors for CH_4, N_2O, CO and NO_X were taken from Table 2.5 (IPCC, 2006a). The emission factor for NMVOC was taken from the 2016 EMEP/EEA Emission Inventory Guidebook.

Germany suffers relatively little wildfire damage in terms of burned area, and thus the relevant CH_4, N_2O, CO, NO_X and NMVOC gas emissions are low. The complete time series for greenhouse gases resulting from wildfires is shown in Table 380.

Table 380: Greenhouse gases emitted via wildfires

Year	Above-ground biomass [t ha⁻¹]	Wildfire burned area [ha]	Emitted GHG [t]				
			CH_4	N_2O	CO	NO_X	NMVOC
1990	170.9	1,606	270.8	15.0	6,165	172.9	544.5
1991	171.0	920	155.3	8.6	3,535	99.1	312.2
1992	171.2	4,908	829.3	45.9	18,879	529.3	1,667.4
1993	171.4	1,493	252.5	14.0	5,749	161.2	507.7
1994	171.5	1,114	188.6	10.4	4,294	120.4	379.2
1995	171.7	592	100.3	5.6	2,284	64.0	201.7
1996	171.9	1,381	234.3	13.0	5,333	149.5	471.0
1997	172.0	599	101.7	5.6	2,316	64.9	204.5
1998	172.2	397	67.5	3.7	1,536	43.1	135.7
1999	172.4	415	70.6	3.9	1,608	45.1	142.0
2000	172.6	581	99.0	5.5	2,253	63.2	199.0
2001	172.7	122	20.8	1.2	474	13.3	41.8
2002	172.9	122	20.8	1.2	474	13.3	41.9
2003	173.6	1,315	225.4	12.5	5,131	143.9	453.1
2004	174.4	274	47.2	2.6	1,075	30.1	94.9
2005	175.1	183	31.7	1.8	722	20.2	63.7
2006	175.8	482	83.7	4.6	1,905	53.4	168.2
2007	176.6	256	44.5	2.5	1,014	28.4	89.6
2008	177.3	539	94.2	5.2	2,145	60.1	189.5
2009	179.3	757	133.9	7.4	3,049	85.5	269.3
2010	181.2	522	93.4	5.2	2,125	59.6	187.7
2011	183.2	214	38.7	2.1	881	24.7	77.8
2012	185.2	269	49.1	2.7	1,118	31.3	98.7
2013	187.2	199	36.7	2.0	836	23.4	73.8
2014	189.1	120	22.4	1.2	510	14.3	45.0

Year	Above-ground biomass [t ha^{-1}]	Wildfire burned area [ha]	Emitted GHG [t]				
			CH_4	N_2O	CO	NO_X	NMVOC
2015	191.1	526	99.1	5.5	2,257	63.3	199.3
2016	193.1	283	53.9	3.0	1,228	34.4	108.4
2017	194.4	395	75.7	4.2	1,724	48.3	152.3
2018	196.2	2,349	454.9	25.2	10,357	290.4	914.7
2019	198.1	2,711	530.0	29.3	12,067	338.3	1,065.7
2020	199.9	368	72.5	4.0	1652	46.3	145.9

6.4.3 Uncertainties and time-series consistency (4.A)

Various uncertainties have to be taken into account in calculation of carbon stocks. The actual uncertainties, however, can only be approximated, with the help of pragmatic approaches.

The uncertainties described in the following chapters are included in a total-error budget for the LULUCF sector that is presented in Chapter 6.1.2.1.

With regard to the uncertainties in the carbon-conversion factor, we call attention to Chapter 6.4.2.2.6.

When aggregated, error estimates (U) for values (1, ..., *i*, ..., *I*) propagate themselves in two different ways. When two values are added or subtracted, the error propagation is additive (cf. Equation 56).

Equation 56:

$$U = \frac{\sqrt{\sum_i (U_i x_i)^2}}{\sum_i x_i}$$

U = Total uncertainty

U_i = Uncertainty for target value

x_i = Quantity of target value

On the other hand, when two values are multiplied or divided, the errors for the two values propagate themselves multiplicatively (cf. Equation 57).

Equation 57:

$$U = \sqrt{\sum_i (U_i)^2}$$

U = Total uncertainty

U_i = Uncertainty for value sought

6.4.3.1 Uncertainties in estimation of areas affected by land-use changes

The land-use changes are determined via a sample-based system, and thus it was possible to calculate the sampling errors for each LULUCF category. The sampling error is calculated in keeping with the formulae in Chapter 6.4.3. Once validation has been completed, all other error sources can be ruled out (cf. also Chapter 6.3.3). All areas have been recorded significantly.

6.4.3.2 Uncertainties in estimation of emission factors of living and dead biomass

Because biomass cannot be directly measured, a number of error sources enter the processes of deriving forest biomass and carbon stocks and of deriving changes in forest biomass and carbon stocks. The errors in the biomass functions and in the carbon-conversion factor are listed and discussed in Chapters 6.4.2.2.4, 6.4.2.2.5 and 6.4.2.2.6. The errors in biomass-conversion factors for dead wood, broken down by tree species and degrees of decomposition, are given in Chapter 6.4.2.3.

The specific errors for the tree-species groups are added to the uncertainties for the above-ground and below-ground biomass and then aggregated to yield an error figure for the total biomass. Because the biomass stocks at the first time point are subtracted from the stocks at the second time point, the uncertainty for the biomass change is obtained via addition. The error for the total biomass change is multiplied by the error for the carbon-conversion factor and by the sampling error. The sampling error is derived from the variance in the sample.

The following tables show the uncertainties for the individual error sources and for the resulting emission factor.

Table 381: Uncertainties in emission factors for living biomass on Forest Land remaining Forest Land, for various periods

FM 1987 – 2002	Error % (biomass conversion)						Error % (C)	SE %	RMSE%
Old German Länder	Spruce	Pine	Beech	Oak	Softwood$_{Foliage}$	All			
Biomass$_{above-ground}$	7.96	11.06	13.39	8.62	36.07	7.04	2.00	6.47	9.77
Biomass$_{below-ground}$	24.52	18.63	34.86	35.60	17.41	13.53	2.00	6.24	15.03
Emission factor						6.67	2.00	5.68	8.76
FM 1993 – 2002	Error % (biomass conversion)						Error % (C)	SE %	RMSE%
New German Länder	Spruce	Pine	Beech	Oak	Softwood$_{Foliage}$	All			
Biomass$_{above-ground}$	11.34	24.66	17.35	12.93	37.15	9.03	2.00	5.43	10.73
Biomass$_{below-ground}$	30.38	27.74	38.90	43.94	22.49	16.82	2.00	5.93	17.97
Emission factor						8.16	2.00	5.51	10.05
FM 2002 – 2008	Error % (biomass conversion)						Error % (C)	SE %	RMSE%
Germany	Spruce	Pine	Beech	Oak	Softwood$_{Foliage}$	All			
Biomass$_{above-ground}$	7.95	11.05	13.30	8.57	35.39	13.69	2.00	23.30	27.10
Biomass$_{below-ground}$	24.47	18.60	34.67	35.39	17.15	18.28	2.00	13.50	22.82
Emission factor						11.71	2.00	18.83	22.17
FM 2008 – 2012	Error % (biomass conversion)						Error % (C)	SE %	RMSE%
Germany	Spruce	Pine	Beech	Oak	Softwood$_{Foliage}$	All			
Biomass$_{above-ground}$	7.95	11.04	13.30	8.57	35.39	6.19	2.00	8.36	10.59
Biomass$_{below-ground}$	24.47	18.60	34.65	35.38	17.15	12.64	2.00	8.93	15.60
Emission factor						5.99	2.00	7.40	9.52
FM 2012 – 2017	Error % (biomass conversion)						Error % (C)	SE %	RMSE%
Germany	Spruce	Pine	Beech	Oak	Softwood$_{Foliage}$	All			
Biomass$_{above-ground}$	7.94	11.05	13.30	8.56	35.39	6.73	2.00	7.62	10.36
Biomass$_{below-ground}$	24.47	18.61	34.67	35.38	17.15	12.33	2.00	6.31	14.00
Emission factor						6.33	2.00	6.54	9.10

Table 382: Uncertainties in emission factors for living biomass on afforestation areas, for various periods

Deforestation (AR), 1987 – 2002	Error % (biomass conversion)						Error % (C)	SE %	RMSE%
Old German Länder	Spruce	Pine	Beech	Oak	Softwood$_{Foliage}$	All			
Biomass$_{above-ground}$	11.23	15.62	18.80	12.10	50.00	18.63	2.00	19.37	26.95
Biomass$_{below-ground}$	34.60	26.30	49.00	50.00	24.23	17.31	2.00	18.92	25.72
Emission factor						15.99	2.00	-16.52	22.99

Deforestation (AR), 1987 – 2002	**Error % (biomass conversion)**						**Error % (C)**	**SE %**	**RMSE%**
Old German Länder	**Spruce**	**Pine**	**Beech**	**Oak**	**Softwood$_{Foliage}$**	**All**			
Afforestation / Reforestation (AR), 2002 – 2008	**Error % (biomass conversion)**						**Error % (C)**	**SE %**	**RMSE%**
Germany	**Spruce**	**Pine**	**Beech**	**Oak**	**Softwood$_{Foliage}$**	**All**			
Biomass$_{above-ground}$	11.23	15.62	18.80	12.10	50.00	26.79	2.00	48.70	55.62
Biomass$_{below-ground}$	34.60	26.30	49.00	50.00	24.23	18.68	2.00	44.38	48.20
Emission factor						21.86	2.00	-39.98	45.57
Afforestation / Reforestation (AR), 2008 – 2012	**Error % (biomass conversion)**						**Error % (C)**	**SE %**	**RMSE%**
Germany	**Spruce**	**Pine**	**Beech**	**Oak**	**Softwood$_{Foliage}$**	**All**			
Biomass$_{above-ground}$	11.23	15.62	18.80	12.10	50.00	20.13	2.00	18.05	27.11
Biomass$_{below-ground}$	34.60	26.30	49.00	50.00	24.23	17.82	2.00	20.10	26.94
Emission factor						17.48	2.00	-15.67	23.48
Afforestation / Reforestation (AR), 2012 – 2017	**Error % (biomass conversion)**						**Error % (C)**	**SE %**	**RMSE%**
Germany	**Spruce**	**Pine**	**Beech**	**Oak**	**Softwood$_{Foliage}$**	**All**			
Biomass$_{above-ground}$	11.23	15.62	18.80	12.10	50.00	17.88	2.00	38.43	42.43
Biomass$_{below-ground}$	34.60	26.30	49.00	50.00	24.23	16.30	2.00	37.11	40.58
Emission factor						15.24	2.00	-32.55	35.95

Table 383: Uncertainties in emission factors for living biomass on deforestation areas, for various periods

Deforestation (DF), 1987 – 2002	**Error % (biomass conversion)**						**Error % (C)**	**SE %**	**RMSE%**
Old German Länder	**Spruce**	**Pine**	**Beech**	**Oak**	**Softwood$_{Foliage}$**	**All**			
Biomass$_{above-ground}$	11.23	15.62	18.80	12.10	50.00	9.41		17.45	19.93
Biomass$_{below-ground}$	34.60	26.30	49.00	50.00	24.23	16.90		19.68	26.02
Emission factor						8.63	2.00	15.13	17.42
Deforestation (DF), 2002 – 2008	**Error % (biomass conversion)**						**Error % (C)**	**SE %**	**RMSE%**
Germany	**Spruce**	**Pine**	**Beech**	**Oak**	**Softwood$_{Foliage}$**	**All**			
Biomass$_{above-ground}$	11.23	15.62	18.80	12.10	50.00	9.13	2.00	23.98	25.73
Biomass$_{below-ground}$	34.60	26.30	49.00	50.00	24.23	16.59	2.00	23.32	28.69
Emission factor						8.47	2.00	21.06	22.70
Deforestation (DF), 2008 – 2012	**Error % (biomass conversion)**						**Error % (C)**	**SE %**	**RMSE%**
Germany	**Spruce**	**Pine**	**Beech**	**Oak**	**Softwood$_{Foliage}$**	**All**			
Biomass$_{above-ground}$	11.23	15.62	18.80	12.10	50.00	12.58	2.00	22.66	26.00
Biomass$_{below-ground}$	34.60	26.30	49.00	50.00	24.23	24.07	2.00	20.98	31.99
Emission factor						11.63	2.00	20.17	23.29
Deforestation (DF), 2012 – 2017	**Error % (biomass conversion)**						**Error % (C)**	**SE %**	**RMSE%**
Germany	**Spruce**	**Pine**	**Beech**	**Oak**	**Softwood$_{Foliage}$**	**All**			
Biomass$_{above-ground}$	11.23	15.62	18.80	12.10	50.00	10.06	2.00	28.69	30.47
Biomass$_{below-ground}$	34.60	26.30	49.00	50.00	24.23	19.01	2.00	27.57	33.55
Emission factor						9.37	2.00	25.52	27.18

Table 384: Uncertainties of emission factors for dead wood, for various periods

	Error % (biomass conversion)													Error % (C)	SE %	RMSE %
Germany	EI1	EI2	EI3	EI4	L1	L2	L3	L4	N1	N2	N3	N4	All			
FM 2008 – 2012	8.59	30.60	24.09	47.41	8.63	30.58	23.76	47.01	12.95	19.81	25.08	17.85	8.59	2.00	26.37	27.80
FM 2012 – 2017	8.91	30.73	23.82	52.92	8.89	30.83	23.61	46.96	12.37	19.75	25.08	18.00	10.03	2.00	22.56	24.77
AF 2008 – 2012	0.00	0.00	0.00	0.00	0.00	0.00	33.33	65.38	17.20	27.92	35.46	25.20	18.81	2.00	41.38	45.50
AF 2012 – 2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00	65.38	0.00	0.00	0.00	0.00	65.38	2.00	98.02	117.84
Deforestation (DF), 2008 – 2012	0.00	0.00	0.00	0.00	12.07	43.24	33.33	65.38	0.00	27.92	35.46	25.20	19.82	2.00	46.73	50.80
Deforestation (DF), 2012 – 2017	0.00	0.00	0.00	0.00	0.00	43.24	33.33	65.38	17.20	27.92	35.46	25.20	16.58	2.00	49.56	52.30

where N = conifers (Nadelholz), L = deciduous trees (Laubholz), but not including oak, EI = oak (Eiche) and 1 – 4 = degree of decomposition

6.4.3.3 Uncertainties in estimation pertaining to emission factors of litter and mineral soils

6.4.3.3.1 Sampling error

In soil sampling, proper separation of litter and mineral soil can present a problem, since the transition between the two compartments cannot always be unambiguously identified. This problem becomes even more important in that carbon concentrations in litter differ considerably from those in the underlying mineral soil. In sampling, imprecise or improper separation of litter from mineral soil can thus have major impacts on the carbon stocks measured in a relevant horizon or depth layer.

6.4.3.3.2 Small-scale variability

Due to the high spatial variability in litter and mineral soil, and because carbon stocks maintain spatial continuity only over short distances, sampling of carbon stocks in such compartments is subject to a high degree of uncertainty. For litter in a beech forest, Schöning et al. (2006) calculated stocks of 4.0 t C ha^{-1}, with a variation coefficient of 38 %. In mineral soil (0 – 36 cm), they found carbon stocks of 64.0 t C ha^{-1}, with variation coefficients between 30 % and 43 %. Similar values were recorded by Liski (1995). He showed that carbon stocks under spruce, within a given horizon, were spatially independent as of a distance of 8 m.

6.4.3.3.3 Representativeness of points within strata

One problem in carrying out analysis in accordance with dominant soil units resulted from the different degrees to which classes were represented. Small classes lack statistical validity with respect to a major basic totality. Where no comparison between BZE I and BZE II data was possible, due to a lack of pertinent data, it was not possible to include the relevant forested dominant-soil-unit area in the calculation. In addition, it was not possible to have all dominant soil units represented, since some are found only on small areas of Germany's territory. Overall, as a result of these difficulties, 4.3 % of the forest area was not taken into account in this context.

6.4.3.3.4 Sampling error

In calculation of the sampling error with regard to stock changes in litter and mineral soil, paired and unpaired samples were differentiated, and stratification of mineral soils was taken into account.

The carbon-stock changes for litter were calculated on the basis of stratified unpaired samples. A sampling error of 0.02 t C ha^{-1} a^{-1}, or 100%, was obtained.

In calculation of carbon-stock changes in mineral soils, the overall sample was divided into a set of paired and a set of unpaired samples. In addition, stratification was carried out, by dominant soil units and the two sample sets. Overall, the sampling error for mineral soils amounted to 0.037 t C ha^{-1} a^{-1}, or 9 %.

6.4.3.3.5 Quantification of methodologically related uncertainties

Another source of uncertainty, in addition to the sampling variance, consists of discrepancies, in individual measurements, which originate in measuring methods and processes. A group of several samples taken independently, at the same location, would exhibit fluctuations in both the carbon concentration and fine-soil fraction – throughout a range determined by the precision of the measuring equipment and methods being used. This fluctuation range in measurement of carbon concentrations was quantified on the basis of the results of ring analyses (Blum & Heinbach, 2006, 2007). In the ring analyses for the BZE II, the repeatability standard deviation for a set of carbon measurements was determined as the mean within-laboratory standard deviation (DIN ISO 5725 2) of several carbon measurements within the relevant laboratories, and the reference standard deviation was determined as the standard deviation of the mean values of the measurements. The reproducibility standard deviation was calculated from those standard deviations. The reproducibility standard deviation serves as a suitable estimate of the measurement uncertainty. The reproducibility standard deviations for mineral-soil measurements were as follows: 0.9 g kg^{-1} for (i.e. for measurements in) lime-free soils, 2.9 g kg^{-1} for calcareous soils and 20.2 g kg^{-1} for organic surface layers. With regard to the BZE I, the values provided by Wolff and Riek (1997) were used, including coefficients of variation ranging from 5-20 % for carbon measurements in mineral soils and from 5-10 % for carbon measurements in organic surface layers. The mean values of such coefficients were used in each case. No ring-analyses results were available as a basis for calculation of the uncertainties relative to fine-soil fractions. For this reason, all the BZE points were selected for which fine-soil-fraction results were available at both relevant inventory time points. The mean deviation between such measurement pairs was calculated. The mean deviation was 193 ± 35 t ha^{-1}. In keeping with the principle of conservative error estimation, it was assumed that the fine-soil fractions did not change between the two inventories, and that the mean deviation plus its spread serves as a measure of the uncertainty in measurement of fine-soil fractions. The uncertainty in the annual carbon-change rate was expanded to include the uncertainties in the relevant individual measurements.

The uncertainties in estimation of the annual rate of change in mineral soils were as follows: for the sampling variance, 0.037 t C ha^{-1} a^{-1}; for the laboratory analysis for carbon determination at the time of the BZE I, 0.058 t C ha^{-1} a^{-1}; for such analysis at the time of the BZE II, 0.056 t C ha^{-1} a^{-1}; and for determination of fine-soil fractions, 0.05 t C ha^{-1} a^{-1}. These uncertainties yielded a total uncertainty of 0.11 t C ha^{-1} a^{-1}. The total uncertainty in estimation of the annual carbon-change rate in the organic surface layer was 0.035 t C ha^{-1} a^{-1}.

6.4.3.4 Time-series consistency

The following conditions are applied to the consistency of the time series:

- Throughout the entire time series, emissions must be calculated with the same method and the same or mutually consistent data sets.
- If any changes are made in a method, recalculations should be carried out with the new method throughout the entire time series.
- New data, such as data from repeat inventories, must be consistent with earlier data.
- If new data become available that lead to an improvement in the inventory, a recalculation should be carried out throughout the entire time series.
- If any errors are identified in estimates, they must be corrected, and the entire pertinent time series has to be recalculated.
- These conditions have been systematically applied to all time series of the submission. Any large differences between corresponding values of two successive years of a time series are due to data periodicity within consistent time series. This is because the same method, and the same data sets, have been used for all years of such time series.

6.4.4 Category-specific quality assurance / control and verification (4.A)

The QC/QA measures carried out for the entire LULUCF sector are set forth in Chapter 6.1.3.

The data sources used in preparation of this inventory fulfill the review criteria of the QSE manual for data sources (QSE-Handbuch für Datenquellen). Quality assurance for input data (ATKIS®, BÜK, official statistics, wildfire statistics; cf. Chapter 6.4.2.1) is the responsibility of the relevant data administrators (cf. the pertinent documentation in the inventory description).

Complete error analysis was carried out for the LULUCF sector, and an attempt was made to quantify all existing sources of error. That work included error calculations, relative to the forest categories, for biomass, dead wood, litter, mineral soils, organic soils and wildfires, and the GHG CO_2, N_2O and CH_4. In Chapter 6.1.2.1, a total-error budget is presented that summarises the results of error analysis.

6.4.4.1 Biomass and dead wood

The estimates of carbon stocks, and of carbon-stock changes, in the biomass and dead-wood pools, at the various relevant times, are based on up-scaling that was carried out at the Thünen Institute for Forest Ecosystems (TI-WO), using data from the NFIs, from the 2008 Inventory Study and the 2017 Carbon Inventory. In the process, the stocks on a nationwide, permanent, systematic sample grid are repeatedly measured. In the NFI 2012, some 420,000 trees, on a total of about 60,000 forest sample plots, were surveyed. The stock changes are derived from the stocks. In each case, the stock change is the net change between the stocks of relevant individual inventory years. It includes growth, the wood harvest and losses via natural disturbances such as storms and mortality. Extensive quality controls are carried out for the purpose of substantiating the results:

- quality checks during field surveys
- quality checks for the collected data sets
- plausibility checks

With regard to the quality assurance developed for the NFI, we refer to the literature for the National Forest Inventory (Schmitz et al., 2005))[114].

In work carried out independently of the TI-WO's calculations, the carbon stocks and carbon-stocks changes for biomass were calculated with a programme developed under the database management system PostgreSQL. The results of the two sets of calculations match.

6.4.4.2 Litter and mineral soils

In order to achieve a consistent laboratory-analysis standard in analysis of sampling carried out in the framework of the BZE, a ring analysis was initiated. To that end, all laboratories underwent a quality test carried out by the Gutachterausschuss Forstliche Analytik ("forestry analysis auditors' committee"; Blum and Heinbach (2006); Blum and Heinbach (2007)). To ensure the comparability of the applicable laboratory methods, only laboratories that participated successfully in the ring analysis were permitted to carry out analysis. Germany also participated in a similar ring analysis at the European level (Cools et al., 2006).

To harmonise laboratory measurements and topographical surveys, rules for determining relevant parameters were defined, in the framework of the BZE II survey, for participating laboratories. This was done with a view to preventing any discrepancies resulting from use of different analysis equipment or methods (König et al. (2005), Wellbrock et al. (2006)). Previous ring analyses served as the basis for approving analytics laboratories. A similar approach was taken with regard to field sampling. On the basis of various preliminary studies, suitable sampling methods were defined, specified and described in a field-sampling manual (Wellbrock et al., 2006).

6.4.4.3 Comparison with results of other countries

A comparison with the results of other countries can yield a basic context for understanding the circumstances prevailing in Germany. In the category Land converted to Forest Land in

[114] Cf. also: https://bundeswaldinventur.de/ and https://bwi.info/

particular, the methods and procedures used to deal with transition time vary widely, and thus results in this area tend not to lend themselves directly to comparison.

The following tables present an intra-European comparison of implied emission factors (IEF) for various pools. The comparison data for the carbon-stock changes of other countries are obtained from the national inventory reports of countries neighbouring Germany. The emission factors have been obtained from the 2021 submission to the UN Climate Secretariat; the 2020 data for Germany have been obtained from the 2022 submission.

Table 385: Carbon-stock changes in living biomass, in forests of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.A.1 – Forest Land remaining Forest Land [t C ha^{-1} a^{-1}]	4.A.2 – Land converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.1. – Cropland converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.2. – Grassland converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.3. – Wetlands converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.4. – Settlements converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.5. – Other Land converted to Forest Land [t C ha^{-1} a^{-1}]
Belgium	0.69	1.70	1.84	1.70	2.07	1.25	0.69
Denmark	0.14	3.03	3.00	3.35	3.62	NO	0.14
France	0.54	1.23	1.45	1.22	1.19	1.18	0.54
UK	0.75	0.97	1.04	0.96	NO	0.97	0.75
Netherlands	1.15	3.36	3.64	3.17	3.65	3.74	1.15
Austria	0.30	1.19	1.20	1.19	1.22	1.22	0.30
Poland	0.33	0.69	0.53	1.21	NO	NO	0.33
Switzerland	0.60	0.54	0.60	0.53	0.50	0.94	0.60
Czech Republic	-1.63	2.03	2.00	2.00	2.05	2.05	-1.63
Germany, 2019	**1.04**	**-1.22**	**1.03**	**-1.65**	**0.76**	**0.56**	**1.04**
Germany, 2020	**0.75**	**-0.51**	**1.03**	**-0.71**	**0.43**	**-0.04**	**1.04**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

Table 386: Carbon-stock changes in dead wood, in forests of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.A.1 – Forest Land remaining Forest Land [t C ha^{-1} a^{-1}]	4.A.2 – Land converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.1. – Cropland converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.2. – Grassland converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.3. – Wetlands converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.4. – Settlements converted to Forest Land [t C ha^{-1} a^{-1}]	4.A.2.5. – Other Land converted to Forest Land [t C ha^{-1} a^{-1}]
Belgium	NA	0.03	0.02	0.03	0.03	0.02	NO
Denmark	0.07	0.00	0.00	0.01	0.01	NO	NO
France	-0.02	0.05	0.09	0.04	0.16	0.06	0.22
UK	0.31	0.03	0.03	0.03	NO	0.03	NO
Netherlands	0.07	NE	NE	NE	NE	NE	NE
Austria	0.06	0.02	0.02	0.02	0.02	0.02	0.02
Poland	NA	NO,NA	NA	NA	NO	NO	NO
Switzerland	0.03	0.15	0.14	0.15	0.35	0.26	0.20
Czech Republic	0.01	0.02	0.02	0.02	0.02	0.02	NO
Germany, 2019	**0.09**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**
Germany, 2020	**0.09**	**0.002**	**0.002**	**0.003**	**0.003**	**0,003**	**0,003**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

Table 387: Carbon-stock changes in litter, in forests of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.A.1 – Forest Land remaining Forest Land [t C ha-1 a-1]	4.A.2 – Land converted to Forest Land [t C ha-1 a-1]	4.A.2.1. – Cropland converted to Forest Land [t C ha-1 a-1]	4.A.2.2. – Grassland converted to Forest Land [t C ha-1 a-1]	4.A.2.3. – Wetlands converted to Forest Land [t C ha-1 a-1]	4.A.2.4. – Settlements converted to Forest Land [t C ha-1 a-1]	4.A.2.5. – Other Land converted to Forest Land [t C ha-1 a-1]
Belgium	NA	0.10	0.08	0.10	0.13	0.10	NO
Denmark	0.47	0.30	0.30	0.33	0.35	NO	NO
France	NE	0.28	0.43	0.26	0.35	0.27	0.30
UK	0.04	0.03	0.03	0.03	NO	0.03	NO
Netherlands	NO	NE	NE	NE	NE	NE	NE
Austria	NE,IE	1.21	1.39	1.25	0.78	1.21	1.21
Poland	NA	NO,NA	NA	NA	NO	NO	NO
Switzerland	-0.03	0.69	0.47	0.70	0.65	0.44	0.68
Czech Republic	NO	0.54	0.54	0.54	0.54	0.54	NO
Germany, 2019	**-0.01**	**0.47**	**0.47**	**0.47**	**0.47**	**0.47**	**0.47**
Germany, 2020	**-0.01**	**0.47**	**0.47**	**0.47**	**0.47**	**0.47**	**0.47**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

Table 388: Carbon-stock changes in mineral soils of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.A.1 – Forest Land remaining Forest Land [t C ha-1 a-1]	4.A.2 – Land converted to Forest Land [t C ha-1 a-1]	4.A.2.1. – Cropland converted to Forest Land [t C ha-1 a-1]	4.A.2.2. – Grassland converted to Forest Land [t C ha-1 a-1]	4.A.2.3. – Wetlands converted to Forest Land [t C ha-1 a-1]	4.A.2.4. – Settlements converted to Forest Land [t C ha-1 a-1]	4.A.2.5. – Other Land converted to Forest Land [t C ha-1 a-1]
Belgium	NA	0.89	2.09	0.67	-0.15	1.53	NO
Denmark	NO,NA	0.16	0.17	NO	NO	NO	NO
France	NE	0.07	1.06	-0.05	NO	0.46	NE
UK	0.40	-0.82	-0.86	-0.81	NO	-0.82	NO
Netherlands	NA	0.00	0.46	-0.30	0.06	0.35	2.23
Austria	-0.18	0.70	1.20	-0.87	NO	2.64	2.91
Poland	0.10	0.26	0.37	-0.20	NO	NO	NO
Switzerland	0.00	1.10	0.69	0.98	1.45	2.27	4.21
Czech Republic	NO	0.28	0.30	0.17	NO	0.33	NO
Germany, 2019	**0.41**	**0.19**	**0.33**	**0.03**	**0.08**	**1.81**	**0.94**
Germany, 2020	**0.41**	**0.21**	**0.31**	**0.12**	**-0.36**	**1.59**	**0.73**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

Table 389: Carbon-stock changes in organic soils of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.A.1 – Forest Land remaining Forest Land [t C ha-1 a-1]	4.A.2 – Land converted to Forest Land [t C ha-1 a-1]	4.A.2.1. – Cropland converted to Forest Land [t C ha-1 a-1]	4.A.2.2. – Grassland converted to Forest Land [t C ha-1 a-1]	4.A.2.3. – Wetlands converted to Forest Land [t C ha-1 a-1]	4.A.2.4. – Settlements converted to Forest Land [t C ha-1 a-1]	4.A.2.5. – Other Land converted to Forest Land [t C ha-1 a-1]
Belgium	NO	NO	NO	NO	NO	NO	NO
Denmark	-1.30	-1.30	-1.30	-1.30	-1.30	NO	NO
France	NO	NO	NO	NO	NO	NO	NO
UK	0.18	-1.83	-1.80	-1.84	NO	-1.83	NO
Netherlands	-0.93	-1.03	-0.97	-1.06	-0.97	-1.05	-0.68
Austria	NO	NO	NO	NO	NO	NO	NO
Poland	-0.68	-0.68	-0.68	-0.68	NO	NO	NO
Switzerland	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
Czech Republic	NO	NO	NO	NO	NO	NO	NO
Germany, 2019	**-2.57**	**-2.57**	**-2.58**	**-2.57**	**-2.58**	**-2.60**	**-2.45**
Germany, 2020	**-2.65**	**-2.66**	**-2.68**	**-2.65**	**-2.66**	**-2.68**	**-2.49**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

6.4.5 Category-specific recalculations (4.A)

This year's submission includes category-specific recalculations for the entire period 1990-2020. The changes, which result from improvements in the data, affect the following pools:

- The sampling network for determining land use and land-use changes has been adjusted (cf. Chapter 6.3.1ff).
- Changed emission factors for biomass. For Forest Land remaining Forest Land, annual EF for biomass were introduced in the 2021 submission. In the present submission, the logging data used for derivation of the annual figures are consistent with the data used for derivation of harvested wood products (cf. also Chapter 6.4.2.2 and Chapter 6.10). The new and old EF for biomass are compared in Table 393. Previous uses are not taken into account in the case of land-use changes leading to Forest Land.
- For dead wood, the afforestation data from the 2017 Carbon Inventory were corrected. The new and old EF for dead wood are compared in Table 392.
- The emission factors for previous uses, in connection with conversions from Woody Grassland to Forest Land, were adjusted (cf. also Chapter 6.1.2.3.5).

Any slight differences between the area data reported in the current and previous year's submissions are due to the effects of correction algorithms used in order to assure consistency between the area-use time series and the newly added data from the last time-series year. In keeping with the assumption that the newest data are the best data, in terms of quality, the previous time series has been adjusted (cf. also Chapter 6.3 ff). The changes in area are summarized in Table 390.

Table 391 shows the emissions as given in the present submission and the last submission, broken down by greenhouse gases, and including the resulting differences.

Justification for the recalculation of forest biomass

Previously, annual figures provided on biomass on Forest Land have been based on the periodic data of the forest inventories. This has meant, as a result, that all years within a given period have the same emission factor (EF). For the time since the last inventory, the EF for the last such period has been carried forward. This method conforms to IPCC rules and is in keeping with the "stock-difference method."

Now, a method has been developed that permits annual differentiation in greenhouse-gas reporting. This method, the "logging factor method," is described in the publication RÖHLING et al. (2016). The reasons why it was necessary to introduce annual differentiation are as follows:

1. In the framework of the Paris climate accord, Germany, in keeping with the requirements of European Union (Regulations (EU) 2018/841, 525/2013 und 529/2013), submitted a National Forestry Accounting Plan (NFAP) with derivation of a Forest Reverence Level (FRL). The method it used in this context for biomass has been criticized by the European Commission (COM), however. For this reason, the method has been changed as called for on page 46 of the Commission Report "ASSESSMENT OF THE REVISED NATIONAL FORESTRY ACCOUNTING PLANS 2021-2025":

"The matrix model used in Germany’s FRL proposal describes the stock-change of living biomass in 2002-2007 and is based on the German National Forest Inventory 2002 and Inventory Study 2008 (see German NFAP). The weighted emission factor of this model (NFAP Addendum and Corrigendum, Table 6, amended to NFAP, Annex 1, Table I-2: -1.72 t CO2-eq ha-1 yr-1), however, is not representative for the full reference period (2000-2009).

In consultations with Germany it was decided to adjust net emissions from living biomass to reflect the full reference period, using a correction factor based on emission factors estimated by the logging factor method as described by Roehling et al. (2016). This method provides annual emission factors by using the periodical averages of stock changes in GHG reporting as a basis, but modulating these with annual harvest data. This can be interpreted as a surrogate method described in IPCC guidelines …"

This change of method, and the pertinent requirement set forth in the European rules, calling for establishment of methodological consistency between greenhouse-gas reporting and NFAPs, is a reason why annually differentiating figures for living biomass have been introduced in greenhouse-gas reporting.

2. With the previous method used for updating the EF beyond the last forest inventory (the 2017 Carbon Inventory), it was not possible to describe the impacts of forest damage, on biomass, in the years 2018 through 2020. Introduction of annual figures for biomass, in keeping with the method of RÖHLING et al. (2016), makes such description possible, since the annual logging data do reflect forest damage – at least to some extent.

With the transition to the logging-factor method (Röhling et al., 2016), derivation of annual logging data now takes account of annual quantities of logged wood as given by logging statistics. The quantities of wood that are logged depend on how forests are managed. They also depend strongly on damage events such as storms, however. In 1990, Germany was hit by a series of hurricanes that damaged about 70 million m^3 of timber. The quantity is equivalent to double the average annual quantity of wood logged at the time. In 2007, hurricane "Kyrill" struck, leaving behind about 37 million m^3 of damaged timber. Each year, forests sequester carbon via the growth of their trees. A forest's carbon storage in a given year is given by the balance between the quantity of forest wood that is logged and the amount of new growth that occurs in the forest. When unusually large quantities of wood are logged, such as in the periods after the storms of 1990 and 2007, carbon storage is reduced. This fact is reflected in the lower emission factor that has resulted, via the change of method, in the years 1990 and 2007. The lower emission factor quantifies the pertinent carbon storage per hectare and year.

Table 390 compares the relevant forest areas as given in the current submission and in last year's submission, while Table 391 compares the emissions as reported in the two submissions.

Table 390: Comparison of the land-use matrix as reported in the 2021 submission and as reported in the 2022 submission

CRF No.	Area [kha]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.A	Forest land	2021	10,838.23	10,889.45	10,940.64	10,943.52	10,963.13	10,973.81	10,982.42	10,991.03	10,999.65	11,008.29
		2022	10,838.41	10,890.11	10,941.79	10,945.03	10,964.92	10,976.55	10,984.90	10,993.25	11,001.60	11,009.95
		Difference	0.18	0.67	1.15	1.51	1.80	2.74	2.48	2.22	1.96	1.66
		in %	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 391: Comparison of emissions as reported in the 2021 and 2022 submissions (in [kt CO_2-eq])

CRF No.		GHG	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.A	Forest land	CO_2	2021	-22,065.98	-79,506.15	-62,199.41	-33,145.99	-50,465.58	-62,541.61	-63,619.31	-63,384.92	-58,069.71	-57,457.64
			2022	-19,707.07	-71,100.39	-51,620.53	-34,757.61	-51,058.87	-61,754.28	-64,173.78	-63,163.65	-56,103.53	-52,764.86
			Difference	2,358.91	8,405.76	10,578.88	-1,611.62	-593.29	787.34	-554.48	221.27	1,966.18	4,692.77
			in %	-12%	-12%	-20%	5%	1%	-1%	1%	0%	-4%	-9%
		CH_4	2021	31.96	32.13	32.27	31.72	31.61	31.66	31.64	31.59	31.55	31.51
			2022	31.97	32.15	32.30	31.79	31.65	31.68	31.67	31.61	31.58	31.53
			Difference	0.01	0.02	0.03	0.07	0.05	0.02	0.03	0.02	0.03	0.02
			in %	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		N_2O	2021	459.61	439.39	429.51	404.12	389.01	374.45	374.61	374.88	375.36	374.34
			2022	460.58	443.71	425.59	396.89	394.52	380.15	379.01	377.83	376.63	373.87
			Difference	0.97	4.31	-3.92	-7.22	5.51	5.70	4.39	2.94	1.27	-0.48
			in %	0%	1%	-1%	-2%	1%	1%	1%	1%	0%	0%

Table 392: Comparison of emission factors, as reported in the 2021 and 2022 submissions, for dead wood (in [t C/ha])

CRF No.		Submission	1990-2001	2002-2007	2008-2011	2012-2018
4.A.1	Forest Land remaining Forest Land	2021	-0.04	-0.10	0.19	-0.09
		2022	-0.04	-0.10	0.19	-0.09
4.A.2	Land converted to Forest Land	2021	-0.03	-0.03	-0.16	-0.22
		2022	-0.03	-0.03	-0.23	0.00

Table 393: Comparison of emission factors, as reported in the 2021 and 2022 submissions, for biomass (in [t C/ha])

Forest Land remaining Forest Land				
Sub-category / Pool	Above-ground biomass		Below-ground biomass	
Submission	2021	2022	2021	2022
1990	-0.19	-0.14	-0.02	-0.01
1991	-1.47	-1.58	-0.14	-0.15
1992	-1.61	-1.71	-0.15	-0.16
1993	-1.60	-1.70	-0.15	-0.16
1994	-1.36	-1.50	-0.13	-0.14
1995	-1.53	-1.34	-0.15	-0.13
1996	-1.40	-1.42	-0.13	-0.13
1997	-1.38	-1.37	-0.13	-0.13
1998	-1.39	-1.35	-0.13	-0.13
1999	-1.40	-1.39	-0.13	-0.13
2000	-1.12	-0.87	-0.11	-0.08
2001	-1.27	-1.34	-0.12	-0.13
2002	-0.46	-0.39	-0.12	-0.10
2003	-0.42	-0.42	-0.11	-0.11
2004	-0.39	-0.39	-0.10	-0.10
2005	-0.35	-0.38	-0.09	-0.10
2006	-0.33	-0.35	-0.08	-0.09
2007	-0.25	-0.26	-0.07	-0.07
2008	-0.97	-0.97	-0.13	-0.13
2009	-1.12	-1.11	-0.15	-0.15
2010	-0.98	-0.99	-0.13	-0.14
2011	-0.96	-0.96	-0.13	-0.13
2012	-0.93	-0.92	-0.16	-0.16
2013	-0.95	-1.00	-0.17	-0.18
2014	-1.01	-0.98	-0.18	-0.18
2015	-0.98	-0.96	-0.17	-0.17
2016	-1.02	-1.02	-0.18	-0.18
2017	-1.02	-1.00	-0.18	-0.18
2018	-0.90	-0.85	-0.16	-0.15
2019	-0.89	-0.78	-0.16	-0.14

6.4.6 Category-specific planned improvements (4.A)

No further improvements are planned at present. Information about the implementation status of planned improvements in the LULUCF sector is presented in Chapter 6.1.4.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

6.5 Cropland (4.B)

6.5.1 Category description (4.B)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**4 B, Cropland**		**CO_2**	**13,762.4**	**1.1%**	**16,656.0**	**2.3%**	**21.0%**
-/-/T2	**4 B, Cropland**		**N_2O**	**233.8**	**0.0%**	**645.6**	**0.1%**	**176.2%**
-/-	4 B, Cropland		CH_4	145.7	0.0%	125.8	0.0%	-13.7%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	RS/NS	CS
N_2O	Tier 2	RS/NS	CS/D
CH_4	Tier 2	RS/NS	CS

The category *Cropland* (4.B) consists of the seven sub-categories *Cropland$_{annual}$, Hops, Vineyards, Orchards, Tree nurseries, Christmas tree plantations and Short-rotation plantations* (cf. also Chapter 6.2.2, Chapter 6.3.2.1 and Table 354). In this submission, a stratified, itemized list of the emissions-calculations results for these sub-categories is also being provided, for the first time, in the CRF tables. The category is a key category for CO_2 emissions in terms of emissions level and trend, and a key category for N_2O emissions pursuant to Approach 2 analysis.

Reporting in the *Cropland* category covers emissions / removals of CO_2 from and to mineral and organic soils, and from and to above-ground and below-ground biomass. It also includes direct and indirect nitrous oxide emissions from humus losses from mineral soils, following land-use conversions to Cropland, and it covers methane emissions from organic soils. In keeping with the IPCC Guidelines (IPCC, 2006a), direct and indirect nitrous oxide emissions from fertiliser application (artificial fertiliser, manure, sewage sludge, etc.), crop residues and drainage of organic soils under cultivation are reported under Agriculture (CRF 3.D). For this reason, in the Cropland chapter, those categories are marked as "IE". Burning of fields and crop residues is prohibited by law in Germany (DirektZahlVerpflV, 2004) and thus is not reported (NO).

Emissions from the land-use category Cropland (the sum consisting of Cropland$_{annual}$, Hops, Vineyards, Orchards, Tree nurseries, Christmas tree plantations and Short-rotation plantations) are listed, separately by pools, in Table 394 and in CRF tables 4, 4.B, 4(II).B, 4(III).B and 4(IV).2. The total emissions from Cropland in 2020 in Germany amounted to 17,427.48 kt CO_2 equivalents. The main emissions sources are soils, especially organic soils under cultivation (65.8 %). Mineral soils contributed 28.6 % of the total emissions. Most emissions from mineral soils resulted from tillage of grassland. The anthropogenically related net emissions of CO_2 from biomass in the Cropland sector are low (5.7 %). The sub-categories Orchards, Tree nurseries and Christmas tree plantations were slight sinks in 2020. In 2020, no land-use changes from Forest Land to Cropland took place. As a result, no emissions from dead organic matter occurred.

Perennial crops account for a much smaller share (< 1%) of the total emissions from Cropland than annual crops (99.8 %) do. In 2020, the sub-categories Orchards and Tree nurseries were slight net sinks; all other sub-categories of Cropland functioned as net sources (Table 394).

The predominating greenhouse gas in the Cropland sector is CO_2, accounting for 16,656.04 Gg CO_2 equivalents (95.6 %). The reported nitrous oxide emissions from decomposition of organic soil matter, as a result of land-use changes leading to Cropland, are low by comparison ((645.63 kt CO_2-eq. ≙ 3.7 %, consisting of direct (527.0 kt CO_2-Eq. (CRF 4(III)) and indirect emissions (118.6 kt CO_2-eq. (CRF 4(IV)). A similar statement can be made for the relevant methane emissions (125.81 kt CO_2-eq. ≙ 0.7 % (CRF 4(II).B), from use of organic soils).

Table 394: CO_2, N_2O and CH_4 emissions [kt CO_2-eq.] from Germany's Cropland, 2020. The table includes both the relevant sums and the upper and lower bounds of the 95 % confidence interval.

Source category	GHG	Cropland, emissions, 2020 [kt CO_2-eq.] Emission	2.5 perc.	97.5 perc.	[%] 2.5 perc.	97.5 perc.
$Cropland_{annual}$ [1)]	∑	**17,310.5**	14,057.4	20,636.5	18.79	19.21
Mineral soils	CO_2 [2)]	**4,318.9**	4,230.1	4,407.7	2.06	2.06
	N_2O_{direct} [3)]	**522.7**	162.5	1,549.7	68.91	196.49
	$N_2O_{indirect}$ [4)]	**117.6**	0.0	448.9	99.99	281.68
Organic soil	CO_2 [2)]	**11,224.3**	7,660.0	12,847.3	31.76	14.46
	N_2O [5)]	**IE**	IE	IE	IE	IE
	CH_4 [6)]	**124.5**	75.3	203.1	39.52	63.19
Biomass	CO_2 [2)]	**1,002.6**	669.3	1,279.8	33.24	27.65
Litter / dead wood	CO_2 [2)]	**0.0**	0.0	0.0	0.00	0.00
		Hops, emissions, 2020				
Source category	**GHG**	**[kt CO_2-eq.] Emission**	**2.5 perc.**	**97.5 perc.**	**[%] 2.5 perc.**	**97.5 perc.**
Hops [1)]	∑	**11.33**	8.41	14.30	25.80	26.19
Mineral soils	CO_2 [2)]	**1.29**	0.78	1.81	39.50	39.50
	N_2O_{direct} [3)]	**0.14**	0.07	0.32	51.66	133.19
	$N_2O_{indirect}$ [4)]	**0.0**	0.01	0.09	78.83	189.39
Organic soil	CO_2 [2)]	**6.28**	3.20	8.85	49.04	40.95
	N_2O [5)]	**IE**	IE	IE	IE	IE
	CH_4 [6)]	**0.12**	0.05	0.21	59.97	79.89
Biomass	CO_2 [2)]	**3.48**	1.96	4.99	43.52	43.60
Litter / dead wood	CO_2 [2)]	**0.00**	0.00	0.00	0.00	0.00
		Vineyards, emissions, 2020				
Source category	**GHG**	**[kt CO_2-eq.] Emission**	**2.5 perc.**	**97.5 perc.**	**[%] 2.5 perc.**	**97.5 perc.**
Vineyards [1)]	∑	**35.18**	26.37	44.29	25.04	25.90
Mineral soils	CO_2 [2)]	**16.97**	13.92	20.01	17.95	17.95
	N_2O_{direct} [3)]	**1.1**	0.58	2.35	45.45	119.93
	$N_2O_{indirect}$ [4)]	**0.2**	0.07	0.65	70.45	170.87
Organic soil	CO_2 [2)]	**0.13**	0.04	0.20	71.16	59.86
	N_2O [5)]	**IE**	IE	IE	IE	IE
	CH_4 [6)]	**0.00**	0.00	0.00	80.35	107.38
Biomass	CO_2 [2)]	**16.77**	6.18	27.44	63.17	63.59
Litter / dead wood	CO_2 [2)]	**0.00**	0.00	0.00	0.00	0.00

Orchards, emissions, 2020						
Source category	**GHG**	**[kt CO_2-Eq.]**			**[%]**	
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Orchards [1]	∑	**-0.18**	-0.15	-0.20	13.02	13.16
Mineral soils	CO_2 [2]	**-18.75**	-17.26	-20.24	7.96	7.96
	N_2O_{direct} [3]	**0.9**	0.31	2.69	67.05	186.43
	$N_2O_{indirect}$ [4]	**0.2**	0.00	0.77	99.99	266.75
Organic soil	CO_2 [2]	**37.59**	22.56	50.41	39.98	34.10
	N_2O [5]	**IE**	IE	IE	IE	IE
	CH_4 [6]	**0.42**	0.23	0.68	44.24	62.62
Biomass	CO_2 [2]	**-20.59**	-17.61	-23.59	14.46	14.57
Litter / dead wood	CO_2 [2]	**0.00**	0.00	0.00	0.00	0.00

Tree nurseries, emissions, 2020						
Source category	**GHG**	**[kt CO_2-eq.]**			**[%]**	
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Tree nurseries[1]	∑	**-11.99**	-10.53	-13.44	12.18	12.08
Mineral soils	CO_2 [2]	**0.87**	0.78	0.96	10.16	10.16
	N_2O_{direct} [3]	**0.4**	0.18	0.97	52.99	148.54
	$N_2O_{indirect}$ [4]	**0.1**	0.01	0.27	85.66	212.67
Organic soil	CO_2 [2]	**23.11**	15.84	27.11	31.47	17.31
	N_2O [5]	**IE**	IE	IE	IE	IE
	CH_4 [6]	**0.22**	0.13	0.35	39.92	61.70
Biomass	CO_2 [2]	**-36.67**	-31.36	-41.98	14.46	14.48
Litter / dead wood	CO_2 [2]	**0.00**	0.00	0.00	0.00	0.00

Christmas tree plantations, emissions, 2020						
Source category	**GHG**	**[kt CO_2-eq.]**			**[%]**	
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Christmas-tree plantations[1]	∑	**43.58**	36.83	50.40	15.50	15.64
Mineral soils	CO_2 [2]	**12.60**	11.27	13.92	10.51	10.51
	N_2O_{direct} [3]	**1.55**	0.65	4.08	58.07	163.21
	$N_2O_{indirect}$ [4]	**0.35**	0.02	1.16	94.04	233.72
Organic soil	CO_2 [2]	**41.19**	27.68	48.19	32.81	16.99
	N_2O [5]	**IE**	IE	IE	IE	IE
	CH_4 [6]	**0.47**	0.28	0.74	40.95	58.51
Biomass	CO_2 [2]	**-10.92**	-8.42	-13.45	22.89	23.15
Litter / dead wood	CO_2 [2]	**0.00**	0.00	0.00	0.00	0.00

Short-rotation plantations, emissions, 2020						
Source category	**GHG**	**[kt CO_2-eq.]**			**[%]**	
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Christmas-tree plantations[1]	∑	**37.43**	32.59	42.41	12.92	13.30
Mineral soils	CO_2 [2]	**2.14**	1.91	2.38	10.93	10.93
	N_2O_{direct} [3]	**0.3**	0.15	0.62	45.48	125.34
	$N_2O_{indirect}$ [4]	**0.1**	0.02	0.17	72.64	179.22
Organic soil	CO_2 [2]	**2.71**	-0.43	5.74	115.92	111.77
	N_2O [5]	**IE**	IE	IE	IE	IE
	CH_4 [6]	**0.13**	-0.06	0.33	147.05	162.82
Biomass	CO_2 [2]	**32.11**	28.45	35.95	11.41	11.95
Litter / dead wood	CO_2 [2]	**0.00**	0.00	0.00	0.00	0.00

1) Sum of the emissions from CRF tables 4.B, 4.(II).B, 4.(III).B, 4.(IV).2

2) CRF Table 4.B

3) CRF Table 4.(III).B

4) The category-specific indirect N_2O emissions are not included and shown as such in the CRF tables; they are included, however, in the sum, for all sub-categories, presented in CRF Table 4.(IV).2.

5) CRF Table 3.D.a.6

6) CRF Table 4.(II).B

Figure 68 and Figure 69 show the trends over time in emissions from Cropland. The total emissions in 2020 were 3,283.98 kt CO_2-Eq -≙ 23.2 % higher than in the reference year 1990. This general trend is due primarily to increases of emissions from mineral soils (198.5%), mainly as a result of tillage of grassland (CRF 4.B.2.1.1; 4.B.2.2.1.1 - 4.B.2.2.1.4). No emissions from deforestation occurred, throughout the entire time series. The emissions resulting from land-use changes from Wetlands to Cropland (94.3 kt CO_2-Eq ≙ 0.5 %) are low, absolutely. At the same time, they exhibit an increase of 968 %, with respect to 1990, which is due mainly to the pool organic soils, followed by the biomass pool. In 2020, conversion of Settlement areas led to negative emissions of 65.7 kt CO_2-Eq. No consistent trend is apparent (Figure 68).

The shapes of the time-series plots – especially the noticeable changes they show – are due primarily to the periodicity in surveying of the relevant area data (cf. Chapter 6.3.5). Land-use changes were determined on the basis of spatially explicit data sets from the years 1990, 2000, 2005, 2010, 2015 and 2020 (cf. Chapter 6.3). Land-use changes that occurred between those years were determined via linear interpolation, and thus the annual conversion areas did not change between the survey time points.

The marked changes in the trends for the year 2000 are due primarily to differences in the databases used. Starting with the reporting year 2000, the area data of the B-DLM in ATKIS can be used as a basis for substantiation of applicable areas and land uses. The resolution (spatial and chronological) of those data is much higher than that of the CORINE Landcover (CLC) data that have to be used for documenting land use in years prior to 2000 (Chapter 6.3.2.2). Although the older data series of the CLC has been adjusted, via the "Overlap Approach" (IPCC (2006a): Vol. 1 Ch. 5.3.3), to the newer, higher-resolution data series of the Basis-DLM, the change of database, from 2000 forward, leads to considerably higher numbers of detectable land-use changes with respect to the 1990 – 2000 period, especially changes from Grassland to Cropland.

Figure 68: GHG emissions from Cropland (total of CO_2, CH_4 and N_2O) **[kt CO_2-eq.] as a result of land use and land-use changes, 1990-2020, by sub-categories (with uncertainties shown only for the total)**

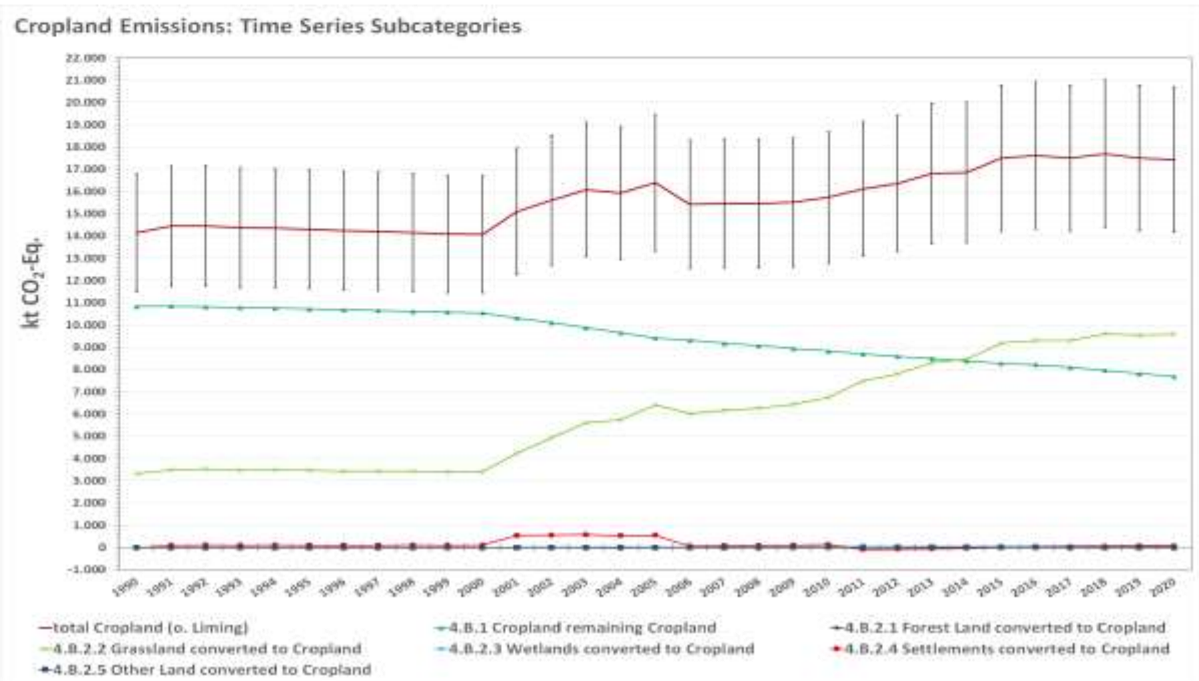
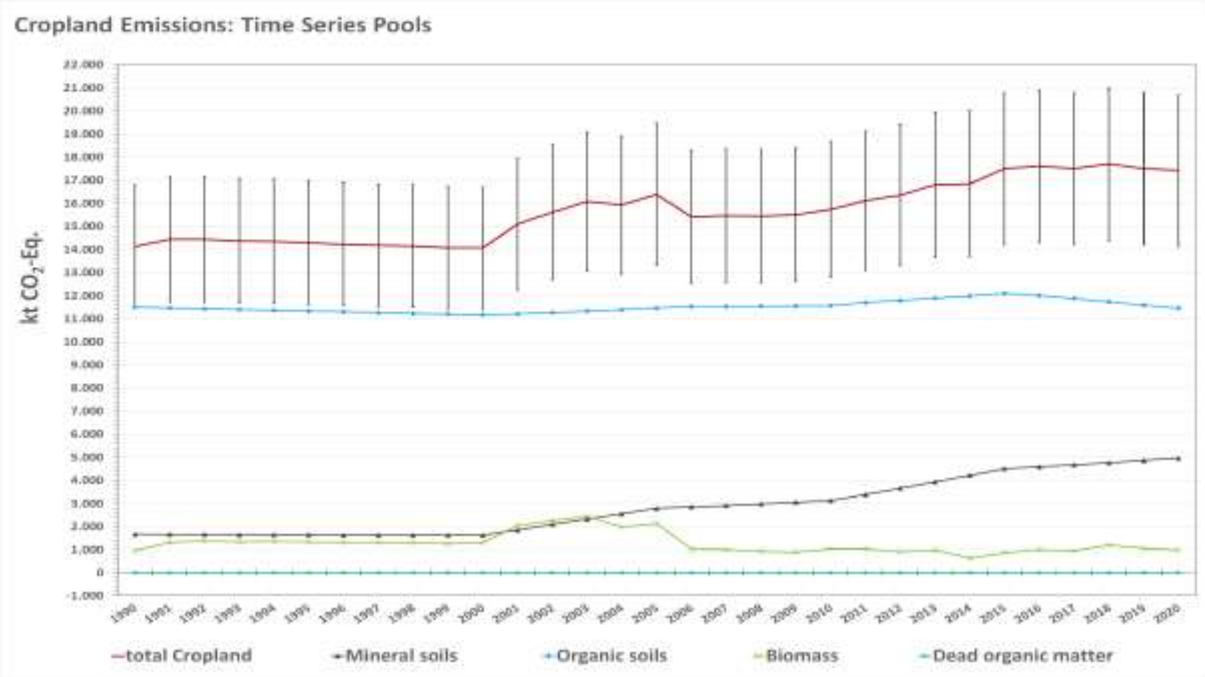


Figure 69: Greenhouse-gas emissions from Cropland, (sum of CO_2, CH_4 and N_2O) [kt CO_2-Eq.] as a result of land use and land-use changes, 1990-2020, by pools (with uncertainties shown only for the total)



6.5.2 Methodological issues (4.B)

6.5.2.1 Data sources

The following data sources / sets been used:

- Statistisches Bundesamt, Fachserie 3, Reihe 3, Land- und Forstwirtschaft, Fischerei, Landwirtschaftliche Bodennutzung und pflanzliche Erzeugung (Federal Statistical Office, Fachserie 3, Reihe 3, agriculture and forestry, fisheries, agricultural soil use and crop cultivation; (Statistisches Bundesamt, FS 3, R 3b)),
- Statistisches Bundesamt, Fachserie 3, Reihe 3.2.1, Land- und Forstwirtschaft, Fischerei, Wachstum und Ernte – Feldfrüchte (Federal Statistical Office, Fachserie 3, Reihe 3, agriculture and forestry, fisheries, growth and harvests – crops; (Statistisches Bundesamt, FS 3, R 3.2.1)),
- Statistisches Bundesamt, Fachserie 3, Reihe 3.1.2, Land- und Forstwirtschaft, Fischerei,– Bodennutzung der Betriebe (Federal Statistical Office, Fachserie 3, Reihe 3, agriculture and forestry, fisheries – soil use by sectoral operations; (Statistisches Bundesamt, FS 3, R 3.1.2)),
- 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use (IPCC, 2006a)
- "Ordinance on application of fertilisers, soil additives, culture substrates and plant additives according to the principles of good practice in fertilization (Ordinance on Fertilisation – Düngeverordnung (DüV))" (Ordinance on Fertilisation in the version as promulgated 27 February 2007 (Federal Law Gazette I, p. 221), last amended by Article 5 (36) of the Act of 24 February 2012 (Federal Law Gazette I p. 212) (Bundesgesetzblatt, 2012).

- Interim report in the research project "Methodenentwicklung zur Erfassung der Biomasse mehrjährig verholzter Pflanzen außerhalb von Wäldern" ("Development of methods for determining the biomass of plants, outside of forests, with multiple years of wood growth") (Pöpken, 2011).
- (Jacobs et al., 2018): Landwirtschaftlich genutzte Böden in Deutschland - Ergebnisse der Bodenzustandserhebung (Agricultural soils in Germany – Results of the Soil Inventory); Johann Heinrich von Thünen Institute, 316 pp. Thünen Report 64; Braunschweig. DOI:10.3220/REP1542818391000

6.5.2.2 Biomass

In the Cropland category, the biomass pool is subdivided in accordance with basic characteristics of the plants concerned (cf. Chapter 6.2.2 and Chapter 6.3.2.1):

- herbaceous plants ($Cropland_{annual}$)
- woody perennial crops (Hops, Vineyards, Orchards, Tree nurseries, Christmas tree plantations and Short-rotation plantations).

The method for determination of GHG emissions from plant biomass of woody perennial crops has been fundamentally modified as of the present submission. Now, the growth stages of plants are modelled chronologically precisely, as a function of crop age and type of management (rotation periods), so that emissions can be reported – in keeping with the requirements of the 2006 IPCC Guidelines – in the year in which they occur. The methods and assumptions used for calculation of carbon-stock changes in above-ground and below-ground biomass of plants are described in Chapter 6.1.2.3, while the specific methods and emission-factor derivations for the various categories are described in the following chapters:

- for herbaceous plants of annual crops, in Chapter 6.1.2.3.3,
- for Hops, in Chapter 6.1.2.3.5.6,
- for Vineyards, in Chapter 6.1.2.3.5.2,
- for Christmas tree plantations, in Chapter 6.1.2.3.5.4,
- for Tree nurseries, in Chapter 6.1.2.3.5.3,
- for Short-rotation plantations, in Chapter 6.1.2.3.5.5.

6.5.2.2.1 Land-use change

Annual and perennial crops are now documented spatially explicitly and completely, and broken down by the sub-categories listed in Chapter 6.5.2.2. In connection with land-use changes leading from/to Cropland, and in keeping with the methods described in Chapter 6.1.2.3.1 ff, the carbon stocks listed in Chapter 6.1.2.3.3 and Chapter 6.1.2.3.4 for above-ground and below-ground biomass are used, as initial and final values, as a basis for calculation of CO_2 removals/emissions in/from the Cropland-biomass pool.

6.5.2.2.2 The remaining category

In the remaining categories $Cropland_{annual}$ and Hops, consistent vegetation structures occur, with the result that biomass in those categories can be assumed to reach dynamic equilibria (and with the result that no emissions occur; the notation key "NA" in entered in the relevant spaces in the tables) (cf. Chapter 6.1.2.3.1). In the sub-categories Vineyards, Orchards, Tree nurseries, Christmas tree plantations and Short-rotation plantations, by contrast, the C stocks of plant biomass are calculated for each reported year. Area conversions between the individual Cropland sub-categories are treated like land-use changes, and explicitly listed as such in CRF- 4.b. Starting now, the area changes between annual crops and listed perennial crops can be documented spatially explicitly and completely. Relevant calculations are carried out using the gain-loss method (2006 IPCC Guidelines) described in Chapter 6.1.2.3.1 ff.

6.5.2.3 Mineral soils

6.5.2.3.1 Land-use change

Calculation of CO_2 emissions resulting from area conversions leading to Cropland is described in Chapter 6.1.2.1, while calculation of direct N_2O emissions is described in Chapter 6.1.2.7 and calculation of indirect N_2O emissions is described in Chapter 6.1.2.8. The emission factors for carbon are shown in Table 336 and Table 337 (Chapter 6.1.2.1.1), while the emission factors for direct nitrous oxide emissions are shown in Table 351 (Chapter 6.1.2.7) and the emission factors for indirect N_2O emissions are shown in Table 352 (Chapter 6.1.2.8). The manner in which the emission factors have been derived is described in Chapter 6.1.2.1, while the pertinent uncertainties are listed in Table 395 (Chapter 6.6.3). The results for emissions from mineral soils are presented as follows:

- CO_2 emissions in CRF tables 4.B.2.1 – 4.B.2.5,
- direct N_2O emissions in CRF tables 4.III.2.1 – 4.III.2.5,
- indirect N_2O emissions in CRF table 4.IV.2.

In keeping with the 2006 IPCC Guidelines (IPCC, 2006a), direct and indirect nitrous oxide emissions from decomposition of organic matter in mineral soils of the Cropland remaining category are reported in the tables for the Agricultural sector (3.D.a.5).

6.5.2.3.2 The remaining category

For areas in the category Cropland remaining Cropland, no carbon-stocks changes in mineral soils in sub-categories of the same name are listed; consequently, no nitrous oxide is emitted via mineralisation of organic soil matter. The assumption that mineral soils in continuous use as cropland in Germany are not sources of carbon and nitrogen emissions is supported by the following arguments:

- Results from 140 regional long-term-study areas (Höper and Schäfer (2012); Fortmann et al. (2012) and Blum and Heinbach (2007)) that show the constancy of carbon stocks since the beginning of the 1990s.
- Initial studies of the carbon balance of cropland areas, carried out at 180 sites of the country-wide Agricultural Soil Inventory (Dreysse, 2015). The models used included the VDLUFA-Humusbilanzierung ("VDLUFA humus balancing") model, which was developed for practical advising (Körschens et al. (2004)), and the "CandyCarbonBalance" model (Franko et al., 2011), which is process-controlled and site-adapted. Both models clearly show that the studied cropland soils under long-term use are not sources of CO_2 (Dreysse, 2015).
- Meta-studies such as Baker et al. (2007) and Luo et al. (2010)) show that the type of soil tillage used has no influence on the total carbon stocks in mineral soils down to observed depths of more than 60 cm.

Along with this evidence, extensive proof of the correctness of the above assumptions can be listed:

1. The results of the nationwide evaluation of German long-term soil monitoring sites (Marx et al., 2016).

2. Time-series analysis for carbon inputs via organic fertilisers and crop residues. The carbon inputs are derived from the relevant nitrogen inputs into Germany's croplands, as calculated for the source categories of the agricultural sector (CRF Table 3.D).
3. The fertilisation recommendations for implementation of the German Fertiliser Ordinance (Düngeverordnung) and the EU Nitrates Directive;

Regarding 1.) The findings obtained in a research project on long-term soil monitoring sites of the German Länder have been compiled, harmonised and synthetically evaluated on a nationwide basis (Marx et al., 2016). The key findings include:

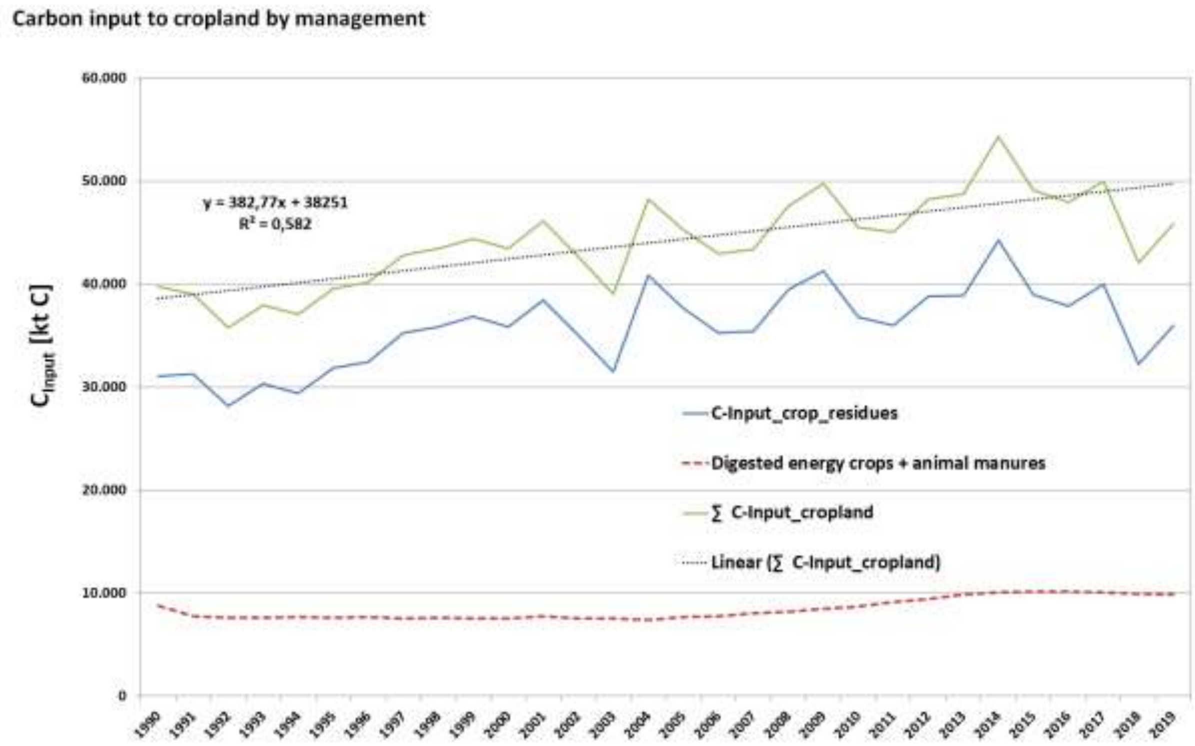
- The nationwide evaluation of the long-term soil monitoring sites, with respect to carbon-stock changes, has confirmed the findings drawn to date at the Länder level. The shares of sites at which no statistically proven changes have occurred clearly predominate. For example, 77 % of the cultivated mineral soils show no carbon-stock change, while 10 % show a significant increase and 13 % show a significant decrease (Marx et al., 2016).
- At 157 long-term (cropland) soil monitoring sites, data suitable for correlation analysis of soil organic carbon stocks and management are available. A positive significant correlation between a) differences in soil organic carbon stocks and b) management was found at only two sites, or about 1.3 % of all sites. The impacts of management on carbon content are marginal (Marx et al., 2016).
- Marx et al. (2016) found that the most important factors influencing soil organic carbon are clay content, precipitation and temperature, followed by other site parameters. Factors tied to management contributed insignificantly to explanation of carbon-content variance in mineral soils under cropland. The study found that the most important factors influencing long-term changes of carbon content were outset carbon content and clay content.

The results of the nationwide evaluation of long-term soil-monitoring sites carried out by Marx et al. (2016) confirm the assumption that the net carbon-stock changes in mineral soils of cropland sites are zero on average. In the main, the changes that do occur are site-related; they are not influenced by management.

Regarding 2.) The trend for carbon inputs via organic fertilisers and crop residues supports independent estimation of the influence of management on the humus balance. A positive trend implies a net carbon sink, while a negative trend is an indication of a possible decrease of carbon stocks. The trend estimate is based on the nitrogen inputs into mineral soils, as determined for the agricultural sector (CRF Table 3.D) section of the German GHG inventory. From those inputs, the carbon inputs via organic fertilisers can be approximated, by multiplying the nitrogen inputs by a mean C/N ratio of 12 (representative for the liquid-manure and solid-manure mixture that predominates in organic fertilisers). 66 % of the organic fertiliser used in Germany is used on cropland, while 34 % is used on grassland (Statistisches Bundesamt, FS 3, R 3.2.2). Figure 70 shows the following results:

- Carbon inputs via organic fertilisers have increased only slightly – but highly significantly – since 1990.
- Carbon inputs via harvest residues have increased considerably since 1990. A differentiated consideration of the period after 2005 shows that, on average, no further increases have occurred over the years.
- Overall, carbon inputs into mineral soils under Cropland have increased since 1990. That said, inputs overall have levelled off, on average, in recent years.

Figure 70: Carbon inputs [kt C] via organic fertilisers and crop residues, in Cropland, 1990 – 2019



The results of this national analysis confirm, independently from the findings obtained via long-term soil monitoring, that mineral soils in the category Cropland remaining Cropland tend to be a net carbon sink – a very slight one, if at all – rather than a net source. The fact that crops contribute less per carbon unit than organic fertilisers, to the soils' humus balance, is further confirmation of the robustness of the assumption that mineral soils under remaining cropland use in Germany are not an emissions source.

Regarding 3.) Yet another indication that mineral soils under permanent cropland do not lose any organic soil substance is provided by the recommendations for fertilisation of annual crops that are given to farmers by the agricultural authorities of the German Länder. The recommendations support the aims of German legislation on fertilisation, the purposes of which include implementing the European Nitrates Directive. Art. 6 of the Fertiliser Ordinance (DüV; Bundesgesetzblatt (2012)) establishes mandatory limits for nitrogen surpluses on cropland. Conformance with the limits is monitored by authorities. The competent authorities of the Länder provide farmers with data and tools for determination of fertilisation requirements. The Fertiliser Ordinance explicitly defines the applicable parameters (such as various site factors, cultivation conditions, management methods, crops, preceding crops, residual content, use of organic fertilisers, etc.). It also calls on farmers to take the results of regional field trials into account in determining fertilisation requirements (Art 3 (2) DüV Bundesgesetzblatt (2012)). In keeping with this orientation, the tools developed by the various Länder for estimation of nitrogen-fertiliser requirements, and the data underlying such tools, are based on regional measurements and fertilisation trials. None of these systems address nitrogen losses from mineralisation of organic soil substance as an issue. Clearly, the only nitrogen sources involved are organic fertilisers and crop residues – mineralisation of organic soil substance does not play a role. It thus follows, as a complement to the results in 1.), that no N_2O emissions from mineralisation of organic soil substance occur in the category Cropland remaining Cropland – and, thus, no carbon losses occur.

Nonetheless, carbon-stock changes in mineral soils are listed in the remaining category for Cropland. Such changes are due to "usage transitions" between the different (and differently named) sub-categories within the Cropland category. Such transitions are treated like land-use changes. The emissions resulting from them are combined (summed) within the remaining category, however (Chapter 6.1.2.1).

The EU Commission, in its "Member State recommendations on reporting systems for cropland & grazing land management emissions & removals" (Ecofys & Environment Agency Austria, 2017), had recommended that a system be developed, for Germany, that would be able to record and report on carbon-stock changes in soils that result from management measures aimed at lowering emissions, or from carbon sequestration via CM and GM. This recommendation is currently being partially implemented. In addition, more-extensive possible solutions for sub-categories with the same name are currently being developed and reviewed.

6.5.2.4 Organic soils

The way in which CO_2, N_2O and CH_4 emissions from organic soils, as a result of land use and land-use changes, have been calculated, and the way in which the relevant emission factors have been derived, are described in Chapter 6.1.2.2. The manner in which the relevant areas and area land uses have been determined is described in Chapter 6.3.1 ff. The annual emissions from land-use changes are calculated in the same way as the emissions from Cropland remaining Cropland. The latter emissions are listed in CRF Table 4.B.1, while emissions from land-use changes in are listed in CRF Tables 4.B.2.1 - 4.B.2.5.

N_2O emissions from cultivated organic soils are reported as part of the Agriculture sector, under Chapter 3.D.a.6 "Cultivation of Histosols."

The areas reported in the Agriculture sector, under Chapter 3.D.a.6 "Cultivation of Histosols," do not differ from those reported in the LULUCF sector (cf. also Chapter 6.1.2.2.1).

The methane emissions from organic soils and from drainage ditches are listed in CRF Table 4(II)B.

6.5.3 Uncertainties and time-series consistency (4.B)

The uncertainties for the emission factors and the activity data were determined in accordance with the 2006 IPCC Guidelines (IPCC, 2006a). Additional relevant information is provided in Chapter 6.1.2.1. Table 395 through Table 402 show the uncertainties in the emission factors for the Cropland category, by pools and sub-categories.

Table 395 highlights the fact that the EF for mineral soils and biomass mainly have standard normal distributions and near-normal distributions. The uncertainties seen in this area are the smallest of all relevant uncertainties. This results from use of results of major, country-wide inventories. In particular, use of the new method has considerably reduced the uncertainties of the emission factors for mineral soils, with respect to the previous year, in the Settlements category. With the exception of the EF for CO_2 from organic soils, which exhibits a right-skewed distribution, the EF for CO_2 from soils tend to show normal distributions. The EF for N_2O emissions from mineral soils show the largest uncertainties. This is due primarily to use of the IPCC default factors.

In Gaussian calculation of error propagation, uncertainties of more than 100 % were calculated for the lower bound of the 95 % confidence interval for the uncertainties for the factors for indirect N_2O emissions. While this calculation method is requirements-conformal, it is not functionally expedient in this context. As a result of the processes on which the indirect N_2O

emissions from mineral soils are based, no negative emissions can occur. For this reason, the uncertainty for the lower bound has been set to 99.9 %.

The large uncertainty seen in the EF for methane and nitrous oxide from organic soils is due to those factors' extremely large variability in field measurements, as well as to the fact that removals are also possible in the case of methane (cf. Chapter 6.1.2.2.2)

The uncertainties for the activity data have a normal distribution, and half of the 95 % confidence interval for the Cropland category falls within the range 0.04 – 196 %. For system-related reasons, the sampling error with the sample-grid system depends on the sample size, and thus on the relevant sub-category's share of the total area (cf. Chapter 6.3). In the Cropland sector, for example, major uncertainties (≥ 100 %) are seen only in those sub-categories whose absolute area is < 5 ha. Area-weighted derivation of a total uncertainty for the area data in the Cropland category yields an uncertainty of 0.04 % [half of the 95% confidence interval].

The total uncertainty for the land-use category Cropland is 18.3 % [2.5 percentile] and 18.7 % [97.5 percentile]. The main contribution to this comes from CO_2 emissions from organic soils.

A similar picture emerges with respect to the LULUCF inventory as a whole: While emissions from the Cropland category, with respect to organic soils, account for a considerable share of national LULUCF emissions, emissions from mineral soils play a significant role only in the case of grassland tillage (cf. Chapter 6.1.2.10).

Table 395: Implied emission factors [t C ha^{-1} a^{-1}] for calculation of GHG emissions from Germany's annual Cropland, and the uncertainties (2.5 % and 97.5 % percentile [%]) of the emission factors on which the emissions calculations are based, differentiated by pools and sub-categories, for the year 2020

$Cropland_{annual}$		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soil, CO_2-C [1)]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	$Cropland_{annual}$	0.0000	6.16	6.16
Hops	$Cropland_{annual}$	-0.0892	5.69	5.69
Vineyards	$Cropland_{annual}$	0.5338	7.24	7.24
Orchards	$Cropland_{annual}$	-0.4446	6.81	6.81
Short-rotation plantations	$Cropland_{annual}$	-0.1128	5.69	5.69
Tree nurseries	$Cropland_{annual}$	-0.0925	5.69	5.69
Christmas tree plantations	$Cropland_{annual}$	-0.0872	5.69	5.69
Grassland (in the strict sense)	$Cropland_{annual}$	-1.1632	1.98	1.98
Woody Grassland	$Cropland_{annual}$	-0.0978	5.69	5.69
Terr. Wetlands	$Cropland_{annual}$	-1.5383	7.56	7.56
Waters	$Cropland_{annual}$	-0.0757	1.74	1.74
Settlements	$Cropland_{annual}$	1.1820	4.56	4.56
Other Land	$Cropland_{annual}$	0.2788	2.23	2.23
Mineral soil, N_2O_{direct} [2)]		[kg N_2O ha^{-1} a^{-1}]	[kg N_2O ha^{-1} a^{-1}]	[%]
Forest Land	$Cropland_{annual}$	0.0000	186.83	487.54
Grassland (in the strict sense)	$Cropland_{annual}$	1.6571	184.93	486.83
Woody Grassland	$Cropland_{annual}$	0.1483	187.53	487.80
Terr. Wetlands	$Cropland_{annual}$	1.8864	188.62	488.21

Cropland$_{annual}$		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soil, $N_2O_{indirect}$ 2)		[kg N_2O ha^{-1} a^{-1}]	[kg N_2O ha^{-1} a^{-1}]	[%]
Forest Land	Cropland$_{annual}$	0.0000	186.83	487.54
Grassland (in the strict sense)	Cropland$_{annual}$	0.3729	184.93	486.83
Woody Grassland	Cropland$_{annual}$	0.0334	187.53	487.80
Terr. Wetlands	Cropland$_{annual}$	0.4244	188.62	488.21
Biomass 3)		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	Cropland$_{annual}$	0.0000	23.55	23.55
Hops	Cropland$_{annual}$	0.0774	9.69	9.69
Vineyards	Cropland$_{annual}$	0.0357	11.79	11.79
Orchards	Cropland$_{annual}$	-0.2426	11.71	11.71
Short-rotation plantations	Cropland$_{annual}$	-1.6838	7.68	9.73
Tree nurseries	Cropland$_{annual}$	-0.6091	19.91	19.91
Christmas tree plantations	Cropland$_{annual}$	-1.4970	26.75	26.75
Grassland (in the strict sense)	Cropland$_{annual}$	-0.0190	16.53	16.53
Woody Grassland	Cropland$_{annual}$	-3.1576	51.66	52.47
Terr. Wetlands	Cropland$_{annual}$	-2.9007	41.57	42.89
Waters	Cropland$_{annual}$	0.5433	11.19	11.19
Peat extraction	Cropland$_{annual}$	0.5638	11.19	11.19
Settlements	Cropland$_{annual}$	-1.0402	45.90	47.36
Other Land	Cropland$_{annual}$	0.1332	11.19	11.19
Dead organic matter 3)		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	Cropland$_{annual}$	0.0000	6.96	6.96

1) The calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

2) The calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

3) The calculation is only for first year of the land-use change; stock change: positive ≙ sink; negative ≙ source

Table 396: Implied emission factors [t C ha^{-1} a^{-1}] for calculation of GHG emissions from Germany's Hops cultivation, and the uncertainties (2.5 % and 97.5% percentile [%]) of the emission factors on which the emissions calculations are based, differentiated by pools and sub-categories, for the year 2020

Hops		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soil, CO_2-C 1)		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Hops	0.0000	8.06	8.06
Cropland$_{annual}$	Hops	0.0009	5.69	5.69
Vineyards	Hops	0.6795	9.41	9.41
Orchards	Hops	-0.4145	8.46	8.46
Short-rotation plantations	Hops	0.0000	7.84	7.84
Tree nurseries	Hops	0.0000	7.84	7.84
Christmas tree plantations	Hops	0.0098	7.84	7.84
Grassland (in the strict sense)	Hops	-0.9010	4.93	4.93
Woody Grassland	Hops	-0.0092	7.84	7.84
Terr. Wetlands	Hops	0.0000	8.56	8.56
Waters	Hops	0.0000	11.09	11.09
Settlements	Hops	1.2097	8.11	8.11
Other Land	Hops	0.0000	8.55	8.55

Hops		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soil, N_2O_{direct} 2)		**[kg N_2O ha^{-1} a^{-1}]**	**[kg N_2O ha^{-1} a^{-1}]**	**[%]**
Forest Land	**Hops**	0.0000	187.14	487.65
Grassland (in the strict sense)	**Hops**	1.2811	185.17	486.92
Woody Grassland	**Hops**	0.0147	187.86	487.92
Terr. Wetlands	**Hops**	0.0000	188.80	488.28
Mineral soil, $N_2O_{indirect}$ 2)		**[kg N_2O ha^{-1} a^{-1}]**	**[kg N_2O ha^{-1} a^{-1}]**	**[%]**
Forest Land	**Hops**	0.0000	187.14	487.65
Grassland (in the strict sense)	**Hops**	0.2882	185.17	486.92
Woody Grassland	**Hops**	0.0033	187.86	487.92
Terr. Wetlands	**Hops**	0.0000	188.80	488.28
Biomass 3)		**[t C ha^{-1} a^{-1}]**	**[t C ha^{-1} a^{-1}]**	**[%]**
Forest Land	**Hops**	0.0000	23.55	23.55
$Cropland_{annual}$	**Hops**	-0.1216	9.69	9.69
Vineyards	**Hops**	0.2530	13.28	13.28
Orchards	**Hops**	-0.1550	12.23	12.23
Short-rotation plantations	**Hops**	0.0000	7.77	9.83
Tree nurseries	**Hops**	0.0000	20.45	20.45
Christmas tree plantations	**Hops**	-2.2359	27.63	27.63
Grassland (in the strict sense)	**Hops**	-0.1333	18.43	18.43
Woody Grassland	**Hops**	-7.5013	52.14	52.95
Terr. Wetlands	**Hops**	0.0000	42.49	43.84
Waters	**Hops**	0.0000	16.54	16.54
Peat extraction	**Hops**	0.0000	16.54	16.54
Settlements	**Hops**	-1.7922	46.65	48.13
Other Land	**Hops**	0.0000	16.54	16.54
Dead organic matter 3)		**[t C ha^{-1} a^{-1}]**	**[t C ha^{-1} a^{-1}]**	**[%]**
Forest Land	**Hops**	0.0000	6.96	6.96

1) The calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

2) The calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

3) The calculation is only for first year of the land-use change; stock change: positive ≙ sink; negative ≙ source

Table 397: Implied emission factors [t C ha-1 a-1] for calculation of GHG emissions from Germany's Vineyards, and the uncertainties (2.5 % and 97.5% percentile [%]) of the emission factors on which the emissions calculations are based, differentiated by pools and sub-categories, for the year 2020

Vineyards		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soil, CO_2-C [1]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Vineyards	0.0000	9.57	9.57
$Cropland_{annual}$	Vineyards	-0.5641	7.24	7.24
Hops	Vineyards	0.0000	9.41	9.41
Orchards	Vineyards	-1.0718	9.90	9.90
Short-rotation plantations	Vineyards	0.0000	9.41	9.41
Tree nurseries	Vineyards	-0.6795	9.41	9.41
Christmas tree plantations	Vineyards	-0.6761	9.41	9.41
Grassland (in the strict sense)	Vineyards	-1.3500	6.05	6.05
Woody Grassland	Vineyards	-0.5557	9.41	9.41
Terr. Wetlands	Vineyards	-1.4361	9.65	9.65
Waters	Vineyards	-0.6795	16.07	16.07
Settlements	Vineyards	0.7356	10.28	10.28
Other Land	Vineyards	-0.3149	11.54	11.54
Mineral soil, N_2O_{direct} [2]		[kg N_2O ha^{-1} a^{-1}]	[kg N_2O ha^{-1} a^{-1}]	[%]
Forest Land	Vineyards	0.0000	187.44	487.76
Grassland (in the strict sense)	Vineyards	1.9215	185.31	486.97
Woody Grassland	Vineyards	0.8096	188.16	488.03
Terr. Wetlands	Vineyards	1.7257	189.02	488.36
Mineral soil, $N_2O_{indirect}$ [2]		[kg N_2O ha^{-1} a^{-1}]	[kg N_2O ha^{-1} a^{-1}]	[%]
Forest Land	Vineyards	0.0000	187.44	487.76
Grassland (in the strict sense)	Vineyards	0.4323	185.31	486.97
Woody Grassland	Vineyards	0.1822	188.16	488.03
Terr. Wetlands	Vineyards	0.3883	189.02	488.36
Biomass [3]		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	Vineyards	0.0000	22.92	22.92
$Cropland_{annual}$	Vineyards	0.0593	11.79	11.79
Hops	Vineyards	0.0000	13.28	13.28
Orchards	Vineyards	-0.7432	11.87	11.87
Short-rotation plantations	Vineyards	0.0000	7.67	9.67
Tree nurseries	Vineyards	-0.6334	19.41	19.41
Christmas tree plantations	Vineyards	-0.0987	25.79	25.79
Grassland (in the strict sense)	Vineyards	0.0119	17.34	17.34
Woody Grassland	Vineyards	-6.5612	50.94	51.73
Terr. Wetlands	Vineyards	0.1180	40.27	41.54
Waters	Vineyards	0.1060	19.20	19.20
Peat extraction	Vineyards	0.0000	19.20	19.20
Settlements	Vineyards	-1.6552	44.79	46.22
Other Land	Vineyards	0.0607	19.20	19.20
Dead organic matter [3]		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	Vineyards	0.0000	6.96	6.96

1) The calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

2) The calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

3) The calculation is only for first year of the land-use change; stock change: positive ≙ sink; negative ≙ source

Table 398: Implied emission factors [t C ha^{-1} a^{-1}] for calculation of GHG emissions from Germany's Orchards, and the uncertainties (2.5 % and 97.5% percentile [%]) of the emission factors on which the emissions calculations are based, differentiated by pools and sub-categories, for the year 2020

Orchards		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soil, CO_2-C [1]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Orchards	0.0000	8.59	8.59
Cropland$_{annual}$	Orchards	0.4606	6.81	6.81
Hops	Orchards	0.3953	8.46	8.46
Vineyards	Orchards	0.9363	9.90	9.90
Short-rotation plantations	Orchards	0.4329	8.46	8.46
Tree nurseries	Orchards	0.4367	8.46	8.46
Christmas tree plantations	Orchards	0.4255	8.46	8.46
Grassland (in the strict sense)	Orchards	-0.5750	5.84	5.84
Woody Grassland	Orchards	0.3648	8.46	8.46
Terr. Wetlands	Orchards	-1.8811	8.76	8.76
Waters	Orchards	-0.0890	12.54	12.54
Settlements	Orchards	1.7184	9.05	9.05
Other Land	Orchards	0.0000	9.88	9.88
Mineral soil, N_2O_{direct} [2]		[kg N_2O ha^{-1} a^{-1}]	[kg N_2O ha^{-1} a^{-1}]	[%]
Forest Land	Orchards	0.0000	187.23	487.69
Grassland (in the strict sense)	Orchards	0.8663	185.28	486.96
Woody Grassland	Orchards	0.0298	187.97	487.96
Terr. Wetlands	Orchards	2.2604	188.84	488.29
Mineral soil, $N_2O_{indirect}$ [2]		[kg N_2O ha^{-1} a^{-1}]	[kg N_2O ha^{-1} a^{-1}]	[%]
Forest Land	Orchards	0.0000	187.23	487.69
Grassland (in the strict sense)	Orchards	0.1949	185.28	486.96
Woody Grassland	Orchards	0.0067	187.97	487.96
Terr. Wetlands	Orchards	0.5086	188.84	488.29
Biomass [3]		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	Orchards	0.0000	17.68	17.68
Cropland$_{annual}$	Orchards	0.6122	11.71	11.71
Hops	Orchards	0.5872	12.23	12.23
Vineyards	Orchards	0.6739	11.87	11.87
Short-rotation plantations	Orchards	-1.4531	7.12	8.77
Tree nurseries	Orchards	-0.0234	14.96	14.96
Christmas tree plantations	Orchards	0.1561	18.49	18.49
Grassland (in the strict sense)	Orchards	0.4879	13.05	13.05
Woody Grassland	Orchards	-6.9257	44.44	45.13
Terr. Wetlands	Orchards	-13.6631	30.32	31.26
Waters	Orchards	1.1007	14.41	14.41
Peat extraction	Orchards	0.0000	14.41	14.41
Settlements	Orchards	-1.0667	35.81	36.94
Other Land	Orchards	0.0000	14.41	14.41
Dead organic matter [3]		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	Orchards	0.0000	6.96	6.96

1) The calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

2) The calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

3) The calculation is only for first year of the land-use change; stock change: positive ≙ sink; negative ≙ source

Table 399: Implied emission factors [t C ha^-1 a^-1] for calculation of GHG emissions from Germany's Other perennial crops (total consisting of tree nurseries, Christmas tree plantations and short-rotation plantations), and the uncertainties (2.5 % and 97.5% percentile [%]) of the emission factors on which the emissions calculations are based, differentiated by pools and sub-categories, for the year 2020

Tree nurseries		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soil, CO_2-C [1)]		[t C ha⁻¹ a⁻¹]	[%]	[%]
Forest Land	Tree nurseries	0.0000	8.06	8.06
Cropland$_{annual}$	Tree nurseries	0.0346	5.69	5.69
Hops	Tree nurseries	0.0000	7.84	7.84
Vineyards	Tree nurseries	0.6151	9.41	9.41
Orchards	Tree nurseries	-0.3523	8.46	8.46
Short-rotation plantations	Tree nurseries	0.0000	7.84	7.84
Christmas tree plantations	Tree nurseries	0.0000	7.84	7.84
Grassland (in the strict sense)	Tree nurseries	-0.9905	4.93	4.93
Woody Grassland	Tree nurseries	0.0000	7.84	7.84
Terr. Wetlands	Tree nurseries	-2.2414	8.56	8.56
Waters	Tree nurseries	-0.0410	11.09	11.09
Settlements	Tree nurseries	1.2491	8.11	8.11
Other Land	Tree nurseries	0.0000	8.55	8.55
Mineral soil, N_2O_{direct} [2)]		[kg N_2O ha⁻¹ a⁻¹]	[kg N_2O ha⁻¹ a⁻¹]	[%]
Forest Land	Tree nurseries	0.0000	187.14	487.65
Grassland (in the strict sense)	Tree nurseries	1.4166	185.17	486.92
Woody Grassland	Tree nurseries	0.0000	187.86	487.92
Terr. Wetlands	Tree nurseries	2.6934	188.80	488.28
Mineral soil, $N_2O_{indirect}$ [2)]		[kg N_2O ha⁻¹ a⁻¹]	[kg N_2O ha⁻¹ a⁻¹]	[%]
Forest Land	Tree nurseries	0.0000	187.14	487.65
Grassland (in the strict sense)	Tree nurseries	0.3187	185.17	486.92
Woody Grassland	Tree nurseries	0.0000	187.86	487.92
Terr. Wetlands	Tree nurseries	0.6060	188.80	488.28
Biomass [3)]		[t C ha⁻¹ a⁻¹]	[t C ha⁻¹ a⁻¹]	[%]
Forest Land	Tree nurseries	0.0000	18.15	18.15
Cropland$_{annual}$	Tree nurseries	0.8882	19.91	19.91
Hops	Tree nurseries	0.0000	20.45	20.45
Vineyards	Tree nurseries	0.9177	19.41	19.41
Orchards	Tree nurseries	-0.3040	14.96	14.96
Short-rotation plantations	Tree nurseries	0.0000	8.47	9.70
Christmas tree plantations	Tree nurseries	0.0000	19.47	19.47
Grassland (in the strict sense)	Tree nurseries	4.9894	20.24	20.24
Woody Grassland	Tree nurseries	0.0000	41.50	42.14
Terr. Wetlands	Tree nurseries	-11.9165	27.94	28.70
Waters	Tree nurseries	1.9359	23.39	23.39
Peat extraction	Tree nurseries	0.0000	23.39	23.39
Settlements	Tree nurseries	-2.7652	32.79	33.76
Other Land	Tree nurseries	0.0000	23.39	23.39
Dead organic matter [3)]		[t C ha⁻¹ a⁻¹]	[t C ha⁻¹ a⁻¹]	[%]
Forest Land	Tree nurseries	0.0000	6.96	6.96

1) The calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

2) The calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

3) The calculation is only for first year of the land-use change; stock change: positive ≙ sink; negative ≙ source

Table 400: Implied emission factors [t C ha^{-1} a^{-1}] for calculation of GHG emissions from Germany's Christmas tree plantations, and the uncertainties (2.5 % and 97.5% percentile [%]) of the emission factors on which the emissions calculations are based, differentiated by pools and sub-categories, for the year 2020

Christmas tree plantations		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soil, CO_2-C 1)		**[t C ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	**Christmas tree plantations**	0.0000	8.06	8.06
$Cropland_{annual}$	**Christmas tree plantations**	0.0346	5.69	5.69
Hops	**Christmas tree plantations**	0.0000	7.84	7.84
Vineyards	**Christmas tree plantations**	0.6151	9.41	9.41
Orchards	**Christmas tree plantations**	-0.3523	8.46	8.46
Tree nurseries	**Christmas tree plantations**	0.0000	7.84	7.84
Christmas tree plantations	**Christmas tree plantations**	0.0000	7.84	7.84
Grassland (in the strict sense)	**Christmas tree plantations**	-0.9905	4.93	4.93
Woody Grassland	**Christmas tree plantations**	0.0000	7.84	7.84
Terr. Wetlands	**Christmas tree plantations**	-2.2414	8.56	8.56
Waters	**Christmas tree plantations**	-0.0410	11.09	11.09
Settlements	**Christmas tree plantations**	1.2491	8.11	8.11
Other Land	**Christmas tree plantations**	0.0000	8.55	8.55
Mineral soil, N_2O_{direct} 2)		**[kg N_2O ha^{-1} a^{-1}]**	**[kg N_2O ha^{-1} a^{-1}]**	**[%]**
Forest Land	**Christmas tree plantations**	0.0000	187.14	487.65
Grassland (in the strict sense)	**Christmas tree plantations**	14.897	185.17	486.92
Woody Grassland	**Christmas tree plantations**	0.1225	187.86	487.92
Terr. Wetlands	**Christmas tree plantations**	0.0000	188.80	488.28
Mineral soil, $N_2O_{indirect}$ 2)		**[kg N_2O ha^{-1} a^{-1}]**	**[kg N_2O ha^{-1} a^{-1}]**	**[%]**
Forest Land	**Christmas tree plantations**	0.0000	187.14	487.65
Grassland (in the strict sense)	**Christmas tree plantations**	0.3352	185.17	486.92
Woody Grassland	**Christmas tree plantations**	0.0276	187.86	487.92
Terr. Wetlands	**Christmas tree plantations**	0.0000	188.80	488.28
Biomass 3)		**[t C ha^{-1} a^{-1}]**	**[t C ha^{-1} a^{-1}]**	**[%]**
Forest Land	**Christmas tree plantations**	0.0000	20.94	20.94
$Cropland_{annual}$	**Christmas tree plantations**	22.035	26.75	26.75
Hops	**Christmas tree plantations**	0.0000	27.63	27.63
Vineyards	**Christmas tree plantations**	22.074	25.79	25.79
Orchards	**Christmas tree plantations**	22.036	18.49	18.49
Tree nurseries	**Christmas tree plantations**	0.0000	9.36	10.62
Christmas tree plantations	**Christmas tree plantations**	0.0000	19.47	19.47
Grassland (in the strict sense)	**Christmas tree plantations**	20.152	27.02	27.02
Woody Grassland	**Christmas tree plantations**	-25.983	44.09	44.76
Terr. Wetlands	**Christmas tree plantations**	22.213	31.65	32.49
Waters	**Christmas tree plantations**	22.110	32.85	32.85
Peat extraction	**Christmas tree plantations**	0.0000	32.85	32.85
Settlements	**Christmas tree plantations**	22.043	36.14	37.20
Other Land	**Christmas tree plantations**	0.0000	32.85	32.85
Dead organic matter 3)		**[t C ha^{-1} a^{-1}]**	**[t C ha^{-1} a^{-1}]**	**[%]**
Forest Land	**Christmas tree plantations**	0.0000	6.96	6.96

1) The calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

2) The calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

3) The calculation is only for first year of the land-use change; stock change: positive ≙ sink; negative ≙ source

Table 401: Implied emission factors [t C ha-1 a-1] for calculation of GHG emissions from Germany's Short-rotation plantations, and the uncertainties (2.5 % and 97.5% percentile [%]) of the emission factors on which the emissions calculations are based, differentiated by pools and sub-categories, for the year 2020

Short-rotation plantations		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soil, CO_2-C [1]		[t C ha-1 a-1]	[%]	[%]
Forest Land	Short-rotation plantations	0.0000	8.06	8.06
Cropland annual	Short-rotation plantations	0.0282	5.69	5.69
Hops	Short-rotation plantations	0.0000	7.84	7.84
Vineyards	Short-rotation plantations	0.6795	9.41	9.41
Orchards	Short-rotation plantations	-0.3694	8.46	8.46
Tree nurseries	Short-rotation plantations	0.0000	7.84	7.84
Christmas tree plantations	Short-rotation plantations	0.0000	7.84	7.84
Grassland (in the strict sense)	Short-rotation plantations	-1.0345	4.93	4.93
Woody Grassland	Short-rotation plantations	-0.0629	7.84	7.84
Terr. Wetlands	Short-rotation plantations	0.0000	8.56	8.56
Waters	Short-rotation plantations	0.0000	11.09	11.09
Settlements	Short-rotation plantations	1.2549	8.11	8.11
Other Land	Short-rotation plantations	0.0000	8.55	8.55
Mineral soil, N_2O_{direct} [2]		[kg N_2O ha-1 a-1]	[kg N_2O ha-1 a-1]	[%]
Forest Land	Short-rotation plantations	0.0000	187.14	487.65
Grassland (in the strict sense)	Short-rotation plantations	1.4709	185.17	486.92
Woody Grassland	Short-rotation plantations	0.0984	187.86	487.92
Terr. Wetlands	Short-rotation plantations	0.0000	188.80	488.28
Mineral soil, $N_2O_{indirect}$ [2]		[kg N_2O ha-1 a-1]	[kg N_2O ha-1 a-1]	[%]
Forest Land	Short-rotation plantations	0.0000	187.14	487.65
Grassland (in the strict sense)	Short-rotation plantations	0.3309	185.17	486.92
Woody Grassland	Short-rotation plantations	0.0221	187.86	487.92
Terr. Wetlands	Short-rotation plantations	0.0000	188.80	488.28
Biomass [3]		[t C ha-1 a-1]	[t C ha-1 a-1]	[%]
Forest Land	Short-rotation plantations	0.0000	9.57	10.60
Cropland annual	Short-rotation plantations	-4.6880	7.68	9.73
Hops	Short-rotation plantations	4.0746	7.77	9.83
Vineyards	Short-rotation plantations	-16.2984	7.67	9.67
Orchards	Short-rotation plantations	-4.3403	7.12	8.77
Tree nurseries	Short-rotation plantations	-4.7982	8.47	9.70
Christmas tree plantations	Short-rotation plantations	0.0000	9.36	10.62
Grassland (in the strict sense)	Short-rotation plantations	-4.4018	7.85	9.85
Woody Grassland	Short-rotation plantations	0.0801	27.89	28.49
Terr. Wetlands	Short-rotation plantations	0.0000	14.71	15.77
Waters	Short-rotation plantations	0.0000	8.12	10.30
Peat extraction	Short-rotation plantations	0.0000	8.12	10.30
Settlements	Short-rotation plantations	-2.4448	18.82	19.80
Other Land	Short-rotation plantations	0.0000	8.12	10.30
Dead organic matter [3]		[t C ha-1 a-1]	[t C ha-1 a-1]	[%]
Forest Land	Short-rotation plantations	0.0000	6.96	6.96

1) The calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

2) The calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

3) The calculation is only for first year of the land-use change; stock change: positive ≙ sink; negative ≙ source

Table 402: Implied emission factors for organic soils under Cropland [t CO2-Eq. ha-1 a-1], and their uncertainties (2.5 % and 97.5% percentile [%]), for the year 2020

Land use	GHG	Emission factor	Uncertainty bounds lower	Uncertainty bounds upper
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
$Cropland_{annual}$	CO_2	34.23	43.20	19.64
	N_2O 2)	IE	83.78	264.86
	CH_4	0.43	57.08	91.29
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Hops	CO_2	32.55	43.20	19.64
	N_2O 2)	IE	83.78	264.86
	CH_4	0.60	57.08	91.29
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Vineyards	CO_2	31.37	43.20	19.64
	N_2O 2)	IE	83.78	264.86
	CH_4	0.21	57.08	91.29
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Orchards	CO_2	33.29	43.20	19.64
	N_2O 2)	IE	83.78	264.86
	CH_4	0.37	57.08	91.29
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Tree nurseries	CO_2	34.70	43.20	19.64
	N_2O 2)	IE	83.78	264.86
	CH_4	0.33	57.08	91.29
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Christmas-tree plantations	CO_2	33.96	43.20	19.64
	N_2O 2)	IE	83.78	264.86
	CH_4	0.39	57.08	91.29
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Short-rotation plantations	CO_2	31.91	43.20	19.64
	N_2O 2)	IE	83.78	264.86
	CH_4	1.49	57.08	91.29

1) Annual calculation; emission: positive ≙ source; negative ≙ sink

2) Is reported under 3.D.a.6 (Agricultural sector)

The calculations are spatially consistent over time and complete for the entire reporting period, 1990-2020.

6.5.4 Category-specific quality assurance / control and verification (4.B)

Details regarding this year's reviews are provided in Chapter 6.1.3.

The data sources used in preparation of this inventory fulfill the review criteria of the QSE manual for data sources (QSE-Handbuch für Datenquellen). Quality assurance for input data (ATKIS®, BÜK, official statistics; cf. Chapter 6.3) is the responsibility of the relevant data administrators (cf. the pertinent documentation in the inventory description).

The emissions-calculation results as presented in the present report cannot be compared with other relevant data sources for Germany, since no such other data sources exist that meet applicable requirements, i.e. provide nationwide coverage, are comprehensive and are independent of the methods and data sources described in the present report.

The following tables present an intra-European comparison of implied emission factors (IEF) for various pools. Values of neighbouring countries, obtained from the 2021 Submission to the Climate Secretariat (UNFCCC NIR Submission 2021 – Inventory year 2019, (UNFCCC)), were used for this comparison. The values for Germany, 2020, were obtained from the current 2020 submission. In none of the compared pools does the comparison show implied emission factors (IEF) that must clearly be considered outliers, especially when the major uncertainties, and the scattering seen in the reported values, are taken into account (cf. Chapter 6.5.3). All EF are normal, and all are similar, in terms of both absolute size and tendencies, to those of various central European neighbouring countries.

Table 403: Carbon-stock changes in living biomass, in croplands of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.B.1. - Cropland Remaining Cropland [t C ha^{-1} a^{-1}]	4.B.2 - Land Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.1 - Forest Land Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.2 - Grassland Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.3 - Wetlands Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.4 - Settlements Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.5 - Other Land Converted To Cropland [t C ha^{-1} a^{-1}]
Belgium	0.00	-0.03	-3.09	NO	NO	NO	NO
Denmark	0.00	0.13	-0.17	0.18	NO	NO	NO
France	0.00	-0.28	-4.43	-0.10	NE	-0.03	NE
UK	0.00	0.08	NO,IE	0.08	NO	0.11	NO
Netherlands	NA	-0.23	-7.68	-0.16	0.37	0.41	0.53
Austria	0.00	-0.01	-1.22	0.05	NO	NO	NO
Poland	0.03	NO	NO	NO	NO	NO	NO
Switzerland	0.21	0.08	-1.87	0.08	0.09	0.20	0.23
Czech Republic	0.00	-0.21	-2.05	-0.16	0.17	NO	NO
Germany, 2019	0.0005	-0.1583	NO	-0.1465	0.2542	-0.4413	0.1378
Germany, 2020	-0.0003	-0.2042	NO	-0.1639	-0.0995	-1.0500	0.1330

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC)

Table 404: Carbon-stock changes in dead organic matter, in croplands of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.B.1. - Cropland Remaining Cropland [t C ha^{-1} a^{-1}]	4.B.2 - Land Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.1 - Forest Land Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.2 - Grassland Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.3 - Wetlands Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.4 - Settlements Converted To Cropland [t C ha^{-1} a^{-1}]	4.B.2.5 - Other Land Converted To Cropland [t C ha^{-1} a^{-1}]
Belgium	NO	0.00	-0.09	NO	NO	NO	NO
Denmark	NO	-0.08	-0.55	NO,NA	NO	NO	NO
France	NE	-0.02	-0.47	NE	NE	NE	NE
UK	NO,NA	NO,IE	NO	IE	NO	NO,IE	NO
Netherlands	NA	-0.03	-2.35	NA	NA	NA	NA
Austria	NO	-0.03	-0.68	NO	NO	NO	NO
Poland	NO	NO	NO	NO	NO	NO	NO
Switzerland	NO	0.00	-0.53	NO	NO	NO	NO
Czech Republic	NO	0.00	-0.05	NO	NO	NO	NO
Germany, 2019	IE	NO	NO	IE	IE	IE	IE
Germany, 2020	IE	NO	NO	IE	IE	IE	IE

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC)

Table 405: Carbon-stock changes in mineral soils, in croplands of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.B.1. - Cropland Remaining Cropland [t C ha⁻¹ a⁻¹]	4.B.2 - Land Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.1 - Forest Land Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.2 - Grassland Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.3 - Wetlands Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.4 - Settlements Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.5 - Other Land Converted To Cropland [t C ha⁻¹ a⁻¹]
Belgium	-0.04	-1.51	-2.26	-1.52	-2.63	NO	NO
Denmark	0.00	-0.08	-0.34	NO,IE	-1.77	NO	NO
France	0.13	-1.09	-1.24	-1.17	NO	0.06	NE
UK	0.33	-1.46	-2.79	-1.47	NO	0.72	NO
Netherlands	NA	-0.53	0.19	-0.55	-0.98	-0.24	1.96
Austria	0.02	-0.98	-0.79	-0.99	NO	NO	NO
Poland	0.00	-0.16	NO	-1.29	NO	NO	NO
Switzerland	0.20	-0.22	-0.83	-0.35	0.44	1.91	2.55
Czech Republic	-0.01	-0.26	-0.25	-0.47	NO	0.06	NO
Germany, 2019	-0.0009	-0.977	-0.084	-1.095	-0.287	1.224	0.277
Germany, 2020	-0.001	-0.986	NO	-1.100	-0.311	1.184	0.277

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC)

Table 406: Carbon-stock changes in organic soils, in croplands of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.B.1. - Cropland Remaining Cropland [t C ha⁻¹ a⁻¹]	4.B.2 - Land Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.1 - Forest Land Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.2 - Grassland Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.3 - Wetlands Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.4 - Settlements Converted To Cropland [t C ha⁻¹ a⁻¹]	4.B.2.5 - Other Land Converted To Cropland [t C ha⁻¹ a⁻¹]
Belgium	-10.00	NO	NO	NO	NO	NO	-10.00
Denmark	-7.55	-0.87	IE	-5.00	IE	NO	-7.55
France	IE	NO	NO	NO	NO	NO	IE
UK	-8.18	-5.14	-8.18	-5.00	NO	NO	-8.18
Netherlands	-3.59	-3.71	-3.31	-3.72	-3.58	-3.81	-3.59
Austria	NO	NO	NO	NO	NO	NO	NO
Poland	-1.00	1.00	NO	-1.00	NO	-1.00	-1.00
Switzerland	-9.52	-8.95	-9.52	-9.52	-9.52	-1.36	-9.52
Czech Republic	NO	NO	NO	NO	NO	NO	NO
Germany, 2019	-9,337	-8,899	-9,511	-8.8866	-9.0809	-9.2354	-9,337
Germany, 2020	-9.425	-9.160	NO	-9.147	-9.408	-9.469	-9.425

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC)

6.5.5 Category-specific recalculations (4.B)

This year's submission includes category-specific recalculations for the entire period 1990 through 2020. The emissions were recalculated in order to take account of new and improved data sources, changes in methods, and error corrections made as part of ongoing inventory improvements. The following measures affected the results of the emissions calculations for the Cropland land-use category:

- Updating of the map data for determination of activity data with regard to designation of land uses and land-use changes, and adaptation of the land-use matrix over time (cf. Chapter 6.3.1ff);
- Implementation of a new method for calculating emissions from phytomass, for perennial woody plants outside of Forest Land (Chapter 6.1.2.3.4 ff);
- New emission factors for dead wood (cf. Chapter 6.4.2.3);
- Correction of the value for carbon and nitrogen stocks of mineral soils, in the category Settlements remaining Settlements (cf. Chapter 6.1.2.1.6 and Chapter 6.8.2.4).

In Table 407 (areas) and Table 408 (emissions), the results of the current recalculations for the Cropland category are compared with the corresponding results in the previous year's submission.

Any slight differences between the area data reported in the current and previous year's submissions are due mainly to the effects of correction algorithms used in order to assure consistency between the area-use time series and the newly added data from the last time-series year. In each case, in keeping with the assumption that the newest data are the best data, in terms of quality, the previous time series is adjusted, if necessary (cf. also Chapter 6.3 ff).

Noteworthy differences in GHG emissions, and affecting the entire time series, are seen mainly for CO_2. Such differences are due primarily to the new method being used to determine perennial biomass outside of Forest Land.

Table 407: Comparison of area data [kha] for the Cropland category as reported in the current submission and in the previous year's submission

CRF No.	Area [kha]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.B	Cropland	2021	13,592.45	13,606.81	13,621.22	13,240.07	12,967.52	12,751.72	12,718.86	12,685.99	12,653.13	12,620.28
		2022	13,589.17	13,603.44	13,617.69	13,236.64	12,964.08	12,748.32	12,717.42	12,686.51	12,655.61	12,624.71
		Absolute difference	-3.28	-3.37	-3.54	-3.42	-3.44	-3.40	-1.44	0.52	2.47	4.44
		in %	-0.02	-0.02	-0.03	-0.03	-0.03	-0.03	-0.01	0.00	0.02	0.04

Table 408: Comparison of greenhouse-gas emissions [kt CO2-eq] for the Cropland category as reported in the current submission and in the previous year's submission

CRF No.		GHG	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.B	Cropland	CO_2	2021	13,511.10	13,295.57	13,091.81	14,716.11	14,644.41	16,252.34	16,436.05	16,305.24	16,542.19	16,336.74
			2022	13,762.36	13,942.36	13,723.43	15,879.71	15,182.25	16,777.70	16,876.37	16,755.89	16,945.31	16,748.90
			Difference	251.25	646.79	631.62	1,163.60	537.84	525.36	440.32	450.66	403.12	412.15
			in %	1.86	4.86	4.82	7.91	3.67	3.23	2.68	2.76	2.44	2.52
		CH_4	2021	146.13	134.95	124.25	144.81	141.66	152.93	139.94	137.78	136.08	135.19
			2022	145.74	134.81	124.21	129.15	131.67	138.47	139.32	138.72	135.92	131.80
			Difference	-0.39	-0.14	-0.04	-15.66	-9.99	-14.46	-0.61	0.94	-0.16	-3.39
			in %	-0.27	-0.10	-0.03	-10.81	-7.05	-9.46	-0.44	0.68	-0.12	-2.51
		N_2O	2021	233.76	229.29	227.27	380.28	418.51	584.35	597.02	611.02	625.83	642.07
			2022	233.76	229.32	227.35	381.26	419.47	584.71	594.62	605.94	618.03	631.35
			Difference	0.00	0.03	0.08	0.99	0.96	0.35	-2.40	-5.08	-7.80	-10.72
			in %	0.00	0.01	0.04	0.26	0.23	0.06	-0.40	-0.83	-1.25	-1.67

6.5.6 Category-specific planned improvements (4.B)

Regionalisation of carbon stocks of mineral soils under Cropland, as a function of site-specific parameters, is being prepared and will soon be implemented. With that move, Germany will implement a pertinent ERT recommendation from the 2020 review process (ARR 2020: L.8, Table 5)

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

6.6 Grassland (4.C)

6.6.1 Category description (4.C)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**4 C, Grassland**		**CO_2**	**26,383.5**	**2.1%**	**18,068.7**	**2.5%**	**-31.5%**
-/-/T2	**4 C, Grassland**		**CH_4**	**872.8**	**0.1%**	**962.6**	**0.1%**	**10.3%**
-/-	4 C, Grassland		N_2O	66.9	0.0%	122.5	0.0%	83.1%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	RS/NS	CS
N_2O	Tier 2	RS/NS	CS/D
CH_4	Tier 2	RS/NS	CS

The category *Grassland* (4.C) is a key category for CO_2 emissions in terms of emissions level, and a key category for CH_4 emissions pursuant to Approach 2 analysis.

In 2020, the net anthropogenic GHG emissions from grassland amounted to 19,153.8 kt CO_2 equivalents. (95% confidence interval: 10,784.4 kt CO_2-eq. ≙ 43.7 % - 24,153.4 kt CO_2-eq. ≙ 26.1%). Drainage of organic grassland soils resulted in emissions of 26,552.6 kt CO_2, 962.6 kt CO_2-eq. of methane, and 28.1 kt CO_2-eq. of nitrous oxide. In the Grassland category, both biomass (-131.8 kt CO_2) and mineral soils (-8,352.1 kt CO_2) functioned as carbon sinks.

These emissions consist of the sum of the emissions from the sub-categories Grassland (in the strict sense) and Woody Grassland, whose GHG emissions differ considerably, both quantitatively and qualitatively. As Table 409 and Figure 71 and Figure 72 show, grassland (in a strict sense) is a significant CO_2 source. Its absolute emissions level, 21,382.2 kt CO_2-eq., is determined primarily by emissions from organic soils (26,340.7 kt CO_2-eq. ≙ 123.2 %), with the fraction for CO_2 emissions (96.5 %) greatly exceeding that for methane (3.5 %). While biomass also functions as a source, and contributes only slightly (9.6%) to the gross emissions of 30,204.5 kt CO_2-Eq., mineral soils under Grassland (in the strict sense) are an ongoing sink for carbon (Table 409). They reduce the gross emissions in the sub-category Grassland (in the strict sense) by 29.2 %.

Table 409: CO_2, N_2O and CH_4 emissions [kt CO_2-eq.] from Grassland, 2020, by sub-categories. The table includes both the relevant sums and the upper and lower bounds of the 95 % confidence interval.

Sub-category / Pool	GHG	Grassland (in the strict sense) Emissions, 2020				
		[kt CO_2-eq.]			[%]	
		Emission	2.5 perc.	97.5 perc.	2.5 perc.	97.5 perc.
Grassland i.t.s.s.$_{total}$ 1)		**21,382.2**	11,097.7	27,510.8	48.10	28.66
Mineral soils	**CO_2 2)**	**-8,822.3**	-8,663.7	-8,981.0	1.80	1.80
	N_2O_{direct} 3)	**1.00**	0.25	3.01	74.73	200.49
	$N_2O_{indirect}$ 4)	**0.23**	0.00	0.87	99.99	286.06
Organic soil	**CO_2 2)**	**26,340.7**	6,297.1	35,696.8	76.09	35.52
	N_2O 5)	**IE**	IE	IE	IE	IE
	CH_4 6)	**959.0**	477.77	1,329.53	50.18	370.36
Biomass	**CO_2 2)**	**2,903.5**	1,800.3	4,025.2	38.00	38.63
Dead organic matter	**CO_2 2)**	**0.00**	0.00	0.00	0.00	0.00

Sub-category / Pool	GHG	Woody Grassland, emissions, 2020 [kt CO_2-Eq.] Emission	2.5 perc.	97.5 perc.	[%] 2.5 perc.	97.5 perc.
Woody Grassland$_{total}$ 7)		**-2,228.4**	-1,704.3	-2,766.0	23.52	24.13
Mineral soils	**CO_2 2)**	**470.21**	448.91	491.51	4.53	4.53
	N_2O_{direct} 3)	**76.05**	23.73	224.94	68.80	195.78
	$N_2O_{indirect}$ 4)	**17.11**	0.00	65.13	99.99	280.62
Organic soil	**CO_2 2)**	**211.88**	182.71	245.30	13.77	15.78
	N_2O 3)	**28.07**	7.15	48.56	74.52	72.98
	CH_4 6)	**3.60**	2.01	6.03	44.03	67.75
Biomass	**CO_2 2)**	**-3,035.3**	-1,976.2	-4,110.9	34.89	35.44
Dead organic matter	**CO_2 2)**	**0.00**	0.00	0.00	0.00	0.00

1) Subtotals of emissions from CRF tables 4.C, 4.(II).C, 4.(IV).2

2) Subtotal of emissions from CRF table 4.C

3) CRF Table 4.(III).C

4) The category-specific indirect N_2O emissions are not included and shown as such in the CRF tables; they are included, however, in the sum, for all sub-categories, presented in CRF Table 4.(IV).2.

5) CRF Table 3.D.a.6

6) CRF Table 4.(II).C

7) Subtotals of emissions from CRF tables 4.C, 4.(II).C, 4.(IV).2, and sum from 4.(III).C

In 2020, the time series for total emissions from Grassland (in the strict sense) includes emissions that have decreased by -21.2 % with respect to the base year. In terms of absolute levels, emissions from organic soils predominate in the time series for total emissions. On the other hand, emissions from biomass and mineral soils have a considerable influence on the trend, with mineral-soils emissions having a particularly strong effect on the qualitative trend of the curve. Mineral soils function as a sink. Over time, that sink function has exhibited a highly significant negative trend; it has increased by 355 % with respect to the base year.

The increase of the amplitude, and the changed trend as of the year 2000, are due primarily to differences in the underlying data. Starting with the reporting year 2000, the area data of the B-DLM in ATKIS can be used as a basis for substantiation of applicable areas and land uses. The resolution (spatial and chronological) of those data is much higher than that of the CORINE Landcover (CLC) data that have to be used for documenting land use in years prior to 2000 (Chapter 6.3.2.2). Although CLC data series, which is older, has been adjusted, via the "Overlap Approach" (2006 IPCC Guidelines (Vol. 1 Ch. 5.3.3), to the newer, higher-resolution data series of the Basis-DLM, the change in the database, as of the year 2000, leads to considerably more detectable land-use changes with respect to the period 1990 - 2000 – especially changes from Cropland to Grassland and between the sub-categories Grassland (in the strict sense) and Woody Grassland.

The shapes of the time-series plots – especially the noticeable changes they show – are due primarily to the periodicity in surveying of the relevant area data (cf. Chapter 6.3.5). Land-use changes were determined on the basis of spatially explicit data sets from the years 1990, 2000, 2005, 2010, 2015 and 2020 (cf. Chapter 6.3). This applies especially to the sub-category Woody Grassland.

Figure 71: CO_2 emissions [kt CO_2 eq.] from grassland (in the strict sense), as a result of land use and land-use changes, 1990-2020, by sub-categories

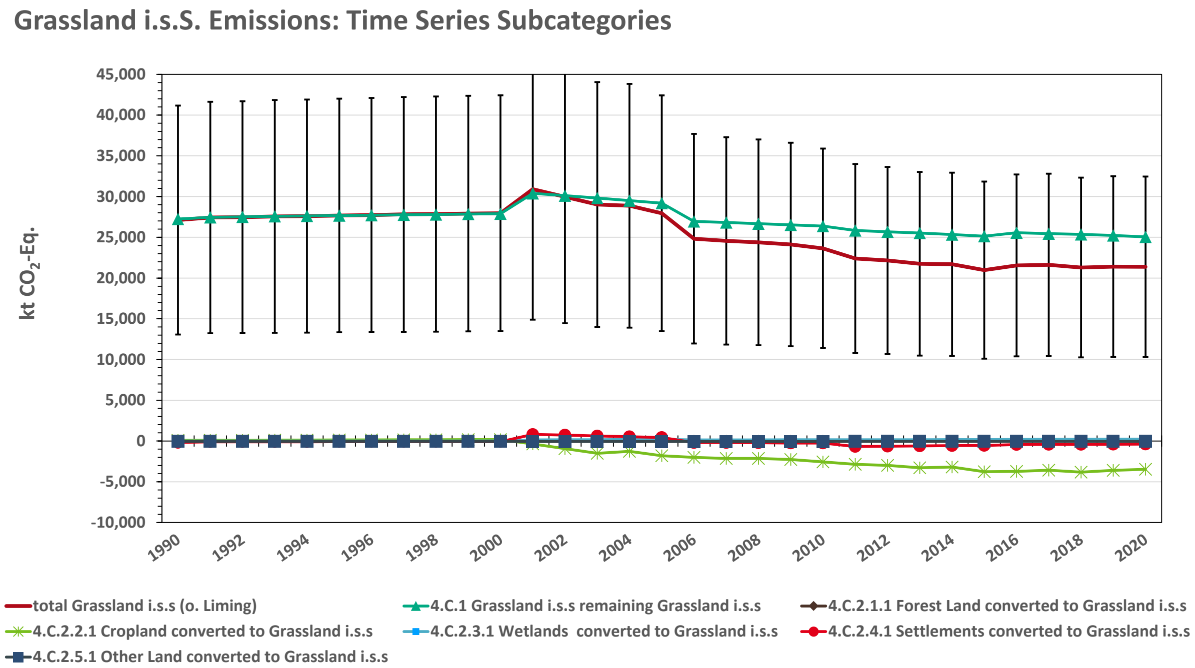
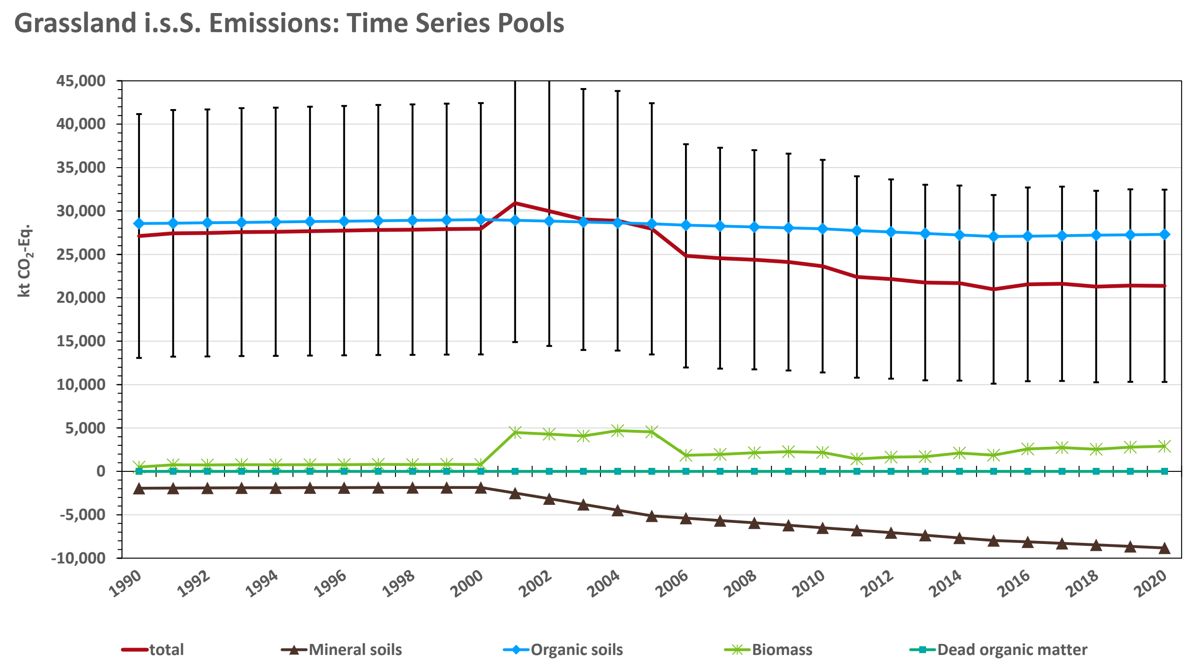


Figure 72: CO_2 emissions [kt CO_2 eq.] from grassland (in the strict sense), as a result of land use and land-use changes, 1990-2020, by pools



The net emissions in the sub-category Woody Grassland are shaped primarily by emissions from the biomass pool. In 2020, that pool was a sink, with emissions of -3,035.3 kt CO_2-eq. The pool's sink effect more than offsets the positive emissions from organic soils (243.5 kt CO_2-eq.) and mineral soils (563,4 kt CO_2-eq.), with the result that the sub-category Woody Grassland was a net carbon sink in 2020 (-2,228.4 kt CO_2-eq.; Table 409 and Figure 73 and Figure 74).

The curve progressions of the time series in Figure 73 and Figure 74 show that, as a result of ongoing use of biomass, and of land-use changes from and to the sub-category Woody Grassland, this sub-category a) is highly dynamic, in keeping with the considerable carbon stocks found in its biomass, and b) is shaped by the 12-year rotation period for hedges and field copses on which the model is based (cf. Chapter 6.1.2.3.6).

Figure 73: CO_2 emissions [kt CO_2-eq.] from Woody Grassland, as a result of land use and land-use changes, 1990-2020, by sub-categories

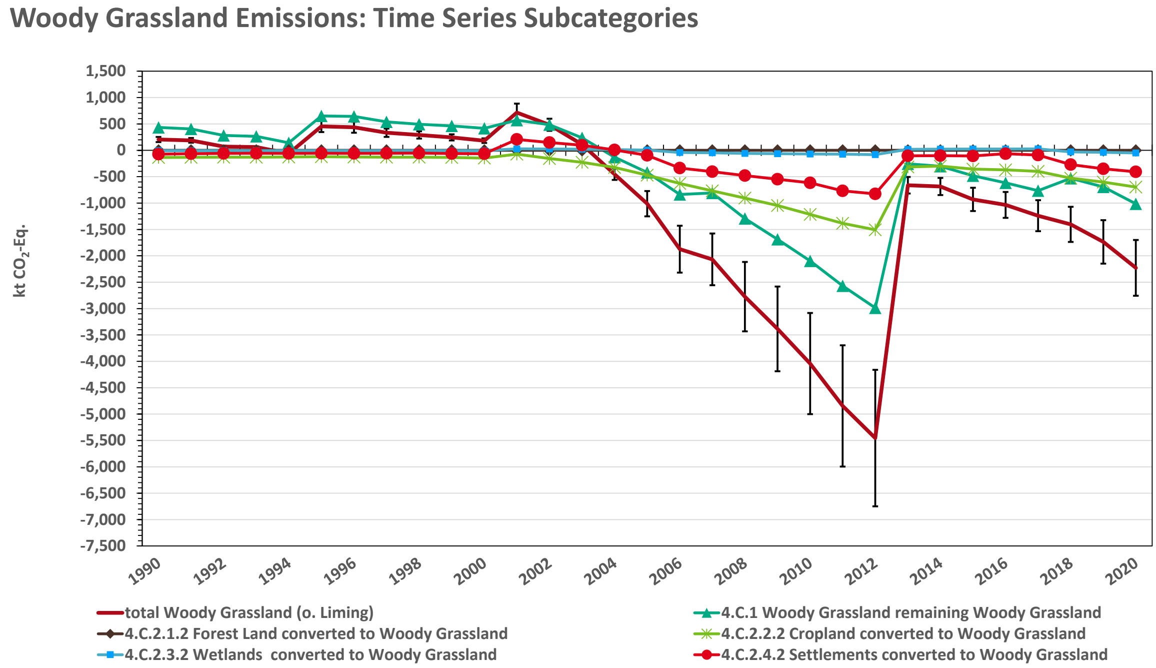
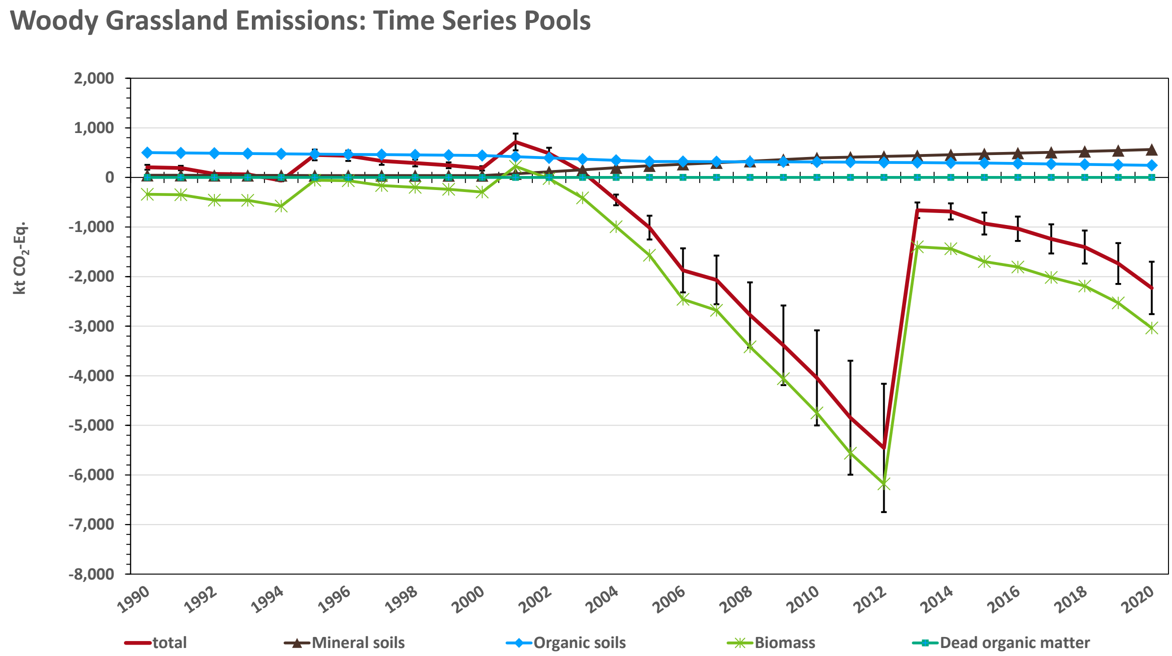


Figure 74: CO_2 emissions [kt CO_2-eq.] from Woody Grasslands, as a result of land use and land-use changes, 1990-2020, by pools



6.6.2 Methodological issues (4.C)

6.6.2.1 Data sources

The following data sources / sets have been used:

- Federal Statistical Office, Fachserie 3, Reihe 3, agriculture and forestry, fisheries, agricultural soil use and crop cultivation; (Statistisches Bundesamt, FS 3, R 3b),
- Federal Statistical Office, Fachserie 3, Reihe 3, agriculture and forestry, fisheries, growth and harvests – crops; (Statistisches Bundesamt, FS 3, R 3.2.1),
- Federal Statistical Office, Fachserie 3, Reihe 3, agriculture and forestry, fisheries – soil use by sectoral operations; (Statistisches Bundesamt, FS 3, R 3.2.1),
- 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use (IPCC, 2006a)
- "Ordinance on application of fertilisers, soil additives, culture substrates and plant additives according to the principles of good practice in fertilization (Ordinance on Fertilisation – Düngeverordnung (DüV))" (Ordinance on Fertilisation in the version as promulgated 27 February 2007 (Federal Law Gazette I, p. 221), last amended by Article 5 (36) of the Act of 24 February 2012 (Federal Law Gazette I p. 212) (Bundesgesetzblatt, 2012).
- Interim report in the research project "Methodenentwicklung zur Erfassung der Biomasse mehrjährig verholzter Pflanzen außerhalb von Wäldern" ("Development of methods for determining the biomass of plants, outside of forests, with multiple years of wood growth") (Pöpken, 2011).
- (Drexler et al., 2021): Carbon sequestration in hedgerow biomass and soil in the temperate climate zone. Regional Environmental Change (2021) 21:74; https://doi.org/10.1007/s10113-021-01798-8; Springer
- (Jacobs et al., 2018): Landwirtschaftlich genutzte Böden in Deutschland - Ergebnisse der Bodenzustandserhebung (Agricultural soils in Germany – Results of the Soil Inventory); Johann Heinrich von Thünen Institute, 316 pp. Thünen Report 64; Braunschweig. DOI:10.3220/REP1542818391000

6.6.2.2 Biomass

In the Grassland category, the phytomass pool is subdivided in accordance with the basic characteristics of the plants involved (cf. Chapter 6.2.3 and Table 354 in Chapter 6.3.2.1)

- herbaceous plants (sub-category Grassland (in the strict sense))
- perennial woody plants in hedges and field copses (sub-category Woody Grassland)

The method for determination of GHG emissions from plant biomass of perennial hedge and field copse plants in the sub-category Woody Grassland (gra2) has been fundamentally modified as of the present submission. Now, the growth stages of plants are modelled chronologically precisely, as a function of crop age and type of management (rotation periods), so that emissions can be reported – in keeping with the requirements of the 2006 IPCC Guidelines – in the year in which they occur. The methods and assumptions used for calculation of carbon-stock changes in above-ground and below-ground biomass of woody plants are described in Chapter 6.1.2.3 ff, while the specific methods and emission-factor derivations for woody plants are described in Chapter 6.1.2.3.6.

In the sub-category Grassland (in the strict sense), the carbon stocks of herbaceous biomass were found to be constant over time (Chapter 6.1.2.3.3). In the Grassland remaining Grassland category (Grassland (in the strict sense), the phytomass is assumed to be in dynamic equilibrium; consequently, no emissions occur. The notation key "NA" is entered in the relevant spaces in the tables (cf. Chapter 6.1.2.3.1). The plant biomass of the sub-category Woody Grassland, on the other hand, is calculated for each reported year (Chapter 6.1.2.3ff and Chapter 6.1.2.3.6). Area conversions between the individual Grassland sub-categories are treated like land-use changes, and explicitly listed as such in CRF 4.C. The area changes between annual and perennial plants can be documented spatially explicitly and completely. Relevant calculations are carried out using the gain-loss method (2006 IPCC Guidelines) described in Chapter 6.1.2.3.1 and Chapter 6.1.2.3.2.

In the tables, "IE" is entered in the spaces for dead organic matter in the Grassland category, since in the model the complete biomass is always taken into account.

6.6.2.3 Mineral soils

No change in carbon stocks in mineral soils is listed for areas remaining as Grassland. The constant level of carbon stocks has been substantiated by the results obtained on 42 German long-term soil monitoring sites (Höper and Schäfer (2012), Fortmann et al. (2012) and BLfU (2011)). The pertinent long-term observations cover a period of 20 – 25 years. During that period, most of the areas studied exhibited no changes in the carbon stocks in mineral soils. Some soils showed slight reductions, while others exhibited slight increases that nearly exactly offset the decreases, in absolute terms. There are no indications that any major changes in management of permanent grassland have occurred since 1990 that could affect carbon stocks in mineral soils. In CRF Table 4.C.1, "NA" has been entered in the spaces "carbon-stock changes in mineral soils" in the remaining categories of Grassland (in the strict sense) and Woody Grassland (cf. Chapter 6.5.2.3.2).

Calculation of CO_2 emissions resulting from conversions to Grassland (in the strict sense) and to Woody Grassland is described in Chapter 6.1.2.1, while the pertinent emission factors and their uncertainties are described in Table 410 and Table 412 in Chapter 6.6.3. The emissions in the categories remaining in a land use are listed in CRF Table 4.C.1, while the emissions resulting from land-use changes are listed in CRF Tables 4.C.2.1-4.C.2.5. The nitrous oxide emissions from mineral soils are included in the values in CRF Tables 4(III).C and 4 (IV).2.

6.6.2.4 Organic soils

In the land-use category Grassland, CO_2, CH_4 and N_2O emissions from organic soils are reported; nitrous oxide emissions are reported solely for the sub-category Woody Grassland, however. N_2O emissions from organic soils under Grassland (in the strict sense) are reported as part of the Agriculture sector, in CRF Table 3.D.a.6 "Cultivation of Histosols" (cf. Chapter 6.5.2). A discussion of the area differences with regard to Grassland as reported in the LULUCF sector and the relevant values listed in CRF Table 3.D.a.6 "Cultivation of Histosols," for the agricultural sector, is provided in Chapter 6.1.2.2.1. The methods used to calculate emissions from organic soils, and to derive the relevant emission factors, are described in Chapter 6.1.2.2.

The annual emissions following land-use changes to Grassland (in the strict sense) are calculated with the same methodology used for emissions from organic soils in the sub-category Grassland (in a strict sense) remaining Grassland (in the strict sense). A similar approach is taken with emissions from organic soils following land-use conversions to Woody Grassland; they are calculated in same way that emissions from the category Woody Grassland remaining Woody Grassland are calculated. The emissions in the remaining categories are listed in CRF Table 4.C.1, while the emissions resulting from land-use changes are listed in CRF Tables 4.C.2.1-4.C.2.5. Methane emissions from organic soils and from drainage ditches, and nitrous oxide emissions from the sub-category Woody Grassland, are listed in CRF Table 4(II).C.

6.6.3 Uncertainties and time-series consistency (4.C)

Table 410 through Table 413 show the uncertainties relative to the emission factors for the sub-categories Grassland (in the strict sense) and Woody Grassland. In the main, the distribution functions exhibit a normal distribution. In some cases, they have a logarithmic and triangular distribution. They are characterised by their upper and lower boundaries. For the implied emission factors determined on the basis of the soil inventories, the uncertainties in the mineral soils pool, in both sub-categories, are of the same, single-digit magnitude. The uncertainties for the biomass and, especially, the uncertainties for the emission factors for Woody Grassland, are considerably larger. Those uncertainties reflect the great diversity of relevant grasslands with woody content in Germany. The greater uncertainty seen in the EF for methane and nitrous oxide from organic soils is due to those factors' extremely large variability in field measurements, as well as to the fact that removals are possible in the case of methane (cf. Chapter 6.1.2.2.2).

The uncertainties for the activity data have a normal distribution, with values between 0.07 – 196.0 % for half of the 95 % confidence interval. In this case as well, the uncertainty depends on the sample size, i.e. on the area share being considered. Weighted by area, the total uncertainty for activity data in the category Grassland is 0.069 %.

The total uncertainty for the land-use category Grassland is 43.7 % [2.5 percentile] and 26.1 % [97.5 percentile], while that for the sub-category Grassland (in the strict sense) is 48.1 % [2.5 percentile] and 28.8 % [97.5 percentile], and that for Woody Grassland is 23.5 % [2.5 percentile] and 24.1 % [97.5 percentile]. In the sub-category Grassland (in the strict sense), CO_2 emissions from organic soils make the largest contribution to the sub-category's total uncertainty. In addition, they make the largest contribution to the variance of the overall inventory (cf. Chapter 6.1.2.10). In the sub-category Woody Grassland, the biomass pool is particularly noticeable. Its contribution to the uncertainty of the inventory as a whole is marginal, however.

Table 410: Emission factors [t C ha^{-1} a^{-1}], with uncertainties [% of central tendency], as used for calculation of 2020 GHG emissions from Grassland (in the strict sense)

$Grassland_{i.t.s.s.}$ Initial land use Mineral soil, CO_2-C 1)	Final land use	Implied emission factor [t C ha^{-1} a^{-1}]	Uncertainty bounds upper [%]	lower [%]
Forest Land	$Grassland_{i.t.s.s.}$	0.0000	5.31	5.31
$Cropland_{annual}$	$Grassland_{i.t.s.s.}$	1.3253	1.98	1.98
Hops	$Grassland_{i.t.s.s.}$	1.3025	4.93	4.93
Vineyards	$Grassland_{i.t.s.s.}$	1.9440	6.05	6.05
Orchards	$Grassland_{i.t.s.s.}$	0.8972	5.84	5.84
Short-rotation plantations	$Grassland_{i.t.s.s.}$	1.1347	4.93	4.93
Tree nurseries	$Grassland_{i.t.s.s.}$	1.3017	4.93	4.93
Christmas tree plantations	$Grassland_{i.t.s.s.}$	1.2891	4.93	4.93
Woody Grassland	$Grassland_{i.t.s.s.}$	1.2626	4.93	4.93
Terr. Wetlands	$Grassland_{i.t.s.s.}$	-0.7605	6.58	6.58
Waters	$Grassland_{i.t.s.s.}$	0.2568	3.11	3.11
Peat extraction	$Grassland_{i.t.s.s.}$	0.0000	0.00	0.00
Settlements	$Grassland_{i.t.s.s.}$	2.4983	4.08	4.08
Other Land	$Grassland_{i.t.s.s.}$	1.6902	2.87	2.87

Grassland$_{i.t.s.s.}$ Initial land use	Final land use	Implied emission factor	Uncertainty bounds upper	lower
Biomass [2]		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	Grassland$_{i.t.s.s.}$	0.0000	23.70	23.70
Cropland$_{annual}$	Grassland$_{i.t.s.s.}$	0.0200	16.53	16.53
Hops	Grassland$_{i.t.s.s.}$	-2.2361	0.00	0.00
Vineyards	Grassland$_{i.t.s.s.}$	0.0715	17.34	17.34
Orchards	Grassland$_{i.t.s.s.}$	-0.3506	13.05	13.05
Short-rotation plantations	Grassland$_{i.t.s.s.}$	-3.1924	7.85	9.85
Tree nurseries	Grassland$_{i.t.s.s.}$	-1.0153	20.24	20.24
Christmas tree plantations	Grassland$_{i.t.s.s.}$	-1.2776	27.02	27.02
Woody Grassland	Grassland$_{i.t.s.s.}$	-3.3836	51.51	52.31
Terr. Wetlands	Grassland$_{i.t.s.s.}$	-1.5445	41.42	42.72
Waters	Grassland$_{i.t.s.s.}$	0.3769	30.30	30.30
Peat extraction	Grassland$_{i.t.s.s.}$	0.9448	30.30	30.30
Settlements	Grassland$_{i.t.s.s.}$	-1.3294	45.71	47.16
Other Land	Grassland$_{i.t.s.s.}$	0.1734	30.30	30.30
Dead organic matter [2]		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	Grassland$_{i.t.s.s.}$	0.0000	6.96	6.96

Forest Land, Cropland: annually variable; all other factors are constant

1) The calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

2) The calculation is only for first year of the land-use change; stock change: positive ≙ sink; negative ≙ source

Table 411: Uncertainties for emission factors [2.5 and 97.5 percentile, in % of central tendency] for emissions from organic soils under Grassland (in a strict sense), 2020

Land use	GHG	Emission factor	Uncertainty bounds lower	upper
Organic soil [1]		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Grassland in the strict sense	**CO_2**	27.6752	89.18	41.62
Grassland in the strict sense	**CH_4**	1.0076	59.89	442.02
Grassland in the strict sense	**N_2O**	3.31	93.48	382.61

1) Annual calculation; emission: positive ≙ source; negative ≙ sink

Table 412: Emission factors [t C ha-1 a-1], with uncertainties [% of central tendency], as used for calculation of GHG emissions in 2020 from Woody Grassland

Woody Grassland Initial land use Mineral soil, CO_2-C 1)	Final land use	Emission factor [t C ha^{-1} a^{-1}]	Uncertainty bounds upper [%]	lower [%]
Forest Land	Woody Grassland	0.0000	8.06	8.06
Cropland$_{annual}$	Woody Grassland	0.0497	5.69	5.69
Hops	Woody Grassland	0.0000	7.84	7.84
Vineyards	Woody Grassland	0.6493	9.41	9.41
Orchards	Woody Grassland	-0.4146	8.46	8.46
Short-rotation plantations	Woody Grassland	-0.0322	7.84	7.84
Tree nurseries	Woody Grassland	-0.0357	7.84	7.84
Christmas tree plantations	Woody Grassland	-0.0105	7.84	7.84
Grassland in the strict sense	Woody Grassland	-1.0525	4.93	4.93
Terr. Wetlands	Woody Grassland	-1.9850	8.56	8.56
Waters	Woody Grassland	-0.0214	11.09	11.09
Peat extraction	Woody Grassland	0.0000	0.00	0.00
Settlements	Woody Grassland	1.2164	8.11	8.11
Other Land	Woody Grassland	0.3646	8.55	8.55
Mineral soil N_2O_{direct} 3)		[kg N_2O ha^{-1} a^{-1}]	[kg N_2O ha^{-1} a^{-1}]	[%]
Grassland in the strict sense	Woody Grassland	1.5246	99.99	486.92
Terr. Wetlands	Woody Grassland	2.3864	99.99	488.28
Mineral soil, $N_2O_{indirect}$ 3)		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Grassland in the strict sense	Woody Grassland	0.3430	99.99	486.92
Terr. Wetlands	Woody Grassland	0.5369	99.99	488.28
Biomass 2)		[t C ha^{-1} 1 a^{-1}]	[t C ha^{-1} 1 a^{-1}]	[%]
Forest Land	Woody Grassland	0.0000	40.39	41.00
Cropland$_{annual}$	Woody Grassland	3.3148	51.66	52.47
Hops	Woody Grassland	0.0000	52.14	52.95
Vineyards	Woody Grassland	0.0268	50.94	51.73
Orchards	Woody Grassland	2.6955	44.44	45.13
Short-rotation plantations	Woody Grassland	4.3466	27.89	28.49
Tree nurseries	Woody Grassland	3.3518	41.50	42.14
Christmas tree plantations	Woody Grassland	3.5330	44.09	44.76
Grassland in the strict sense	Woody Grassland	3.0766	51.51	52.31
Terr. Wetlands	Woody Grassland	3.7701	41.70	42.42
Waters	Woody Grassland	4.9696	54.73	55.58
Peat extraction	Woody Grassland	7.6840	54.73	55.58
Settlements	Woody Grassland	2.1783	39.76	40.52
Other Land	Woody Grassland	6.5958	54.73	55.58
Dead organic matter 2)		[t C ha^{-1} 1 a^{-1}]	[t C ha^{-1} 1 a^{-1}]	[%]
Forest Land	Woody Grassland	0.0000	6.96	6.96

Forest Land, Cropland: annually variable; all other factors are constant

1) The calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

2) The calculation is only for first year of the land-use change; stock change: positive ≙ sink; negative ≙ source

3) The calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

Table 413: Uncertainties for emission factors [2.5 and 97.5 percentile, in % of location scale] for emissions from organic soils under Woody Grassland, 2020

Land use Organic soil[115]	GHG	Emission factor [t CO_2-eq. ha^{-1} a^{-1}]	Uncertainty bounds lower [%]	 upper [%]
Woody Grassland	**CO_2**	9.6566	20.74	24.20
Woody Grassland	**CH_4**	0.1639	68.73	106.18
Woody Grassland	**N_2O**	1.2793	99.99	117.86

For both the sub-categories Grassland (in the strict sense) and Woody Grassland, the calculations are spatially and chronologically consistent and complete for the entire reporting period, 1990-2020.

6.6.4 Category-specific quality assurance / control and verification (4.C)

Details regarding this year's reviews are provided in Chapter 6.1.3.

The data sources used in preparation of this inventory fulfill the review criteria of the QSE manual for data sources (QSE-Handbuch für Datenquellen). Quality assurance for input data (ATKIS®, BÜK, official statistics) is the responsibility of the relevant data administrators (cf. the pertinent documentation in the inventory description).

The emissions-calculation results as presented in the present report cannot be compared with other relevant data sources for Germany, since no such other data sources exist that meet applicable requirements, i.e. provide nationwide coverage, are comprehensive and are independent of the methods and data sources described in the present report.

To provide context for the German results, the national IEF for the individual pools were compared with the corresponding values for Germany's neighbours. For this comparison, the emission factors given in the 2021 submissions to the UNFCC Secretariat were used. The 2020 factors for Germany were taken from the current 2022 Submission. As the following tables show, Germany's IEF for CO_2 from drainage of organic soils under grassland is similar to those of neighbouring countries with similarly intensive peatland use, such as Austria, Denmark, Switzerland and the Netherlands.

In category 4.C.1, the carbon-stock changes in mineral soils and in biomass, as reported for Germany, refer to changes between Grassland (in the strict sense) and Woody Grassland. The mean emission factors are very low, since only a small area share is involved. Such changes are handled very differently from country to country, and thus the relevant mean emission factors of different countries cannot be directly compared.

In Germany, land-use conversions to Grassland create a strong sink in mineral soils of Grassland (with the exception of LUC from Terrestrial Wetlands; they represent a source). The relevant values are comparable, in terms of magnitude and trend, with those of most neighbouring countries. Overall, the German IEF for 2019 is somewhat higher than the average of the values for the other countries.

In addition, Germany's IEF for biomass in transition categories is of the same order as the corresponding values of neighbouring countries. The spread for the IEF for biomass is considerably larger than it is in connection with mineral soils, however. The reason for this has to do with country-specific category boundaries – and, thus, with category composition (in Germany, the figure is a mixed value reflecting Grassland (in the strict sense) and Woody

[115] Annual calculation; emission: positive ≙ source; negative ≙ sink

Grassland). A noticeably large change, with respect to the previous year's values, is seen in the German IEF for the transition category Forest Land converted to Grassland.

Table 414: Carbon-stock changes in living biomass, in grassland of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.C.1. - Grassland Remaining Grassland [t C ha^{-1} a^{-1}]	4.C.2 – Land Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.1 - Forest Land Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.2 - Cropland Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.3 - Wetlands Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.4 - Settlements Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.5 - Other Land Converted To Grassland [t C ha^{-1} a^{-1}]
Belgium	NO	-0.61	-7.25	NO	NO	NO	NO
Denmark	-0.05	-0.13	-0.18	NO	NO	NO	NO
France	0.02	-0.11	-1.36	0.05	NE	0.48	NE
UK	0.00	-0.09	-0.98	-0.07	NO	0.04	NO
Netherlands	0.01	-0.01	-4.62	0.17	0.52	0.65	0.63
Austria	NA	-0.56	-1.34	-0.06	NO	NO	NO
Poland	NO	0.18	NO	0.22	NO,IE	NO,IE	NO
Switzerland	NO	0.04	-4.58	0.13	0.49	NO	NO
Czech Republic	NO	0.03	-2.80	0.08	0.27	NO	NO
Germany, 2019	0.005	0.531	-3.358	0.188	0.506	0.163	0.684
Germany, 2020	-0.018	0.070	NO	0.135	0.369	-0.652	1.688

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC)

Table 415: Carbon-stock changes in dead organic matter, in grassland of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.C.1. - Grassland Remaining Grassland [t C ha^{-1} a^{-1}]	4.C.2 – Land Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.1 - Forest Land Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.2 - Cropland Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.3 - Wetlands Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.4 - Settlements Converted To Grassland [t C ha^{-1} a^{-1}]	4.C.2.5 - Other Land Converted To Grassland [t C ha^{-1} a^{-1}]
Belgium	NO	-0.05	-0.56	NO	NO	NO	NO
Denmark	NO	-0.01	-0.18	NO	NO	NO	NO
France	NE	-0.02	-0.16	NE	NE	NE	NE
UK	NA	-0.01	-0.32	IE	NO	IE,NA	NO
Netherlands	NA	-0.10	-1.86	NA	NA	NA	NA
Austria	NO	-0.33	-0.85	NO	NO	NO	NO
Poland	NO	NO	NO	NO	NO	NO	NO
Switzerland	NO	-0.21	-0.88	NO	NO	NO	NO
Czech Republic	NO	0.00	-0.12	NO	NO	NO	NO
Germany, 2019	IE	-0.0011	-2.465	IE	IE	IE	IE
Germany, 2020	IE	NO	NO	IE	IE	IE	IE

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC)

Table 416: Carbon-stock changes in mineral soils, in grassland of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.C.1. - Grassland Remaining Grassland [t C ha-1 a-1]	4.C.2 – Land Converted To Grassland [t C ha-1 a-1]	4.C.2.1 - Forest Land Converted To Grassland [t C ha-1 a-1]	4.C.2.2 - Cropland Converted To Grassland [t C ha-1 a-1]	4.C.2.3 - Wetlands Converted To Grassland [t C ha-1 a-1]	4.C.2.4 - Settlements Converted To Grassland [t C ha-1 a-1]	4.C.2.5 - Other Land Converted To Grassland [t C ha-1 a-1]
Belgium	0.18	1.72	-0.79	2.06	-0.31	1.80	NO
Denmark	NO,IE	0.01	0.20	IE	NO	NO	NO
France	0.00	0.91	0.03	1.01	NO	1.87	NE
UK	0.15	0.65	-0.88	0.60	NO,IE	1.62	NO
Netherlands	0.00	0.75	0.54	0.80	0.04	0.60	3.73
Austria	0.00	0.93	0.82	1.00	NO	NO	NO
Poland	0.00	0.91	NO	1.00	NO	NO	NO
Switzerland	-0.12	0.39	-1.12	0.36	1.87	2.05	1.65
Czech Republic	0.02	0.44	-0.08	0.47	NO	0.35	NO
Germany, 2019	0.008	1.361	0.959	1.271	0.026	2.312	1.380
Germany, 2020	0.008	1.354	NO	1.271	0.023	2.247	1.377

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC)

Table 417: Carbon-stock changes in organic soils, in grassland of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.C.1. - Grassland Remaining Grassland [t C ha-1 a-1]	4.C.2 – Land Converted To Grassland [t C ha-1 a-1]	4.C.2.1 - Forest Land Converted To Grassland [t C ha-1 a-1]	4.C.2.2 - Cropland Converted To Grassland [t C ha-1 a-1]	4.C.2.3 - Wetlands Converted To Grassland [t C ha-1 a-1]	4.C.2.4 - Settlements Converted To Grassland [t C ha-1 a-1]	4.C.2.5 - Other Land Converted To Grassland [t C ha-1 a-1]
Belgium	-1.89	NO	NO	NO	NO	NO	NO
Denmark	-5.86	-10.41	-10.41	IE	NO	NO	NO
France	IE	NO	NO	NO	NO	NO	NO
UK	-0.60	-2.29	-2.29	NO	NO	NO	NO
Netherlands	-4.09	-3.78	-2.52	-3.82	-3.91	-3.90	-2.07
Austria	-6.40	NO	NO	NO	NO	NO	NO
Poland	-0.25	-0.25	NO	-0.25	-0.25	-0.25	-0.25
Switzerland	-9.08	-8.90	-7.92	-9.33	-7.84	-1.97	2.96
Czech Republic	NO	NO	NO	NO	NO	NO	NO
Germany, 2019	-7.31	-7.93	-9.74	-8.13	-5.97	-7.33	-6.70
Germany, 2020	-7.39	-7.80	NO	-7.95	-6.47	-7.18	-6.68

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC)

6.6.5 Category-specific recalculations (4.C)

This year's submission includes category-specific recalculations for the entire period 1990 through 2020. The emissions were recalculated in order to take account of new and improved data sources, changes in methods, and error corrections made as part of ongoing inventory improvements. The following measures affected the results of the emissions calculations for the Grassland land-use category:

- Updating of the map data for determination of activity data with regard to designation of land uses and land-use changes, and adaptation of the land-use matrix over time (cf. Chapter 6.3.1ff);
- Implementation of a new method for calculating emissions from phytomass, for perennial woody plants outside of Forest Land (Chapter 6.1.2.3.4 ff);
- New emission factors for dead wood (cf. Chapter 6.4.2.3);
- Adjustment of the emission factors for biomass in connection with land-use changes from Woody Grassland to Forest Land (cf. also Chapter 6.1.2.3.6)

- Correction of the value for carbon and nitrogen stocks of mineral soils, in the category Settlements remaining Settlements (cf. Chapter 6.1.2.1.6 and Chapter 6.8.2.4).

In Table 418 (areas) and Table 419 (emissions), the results of the current recalculations for the Grassland category are compared with the corresponding results in the previous year's submission.

Any slight differences between the area data reported in the current and previous year's submissions are due to the effects of correction algorithms used in order to assure consistency between the area-use time series and the newly added data from the last time-series year. In each case, in keeping with the assumption that the newest data are the best data, in terms of quality, the previous time series is adjusted, if necessary (cf. also Chapter 6.3 ff).

The differences in the CO_2 emissions are due primarily to the change in the method used to determine the biomass of perennial woody plants.

Table 418: Comparison of area data [kha] for the Grassland category as reported in the current submission and in the previous year's submission

CRF No.	Area [kha]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.C	Grassland	2021	6,801.27	6,723.20	6,645.09	6,761.19	6,824.96	6,796.21	6,789.88	6,783.53	6,777.17	6,770.80
		2022	6,806.23	6,727.26	6,648.27	6,764.14	6,827.79	6,798.96	6,793.40	6,787.83	6,782.24	6,776.62
		Difference	4.97	4.06	3.19	2.95	2.83	2.75	3.52	4.30	5.07	5.82
		in %	0.07	0.06	0.05	0.04	0.04	0.04	0.05	0.06	0.07	0.09

Table 419: Comparison of greenhouse-gas emissions [kt CO_2-eq] in the Grassland category as reported in the current and previous year's submissions

CRF No.		GHG	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.C	Grass land	CO_2	2021	26,094.43	26,363.18	26,590.39	22,334.11	19,420.19	17,603.19	17,401.39	17,387.31	16,921.52	17,006.82
			2022	26,383.49	27,186.91	27,185.91	25,931.21	18,542.71	18,966.20	19,437.03	19,297.09	18,812.68	18,590.78
			Difference	289.07	823.72	595.52	3,597.10	-877.48	1,363.01	2,035.64	1,909.78	1,891.16	1,583.96
			in %	1.11	3.12	2.24	16.11	-4.52	7.74	11.70	10.98	11.18	9.31
		CH_4	2021	1,063.20	1,074.14	1,084.77	1,080.79	1,123.84	1,126.00	1,129.50	1,125.61	1,121.63	1,116.91
			2022	872.79	882.21	891.61	921.76	955.83	966.29	963.12	960.56	960.15	961.01
			Difference	-190.41	-191.93	-193.16	-159.02	-168.02	-159.70	-166.38	-165.06	-161.48	-155.90
			in %	-17.91	-17.87	-17.81	-14.71	-14.95	-14.18	-14.73	-14.66	-14.40	-13.96
		N_2O	2021	2,020.59	2,034.60	2,048.69	1,983.61	1,953.56	1,894.53	1,887.03	1,877.72	1,867.01	1,855.02
			2022	2,019.92	2,034.07	2,048.18	1,983.19	1,952.94	1,894.04	1,887.99	1,880.78	1,872.80	1,863.82
			Difference	-0.67	-0.54	-0.50	-0.43	-0.61	-0.49	0.96	3.06	5.79	8.80
			in %	-0.03	-0.03	-0.02	-0.02	-0.03	-0.03	0.05	0.16	0.31	0.47

6.6.6 Category-specific planned improvements (4.C)

Regionalisation of carbon stocks of mineral soils under Grassland, as a function of site-specific parameters, is being prepared and will soon be implemented. With that move, Germany will implement a pertinent ERT recommendation from the 2020 review process (ARR 2020: L.8, Table 5).

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

6.7 Wetlands (4.D)

6.7.1 Category description (4.D)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	**4 D, Wetlands**		**CO_2**	**3,705.8**	**0.3%**	**4,452.2**	**0.6%**	**20.1%**
-/-/T2	**4 D, Wetlands**		**CH_4**	**335.1**	**0.0%**	**683.7**	**0.1%**	**104.0%**
-/-	4 D, Wetlands		N_2O	34.1	0.0%	42.4	0.0%	24.2%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	RS/NS	CS
N_2O	Tier 2	RS/NS	CS
CH_4	Tier 2	RS/NS	CS

The category *Wetlands* is a key category for CO_2 emissions in terms of emissions level and trend and a key category for CH_4 emissions pursuant to Approach 2 analysis.

In Germany, the land-use category Wetlands primarily includes the country's peatlands, and its other wetlands that cannot be assigned to any of the other land-use categories. In the present report, such other wetlands are combined under the headings "Other Wetlands"/"Terrestrial wetlands," "Flooded land," and "Peat extraction" (areas used for production of horticultural peat).

Quantified area allocations to the individual sub-categories, as well as remarks regarding the pools and GHG from the remaining and transition categories that, pursuant to the 2006 IPCC Guidelines (IPCC, 2006a) and the 2013 IPCC Wetland Supplements (IPCC et al., 2014b), are to be reported on, are presented in Chapter 6.2.4.

The results of the emissions calculations for the year 2020 are shown in Table 420, while the emissions trends, by categories and sub-categories, are presented in Figure 75 and Figure 76.

Table 420: CO_2, N_2O and CH_4 emissions [kt CO_2-eq.] from Germany's wetlands, 2020. The table includes both the relevant sums and the upper and lower bounds of the 95 % confidence intervals.

Sub-category / Pool	GHG	Terrestrial Wetlands [kt CO_2-eq.] Emission	2.5 perc.	97.5 perc.	[%] 2.5 perc.	97.5 perc.
Terrestrial Wetlands$_{total}$		**2,350.2**	1,282.8	3,538.1	45.42	50.55
Mineral soils	CO_2	**-42.55**	-36.20	-48.89	14.91	14.91
	N_2O_{direct}	NO	NO	NO	NO	NO
	$N_2O_{indirect}$ 1)	NO	NO	NO	NO	NO
Organic soil	CO_2	**2,022.8**	784.12	3,387.5	61.24	67.47
	N_2O	**34.92**	8.71	105.00	75.07	200.65
	CH_4	**452.02**	171.93	814.62	61.96	80.22
Biomass	CO_2	**-144.62**	-108.50	-181.75	24.97	25.67
Litter / dead wood	CO_2	**27.60**	18.58	36.88	32.66	33.63
Sub-category / Pool	**GHG**	**Waters [kt CO_2-eq.] Emission**	**2.5 perc.**	**97.5 perc.**	**[%] 2.5 perc.**	**97.5 perc.**
Waters$_{total}$		**486.61**	394.20	579.60	18.99	19.11
Mineral soils	CO_2	NO	NO	NO	NO	NO
	N_2O	NO	NO	NO	NO	NO
Organic soil	CO_2	NO	NO	NO	NO	NO
	N_2O	NO	NO	NO	NO	NO
	CH_4 2)	**228.93**	150.14	307.72	34.42	34.42
Biomass	CO_2	**231.37**	182.20	281.64	21.25	21.73
Litter / dead wood	CO_2	**26.31**	22.62	30.00	14.03	14.03

Sub-category / Pool	GHG	Peat extraction				
		[kt CO_2-eq.]			[%]	
		Emission	2.5 perc.	97.5 perc.	2.5 perc.	97.5 perc.
Peat extraction$_{total}$		**2,341.4**	1,473.3	3,209.5	37.08	37.08
Mineral soils	CO_2	NO	NO	NO	NO	NO
	N_2O_{direct}	NO	NO	NO	NO	NO
Organic soil	CO_2	**2,302.6**	1,434.6	3,170.6	37.70	37.70
	N_2O	**7.44**	3.65	11.23	50.89	50.89
	CH_4	**2.75**	1.13	5.06	58.76	84.20
Biomass	CO_2	**28.2**	18.49	38.09	34.39	35.20
Litter / dead wood	CO_2	**0.5**	0.09	0.82	80.3	80.3

1) The category-specific indirect N_2O emissions are not included and shown as such in the CRF tables; they are included, however, in the sum presented in CRF Table 4.(IV).2 for all sub-categories.
2) Only drainage ditches

In 2020, a total of 5,178.2 kt CO_2-eq. were emitted from Wetlands (95 % confidence interval: 3,759.0 – 6,708.2 kt CO_2-eq.). As Table 420 shows, emissions from the land-use category Wetlands are tied mainly to CO_2 emissions from organic soils (83.5 %). These emissions consist of two major components of about equal size: CO_2 emissions from peat extraction (53.2 %) and CO_2 emissions from drainage of terrestrial organic soils (46.7 %). Emissions of methane (13.2 %) and nitrous oxide (0.8 %) are low, in comparison to the total emissions, as are CO_2 emissions from biomass (2.2 %). In the sub-category "Waters," the latter functions as a source, while in the sub-category "Terrestrial Wetlands," it functions as a sink. Emissions from mineral soils are negative and, therefore, function as a sink. Their share of overall emissions is very small, however (- 0.8 %).

Emissions from industrial peat extraction are divided into emissions that occur in extraction areas, during peat extraction (on-site emissions), and emissions that are emitted during application of peat products (off-site emissions). In 2020, the latter amounted to 2,212.98 ± 867.5 kt CO_2-eq. and thus were the main factor responsible for the magnitude of total emissions from peat extraction (94.5 %). The on-site emissions, at 99.8 kt CO_2-eq., (-12.0 % / +15.6 %), are relatively low by contrast. Their dominant component is CO_2 (90.6 %), followed by methane (2.8 %) and nitrous oxide (7.5 %).

As the time series in Figure 75 and Figure 76 show, total emissions increased in 2020 with respect to the base year (27.1 %), as the result of an interim intensification of conversion of grassland, forest land and settlement areas. The emissions increase has occurred primarily in the pools organic soils and biomass (Figure 75). The trend curve is shaped primarily by emissions from peat extraction and from drainage, and from organic soils, in the sub-category Terrestrial Wetlands. While the former emissions reflect the annual quantities of peat that are produced, and have remained about the same over the years, emissions from organic soils in the sub-category Terrestrial Wetlands have increased sharply (+37.5 %).

Figure 75: CO_2 emissions [kt CO_2 -eq.] from Wetlands, as a result of land use and land-use change, 1990-2020, by sub-categories

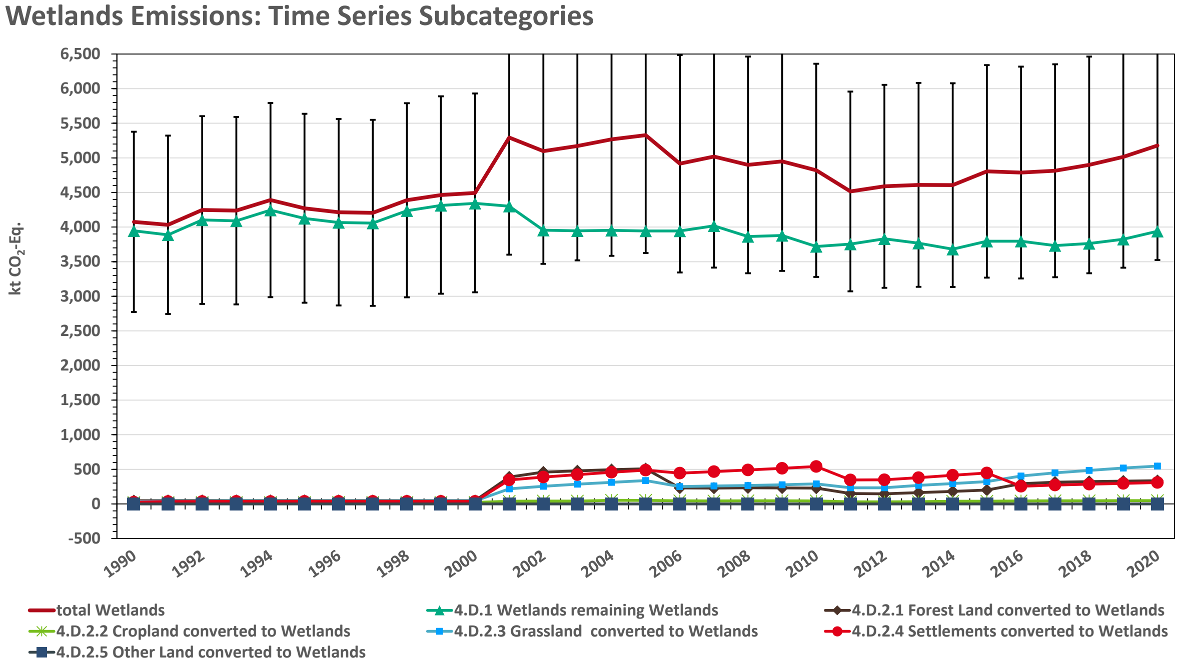
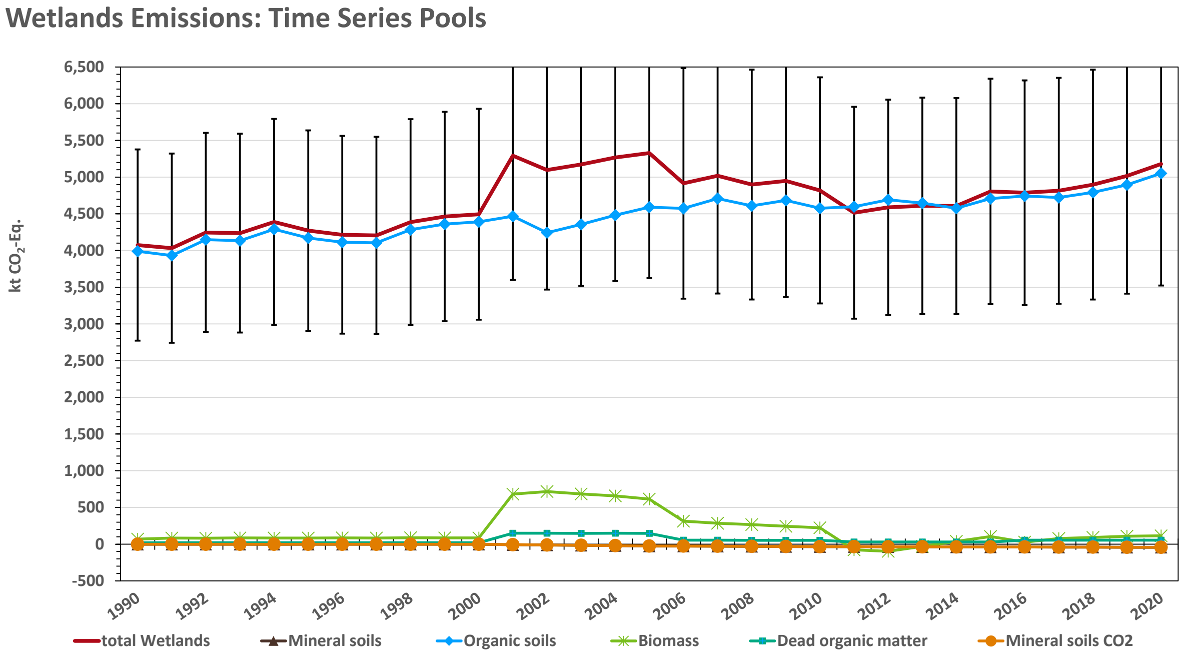


Figure 76: CO_2 emissions [kt CO_2-eq.] from Wetlands, as a result of land use and land-use changes, 1990-2020, by pools



6.7.2 Methodological issues (4.D)

6.7.2.1 Data sources

The production-quantity data for industrial peat extraction were taken from official German statistics (Statistisches Bundesamt, FS 4, R 3.1).

For further sources, cf. Chapters 6.3.2 and 6.2.

6.7.2.2 Biomass

Water areas are free of vegetation cover, and thus the biomass carbon stocks are zero and are always reported in the CRF tables as NO (not occurring); the same applies to peat-extraction areas.

For areas in the sub-category "Terrestrial Wetlands," a new method for calculating biomass has been introduced. The method is described in detail in Chapter 6.1.2.3ff and, specifically for Terrestrial Wetlands, in Chapter 6.1.2.3.7. Changes in biomass carbon stocks, as a result of land-use changes, are calculated with the procedures and methods described in Chapter 6.1.3.

The implied emission factors and pertinent uncertainties are presented in Table 422 (Chapter 6.7.3).

6.7.2.3 Mineral soils

It was assumed that no changes in the carbon stocks of mineral soils occurred in connection with land-use conversions to water bodies (NO in CRF table 4.D.1). The mineral soils in the remaining categories of Terrestrial Wetlands and Waters are assumed to be in equilibrium. For this reason, "NA" is entered in the relevant spaces of the CRF tables.

For the sub-category Terrestrial Wetlands, changes in mineral-soil organic carbon stocks, as a result of land-use changes, are calculated with the procedures and methods described in Chapter 6.1.2.1.

The implied emission factors and pertinent uncertainties are presented in Table 422 (Chapter 6.7.3).

6.7.2.4 Organic soils

The emissions have been calculated in keeping with the methods described in Chapter 6.1.2.2. In the present submission, a reference error in the algorithm for calculation of methane emissions from the sub-category Waters has been corrected; the algorithm now refers to the correct emission factor for methane from drainage ditches.

6.7.2.5 Peat extraction

Greenhouse-gas emissions from peat extraction were calculated in conformance with the provisions of the 2006 IPCC Guidelines, following the Tier 2 methodology. The total emissions, comprising both on-site and off-site emissions, were calculated via the equations 7.2 through 7.5 of the 2006 IPCC Guidelines (IPCC, 2006a). In the sub-category Peat extraction, CO_2 emissions (on-site: emissions and DOC; off-site: produced and spread peat), CH_4 emissions (emissions, and emissions from drainage ditches) and N_2O emissions (on-site) are reported. The manner in which the relevant emission factors are derived is described in Chapter 6.1.2.2. The estimates are based on the following activity data:

- Calculation of on-site emissions: The areas on which industrial peat extraction takes place, and the amounts of shifting of areas to and from those areas, were determined with the Basis-DLM (cf. Chapter 6.3). The relevant data sets were not completely added to the Basis-DLM until 2008. As a result, the peat-extraction areas determined for 2008 are used in calculating the on-site emissions for all years prior to 2008. As of 2008, the current values determined for the relevant survey reference year in each case are used.
- Calculation of off-site emissions: annual production quantities; these are obtained from official German statistics (Statistisches Bundesamt, FS 4, R 3.1).

Equation 7.3 (IPCC, 2006a):

$$CO_2\text{-eq.}_{peat\ extraction} = CO_2\text{-eq.}_{on\text{-}site} + CO_2\text{-eq.}_{off\text{-}site}$$

CO_2-eq.$_{peat\ extraction}$: GHG emissions from peat extraction [t CO^2-eq. a^{-1}]

CO_2-eq.$_{on\text{-}site}$: GHG emissions that occur on-site, during production [t CO_2-eq. a^{-1}]

CO_2-eq.$_{off\text{-}site}$: GHG emissions that occur via extracted peat that is spread for horticultural purposes [t CO_2-eq. a^{-1}]

In Germany, only peat from raised bogs is extracted. For this reason, Equation 7.4 (IPCC, 2006a) was modified in the following manner:

$$CO_2\text{-eq.}_{on\text{-}site} = A_{peat,\ oligotrophic} \times (EF_{peat,\ oligotrophic\_CO2} + EF_{peat,\ oligotrophic\_N2O} + EF_{peat,\ oligotrophic\_CH4})$$

CO_2-eq. $_{on\text{-}site}$: On-site emissions that occur on site during peat production [t CO_2-eq. a^{-1}]

$A_{peat,\ oligotrophic}$: Peat-extraction area on raised bogs [ha]

$EF_{peat,\ oligotrophic\_(CO2,\ N2O,\ CH4)}$: Country-specific emission factors for raised bogs on which peat extraction is taking place [t CO_2-eq. ha^{-1} a^{-1}] (cf. Chapter 6.1.2.2)

Off-site emissions were calculated with Equation 7.5 (IPCC, 2006a):

$$CO_2\text{-eq.}_{off\text{-}site} = Vol_{peat\_dry} \times Cfraction_{vol\_peat}$$

$CO_{2off\text{-}site}$: CO_2-eq. emissions that occur via extracted peat that is spread for horticultural purposes [t CO_2-eq. a^{-1}]

Vol_{peat_dry}: Volume of air-dried peat [m^3]

$C_{fraction\ vol\_peat}$: Carbon fraction with respect to the volume of air-dried peat [0.2567 t CO_2-eq. m^3 air-dried peat (IPCC (2006a), Tab. 7.5)]

The emission factors for the on-site emissions are listed in Table 425 (Chapter 6.7.3) . The off-site emissions, calculated from the quantities of peat produced, and the IEF for the off-site emissions, are shown in Table 421.

Table 421: Peat extraction: $IEF_{off\text{-}site}$ [t CO_2-Eq. ha^{-1} a^{-1}] and off-site emissions [kt CO_2-Eq.]

Peat extraction Year	IEF [t CO_2-eq. ha^{-1} a^{-1}]	Off-site emissions [kt CO_2-eq.]
1990	95.5	2,029.5 ± 795.6
1995	103.7	2,203.9 ± 863.9
2000	113.7	2,416.2 ± 947.2
2005	102.5	2,179.6 ± 854.4
2010	98.83	1,991.5 ± 780.7
2011	103.05	2,030.5 ± 796.0
2012	109.38	2,106.0 ± 825.6
2013	108.57	2,042.0 ± 800.5
2014	106.35	1,952.7 ± 765.5
2015	115.34	2,066.4 ± 810.0
2016	120.73	2,069.5 ± 811.2
2017	122.66	2,007.6 ± 787.0
2018	130.51	2,035.9 ± 798.1
2019	141.61	2,097.2 ± 822.1
2020	157.56	2,212.9 ± 867.5

6.7.3 Uncertainties and time-series consistency (4.D)

The time series for activity data provided by the Federal Statistical Office for peat extraction are consistent and available for the entire reporting period. Pursuant to the Federal Statistical Office, the uncertainties for these activity data are "0", since the data have been obtained via an exhaustive survey entailing an obligation to provide information. Nonetheless, an uncertainty of 20 % is assumed, in keeping with the 2006 IPCC Guidelines. That uncertainty is due primarily to the uncertainty in conversion, for peat, of volume units to mass units. The uncertainties listed in Table 422 and Table 425, ranging up to 40 % for Peat extraction, are the result of uncertainties propagation. They are due especially to the large uncertainties in the IPCC default values used. The statements made in Chapter 6.5.3 and Chapter 6.6.3 also apply to the uncertainties for the emission factors for methane and nitrous oxide.

The activity data and area data have a normal distribution. Their uncertainties, depending on the area and sampling sizes involved, range from 0.26 to 196 %. The total uncertainty for the area data in the category Wetlands is 0.23 %.

The total uncertainty for emissions in the land-use category Wetlands is -27.4 % / +29.5 % [95% percentile], while that for the sub-category Terrestrial Wetlands is -45.4 % / +50.5 %; that for Wetlands is -19.0 % / +19.1 %; and that for Peat extraction is +37.1% / +37.1%. The Wetlands category's contributions to the total emissions and the total uncertainty in the LULUCF sector are very small. Only the values tied to peat extraction and to organic soils in the sub-category Terrestrial Wetlands are large enough to be perceptible.

Table 422: Implied emission factors and uncertainties [in % of central tendency] used for calculation of GHG emissions from Terrestrial Wetlands for 2020, by pools and sub-categories

$Wetlands_{terrestrial}$ Initial land use	Final land use	Implied emission factors	Uncertainty bounds lower	Uncertainty bounds upper
Mineral soils CO_2-C[116]		[$t\ C\ ha^{-1}\ a^{-1}$]	[%]	[%]
Forest Land	$Wetlands_{terrestrial}$	2.3607	8.61	8.61
$Cropland_{annual}$	$Wetlands_{terrestrial}$	2.3236	7.56	7.56
Hops	$Wetlands_{terrestrial}$	0.0000	8.56	8.56
Vineyards	$Wetlands_{terrestrial}$	0.0000	9.65	9.65
Orchards	$Wetlands_{terrestrial}$	0.0000	8.76	8.76
Short-rotation plantations	$Wetlands_{terrestrial}$	0.0000	8.56	8.56
Tree nurseries	$Wetlands_{terrestrial}$	0.0000	8.56	8.56
Christmas tree plantations	$Wetlands_{terrestrial}$	0.0000	8.56	8.56
$Grassland_{i.t.s.s.}$	$Wetlands_{terrestrial}$	1.0626	6.58	6.58
Woody Grassland	$Wetlands_{terrestrial}$	1.9401	8.56	8.56
Waters	$Wetlands_{terrestrial}$	0.2660	12.02	12.02
Peat extraction	$Wetlands_{terrestrial}$	/	/	/
Settlements	$Wetlands_{terrestrial}$	3.4049	9.25	9.25
Other Land	$Wetlands_{terrestrial}$	2.6900	3.69	4.69
Mineral soil, N_2O_{direct}[117]		[$kg\ N_2O\ ha^{-1}\ a^{-1}$]	[$kg\ N_2O\ ha^{-1}\ a^{-1}$]	[%]
$Grassland_{i.t.s.s.}$	$Wetlands_{terrestrial}$	0	99.99	487.00
Mineral soil, $N_2O_{indirect}$[118]		[$kg\ N_2O\ ha^{-1}\ a^{-1}$]	[$kg\ N_2O\ ha^{-1}\ a^{-1}$]	[%]
$Grassland_{i.t.s.s.}$	$Wetlands_{terrestrial}$	0	99.99	487.00
Biomass[119]		[$t\ C\ ha^{-1}\ a^{-1}$]	[%]	[%]
Forest Land	$Wetlands_{terrestrial}$	-0.6274	27.68	28.35
$Cropland_{annual}$	$Wetlands_{terrestrial}$	0.5268	41.57	42.89
Hops	$Wetlands_{terrestrial}$	0.0000	42.49	43.84
Vineyards	$Wetlands_{terrestrial}$	0.0000	40.27	41.54
Orchards	$Wetlands_{terrestrial}$	0.0000	30.32	31.26
Short-rotation plantations	$Wetlands_{terrestrial}$	0.0000	14.71	15.77
Tree nurseries	$Wetlands_{terrestrial}$	0.0000	27.94	28.70
Christmas tree plantations	$Wetlands_{terrestrial}$	3.0077	31.65	32.49
Grassland (in the strict sense)	$Wetlands_{terrestrial}$	1.3102	41.42	42.72
Woody Grassland	$Wetlands_{terrestrial}$	-1.7110	41.70	42.42
$Wetlands_{terrestrial}$	$Wetlands_{terrestrial}$	0.0000	0.00	0.00
Waters	$Wetlands_{terrestrial}$	2.0981	47.94	49.47
Peat extraction	$Wetlands_{terrestrial}$	2.8175	47.94	49.47
Settlements	$Wetlands_{terrestrial}$	0.5980	35.81	36.95
Other Land	$Wetlands_{terrestrial}$	0.0000	47.94	49.47

116 Calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source
117 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink,
118 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink,
119 Calculation only for the first year following the pertinent land-use change

Wetlands$_{terrestrial}$		Implied emission factors	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Mineral soils CO_2-C[116]		[t C ha^{-1} a^{-1}]	[%]	[%]
Dead organic matter		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	**Wetlands$_{terrestrial}$**	-0.7293	6.96	6.96

Positive: sink; negative: Source

Table 423: Emission factors and uncertainties [in % of central tendency] used for calculation of GHG emissions from Waters for 2020, by pools and sub-categories

Waters		Implied emission factors	Uncertainty bounds	
Initial land use	Final land use		upper	lower
Mineral soils CO_2-C[120]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	**Waters**		No emissions	
Cropland$_{annual}$	**Waters**		No emissions	
Hops	**Waters**		No emissions	
Vineyards	**Waters**		No emissions	
Orchards	**Waters**		No emissions	
Short-rotation plantations	**Waters**		No emissions	
Tree nurseries	**Waters**		No emissions	
Christmas tree plantations	**Waters**		No emissions	
Grassland$_{i.t.s.s.}$	**Waters**		No emissions	
Woody Grassland	**Waters**		No emissions	
Settlements	**Waters**		No emissions	
Waters	**Waters**		No emissions	
Other Land	**Waters**		No emissions	
Mineral soil, N_2O_{direct}[121]	[%]		[kg N_2O ha^{-1} a^{-1}]	
Grassland$_{i.t.s.s.}$	**Waters**		No emissions	
Mineral soil, $N_2O_{indirect}$[122]	[%]		[kg N_2O ha^{-1} a^{-1}]	
Grassland$_{i.t.s.s.}$	**Waters**		No emissions	
Biomass[123]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	**Waters**	-1.8150	27.18	27.18
Cropland$_{annual}$	**Waters**	-0.2819	11.19	11.14
Hops	**Waters**	0.0000	16.54	16.54
Vineyards	**Waters**	0.0000	19.20	22.88
Orchards	**Waters**	-0.6268	14.41	14.92
Short-rotation plantations	**Waters**	0.0000	8.12	16.10
Tree nurseries	**Waters**	-10.2114	23.39	23.39
Christmas tree plantations	**Waters**	-2.5104	32.85	32.85
Grassland (in the strict sense)	**Waters**	-0.3679	30.30	30.30
Woody Grassland	**Waters**	-3.6292	54.73	55.21
Wetlands$_{terrestrial}$	**Waters**	-1.8745	47.94	42.59
Waters	**Waters**	0.0000	1.00	0.00
Peat extraction	**Waters**	0.0000	0.00	0.00
Settlements	**Waters**	-0.4371	50.92	47.87
Other Land	**Waters**	0.0000	0.00	0.00
Dead organic matter	[%]	[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	**Waters**	-0.9156	6.96	27.31

Positive: sink; negative: Source

120 Calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source
121 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink,
122 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink,
123 Calculation only for the first year following the pertinent land-use change

Table 424: Emission factors and uncertainties [in % of central tendency] used for calculation of GHG emissions from peat extraction in 2020, by pools and sub-categories

Peat extraction Initial land use Mineral soils CO_2-C[124]	Final land use	Implied emission factors [t C ha^{-1} a^{-1}]	Uncertainty bounds upper [%]	 lower [%]
Forest Land	Peat extraction		No emissions	
$Cropland_{annual}$	Peat extraction		No emissions	
Hops	Peat extraction		No emissions	
Vineyards	Peat extraction		No emissions	
Orchards	Peat extraction		No emissions	
Short-rotation plantations	Peat extraction		No emissions	
Tree nurseries	Peat extraction		No emissions	
Christmas tree plantations	Peat extraction		No emissions	
$Grassland_{i.t.s.s.}$	Peat extraction		No emissions	
Woody Grassland	Peat extraction		No emissions	
Settlements	Peat extraction		No emissions	
Waters	Peat extraction		No emissions	
Other Land	Peat extraction		No emissions	
Mineral soil, N_2O_{direct}[125]				
$Grassland_{i.t.s.s.}$	Peat extraction		No emissions	
Mineral soil, $N_2O_{indirect}$[126]				
$Grassland_{i.t.s.s.}$	Peat extraction		No emissions	
Biomass[127]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Peat extraction	-3.8325	27.18	27.18
$Cropland_{annual}$	Peat extraction	-0.6939	11.19	11.19
Hops	Peat extraction	0.0000	16.54	16.54
Vineyards	Peat extraction	0.0000	19.20	19.20
Orchards	Peat extraction	0.0000	14.41	14.41
Short-rotation plantations	Peat extraction	0.0000	8.12	10.30
Tree nurseries	Peat extraction	0.0000	23.39	23.39
Christmas tree plantations	Peat extraction	-2.5266	32.85	32.85
Grassland (in the strict sense)	Peat extraction	-0.7344	30.30	30.30
Woody Grassland	Peat extraction	-2.9520	54.73	55.58
$Wetlands_{terrestrial}$	Peat extraction	-5.1925	47.94	49.47
Waters	Peat extraction	0.0000	0.00	0.00
Peat extraction		0.0000	1.00	2.00
Settlements	Peat extraction	-4.2686	50.92	52.55
Other Land	Peat extraction	0.0000	0.00	0.00
Dead organic matter		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Peat extraction	-1.9333	6.96	6.96

Positive: sink; negative: Source

124 Calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source
125 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink,
126 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink,
127 Calculation only for the first year following the pertinent land-use change

Table 425: Uncertainties for emission factors [2.5 and 97.5 percentile, in % of location scale] for emissions from organic soils, for Wetlands and peat extraction, 2020

Land use	GHG	Emission factor	Uncertainty bounds	
			lower	upper
Organic soil[128]		[t CO_2-eq. ha^{-1} a^{-1}]	%	%
Wetlands$_{terrestrial}$	CO_2	18.6217	94.48	104.20
Wetlands$_{terrestrial}$	N_2O	0.3215	99.99	314.29
Wetlands$_{terrestrial}$	CH_4	4.1613	97.88	127.12
Peat extraction	CO_2	129.9438	9.70	9.38
Peat extraction	N_2O	0.4199	63.27	51.06
Peat extraction	CH_4	0.1551	78.64	84.42

The calculations are spatially and chronologically consistent and complete for the entire reporting period, 1990 – 2020.

6.7.4 Category-specific quality assurance / control and verification (4.D)

Details regarding this year's reviews are provided in Chapter 6.1.3.

The data sources used in preparation of this inventory fulfill the review criteria of the QSE manual for data sources (QSE-Handbuch für Datenquellen). Quality assurance for input data (ATKIS®, BÜK, official statistics) is the responsibility of the relevant data administrators (cf. the pertinent **documentation in the inventory description).**

The emissions-calculation results as presented in the present report cannot be compared with other relevant data sources for Germany, since no such other data sources exist that meet applicable requirements, i.e. provide nationwide coverage, are comprehensive and are independent of the methods and data sources described in the present report.

A comparison of Germany's implied emission factors, in the Wetlands category, with those of European neighbouring countries (Table 426) shows that the IEF hardly lend themselves to comparison. This is due to differences between the pertinent combinations of soil types. This can be illustrated as follows: In the organic soils pool in category 4.D.1, Germany has the second-lowest emission factor, and its factor is very close to the values of Denmark and Switzerland. National definitions play an especially strong role in the Wetlands category. In Germany, for example, the emissions counted in it include those from peat extraction, and the related off-site emissions. Since the applicable national circumstances differ widely from country to country, the various implied emission factors span a wide range overall.

The present comparison considers values of neighbouring countries, as reported in the countries' 2021 submissions to the UNFCC Secretariat (reporting year 2019). The values for Germany were obtained from the current 2022 submission (reporting year 2020).

[128] Annual calculation; emission: positive ≙ source; negative ≙ sink

Table 426: Carbon-stock changes in various pools, in wetlands of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.D.1. 4.E.1 – Wetlands Remaining Wetlands			4.D.2 – Land Converted To Wetlands			
	Biomass	Dead organic matter	Organic soils	Biomass	Dead organic matter	Mineral soils	Organic soils
	[t C ha⁻¹ a⁻¹]	[t C ha⁻¹ a⁻¹]	[t C ha⁻¹ a⁻¹]	[t C ha⁻¹ a⁻¹]	[t C ha⁻¹ a⁻¹]	[t C ha⁻¹ a⁻¹]	[t C ha⁻¹ a⁻¹]
Belgium	NO	NO	NO	-1.22	-0.07	1.41	NO
Denmark	NO	NO	-5.61	-0.15	NO	NO	NO
France	NE	NE	NE	-0.51	-0.06	NO	NE
UK	0.00	NO,NA,IE	-0.16	-5.62	-2.00	NO,NA	-0.73
Netherlands	NO,NA	NO,NA	NO,NA	-0.59	-0.07	0.83	-0.32
Austria	NO,NE	NO,NE	NO,NE	-0.49	-0.15	NO	NO
Poland	NO	0.00	-0.06	-0.03	-6.44	NO,NA	NO,NA
Switzerland	0.00	NO,IE	-4.85	-1.08	-0.17	-0.68	-4.38
Czech Republic[1)]	NA	NA	NA	-0.44	-0.01	NA	NA
Germany, 2019	**0.013**	**IE**	**-4.56**	**-0.30**	**-0.11**	**0.11**	**-3.79**
Germany, 2020	**0.01**	**IE**	**-6.63**	**-0.24**	**-0.10**	**0.11**	**-3.88**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

1) "Land Converted to Wetland" values only for "FL, CL, GL converted to other wetlands"

6.7.5 Category-specific recalculations (4.D)

This year's submission includes category-specific recalculations for the entire period 1990 through 2020. The emissions were recalculated in order to take account of new and improved data sources, changes in methods, and error corrections made as part of ongoing inventory improvements. The following measures affected the results of the emissions calculations for the Wetlands land-use category:

- Updating of the map data for determination of activity data with regard to designation of land uses and land-use changes, and adaptation of the land-use matrix over time (cf. Chapter 6.3.1ff);
- Implementation of a new method for calculating emissions from biomass, for perennial woody plants outside of Forest Land (Chapter 6.1.2.3.4 ff);
- New emission factors for dead wood (cf. Chapter 6.4.2.3);
- Correction of the value for carbon and nitrogen stocks of mineral soils, in the category Settlements remaining Settlements (cf. Chapter 6.1.2.1.6 and Chapter 6.8.2.4).
- Correction of the algorithm for calculation of methane emissions in the sub-category Waters (Chapter 6.7.2.4)

In Table 427 (areas) and Table 428 (emissions), the results of the current recalculations for the Wetlands category are compared with the corresponding results in the previous year's submission.

Minor differences between the area data in the current submission, and the corresponding data in the previous year's submission, are due to a) the change in the method for determining the areas of drainage ditches on organic soils; and b) the use of correction algorithms that ensure consistency, in the area-use time series, with newly added data of the last time-series year. In each case, in keeping with the assumption that the newest data are the best data, in terms of quality, the previous time series is adjusted, if necessary (cf. also Chapter 6.3 ff).

The differences between the present submission and the previous year's submission, with respect to CO_2-emissions figures, are partly due to the change in the method for determination of emissions from perennial biomass, and partly due to emissions from organic soils that are tied to minor differences of areas and to differences of water levels.

Correction of the algorithm for calculation of methane emissions from the sub-category Waters led to considerable percentage differences between the two submissions.

Table 427: Comparison of area data [kha] for the Wetlands category as reported in the current and previous year's submissions

CRF No.	Area [kha]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.D	Wetlands	2021	648.42	649.93	651.45	676.48	707.25	728.46	731.50	734.56	737.65	740.69
		2022	648.15	649.78	651.45	676.47	707.20	728.30	730.99	733.68	736.41	739.15
		Difference	-0.27	-0.15	0.00	-0.01	-0.05	-0.16	-0.51	-0.88	-1.23	-1.54
		in %	-0.04	-0.02	0.00	0.00	-0.01	-0.02	-0.07	-0.12	-0.17	-0.21

Table 428: Comparison of greenhouse-gas emissions [kt CO_2-eq] in the Wetlands category as reported in the current and previous year's submissions

CRF No.		GHG	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.D	Wetlands	CO_2	2021	3,668.32	3,850.09	4,070.60	4,554.24	4,308.07	4,263.93	4,217.73	4,185.81	4,242.89	4,333.77
			2022	3,705.75	3,901.24	4,122.67	4,835.45	4,231.66	4,155.09	4,127.28	4,140.14	4,208.88	4,308.83
			Difference	37.43	51.15	52.07	281.21	-76.42	-108.83	-90.45	-45.67	-34.02	-24.95
			in %	1.02	1.33	1.28	6.17	-1.77	-2.55	-2.14	-1.09	-0.80	-0.58
		CH_4	2021	363.06	363.91	364.72	353.84	436.95	480.05	494.89	498.69	502.35	506.25
			2022	335.07	336.04	337.08	453.62	546.99	608.55	619.02	631.99	647.14	664.27
			Difference	-27.99	-27.87	-27.65	99.78	110.04	128.50	124.13	133.30	144.79	158.01
			in %	-7.71	-7.66	-7.58	28.20	25.18	26.77	25.08	26.73	28.82	31.21
		N_2O	2021	34.10	34.18	34.27	38.65	40.68	40.97	41.23	41.51	41.76	41.99
			2022	34.10	34.18	34.27	38.65	40.71	41.03	41.32	41.60	41.87	42.14
			Difference	0.00	0.00	0.00	0.00	0.03	0.06	0.09	0.09	0.11	0.15
			in %	0.00	0.00	0.00	0.00	0.07	0.14	0.21	0.22	0.26	0.36

6.7.6 Category-specific planned improvements (4.D)

Regionalisation of carbon stocks of mineral soils of Terrestrial Wetlands, as a function of site-specific parameters, is being prepared and will soon be implemented. With that move, Germany will implement a pertinent ERT recommendation from the 2020 review process (ARR 2020: L.8, Table 5).

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

6.8 Settlements (4.E)

6.8.1 Category description (4.E)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	4 E, Settlements		CO_2	1,776.6	0.1%	1,075.9	0.2%	-39.4%
-/-/T2	**4 E, Settlements**		**N_2O**	**170.9**	**0.0%**	**326.3**	**0.0%**	**90.9%**
-/-	4 E, Settlements		CH_4	48.0	0.0%	65.3	0.0%	35.9%

* Nitrous oxide emissions; direct and indirect emissions from mineral soils, and emissions from organic soils

** Methane emissions from organic soils

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2	RS/NS	CS
N_2O	Tier 2	RS/NS	CS/D
CH_4	Tier 2	RS/NS	D

The category *Settlements* has been identified, via Approach 2 analysis, as a key category for N_2O.

Reporting for the land-use category Settlements has to cover CO_2 emissions / removals in the pools soil, biomass and dead organic matter on land designated for settlement and transport uses. Precise definitions and category allocations are presented in Chapter 6.2. In sub-category 4.H, N_2O emissions from drained soils are reported, since no sub-tables for this purpose have been created for 4.E in the CRF Reporter. The results of the estimation of relevant GHG emissions are presented in Table 429 and in Figure 77 and Figure 78.

Table 429: CO_2, N_2O and CH_4 emissions [kt CO_2-eq.] from Germany's Settlements, 2020. The table includes both the relevant sums and the upper and lower bounds of the 95 % confidence interval.

Category	GHG	Emissions, Settlements, 2020 [kt CO_2-eq.]			[%]	
		Emission	2.5 perc.	97.5 perc.	2.5 perc.	97.5 perc.
$Settlements_{total}$ [1)]		**1,467.4**	1,211.4	1,707.4	17.44	16.36
Mineral soils	CO_2 [2)]	**1,202.2**	1,061.0	1,343.4	11.74	11.74
	N_2O_{direct} [3)]	**133.92**	72.53	303.66	45.84	126.74
	$N_2O_{indirect}$ [4)]	**30.13**	8.02	84.76	73.38	181.27
Organic soil	CO_2 [2)]	**2,425.0**	1,542.8	2,864.8	36.38	18.14
	N_2O [5)]	**162.23**	57.40	591.09	64.62	264.35
	CH_4 [5)]	**65.27**	40.05	105.01	38.64	60.89
Biomass	CO_2 [2)]	**-2,933.18**	-2,136.30	-3,755.23	27.17	28.03
Litter / dead wood	CO_2 [2)]	**381.84**	352.60	411.08	7.66	7.66

1) Sum of the emissions from CRF tables 4.E, 4.(II).H, 4.(III).E, 4.(IV).2

2) CRF Table 4.E

3) CRF Table 4.(III).E

4) The category-specific indirect N_2O emissions are not included and shown as such in the CRF tables; they are included, however, in the sum, for all sub-categories, presented in CRF Table 4.(IV).2.

5) CRF Table 4.(II).H

In 2020, greenhouse-gas emissions from Germany's settlement and transport areas, as a result of land use and land-use changes, amounted to 1,467.4 kt CO_2 (Table 429). The source for the majority of these emissions is soils, which account for 99.6 % of the net emissions of this land-use category, with emissions from organic soils (62.9 %) predominating (mineral soils, 37.1 %). Biomass, with emissions of -12.3 kt CO_2-eq., is a sink.

With respect to the base year, emissions in 2020 show a net decrease of -528.1 kt CO_2-Eq. ≙ -26.5 % (Figure 77, Figure 78). The trend is inconsistent. In the main, it is shaped by emissions from biomass and mineral soils, followed by emissions from land-use changes from Forest Land, Cropland and Grassland to Settlements.

The shapes of the time-series plots – especially the noticeable changes they show – are due primarily to the changes in area data that have occurred as of the relevant explicitly defined survey dates (cf. Chapter 6.3.5). The transition between data sources (repeatedly described above) – CORINE (1990 - 2000), B-DLM of ATKIS® (2000 - 2020) (cf. Chapter 6.3.2.2) – is also apparent in the Settlements category. In addition, the impacts of the new method for biomass determination are manifest: Considerable time passes before the gradual increase of the carbon stocks in the woody-plant biomass of new Settlements compensates for the large, and immediately occurring, losses of plant biomass from the previous uses.

Figure 77: **GHG emissions [kt CO_2-eq.] resulting from land use and land-use changes, from Settlements, 1990 – 2020, by sub-categories**

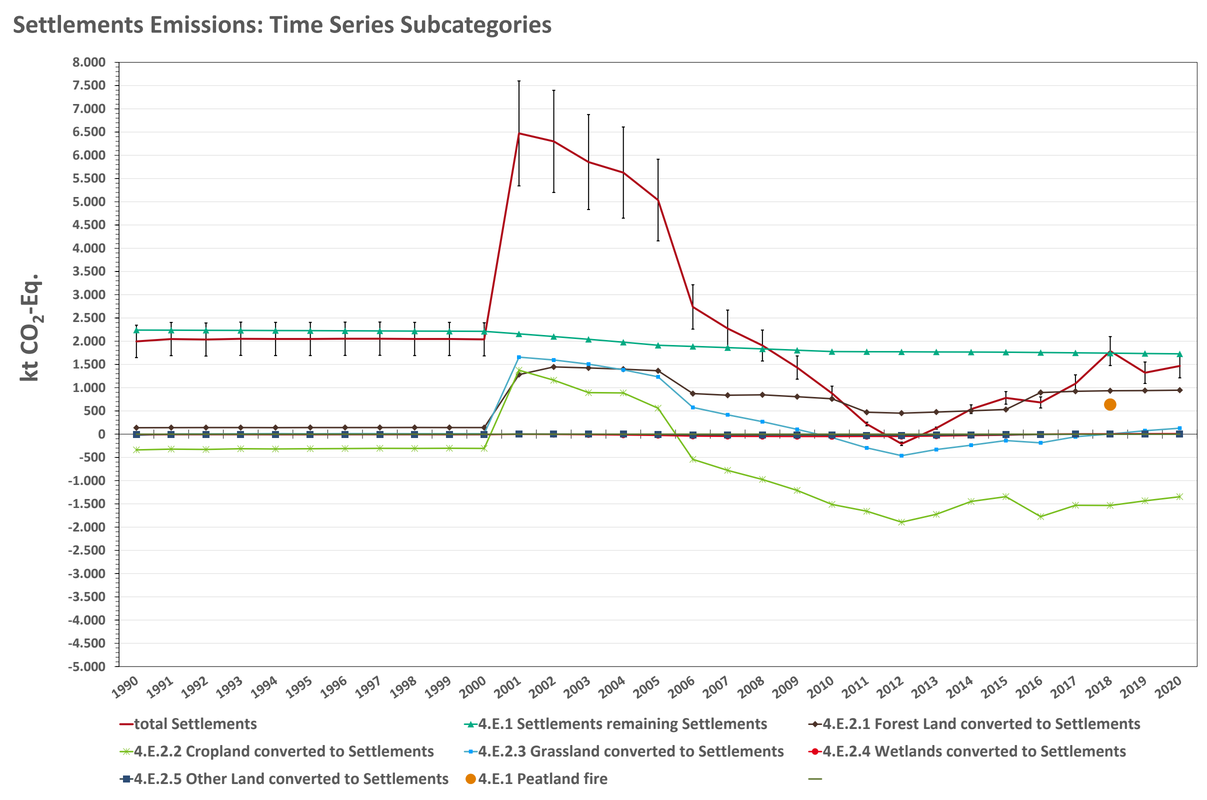
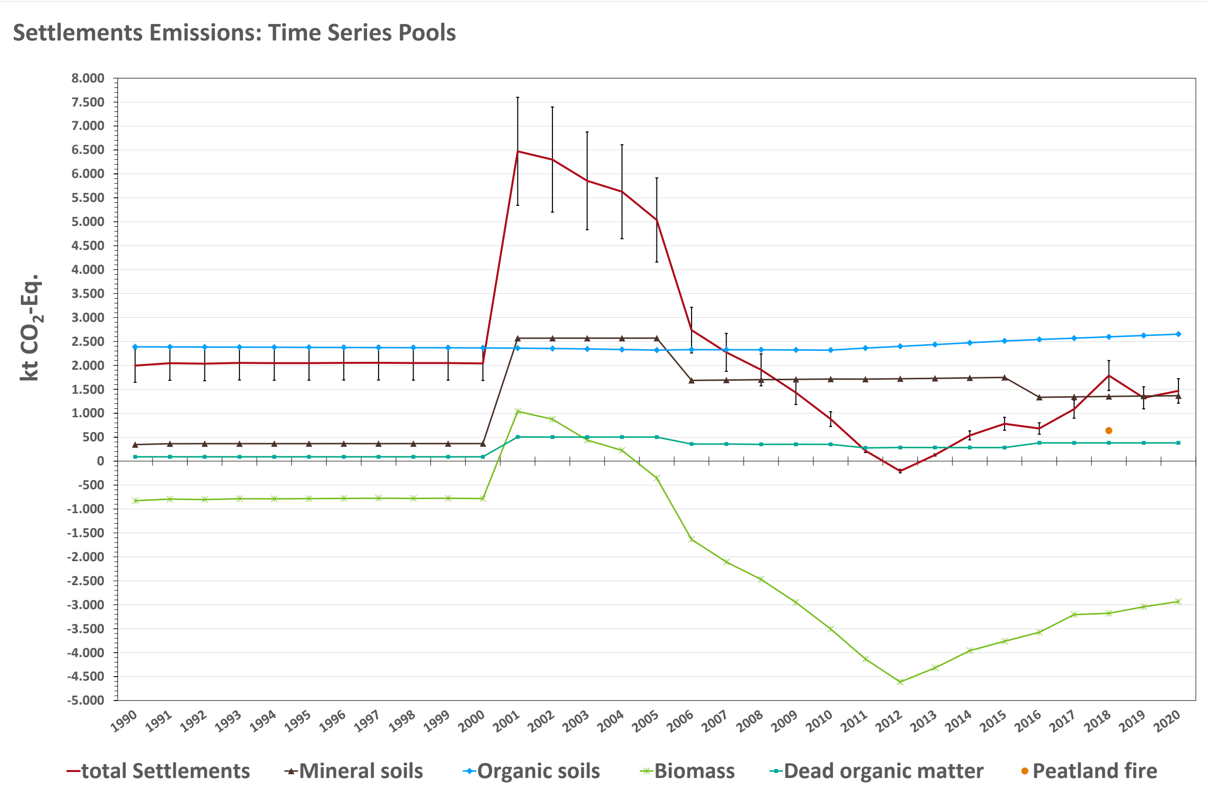


Figure 78: **GHG emissions [kt CO_2-eq.] resulting from land use and land-use changes, from Germany's Settlements, 1990 – 2020, by pools**



6.8.2 Methodological issues (4.E)

6.8.2.1 Data sources

Further information about the data sources is provided in Chapter 6.3.2.

6.8.2.2 Biomass

For areas in the sub-category "Settlements," a new method for calculating biomass has been introduced. The method is described in detail in Chapter 6.1.2.3ff and, specifically for Settlement areas, in Chapter 6.1.2.3.7.

The carbon stocks of dead wood and litter are taken into account in connection with the living biomass. "IE" is entered in the pertinent spaces in the CRF table.

6.8.2.3 Mineral soils

In the case of Settlements remaining Settlements, it is assumed that no carbon-stock changes in mineral soils occur. For this reason, "NA" is entered in the relevant spaces in the tables. Carbon-stock changes are reported for land-use conversions to Settlements, however. Further information about the methods used is provided in Chapter 6.1.2.1. The manner in which the emission factors have been derived and verified, with the sealed area being taken into account, is described in Chapter 6.1.2.1.6.

As a result of correction of an erroneous algorithm for calculation of carbon and nitrogen stocks in mineral soils, in the category "Settlements remaining Settlements," the relevant values had to be corrected by 5.5 % with respect to the previous year's submission; for carbon stocks, the correction was from 36.81 t C ha^{-1} to 38.84 t C ha^{-1}, while for nitrogen stocks it was from 3.27 t N ha^{-1} to 3.45 t N ha^{-1}.

6.8.2.4 Organic soils

It has also been assumed that organic soils in Settlements have been drained. Since no data have been collected specifically with regard to drainage of organic soils in Settlements, it is assumed that such soils are drained in the same manner that Grassland is drained, and thus the relevant emission factor for such drainage is used (Chapter 6.6.2.4). It has been modified with respect to the previous year. A detailed analysis of organic soils areas in Settlements found that such areas are sealed to a degree of only 15 % on average – and not, as had previously been assumed, to a degree of 50 %. With this new area factor, the emission factor for Grassland has been corrected to 3.91 kg N_2O-N ha^{-1} as a result.

In cases involving land-use conversions to Settlements, the relevant value for Settlements remaining Settlements is used from the outset.

6.8.2.5 Wildfires

No human-caused wildfires occurred in 2020 that would be comparable to the peat fire of 2018 (NIR 2020, Chapter 6.8.2.5) (NO).

6.8.3 Uncertainties and time-series consistency (4.E)

The consistency of the time series is assured with regard to the activity data and emission factors.

The emission factors and uncertainties for the land-use category "Settlements" are shown in Table 430 and Table 431. With the exception of the EF for CO_2 from organic soils, which exhibits a right-skewed distribution, the EF for CO_2 from soils tend to show normal distributions. Those for nitrous oxide and methane have log-normal distributions throughout. The remarks presented in Chapter 6.5.3 apply to the major uncertainties relative to direct and indirect nitrogen emissions.

The uncertainties for the activity data, for the year 2020, range from 0.09% to 196 %, depending on the area size concerned. The total uncertainty for the activity data in the Settlements category is 0.084 %.

The total uncertainty for the land-use category Settlements is -17.4 % / +16.4% (95-% percentile). It is shaped primarily by the uncertainty for emissions from organic soils.

Table 430: Implied emission factors, and their uncertainties [in % of central tendency], used for calculation of GHG emissions from Settlement and Transport areas for 2020, by pools and sub-categories

Settlements	Area	Emission factor	Uncertainty bounds	
Initial land use	Final land use		upper	lower
Mineral soils CO_2-C[129]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Settlements	-0.3854	22.07	22.07
$Cropland_{annual}$	Settlements	-0.1981	18.82	18.82
Hops	Settlements	-0.4016	21.78	21.78
Vineyards	Settlements	-0.1968	24.69	24.69
Orchards	Settlements	-0.2052	22.55	22.55
Short-rotation plantations	Settlements	-0.7481	21.78	21.78
Tree nurseries	Settlements	-0.5827	21.78	21.78
Christmas tree plantations	Settlements	-0.6287	21.78	21.78
Grassland in the strict sense	Settlements	-0.4308	19.00	19.00
Woody Grassland	Settlements	-0.4741	21.78	21.78
Terr. Wetlands	Settlements	-0.7539	22.26	22.26
Waters	Settlements	0.0000	18.74	18.74
Other Land	Settlements	0.0000	20.07	20.07
Mineral soil, N_2O_{direct}[130]		**[kg N_2O ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	Settlements	0.0801	99.99	489.43
$Cropland_{annual}$	Settlements	0.0636	99.99	488.27
Hops	Settlements	0.1314	99.99	489.66
Vineyards	Settlements	0.0672	99.99	491.51
Orchards	Settlements	0.0669	99.99	490.13
Short-rotation plantations	Settlements	0.2447	99.99	489.66
Tree nurseries	Settlements	0.1906	99.99	489.66
Christmas tree plantations	Settlements	0.2056	99.99	489.66
Grassland (in the strict sense)	Settlements	0.1378	99.99	488.34
Woody Grassland	Settlements	0.1551	99.99	489.66
Terr. Wetlands	Settlements	0.2038	99.99	490.06
Other Land	Settlements	0.0000	99.99	488.85
Mineral soil, $N_2O_{indirect}$[131]		**[kg N_2O ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	Settlements	0.3559	99.99	489.43
$Cropland_{annual}$	Settlements	0.2827	99.99	488.27
Hops	Settlements	0.5839	99.99	489.66
Vineyards	Settlements	0.2986	99.99	491.51
Orchards	Settlements	0.2971	99.99	490.13
Short-rotation plantations	Settlements	1.0875	99.99	489.66
Tree nurseries	Settlements	0.8471	99.99	489.66
Christmas tree plantations	Settlements	0.9139	99.99	489.66
Grassland (in the strict sense)	Settlements	0.6125	99.99	488.34
Woody Grassland	Settlements	0.6892	99.99	489.66
Terr. Wetlands	Settlements	0.9059	99.99	490.06
Other Land	Settlements	0.0000	99.99	488.85

129 Calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source
130 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink
131 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

Settlements Initial land use	Area Final land use	Emission factor	Uncertainty bounds upper	 lower
Biomass[132]		**[kt C ha^{-1} 1 a^{-1}]**	**[%]**	**[%]**
Forest Land	Settlements	-1.0082	31.97	32.86
Cropland$_{annual}$	Settlements	1.0746	45.90	47.36
Hops	Settlements	1.9063	46.65	48.13
Vineyards	Settlements	1.9063	46.65	48.13
Orchards	Settlements	0.9962	44.79	46.22
Short-rotation plantations	Settlements	-0.1448	18.82	19.80
Tree nurseries	Settlements	0.7843	32.79	33.76
Christmas tree plantations	Settlements	0.2165	36.14	37.20
Grassland in the strict sense	Settlements	1.0321	45.71	47.16
Woody Grassland	Settlements	-2.2417	39.76	40.52
Terr. Wetlands	Settlements	-3.3365	35.81	36.95
Waters	Settlements	1.4194	50.92	52.55
Peat extraction	Settlements	1.8220	50.92	52.55
Other Land	Settlements	0.0000	50.92	52.55
Dead organic matter[133]		**[kt C ha^{-1} 1 a^{-1}]**	**[kt C ha^{-1} 1 a^{-1}]**	**[%]**
Forest Land	Settlements	-1.0867	6.96	6.96

Table 431: Uncertainties for emission factors [2.5 and 97.5 percentile, in % of central tendency] for emissions from organic soils under settlements, 2020

Land use	GHG	Emission factor	Uncertainty bounds lower	 upper
Organic soil[134]		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Settlements	CO_2	26.8231	52.80	26.19
Settlements	CH_4	0.7219	58.37	92.10
Settlements	N_2O	1.7945	93.48	382.61

6.8.4 Source-specific quality assurance / control and verification (4.E)

Details regarding this year's reviews are provided in Chapter 6.1.3.

The data sources used in preparation of this inventory fulfill the review criteria of the QSE manual for data sources (QSE– Handbuch für Datenquellen). Quality assurance for input data (ATKIS®, BÜK, official statistics) is the responsibility of the relevant data administrators (cf. the pertinent documentation in the inventory description).

The emissions-calculation results as presented in the present report cannot be compared with other relevant data sources for Germany, since no such other data sources exist that meet applicable requirements, i.e. provide nationwide coverage, are comprehensive and are independent of the methods and data sources described in the present report.

The following tables compare Germany's implied emission factors, for the category Settlements, with those of neighbouring European countries. The values of neighbouring countries that were used for this comparison were obtained from the 2021 submissions to the Climate Secretariat. The values for Germany were obtained from the 2021 and 2022 submissions.

The biomass IEF given in the present submission show the transition categories to be a sink overall; only the "from Forest Land" transition category functions as a source in this regard. With regard to the biomass pool, neighbouring countries' values vary widely in terms of their levels and absolute quantities (the values range from source to sink). Only Austria's trend is qualitatively similar to Germany's trend.

The IEF for the other pools do not differ widely, in terms of trend and level, from those of neighbouring countries.

132 Calculation only for first year of land-use change, stock change: positive ≙ sink; negative ≙ source
133 Calculation only for first year of land-use change; stock change: positive ≙ sink; negative ≙ source
134 Annual calculation; emission: positive ≙ source; negative ≙ sink

Table 432: Carbon-stock changes in living biomass in Settlements of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.E.1. - Settlements Remaining Settlements [t C ha^{-1} a^{-1}]	4.E.2 - Land Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.1 - Forest Land Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.2 - Cropland Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.3 - Grasslands Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.4 - Wetlands Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.5 - Other Land Converted To Settlements [t C ha^{-1} a^{-1}]
Belgium	NO	-0.49	-4.90	NO	NO	NO	NO
Denmark	NO	-0.15	-0.97	-0.13	-0.05	-0.06	NO
France	-0.03	-0.70	-3.79	-0.03	-0.34	NE	-0.03
UK	NA	-0.23	-3.89	-0.11	-0.03	-3.18	NA
Netherlands	NA	-0.86	-5.59	-0.22	-0.62	NO,NE	NA
Austria	NO	0.47	-0.83	0.64	0.40	NO	NO
Poland	0.05	-0.44	-1.70	0.00	-0.99	NO	0.05
Switzerland	0.00	-0.53	-4.56	-0.18	-0.13	0.12	0.00
Czech Republic	NO	-0.30	-3.45	NO	NO	NO	NO
Germany, 2019	**NO**	**0.0031**	**-1.427**	**0.201**	**0.064**	**0.720**	**NO**
Germany, 2020	**NO**	**0.738**	**-1.008**	**1.069**	**0.727**	**0.751**	**NO**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

Table 433: Carbon-stock changes in dead organic matter in Settlements of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.E.1. - Settlements Remaining Settlements [t C ha^{-1} a^{-1}]	4.E.2 - Land Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.1 - Forest Land Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.2 - Cropland Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.3 - Grasslands Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.4 - Wetlands Converted To Settlements [t C ha^{-1} a^{-1}]	4.E.2.5 - Other Land Converted To Settlements [t C ha^{-1} a^{-1}]
Belgium	NO	-0.01	-0.15	NO	NO	NO	NO
Denmark	NO	-0.08	-2.21	NO	NO	NO	NO
France	NE	-0.07	-0.46	NE	NE	NE	NE
UK	NA	-0.05	-1.17	IE,NA	IE,NA	-0.37	NO
Netherlands	NA	-0.12	-1.60	NA	NA	NA	NA
Austria	NO	-0.03	-0.57	NO	NO	NO	NO
Poland	NO	-0.04	-0.62	NO	NO	NO	NO
Switzerland	NO	-0.07	-0.88	NO	NO	NO	NO
Czech Republic	NO	-0.01	-0.08	NO	NO	NO	NO
Germany, 2019	**IE**	**-0.11**	**-1.24**	**IE**	**IE**	**IE**	**IE**
Germany, 2020	**IE**	**-0.10**	**-1.09**	**IE**	**IE**	**IE**	**IE**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

Table 434: Carbon-stock changes in mineral soils, in Settlements of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.E.1. - Settlements Remaining Settlements [t C ha⁻¹ a⁻¹]	4.E.2 - Land Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.1 - Forest Land Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.2 - Cropland Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.3 - Grasslands Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.4 - Wetlands Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.5 - Other Land Converted To Settlements [t C ha⁻¹ a⁻¹]
Belgium	NO	-1.04	-2.21	NO	-1.63	NO	-1.04
Denmark	NO	-0.87	-1.48	-0.81	-1.51	NO	-0.87
France	NE	-0.97	-1.55	-0.16	-1.65	NE	-0.97
UK	-0.32	-2.75	-5.85	-1.40	-3.30	-0.32	-2.75
Netherlands	NA	-0.21	-0.39	0.51	-0.50	NA	-0.21
Austria	NA	-1.03	-2.93	-0.52	-1.52	NA	-1.03
Poland	NO	-1.45	-2.51	-1.41	-1.87	NO	-1.45
Switzerland	0.06	-0.51	-0.98	-0.35	-0.53	0.06	-0.51
Czech Republic	NO	-0.13	-0.29	-0.05	-0.41	NO	-0.13
Germany, 2019	**NO**	**-0.346**	**-0.438**	**-0.220**	**-0.485**	**-0.031**	**-0.081**
Germany, 2020	**NO**	**-0.312**	**-0.385**	**-0.200**	**-0.435**	**-0.029**	**NO**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

Table 435: Carbon-stock changes in organic soils, in Settlements of various countries (Germany, for 2019 & 2020; other countries, for 2019)

Country	4.E.1. - Settlements Remaining Settlements [t C ha⁻¹ a⁻¹]	4.E.2 - Land Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.1 - Forest Land Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.2 - Cropland Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.3 - Grasslands Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.4 - Wetlands Converted To Settlements [t C ha⁻¹ a⁻¹]	4.E.2.5 - Other Land Converted To Settlements [t C ha⁻¹ a⁻¹]
Belgium	NO	NO	NO	NO	NO	NO	NO
Denmark	NO	NO	NO	NO	NO	NO	NO
France	NO	NO	NO	NO	NO	NO	NO
UK	-0.92	-2.22	-1.43	NO	-5.00	-7.90	NO
Netherlands	-4.13	-4.03	-3.81	-3.91	-4.07	-3.97	-3.15
Austria	NO	NO	NO	NO	NO	NO	NO
Poland	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	NO
Switzerland	-2.53	-5.17	-7.06	-5.17	-5.16	-5.78	NO
Czech Republic	NO	NO	NO	NO	NO	NO	NO
Germany, 2019	**-7.21**	**-7.25**	**-6.68**	**-7.61**	**-7.13**	**-7.30**	**-6.78**
Germany, 2020	**-7.28**	**-7.38**	**-6.90**	**-7.61**	**-7.39**	**-6.34**	**-6.87**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021a)

6.8.5 Category-specific recalculations (4.E)

This year's submission includes category-specific recalculations for the entire period 1990 through 2020. The emissions were recalculated in order to take account of new and improved data sources, changes in methods, and error corrections made as part of ongoing inventory improvements. The following measures affected the results of the emissions calculations for the Settlements land-use category:

- Updating of the map data for determination of activity data with regard to designation of land uses and land-use changes, and adaptation of the land-use matrix over time (cf. Chapter 6.3.1ff);
- Implementation of a new method for calculating emissions from biomass, for perennial woody plants outside of Forest Land (Chapter 6.1.2.3.4 ff);
- New emission factors for dead wood (cf. Chapter 6.4.2.3);,
- Correction of the value for carbon and nitrogen stocks of mineral soils, in the category Settlements remaining Settlements (cf. Chapter 6.1.2.1.6 and Chapter 6.8.2.4).

- Modification of the emission factor for nitrous oxide emissions from organic soils under Settlements (Chapter 6.8.2.4)

In Table 436 (areas) and Table 437 (emissions), the results of the current recalculations for the Settlements category are compared with the corresponding results in the previous year's submission.

Any slight differences between the area data reported in the current and previous year's submissions are due to the effects of correction algorithms used in order to assure consistency between the area-use time series and the newly added data from the last time-series year. In each case, in keeping with the assumption that the newest data are the best data, in terms of quality, the previous time series is adjusted, if necessary (cf. also Chapter 6.3 ff).

With regard to CO_2 emissions, the very large differences between the present submission and the previous year's submission are due, for the most part, to changes in the methods used to determine emissions from perennial biomass. As a result of those changes, the sink function for CO_2 emissions from biomass has increased by a factor of more than 240 in the Settlements category. By contrast, the differences in the area of emissions from soils, with respect to the previous year's submission, are less than 10 %. They are due primarily to the aforementioned minor changes in the relevant areas.

The large percent changes in nitrous gas emissions, between the report years, are tied almost completely to emissions from organic soils. They result from use of the modified emission factor for organic soils under Settlements.

Table 436: Comparison of area data [kha] for the Settlements category (4.E) as reported in the current and previous year's submissions

CRF No.	Area [kha]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.E	Settlement	2021	3,842.00	3,858.30	3,874.59	4,122.81	4,286.05	4,501.28	4,529.34	4,557.41	4,585.46	4,613.52
		2022	3,840.57	3,857.17	3,873.78	4,121.78	4,284.91	4,499.34	4,525.26	4,551.20	4,577.11	4,603.03
		Difference	-1.44	-1.13	-0.80	-1.03	-1.14	-1.94	-4.08	-6.22	-8.35	-10.49
		in %	-0.04	-0.03	-0.02	-0.02	-0.03	-0.04	-0.09	-0.14	-0.18	-0.23

Table 437: Comparison of greenhouse-gas emissions [kt CO_2-eq] in the Settlements (4.E) category as reported in the current and previous year's submissions

CRF No.		GHG	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.E	Settlement	CO_2	2021	2,429.08	2,429.97	2,433.25	3,801.32	3,430.93	3,612.79	4,040.08	4,091.21	4,054.91	4,122.12
			2022	1,776.57	1,812.06	1,806.38	4,529.69	471.74	351.63	303.79	704.11	1,308.65	932.21
			Difference	-652.51	-617.91	-626.87	728.37	-2,959.19	-3,261.16	-3,736.30	-3,387.10	-2,746.25	-3,189.91
			in %	-26.86	-25.43	-25.76	19.16	-86.25	-90.27	-92.48	-82.79	-67.73	-77.39
		CH_4	2021	47.97	46.51	45.35	56.19	58.68	63.73	63.73	65.75	67.67	69.57
			2022	48.03	46.73	45.31	52.75	56.95	61.93	63.45	65.00	65.81	65.94
			Difference	0.06	0.22	-0.03	-3.44	-1.73	-1.80	-0.28	-0.75	-1.86	-3.62
			in %	0.13	0.47	-0.07	-6.12	-2.95	-2.82	-0.44	-1.14	-2.75	-5.20
		N_2O	2021	96.71	129.96	129.61	396.33	291.38	303.75	268.55	271.12	273.53	275.56
			2022	170.94	189.56	188.76	454.43	349.60	366.48	315.27	318.13	320.92	323.68
			Difference	74.23	59.60	59.15	58.11	58.22	62.73	46.72	47.01	47.39	48.12
			in %	76.76	45.86	45.64	14.66	19.98	20.65	17.40	17.34	17.33	17.46

6.8.6 Category-specific planned improvements (4.E)

Regionalisation of carbon stocks of mineral soils of Settlements, as a function of site-specific parameters, is being prepared and will be implemented in the next submission. With that move, Germany will implement a pertinent ERT recommendation from the 2020 review process (ARR 2020: L.8, Table 5).

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

6.9 Other Land (4.F)

6.9.1 Category description (4.F)

Since, by definition, the areas in the land-use category Other Land consist of areas that are not managed, the sizes of such areas are included solely for the purpose of completing the area matrix. Emissions within the meaning of the 2006 IPCC Guidelines cannot occur on such areas. Therefore, no emissions are reported. For this reason, NO is entered in all relevant cells of CRF table 4.F, with the exception of the space for the area of the remaining category.

In emissions calculation, "Other Land" areas are taken into account solely as the initial land-use category in connection with land-use changes to other categories. No conversions back to "Other Land" take place, since, by definition, land that has been used once can no longer be returned to an unused land-use category.

The carbon stocks of the biomass and dead organic matter categories in the "Other Land" category are zero.

The carbon stocks of mineral soils in the "Other Land" category are listed in Chapter 6.1.2.

Organic soils in the "Other Land" category are not drained.

6.9.2 Uncertainties and time-series consistency (4.F)

The uncertainties for the emission factors and the activity data were determined in accordance with the 2006 IPCC Guidelines (IPCC, 2006a). Additional relevant information is provided in Chapter 6.1.2.1.

The time series is complete and consistent.

6.9.3 Category-specific quality assurance / control and verification (4.F)

Details regarding this year's reviews are provided in Chapter 6.1.3.

6.9.4 Category-specific recalculations (4.F)

This year's submission includes category-specific recalculations for the entire period 1990 through 2020. The areas were recalculated in order to take account of new and improved data sources, changes in methods, and error corrections made as part of ongoing inventory improvements. The following measure affected the results of the land-area calculations for the land-use category Other Land:

- Updating of the map data for determination of activity data with regard to designation of land uses and land-use changes, and adaptation of the land-use matrix over time (cf. Chapter 6.3.1ff);

In Table 438, the results of the current recalculations of the areas in the category Other Land are compared with the corresponding areas reported in the previous year's submission.

Any slight differences between the area data reported in the current and previous year's submissions are due mainly to the effects of correction algorithms used in order to assure consistency between the area-use time series and the newly added data from the last time-series year. In each case, in keeping with the assumption that the newest data are the best data, in terms of quality, the previous time series is adjusted, if necessary (cf. also Chapter 6.3 ff).

Table 438: Comparison of area data [kha] for the Other Land category as reported in the current and previous year's submissions

CRF No.	Area [kha]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
4.F	Other Land	2021	67.76	62.44	57.14	46.06	41.22	38.66	38.13	37.60	37.07	36.55
		2022	67.59	62.36	57.14	46.06	41.22	38.66	38.16	37.66	37.16	36.66
		Difference	-0.16	-0.08	0.00	0.01	0.00	0.00	0.03	0.05	0.09	0.11
		in %	-0.24	-0.13	0.01	0.01	0.01	0.00	0.07	0.14	0.23	0.31

6.9.5 Category-specific planned improvements (4.F)

Not applicable, since no greenhouse-gas sources and sinks are reported in this category.

6.10 Harvested wood products (4.G)

6.10.1 Category description (4.G)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	4 G, Harvested Wood Products		CO_2	-1,330.4	-0.1%	-8,651.3	-1.2%	550.3%

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS/Tier 2	IS/NS	D

The source category Harvested Wood Products is a key category in terms of emissions level and trend.

As in the previous years, the contribution of HWP to greenhouse gas emissions by sources and removals by sinks in the LULUCF sector in Germany was estimated with the WoodCarbonMonitor model (Rüter, 2017) by means of the calculation approach based on production data for wood products. The estimate covers all HWP that are produced in Germany and which consist of wood originating from domestic harvest that is used as material (not energy).

For reasons of consistency, the calculation conforms to the methods prescribed in Chapter 2.8 of the 2013 IPCC KP Supplement (IPCC et al., 2014a) since, pursuant to Footnote 12 in CRF Table 4.G-s1 in Annex II of Decision 24/CP.19 on revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention[135] (UNFCCC, 2014), the approach chosen (approach B) may refer either to the 2006 IPCC Guidelines (IPCC, 2006a) or to any other IPCC methodological guidance reflecting this approach. The system boundaries described in the rules of the 2013 IPCC KP Supplement (IPCC et al., 2014a) for estimating the HWP contribution are consistent with the system boundaries of the approach referred to in Table 12.1 of the 2006 IPCC Guidelines (IPCC, 2006a) as "variable 2A" (production approach for wood products for material use).

In the interest of transparency, pursuant to CRF Table 4.Gs1, wood products for material use are divided into products that, following their production, are consumed in Germany, and products that have subsequently been exported. The carbon storage effect of wood in solid waste disposal sites is not taken into account. The biomass from short-rotation plantations is used exclusively

[135] Footnote 12 of CRF table sheet 4.G-s1

for energy purposes in Germany (cf. category 1.A, Chapter 3.2), and is thus not reported under Harvested Wood Products (HWP).

Figure 79: Net CO_2 emissions and removals in HWP (in kt CO_2)

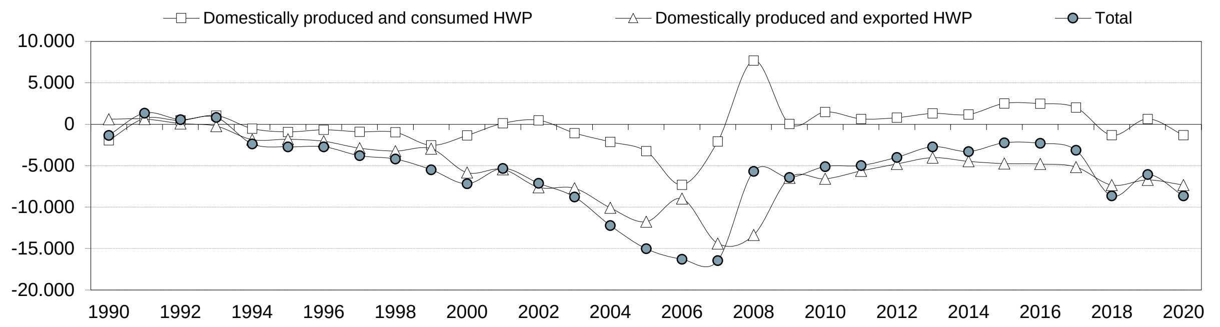
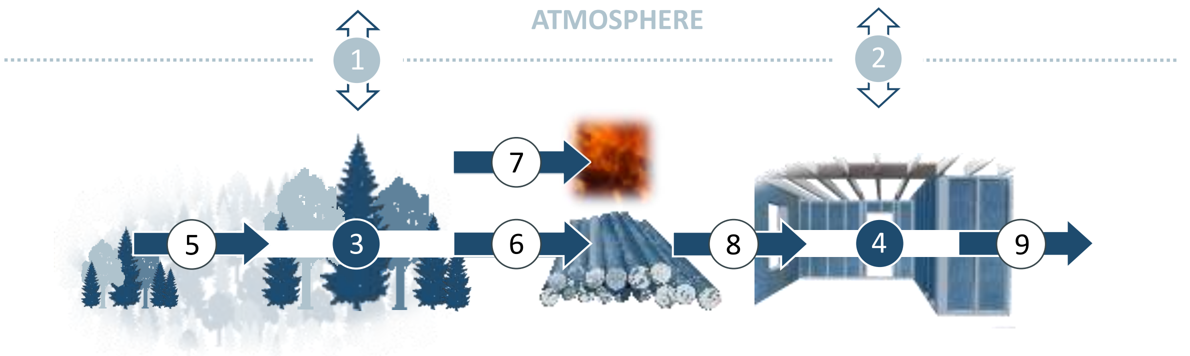


Figure 80 presents an overview of the carbon flows linked to forest and wood use that are reported as "gains" and "losses" in the defined forest carbon pools (here: only living biomass (3); see Chapter 6.4.2.2) and harvested wood products (4). The atmospherically relevant CO_2 emissions, and their removals (living biomass 1 and harvested wood products 2), are determined on the basis of the changes in these defined stocks.

Figure 80: Carbon flows and carbon stocks, and their CO_2 emissions and removals throughout the Forest Land / harvested wood products chain



CO_2 emissions and removals in the carbon pools FOREST[a] and HARVESTED WOOD PRODUCTS		[in kt CO_2e]
1	FOREST[a]	-29,334
2	HARVESTED WOOD PRODUCTS	-8,651
Magnitude of the defined carbon pools[e]		[in kt C]
3	FOREST[a]	1,230,070
4	HARVESTED WOOD PRODUCTS	293,029

Carbon flows [b] from and to the carbon pools		[in kt C]
5	gains (FOREST)	43.264
6	losses (FOREST) *(harvested wood[c] for material use)*	-18.429
7	losses (FOREST) *(harvested wood for mainly energy use[d])*	-16.835
8	gains (HARVESTED WOOD PRODUCTS)	13.776
9	losses (HARVESTED WOOD PRODUCTS)	-11.417

[a] here: living biomass only
[b] during the inventory year (gains positive, losses negative)
[c] based on the harvest statistics of the Federal Statistical Office (Statistisches Bundesamt, StBA) (industrial roundwood) in m³
[d] based on the difference between StBA-harvest statistics (industrial roundwood) und inventory calibrated harvest as Loss of reserve solid cubic metres (RSCM) (see Figure 70)
[e] at the end of the inventory year (FOREST: based on data of Carbon Inventory 2017 (CI 2017), see www.bwi.info)

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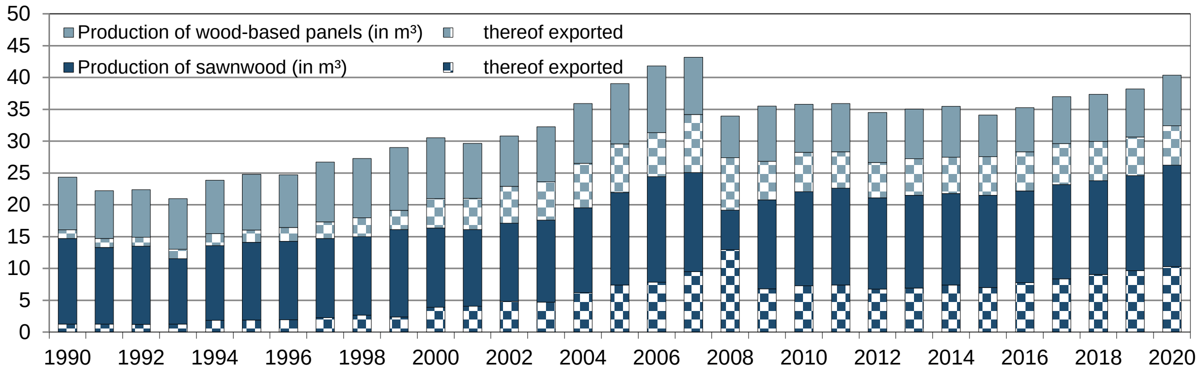
6.10.2 Methodological issues (4.G)

6.10.2.1 Activity data

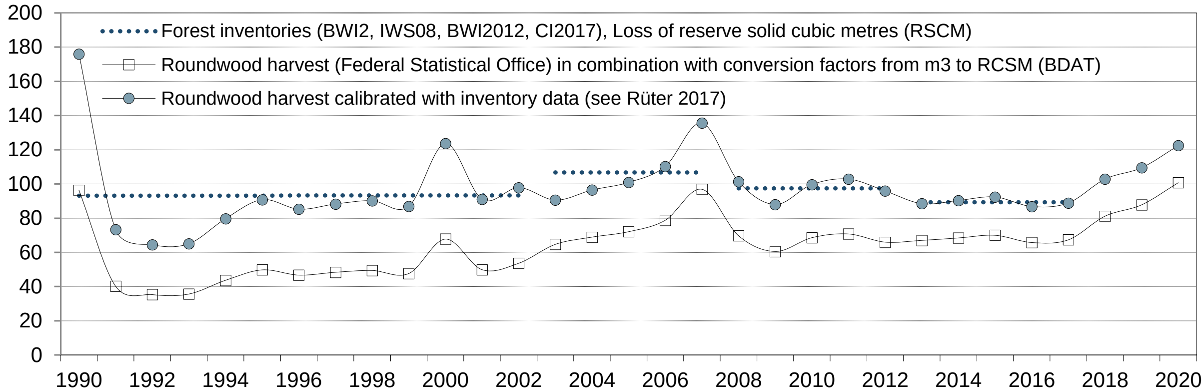
Figure 81 shows the development of production quantities in the semi-finished product categories sawnwood and wood-based panels since 1990, broken down by the wood quantities remaining in Germany (production, less exports) and the quantities exported (exports) according to the data of the Food and Agriculture Organization of the United Nations (UN FAO) (FAO, 2020). These time series correspond to the data proposed in the 2006 IPCC Guidelines (IPCC, 2006a) for estimation of the HWP contribution following the Tier 1 methodology (Chapter 12.2.1 IPCC (2006a): 12.9).

Figure 81: Sawn wood and wood-based panels produced in Germany [Mm³] (FAO, 2020)



In line with the IPCC Guidelines, and in a first step, the feedstock fraction in HWP from domestically harvested wood was calculated. To this end, and in a first step, the national logging statistics covering the five main wood-type groups (Statistisches Bundesamt, FS 3, R 3.3.1) were calibrated with the Forest Inventory data on standing timber losses from forests (cf. Chapter 6.4.2.1.1), in accordance with the methodological guidlines of IPCC (2014a) (Figure 82), since the statistics underestimate the annual roundwood production by about 30 %. The reasons for this statistical underestimation of the harvest include the fact that some harvested raw wood is lost or is not used, and that some wood is used as firewood, for example by private households (private, small-scale wood buyers). Such wood is not covered by the statistics. This calibration also ensures methodological consistency with the projected time series of the reported FMRL (cf. Chapter 11.5.3.4). Details on the further use of the time series on roundwood harvest calibrated with inventory data (which is expressed in millions of losses of reserve solid cubic metres), in line with the provisions of IPCC et al. (2014a), are provided in Rüter (2017).

Figure 82: National harvest statistics, and their calibration with forest-inventory data [in millions of losses of reserve solid cubic metres], (Statistisches Bundesamt, FS 3, R 3.3.1) and Chapter 6.4.2.1.1

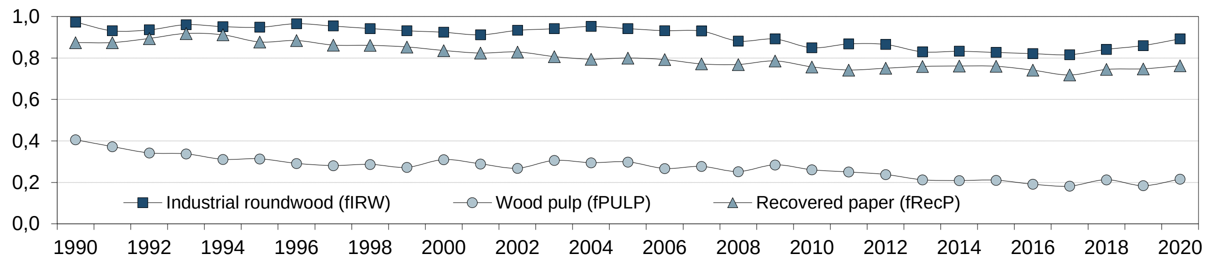


In a second step, a domestic feedstock factor $f_{DP}(i)$ was determined that, for the semi-finished product categories sawnwood and wood-based panels, is based on FAO data on the feedstock category industrial roundwood. For the calculation of the fraction of the feedstock coming from domestic harvest in the product category paper and paperboard, the use of recovered paper in paper production was taken into account, in addition to the feedstock category wood pulp as proposed in the 2013 IPCC KP Supplement (IPCC et al. (2014a), since the recovered paper-fraction in paper and paperboard that is produced in Germany exceeds 70 %. As in the previous reporting years, the fraction *p* of recovered paper used in paper products was determined by means of the proportion of the calculated consumption of wood pulp and recovered paper in Germany (cf. Chapter 6.10.5).

Along with the factors for industrial roundwood (fIRW) and wood pulp (fPULP), which were calculated using Equations 2.8.1 and 2.8.2 of the 2013 IPCC KP Supplement (IPCC et al. (2014a): 2.115), another factor for recovered paper was determined, via the same approach using FAO data (fRecP) (Figure 83). That factor was considered in the calculation of product fractions originating from domestic harvest by means of Equation 2.8.4 of the 2013 IPCC KP Supplement (IPCC et al. (2014a): 2.118) for the HWP category 'paper and paperboard.'

$$f_{DP}(i) = \{f_{IRW}(i) * (1-p) * f_{PULP}(i)\} + p * f_{RecP}(i)$$

Figure 83: Development of the domestic feedstock factor fDP(i) for the feedstock categories considered (FAO, 2020)



In a final step, the carbon contained in the products was allocated to the respective land-use classes from which the relevant feedstock originates (IPCC et al. (2014a): Chapter 2.8.1.2). For this purpose, the roundwood-harvest, calibrated with inventory data, can be assigned to Forest Land remaining Forest Land (source category 4.A.1, Chapter 6.2.1), and to those areas subject to land-use changes from Forest Land to other categories (cf. Table 439). In line with IPCC requirements, HWP from deforestation are taken into account on the basis of instantaneous oxidation (cf. Chapter 2.8.2 IPCC et al. (2014a)). Consequently, the annual share of harvest originating from managed forest areas fFM(i) can be calculated on the basis of the available inventory information for Germany and of Equation 2.8.3 (IPCC et al. (2014a): 2.116).

Table 439: Annual wood-harvest fraction from Forest Land remaining Forest Land

Time period	$f_{FM}(i)$
1990 – 2002	0.98989
2003 – 2007	0.99202
2008 – 2012	0.98881
2013 – 2017	0.98137

6.10.2.2 Emission factors

The carbon outflows from the carbon pool are calculated with the default values listed in Table 2.8.2 of the 2013 IPCC KP Supplement (IPCC et al., 2014a). Those values are based on the standard values given in Table 3a.1.3 of the 2003 IPCC GPG (IPCC, 2003).

6.10.2.3 Calculation method used

In order to calculate the contribution of HWP used as material to the delayed release of CO_2 emissions on the basis of carbon-stock changes, Germany uses the exponential decay function described in the IPCC Guidelines, in combination with the HWP categories described in Table 2.8.1 of the 2013 IPCC KP Supplement. That approach is in line with the standard method described in the 2006 IPCC Guidelines (Equation 12.1 IPCC (2006a): 12.11), as well as with the standard Tier 2 method described in the 2013 IPCC KP Supplement (Equation 2.8.5). For the carbon conversion calculation of the HWP category wood-based panels, the detailed factors, and for the HWP category paper and paperboard, the aggregated conversion factors listed in Table 2.8.1 (IPCC et al., 2014a) are used. The carbon quantities in the HWP categories non-coniferous and coniferous sawnwood are calculated by means of the factors described in Rüter (2011) (cf. also UNFCCC (2011)), in order to represent the tree species that are typically used in Germany for the production of sawnwood correlating with the roundwood-harvest statistics (Statistisches Bundesamt, FS 3, R 3.3.1). For coniferous sawnwood, the factor amounts to 0.225 t C/m^{-3}, while for non-coniferous sawnwood it is 0.335 t C/m^{-3}.

Time series of adequate data quality for HWP and the relevant feedstock categories are available only for the period since German reunification in 1990. For that reason, and in order to reduce the uncertainties associated with the activity data, the initial value of the carbon stock in HWP is calculated on the basis of Equation 2.8.6 (IPCC et al., 2014a), with $C(t_0)$ = 1990.

Further, detailed information on the method used is provided in Rüter (2017).

6.10.3 Uncertainties and time-series consistency (4.G)

The time series for HWP activity data from the UN FAO database are consistent and are available for the entire period covered by the report. Pursuant to the information provided in the relevant chapter of the 2013 IPCC KP Supplement (IPCC et al., 2014a), the uncertainties for these time series amount to -25/+5 % (cf. also Chapter 11.3.1.5.3).

6.10.4 Category-specific quality assurance / control and verification (4.G)

The WoodCarbonMonitor calculation model was previously used in 2011 to determine the HWP contribution to the reference level for the second commitment period under the Kyoto Protocol, for other EU Member States as well. Following cross-checking against their national data and any existing models, 16 additional countries used the data for their submissions to the Climate Secretariat (Belgium, Bulgaria, the Czech Republic, Denmark, Estonia, France, Greece, Hungary, Italy, Latvia, Lithuania, the Netherlands, Poland, Romania, Slovakia and Spain). Then, an international team of experts at the Secretariat evaluated those data together with the model and its underlying assumptions (Rüter (2011) and UNFCCC (2011)).

The subsequent adjustment of the reported time series to the HWP calculation rules pursuant to Decision 2/CMP.7 was also facilitated with the model within the framework of preparation of Chapter 2.8 "Harvested Wood Products" of the 2013 IPCC KP Supplement (IPCC et al., 2014a) (Rüter et al. (2014) and Rüter (2017); cf. Chapters 3.2.2 and 4.4 and the Annex).

In the context of the evaluation of the EU Member States' reference-value projections pursuant to Regulation 2018/841 (European Parliament and Council of the European Union, 2018), the model was repeatedly used in 2019 in combination with the G4M model, in order to cross-check, on behalf of the EU Commission, the country-specific HWP calculations and their underlying data and assumptions (Forsell et al. (2018) and Forsell et al. (2019)).

Additional general information about the quality control (QC) and quality assurance (QA) that have also been carried out for HWP is provided in Chapter 6.1.3.

6.10.5 Category-specific recalculations (4.G)

In the current reporting year, as in the previous years, the data used in the previous year, from the last available year in the FAOSTAT database (here: 2019) have been corrected for several product categories. This takes account of the fact that the production-statistics values for the relevant current reporting year are always provisional; they do not become available as final values until the following year (i.e., the 2019 values are available as final values in FAO (2020)). At the same time, the time series for the semi-finished product category fibreboard, a subset of the wood-based panels data in the FAOSTAT database, has been corrected retroactively, back to the year 1995. This has an effect on the estimated net-emissions time series, and on the recalculations of the HWP feedstock categories used for calculating the feedstock factors for the year 2018 (cf. Figure 81).

The relevant changes with respect to the previous year are shown in Table 440.

Table 440: Comparison of HWP net CO_2 emissions as reported in the 2021 and 2022 submissions

	Net emissions [kt CO_2]	1995	2000	2005	2010	2015	2016	2017	2018
Sub.2020	From exported wood materials	-699	-2,691	-5,179	-2,567	-1,824	-1,756	-1,983	-1,840
	From domestically consumed wood materials	-694	-1,066	-1,535	2,653	2,619	2,287	2,296	62
	From exported paper and paperboard	-1,018	-1,236	-2,195	-817	-462	-69	29	162
	From domestically used paper and paperboard	-189	-333	-361	265	412	587	601	-126
	From exported sawn lumber	-409	-1,911	-4,447	-3,207	-2,578	-3,017	-3,329	-3,902
	From domestically used sawn lumber	1	160	-1,526	-503	51	163	-18	-287
Sub.2021	From exported wood materials	-380	-2,682	-5,122	-2,562	-1,706	-1,707	-1,856	-1,856
	From domestically consumed wood materials	-733	-1,175	-1,361	1,724	2,054	1,740	1,435	251
	From exported paper and paperboard	-	-	-	-	-	-	-	-480
	From domestically used paper and paperboard	-	-	-	-	-	-	-	133
	From exported sawn lumber	-	-	-	-	-	-	-	-4,996
	From domestically used sawn lumber	-	-	-	-	-	-	-	-1,704

6.10.6 Category-specific planned improvements (4.G)

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

6.11 Other sectors (4.H)

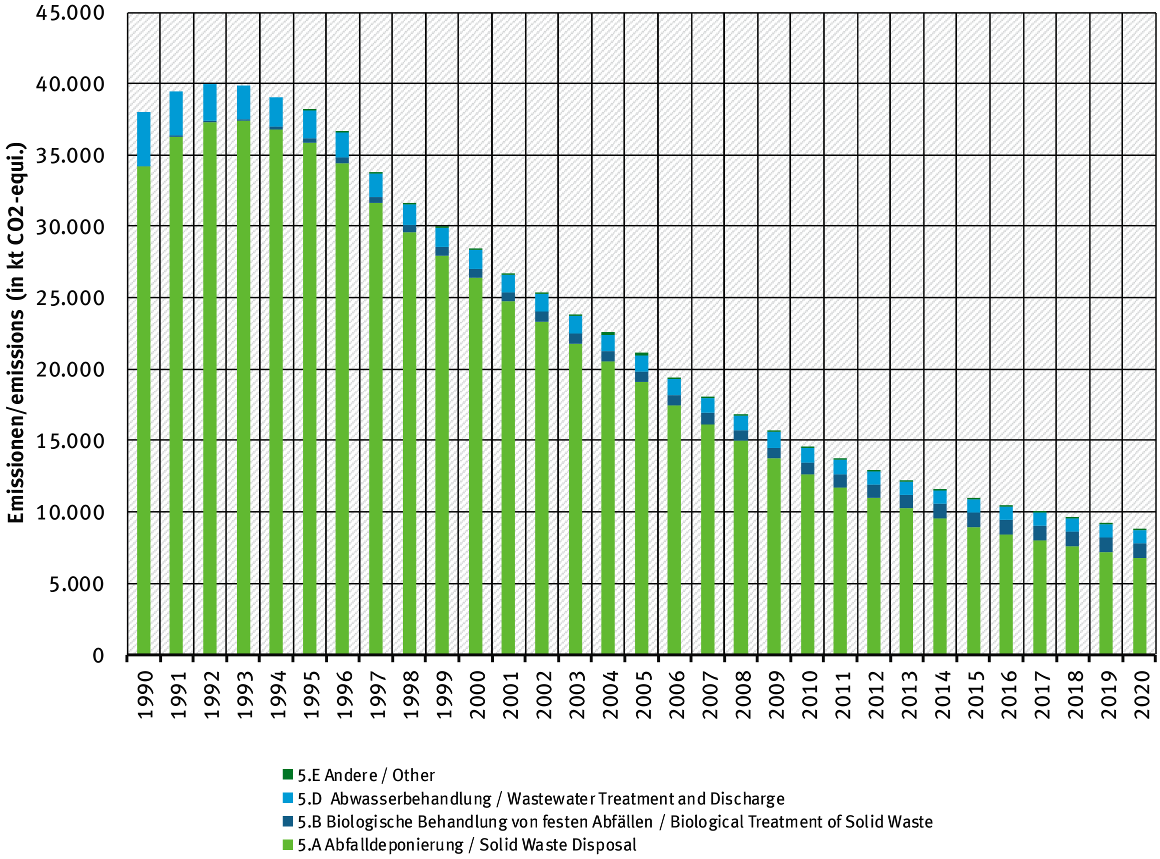
In 4.H, N_2O emissions caused by cultivation of organic soils, and originating in the category *Settlements* (162.23 kt CO_2-eq. for 2020)[136], are reported in Table 4 (II), on a makeshift basis, because the CRF Tables of the CRF Reporter do not allow for such emissions. On a makeshift basis, CO_2 and CH_4 emissions are reported in Table 4 E as "included elsewere" (IE). In the current NIR, the pertinent results are listed in the chapter on Settlements (Chapter 6.8.1).

[136] In the 2021 NIR, 28,399,4 kt CO_2-Eq. were reported for 2019 in this category. That was an error. The correct value for the 2021 submission, under 4 H, is 95.3 kt CO_2-Eq for 2019.

7 Waste and Waste Water (CRF Sector 5)

7.1 Overview (CRF Sector 5)

Figure 84: Overview of greenhouse-gas emissions in CRF Sector 5



7.2 Solid waste disposal on land (5.A)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
L/T	5 A, Solid Waste Disposal		CH_4	34,200.2	2.7%	6,769.6	0.9%	-80.2%

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	NS	CS

The category *Solid waste disposal on land* is a key category of CH_4 emissions in terms of emissions level and trend.

Only managed disposal in landfills (5.A.1) is relevant for purposes of German emissions reporting under CRF 5.A. "Wild" or illegal dumping of solid waste (CRF 5.A.2) is prohibited by law in Germany.

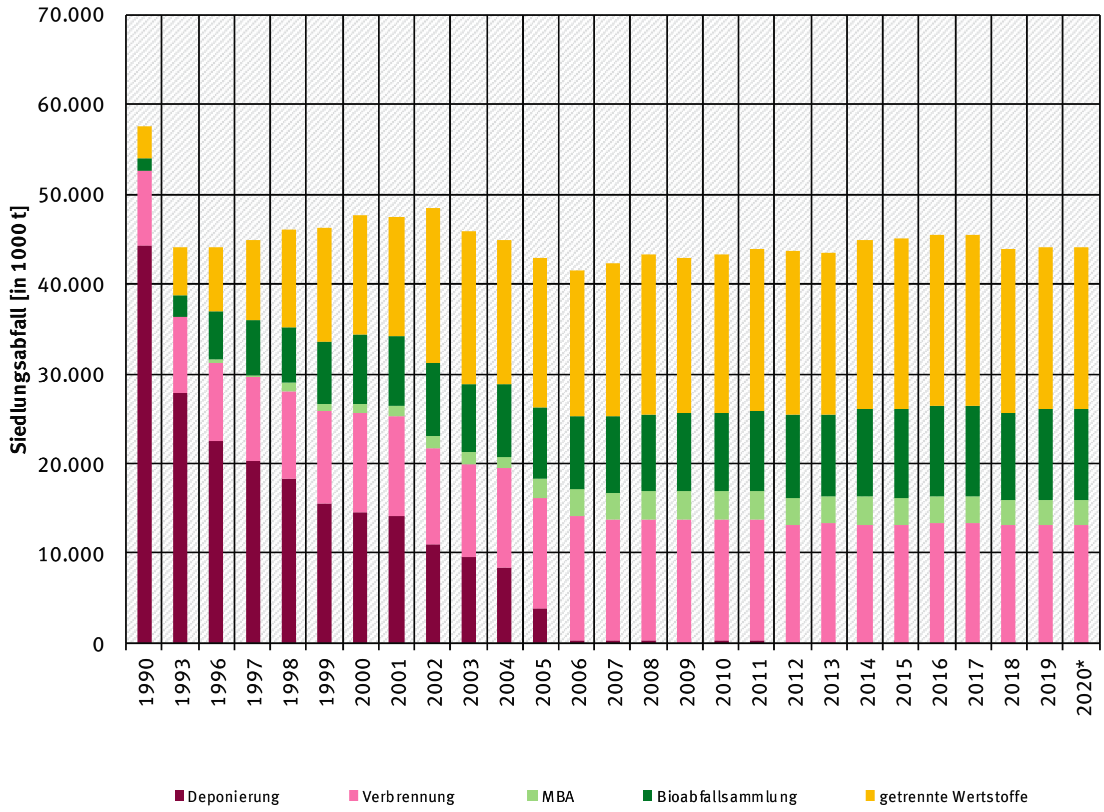
7.2.1 Managed disposal in landfills – landfilling of settlement waste (5.A.1)

7.2.1.1 Category description (5.A.1)

In the period since 1990 (and previously, to some extent), a number of legal provisions have been issued pertaining to Germany's waste-management sector, and a number of relevant organisational measures have been initiated. These moves have had a strong impact on trends in emissions from waste-landfilling. Relevant developments have included intensified collection of biodegradable waste from households and the commercial sector, intensified collection of other recyclable materials, such as glass, paper/cardboard, metals and plastics; separate collection of packaging; and recycling of packaging. In addition, incineration of settlement waste has been expanded, and mechanical biological treatment of residual waste has been introduced. As a result of all these measures, amounts of landfilled municipal waste decreased sharply from 1990 to 2006 (cf. Figure 85). As the figure shows, over half of settlement waste produced in Germany today is gleaned for recyclable materials (separate collection of recyclable materials and biodegradable waste), and is not incinerated or landfilled. With regard to emissions from landfills, this procedure has only a very small impact on the total emissions in the relevant current report year, since those emissions are determined predominantly by the waste that has been landfilled in the past.

In 2004, about 330 landfills for settlement waste were in operation in the Federal Republic of Germany. By that year, strict legal regulations were already in place that require such landfills to have equipment for recovering and treating landfill gas. Those regulations have extensively reduced methane emissions from such facilities. In June 2005, in keeping with new, stricter requirements under the Ordinance on Environmentally Compatible Storage of Waste from Human Settlements (Abfallablagerungsverordnung) and the Landfill Ordinance (Deponieverordnung), over half of all landfills were closed. As a result, only about 150 landfills for settlement waste are now still in operation. In addition, landfilling of biologically degradable waste has been prohibited since June 2005. As a result, no landfilling of waste leading to significant methane formation has occurred since then. For conformance with pertinent requirements, settlement waste and other biodegradable waste must be pre-treated via thermal or mechanical-biological processes. In waste landfilled after 2006, only small quantities of waste, and only a few waste components within that waste, contribute to landfill-gas formation. Those components (such as residues from treatment in MBT facilities; small wood fractions in processed construction rubble) have very low methane-formation potential. As landfill-gas formation in older landfills drops off, methane emissions from landfills will again decrease extensively and will then, in the long term, stabilise at a very low level.

Figure 85: Changes in pathways for management of settlement waste, for the period as of 1990, with intermediate years



By reducing landfill methane emissions from about 1400 kt CH_4 in 1990 to about 270 kt in 2020, Germany's waste-management sector has made an important contribution to climate protection. Experience gained by Germany's waste-management sector shows that reductions of landfilled quantities of biodegradable waste can provide significantly higher contributions to climate protection than can recovery and treatment of landfill gas.

7.2.1.2 Methodological issues (5.A.1)

The method presented in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC (2006a): *Chapter 3.2.1.1)* for calculation of CH_4 emissions from landfills is based on the "first order decay" method (FOD method). The relevant detailed method used in Germany lies between Tier 2 and Tier 3. The Tier 3 method requires national activity data, and country-specific values for DOC, DOC_F and half-lives (k values). Currently, Germany uses national activity data and DOC_F, but it uses country-specific DOC and k values only to a partial extent. Where values are lacking, Germany uses default values from the IPCC Guidelines.

The following section describes the FOD method, and the relevant parameters used, for determining methane formation in landfills.
The FOD method uses the following equations:

Equation 58: (2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3.2.1.1, Equation 3.6)

$$CH_4\ produced\ in\ year\ t\ \left(\frac{kt}{year}\right) = DDOCm\ decomp_t\ \times F \times 16/12$$

Where:

CH_4 produced in year t	*= Quantity of CH_4 produced by relevant biologically degradable waste*
DDOCm $decomp_T$	*= Mass of the biodegradable DOC that decomposes in year T*
F	*= Percentage share of CH_4 with respect to landfill gas*
16/12	*= Stoichiometric factor for conversion of C to CH_4*
t	*= Inventory year*

The following also holds:

Equation 59: (2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3.2.1.1, Equation 3.2)

$$DDOC_m = W \times DOC \times DOC_f \times MCF$$

Where:

DDOCm	= Mass of biodegradable and landfilled DOC, (kt)
W	= Mass of landfilled waste (kt)
DOC	= Fraction of biodegradable organic carbon in the year in which landfilling takes place (Gg C / kt waste)
DOCf	= DOC fraction that is biodegradable under anaerobic conditions
MCF	= Methane-correction factor for the DOC fraction that is biodegradable under anaerobic conditions, for year x

In western Germany (the former Federal Republic of Germany), the law permits only orderly landfilling. This has been the case since 1972. In 1989/90, in connection with German reunification, the relevant standards were extended to the new German Länder. The inventory calculations take account of all waste landfilled since 1950, regardless of whether the landfills in which the waste is now located have been decommissioned or are still in operation.

In calculations, an MCF of 0.6 (the default value for unclassified landfills; cf. Chapter 7.2.1.2.3) is used for the emissions contributions of all waste landfilled between 1950 and 1972. For the period 1973-1989, the same MCF of 0.6 is used for the new German Länder, and an MCF of 1 is used for the old German Länder. For purposes of emissions calculation for the inventory, data from that period have been used to obtain a weighted MCF, for Germany as a whole, that reflects the various waste fractions' percentage contributions to the total for Germany as a whole. The emissions from waste landfilled since 1990 are calculated with an MFC of 1.

Germany uses the IPCC Waste Model, which was developed on the basis of Equations 3.4 and 3.5 of the 2006 IPCC Guidelines (IPCC, 2006a). Under this approach, the total quantity of biodegradable DOC in landfills is calculated for each year, in order to calculate the quantity of DOC that is broken down, in each year, into CH_4 and CO_2:

Equation 60: (2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3.2.1.1, Equation 3.5

$$DDOCma_t = DDOCmd_t + (DDOCma_{t-1} * e^{-k})$$

Where:

t	*= Inventory year*
$DDOCma_t$	*= DDOCm accumulated in the landfill at the end of year t (kt)*
$DDOCma_{t-1}$	*= DDOCm accumulated in the landfill at the end of year t-1 (kt)*
$DDOCmd_t$	*= DDOCm added to the landfill in year t (kt)*
k	*= Reaction constant – methane-formation rate (1/year) = $\ln(2)/t_{1/2}$ (year $^{-1}$)*
$t_{1/2}$	= half-life (years)

Equation 61: (2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3.2.1.1, Equation 3.6)

$$DDOCm\ decomp_t = DDOCma_{t-1} \times (1 - e^{-k})$$

Where:

t = Inventory year

DDOC $decomp_t$ = DDOCm that decomposes in the landfill in year t (kt)

A multi-phase model was applied. In addition, the calculation was carried out with different half-lives for the different waste fractions involved, and the results so obtained were summed.

To obtain the final CH_4-emissions result, methane that is recovered and then flared, or then used for energy recovery, is deducted, and a correction factor is applied that accounts for methane oxidation in landfill covering layers, as shown by Equation 3.1 (IPCC, 2006a):

Equation 62: ***(2006 IPCC Guidelines, Chapter 3.2.1.1, Equation 3.1)*****:**

CH_4 emitted in year t (kt/year) = (CH_4 produced in year t – R(t)) • (1- OX)

Where

R(t) = CH_4 recovered in year t

OX = Oxidation factor (fraction)

With the IPCC Waste Model, users may define a time period during which landfilled waste has not yet begun producing gas, i.e. a period of delay until gas formation begins. The 2006 IPCC Guidelines (IPCC, 2006a) recommend 6 months as a standard value for this delay period. As a result of discussions with national waste experts, and on the basis of measurements of CH_4 formation following landfilling, a delay-period value of 3 months has been chosen. This change has only a slight effect on emission calculations.

For purposes of calculation, the relevant quantities of settlement waste (MSW_T), and the fraction of settlement waste that is landfilled (MSW_F), must be determined. For the FOD method, settlement-waste-production quantities have to be determined throughout the past few decades. Pursuant to the 2006 IPCC Guidelines, estimates should be made of the different waste-type fractions contained in landfilled settlement waste, since the further emissions-calculation procedure is based on the fact that different waste types have different DOC values.

7.2.1.2.1 Quantities of landfilled waste

The FOD model calculates emissions from landfilled settlement waste, landfilled industrial waste and landfilled sewage sludge.

The pertinent quantities of this landfilled waste are obtained from the statistics of the Federal Statistical Office. Data through the year 2018 were taken from Statistisches Bundesamt (FS 19, R1). After that year, publication of series FS 19, R1 was discontinued. The data for the period as of 2019 that are required for reporting are provided to the Federal Environment Agency for that purpose, however – in an unchanged table format. To obtain such statistics, the Federal Statistical Office carries out an exhaustive survey that is based on annual surveys of waste types, origins and final destinations, as well as on surveys taken of the pertinent waste-storage facilities, every two years, that focus on specific equipment of the facilities. The activity data for the current report year in each case have to be estimated, since official waste statistics are published with a one-year time lag. Estimates are carried out by extrapolating from the data of the last two previous years. In each case, such estimates are replaced in the following year with the relevant figures from survey statistics. Recalculations for the year prior to the past year thus have to be carried out on an annual basis.

The surveys of landfilled quantities of settlement waste in the old German Länder commenced in 1975, on the basis of the Environmental Statistics Act of 1974. Waste quantities for the period from 1950 to 1975 were extrapolated on the basis of population data.

For the new German Länder, data on landfilled quantities of settlement waste, differentiated by Länder, are available for the years 1990 and 1993. For the 1980s in the former GDR, Andreas (2000) has presented data that provide information about per-capita landfilled quantities of waste, waste composition, landfill types and types of waste storage involved. The per-capita quantities of landfilled waste in the former GDR, at 190 kg/person, were considerably lower than the corresponding quantities in the old German Länder (330 kg / person and year). The reason for this was that larger percentages of waste were recycled in the former GDR. In 1990, the year of German reunification, landfilled quantities of waste increased sharply in the new German Länder, to the extent that the relevant per-capita quantities even outstripped the corresponding quantities in the old German Länder. The reasons for this were that the former GDR's recycling systems collapsed in that year and that a flood of new products suddenly became available, leading to high levels of replacement purchases and to sharply increasing quantities of packaging waste. Since 1990, per-capita waste quantities in both parts of Germany have slowly been moving into alignment.

The inventory calculations include data, covering the entire period as of 1950, on landfilled sewage-sludge quantities of the old and new German Länder (the former Federal Republic of Germany and the former GDR). No statistical data are available relative to landfilling in the new German Länder / the former GDR. The applicable waste compositions (including those of sewage sludge fractions) have been estimated on the basis of findings of a research project that in the 1990s studied waste inventories of GDR landfills.

In the former GDR, all non-recycled waste quantities were landfilled.

The quantities of industrial waste landfilled between 1975 and 1996 were derived on the basis of total quantities of landfilled waste. While the total quantities include industrial waste, the total-waste figures are not broken down to show industrial waste separately. Since 1996, the Federal Statistical Office has published differentiated data on waste-landfilling by industry. The relevant inventory takes account of the landfilled waste quantities from industrial sectors as follows:

- Waste from agriculture, horticulture, forestry, fisheries and food processing
- Waste from wood processing
- Waste from production of pulp, paper and carton
- Waste from the textile industry
- Packaging waste, absorbent and filtration materials, wiping cloths and protective clothing
- Wood fractions in construction and demolition waste (data since 1975)

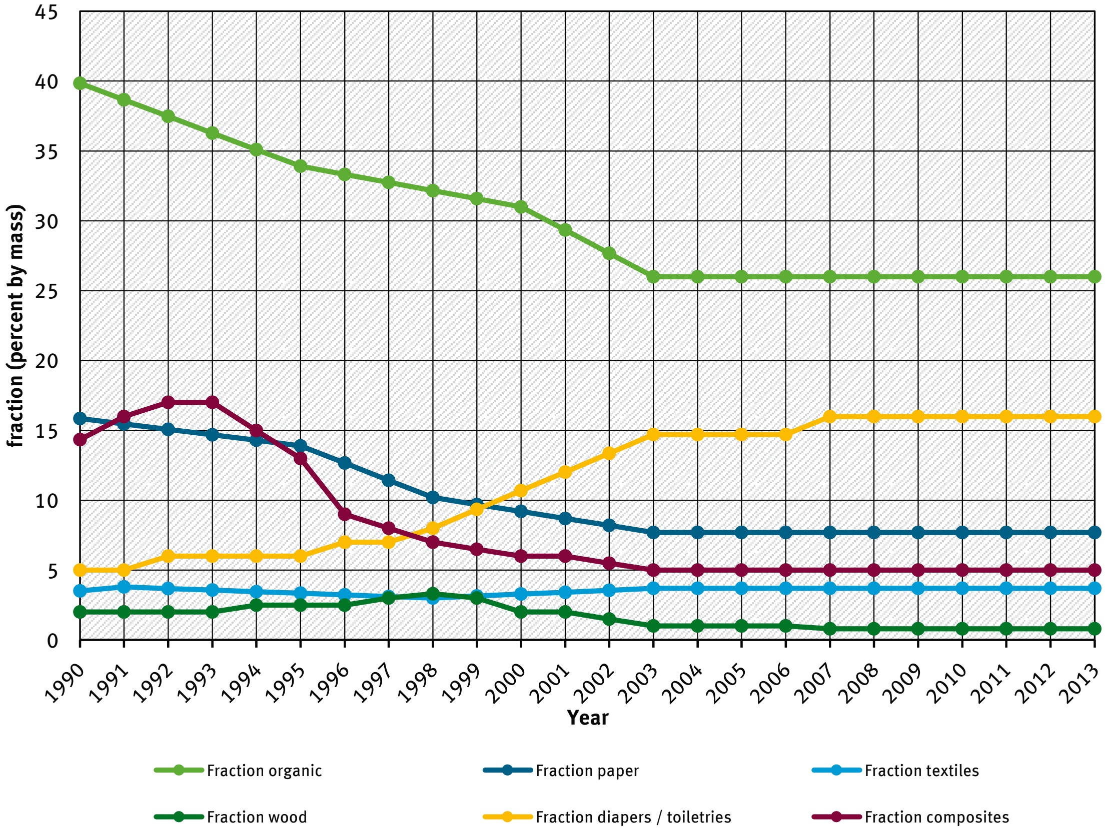
Extrapolations between waste production and production data of relevant sectors, for the 1996-2002 period, produced no satisfactory statistical relationships. While production figures increased, waste-production figures decreased – considerably, in part – as a result of changes in production processes. Due to the lack of statistical relationships, the figures for landfilled waste quantities were kept constant for the period between 1950 and 1975. Changes in assumptions relative to industrial waste in the 1950-1970 period have only a very marginal effect on emissions in the base year.

For the entire period as of 1950, and for all relevant types of waste, including sewage sludges, complete and seamless data series are thus available that are based on the best-available sources for the various sub-periods concerned.

7.2.1.2.2 Waste composition

For the inventory calculations pursuant to the FOD method, landfilled waste has to be divided into the landfill-waste fractions organic waste, garden and park waste, paper, wood, diapers and textiles, composite materials, sewage sludge and MBT output. To some extent, waste statistics include separate listings for these categories. On the other hand, such statistics also include landfilled quantities of mixed settlement waste that, for calculation purposes, have to be subdivided into the aforementioned fractions. To this end, numerous studies of the components of mixed settlement waste were evaluated, with a view to determining the historical development of waste fractions (organic waste, garden and park waste, paper, wood, diapers and textiles, composite materials). In the years 1980 and 1985, mixed-waste compositions were determined for the entire territory of the former Federal Republic of Germany (Barghorn et al., 1986; Greiner et al., 1983). For the subsequent period, many studies, carried out by individual cities, administrative districts and Länder, are available. Some of these have already been evaluated and combined within overarching studies. From such studies, time series for waste composition for the period between 1980 and 2013 have been selected (cf. Figure 86) that have been derived via evaluation of existing studies covering household waste, household-waste-like commercial waste and bulky waste (these waste types are listed separately in the pertinent national statistics). In 2014, existing evaluations of waste-composition studies were reviewed, and more-recent studies of residual-waste composition in the period 2006 through 2013 were identified (6 studies) and evaluated. These more-recent studies have confirmed existing assumptions regarding the composition of mixed-waste fractions, and thus the relevant data for the period as of 2014 have been carried forward without change. As a result of the legal changes described above, landfilling of mixed settlement waste has decreased sharply since 2005 (in fact, a decrease from 5.8 million tonnes in 2004 to 2,000 tonnes in 2013 has been registered). Consequently, there is less need to precisely determine residual-waste fractions for the period as of 2005, and fewer studies on waste composition have since been commissioned at the Federal, Länder, administrative-district and municipal levels.
As to waste composition in the new German Länder, the figures provided by ANDREAS (2000) for the 1980s in the former GDR were adopted (composition of household waste: 28 % vegetable waste, 14 % paper/cardboard, 2.3 % wood, rubber, composites, 3 % textiles; household waste accounted for only 16 % of total landfilled waste quantities, however). Quantities of settlement waste landfilled in the former GDR contain smaller fractions of biodegradable materials and large inorganic fractions (primarily ash from household combustion systems). Food waste was collected and used as feed; feeds tended to be scarce during certain periods of time. Paper was collected; it was also a scarce resource. Wood and paper were often burned in ovens for purposes of heating and cooking. The "SERO" recycling system efficiently collected the country's relatively small fractions of plastic packaging. Deposit systems were operated for glass, and glass was also collected. All in all, the former GDR's economy was subject to scarcities of resources, and this led to efficient waste recycling. Ash from household combustion systems accounted for large fractions of landfilled quantities of household waste.

Figure 86: Trends in household-waste composition between 1990 and 2013



The waste quantities stored in landfills are recorded by the Federal Statistical Office, in terms of separate fractions based on waste codes. For purposes of emission calculation, all waste types that can contribute to landfill-gas formation are taken into account, and each waste type is separately assessed in terms of its waste composition. Table 441 shows the waste types of relevance for landfill-gas formation (wood fractions of construction and demolition waste have been taken into account). The recovered quantities of landfill gas are based on official statistical data.

Since 1 June 2005 only waste with a total carbon content < 3 %, and mechanically and biologically treated settlement waste, may be landfilled in Germany. Since that time, landfilled waste quantities have decreased very sharply and now make only very small contributions to gas formation. Table 441 outlines the development of quantities of landfilled biodegradable waste. Data for the current inventory year do not become available in time for the inventory report. For the current report, therefore, the waste-quantity and waste-composition trends of the previous year are linearly extrapolated. Then, in the following year, the relevant figures are recalculated.

Table 441: Quantities of biologically degradable waste, by waste fractions

Waste fraction	Units	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Organic waste	[kt]	16,844	7,515	3,202	813	6	1	2	1	0	0	0
Garden and park waste	[kt]	0	0	54	26	0	0	0	0	2	0	0
Paper	[kt]	9,095	4,372	1,421	426	7	1	4	9	8	5	3
Wood	[kt]	2,658	1,889	1,037	238	0	0	0	0	0	0	0
Diapers + textiles	[kt]	3,572	2,082	2,241	519	5	2	3	2	2	1	1
Composite materials	[kt]	5,587	2,644	621	155	1	0	0	0	0	0	0
Sewage sludge	[kt]	2,494	1,024	452	634	27	81	57	16	26	40	54
Output from MBT facilities	[kt]	0	0	370	1170	991	714	618	610	515	508	500

In 2011/12, the residual-gas emissions from landfill storage of mechanically and biologically treated waste were quantified in an expert assessment (Stegmann & Partner, 2012). The assessment confirmed the low emissions contributions from landfilling of MBA waste that had been determined in emission calculation. It thus confirmed the national values used in emission calculation. The mechanical-biological (waste) treatment (MBT) process is described in Chapter 7.6.1.

In keeping with the recommendations provided in the inventory review 2010 (paragraph 146, UNFCCC (2010)), additional information is provided in this regard as of the 2011 report. Table 442 shows the landfilled waste quantities, and Table 451 shows the total quantities of settlement waste – in each case, per capita and day – for the period as of 1990.

In Germany, landfilling of settlement waste has decreased very sharply since 2005, and that trend is also reflected in the per-capita quantity of landfilled household waste. Such waste is now managed almost completely in incineration systems (waste incineration systems or systems for co-incineration in industrial combustion systems) and MBT facilities. In general, the per-capita quantity of settlement waste has remained constant.

Table 442: Per-capita quantities of landfilled household waste

	Units	1990	1995	2000	2005	2010
Per-capita quantities of landfilled waste	kg/capita/day	1.604	0.855	0.551	0.181	0.041
	Units	**2015**	**2016**	**2017**	**2018**	**2019**
Per-capita quantities of landfilled waste	kg/capita/day	0.031	0.025	0.025	0.021	0.020
	Units	**2020**				
Per-capita quantities of landfilled waste	kg/capita/day	0.019				

Table 443: Per-capita quantities of settlement waste

	Units	1995	2000	2005	2010	2015
Production of settlement waste per capita	kg/capita/day	1.715	1.776	1.568	1.680	1.693
	Units	**2016**	**2017**	**2018**	**2019**	**2020**
Production of settlement waste per capita	kg/capita/day	1.731	1.714	1.659	1.668	1.693

7.2.1.2.3 MCF (methane correction factor)

In the Federal Republic of Germany, until 1972, when the first Waste Act was introduced, waste was usually stored in uncontrolled landfills; such landfills were closed after 1972. After 1972, waste was stored in managed landfills. For the old German Länder, therefore, a default MCF value of 0.6 is used for "unclassified landfills" ("nicht zugeordnete Deponien") for the period through 1972 (Chapter 3.2.3, (IPCC, 2006a). After 1972, the default value for controlled anaerobic landfills – 1 – is used.

Data are available from a 1989 survey of the territory of the former GDR that covered 120 managed landfills, some 1,000 controlled storage sites and some 10,000 uncontrolled dump sites (Institut für Umweltschutz (1990): p. 56, Table 12). Consequently, for the territory of the former GDR, an MCF of 0.6 (default value for unclassified landfills) has been assumed to apply for the period 1950 through 1989; Chapter 3.2.3, (IPCC, 2006a). Upon German reunification, the Federal

Republic of Germany's waste laws were extended to the territory of the new German Länder, and transitional regulations were introduced to ensure that facilities – including both decommissioned facilities and still-operational facilities in which waste was (or is) produced or disposed of – were accounted for and that suitable clean-up measures were initiated (BMU (1990): p. 46). Uncontrolled landfills were closed in 1990, facilities permitted to remain open were secured, cleaned up and modernised/expanded in keeping with the standards of Federal German waste law, and sites for new facilities were sought.

As of 1990, the Federal Statistical Office has collected statistics on both parts of Germany. For purposes of calculation for the period after 1990, an MCF of 1 (default value for controlled anaerobic landfills) is used for all of Germany's territory. Experts of the Federal Environment Agency consider the IPCC default value for controlled anaerobic landfills to be a suitable value for landfills in Germany.

7.2.1.2.4 DOC

Both national data and IPCC default factors are used for DOC, the proportion of degradable organic carbon in waste. All DOC values refer to wet waste, since the statistical data for waste quantities landfilled in Germany are collected on wet waste. Table 444 provides an overview of the DOC values used.

In keeping with the review results from the ARR 2015/2016 and 2018, Germany is making an intensive effort to discuss the sources for the data given in Table 444:

- For garden and park waste, paper and paperboard, wood and straw, and textiles and diapers, IPCC default values are used (Table 2.4, Chap. 2.3.1 (IPCC, 2006a)). For such waste, no sufficiently reliable national values are available. The default values are seen as realistic, in terms of order of magnitude, by experts of the Öko-Institut Institute for Applied Ecology and of the Federal Environment Agency.
- The DOC for organic waste has been obtained from national studies (Wallmann, 1999). At 18 %, it is somewhat higher than the default value.
- The Guidelines provide no default values for composite materials. In the context of a research project for preparation of the ICR 2010, the relevant national value was estimated by the research contractor (Öko-Institut) at 10 %. During the ICR, that value was accepted by the responsible IPCC expert.
- For sewage sludge, the 2006 IPCC Guidelines (Chap. 2.3.2, (IPCC, 2006a)) give a default DOC of 50% with respect to dry matter. From the 1980s until 2005, virtually all of the sewage sludge that was landfilled was mechanically dewatered sludge with an average dry-matter content of about 30%. From this average DM content of landfilled municipal and industrial sewage sludge, and the default value for dry sewage sludge, an average DOC value of 15% was derived. That value is used, as a national value, for the period until 2005. Since 1 June 2005, only waste with a total carbon content < 3 % may be landfilled in Germany. This also applies for sewage sludge, and thus a national DOC value of 3% DOC is used in calculations for the period as of 2006.

- The Guidelines provide no default values for mechanically and biologically treated waste (MBT waste). A study commissioned by the Federal Environment Agency (Stegmann & Partner, 2012) has shown that mechanical-biological treatment greatly reduces the DOC content of waste. Following such treatment, a landfill fraction contains less than 10 % of the DOC content (as a percentage) it originally had prior to the treatment. MBT facilities treat the entire spectrum of residual settlement waste and household-waste-like commercial waste. The average DOC of waste that undergoes mechanical and biological treatment is estimated at 23 %. The national DOC value for landfilled MBT waste, 2.3 %, is the value that remains, on average, following a 90 % reduction via the treatment process.

Table 444: DOC values used

Fraction	DOC values		Source
	IPCC 2006 default (wet waste)	used	
Organic waste	15 %	**18%**	(Wallmann, 1999)
Garden and park waste	20 %	**20%**	Table 2.4, Chap. 2.3.1, (IPCC, 2006a)
Paper and paperboard	40 %	**40%**	Table 2.4, Chap. 2.3.1, (IPCC, 2006a)
Wood and straw	43 %	**43%**	Table 2.4, Chap. 2.3.1, (IPCC, 2006a)
Textiles	24 %	**24%**	Table 2.4, Chap. 2.3.1, (IPCC, 2006a)
Diapers	24 %	**24%**	Table 2.4, Chap. 2.3.1, (IPCC, 2006a)
Composite materials	N. e.	**10%**	In-Country Review, 2010 (Öko-Institut)
Sewage sludge	50 % (dry)	until 2005, **15%** as of 2006, **3%**	Determined computationally from the IPCC default for sewage sludge, referenced to dry matter; after 2006, an assumed DOC of 3% is used
Waste from MBT facilities	N. e.	**2.3%**	National value (10 % of the average DOC of landfilled fractions from the current year) (Stegmann & Partner, 2012);

7.2.1.2.5 DOC_F

DOC_F, the DOC fraction that can be converted into landfill gas, is put at 50 % for settlement waste, on the basis of a national study (Rettenberger et al. (1997): p. 277). That value is in keeping with the IPCC default of 0.5 (Chapter 3.2.3, (IPCC, 2006a)).

7.2.1.2.6 F = Fraction of CH_4 in landfill gas

In calculation of methane formation, the IPCC default value for F, 50%, is used throughout the entire time series (ibid.). That value has been confirmed by a national research project (Schön et al., 1993).

Table 445: Fraction of CH_4 in landfill gas

Fraction of CH_4 in landfill gas	2004	2006	2008	2010	2012	2014	2016	2018
Landfills in the operational and closure phases	49 %	50 %	49 %	48 %	48 %	47 %	45 %	42
Landfills in the aftercare phase	N. e.	N. e.	N. e.	42 %	40 %	38 %	32 %	32 %

Source: (Statistisches Bundesamt, 2018), Table 1.5

In recent years, the methane concentrations in recovered landfill gas (Table 445) have been decreasing, however. Presumably, this decrease in methane concentrations is due to oxidation effects in the gas-recovery systems, effects that intensify as gas formation decreases.

7.2.1.2.7 Half-life

The calculation model is a multi-phase model that takes account of the different half-lives of different waste fractions. Table 446 shows the half-lives and the methane-formation rate used for the pertinent waste fractions. In conformance with the recommendations provided in the 2010 inventory review (paragraph 146, FCCC/ARR/2010/DEU), additional information has been provided for reporting as of 2011. The constant methane-formation rate that appears in the FOD method corresponds to the time required for biodegradable organic carbon in waste to decompose to the point at which it has lost half of its original mass. It thus can be derived from the half-lives of the various relevant fractions, in keeping with Equation 63.

The slight differences seen in the k values – between default and national values – are due to the following circumstances: The earlier versions of the IPCC tables (the versions distributed in connection with the publication of the 2006 IPCC Guidelines) for estimating methane emissions from landfilling of solid waste are based on half-lives. In later versions of the IPCC model table, this estimation basis was changed. In those earlier versions, the available selection of parameters included only half-lives – and no k values (unfortunately, the relevant file names did not include version numbers). The original version of the IPCC model table includes a "half-life" spreadsheet with embedded calculation of k values on the basis of half-lives as well as calculation of half-lives on the basis of k values (i.e. the vice-versa direction). Consequently, the standard half-life values shown in Table 446 are the standard parameters presented in the earlier version of the IPCC model table. The k values shown in this table have been obtained by calculating k on the basis of the standard half lives, using the embedded calculation tool in the model table. Until the ARR 2018, it was assumed that the basic conversions provided by the IPCC's table tools were correct, and thus the rounding that they involved was not checked. The ARR has now called attention to inconsistencies. Those inconsistencies are due to the differences between Table 3.3 and Table 3.4 of the 2006 IPCC Guidelines. For food waste and sewage sludge, for example, we used the half-life given in Table 3.4, 4 years. That figure is equivalent to a value of 0.173 for k. Table 3.3 gives a value of 0.185 (not 0.173) for food waste, however, which is equivalent to a half-life of 3.747. As a result, Tables 3.3 and 3.4 are inconsistent with each other with regard to food waste and sewage sludge (all other values are consistent, however). Since we began our calculation on the basis of the older model table, we have based our calculation on the temperate / wet climate-zone data given in Table 3.4.

For calculation purposes, the national values were used, which are oriented largely to the IPCC default values. According to the assessment of Federal Environment Agency experts, these national values, when used in the calculation model, yield realistic results for methane formation in landfills containing biologically degradable waste. At landfills where no biologically degradable waste has been landfilled, for prolonged periods, it is increasingly clear that the current calculation leads to an overestimation of methane formation, meaning that review and adjustment of the relevant half-lives and k values are required.

The current discrepancies between our results and the specified values are minimal – and will cancel out when the announced improvement (cf. Chapter 7.2.1.6) is carried out. For this reason, the responsible review expert for the 2018 ARR has concluded that the adjustment of the calculation can safely be delayed until the results of the relevant pending research project become available.

Equation 63: (2006 IPCC Guidelines)

$$k = \ln 2 / t_{1/2}$$

Table 446: Half-lives and constant methane-formation rates of waste fractions

Type of waste	Half-life (years)		CH4 formation rate (k value)	
	IPCC default value*	National value	IPCC default value*	National value
Food waste	4		0,185	0.173
Garden/park waste	7		0.1	0.099
Paper / cardboard	12		0.06	0.058
Wood	23		0.030	0.030
Textiles / diapers	12		0.06	0.058
Composite materials	--	12	---	0.058
Sewage sludge	4		0,185	0.173
Waste from MBT facilities	--	12	--	0.058

* Wet temperate

7.2.1.2.8 Landfill-gas use

The "TA Siedlungsabfall" of 1993[137] made gas recovery one of the prerequisites for licensing of landfills for settlement waste. The amended version of the Environmental Statistics Act (UStatG) of 2005 mandates that in future the Federal Statistical Office, in its surveys, is to take account of, and publish, levels of landfill-gas recovery. For the years 2004, 2006 and 2008, and with regard to landfill-gas recovery and use, Fachserie 19 of 12 July 2012 includes only data for landfills in the operation and closure phases. Collection of gas-collection data for all landfills, i.e. including landfills in the follow-on care phase, began for the first time for the year 2010. For calculation of collected quantities of landfill gas, the Federal Statistical Office collects data on collected volumes of landfill gas, along with the relevant methane fraction in percent by volume. The relevant methane fraction is in keeping with the values given in Chapter 7.2.1.2.6 (for verification purposes). The pertinent collected quantities of methane are calculated from that data, for purposes of climate reporting in the NIR.
In Germany, landfill operators are subject to monitoring obligations, under the Landfill Ordinance (Deponieverordnung), that require them to measure collected quantities of landfill gas, and the methane concentrations in the gas, and to document such measurements in annual reports. The resulting data are then collected by the Federal Statistical Office, at two-year intervals, on the basis of the Environmental Statistics Act (Umweltstatistikgesetz).
For this reason, no recalculations of collected quantities of landfill gas, on the basis of energy data, are required for the NIR.

Through the year 2010, as a result of the above-described data gaps, total quantities of collected landfill gas were determined by combining data from the energy sector and from Fachserie 19.

The quantities of methane listed in Table 447 include both the landfill-gas quantities used for energy generation and those flared off.

[137] Technical instructions on recycling, treatment and other management of settlement waste (Third general administrative provision on the Waste Act (Abfallgesetz)) of 14 May 1993

Table 447: Methane collection in landfills

Year	Methane formation in Gg	Collected quantity of methane, in Gg			
		Landfilling and decommissioning phases, in Gg	After-closure phase, in Gg	Total quantity, in Gg	Recovery rate in %
1990	1614			94	5.8
1991	1715			105	6.1
1992	1772			115	6.5
1993	1787			125	7.0
1994	1770			136	7.7
1995	1738			146	8.4
1996	1690			160	9.5
1997	1629			222	13.6
1998	1559			242	15.5
1999	1490			247	16.6
2000	1423			251	17.6
2001	1353			252	18.7
2002	1288			254	19.7
2003	1222			254	20.8
2004	1158	236	11	247	21.3
2005	1094			247	22.6
2006	1018	231	11	242	23.8
2007	937			220	23.5
2008	865	190	11	201	23.2
2009	800			191	23.8
2010	741	171	11	181	24.4
2011	689			167	24.2
2012	641	140	14	154	24.0
2013	598			143	24.0
2014	559	121	13	134	24.0
2015	523			126	24.0
2016	490	107	11	118	24.1
2017	460			107	23.2
2018	432	85	12	97	22.3
2019	407			87	21.5
2020	383			82	21.5

Source: Statistisches Bundesamt (FS 19, R1)

The data include gaps, since official statistical data are available only for certain single years; such gasp were closed via -/ extrapolation and qualified estimates.

For the years through 1998, proportional gas-recovery rates (i.e. expressed as percentages) from earlier estimates continue to be used (cf. the 2012 NIR for the relevant sources and data derivation), and the recovered quantities of methane have been calculated from the methane formation and the pertinent methane-recovery rate (with the latter expressed as a percentage).

For the years 1999 through 2003, the proportional collection rates (expressed as percentages) have been interpolated from the values for 1998 (old method) and 2004. The recovered quantities of methane were calculated from the total methane formation and the relevant proportional recovery rate (expressed as a percentage).

For the years 2004, 2006 and 2008, Federal Statistical Office data are available only for landfills in operational and closure phases. The total quantities of methane recovered at all landfills were determined by adding a) the methane quantities determined for 2010, for landfills in the after-closure phase, and b) the pertinent annual figures, for landfills in the landfilling and decommissioning phases, for 2004, 2006 and 2008.

For even years in the period as of 2010, complete Federal Statistical Office data on gas collection at all landfills are not available, since the Federal Statistical Office collects such data only every second year, For those years, the proportional (percentage) rates of landfill-gas recovery were thus obtained via interpolation between the relevant previous and subsequent years, and the collected quantities of gas were then calculated from the gas formation and the applicable proportional (percentage) collection rate. For the relevant current year, the proportional (percentage) gas-collection rate is extrapolated from the values for the two previous years. The figures are then recalculated as soon as the underlying statistics are updated.

7.2.1.2.9 Flares

In 2018, a total of 97 Gg methane was collected, together with landfill gas. Of that quantity, a fraction of about 20 Gg, which was not suitable for energy-related use, was burned off in flares. In Germany, landfill-gas flares are subject to very stringent requirements, via the Technical Instructions on Air Quality Control (TA Luft): the combustion has to take place in a remote high-temperature flare; the residence time within the combustion zone has to be at least 0.3 seconds; and the combustion temperature has to exceed 1,000°C. As a result, landfill-gas flares achieve nearly complete combustion, with correspondingly low methane emissions. Manufacturers of such flares guarantee a combustion efficiency >99.9 %.

Since the greenhouse-gas emissions from the category landfill-gas flares in 5.A account for less than 0.05 % of the total inventory (not including LULUCF), and since they do not exceed 500 kt CO_2 equivalents (significance thresholds pursuant to FCCC/SBSTA/2013/L.29/Add.1), and since annual recording cannot be assured (in keeping with FCCC/SBSTA/2013/L.29/Add.1, para 37), we opt not to report on this area (IPCC, 2006a). A one-time quantitative estimation of the emissions from landfill-gas flares that are thus not being included in the inventory has yielded a figure of about 0.5 kt CO_2 equivalent. In addition, a compilation of all sources listed as "not estimated" is presented in Annex 5 (Annex Chapter 21) of the present report.

7.2.1.2.10 Oxidation factor

As to the factor determining the proportion of CH_4 that is oxidised in landfill covering layers, the IPCC default value of 0.1 was adopted for the entire time series. While in the early 1990s the former GDR probably had a higher percentage of uncontrolled landfills than did the old German Länder, a research project has found that the former GDR's landfills have a low CH_4-formation potential, and thus use of the factor 0.1 is also justified for that period (BMBF & UBA, 1998). Experts of the Federal Environment Agency consider the IPCC default value for the oxidation factor to be realistic in terms of its order of magnitude.

7.2.1.3 Uncertainties and time-series consistency (5.A.1)

Over the long, 30-year period covered by the activity data, inconsistencies in the time series are unavoidable, since the pertinent waste categories and survey methods changed several times as a result of improvements in legislation and waste statistics. In Germany, special problems arise especially via German reunification and the resulting merging of two different economic and statistical systems. For this reason, considerable effort has to be invested in reviewing data consistency and allocations to the reported categories, in the interest of making time series as consistent as possible.

For some years now, there have been growing indications in Germany that the IPCC's FOD model for calculating landfill-gas formation, and the resulting methane emissions, produces significant overestimations with regard to actual landfill behaviour. Experts of the Federal Environment Agency thus estimate the uncertainties for calculation of methane emissions from landfills to be +10% and -50 %.

7.2.1.4 Category-specific quality assurance / control and verification (5.A.1)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

For verification of the results, the implied emission factors (IEF) derived in the GHG locator were compared with those of other countries. An international comparison of 2020 reporting shows that Germany had the second-highest value, 0.41. The reasons why its value is relatively high are that a) quantities of landfilled waste with biodegradable fractions have been decreasing sharply in Germany since the 1990s, and b) nearly all gas being produced by landfilled waste is being produced by waste that was landfilled prior to 2005 (cf. Chapter 7.2.1.2.2).

Inernationally, landfilling of biologically degradable waste is still widely practiced. Very few countries have reduced landfilling of biologically degradable waste to the extent Germany has. At about the same time that Germany introduced its pertinent legislation on waste, Austria and Switzerland adopted similar laws. Austria ranks third in the relevant IEF comparison. Its value, at 0.26, is about the same as Germany's. No comparative data are available for Switzerland.

7.2.1.5 Category-specific recalculations (5.A.1)

Because the Federal Statistical Office's waste statistics appear with a one-year time lag for data on quantities and compositions of landfilled waste, and because data on collected quantities of landfill gas are collected at two-year intervals, recalculations have to be carried out, on an annual basis, for the year prior to the previous year. In addition, the data for the current report year have to be estimated. In the following year, the data so estimated are replaced with the latest official data. Since the recalculations that this necessitates each year are very insignificant overall, they are not additionally reported here.

In addition to the execution of these annual recalculations, the methane density used for calculations was consolidated with values in other inventory categories. The density value was adjusted from 0.716 to 0.717 kg/m^3. This leads to a very minor change in the reported emissions, throughout the entire time series. Because the changes are so slight, they are not listed explicitly here.

7.2.1.6 Planned improvements, category-specific (5.A.1)

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter. No additional improvements are planned at present.

7.3 Biological treatment of solid waste (5.B)

In category 5.B, emissions from composting systems (5.B.1) and from digestion of biowaste in biogas plants (5.B.2) are reported. Both facility types in category 5.B treat separately collected biowaste and produce compost or digestates that are used in the agricultural or horticultural sectors. This is the difference with regard to the mechanical-biological treatment covered in category 5.E. Those facilities handle mixed settlement waste (residual waste). The residues from those facilities are either landfilled or incinerated.

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/T	5 B, Biological Treatment of Solid Waste		CH_4	25.3	0.0%	713.7	0.1%	2716.6%
-/-/T2	**5 B, Biological Treatment of Solid Waste**		**N_2O**	**16.0**	**0.0%**	**309.9**	**0.0%**	**1840.9%**

The category *Biological treatment of solid waste* is a key category for CH_4 emissions in terms of trend, and a key category for N_2O emissions pursuant to Approach 2 trend analysis.

7.3.1 Composting facilities (5.B.1)

7.3.1.1 Category description (5.B.1)

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	NS	CS
N_2O	Tier 2	NS	CS

In Germany, annually increasing fractions of biodegradable waste are being separately collected and treated. The emissions reported under 5.B.1 originate in composting facilities that, primarily, compost biowaste separately collected from households, along with garden and park waste. The composts produced from such waste are used in the agricultural and horticultural sectors.

The area of composting includes centralised composting of separately collected biowaste as well as the composting that residents carry out in their own gardens (home composting). For this area, no reliable data are available on the relevant quantities involved and the emissions produced. For this reason, we do not report on these emissions.

7.3.1.2 Methodological issues (5.B.1)

Nitrous oxide and methane emissions from composting of kitchen and garden waste are reported in keeping with the 2006 IPCC Guidelines (IPCC, 2006a). On the other hand, we use our own national emission factors, which were obtained via a research project (Cuhls et al., 2015). The methane and nitrous oxide emissions are calculated in accordance with the following formula:

$$E = M * EF$$

E = Emissions in kg

M = Mass of biowaste [kt]

EF = Emission factor [kg/kt]

Activity data

Since 1980, the Federal Statistical Office has regularly collected and published data, in various forms, on waste quantities managed in composting facilities (Statistisches Bundesamt, FS 19, R 1, Tabelle 7). To this end, it carries out exhaustive surveys of waste treatment facilities. Currently, the quantities of biowaste treated in composting systems are calculated by summing the waste quantities in the lines "biowaste composting systems" ("Bioabfallkompostierungsanlagen"), "garden-waste composting systems" (""Grünabfallkompostierungsanlagen") and "sewage-sludge composting systems" ("Klärschlammkompostierungsanlagen"). Also, the waste fraction that is composted in "other biological treatment facilities" is calculated and added to the above results. For this calculation, the percentage share of the compost produced in such systems, with respect to the total output of "other biological treatment facilities" (compost and digestates) listed in Table 7.3 (ibid.), is applied to the input waste quantity.

In the years 1990 through 2005, statistical surveys of waste quantities were less detailed than they were later on. In addition, they were not always carried out in the same manner, and they were carried out at different yearly intervals. For this reason, different values had to be interpolated in different ways, to some extent, and some values had to be extrapolated into the past.

The activity data for the current report year have to be estimated, since official waste statistics are published with a two-year time lag. For this reason, the entire quantity of waste input into composting systems is extrapolated, on the basis of the trend for the previous 3 years. Then, in the relevant subsequent year, that figure is replaced with the applicable statistical-survey figure. Recalculations are thus required annually.
In preparation for the decision in factor of this procedure, review was carried out to determine the effects this extrapolation method has when it is carried out separately for each type of treatment facility. Because the trends are unclear, fluctuations – wide fluctuations, in some cases – can occur in the calculated activity data. Where they occur, experts do not consider them valid. On the other hand, extrapolation of only the summed waste quantity generates a value that experts view as probably closer to the expected future value.

Emission factors

Emission factors for composting of biowaste were determined in the framework of a research project (Cuhls et al., 2015). In that project, emissions measurements, covering methane, nitrous oxide and ammonia, were carried out at 19 composting facilities. From the results of those measurements, and from findings obtained via study of the literature, aggregated emission factors were extrapolated for the entire pool of such facilities in Germany. The factors take account both of the different facility technologies used in Germany and of the different types of biowaste used as input materials. In some facilities, very high emissions measurements resulted, and thus the average value is very high. Most facilities carried out several different measurement phases, to take account of different atmospheric / meteorological conditions (summer/winter) and to rule out the possibility that such conditions were the reason for especially high or low values. In the framework of a peer review (with the research contractor, the UBA and experts taking part), the very high measurements were identified as outliers and classified as non-representative. For this reason, it was agreed, with the research contractor (Cuhls et al.), to use the median values as the emission factors. All measured emissions values entered into the derivation of the median values. The process of deriving the EF began with determination of individual EF for each different treatment technology. Then, each treatment technology was weighted in keeping with the quantities of waste treated in pertinent facilities in Germany (Cuhls et al., 2015), Table 5-1, which lists the various technologies involved and their shares of treated biowaste). Finally, the various EF were combined, with the help of the determined weighting factors, to form the currently used EF.

The following emission factors were obtained for composting of biowaste (Cuhls et al., 2015), p. 136; page 142 in the English version):

$EF\text{-}CH_4 = 1{,}400 \text{ g } CH_4/ \text{ t biowaste}$

$EF\text{-}N_2O = 74 \text{ g } N_2O/ \text{ t biowaste}$

It should be noted that the study's findings included the result that C and N content levels in biowaste do not play a relevant role in the emissions of CH_4 and N_2O. At the beginning of the study, garden waste and kitchen waste were considered separately, due to their different C and N content levels. However, the study found that neither of the two content levels is a relevant emissions driver. The conditions under which waste is treated are the most important factor driving emissions from composting systems. And aeration and temperature are the key factors with regard to formation of CH_4 and N_2O during the composting process. Moisture concentrations also play a role. Consequently, the research project differentiates not between the different types of waste, but between the different types of treatment technologies involved. In simple composting plants without forced aeration, kitchen waste is not treated by itself, due to that waste type's high moisture levels and paucity of structure-creating components. The waste that is composted in such plants usually consists of green waste (garden and park waste) – or mixtures of such waste and small fractions of kitchen waste. Kitchen waste, on the other hand, is usually composted in closed systems with forced aeration.

The aforementioned national emission factors include both the emissions from the composting process, and from pertinent storage, and the emissions from use of the produced compost. Such use comprises both the spreading of the digestates and the later mineralisation of the pertinent nitrogen in the soil. The calculation is described in Chapter 5.3.3 of Cuhls et al. (pages 102 – 109). Pursuant to Cuhls et al., the N_2O emission factor for composting of biowaste, and for use of compost, amounts to a total of 74 g N_2O / t biowaste, and thus is within the uncertainty range of the IPCC default factor, 60 - 600 g (Vol. 5, Chapter 4.1.3.1):

- The emissions from treatment amount to 49 g N_2O / t biowaste.
- The emissions from storage / use / mineralisation amount to 25 g N_2O / t biowaste.
- The default factor for composting is 300 g N_2O / t biowaste.

In general, the nitrous oxide emissions following fertilisation with compost are very low, since the nitrogen contained in compost is organically bound and mineralises very slowly. Because nitrogen is released slowly under such conditions, it is largely absorbed by plants, and very little nitrogen is directly available (for example, in the form of nitrate) for conversion into nitrous oxide (Cuhls et al., 2015).

7.3.1.3 Uncertainties and time-series consistency (5.B.1)

Activity data

The uncertainties for the composted waste quantities (2 %) are considered to be very low, since the quantities are based on an exhaustive survey.

Emission factors

The uncertainties for the emission factors are high. They depend on the type of facility/plant in question, on waste composition and on the effectiveness of the biofilters used. The pertinent figures from the literature and from other countries vary so widely that uncertainties of +400 % to -69 % for CH_4, and of +177 % to -46 % for N_2O, are assumed. The uncertainties were determined in the framework of the aforementioned research project (Cuhls et al., 2015).

7.3.1.4 Source-specific quality assurance / control and verification (5.B.1)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The activity data are based on figures from federal waste statistics. No more-comprehensive or more-precise data are available.

The emission factors were determined on the basis of an evaluation of the relevant available literature, as well as on the basis of measurements. A literature search carried out by Oonk and Lambert (2017) also failed to turn up more recent data on emissions from biowaste-treatment facilities, and it confirmed the emission factors used by Germany.

The emission factor used for methane, at 1.4 g CH_4/kg waste, is lower than the default value of 4 g. However, it does lie within the range for that value, 0.03 to 8 g CH_4/kg waste. In addition, the emission factor used for nitrous oxide, at 0.074 g N_2O/kg waste, is lower than the relevant default value, 0.3 g. It, too, lies within the range for its corresponding default value – which, in this case, is 0.06 to 0.6 g N_2O/kg waste. An important reason why the emission factor is so low is that treatment plants in Germany have high technical standards (active ventilation, temperature monitoring and control, regular turning of compost heaps).

For the same reason, the IEF for CH_4 and N_2O lie well within the lower third of the ranges for reporting countries (GHG Locator 2020). The IEF for methane is of approximately the same magnitude as Italy's value, and it is higher than the values of comparable countries, such as the Netherlands and Switzerland. The IEF for nitrous oxide lies within the lower part of the range, but it is of the same order of magnitude as the values of Switzerland and the Netherlands.

A comparison, carried out for the 2020 report, of Germany's emission factors (cf. Table 448) and those of Austria, Belgium and Denmark shows that Germany's CH_4 EF lies in the middle of the range. For nitrous oxide, its EF is somewhat lower, but on the same order of magnitude, than/as those of Austria and Belgium.

Table 448: Comparison of emission factors for composting

EF in g/t	Germany	Austria	Belgium	Denmark
Methane CH_4	1400	750	750	4000 (4200)
Nitrous oxide N_2O	74	100	96	240 (120)

Source: For Germany, current submission; for other countries, the 2019 submission (UNFCCC, 2020)

Note regarding the table: The figures for Denmark: EF for biowaste (EF for garden waste)

7.3.1.5 Category-specific recalculations (5.B.1)

In each case, when the inventory data for the current year are being prepared, the most recent available statistical data (Statistisches Bundesamt, FS 19, R 1) on landfilled quantities of waste are the data for the previous reporting year; the Federal Statistical Office's waste quantities appear with a two-year time lag. For this reason, and as described above, the figures for the current report year are extrapolated on the basis of the activity-data trend of the past three years. In the relevant subsequent year, the data so extrapolated are replaced with the data obtained via statistical survey. For this reason, each year, the previous year's figures have to be recalculated.

In the annual quality assurance procedure, minor rounding errors in the activity data were identified. These errors have been corrected. In light of the negligibility of the resulting recalculation, we refrain from presenting it in detail.

Slightly more relevant revisions were carried out to take account of a corrected transfer error in the CSE that affected the activity data of the year 2010. The recalculations for the year 2019 are shown together with those for the year 2010.

Table 449: Recalculations, CRF 5.B.1

Designation	Units	Report year	2010	2019
Waste quantities managed in composting systems (TOTAL)	[kt]	2022	8,608.6	8,849.4
		2021	8,609.2	8,792.8
CH_4	[t]	2022	12,052.0	12,389.2
		2021	12,052.9	12,309.9
N_2O	[t]	2022	637.0	654.9
		2021	637.1	650.7

7.3.1.6 Category-specific planned improvements (5.B.1)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

7.3.2 Digestion plants (5.B.2)

7.3.2.1 Category description (5.B.2)

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	NS	CS
N_2O	Tier 2	NS	CS

In Germany, annually increasing fractions of biodegradable waste are being separately collected and treated. The emissions reported under 5.B.2 come from biowaste digestion plants that primarily digest separately collected biowaste from households, food waste from cafeterias and restaurants and biowaste from food production and processing. They do not include emissions from digestion of sewage sludge. In some biowaste digestion plants, manure (especially slurry) is also digested. The relevant quantities are calculated out of the input waste, since their emissions are already included under CRF category 3 B (cf. also Chapters 5.1.3.6.5 and 5.1.4, NIR 2018).

Such digestion processes are operated specifically for the purpose of generating biogas – and, thus, for producing a fuel (unlike composting). For this reason, most of the so-generated biogas is collected and used for energy generation, and only a small fraction is flared off. Quantity data on the two types of gas quantities involved are recorded directly at the relevant plants, and the data are collected for statistical purposes at two-year intervals. The results of such surveys are shown in annual waste statistics ((Statistisches Bundesamt, FS 19, R 1), Table 1.5). Methane emissions from combustion of biogas for energy generation are reported in the section for the energy sector, in 1.A.1.a.

Digestates produced from such separately collected waste are used for agricultural and horticultural purposes. Digestion of biowaste, in biogas plants, has been statistically recorded only since 1999 (Statistisches Bundesamt, ibid.). Such digestion has been reported since 1998, however, on the basis of an expert judgement whereby the activity data for that year were half as large as those for 1999. In earlier years, biowaste digestion took place on a largely negligible scale. Since then, it has been growing in importance, however. As of the 2015 NIR, therefore, and in keeping with the 2006 IPCC Guidelines, the inventory now also reports on biowaste digestion in biogas plants.

7.3.2.2 Methodological issues (5.B.2)

Nitrous oxide and methane emissions from digestion of biowaste are reported in keeping with the 2006 IPCC Guidelines. On the other hand, we use our own national emission factors, which were obtained via a research project (Cuhls et al., 2015). The methane and nitrous oxide emissions are calculated in accordance with the following formula:

$$E = M * EF$$

E = Emissions in kg

M = Mass of biowaste [kt]

EF = Emission factor [kg/kt]

The quantities of gas from biowaste digestion that are used for energy generation, and the gas quantities that are flared off, are also reported; since 2004, these data have been directly recorded in waste statistics at two-year intervals ((Statistisches Bundesamt, FS 19, R 1), Table 1.5).

Activity data

Since 1999, the Federal Statistical Office has regularly collected and published data, in various forms, on waste quantities managed in biowaste digestion plants (Statistisches Bundesamt, FS 19, R 1). To this end, it carries out exhaustive surveys of waste treatment facilities. Currently, the quantities of biowaste treated in digesting systems are calculated by summing the lines "biogas and digesting plants" ("Biogas- und Vergärungsanlagen") and "combined composting and digestion plants" ("Kombinierte Kompostierungs- und Vergärungsanlagen"). Also, the waste fraction that is digested in "other biological treatment facilities" is calculated and added to the above results. For this calculation, the percentage share of the digestates produced in such systems, with respect to the total output of "other biological treatment facilities" (compost and digestates) listed in Table 7.3 (ibid.), is applied to the managed waste quantity.

Any quantities of manure (especially slurry) that enter biowaste digestion plants are deducted from the total quantities of waste managed in such plants, since such manure (and slurry) is already included in CRF category 3B. This is achieved with the help of waste statistics as follows: the quantity listed under waste code 020106 is deducted from the total quantity. This approach, which is designed to prevent double-counting, has been coordinated with the experts responsible for category 3.

In the years 1990 through 2005, statistical surveys of waste quantities were less detailed than they were later on. In addition, they were not always carried out in the same manner, and they were carried out at different yearly intervals. For this reason, different values had to be interpolated in different ways, to some extent, and some values had to be extrapolated into the past.

The activity data for the current report year have to be estimated, since official waste statistics are published with a two-year time lag. For this reason, the total quantity of waste input into digesting systems is extrapolated, on the basis of the trend for the previous 3 years. Then, in the relevant subsequent year, that figure is replaced with the applicable statistical-survey figure. A similar procedure is carried out for the quantities of gas that are collected and flared off. Recalculations are thus required annually.

In preparation for the decision in factor of this procedure, review was carried out to determine the effects this extrapolation method has when it is carried out separately for each type of treatment facility. Because the trends are unclear, fluctuations – wide fluctuations, in some cases – can occur in the calculated activity data. Where they occur, experts do not consider them valid. On the other hand, extrapolation of the summed waste quantity generates a value that experts view as probably closer to the expected future value.

Emission factors

Emission factors for digestion of biowaste were determined in the framework of a research project (Cuhls et al., 2015). In that project, emissions measurements, covering methane, nitrous oxide and ammonia, were carried out at 16 digesters. From the results of those measurements, and from findings obtained via study of the literature, aggregated emission factors were extrapolated for the entire pool of such facilities in Germany. The factors take account both of the different facility technologies used in Germany and of the different types of biowaste used as input materials. In some facilities, very high emissions measurements resulted, and thus the average value is very high. Most facilities carried out several different measurement phases, to take account of different atmospheric / meteorological conditions (summer/winter) and to rule out the possibility that such conditions were the reason for especially high or low values. In the framework of a peer review (with the research contractor, the UBA and experts taking part), the very high measurements were identified as outliers and classified as non-representative. For this reason, it was agreed, with the research contractor (Cuhls), to use the median values as the emission factors. All measured emissions values entered into the derivation of the median values. The process of deriving the EF began with determination of individual EF for each different treatment technology. Then, each treatment technology was weighted in keeping with the quantities of waste treated in pertinent facilities in Germany (Cuhls et al., 2015), Table 5-1, which lists the various technologies involved and their shares of treated biowaste). Finally, the various EF were combined, with the help of the determined weighting factors, to form the currently used EF.

The following emission factors were obtained for digestion of biowaste (Cuhls et al., 2015), p. 136; page 142 in the English version):

EF-CH_4 = 2,800 g CH_4/ t biowaste

EF-N_2O = 67 g N_2O/ t biowaste

The aforementioned national emission factors include both the emissions from the digestion process, and from pertinent storage, and the emissions from use of the produced digestates. Such use comprises both the spreading of the digestates and the later mineralisation of the pertinent nitrogen in the soil. The calculation is described in Chapter 5.3.3 of Cuhls et al. (pages 102 – 109). Pursuant to Cuhls et al., the N_2O emission factor for anaerobic digestion of biowaste, and for use of the resulting digestates, amounts to a total of 67 g N_2O / t biowaste:

- The emissions from treatment amount to 45 g N_2O / t biowaste (ibid. p. 134).
- The emissions from storage / use / mineralisation amount to 22 g N_2O / t biowaste.

The IPCC provides no default factor for anaerobic digestion, under the assumption that the pertinent N_2O emissions are negligible.

In general, the nitrous oxide emissions following fertilisation with digestates are very low, since the nitrogen contained in digestates is organically bound and mineralises very slowly. Because nitrogen is released slowly under such conditions, it is largely absorbed by plants, and very little nitrogen is directly available (for example, in the form of nitrate) for conversion into nitrous oxide (Cuhls et al., 2015).

Information on emissions from digestion in the agricultural sector is provided in chapters 5.1.3.6.5 (category 3.B) and 5.1.4 (categories 3.D and 3.J).

7.3.2.3 Uncertainties and time-series consistency (5.B.2)

Activity data

The uncertainties for the waste quantities treated in digestion plants are considered to be very low (2 %), since the quantities are based on an exhaustive survey. This also applies to the statistical data collected on the gas quantities from biowaste digestion facilities that are used and on those that are flared off.

Emission factors

The uncertainties for the emission factors are high. They depend on the type of facility/plant in question, on waste composition and on the effectiveness of the biofilters used. The pertinent figures from the literature and from other countries vary so widely that uncertainties of +179 % to -77 % for CH_4, and of +320 % to -37 % for N_2O, are assumed. The uncertainties were determined in the framework of the aforementioned research project (Cuhls et al., 2015).

7.3.2.4 Source-specific quality assurance / control and verification (5.B.2)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The activity data consist of figures from federal waste statistics. No more-comprehensive or more-precise data are available.

The emission factors were determined on the basis of an evaluation of the relevant available literature, as well as on the basis of measurements. A literature search carried out by Oonk and Lambert (2017) also failed to turn up more recent data on emissions from biowaste-treatment facilities, and it confirmed the emission factors used by Germany.

The emission factors for methane and nitrous oxide that were determined in the research project include both anaerobic treatment of biowaste and aerobic final composting of digestates. For this reason, the value used for methane, at 2.8 g CH_4/kg waste, is considerably higher than the default value of 1 g CH_4/kg waste. However, it does lie within the range for that value, 0 to 8 g CH_4/kg waste. The Guidelines provide no emission factor for nitrous oxide – presumably, because they consider only the relevant anaerobic process.

A comparison of the CH_4-IEF with the IPCC default values shows that the former is considerably larger than the latter. The reason for this is that the IEF is calculated as follows, in keeping with the calculation method given in the CRF: IEF = (CH_4 emissions + CH_4 recovered + CH_4 flared off) / annual quantity of waste in digestion plants. The German CH_4-emissions figure, however, is based solely on emissions that occur during treatment. The data on quantities of CH_4 that are recovered and flared off are obtained from national statistics. They are not of relevance for the emission calculation, since they are used for energy generation or are negligibly low. Consequently, the CRF method for IEF calculation is misleading – at least it is not useful for any comparison of the various countries, since countries that do not recover and flare off CH_4 achieve the EF default values. Countries that collect CH_4 and use it for energy generation do not achieve the default values – in fact, they greatly exceed them, since the recovered and flared-off quantities of CH_4 that are involved naturally greatly exceed the quantities of CH_4 that are diffusely emitted.
This assessment is confirmed by a look at the IEF of the reporting countries (GHG Locator 2020) – the values exhibit an extremely wide range, and they do not lend themselves to comparison.

As described above, the Guidelines provide no EF for N_2O, because such emissions are seen as negligible. Consequently, apart from Germany, only the Netherlands reports emissions in this area. The two countries' IEF values are quite similar.

A comparison, carried out for the 2020 report, of Germany's emission factors for methane emissions from biowaste digestion plants and the factors of Austria and Denmark shows that the latter two countries list their emissions as a loss, expressed as a percentage of the total quantity of methane formed. Conversion of the German emission factor to this perspective yields a loss of 5.7%. That value is directly comparable to those of the two other countries mentioned.

None of the countries reports on nitrous oxide emissions from digestion plants.

Table 450: Comparison of emission factors for digestion

EF in g/t	Germany	Austria	Denmark
Methane CH_4	2800 (5.7%)	5%	4%
Nitrous oxide N_2O	74	-	-

Source: For Germany, current submission; for other countries, the 2019 submission (UNFCCC, 2020)

7.3.2.5 Category-specific recalculations (5.B.2)

In each case, when the inventory data for the current year are being prepared, the most recent available statistical data (Statistisches Bundesamt, FS 19, R 1) on landfilled quantities of waste are the data for the previous reporting year; the Federal Statistical Office's waste quantities appear with a two-year time lag. For this reason, and as described above, the figures for the current report year are extrapolated on the basis of the activity-data trend of the past three years. In the relevant subsequent year, the data so extrapolated are replaced with the data obtained via statistical survey. For this reason, each year, the previous year's figures have to be recalculated.

In the annual quality assurance procedure, minor rounding errors in the activity data in the CSE were identified. These errors have been corrected. In light of the negligibility of the resulting recalculation, we refrain from presenting it in detail. The following presents the recalculations for 2019.

Table 451: Recalculations, CRF 5.B.2

Designation	Units	Report year	2019
Waste quantities managed in biogas and digestion plants (TOTAL)	[kt]	2022	5,752.9
		2021	5,624.1
CH_4	[t]	2022	16,108.1
		2021	15,747.6
N_2O	[t]	2022	385.4
		2021	376.8

In addition to the execution of these annual recalculations, the methane density used for calculation of collected and flared quantities of methane (additional information) was consolidated with values in other inventory categories. The density value was adjusted from 0.716 to 0.717 kg/m^3. This leads to a very minor change in the reported quantities of methane, throughout the entire time series. Because the changes are so slight, they are not listed explicitly here.

7.3.2.6 Category-specific planned improvements (5.B.2)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

7.4 Waste incineration (5.C)

In Germany, all plant(facility)-based waste incineration either is tied completely to energy generation or takes place in the crematorium sector. In order to prevent double-counting, the emissions that occur in connection with waste incineration with energy generation are reported in the energy section (CRF 1.A.1.a, Chapter 3.2.6). In 5.C, only emissions of NO_X, SO_2 and NMVOC from crematoriums (facilities) and NO_X, SO_2, CO and NMVOC from bonfires (open combustion carried out in connection with cultural customs) are reported.

7.4.1 Crematoriums

Gas	Method used	Source for the activity data	Emission factors used
NOX, SO2, NMVOC	Tier 1	AS	CS

The data on cremations are calculated from figures of the Federal association of German funeral homes (Bundesverband Deutscher Bestatter e.V.) and from the official death rates for Germany

(W. Statistisches Bundesamt, 2021b). Cremations have been accounting for a growing share of all funerals (Bundesverband Deutscher Bestatter, 2021), and thus the absolute numbers of cremations have been growing as well (the number has increased to about 700,000 per year). As a result, the listed pertinent emissions show an increasing trend. Since the CRF Reporter calls for the units "kt" to be used for the activity data, the CRF tables list a calculated figure. For reasons of reverence, the relevant conversion is not described here in detail. It is comparable to that found in other publications, however.

The following figures provide an overview of the actual numbers of cremations involved:

Table 452: Actual number of cremations

Cremations	1990	1995	2000	2005	2010	2015	2019	2020
Number (in thousands)	169	316	328	365	427	574	658	710

Source: Own calculations

No greenhouse-gas emissions are calculated, but the precursor substances NO_X, SO_2, CO and NMVOC are taken into account. Emissions of these substances are calculated using the EF default values in the EMEP/EEA Air Pollutant Emission Inventory Guidebook 2013.

Plans call for reviewing the suitability of the emission factors listed in the 2016 EMEP Guidebook and for taking the latest pertinent measurements into account.

7.4.2 Bonfires and similar open combustion

Gas	Method used	Source for the activity data	Emission factors used
NOX, SO2, CO, NMVOC	Tier 1	M, Q	C

The emissions taken into account in connection with open combustion of wood and green waste, for traditional purposes – e.g. emissions from customs such as Easter bonfires (in Germany) – include biogenic carbon dioxide and NO_X, SO_2, CO and NMVOC emissions.

The applicable number of such culturally oriented bonfires was determined in the framework of a project carried out by experts (Wagner & Steinmetzer, 2018) and involving surveys of municipalities and statistical extrapolations for Germany for the year 2016. In keeping with the consensus of the participating experts, the numbers of fires are assumed to exhibit a declining trend throughout the entire period in question.

In light of the restrictions of public activities prevailing during the pandemic, a model entailing considerably fewer numbers of traditional events was sought. Beginning in the relevant expert project, two types of fires were differentiated: campfires in (more or less) private settings, and Easter bonfires in more-public settings. The calculations are carried out separately for these two types of fire settings, and a model incorporating a continuing decrease in such fires is used. In particular, the approach used for Easter bonfires applies general, percentage-based decreases, and an additional 5 % decrease in 2019 to account for various cancellations related to wildfire risks. In 2020, an additional decrease of 70 percent was modelled, to reflect cancellations related to pandemic-control measures (no complete discontinuation of such bonfires took place in Germany; there were exceptions and later staging of events that had been postponed).

Slight recalculations were required to take account of model adjustments for the period as of 2017. The recalculations for 2019 are of greater magnitude, due to the aforementioned model assumptions, but they do not involve any fossil-based greenhouse gases.

No further improvements are planned at present.

7.5 Wastewater treatment (5.D)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/T	**5 D 1, Domestic Wastewater**		**CH_4**	**2,563.2**	**0.2%**	**435.5**	**0.1%**	**-83.0%**
-/-/T2	**5 D 1, Domestic Wastewater**		**N_2O**	**1,157.5**	**0.1%**	**431.7**	**0.1%**	**-62.7%**
-/-	5 D 2, Industrial Wastewater		N_2O	31.6	0.0%	26.8	0.0%	-15.2%
-/-	5 D 2, Industrial Wastewater		CH_4	9.3	0.0%	47.2	0.0%	410.5%

The category *Wastewater treatment – domestic wastewater* is a key category for CH_4 emissions in terms of trend, and a key category for N_2O emissions pursuant to Approach 2 level & trend analysis. Because relevant emissions have been falling very sharply since 1990, and thus an extremely low emissions level has been attained, the Single National Entity has decided, as part of its resources prioritisation, not to apply the more stringent methods to this category that are required for key categories.

7.5.1 Domestic wastewater treatment (5.D.1)

More than 99% of all municipal wastewater treatment (with respect to annual wastewater quantities) in Germany takes place in centralised wastewater treatment plants. Some 97% of all households (with respect to population) are connected to such plants via public sewer systems. The remaining 3% of the population are served by other types of wastewater-treatment systems (small wastewater treatment plants, cesspools and septic tanks). All of the aforementioned forms of wastewater treatment (centralised wastewater treatment plants, small wastewater treatment plants, cesspools and septic tanks) fall into the area of municipal wastewater treatment. In addition to domestic wastewater, municipal wastewater treatment plants also treat indirect discharges of industry and commerce (amounting to about 30% of wastewater, with respect to connected numbers of inhabitants or population equivalents) and precipitation water from mixed sewer systems.

Most of the municipal wastewater treatment plants in Germany use the activated sludge process. Also, over 90% of the wastewater produced in Germany is treated in plants that are equipped with denitrification systems. In most cases, the primary sludge produced in pre-clarification, and the excess sludge resulting from the activated sludge process, are stabilised in digestion towers located either on site or at major wastewater treatment plants. Such towers are designed to produce sewage gas, which is used for energy generation. Once it has been digested, sludge is usually dried and then incinerated – ideally, for the purpose of recovering valuable raw materials such as phosphorous. Direct use of (digested) sewage sludge, as such, in agriculture, has been decreasing.

Pursuant to Annex 1 of the German Waste Water Ordinance (Abwasserverordnung), municipal wastewater treatment plants in Germany are divided into size classes, on the basis of their biological oxygen demand, as shown in the table below. Via information provided in the EU Urban Waste-Water Treatment Directive (Art. 2 No. 6 91/271/EEC → 1 population equivalent (p.e.) = 60 g BOD_5 / d), classifications on the basis of biochemical oxygen demand can be converted into classifications on the basis of population equivalents.

Table 453: Size classes of wastewater treatment facilities pursuant to Annex 1 of the Waste Water Ordinance (Abwasserverordnung)

Samples pursuant to size classes of wastewater treatment facilities	Biochemical oxygen demand (BOB5) [kg/d]	Population equivalent, p.e. [-]
Size class 1	< 60	< 1,000
Size class 2	60 – 300	1,000 – 5,000
Size class 3	> 300 - 600	> 5,000 – 10,000
Size class 4	> 600 – 6,000	> 10,000 – 100,000
Size class 5	> 6,000	> 100,000

Pursuant to the IPCC Guidelines, the most important greenhouse gases with regard to municipal wastewater treatment are methane and nitrous oxide. With respect to methane, sludge treatment has been identified as a key source; with respect to nitrous oxide, the activated sludge process has been so identified. Little data, either national or international, are available on these areas.

With respect to Germany's total emissions, only a very small share of these substances (about 0.1%) comes from municipal wastewater treatment. The sector's emissions show a decreasing trend. With respect to the year 1990, the sector's emissions (CO_2 equivalents) have decreased by more than 75%. In the view of the Federal Environment Agency (UBA), this decrease is due primarily to increasing levels of connection to municipal wastewater treatment and to elimination of open sludge digestion.

Until 1990, Germany was divided into the Federal Republic of Germany and the German Democratic Republic. The special circumstances arising from this division, and the differences between the two countries, are described in the relevant sections of the present report.

7.5.1.1 Methane emissions from domestic wastewater treatment (5.D.1 domestic wastewater treatment)

7.5.1.1.1 Category description (5.D.1 municipal wastewater treatment)

Gas	Method used	Source for the activity data	Emission factors used
CH_4	D/CS	NS	D/CS
N_2O	D/CS	NS	D/CS

The category *Wastewater treatment – domestic wastewater* is a key category for CO_4 emissions in terms of trend.

A total of 99.5% of the wastewater annually produced in Germany is treated in centralised wastewater treatment plants (Statistisches Bundesamt, FS 19, R 2.1.3a). Methane occurs in such treatment, as a result of the anaerobic metabolic processes it entails. While probably all wastewater treatment process steps contribute to such emissions, sludge digestion and stacking of digested sludge account for the largest shares of the emissions. Sludge thickening, grit-chamber processes and denitrification account for considerably smaller shares of the emissions.

The remaining 0.5 % of wastewater is treated in small wastewater treatment plants or is collected, for later transport to wastewater treatment plants, in cesspools or septic tanks with no drainage. In cesspools and septic tanks, processes (partly aerobic, partly anaerobic) can occur that lead to methane formation.

The organic loads discharged into cesspools and septic tanks have decreased since 1990, since the degree of connection to wastewater treatment plants has continually increased during that period as a result of requirements imposed by the EU Urban Waste-Water Treatment Directive (cf. Art. 3 & 7 of 91/271/EEC).

Until the early 1990s, open sludge digestion was used, for sludge stabilisation, in the German federal states of the former GDR. Following a period of gradual reduction, open sludge digestion was completely terminated in 1994 (cf. Chapter 7.5.1.2.1). As a result, this sector's CH_4 emissions show a sharply decreasing trend.

7.5.1.1.2 Methodological issues (5.D.1 wastewater treatment)

Equation 6.1 (IPCC (2006a): Vol. 5, Chapter 6.2.2.), which the IPCC has recommended for calculation of CH_4 emissions from domestic wastewater, cannot be applied to the situation in Germany, as is explained below. Two of the two population fractions (U_i) listed in Table 6.5 of the IPCC Guidelines (ibid.) – rural and urban-high – contribute to the emissions concerned. In addition, the pertinent primary and secondary sludges are used for generation of CH_4 in digestion towers. The resulting methane is recovered, and the total quantity of CH_4 produced in the process far exceeds the CH_4 emissions calculated via Equation 6.1. As a consequence, the pertinent value resulting from the IPCC equation would be negative. What is more, sewage sludge is used (incinerated, for example, or used as a secondary raw material for agricultural or landscaping purposes) only after the sewage gas from it has been recovered, i.e. after it has been fully digested. For this reason, the term "sludge removed" as used within the meaning of the Guidelines is not appropriate, since the sewage sludge is already fully digested and no longer has any BOD_5 (cf. also Chapter 7.5.1.2.1). Furthermore, the data available in Germany on numbers of persons connected to cesspools and septic tanks are much more precise than the values for U_i and $T_{i,j}$ (degree of utilisation of treatment system) that can be derived with Table 6.5 of the IPCC Guidelines. All in all, the 2006 Guidelines method is too limited to be suitable for the situation actually prevailing in Germany. For the above-described reasons, calculation is carried out not with the relevant equation in the 2006 IPCC Guidelines, but with the 1996 IPCC method – with that method supplemented in accordance with the requirements set forth in the 2006 IPCC Guidelines.

The calculation of **methane emissions from wastewater treatment plants** is based on a limited number of measurements from Becker et al. (2012). An emission factor of 0.26 kg methane per year and inhabitant can be derived from the data given in that publication. The measurements were carried out at three municipal wastewater treatment plants. All in all, they comprise all potentially emissions-relevant mechanical and biological process steps in wastewater treatment (grit chamber, nitrification, denitrification, P elimination), including sludge treatment (primary and excess sludge, sludge digestion, sludge stacking). The study covered only a very limited number of measurements. For this reason, the resulting EF should be seen more as the result of sampling, and less as a representative emission factor. Furthermore, the uncertainty is also quite high, in light of the wide range covered by the measurements, and of the small number of measurements involved. It is of limited reliability, both from a scientific standpoint and in light of the IPCC's quality standards for reference sources. During the 2016 In Country Review, Germany was informed that it is required to use the above EF, however.

Because municipal wastewater treatment plants in Germany tend to have the same types of equipment, with regard to biological wastewater treatment, this emission factor is applied to all wastewater treatment plants.

Since virtually all of Germany's inhabitants (about 97 %) are connected to one of the some 9100 wastewater treatment plants in the country (Statistisches Bundesamt, FS 19, R 2.1.2), the country's total population is used as the activity data. Because the total-population figure is used in the calculations, and because small wastewater treatment plants and cesspools and septic tanks are taken into account, the result may safely be considered to be conservative. Any emission factor for small wastewater treatment plants would probably be lower, because such plants lack sludge treatment. While wastewater from cesspools and septic tanks is taken to municipal wastewater treatment plants – meaning that it also has to be considered here – such wastewater is already partly digested by the time it reaches such treatment plants. As a result, the emissions figures for wastewater treatment plants and those for cesspools and septic tanks overlap somewhat. Due to a lack of precise data, such overlapping cannot be precisely quantified. On the other hand, it is of very small magnitude and thus can be neglected. The development for the period as of 1990 that underlies the trend in the emission factor is based on a technical article (Grün et al., 2013). Its specific considerations applying to the catchment area of the "Emscher System" (North Rhine – Westphalia) have been generalised and, on the basis of expert judgements, taken as representative for Germany as a whole. This may be considered plausible in light of the highly consistent standards of wastewater treatment technology and plant management prevailing throughout the municipal wastewater treatment sector. The technical article assumes that emissions will be cut in half as a result of improvements in plant technology and plant management in the period 1990 through 2020. It must be noted that this development has been derived solely from the aforementioned improvements to wastewater treatment plants (such as more-efficient aeration systems, and optimised operational management); it does not take account of the specific emissions reductions resulting from conversions of previously open sewer systems in the Emscher catchment basin. This means that the special aspects of the Emscher systems (in comparison to the average German wastewater treatment plants) have not entered into the trend as determined. For calculation of the individual emission factors for the years as of 1990, the above-described emission factor for the year 2011 is used as a fixed starting value. The emission factor for 1990 was determined via a linear equation, in combination with the assumption that the value for 2020 would be half as large as that for 1990. The emission factors for the other years can be determined via linear interpolation. Because the calculation method, described here, that is used to determine the emission factor for emissions from wastewater treatment plants makes use of real measurements, there is no point in applying a methane correction factor (MCF).

Organic loads from **cesspools and septic tanks** are calculated pursuant to the IPCC method, in which the number of persons connected to cesspools or septic tanks (P) is multiplied by the average organic load per person. The average organic load is assumed to be 60 g BOD_5 per inhabitant (Gujer, 2006). While that is the specific value for Germany, it is also used throughout Europe as a statistical average (91/271/EWG, 1991). The IPCC default value for Germany, at 62 g, is of the same order of magnitude (2006 IPCC Guidelines, (2006a): Vol. 5, Chapter 6, Table 6.4).

Methane emissions from cesspools and septic tanks are also determined in keeping with the IPCC method. The IPCC default value for methane formation potential (0.6 kg CH_4 / kg BOD_5) has been used. Pursuant to IPCC (IPCC (2006a): Chapter 6.1, page 6.7), the methane correction factor (MCF) depends on temperature. No significant methane production occurs at temperatures below 15°C.

In light of the long-term mean soil temperature in Germany (DWD, 2013) at a depth of 1 m, the soil temperature in summer months ranges between 15 and 18°C. Methane thus can form during summer months, since the relevant cesspools and septic tanks are situated at about such a depth. In keeping with Gibbs and Woodbury (1993), the MCF for this period (about 3.5 months) is conservatively estimated to be 0.35. Throughout the rest of the year, the temperatures are below – significantly, in part – the IPCC's 15°C boundary. They drop to about 3.8 °C. In keeping with Gibbs and Woodbury (1993), the MCF for this period (about 8.5 months) is conservatively estimated to be 0.1 (according to the IPCC, an MCF of 0 would be justified). Furthermore, since the cesspools and septic tanks are regularly emptied, for transport of their wastewater to treatment plants, and thus no sedimentation or sludge concentration occurs, the values used are assumed to be realistic or even conservative. The figures given by Gibbs and Woodbury (1993) refer to studies on methane formation in animal manure (slurry). Since no similar data, either national or international, for human excretions are available, and since the pertinent IPCC default values are not applicable to the German situation, the MCF values determined in that study (ibid.) are assumed to be applicable to the task of determining a national MCF. In the present context, the MCF describes the methane-formation potential achieved by the waste management system used. Systems for slurry storage usually consist of non-mixing systems with regular, but discontinuous, waste addition and withdrawal. This description appears sufficiently applicable to cesspools and septic tanks. In addition, the effects of any substrates, with regard to MCF, are tied to purely technical aspects. Since a substrate's methane-formation potential is described by B_o, for comparison purposes it suffices to consider its dry matter (mass percentage). The applicable mass percentage is assumed to be 5% for swine slurry, and 7.5% for cattle slurry (LfL Bayern, 2009). The percentage for thickened primary sludge from wastewater treatment is about 5-10% (DWA, 2007). The Federal Environment Agency assumes that the relevant values in raw wastewater, even in areas with lower water use that are not connected to the public sewer system, are considerably below the aforementioned values – and, thus, also below the values prevailing in slurry dry matter. This seems plausible given that such wastewater has inflows of grey water and toilet wastewater, and that straw bedding is used in animal husbandry. Consequently, it is safe to say that, as a result of the thinner suspension involved (which implies a lower oxygen consumption), anaerobic conditions arise more slowly in such wastewater than they do in stored slurry, and conversion to methane is correspondingly delayed. Furthermore, cesspools and septic tanks are ventilated only via a ventilation opening, while storage tanks for slurry are often completely open. As a result, the described approach is likely to be a conservative one. Review of the MCF reported in Thünen-Report No. 77 (Haenel, 2020), for storage of swine slurry (0.25), highlights the conservative nature of the MCF we have chosen (0.35). Since no specific data regarding the transferability of this result are available, the uncertainty for it is estimated to be 20% (cf. Chapter 7.5.1.1.3). A research project completed in 2018 (unpublished) explored whether any better data, either national or international, are available for derivation of a country-specific MCF. To this end, an extensive study of the pertinent literature was carried out. In addition, national manufacturers of cesspools and septic tanks, and national scientific and university institutions, were surveyed as whether any measurements on methane formation in cesspools and septic tanks are available. The study found that the very few measurements published in the international literature do not support any conclusions with regard to derivation of a national MCF. Furthermore, neither the manufacturers nor the surveyed institutions have any information regarding methane formation. For this reason, the MCF presented here will continue to be used in future, at least until suitable measurements become available.

The above-described conditions and temperature distribution in the soil yield a mathematically averaged MCF for Germany of 0.173.

The MCF is determined as follows:

$$MCF = (0.35 * 3.5\ months + 0.1 * 8.5\ months) / 12\ months$$

(Gibbs and Woodbury 1993) use an estimate of 0.35 for temperatures > 15° C and an estimate of 0.1 for temperatures < 15° C

The emissions are calculated as follows:

$$CH_4 = BOD_{5Y} \times B_o \times MCF$$

$$BOD_{5Y} = P_{cesspool,\ septic\ tanks} \times BOD_5 \times 365 \times 0.001$$

Where

MCF = *Methane correction factor, 0.173*

B_o	= *Default value for max. CH_4 formation capacity, 0.6 kg CH_4 / kg BOD_5*
$P_{cesspools, septic tanks}$ *septic*	= *Number of persons connected to cesspools or tanks*
BOD_{5Y}	= *BOD_5 in g / year*
BOD_5	= *60 g / day x persons*

Calculation pursuant to more-stringent requirements (in keeping with higher-Tier methods, or higher hierarchical levels), as required for key categories, is not feasible, since the substance flows for cesspools and septic tanks without drainage are not separately recorded.

With regard to verification of the MCF used, cf. Chapter 7.5.1.1.4.

The following table presents inhabitant data for Germany as a whole and for inhabitants connected to cesspools and septic tanks. The values for the period 1990-2015 have been recorded at five-year intervals, while those for the period as of 2017, i.e. for the last five years, have been recorded on an annual basis. Overall, the values provide a framework for following the calculations described in this section.

Table 454: Inhabitants of Germany as a whole, and inhabitants connected to cesspools and septic tanks

Inhabitants [1000s of persons]	1990	1995	2000	2005	2010	2015	2017	2018	2019	2020
Cesspools and septic tanks	8234.425	6434.800	1266.667	875.667	575.000	448.609	387.982	367.773	347.564	8234.425
Germany as a whole	79753.227	81307.715	81456.617	81336.663	80284.071	82175.684	83019.213	83166.711	83155.031	79753.227

The **total emissions of methane** from the area of municipal wastewater treatment are obtained as the sums of the emissions (as described in detail) from wastewater treatment plants, cesspools and septic tanks and open sludge digestion (cf. Chapter 7.5.1.2.2.3).

7.5.1.1.3 Uncertainties and time-series consistency (5.D.1 wastewater treatment)

As described in section 7.5.1.1.2, the MCF value has been adjusted in keeping with the climatic conditions prevailing in Germany (long-term average soil temperature at a depth of 1m). The uncertainty for the value is ± 20 % (UBA expert estimate).

In addition, the following uncertainties are also used (all are expert estimates):

- The emission factor for CH_4 from wastewater treatment plants = ± 25 %
  The uncertainty is obtained from the range for CH_4 emissions (± 28.6%) given in the literature (Becker et al. (2012)) and the probable 95th percentile derived from it.
- Inhabitants with cesspools or septic tanks = ± 3 %
- BOD_5 = ± 30 %
- B_0 = ± 30 %

The activity data for organic loads in cesspools and septic tanks are based on figures of the Federal Statistical Office (Statistisches Bundesamt, FS 19, R 2.1.3a). Every three years, the Federal Statistical Office conducts a survey – without determining the relevant uncertainties – of the numbers of inhabitants who are not connected to the public sewer system and whose wastewater is disposed of via cesspools and septic tanks. Data for interim years are linearly interpolated or extrapolated. No other data sources are available. The results of such surveys may be considered very precise, since the surveys are exhaustive.

Until 1995, data for the old and new Federal Länder were determined separately; since then, a single value for all of Germany has been determined in each case. This does not affect the consistency of the time series.

7.5.1.1.4 Category-specific quality assurance/ control and verification (5.D.1 Wastewater treatment)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

Since the above-described research project (unpublished; cf. Chapter 7.5.1.1.2) was unable to find a country-specific MCF for calculation of emissions from cesspools and septic tanks, and since the reference source currently being used (Gibbs and Woodbury (1993)) in this area seems problematic from a scientific perspective, the national MCF derived from that source was subjected to multi-step verification.

In a first step, verification was carried out with the help of the considerations and information provided in the IPCC Refinements (2019) (IPCC, 2019b)}, which has not yet entered into force, and with the help of the references cited in that source. Even when that source's constraints are applied – 12 °C as the temperature limit for biological activity; use of air temperature instead of soil temperature; and use of an MCF of 0.4 (the lower bound for cesspools and septic tanks) – the MCF resulting for Germany, 0.225 (0.4*5 months + 0.1*7 months = 0.225) differs only slightly from the MCF we obtained. The pertinent study cited in the Refinements, (Leverenz, 2010), obtained an MCF of 0.22. That value is only slightly higher than the MCF derived for Germany, 0.173, and it supports the basic plausibility of that value. At the same time, a number of fundamental aspects apply in Germany that imply that the country's MCF should be lower than the MCF determined by Leverenz. In all likelihood, the slight discrepancy is due to differences in climatic conditions, since the average annual air temperatures prevailing in Germany are lower, overall, than those prevailing in San Francisco, California. In addition, cesspools and septic tanks are installed underground in Germany. The minimum installation depth for them is 0.5 m. At that depth, only their vent pipes (which rise above the ground surface) are in contact with the atmosphere, for purposes of gas balancing. Consequently, such a system would not be expected to have any airflow moving from outside into the inside of the tank, meaning that it would experience extremely little influence from oxygen carried into the tank. Furthermore, temperatures within the tank would not at all be affected by the high air temperatures typically prevailing in summer. In addition, the average ground temperatures in Germany in the summer are lower, on the whole, than prevailing air temperatures, meaning they would be lower still than the air temperatures prevailing in San Francisco. Influxes of warm water are seen as insignificant, since the quantities involved are small in volume, and since the cooling effects of surrounding soil are considerably higher than those of surrounding air. Within UBA, such influxes are seen to have little importance. In addition, the study of LEVERENZ et al (Leverenz, 2010) considers systems with connected ground irrigation. The systems used in Germany, by contrast, are drainless systems that have to be emptied by tank trucks, at correspondingly more-frequent intervals. As a result of this basic design aspect, as (Leverenz, 2010) show, the onset of methanogenesis in such systems takes several months. That, in turn, means that if they are frequently emptied, they can be expected to have a low MCF.
The results of (Leverenz, 2010) were confirmed, in the following year, by (Diaz-Valbuena, 2011), which also cite a BOD_5 load of 85 to 90 g BOD_5/inhabitant/day. The German BOD_5 value is 60 g BOD_5/inhabitant/day, a level at which even less organic material is available for methanogenesis.

In light of the above-described calculations and arguments overall, we consider the German MCF to be confirmed.

In a second approach, the MCF was verified on the basis of alternative activity data. Instead of a calculation via the annual organic load, via BOD_5 = 60g/d*inhabitant, that approach used a calculation via the specific wastewater production per inhabitant, in the non-central sector (83l/d*inhabitant), and an average BOD_5 inflow concentration (750 mg/l) (BDZ, 2017). The alternative activity data were obtained from a study of small wastewater treatment plants. It may be assumed that, because removal of wastewater from cesspools and septic tanks is subject to charges, users of such systems use less water than do users of small wastewater treatment plants. Consequently, the upper value for the BOD_5 concentration has been adopted. The values so obtained are nearly identical to the values obtained for reporting purposes.

Table 455: Verification of CH_4 from cesspools and septic tanks

CH_4 from cesspools and septic tanks [kt]	2015	2016	2017	2018	2019	2020
via BOD5 load / inhabitant (Gujer)	1.020	0.974	0.928	0.882	0.836	0.790
via BOD5 concentration and wastewater production (BDZ)	1.058	1.010	0.963	0.915	0.867	0.820

The IPCC Guideline for calculation of emissions from central wastewater treatment systems is not applicable. A comparison with the IPCC method and default values yields approximately triple the emissions for cesspools and septic tanks. That approach is considered inapplicable, however, because the ambient temperature reduces methanogenesis. For this reason, a country-specific MCF was derived. For such systems as well, a method tailored to Germany, based on measurements, has been used.

In a third approach, the MCF for cesspools and septic tanks was verified via a general comparison with the approaches taken by other countries. That comparison considers the entire wastewater treatment sector as a whole; the MCF (where available in the reports considered) is one aspect of the consideration. The method used, and the resulting emission factors, were compared with the methods and factors of countries that have similar wastewater system standards. In each case, the 2020 NIR was considered, and the parameters used have good overall comparability. The following specific results emerged:

- Austria: Similar method for determining emissions from cesspools and septic tanks; slightly higher MCF (0.27). The difference in the MCF is due to differences in the temperatures considered, although it is unclear whether the Austrian result is tied to air temperatures or ground temperatures. No consideration of emissions from wastewater treatment in wastewater treatment plants, and no consideration of emissions from sludge treatment.
- Switzerland: No consideration of inhabitants not connected to the public sewer system. Because such inhabitants account for a very small share of the total population, their systems are considered negligible. Other reasons given as to why those systems are negligible are that a) as in Germany, such systems are usually installed underground; and b) they have low average temperatures. A combined approach, considering both municipal and industrial wastewater, is taken in considering emissions from central wastewater treatment plants. Relevant calculations are made with the IPCC method and default values. Overall, an EF of 0.89 kg CH_4/inhabitant*a results. The EF for Germany (for 2018, 0.21 kg CH_4/inhabitant*a) is of the same order of magnitude. It is lower, however.

- The Netherlands: Consideration of cesspools and septic tanks. Relevant calculations are made in accordance with the IPCC Guideline. Emissions from centralized wastewater treatment are calculated in keeping with the IPCC Guidelines, and using a country-specific EF. The resulting per-inhabitant EF = 0.46 kg CH_4/inhabitant*a. That EF is close to the EF used for Germany.
- Denmark: Calculation for both central and non-central systems, as well as for anaerobic systems (such as systems for sewage-sludge stabilization), including systems for industrial wastewater. The calculations are carried out with the methods given by the IPCC Guidelines, but with reference to country-specific EF. The per-inhabitant EF for the total emissions from the wastewater sector is EF = 0.35 kg CH_4 /inhabitant*a. That EF is also close to the EF used for Germany.

A comparison of the methane-emissions IEF with the IEF of other countries (GHG Locator 2020) shows that Germany's value is slightly higher than those of most of the comparable countries. This is due to use of the above-described calculation method, which diverges from the IPCC-Guidelines method, and to the fact that partly digested wastewater from cesspools and septic tanks, and from small wastewater treatment plants, has been taken into account in consideration of emissions from central wastewater treatment plants.

7.5.1.1.5 Source-specific recalculations (5.D.1 Wastewater treatment)

For reporting purposes, the approach described in 7.5.1.1.2 for determining methane emissions from cesspools and septic tanks is carried out within the Central System of Emissions (CSE), using the implied emission factor (IEF), and the annual total organic load in wastewater (TOW), for Germany. As a result of the adjustment of factor I, from 1.25 (default, 2006 IPCC Guidelines (IPCC (2006a): Vol. 5, Chapter 6.2.2.3, Equation 6.3) to 1.3 (to reflect a figure of about 30% industrial and commercial wastewater as indirect discharges; cf. Chapter 7.5.1.3.2 regarding $F_{IND-COM}$), both values change, as shown in the following table. With the method being used, this has no impacts on emissions, however.

Table 456: Recalculation of IEF and TOW to take account of adjustment of factor I

Designation	Units		1990	2000	2010	2015	2017	2018	2019
Organic load (BOD5/year), for Germany as a whole	[kt/a]	NIR2022	2270.574	2319.070	2285.688	2339.542	2357.098	2363.557	2367.756
Organic load (BOD5/year), for Germany as a whole	[kt/a]	NIR2021	2183.245	2229.875	2197.776	2249.559	2266.441	2272.651	2276.689
Implied emission factor	[kg/kg]	NIR2022	0.00824402	0.001241624	0.000571864	0.000435892	0.000393665	0.000373153	0.000353089
Implied emission factor	[kg/kg]	NIR2021	0.00857378	0.001291289	0.000594738	0.000453327	0.000409412	0.000388079	0.000367213

7.5.1.1.6 Planned improvements, category-specific (5.D.1 Wastewater treatment)

In a national research project, measurements of methane and nitrous oxide emissions were carried out, with the aim of using the measurements as a basis for deriving emission factors for the area of municipal wastewater treatment. That project has not yet been completed, due to pandemic-related delays in the expert assessment of the project, and to changes of task assignments as a result of restructuring in the affected UBA specialised department. The UBA will be able to carry out a final assessment of the project results only after the project's completion.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

7.5.1.2 Methane emissions from municipal sludge treatment (5.D.1 Sludge treatment)

7.5.1.2.1 Category description (5.D.1 Sludge treatment)

As a general rule, the treatment of municipal sewage sludge comprises two treatment stages:

- Water removal via mechanical processes (chamber-filter press, cyclone); evaporation in sludge-drying lagoons or sludge-drying beds
- Stabilisation: Aerobic stabilisation (open pool with oxygen input); or anaerobic stabilisation in digestion tower
- (until 1993: open sludge digestion)

The secondary sludge (excess sludge) occurring in wastewater treatment, and the pertinent primary sludge, are anaerobically treated, together, in digestion towers and thus anaerobically stablised. That process produces digested sludge. That sludge, in turn, undergoes further treatment in wastewater treatment facilities and leaves such facilities as sewage sludge. Use of this process ensures that the sewage sludge is free of readily biodegradable substances and has been completely digested. It is assumed that digested sludge produces no methane emissions. The emissions from sludge treatment are an integral component of the emission factor described in 7.5.1.1.2. Consequently, all of the emissions originating in sewage sludge are taken into account in 5.D.1. No emissions occur in other sectors. No information is available with regard to the quantities of sludge involved prior to digestion.

The purpose of sludge stabilisation is to prevent uncontrolled sludge digestion. In large systems, digestion is aerobic. In smaller ones, sludge is digested aerobically or is transported to larger plants for anaerobic stabilisation.[138]. The amount of digester gas produced via anaerobic sludge stabilisation depends especially on the composition of the sewage sludge, the temperature and the reaction conditions. Gas so produced is usually recovered for energy generation in combined heat/power generating systems (CHP). It is reported under 1.A.1.

With reference to population figures, mechanical *dehydration* + treatment in a digestion tower (with dehydration before or after the digestion-tower treatment) currently represents the main treatment method (some treatment is also carried out in small, rural sewage treatment plants). Moreover, sewage sludge is generally stabilised prior to subsequent use.

Until the early 1990s, in eastern Germany sludge was still stabilised via open digestion, a process that produced methane emissions. Open sludge digestion is no longer practiced. It was phased out gradually, and was then completely discontinued in 1994. Emissions from open sludge digestion continue to be the reason, however, why NO is reported for this point in the CRF, instead of IE (for the energy-related use under 1.A.1 – see above), since this technique, with its related emissions, was used through 1993.

The sewage sludge and the treated wastewater are the final products of wastewater treatment.

In Germany, sewage sludge remaining after biological wastewater treatment is managed in the following ways (where applicable, after dehydration and stabilisation):

- <u>Thermal utilisation:</u> no methane emissions occur. Thermal utilisation requires energy inputs and thus is allocated to CRF 1.

[138] In 2016, digester gas was recovered in a total of 1,258 wastewater treatment facilities (Statistisches Bundesamt, 2017).

- Recycling for substance recovery: the most important procedures for recycling sewage sludge for substance recovery include a) recycling in agriculture, – i.e. use as a secondary-raw-material fertiliser pursuant to the Ordinance on Sewage Sludge (Klärschlammverordnung) and the Fertiliser Ordinance (Düngemittelverordnung); b) use in landscaping; and c) use in other areas that are of negligible importance.

Table 457: Use of digested sewage sludge

Sewage sludge Dry matter DM [t]	2016	2017	2018	2019	2020
Total quantity	1,773,186	1,713,185	1,747,230	1,740,089	1,740,089
Thermal utilisation	*1,142,893*	*1,190,156*	*1,295,188*	*1,293,246*	*1,293,246*
- Mono-incineration	*460,411*	*478,493*	*496,463*	*490,141*	*490,141*
- Co-incineration	*615,928*	*648,108*	*761,959*	*768,961*	*768,961*
- Unknown	*66,554*	*63,555*	*36,766*	*34,144*	*34,144*
Landfill	0	0	0	0	0
Recycling for substance recovery	*624,000*	*516,158*	*436,146*	*433,723*	*433,723*
- Agriculture	*423,497*	*311,905*	*280,325*	*287,484*	*287,484*
- Landscaping-related measures	169,439	171,633	122,615	58,597	58,597
- Composting	0	0	0	0	0
- Other	31,064	32,620	33,206	87,642	87,642
Other direct utilisation	6,293	6,871	15,896	13,120	13,120

The activity data for sewage-sludge utilisation are based on data of the Federal Statistical Office (Statistisches Bundesamt, ab 2010). The relevant report appears every 3 years. The figures for interim years are taken from the publication "Wasserwirtschaft Öffentliche Abwasserentsorgung Klärschlammverwertung aus der biologischen Abwasserbehandlung“ ("Water resources sector, public wastewater management, use of sewage sludge from biological wastewater treatment" (Statistisches Bundesamt, ab 2013). No data are available for the period prior to 1998 and for the years 1999-2000, 2002-2003 and 2005. No interpolation is possible, because a statistical conversion for the period as of 2007 makes it impossible to form a 100% sum (Wiechmann et al., 2013). No data are available for the current inventory year; for this reason, only the data of the previous years can be presented here. For 2013, the Federal Statistical Office reported for the first time in this regard, under "substance recovery" ("Stoffliche Verwertung")[139].

The activity data for sewage-sludge utilisation for the previous years are available in the relevant editions of the NIR.

7.5.1.2.2 Methodological issues (5.D.1 Sludge treatment)

7.5.1.2.2.1 Digester gas

As described above, the digester gas that is produced by the digestion process, in large wastewater treatment plants, is recovered and used for energy generation. The methane content in digester gas is nearly 65 % (Schön et al., 1993). The relevant quantity of methane per raw-gas volume (Statistisches Bundesamt, ab 2012) is determined as follows:

$$M_{methane} = V_{raw\ gas} \times 0.65 \times \sigma \times 0.000001$$

Where

$M_{methane}$ = Mass of methane produced via digestion (kt)

$V_{raw\ gas}$ = Volume of digester gas produced (m^3)

0.65 = Conversion factor for determination of the methane contained in the digester gas

σ = Density of methane (0.717 kg/m^3) (Vogel & Synowietz, 1974)

[139] This includes provision to drying facilities in cases in which further disposal steps are not known.

7.5.1.2.2.2 Digester-gas losses

Operators report data on digester-gas collection and sewage-sludge utilisation annually to the Federal Statistical Office, on the basis of the Act on Energy Statistics. From consultations with staff at several wastewater treatment facilities with digester-gas collection, we learned that the losses, with respect to the facilities' potential energetic utilisation, may be assumed to amount to 5 %. This confirms the relevant figures of the Federal Statistical Office (Statistisches Bundesamt, ab 2012). It is assumed that most of this gas is burned in flares. Such flaring losses in connection with gas collection result via technical difficulties, damage and maintenance measures. When such factors arise, flaring is carried out for safety reasons. Such gas flares are designed to be able, in emergencies, to burn all of the gas being collected. In addition, they are equipped with automatic ignition. The reported losses can also be due to discrepancies between the accuracy of measurements made at gas-production sites and the accuracy of measurements made at consumption sites. Normally, gas routed to flares is not separately measured. As a result, no details on the nature of such losses can be provided here.

Any losses that occur in such facilities are taken into account by the calculations described under 7.5.1.1.2, since the area of sludge treatment has been included in determination of the emission factor.

7.5.1.2.2.3 Open sludge digestion

Open sludge digestion is no longer practiced in Germany. The pertinent data for the years 1990 – 1994 were most recently reported in the 2015 NIR. An emission factor of 210 kg CH_4/t TS is used for open sludge digestion in the new German Länder, in keeping with the results of the study Schön et al. (1993).[140] The activity rates for the years 1990 to 1992 were communicated personally to the Federal Environment Agency by the then Chief Inspector of the former GDR's water-processing plants.

In keeping with the fact that open sludge digestion is prohibited in the Federal Republic of Germany, use of that treatment method was gradually reduced in the new German Länder until 1994 and then was completely discontinued as of 1994.

7.5.1.2.3 Uncertainties and time-series consistency (5.D.1 Sludge treatment)

7.5.1.2.3.1 Digester gas

The uncertainties in determination and calculation of the applicable quantities of methane are assessed as follows (UBA expert assessment):

Volume of digester gas produced = ± 5 %

The uncertainties originate in the measurement inaccuracies of the measuring devices used

Methane content in digester gas = ± 15 %

Varies in keeping with the composition of the wastewater – and, thus, of the composition of the sludge

Density of methane = ± 30 %

The literature gives a range of different densities for methane (depending on temperature, etc.)

The figure for the quantity of digester gas produced is based on data of the Federal Statistical Office. The time series are thus internally consistent. The relevant surveys are carried out annually. The results of the surveys are considered accurate.

140 The emission factor was determined via the difference between methane emissions from psychrophilic sludge stabilisation in the new German Länder and the total amount of sewage sludge produced.

7.5.1.2.3.2 Open sludge digestion

Since the uncertainties connected with open sludge digestion have not been estimated, the default values (conservative factors) given in UNFCCC Decision 20/CMP.1 (p. 39ff) (UNFCCC, 2006) are used. The activity rates between 1990 and 1992 are based on a personal communication of the then-chief inspector of the water-processing operations of the GDR; those for 1993, on the other hand, are based on estimates of the Federal Environment Agency (UBA).

7.5.1.2.4 Category-specific quality assurance / control and verification (5.D.1 Sludge treatment)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The methane content in sewage gas was determined with an average-methane-content figure (65 %) (Schön et al., 1993) that has been compared with data of the Federal Statistical Office (Statistisches Bundesamt, ab 2012). For 2015, an average sewage-gas methane content of 63.17 % was obtained from data of the Federal Statistical Office. The value used is thus considered verified.

No comparable emissions data for Germany, or other data on methane collection from wastewater treatment plants, are known.

7.5.1.2.5 Source-specific recalculations (5.D.1 Sludge treatment)

In the last report, the values for sewage-sludge collection and losses for the year 2019 were 2018 values that were carried forward. The actual values have since been made available by the Federal Statistical Office and thus can now be included in the report.

7.5.1.2.6 Category-specific planned improvements (5.D.1 Sludge treatment)

At present, improvements seem neither necessary nor possible, since no further activity data are available.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

7.5.1.3 Nitrous oxide emissions from municipal wastewater (5.D.1 Nitrous oxide emissions from municipal wastewater)

7.5.1.3.1 Category description (5.D.1 Nitrous oxide emissions from municipal wastewater)

Municipal wastewater contains numerous nitrogen compounds. In bacterial decomposition processes, part of the available organic nitrogen is converted back into biomass.

Direct emissions: Nearly all of the municipal wastewater-treatment plants in Germany are operated with an additional nitrification and denitrification stage that complements the plants' biological wastewater treatment and that enables them to eliminate virtually all of the nitrogen remaining in wastewater. In nitrification, the nitrogen compounds in the wastewater are converted into nitrate, under aerobic conditions. In denitrification, the nitrogen bound in the nitrate is converted into molecular nitrogen and nitrogen oxides. Under unfavourable conditions (cf. also Chapter 7.5.2.2.1), nitrous oxide (N_2O) can occur as a by-product / intermediate product in both processes, although denitrification is the predominate source in this regard (IPCC (2006a): Vol. 5, Chapter 6.1, p. 6.8).

Indirect emissions: The nitrogen that remains in wastewater following wastewater treatment enters into water bodies. There, under certain circumstances, microbial decomposition processes can also take place in which nitrous oxide can be formed and emitted.

The total emissions of nitrous oxide that are produced via municipal wastewater are determined as a combination of the direct nitrous oxide emissions (N_2O_{Plants}) and indirect nitrous oxide emissions ($N_2O_{Effluent}$). The total emissions are obtained as follows:

$$N_2O_{Total} = N_2O_{Plants} + N_2O_{Effluent}$$

The emissions show a strongly decreasing trend, as a result of extensive additions of denitrification systems to wastewater treatment facilities in the period 1990 through about 2001. This is due to implementation of the EU Urban Waste-Water Treatment Directive (91/271/EWG, 1991) which, in the early 1990s, made nutrient removal in wastewater treatment plants part of the state of the art. Nutrient removal technology has since reached high technological standards, and a slightly decreasing emissions trend became established in about 2005.

7.5.1.3.2 Methodological issues (5.D.1 Nitrous oxide emissions from municipal wastewater)

Direct emissions

Pursuant to the 2006 IPCC Guidelines, only countries with modern wastewater treatment facilities are required to report direct emissions. Such facilities include nitrification and denitrification stages. As described above, nitrous oxide emissions occur, pursuant to the IPCC (ibid.), primarily in denitrification. For this reason, in the following the fraction of German wastewater treatment plants with denitrification equipment (T_{Plant}) – and not the fraction of plants with nitrification equipment – is used for the calculations. 97 % of wastewater treatment plants are equipped with nitrification, while 96 % have denitrification (Statistisches Bundesamt, FS 19, R 2.1.3a). Calculation of the nitrous oxide emissions takes account of municipal wastewater-treatment plants that are equipped with denitrification.

Pursuant to the 2006 IPCC Guidelines (IPCC (2006a): Vol. 5, Chapter 6.3.1.3, Equation 6.9), nitrous oxide emissions as calculated as follows:

$$N_2O_{PLANTS} = P \bullet T_{PLANT\ DENI} \bullet F_{IND-COM} \bullet EF_{PLANT}$$

Where

N_2O_{PLANTS}	=	Total annual N_2O emissions of plants, in kg N_2O/year)
P	=	Population
$T_{PLANT\ DENI}$	=	Degree of utilisation of modern wastewater treatment plants with denitrification, %/100 (i.e. with respect to the total wastewater load in Germany)
$F_{IND-COMM}$	=	Fraction of protein of industrial / commercial origin that is managed via wastewater; country-specific value = 1.3
EF_{PLANT}	=	Emission factor; 3.2 g N_2O/person x year

While for the nitrous-oxide emission factor the IPCC default value is used, the number of inhabitants (P = population), the degree of use of modern centralised wastewater treatment plants with denitrification ($T_{PLANT\ DENI}$) and the share of protein from industrial and manufacturing operations that is managed via municipal plants ($F_{IND-COMM}$) are all values that have been determined country-specifically.

In keeping with the share of commercial and industrial wastewater (2016: 38,478,100 population equivalents; p.e. = 32,8%) of the total organic wastewater load in municipal wastewater-treatment plants (2016: 117,448,800 population equivalents in total; p.e. = 100%) (Statistisches Bundesamt, FS 19, R 2.1.3b), amounting to about 30%, $F_{IND-COMM}$ has been set at 1.3.

Indirect emissions

In keeping with the method proposed by the 2006 IPCC Guidelines, first the total annual quantity of nitrogen in wastewater effluent is determined. For countries with modern wastewater treatment plants, this is to be determined in accordance with the following formula:

$$N_{Effluent} = (P \times Protein \times F_{NPR} \times F_{Non\text{-}con} \times F_{Ind\text{-}comm}) - N_{Sludge} - N_{WWT}$$

(IPCC (2006a): Vol. 5, Chapter 6.3.1.3. Equation: 6.8)

Where

$N_{EFFLUENT}$	=	Total annual quantity of nitrogen in wastewater effluent, in kg N/year
P	=	Population
Protein	=	Per-capital protein consumption, in kg/person/year
F_{NPR}	=	Nitrogen fraction in protein; default = 0.16 kg N / kg protein
$F_{NON\text{-}CON}$	=	Fraction of non-consumed protein in wastewater; default = 1.1
$F_{IND\text{-}COM}$	=	Factor of protein of industrial / commercial origin that is managed via wastewater; the country-specifically adjusted value used = 1.3
N_{SLUDGE}	=	Nitrogen removed with sludge; default = 0 in kg N / year
N_{WWT}	=	Nitrogen fraction in the nitrous oxide occurring in connection with wastewater treatment
	=	N_2O_{PLANTS} x 28/44 in kg N/year
28/44	=	Factor for conversion of N_2O to N_2

According to UBA experts, this method is erroneous, however, and ineffective by itself, since it does not take account of the N-removal performance of wastewater treatment plants' denitrification stages. For calculation of more-realistic values, the above equation has to be adjusted as shown below.

For the years 2006-2013, data on the average N content of the wastewater flowing into ($N_{influent}$) and out of ($N_{effluent}$) German wastewater treatment plants are available (DWA, ab 1988 - jährlich). From those data, biological wastewater treatment plants in Germany were determined to have an average N-removal efficiency of 81.2 % in the years mentioned. In the interest of data comparability, $T_{Plant\ deni}$ was determined, via selection of wastewater treatment plants with denitrification. In the following, the factors to be taken into account include a) the removal efficiency of wastewater treatment plants with denitrification[141] and b) the N load of all plants without biological wastewater treatment. The factor N_{WWT} does not suffice for this purpose, since it includes only the nitrogen fraction in the nitrous oxide that is produced (direct emissions); it does not include the N fraction in the molecular nitrogen produced via denitrification. Therefore, the factor N_{WWT} is not taken into account in the determination. In addition, the factor N_{SLUDGE} is also not included, since the N_{SLUDGE} value used by Germany is equal to 0, and since nitrogen elimination from the sludge is already taken into account via the new $F_{ELIMINATION}$. These considerations lead to the following formula for calculation:

$$N_{EFFLUENT} = (P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM})$$

That formula applies for plants without nitrogen elimination.

For calculation of the N load ($N_{Effluent\ with}$) in the effluent of plants **with** nitrogen elimination, the elimination factor $F_{ELIMINATION}$ is introduced. The formula is thus as follows:

$$N_{EFFLUENT\ with} = (P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM}) \times (1 - F_{ELIMINATION}) \times T_{PLANT\ Deni}$$

[141] Only installations with denitrification are considered, since nitrous oxide formation is more likely in such installations.
In its surveys, DWA does not break the data down in accordance with individual treatment stages.

Where

$F_{ELIMINATION}$ = Factor for nitrogen-elimination performance in wastewater treatment plants = N effluent / N influent = 81.2 / 100
(DWA, ab 1988 - jährlich)

$T_{PLANT\ Deni}$ = Degree of utilisation of modern wastewater-treatment plants with denitrification,

%/100 (i.e. with respect to the entire wastewater load in Germany)

$N_{EFFLUENT\ with}$ = N load in the effluent of wastewater treatment plants (plants with N elimination)
$N_{EFFLUENT\ without}$ = N load in the effluent of wastewater treatment plants (plants without N elimination)

The N load ($N_{Effluent\ without}$) in the effluent of wastewater treatment plants without biological wastewater treatment is calculated as follows:

$$N_{EFFLUENT\ without} = (P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-COMM}) \times (1 - T_{PLANT\ Deni.})$$

Then, the nitrogen loads in the effluent of wastewater treatment plants with denitrification and in the effluent of wastewater treatment plants without biological wastewater treatment are added, to yield the total N load in the effluent of all wastewater treatment plants:

$$N_{Effluent} = N_{Effluent\ with} + N_{Effluent\ without}$$

$$= (P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-COMM}) \times (1 - F_{ELIMINATION}) \times T_{PLANT\ Deni.} + (P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM}) \times (1 - T_{PLANT\ Deni.})$$

The result obtained with the above-described procedure has been verified via comparison with alternative data (UBA, 2016), and it thus seems to be correct (cf. Chapter 7.5.1.3.6).

With regard to the emission factor for nitrous oxide, and to the nitrogen fraction in protein, the IPCC default values are used. For the average per-capita protein intake, the share of protein from industrial and manufacturing operations that is managed via municipal wastewater treatment plants ($F_{IND-COM}$), and the number of inhabitants, country-specifically determined values are used. The value for non-consumed protein in households ($F_{NON-CON}$) is so low, because waste disposal via wastewater (garbage disposal units) is not widespread in Germany. No general bans on the use of such appliances apply, however. The details pertaining to use of such appliances are governed by local wastewater regulations. From the perspective of the UBA, it is not a good idea to introduce kitchen waste into wastewater streams, due to the energy and water consumption then involved in transporting the waste to wastewater treatment plants and separating it out at the plants.

As of 2015, the average protein intake per person and day, throughout the entire reporting period, has been determined only on the basis of the data in the FAOSTAT database (FAOSTAT, ab 2015). The data differ only insignificantly from the data in the FAO Statistical Yearbook. The FAO data are a reflection of the protein supply. The actual protein consumption that is of relevance for wastewater pathways is much lower, however, because much food that is produced is not consumed (because some is thrown away in stores and in private households; and because some is thrown away, as waste, in production, etc.). Since no data on actual consumption are available, a factor of 0.8 is used for conversion of the supply into actual consumption: Pursuant to (Insitut, 2019), about 64 million t of food are produced in Germany, and about 12 million t of that food is thrown away without being consumed. The resulting fraction of disposed-of food, about 20%, yields the factor introduced above.

The nitrous oxide emissions are determined as follows, in keeping with the IPCC method:

$N_2O_{Emissions} = N_{EFFLUENT} \times EF_{EFFLUENT} \times 44/28$

Where

$N_2O_{Emissions}$ = N_2O emissions, in kg N_2O/year

$N_{EFFLUENT}$ = Nitrogen discharged into the aquatic environment, in kg N/year

$EF_{EFFLUENT}$ = Emission factor for N_2O emissions released into wastewater, in kg N_2O-N/kg N (default = 0.005)

44/28 = Factor for conversion of N_2O-N to N_2O

Due to the great many plants concerned, calculation with higher-Tier methods is not feasible. What is more, the Federal Statistical Office does not list the substance flows of wastewater treatment plants separately.

The **total emissions of nitrous oxide** from the area of municipal wastewater treatment are obtained as the sum of the relevant direct and indirect emissions described in detail.

7.5.1.3.3 Uncertainties and time-series consistency (5.D.1 Nitrous oxide emissions from municipal wastewater)

The following uncertainties are used (all are UBA expert estimates):

P (population)	=	± 5 %
$T_{Plant\ deni}$ (wastewater treatment plants with denitrification)	=	± 5 %
$F_{Ind\text{-}comm}$	=	± 25 %
Protein consumption	=	± 25 %

The activity data are based on data of the Federal Statistical Office. The population of Germany is determined on an annual basis, while the quantity of wastewater treated in wastewater-treatment facilities with denitrification is determined every three years (without determination of pertinent uncertainties). The results of the surveys may be considered very precise, since the surveys are exhaustive. The figures for the years prior to 1998 have been extrapolated. They are plausible, since inclusion of nitrogen elimination processes in wastewater treatment began to be expanded in Germany as of the beginning of the 1990s. The figures for the years after 2013 have been carried forward from earlier years. All other lacking data have been linearly interpolated.

The uncertainties for the EF_{Plant} have been taken from (IPCC (2006a): Vol. 5, Table 6.11); they are - 37.5 % and + 150 %. UBA experts consider that value to be plausible.

The uncertainty for the average N-removal efficiency of German wastewater treatment plants is estimated at ± 5 %.

The average daily protein supply for the period as of 1990 has been obtained from the database (FAOSTAT, ab 2015). The relevant value had to be carried forward, due to a lack of more-current data for the period as of 2017. The uncertainty for the protein consumption calculated on the above basis is assessed as ± 25% (UBA expert estimate).

The average nitrogen fraction in protein (F_{NPR}) is 16 % ± 1%. In obtaining this value, it was assumed that Bovine serum albumin is the standard protein. In light of the aforementioned standard deviation (± 1%), the uncertainty would be about ± 6 % (with respect to the 16% fraction). It is estimated to total ± 7 %, however, since the relevant wastewater contains a broader spectrum of protein (UBA expert estimate).

In addition, the following uncertainties have also been used (all are UBA expert estimates):

$F_{NON-CON}$, = ± 30 %

$F_{IND-COM}$ = ± 25 %

The uncertainties for the $EF_{EFFLUENT}$ have been obtained from (IPCC (2006a): Vol. 5, Table 6.11).

7.5.1.3.4 Category-specific quality assurance / control and verification (5.D.1 Nitrous oxide from municipal wastewater)

General and category specific quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

The formula adapted via $F_{ELIMINATION}$, for determination of the N effluent into water bodies, was verified with the average values, as published in the comparison of the performance of municipal wastewater treatment plants (Leistungsvergleich Kommunaler Kläranlagen), for N discharges into water bodies (DWA, ab 1988 - jährlich). Currently, verification is being carried out with data for the years 2006-2015. Data provided under the Urban Waste Water Treatment Directive (reporting by the Federal Government to the EU pursuant to 91/271/EEC (UBA, 2016)) are used as an additional data source for verification. The data in both data sources are completely independent of the data used with the above-described calculation method. The following table shows the results of calculation of $N_{Effluent}$ (indirect emissions) on the basis of the following: the 2006 IPCC method; the modified IPCC method (nitrogen elimination factor $F_{Elimination}$); the measurements obtained by the German Association for Water, Wastewater and Waste (DWA); a mixed method using DWA data and data of the Federal Statistical Office; and data provided under the Urban Waste Water Treatment Directive.

Table 458: Comparison of $N_{EFFLUENT}$ as determined on the basis of various sources; (kt N/year)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
With the IPCC 2006 method										
$N_{EFFLUENT}$	646.3	666.4	656.6	662.6	656.7	665.0	658.1	658.7	673.7	686.6
With the modified IPCC 2006 method										
$N_{EFFLUENT}$	157.3	154.2	150.7	150.8	148.3	148.8	145.9	144.7	150.3	155.6
With DWA data on N effluent & wastewater quantities										
$N_{EFFLUENT}$	71.5	86.1	86.5	82.7	87.0	77.9	79.1	81.7	72.8	72.3
With DWA data on N effluent & wastewater-quantity data of the Federal Statistical Office										
$N_{EFFLUENT}$	80.8	90.6	95.4	95.1	92.9	90.4	88.9	87.4	84.8	84.1
On the basis of (UBA 2016)										
$N_{EFFLUENT}$			87.3	-	82.6	-	83.1	-	75.1	-

The values for the N load in the effluent ($N_{Effluent}$) yielded by the above-described modified method are considerably lower than those obtained via the IPCC method. The values calculated with the modified IPCC method are confirmed by the data sources used for verification. The various results are all of the same order of magnitude. The modified method yields the highest values overall, and thus may be considered a conservative method. The more-pronounced discrepancy seen with the modified method can be ascribed to the IPCC default emission factor used. In light of this verification, it must be considered too high. Nonetheless, in spite of its probable overestimation of the real N load in the effluent, and of the related possible N_2O emissions, it lies within the range allowed by the uncertainties.

Alternative data sources for the average protein intake per person and day include:

- The 1991 food table for practical applications (Senser & Scherz, 1991) gives an average protein intake of 94 g/inhabitant and day.

- The nutrition report of the German Nutrition Association (Deutsche Gesellschaft für Ernährung) (DGE, 2008)[142] used estimated food-consumption data for 2005/2006 to estimate average daily protein intake. From that data, an average value of about 79 g protein / person and day[143] was derived.
- As of the 2017 NIR, the FAOSTAT database (FAOSTAT, ab 2015) is used for determination of N_2O emissions in wastewater, since it contains a consistent time series. It is internationally comparable, and it is regularly updated. The Federal Environment Agency has no information to the effect that the country-specific values in the food table and in the 2008 nutrition report are more precise or enjoy greater national acceptance. In addition, many countries use the FAO database; as a result, the emissions-determination process used by Germany is internationally comparable. A European comparison shows that the daily protein requirements assumed for Germany lie within the middle of the overall range. The FAO data do not take account of the protein fractions that are not consumed – and that are disposed of instead upon utilisation. For Germany, the WWF (2015) assumes consumption waste of up to 16 % for meat, eggs and milk.

The protein-consumption data used by the FAO are derived on the basis of production data (supplied by the Federal Statistical Office) and trade data (EUROSTAT). The relevant work considers and studies five different, successive losses along the value chain, including harvest, post-harvest, process, distribution and consumption losses (WWF, 2015).

As described above, the IPCC method for determination of nitrous oxide emissions is only partly applicable, since it does not take account of the nitrogen load eliminated via denitrification and thus considerably overestimates the emissions. For this reason, an adjusted method has been used. The EF of the 2006 IPCC Guidelines is used as a default value. Currently, no data are available that would support determination of a country-specific EF, in an approach analogous to that used for methane.

A comparison of the IEF for nitrous oxide emissions in the area of domestic wastewater treatment with various corresponding international IEF (GHG Locator 2020) shows good agreement with most other countries. This can be attributed to use of the calculation method pursuant to the IPCC Guidelines. As the example of Austria shows, noticeably higher IEF can be tied to use of a country-specific method.

The method used, and the resulting emission factors, were compared with the methods and factors of countries that have similar wastewater system standards. In each case, the 2020 NIR was considered. The following results emerged:

- Austria: Its calculation has been carried out via an approach similar to that of the IPCC Guidelines. But instead of focusing on protein consumption, it has been able to look at measured nitrogen values. To calculate emissions from central wastewater treatment, it has used a country-specific EF based on measurements. That EF, at 43g N_2O/inhabitant*a, is considerably higher than the IPCC default value of 3.2g N_2O/inhabitant*a, which Germany has used. To determine emissions from effluent, it has used the default value (0.005kg N_2O-N/kg N), as Germany has.

[142] The nutrition report is published every four years.
[143] This value was obtained with the help of the rough estimate that each population group in Germany consists of 50 % men (90.8 g/day) and 50% women (66.7 g/day).

- Switzerland: Its calculations for emissions from wastewater treatment and from the pertinent effluent are in keeping with the IPCC Guideline. To take account of the N load removed via sewage sludge, it is able to draw on country-specific data. Like Germany, it has applied the EF in keeping with the relevant default values. Its resulting EF, 0.039 kg N_2O/inhabitant*a, is of the same order of magnitude as the value derived for Germany (0.019 kg N_2O/inhabitant*a).
- The Netherlands: It has used the default values, in combination with country-specific activity data. Its resulting per-inhabitant EF = 0.015 kg N_2O/inhabitant*a. That value is similar to the EF derived for Germany, 0.019 kgN_2O/inhabitant*a.
- Denmark: Its calculations have been based on country-specific activity data. Its calculation for emissions from wastewater treatment plants uses a country-specific EF = 0.0032 kg N_2O-N/kg N that, due to the units it is expressed in, is not directly comparable. To determine emissions from effluent, it has used the default EF (0.005 kg N_2O-N/kg N). Its total emissions, with respect to population, and not including industrial wastewater, yield an EF = 0.034 kg N_2O/inhabitant*a.

7.5.1.3.5 Category-specific recalculations (5.D.1 Nitrous oxide from municipal wastewater)

As a result of the availability of updated FAO data on protein supply, for the period as of 2014, the emissions from effluent – and, thus, the total emissions – have increased slightly.

The adjustment of $F_{IND-COM}$ to 1.3, to take account of a higher (by comparison with the default value) share of industrial and commercial wastewater in the total wastewater load managed in municipal wastewater-treatment plants, leads to slightly higher indirect emissions – and, thus, total emissions – throughout the entire timeline since 1990.

The correction involving a focus on protein consumption, instead of on the protein supply, however, leads to lower indirect emissions – and, thus, total emissions – throughout the entire timeline.

Table 459: Recalculation of N_2O emissions

Protein intake	Units		1990	2000	2010	2014	2015	2016	2017	2018	2019
Protein supply	[g/capita/d]	2022 NIR	96.66	94.46	101.89	103.36	104.08	104.95	104.20	104.20	104.20
Protein consumption	[g/capita/d]	2022 NIR	77.33	75.57	81.51	83.31	84.11	83.74	83.24	84.32	84.32
per capita and year	[kg/capita/a]	2022 NIR	28.225	27.582	29.752	30.409	30.701	30.564	30.383	30.777	30.777
		2021 NIR	35.281	34.478	37.190	37.726	37.989	38.307	38.033	38.033	38.033
N_2O, indirect (effluent)	**Units**		**1990**	**2000**	**2010**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
NEFFLUENT Real	[kt]	2022 NIR	492.02	183.33	123.37	125.99	130.76	132.77	134.50	138.77	141.21
NEFFLUENT Real	[kt]	2021 NIR	591.37	220.34	148.28	150.30	155.57	160.01	161.89	164.89	167.79
N_2O emissions	[kt]	2022 NIR	3.866	1.440	0.969	0.990	1.027	1.043	1.057	1.090	1.110
N_2O emissions	[kt]	2021 NIR	4.646	1.731	1.165	1.181	1.222	1.257	1.272	1.296	1.318
N_2O, direct	**Units**		**1990**	**2000**	**2010**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
N_2O emissions	[kt]	2022 NIR	0.018	0.268	0.318	0.323	0.326	0.326	0.325	0.324	0.323
N_2O emissions	[kt]	2021 NIR	0.018	0.258	0.306	0.311	0.313	0.313	0.313	0.312	0.311
N_2O, total	**Units**		**1990**	**2000**	**2010**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Total N_2O	[kt]	2022 NIR	3.88	1.71	1.29	1.31	1.35	1.37	1.38	1.41	1.43
Total N_2O	[kt]	2021 NIR	4.66	1.99	1.47	1.49	1.54	1.57	1.58	1.61	1.63

7.5.1.3.6 Planned improvements, category-specific (5.D.1 Nitrous oxide from municipal wastewater)

In a national research project, measurements of methane and nitrous oxide emissions were carried out, with the aim of using the measurements as a basis for deriving emission factors for the area of municipal wastewater treatment. That project has not yet been completed, due to pandemic-related delays in the expert assessment of the project, and to changes of task assignments as a result of restructuring in the affected UBA specialised department. The UBA will be able to carry out a final assessment of the project results only after the project's completion.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

7.5.2 Industrial wastewater treatment (5.D.2)

7.5.2.1 Methane emissions from industrial wastewater treatment (5.D.2)

7.5.2.1.1 Category description (5.D.2 CH_4)

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier2/CS	NS	CS
N_2O	Tier 2/CS	NS	CS

Emissions from industrial wastewater treatment are not a key category.

The CH_4 emissions reported here relate only, in keeping with IPCC (2006a), to that wastewater fraction that is treated in industrial wastewater treatment facilities. The industrial wastewater fraction that is sent to municipal facilities is included under 5.D.1 (municipal wastewater treatment).

The foundations for calculation of CH_4 emissions from industrial wastewater treatment are described in detail in the underlying research report Austermann-Haun and Witte (2014).

In Germany, the biological stage of industrial wastewater treatment is operated aerobically in some areas, and anaerobically in others. Digester gas, consisting largely of CO_2 und CH_4, occurs when organic substances in wastewater are broken down anaerobically.

In Germany today, industrial wastewater is treated anaerobically in many sectors. Such treatment is especially prevalent in the food industry. Data on the relevant plant equipment and systems used in this area are not systematically collected in Germany. On the other hand, an evaluation of (Austermann-Haun and Witte (2014)) shows that 184 anaerobically operating facilities are currently in service in Germany, at a total of 136 plants. The plants involved cover a total of 26 industrial sectors, throughout a spectrum that includes such diverse areas as vegetable processing, sugar production, paper production and production of cleansers. The largest COD loads that are treated anaerobically occur in pulp and paper production, sugar production and the breweries sector.

The systems used for anaerobic industrial wastewater treatment especially include sludge-bed reactors (upflow anaerobic sludge blanket (UASB) and expanded granular sludge bed (EGSB) reactors). Anaerobic activated sludge processes are also used. All relevant facilities are equipped with gas flares with automatic ignition, as required by law. Only one plant, a relatively small sugar plant, treats its wastewater in anaerobic ponds.

Almost all of the resulting digester gas is recovered and combusted either to provide process heat (where it replaces town gas) or to generate electricity. Use for energy recovery is reported under CRF 1.A.1. The sewage-gas-quantity data published by the Federal Statistical Office include both the digester gas occurring in this category and the gas occurring at municipal plants (telephone conversation between UBA expert and the Federal Statistical Office, 23 August 2016).

The only CH_4 emissions that are relevant for Germany, therefore, are those that occur via unintended releases. Such unintended releases can include:

- CH_4 present in the liquid-phase effluent of methane reactors (the solubility of methane is temperature-dependent; cf. the section "Methodological issues"),
- Losses from gas-storage systems,
- Losses via sludge removal from pellet-storage systems (systems for storage of granulated sludge from sludge blanket reactors),
- Gas that forms in non-aerated pond systems of the sugar industry,
- Gas that forms in acidification reactors,
- Losses via leaks/malfunctions/flaring losses.

All of the gas flares used with relevant gas-collection systems are emergency/shutdown flares; i.e. they also come into play when systems (such as combined heat-and-power (CHP) generating systems) have to be shut down for maintenance purposes. Such gas flares are designed to be able, in emergencies, to burn all of the gas being recovered. The gas quantities routed through gas flares are not recorded. The flares are used as emergency flares, meaning that the quantities of combusted gas in this area of application are near zero. Gas flares are equipped with automatic ignition systems that assure reliable burning of collected gas during disruptions of normal system operation. During the start-up and shut-down phases of digesters, the methane that is produced may be burned via gas flares, if methane concentrations are too low for other use. In seasonally operating plants, this occurs at the beginning and end of the operational season. The methane emissions from high-performance gas flares are assessed by experts as "zero."

According to experts (Austermann-Haun & Witte, 2014), in the area of anaerobic industrial wastewater treatment, two malfunctions involving gas losses have occurred in Germany in recent decades as a release of leakage from methane reactors' gas-containment vessels. As a result of the odour emissions that accompany them, such leaks are quickly discovered, located and eliminated. In 1992, odour emissions at a wastewater treatment plant led to the discovery of a leak in a methane reactor's glass-fibre reinforced plastic (GRP) roof. A second case of leakage occurred in 2013, in the steel roof of a methane reactor. As a result of the small number of such malfunctions (2 in a total of 30 years of operation of a pool of methane reactors that now numbers 184), the methane emissions from malfunctions involving leakage are classified as negligible.

Other types of malfunctions – for example, malfunctions that inhibit the methane bacteria – do not result in any methane emissions.

7.5.2.1.2 Methodological issues (5.D.2 CH_4)

The calculation method selected is in keeping with Tier 2.

For 20 of the 26 relevant industrial sectors, the annual COD load was calculated via the equation (IPCC (2006a): Vol. 5, Chapter 6.2.3.3, Equation 6.6). To that end, the applicable production quantities for 2013, and the applicable specific wastewater production as given in federal statistics (Statistisches Bundesamt, FS 4, R 3.1), were determined for each industrial sector and then combined with the relevant specific COD concentrations in the raw wastewater given in the research report. In this connection, it must be noted that wastewater statistics are updated only once every three years. Interim years are thus interpolated, while (data for) subsequent years are carried forward without change, until the next update, and then, when the update becomes available, are recalculated.[144] For 6 industrial sectors (Manufacture of grain mill products

[144] These changes have no impact on the reported methane emissions, because such emissions, as described below, are calculated by other means. In general, the Federal Statistical Office does not provide updates of wastewater statistics until after the NIR's editorial deadline.

(industrial sector (Wirtschaftszweig) code WZ 10.61), Manufacture of prepared meals and dishes (WZ 10.85), Manufacture of other organic basic chemicals (WZ 20.14), Manufacture of fertilisers and nitrogen compounds (WZ 20.15), Manufacture of plastics (WZ 20.16) and Manufacture of soap, detergents and cleaning and polishing preparations (WZ 20.41)), the literature provided no data on specific wastewater production. As a result, it was not possible to calculate the annual COD load for those sectors.

$$TOW_i = P_i \cdot W_i \cdot COD_i$$

Where

TOW_i	= Total organically degradable material in the wastewater of industrial sector i (annual COD load), in kg COD / year
i	= Industrial sector
P_i	= Total industrial product for industrial sector i, in t / year
W_i	= Wastewater generated in industrial sector i, in $m^3/t_{product}$
COD_i	= Chemical oxygen demand (degradable organic components in industrial wastewater), in kg COD/m^3

Since it is good practice to calculate with country-specific data, and since country-specific data area available for Germany, we use our own method for calculation of total methane emissions, rather than the IPCC method (IPCC (2006a): Vol. 5, Chapter 6.2.3.1, Equation 6.4). The total methane emissions from industrial wastewater treatment are calculated with the following formula:

$$CH_4\ Emissions = \sum_i \left[\left(TOW_i \cdot \omega_{ANR,i} \cdot \omega_{CSB,i} \cdot EF_{CH4,gelöst,i} \right) + E_{CH4,GS,i} + E_{CH4,PS,i} + E_{CH4,AT,i} \right]$$

Where:

$CH_4\ Emissions$	= CH_4 emissions in the inventory year, in kg CH_4/a
TOW_i	= Total organically degradable material in the wastewater of industrial sector i (annual COD load), in kg COD/a
i	= Industrial sector
$\omega_{ANR,i}$	= Percentage share for anaerobic treatment, for industrial sector i
$\omega_{CSB,i}$	= Degree of COD degradation in anaerobic treatment, for industrial sector i
$EF_{CH4,gelöst,i}$	= Emission factor for CH_4 dissolved in water, in industrial sector i, in kg CH_4 / kg $COD_{eliminated}$
$E_{CH4,GS,i}$	= CH_4 emissions from gas-storage systems in industrial sector i, in kg CH_4/a
$E_{CH4,PS,i}$	= CH_4 emissions from systems for storage of anaerobically granulated sludge in industrial sector i, in kg CH_4/a
$E_{CH4,AT,i}$	= CH_4 emissions from wastewater ponds in industrial sector i, in kg CH_4/a

The specific emission factors $EF_{CH4,gelöst,i}$ for methane dissolved in the water phase have been calculated on the basis of Henry's law, and they are listed in the research report. A pressure of 1.043 bar is used as a basis. The temperature, which is always sector-specific, varies between 32°C and 37°C.

The emissions from gas-storage systems are based on the permissible rates of leakage from such storage systems. On this basis, the CH_4 emissions per gas-storage system have been calculated as 20 m^3 CH_4 / year.

The emissions from systems for storage of anaerobically granulated sludge have been set at 0 kg CH_{4b} / year, since the emissions from this area are considered to be negligible (expert assessment). Similarly, the CH_4 emissions from malfunctions have been set at 0 kg CH_4 / year.

The methane emissions from acidification reactors are negligible, as a result of such reactors' unfavourable conditions for methane formation, and have been set at 0 kg CH_4 / year.

The emission factor for wastewater ponds was determined using Equation 6.5 and Table 6.8 from (IPCC (2006a): Vol. 5, Chapter 6). For Bo, the IPCC default value has been used; for the MCF, 0.2 has been used, for a pond depth of no more than 2 metres.

The time series for the period as of 1990 was obtained on the basis of trends in anaerobic industrial wastewater treatment – especially with regard to capacities for treatment of COD loads. The entire time series for the period from 1990 to 2013 has been published in the 2015 NIR. Until the next updating of the database, the data as of 2014 will be carried forward with growth of 2 percent per year – under the assumption that moderate additions of anaerobically operating facilities will take place (expert assessment). The following table provides an overview of the time series. The percent values given show the changes in comparison to the reference year 2013. The table also shows the annual COD loads upon which the calculation is based. The calculations produce an implied emission factor of 1.86 kg CH_4/t COD.

Table 460: Time series for CH_4 emissions from industrial wastewater treatment

Year	Anaerobically treated annual COD loads [t/a]	CH_4 emissions [kg CH_4 / year]
1990	198,477	22 %
1995	332,950	37 %
2000	493,357	56 %
2005	744,371	84 %
2010	854,374	96 %
2013	888,757	100 %
2014	906,532	102 %
2015	924,307	104 %
2016	942,083	106 %
2017	959,857	108 %
2018	977,632	110 %
2019	995,407	112 %
2020	1,013,183	114 %

The TOW figures for the individually considered sub-sectors are shown in Table 9 in Austermann-Haun and Witte (2014). For the chemical industry, the food industry, and the paper and pulp industry, the total TOW was determined on the basis of an average COD concentration and the absolute wastewater quantity (Table 462). This total-TOW figure from the formula $TOW_i = P_i \cdot W_i \cdot COD_i$ has not been used for calculation of CH_4 emissions, however, because those emissions, as described above, were calculated using a country-specific method, and on the basis of sub-sector-specific TWO_i values. In the country-specific method, and in keeping with the formula term $TOW_i \cdot \omega_{ANR,i} \cdot \omega_{CSB,i} \cdot EF_{CH4,gelöst,i}$ given above, the fraction of anaerobically treated wastewater for each sector or sub-sector $\omega_{ANR,i}$ was taken into account, and the sector-specific maximum degree of degradation $\omega_{CSB,i}$, and the applicable temperature-dependent and sector-dependent fraction of dissolved methane $EF_{CH4,gelöst,i}$, were applied to each sector-specific TWO_i. The sector-specific parameters are listed in the following Table 461 (cf. also Table 12 in Austermann-Haun and Witte (2014)).

The various sub-sectors differ in terms of the fractions of wastewater (cf. $\omega_{ANR,i}$ in Table 461) and, thus, of total TOW, that they treat in anaerobic installations. Only treated quantities of TOW can lead to methane emissions. In derivation of the IEF, the total TOW quantity for the source category involved, and not only the TOW quantity treated anaerobically, is the reference value. This approach leads to comparatively very low IEF.

Table 461: Parameters used to determine emissions of dissolved methane from anaerobic treatment of industrial wastewater (for reference year 2013)

WZ code	TOWi [t CSB/a] (rounded)	$\omega_{ANR,i}$ [%]	$\omega_{CSB,i}$ [$EF_{CH4,dissolved,i}$]	[kg CH_4/kg CSB_{eli}]%]
10.20 Fish processing	12,000	9.0	77.5	0.00455
10.31 Potato processing	47,000	35.6	85	0.00244
10.32 Manufacture of fruit and vegetable juices	12,000	96.3	80	0.00838
10.39 Other processing of fruit and vegetables	80,000	8.7	85	0.00097
10.51 Milk processing	109,000	7.3	77.5	0.00615
10.52 Production of ice cream	17,000	8.2	80	0.00196
10.61 Manufacture of grain mill products	NN	NN	80	NN
10.62 Manufacture of starches and starch products:				
– potato starch	1,000	94.0	75	0.00087
– wheat starch	18,000	36.0	75	0.00087
10.71 Production of baked goods	268,000	0.2	80	0.00093
10.81 Production of sugar	64,000	95.1	95	0.00085
10.82 Confectionary production	43,000	10.1	95	0.00165
10.83 Processing of coffee and tea, production of coffee substitutes	49,000	2.1	75	0.00067
10.84 Manufacture of condiments and seasonings	12,000	0.2	80	0.00395
10.85 Manufacture of prepared meals and dishes	NN	NN	80	NN
10.89 Manufacture of other food products				
– Baking yeasts	2,000	86.2	90	0.00223
– Other yeasts	7,000	32.1	90	0.00223
10.9 Production of animal feed	24,000	3.5	70	0.00258
11.02 Manufacture of wine from grapes	18,000	1.0	90	0.00177
11.05 Production of beer	88,000	28.0	85	0.00748
11.06 Production of malt	4,000	1.1	80	0.01236
11.07 Manufacture of soft drinks; production of mineral waters	21,000	5.2	80	0.00656
17.1 Manufacture of pulp, paper and paperboard	759,000	39.1	70	0.00578
20.14 Manufacture of other organic basic chemicals	NN	NN	80	NN
20.15 Manufacture of fertilisers and nitrogen compounds	NN	NN	80	NN
20.16 Manufacture of plastics	NN	NN	72	NN
20.41 Manufacture of soap, detergents and cleaning and polishing preparations	NN	NN	80	NN
Total (rounded)	**1,653,000**			

It was not possible to determine average COD quantities for other sectors. In addition to the sectors previously included, the 2006 IPCC Guidelines also provide default values for "Organic Chemicals," "Plastic & Resins" and "Soap & Detergents." In German statistics, these sources are combined in a different way: Under the heading "Chemische Erzeugnisse" ("chemical products"), wastewater statistics list products with WZ 2008 Code 20. This group include organic chemistry (WZ 2008 Code 20.14), plastics and resins (Code 20.1) and soap and cleansers (Code 20.4). Code 22 lists end products – plastic and rubber products. In this regard, it differs from Code 20.4, in which precursors are reported. The default value reported in 2006 IPCC (IPCC (2006a): Vol. 5, Chapter 6) refers to precursors. The reporting to date thus already includes the required additional product categories. (IPCC, 2006a) notes that the default values have to be used with care, since they are industry-specific, process-specific and country-specific.

Table 462: Calculation of the TOW for 2020, direct discharges

Industrial sector	Average COD [kg/m³]	Wastewater quantity (2020) [m³]	TOW (2020 [t COD/year]
Chemical industry	3 1)	265,964,683	770,894
Food industry	3 2)	63,109,135	179,407
Paper and pulp industry	2 2)	199,996,920	399,994
			1,350,295

1) 2006 IPCC Guidelines, IPCC (2006a): Vol. 5, Chapter 6, Table 6.9.

2) Expert judgement, Federal Environment Agency

7.5.2.1.3 Uncertainties and time-series consistency (5.D.2 CH_4)

Experts put the uncertainty for the total methane emissions at ± 50 %. The reasons for this include a lack of data for some industrial sectors, differences between methane reactors' operational pressures, differences between the membranes used in gas-storage systems and the fact that it is not known how many gas-storage systems are in service.

7.5.2.1.4 Category-specific quality assurance / control and verification (5.D.2, CH4)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

In the framework of the acceptance process, the underlying research reports were subjected to review and quality assurance by the relevant UBA expert.

It is not usefully feasible to compare a) the results obtained with the chosen country-specific method with b) the results obtained with the method described in IPCC (2006a), since only the approach chosen is feasible in light of the technical realities (cf. "Category description") and the prevailing data situation. The data cannot be cross-checked against ETS data, since the described installations are not subject to emissions trading requirements.

In addition, for purposes of plausibility checking, an attempt was made to consult comparable data from the inventory reports of other countries. To this end, for the 2021 inventory report, various countries with climatic conditions, and structural / technical frameworks, similar to those of Germany were selected from the 2020 inventory reports:

- In its 2020 NIR, Austria modified its method. It now assumes that methane emissions from industrial wastewater treatment are equivalent to 1 % of the quantity of CH_4 produced in anaerobic systems.
- In the Netherlands, methane emissions are reported on the basis of the IPCC default values, in conjunction with country-specific data on TOW and with other specific adjustments. No current information about the COD quantities treated in industrial wastewater treatment plants is available. Here as well, therefore, data availability is the limiting factor. The data cannot be compared directly. No methodological changes with regard to previous years have been made.

- In Denmark, no distinction is made between industrial and municipal installations. The method is in keeping with the IPCC Guidelines.

A comparison of the IEF for methane with the figures published in other countries' reports (GHG Locator) shows that the IEF described here is lower – in some cases, considerably so – than the other countries' figures. The reasons for this are that a) the methane emissions have been determined via a country-specific method, and b) as described above, only the TOW treated anaerobically can lead to methane emissions.

Further verification is not feasible, since no additional specific data on this category are available for Germany.

7.5.2.1.5 Category-specific recalculations (5.D.2 CH_4)

No recalculations are required.

7.5.2.1.6 Planned improvements, category-specific (5.D.2 CH_4,)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

7.5.2.2 Nitrous oxide emissions from industrial wastewater treatment (5.D.2 N_2O)

7.5.2.2.1 Category description (5.D.2 N_2O)

Nitrous oxide emissions can occur as a by-product of biological wastewater treatment with added nitrogen elimination. They occur mainly in connection with denitrification, although they are presumed to occur also in connection with nitrification. (Cf. IPCC (2006a), Vol. 5, Chapter 6.1, page 6.8.) Presumably, in such treatment, reduction from N_2O to N_2 is hindered by various influencing factors, such as free oxygen, high concentrations of nitrite, ammonium and/or sulphides, and such hindrance leads to the formation of N_2O (Austermann-Haun and Carozzi (2011): page 2-12 ff).

The majority of industrial wastewater is treated in municipal wastewater treatment plants. Consequently, that majority is covered in 5.D.1. For this reason, only industrial direct discharges are considered under 5.D.2.

7.5.2.2.2 Methodological issues (5.D.2 N_2O, industrial)

The 2006 IPCC Guidelines do not mandate, or provide regulations for, calculation of N_2O emissions from industrial sectors (IPCC (2006a): Vol. 5, Chapter 6.3.4). Neither a relevant decision tree nor any higher-Tier calculation methods are available. The calculation methods presented in the following are thus seen in the context of the decision tree and the Tier classification for CH_4 (industrial). The approach used here is thus in keeping with a Tier 2 calculation method.

In the inventory report, the statistical input data for 2020 have been included. In general, due to the extremely small significance of this category, to limitations of resources, and to the large number data sources used, the statistical input data can be updated only at irregular intervals. In all other years, therefore, the data are carried forward from the last updated year.

For determination of nitrous oxide emissions from industrial wastewater treatment, a research project collected data on product-specific wastewater production, on nitrogen concentrations and on COD (chemical oxygen demand) for all industrial areas and then, on the basis of annual production figures, determined annual nitrogen loads. The underlying data on nitrogen loads

have been obtained from information sheets of the DWA (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.; German association of the water, wastewater and waste-management industries). They reflect the current, recognised state of scientific research. The statistical data used are taken from annual publications of the Federal Statistical Office, and they are recorded in the Federal Environment Agency's internal database for calculations. Apart from just a few exceptions, the activity data are provided directly by the Federal Statistical Office, via data delivery. Also, queries can be submitted via the Federal Statistical Office's "Genesis-Online" Internet portal. In addition, brewery industry statistics are used, and data on milk processing and sugar production are obtained from the Federal Agency for Agriculture and Food (BLE). Data on processing of animal by-products are obtained from Servicegesellschaft Tierische Nebenprodukte mbH.
The procedure used for calculation of nitrous oxide emissions is set forth in detail in Austermann-Haun and Carozzi (2011). A COD:N ratio < 40 served as the threshold criterion for assuming that the wastewater of a given sector had a nitrogen surplus that would be able to cause nitrous oxide emissions in subsequent biological wastewater treatment. A possibility that nitrous oxide could be emitted in biological wastewater treatment can be assumed only if the wastewater contains so much nitrogen that, after conversion into biomass, a residual amount of nitrogen remains that has to be removed via biological nitrogen elimination. Similar values, pertaining to the design of denitrification systems, are given in ATV-DVWK-Arbeitsblatt A 131 (worksheet A 131 of the German association of the water, wastewater and waste-management industries (DWA)). For the sake of simplicity, the nitrogen load is assumed to be 2 to 2.5 % of the COD concentration (2.5 % is equivalent to a COD:N ratio of 40:1). The data compilation made it possible to identify the 6 industrial sectors that are most important in this regard. Together, those sectors account for some 75 % of the nitrogen load from industrial wastewater treatment (Austermann-Haun & Carozzi, 2011). These include:

- Slaughterhouse and meat-processing operations,
- Milk processing,
- Processing of animal by-products,
- Beer production,
- Sugar production,
- Wheat starch production.

Data for the textile industry (7.5 % of the total nitrogen load) and for potato processing (2.6 % of the total nitrogen load) have not been included, since the wastewater from those areas has a COD:N ratio greater than 40 and thus, according to the findings of the research report, does not lead to formation of nitrous oxide. Production of potato starch is not considered relevant with regard to formation of nitrous oxide – that area accounts for less than 0.4 % of the total nitrogen load in wastewater. The remaining some 15 % of the total nitrogen load are spread over many individual sectors with unclear data situations (especially the ratio COD:N). Most of these sectors discharge their nitrogen loads into municipal wastewater treatment plants, as indirect dischargers; this is already covered by the emissions reporting under 5.D.1.

The annual nitrogen load that is discharged into raw wastewater is determined on the basis of the mean product-specific nitrogen loads for the 6 aforementioned industrial sectors, as well as of the pertinent annual production figures. In the process, it is assumed that, as a result of organisational and technical measures, such discharges were gradually reduced to the level seen in 2010, and that the nitrogen quantity discharged into wastewater in 1990 was 30 % higher than that level (expert estimate). For the years 1990 through 2000, annual nitrogen-load reductions of 2 percentage points are assumed, while one-percent reductions are assumed for the period 2000 through 2010 (expert estimate). As of 2010, the nitrogen load per cubic metre of wastewater is assumed to be constant (expert estimate).

The activity-data calculation was carried out as follows:

$$AD = \sum_B [NF_B \times PZ_B \times 10^{-6}]$$

Where

AD	= Total activity data [t N_Z /a] = average N load in the inflow = N_Z
NF_B	= Average specific N load for the relevent sector [g N per unit]
PZ_B	= Production figures for the year 2010, for the relevant sector [number of units / a]
10^{-6}	= Factor for conversion of g into t

The N_2O emission factor was determined, in the aforementioned research project, by analysing various data from the literature. From those data, a weighted mean value was formed. As a result, it was found that 1 % of the nitrogen load in a wastewater treatment plant is emitted as N_2O-N (cf. also Chapter 7.5.2.2.4).

$$N_2O = EF \times AD \times 44/28$$

Where

N_2O	= N_2O emissions in t N_2O / a
EF	= Emission factor of 0.01 t N_2O-N / t N
44/28	= Stoichiometric factor for conversion of N_2O-N to N_2O

In addition, the shares of direct dischargers in the various individual sectors were determined and taken into account in the calculation.

The aforementioned formula yields the IEF:

IEF [N_2O-N]: EF x 44/28 = 0.01 x 44/28 kg N_2O/kg N = 0.0157 kg N_2O/kg N

The nitrous-oxide-formation rate in the sectors considered differs significantly from the corresponding formation rate in municipal wastewater treatment plants; the rate for industrial wastewater treatment plants is higher, by a factor of 100, than that for municipal plants. This is due to the above-described COD:N ratio and to the resulting better conditions, in industrial plants, for N_2O formation.

7.5.2.2.3 Uncertainties and time-series consistency (5.D.2 N_2O)

The uncertainties in the production figures originate in the relevant Federal statistics, and other statistics, all of which are based on exhaustive surveys. The uncertainties for the data are thus likely to be very low. The production statistics are updated annually, and the wastewater statistics are updated at three-year intervals. Wastewater statistics, with data for the current report year, do not appear until after the editorial deadline for the NIR.

In the aforementioned research project, the N_2O emission factor was determined (by expert estimate) to have a very high uncertainty of - 99.9 % / + 300 %.

The mean specific nitrogen loads in the various relevant sectors have the uncertainties shown in (Table 463). The uncertainties were determined via expert estimates. In a conservative estimate, the uncertainty for the total nitrogen load (activity data) is assumed to be -50 % / +50 % (expert estimate)

Table 463: Uncertainties for the mean specific nitrogen loads for the 4 industrial sectors that are most important in this regard

Mean spec. N load of the industrial sector	Uncertainty, upper bound	Uncertainty, lower bound
Slaughtering of swine	40	40
Slaughtering of sheep	50	50
Slaughtering of goats	50	50
Slaughtering of cattle	40	40
Slaughtering of horses	50	50
Slaughtering of poultry	40	40
Meat processing	40	40
Processing of animal by-products	20	20
Milk processing	15	15
Beer production	30	30
Sugar production	30	30
Wheat-starch production	30	30

7.5.2.2.4 Category-specific quality assurance / control and verification (5.D.2, N_2O)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

In the framework of the acceptance process, the underlying research reports were subjected to review and quality assurance by the relevant UBA expert.

The activity data come mainly from national statistics, and they have been reviewed for any conspicuous changes with respect to the previous year. Relatively large changes can be explained as the result of climatic effects (impacts on harvests) and of structural changes. In 2020, pandemic-related changes in consumption and production patterns occurred. Ultimately, these changes do not seem to have affected total nitrogen loads, however – the fluctuations in comparison to the previous year amount to about 1 % for 2019 and 2020.

A comparison of Germany's N_2O-IEF (determined as part of national calculations; cf. Chapter 7.5.2.2.2) with those of other reporting countries (GHG Locator) shows that Germany's value lies clearly within the range formed by the values of nearly all reporting countries.

The data cannot be cross-checked against ETS data, since the described installations are not subject to emissions trading requirements. The described activity data have been obtained from the public statistics of the Federal Statistical Office, with the exception of the data for processing of animal by-products; those data have been taken from the report of the "Servicegesellschaft tierische Nebenprodukte". No further activity data of relevance for plausibility checking are available at present.

In addition, for purposes of plausibility checking, an attempt was made to consult comparable data from the inventory reports of other countries. To this end, for the 2021 inventory report, various countries with climatic conditions, and structural / technical frameworks, similar to those of Germany were selected from the 2020 inventory reports:

- In Austria, N_2O emissions from industrial wastewater treatment are now being determined, for the first time, via a country-specific method. A detailed comparison cannot be carried out, however, since the method is described in an unpublished report from 2019.

- In the Netherlands, N_2O emissions from industrial wastewater treatment are classified as irrelevant in comparison to N_2O emissions from municipal wastewater treatment, and they are not reported. For this reason, no comparison with that country's data was possible.
- In Denmark, industrial wastewater treatment is considered via a country-specific method. Denmark's method is similar to the approach used by Germany. It has used an emission factor EF_{N20} direct of 0.0032.

Austermann-Haun and Carozzi (2011) lists a study, in the pertinent literature, on nitrous oxide emissions from wastewater treatment. The emission factors used in the present context have been derived from that study.

Further verification is not feasible, since no additional specific data on this category are available for Germany.

The approach used differs from the IPCC default method given in IPCC (2006a), Vol. 5, Chapter 6.3.1.2, page 6.25. In that source, the IPCC gives a value range of 0.0005 – 0.25 kg N_2O-N/kg –N (default: 0.005 kg N_2O-N/kg –N). In the above-described research project, a country-specific emission factor of 0.01 kg N_2O-N/kg –N was determined; that value is being used for the emissions reporting. The emission factor used is thus larger, by a factor of two, than the default value. It still falls within the given range, however.

7.5.2.2.5 Category-specific recalculations (5.D.2 N_2O)

No recalculations are required.

7.5.2.2.6 Planned improvements, category-specific (5.D.2 N_2O)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

7.6 Other sectors (5.E)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2020 (kt CO_2-eq.)	(fraction)	Trend 1990-2020
-/-	5 E, Other		CH_4	0.0	0.0%	2.4	0.0%	-
-/-	5 E, Other		N_2O	0.0	0.0%	33.6	0.0%	-

The category 5.E – Other is not a key category.

At present, only emissions from mechanical-biological waste treatment are reported in category 5.E.

Emissions from accidental fires in buildings and vehicles are also assigned to this category, but this is of no current relevance with regard to greenhouse gases, since such emissions from accidental fires account for less than 0.05 % of the total inventory (not including LULUCF). Furthermore, they account for considerably less than 500 kt CO_2-equivalents, and it cannot be assured that surveys of such fires will be carried out annually (UNFCCC, 2013a). The theoretically resulting time series would show less than 100 kt CO_2 equivalents per year, under the assumption that less than 20 percent of the material burned in such fires is of fossil origin (expert judgement made without access to suitable activity data). A description of the method for calculating emissions of particulates and other pollutants has been provided in the inventory report for the CLRTAP[145].

7.6.1 Other areas – mechanical biological waste treatment (MBT) (5.E Other MBT)

7.6.1.1 Category description (5.E Other MBT)

Gas	Method used	Source for the activity data	Emission factors used
CH_4	Tier 2	NS	CS
N_2O	Tier 2	NS	CS

In Germany, a distinction is made between a) biological treatment of separately collected biowaste (cf. 7.3) and b) biological treatment of residual waste. The purpose of biowaste treatment is to produce compost (cf. 7.3.1) or digestates (cf. 7.3.2) that can be used as fertiliser. The purpose of mechanical-biological treatment of residual waste is to pre-treat organic waste so that it can be landfilled or used for energy generation. The emissions-control requirements pertaining to treatment of residual waste are stricter than those pertaining to biowaste treatment. For this reason, the emission factors for MBT are considerably lower than those for composting and digestion of biowaste. The relevant waste streams are separately recorded in federal statistics.

Since the 1990s, mechanical biological processes have been used extensively in Germany for managing miscellaneous waste. Initially, relevant plants had relatively simple designs and were not fitted for waste-gas collection and treatment. As processes have improved, however, closed systems, with "biofilters" for waste-gas scrubbing, have gradually become the norm. While the waste-gas-scrubbing processes used by such plants have significantly reduced the plants' odour emissions, they have not reduced greenhouse-gas emissions.

Landfilling of organic and biologically degradable waste has been prohibited in the Federal Republic of Germany since 1 June 2005. Miscellaneous settlement waste, and other waste of similar composition, may thus be landfilled only following pre-treatment. Along with thermal waste-treatment processes (waste incineration), mechanical-biological processes are increasingly being used for this purpose. MBT-treatment capacities have been considerably expanded since the termination of landfilling of untreated waste in 2005. The 30th Ordinance Implementing the Federal Immission Control Act (30. BImSchV, 2017) mandates strict technical requirements and maximum permitted levels for new MBT plants as of 1 March 2001. The transitional provisions for old plants called for such plants to be retroffited by no later than 1 March 2006. The emission standards mandated by the 30th BImSchV can be reliably achieved, under the current state of the art, only with thermal waste-gas treatment (such as regenerative thermal oxidation – RTO).

For MBT installations, the 30th BImSchV limits total organic carbon (TOC) emissions loads to 55 g per tonne of treated waste and N_2O loads to 100 g per tonne of treated waste. A number of reviews have found that all German installations reliably meet the emissions limits, and that many installations even remain considerably below them (cf. Table 464). The emissions limits and the emission factors are oriented to wet material; waste quantities are recorded in those terms when delivered to the installations.

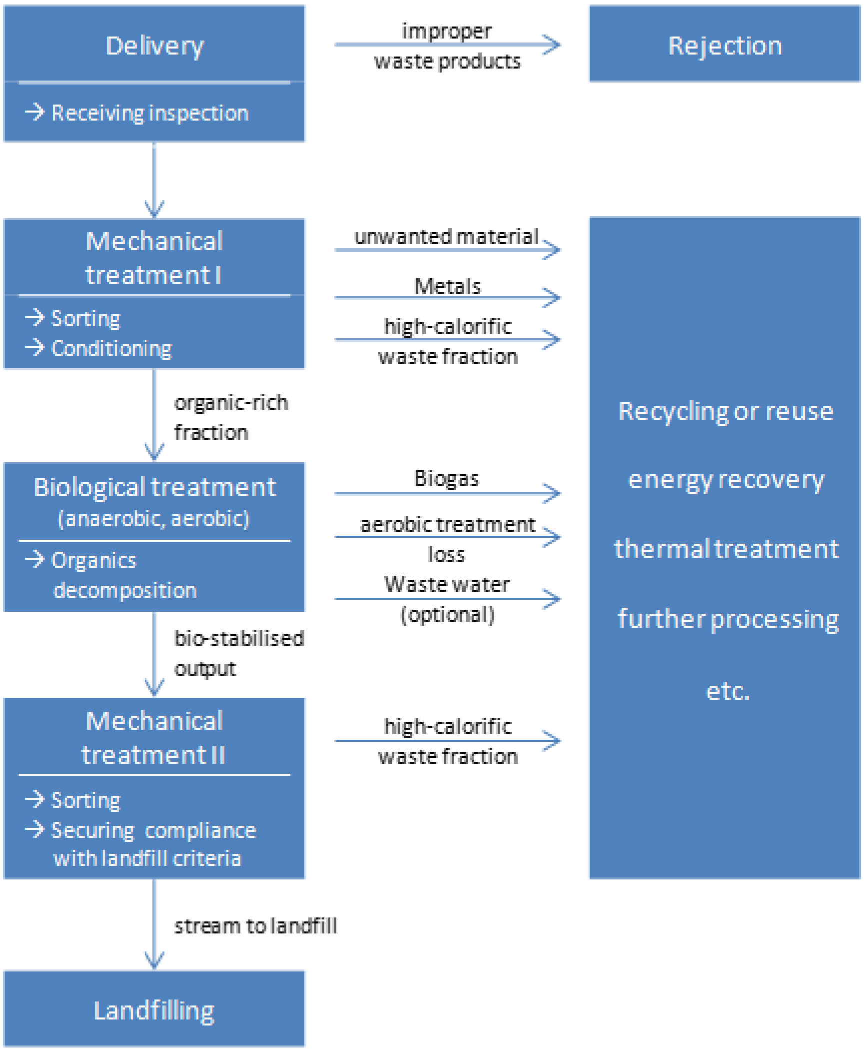
Nearly all new facilities were commissioned in 2005. Via expansions and operational upgrades, nearly all old facilities were brought into conformance with the 30th BImSchV by 2005. For 2005, it is not possible to correlate waste quantities with the various plant technologies used to treat waste, due to the dynamic changes that took place in that year. Consequently, no differentiated correlation of emissions to technologies is possible. For this reason, emissions

[145] Informative Inventory Report (IIR): www.iir.umweltbundesamt.de

through the year 2005 are calculated solely with the higher emission factors applying to the older-facility systems. Emissions as of the year 2006 are calculated with the lower emission factors for the new (or modernised) facilities.

Currently, about 3.75 million t of waste are treated annually in mechanical-biological waste treatment plants in Germany. In treatment, about 3.25 million t of residues occur. Of these, 0.69 million t are declared as waste for disposal (with a large fraction for storage in landfills); 2,45 million t are declared as waste for recycling (largely, for use as substitute fuels); and 0.1 million t are declared as other residues (such as secondary raw materials and products) (all data: Federal Statistical Office; GENESIS-ONLINE; Table 32111-0003). The remainder of 0.49 million t consists of mass losses, in the treatment process, occurring via biodegradation of organic fractions and evaporation or drainage (wastewater) of the water in the waste.

Figure 87: Substance-flow scheme for mechanical biological waste treatment (MBT)[146]



7.6.1.2 Methodological aspects (5.E Other: MBT)

The calculation method is in keeping with the standard calculation method: AD x EF = Emissions

146 Source: VDI 3475 Blatt 3, Emisssionsminderung - Anlagen zur mechanisch-biologischen Behandlung von Siedlungsabfällen, 2006-12 (amended)

Activity data (AD):

MBT have been operated in Germany only since 1995. For reporting purposes, the current data of the Federal Statistical Office are used (Statistisches Bundesamt, 2018). The Federal Statistical Office has regularly collected pertinent data since 1995. Through 2019, these data were published by the Federal Statistical Office as "Fachserie 19, Reihe 1" (Statistisches Bundesamt, 2018). As of 2020, publication has been discontinued, and the Federal Statistical Office has been providing the activity data via GENESIS-ONLINE (Statistisches Bundesamt (o.J.-b): Table 32111-0003).

Emission factors (EF)

In the 1990s, emissions from mechanical biological waste treatment were studied in a major collaborative research project supported by the Federal Ministry of Education and Research (BMBF). In a project carried out in 2003, the Institute for Energy and Environmental Research (IFEU 2003) refined the emission factors developed by the collaborative research project. In doing so, it differentiated between mechanical biological waste-treatment processes that were open (with no waste-gas collection and treatment) and processes that were closed (with waste-gas collection and treatment in biofilters). For methane, the emission factors for both types of processes were considered to be the same, since that substance is hardly broken down at all in biofilters. The N_2O emission factor for closed systems was considered to be higher than the EF for open systems, since N_2O also forms in biofilters, via oxidation of ammoniacal nitrogen.

For open mechanical biological waste-treatment facilities, the following emission factors resulted:

EF-N_2O = 190 g N_2O / t waste
EF-CH_4 = 150 g CH_4 / t waste

For closed MBT facilities with biofilters, and for the period prior to 2005, the same study obtained the following emission factors:

EF-N_2O = 375 g N_2O / t waste
EF-CH_4 = 150 g CH_4 / t waste

Since June 2005, as a result of new legal provisions (30th Ordinance Implementing the Federal Immission Control Act – BImSchV), the only facilities in operation are closed MBT. Such facilities have more-effective waste-gas-scrubbing processes that, logically enough, lead to lower emission factors. The 30th BImSchV requires continuous emissions measurements with respect to organic substances and N_2O, and it limits the pertinent permissible emissions loads. The emissions loads are determined on the basis of the monthly average concentrations, measured as half-hour averages, and of the waste quantities treated in the relevant monthly period.

In 2013, in order to assess this new situation, and working in the framework of data collection for revision of the Best Available Techniques Reference Document "Waste Treatment," the Federal Environment Agency, in cooperation with the Arbeitsgemeinschaft stoffstromspezifische Abfallbehandlung ((ASA); Working group for substance-stream-specific waste treatment (association of MBT operators)), collected emissions data on MBT. The emissions data for methane and N_2O proved to be considerably below the maximum permitted levels (Table 464).

Table 464: Emissions of MBT

Emissions parameter (exhaust gas)	Framework conditions (normal conditions)	Emissions range 16 installations		Emission factor (average value)	Maximum permitted levels 30. BImSchV
Total carbon ($C_{ges.}$)	Monthly averages Load in **g C_{total} / t waste** Calculated from half-hour averages	Lower values **Median** Upper values	2.3 – 21.8 **8.36 – 30.7** 10.6 – 44.0	***19; 5*** (26.1 g CH_4/t)	**55**
Nitrous oxide (N_2O)	Monthly averages Load in **g N_2O / t waste** Calculated from half-hour averages	Lower values **Median** Upper values	0.01 – 33.3 **1.54 – 59.0** 6.23 - 108	***30.3***	**100**

The emissions data reported in the survey are representative for existing German installations and take all MBT types used in Germany into account. The data requested in the survey include the ranges of the emissions loads at the relevant installations. In responses from total of 16 installations, the lower values of the emissions ranges, at individual installations, ranged from 2.3 to 21.8 g/t waste for C_{total} and from 0.01 to 33.3 g/t waste for N_2O. The upper values of the ranges ranged from 10.6 to 44.0 g/t waste for C_{total} and from 6.23 to 108 g/t waste for N_2O. The medians of the lower values were 8.36 g C_{total}/t waste and 1.54 g N_2O/t waste; the medians of the upper values were 30.7 g C_{total}/t waste and 108 g N_2O/t waste.

On the basis of this survey, the emission factors for years as of 2006 have been brought into line with the actual installation emissions. For the emission factors, in each case the average values of the medians of the lower and upper emissions values were used; i.e.:

EF-N_2O = 30.3 g N_2O / t waste

EF-CH_4 = 26.1 g CH_4 / t waste (under stoichiometric conversion, 19.5 g C_{total} are equivalent to 26.1 g CH_4; 12 g C = 16 g CH_4)

7.6.1.3 Uncertainties and time-series consistency (5.E Other MBT)

The uncertainties for mechanically-biologically treated waste quantities are considered to be very small (2 %), since the relevant data were obtained via an exhaustive survey, the quality of reporting to the Federal Statistical Office is good and operators have an interest in high-quality reporting. The uncertainties for the emission factors for the period prior to 2005 depend on the type of facility/plant in question, on the type of process used at the relevant time and on the effectiveness of the biofilters used. As a result of the underlying research project (IFEU; see above), and in keeping with the widely varying figures given in the literature, the uncertainties for methane were determined to be ± 60%, while those for nitrous oxide were determined to be ± 100% (open MBTs) and ± 60% (closed MBTs).

As of 2006, all installations in operation are closed installations with exhaust-air collection and treatment. The emissions of CH_4 and NO_2 are measured continuously. They fluctuate, throughout large ranges, at all individual installations, depending on operating status and waste composition. In keeping with this fact, and the good quality of the database, experts at the Federal Environment Agency estimate the uncertainties, for the period as of 2006, as being ± 20 %.

For technical reasons, it is not possible to show the resulting jump in the uncertainties, over the course of the time series, within the Central System of Emissions (CSE). For this reason, a prioritisation has been carried out whereby exact quantification of the uncertainties for the current values is considered to be considerably more important. Consequently, as of the 2022 report the uncertainties have been adjusted to ± 20 %, throughout the entire time series. The reference value for 1990 is not affected by this adjustment, since GHG emissions of MBT have been reported only since 1995.

7.6.1.4 Category-specific quality assurance / control and verification (5.E Other MBT)

General quality control and a quality assurance have been carried out by category experts and the Single National Entity, in conformance with the requirements of the QSE-manual and its associated applicable documents.

A comparison with the reports of other countries was carried out in connection with the 2021 report. In the process, it emerged that an IEF comparison is not possible, however, because Germany is so far the only country that reports GHG emissions of MBT in its national greenhouse-gas inventory; no IEF from other countries are available for a comparison.

7.6.1.5 Category-specific recalculations (5.E Other MBT)

In each case, when the inventory data for the current year are being prepared, the most recent available statistical data 7.6.1.2 on landfilled quantities of waste are the data for the previous reporting year, because the Federal Statistical Office's waste quantities appear with a one-year time lag (cf. Chapter 7.6.1.2) activity data). The figures for the current report year are thus being linearly extrapolated on the basis of the trend of the last two previous years. In the following year, the data so carried forward are replaced with the latest official data. For this reason, each year, the previous year's figures have to be recalculated,

Table 465: Recalculations, MBT 2019

Designation	Units	Report year	2019
Waste quantities treated	[t]	2022	3,744,400
		2021	3,718,600
CH_4	[kg]	2022	97,729
		2021	97,055
N_2O	[kg]	2022	113,455
		2021	112,674

7.6.1.6 Planned improvements, category-specific (5.E Other MBT)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

8 Other (CRF Sector 6)

In keeping with recommendations made by the UNFCCC Expert Team in the 2016 In Country Review, no greenhouse gases are reported in CRF Category 6. Because certain relevant categories of the CRF Reporter do not support data entry, the non-greenhouse gases NO_X, CO and NH_3 are subsumed under CRF 6. The actual allocation involved is shown in the following table:

Table 466: Actual allocation of the non-greenhouse gases listed under CRF 6

Gas	Quantity in kt	Actual allocation
CO	0.11	1.B
NO_X	0.03	1.B
NH_3	606.72	3

9 Indirect CO_2 & N_2O

In the national inventory , indirect CO_2 emissions from CH and NMVOC, and indirect N_2O emissions from NO_X and NH_3, are listed only in individual cases. Where pertinent figures are provided, they are normally treated as a regular part of the inventory.

Specifically, the parts in question include:

- CRF 1.A: Since the emissions are calculated on the basis of a carbon mass balance, indirect CO_2 is taken into account via the calculation method. It cannot be listed separately, however.
- CRF 2.D.1 & 3: The NMVOC emissions from lubricants (cf. also Chapter 4.5.1) and from solvent use (cf. also Chapter 4.5.3) are converted into indirect CO_2 and reported in CRF Table2(I).A-Hs2.
- CRF 3: In CRF Tables 3.B(b) and 3.D, indirect N_2O emissions from atmospheric deposition and leaching / surface runoff are reported.
- CRF 4: Indirect N_2O emissions from leaching / surface runoff are reported in CRF Table 4(IV).

10 Recalculations and improvements

10.1 Explanation and justification of the recalculations

10.1.1 Greenhouse-gas inventory

10.1.1.1 General procedure

There are a number of other reasons, in addition to the need for corrections, why recalculations and improvements can be necessary:

- Additional data become available that make it possible to close gaps in the inventory.
- A data source has changed.
- The method used for the source category has been adapted to provisions of the *Good Practice Guidance*.
- The source category has become a key category, thus necessitating a change of methods.
- New country-specific calculation procedures need to be used.
- Recommendations and results provided by reviews have been implemented.

10.1.1.2 Recalculations in the 2022 inventory, by source categories

This year's recalculations were necessitated by a range of methodological adjustments, some of which led to significant changes in the affected source categories, as well as by further improvements in details.

The inventories contain improvements in the following areas (unless otherwise indicated, in each case the changes refer to the entire pertinent time series):

Energy

In source category 1.A, after the final Energy Balance for report year 2019 became available, the following recalculations for the various relevant fuels were carried out:

(in millions of tonnes of CO_2-equivalents)	2021 Submission	2022 Submission	Change with respect to 2021 Submission	
Total emissions, CRF 1.A	660.7	657.7	-3.0	-0.5%
Petroleum	251.1	246.9	-4.2	-1.7%
Natural gas and mine gas	168.1	167.5	-0.6	-0.3%
Lignite	126.3	126.6	0.3	0.3%
Hard coal	93.7	94.8	1.1	1.2%
Other fuels / fuels	21.5	21.9	0.4	1.7%

Source: Own calculations

Larger changes occurred in the areas of petroleum and hard coal. The recalculations for natural gas and lignite, on the other hand, are relatively minor.

When final waste data became available, recalculations for the area of other fuels were carried out.

When all fossil fuels are taken into account, changes amouting to about 3.0 million t CO_2 result for source category 1.A.

(Additional, on an excerpt basis)

- Routine updating of the TREMOD and TREMOD MM calculation models
- Correction of the breakdown of avgas by the areas domestic flights and international flights (1.A.3.a, 1.D.1.a)
- Revision of the input quantities of solid fuels in steam railways, as of 1990 (1.A.3.c)

- Fundamental revision of the E.M.M.A. calculation model, for the period as of 1990 (1.A.3.d, 1.D.1.b)
- Correction of the net calorific value for gasoline, (1.A.5.b)
- Correction of the figure for production of hard-coal coke in 2019 (1.B.1)
- First-time inclusion of emissions from canister-based refueling of motorboats, including impacts on NMVOC emissions (for the period as of 1990) (1.B.2)
- New allocation of emissions from storage, for the period as of 1990 (1.B.2)

Industrial processes & product use

- Implementation of data from the final Energy Balance, for the period as of 2017 (2.C.1)
- Adjustment of the production quantity, 2019 (2.C.2)
- Consideration of motor-vehicle transmission oils, and revision of co-combusted quantities of lubricants, for the period as of 1990 (2.D.1)
- Compensation for rounding differences, for the period as of 1990 (2.D.2)
- Adjustment of foreign-trade statistics, 2019 (2.D.2, 2.G.4)
- New calculation of emissions from solvents, for the period as of 2018 (2.D.3)
- Improvement of the calculation method for blown asphalt, for the period as of 1990 (2.D.3.g)
- Correction of static data on charges, refrigerant fractions, percentages of automobiles with air conditioners, and input data, for the period as of 2006 (2.F.1)
- Correction of domestic consumption, and first-time data collection pursuant to the Environmental Statistics Act (Umweltstatistikgesetz), for the period as of 2005 (2.F.2)
- Updating of the charges in ORC systems, for the period as of 2018 (2.G.4)

Agriculture

- Use of data from the 2020 agricultural census, for the period as of 2000 (3A, 3B, 3D)
- Animal-population data: Updating of figures for weaners and fattening pigs (3.A, 3.A, 3.B).
- Poultry, horses, goats: Updating of animal counts in keeping with the 2020 agricultural census, for the period as of 2017 (3A, 3B, 3D)
- Suckler cows: Adjustment of figures for starting weight, energy requirements and feeding, for the period as of 1990 (3.A, 3.B, 3.D)
- Heifers: Correction of composition of feed ingredients, for the period as of 1990 (3.A, 3.B, 3.D)
- Male beef cattle: Updating of figures for age at slaughter and weight at slaughter (3.A, 3.A, 3.B)
- Dairy cows: Updating of figures for milk yield and weight at slaughter, 2019 (3.A, 3.B, 3.D)
- Fattening pigs: Updating of feeding data, for the period as of 1990 (3.A, 3.B, 3.D)
- Sows: Updating of the numbers of piglets per sow, 2019 (3.A, 3.B, 3.D)
- Fattening pigs and weaners: Updating of starting weights and final weights, (3.A, 3.B, 3.D)
- Broilers: Updating of the data on crude-protein content in feed and on feed conversion; updating of the data on total gross meat quantity obtained at slaughter, 2019 (3.B, 3.D)
- Turkeys: Updating of the data on weight at slaughter, weight gain and feed-conversion coefficients, for the period as of 2017 (3.A, 3.B, 3.D)
- Pullets and laying hens: Revision of starting weights and final weights, for the period as of 1990 (3.A, 3.B, 3.D)
- Geese: Adjustment of N excretions, for the period as of 1990 (3.A, 3.B, 3.D)

- New Tier 2 emission factors for direct N_2O emissions from application of mineral fertiliser, manure, sewage sludge, and digestates from crop residues (3.D)
- Manure digestion: Revision of activity data, for the period as of 1990 (3.B, 3.D)
- Digestion of energy crops: Updating of activity data, 2019 (3.D, 3.J)
- Mineral fertiliser, liming, urea application: Revision of cross-year activity data (3.D, 3.G, 3.H, 3.I)
- Sewage sludge: Updating of the N quantities applied, 2019 (3.D)
- Cultivated organic soils: Updating of areas and emissions, for the period as of 1990 (3.D)
- Mineralisation organic soil substance (cropland): Updating of N quantities, for the period as of 1990 (3.D)
- Crop residues: Updating of N quantities, for the period as of 2000 (3.D)

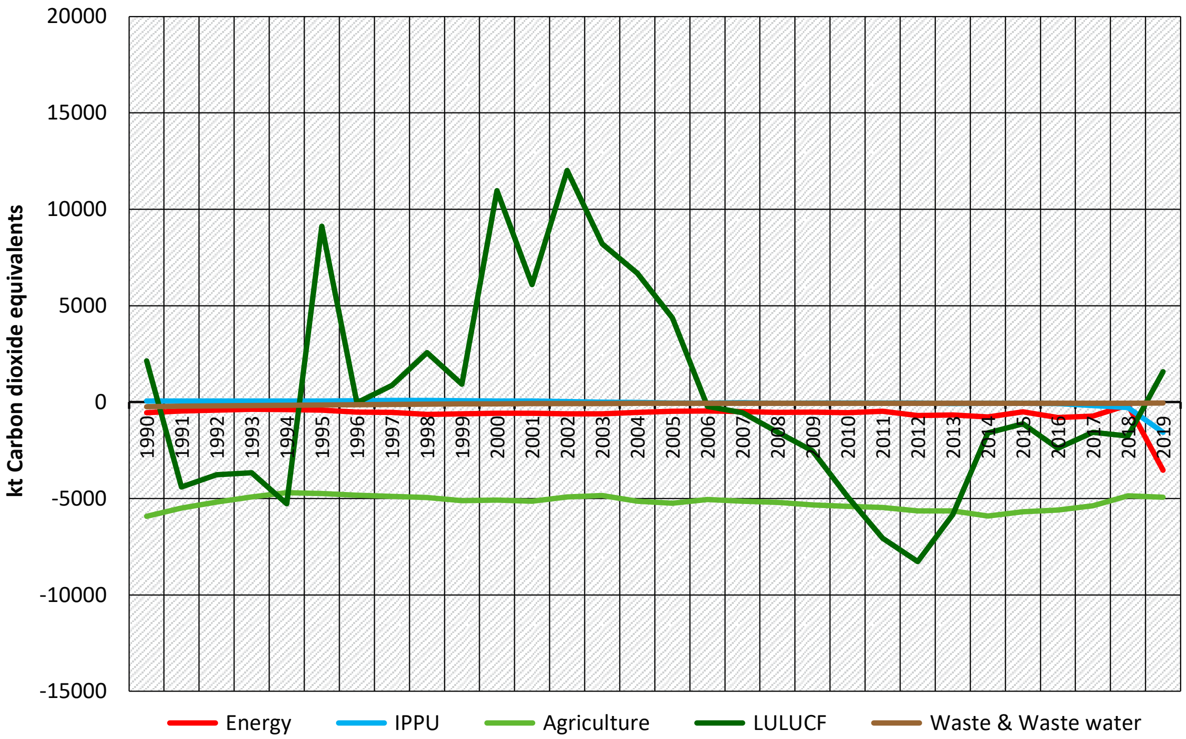
Land use, land-use change and forestry:

- Revision of emission factors for forest biomass
- Dead wood: Correction of the EF for afforestation
- Adjustment of the emission factors for previous uses, in connection with conversions from Woody Grassland (Grassland) to Forest Land
- Harvested wood products: Correction of FAOSTAT data for 2019 that, until recently, were still provisional
- Correction of fibreboards as a sub-quantity of wood materials (FAOSTAT), for the period as of 1995
- Cropland: The sub-category "Other perennial crops" has been replaced with the new sub-categories "Tree nurseries", "Christmas tree plantations" and "Short-rotation plantations"
- Implementation of models for calculation and monitoring of carbon stocks in the biomass of perennial plants outside of forest land

Waste and wastewater:

- Updating of statistical data, 2018 (5.A.1)
- Sector-specific consolidation of the density of methane, for the period as of 1990 (5.A.1, 5.B.2, 5.E.1)
- Correction of rounding errors in activity data (5.A.1, 5.B.2)
- Adjustment of FIND-COM, and conversion of the calculation for protein quantity, for the period as of 1990 (5.D.1)

Figure 88: Change in total emissions, throughout all categories, with respect to the 2021 Submission



10.1.1.3 Recalculations in the 2022 inventory, by substances

Recalculations were carried out in the following source categories (cf. also the specifications in 10.1.1.2):

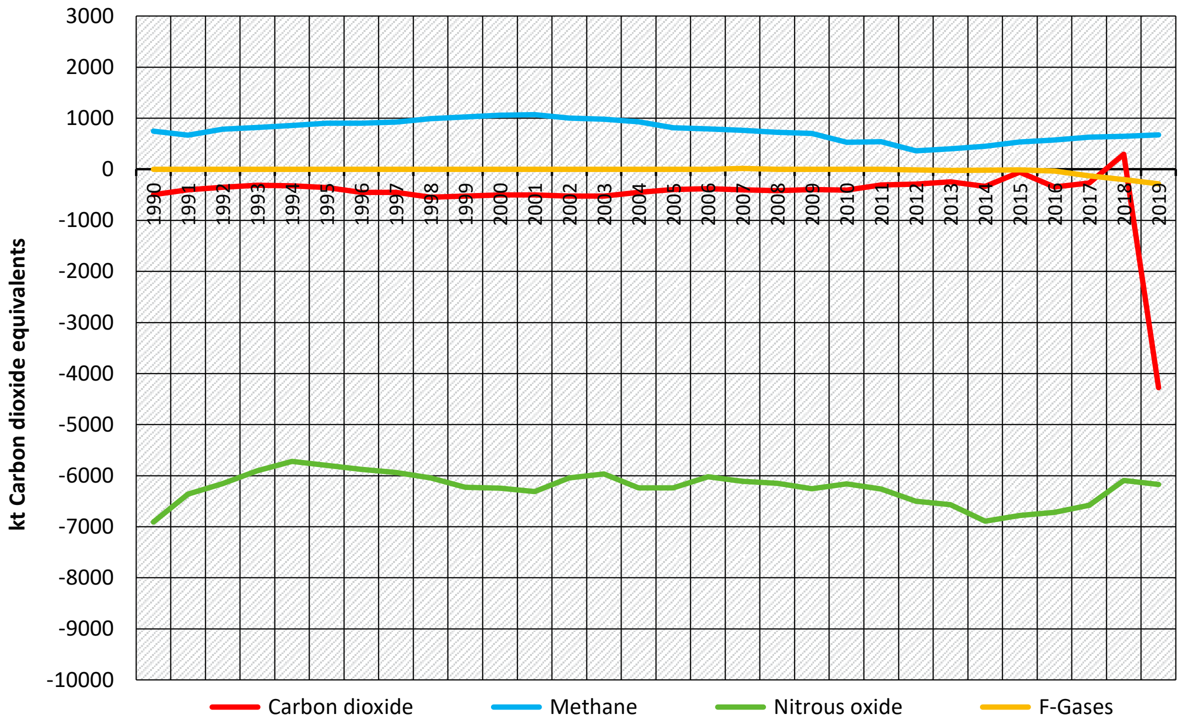
Table 467: Overview of the main CRF categories affected by recalculations

CRF	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3
1 – Energy	x	x	x				
2 – IPPU	x	x	x	x	x	x	x
3 – Agriculture	x	x	x				
4 – LULUCF	x	x	x				
5 – Waste & wastewater		x	x				

Table 468: Percentage changes with respect to last year's report

		Base year	2019
Total (CO_2 equiv.)		-0.53%	-1.24%
CO_2	1990:	-0.05%	-0.60%
CH_4		0.63%	1.37%
N_2O		-10.6%	-17.6%
F gases	1995:	0.00%	-2.05%

Figure 89: Recalculation of total emissions of individual GHG, throughout all source categories, with respect to the 2021 Submission



10.1.1.4 Recalculations carried out to implement results of the review process

With respect to the 2021 submission, a number of recalculations were carried out as the result of provided information or of recommendations from reviews. Details in this regard are provided in the relevant chapters for the affected sectors.

10.1.2 KP-LULUCF inventory

10.1.2.1 General procedure

The methods used for recalculations under the Kyoto Protocol are the same as those used under the Convention. Detailed information on the general procedure is provided in Chapter 10.1.1.1.

10.1.2.2 Recalculations in the 2022 inventory, by categories

The recalculations were carried out in connection with the KP categories Afforestation (A), Deforestation (D) and Forest management (FM), which Germany is required to report on, and with Cropland management (CM) and Grazing land management (GM). They were needed because emission factors (such as those for forest biomass and dead wood, and those used in connection with Settlements) (cf. Chapters 10.1.1.1 and 11.3.1.4), and certain calculation and survey methods (such as the method for calculating emissions and areas of organic soils, and emissions and areas of mineral soils in the case of LUC tied to settlements), were modified.

For *Harvested Wood Products (HWPs)*, the product categories a) paper and paperboard, b) sawn lumber and c) wood materials were updated and corrected, with the help of the FAO database (cf. Chapter 6.10.5).

10.1.2.3 Recalculations in the 2022 inventory, by substances

The changes described affect the emissions levels of all reported greenhouse gases.

10.2 Impact on emissions levels

10.2.1 Greenhouse-gas inventory

The changes with respect to the 2021 Submission, at -0.53 % for 1990 and -1.24 % for 2019, are larger than the corresponding changes in the previous submission. This is due primarily to recalculations, affecting the entire time series, in the *Agriculture* sector.

Table 471 and Table 472 show the changes in emissions as reported for 1990 and for 2019, for the various CRF sectors.

The inventory has been further improved with regard to completeness and accuracy.

Table 469: Recalculation of total national GHG emissions (without LULUCF)

	2021 Submission	2022 Submission	Change with respect to 2020 Submission	
	[kt CO_2-eq.)	[kt CO_2-eq.)	[kt CO_2-eq.)	[%)
1990	1,248,577	1,241,919	-6,658	-0.53%
1995	1,120,555	1,115,305	-5,250	-0.47%
2000	1,042,612	1,036,926	-5,686	-0.55%
2005	992,530	986,709	-5,820	-0.59%
2010	941,805	935,768	-6,037	-0.64%
2011	917,274	911,244	-6,030	-0.66%
2012	923,342	916,901	-6,441	-0.70%
2013	940,420	933,987	-6,432	-0.68%
2014	901,255	894,465	-6,791	-0.75%
2015	904,262	897,954	-6,308	-0.70%
2016	907,968	901,442	-6,526	-0.72%
2017	892,076	885,729	-6,346	-0.71%
2018	855,890	850,542	-5,348	-0.62%
2019	809,799	799,734	-10,065	-1.24%

Source: Own calculations

Considerable corrections, with respect to the previous report, were made in the emissions data for memo items. These are due primarily to revision of the calculation model used for maritime transports, as well as to recalculation of emissions pursuant to KP reporting under articles 3.3 and 3.4.

Table 470: Recalculation of inventory data that are reported as memo items

	1990	2019
Emissions reported as memo items:	**5.42%**	**4.89%**
From international transports	3.86%	0.39%
of which: international civil air transport	0.01%	-0.04%
of which: international maritime navigation	11.0%	4.0%
From multilateral military missions	NE	NE
CO_2 from combustion of biomass	0.00%	2.09%
KP Reporting	14.0%	-13.1%
captured CO_2 (CCS)	NO	NO

Source: Own calculations

10.2.1.1 Impacts on emissions levels of categories in 1990

Total emissions (not including LULUCF) for 1990 were downwardly corrected, by a total of about 0.53 %, or 6,658 kt CO_2 equivalents (cf. Table 471).

The key corrections with impacts on the inventory were carried out in the *Agriculture* sector (-5,928 kt | -7.75 %).

In addition, relatively minor corrections were carried out in the sectors *Energy* (-555 kt), *Industrial processes and product use* (+58 kt) and *Waste & wastewater (*-232 kt).

Since the previous submission, the net CO_2 emissions for the *LULUCF* sector, at +2,284 kt, have again been upwardly corrected, to a noticeable degree (+10 %). At the same time, the pertinent methane and nitrous oxide emissions decreased by 143 kt, or 5.61 %.

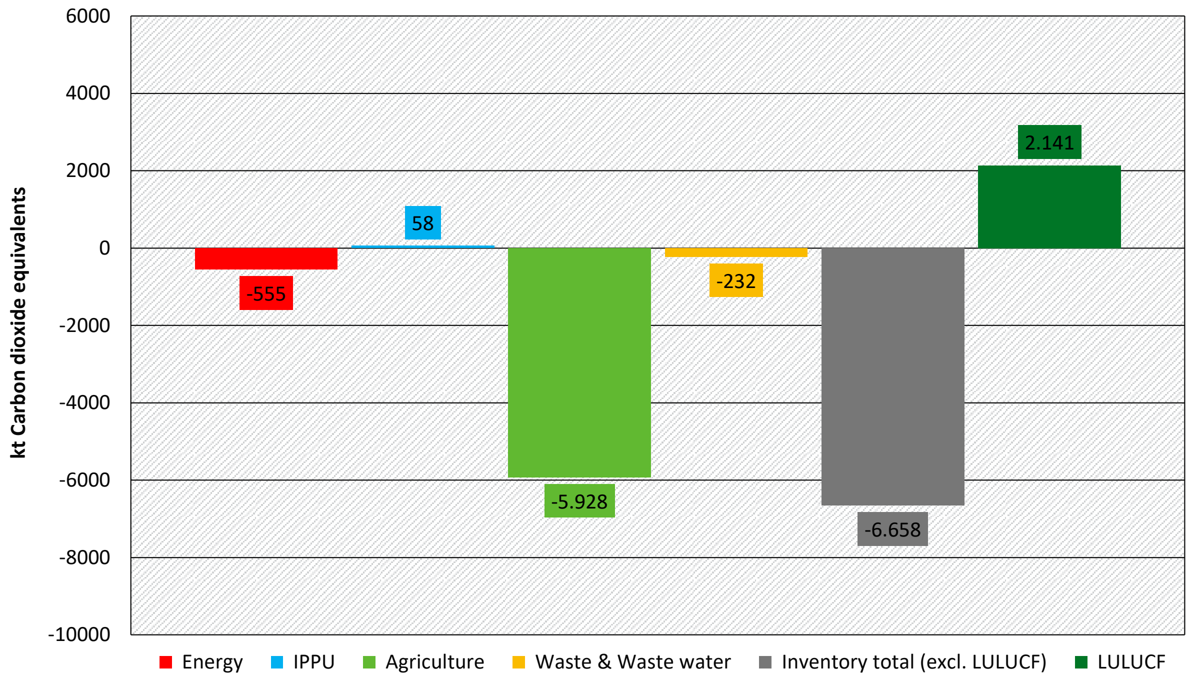
More-detailed pertinent information, in addition to that provided in the following table, is available in CRF tables 8(a)s1 through 8(a)s4.

Table 471: Recalculation of CRF-specific total GHG emissions, 1990

	2021 Submission [kt CO_2-eq.]	2022 Submission [kt CO_2-eq.]	Change with respect to 2021 [kt CO_2-eq.]	[%]
Total national emissions (without LULUCF)	**1,248,577**	**1,241,919**	**-6,658**	**-0.53%**
1. Energy	1,036,998	1,036,444	-555	-0.05%
2. IPPU	96,833	96,891	58	0.06%
3. Agriculture	76,509	70,581	-5,928	-7.75%
4. Land-use changes and forestry	24,862	27,003	2,141	-8.61%
CO_2 (net emissions / removals)	*22,307*	*24,591*	*2,284*	*10.2%*
N_2O + CH_4 (emissions)	*2,555*	*2,412*	*-143*	*-5.61%*
5. Waste & wastewater	38,235	38,003	-232	-0.61%

Source: Own calculations

Figure 90: Absolute changes in CRF sectors and the inventory as a whole, for the year 1990



10.2.1.2 Impacts on emissions levels of categories in 2019

The total emissions reported for the year 2019, not including those from LULUCF, have been downwardly corrected, considerably, by comparison to the 2021 submission – by 10,065 kt CO_2 equivalents, or 1.24 % (cf. Table 472).

The key corrections in this regard are distributed among the sectors *Energy* (-3,526 kt | -0.52 %), *Agriculture* (-4,927 kt | -7.97 %) and *Industrial processes and product use* (-1,566 kt | -2.55 %).

In addition, smaller changes have been made in the *Waste & wastewater* sector (-46 kt | -0.50 %).

In the *LULUCF* sector, CO_2 sink performance decreased by 1,541 kt in 2019. Methane and nitrous oxide emissions increased marginally (+31 kt, or 0.91 %).

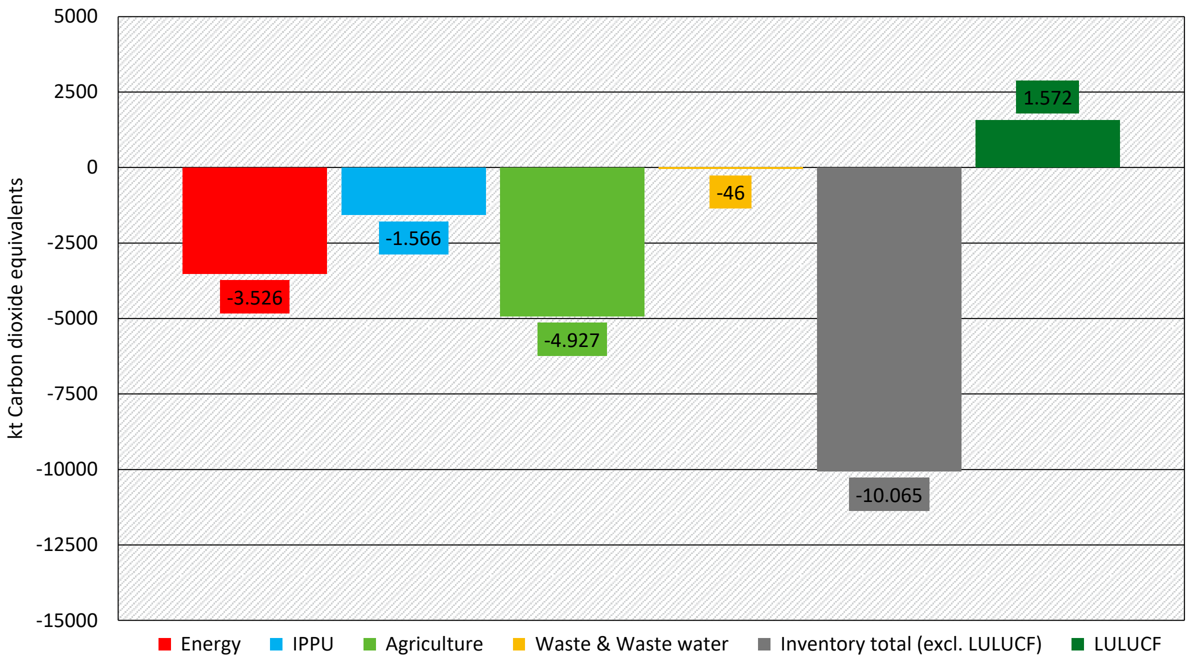
More-detailed pertinent information, in addition to that provided in the following table, is available in CRF tables 8(a)s1 through 8(a)s4.

Table 472: Recalculation of CRF-specific total GHG emissions, 2019

	2021 Submission	2022 Submission	Change with respect to 2021	
	[kt CO_2-eq.]	[kt CO_2-eq.]	[kt CO_2-eq.]	[%]
Total national emissions (without LULUCF)	**809,799**	**799,734**	**-10,065**	**-1.24%**
1. Energy	677,361	673,836	-3,526	-0.52%
2. IPPU	61,356	59,790	-1,566	-2.55%
3. Agriculture	61,839	56,912	-4,927	-7.97%
4. Land-use changes and forestry	-16,464	-14,892	1,572	9.55%
CO_2 (net emissions / removals)	*-19,805*	*-18,264*	*1,541*	*7.78%*
N_2O + CH_4 (emissions)	*3,341*	*3,372*	*31*	*0.91%*
5. Waste & wastewater	9,243	9,196	-46	-0.50%

Source: Own calculations

Figure 91: Absolute changes in CRF sectors and the inventory as a whole, for the year 2019



10.2.2 KP-LULUCF inventory

10.2.2.1 Impacts on emissions levels of categories in 1990

The results of the recalculations for 1990, with regard to the emissions in the individual KP categories, are shown in Table 473. All in all, an emissions increase of 29.04% occurred.

Some categories exhibit marked changes. On the one hand, these are due to differences in the pertinent activity data, resulting from updating of B-DLM data set of ATKIS® (cf. Chapter 6.3). On the other hand, they result from changes in emission factors for forest biomass and dead wood, and for Settlements, as well as from improvements in methods for derivation of organic-soil data.

Table 473: Recalculation of total emissions for 1990, in kt CO_2 equivalents

Land-use category	2021 Submission	2022 Submission	Change with respect to 2021	
	[kt CO_2-eq.]	[kt CO_2-eq.]	[kt CO_2-eq.]	[%]
Afforestation (KP 3.3)	677.9374	527.794	-150.143	-22.15%
Deforestation (KP 3.3)	206.771	286.824	80.053	38.72%
Forest management (KP 3.4)	-22,220.671	-21,213.242	1,007.429	-4.53%
Cropland management (KP 3.4)	10,749.908	14,141.849	3,391.941	31.55%
Grassland management (KP 3.4)	26,752.484	27,118.388	365.904	1.37%
Total	16,166.429	20,861.613	4,695.184	29.04%

Source: Own calculations

10.2.2.2 Impacts on emissions levels of categories in 2020

The impacts of the recalculations, on GHG emissions in the KP categories for the year 2020, are moderate (cf. Table 474). Overall, a 35.6% reduction of the sink function is now listed.

The other categories, with the exception of the categories afforestation and deforestation, show an increase of net emissions and a decrease of net removals. In the Forest Land category, these changes are tied mainly to use of changed emission factors for biomass; in the grassland-management category, they are tied to changes in methods for calculating GHG emissions from organic soils.

Table 474: Recalculation of total emissions for 2019, in kt CO_2 equivalents

Land-use category	2021 Submission	2022 Submission	Change with respect to 2021	
	[kt CO_2-eq.]	[kt CO_2-eq.]	[kt CO_2-eq.]	[%]
Afforestation (KP 3.3)	-564.984	-725.089	-160.105	28.34%
Deforestation (KP 3.3)	1,646.275	1,274.136	-372.139	-22.60%
Forest management (KP 3.4)	-56,930.324	-54,098.446	2,831.878	-4.97%
Cropland management (KP 3.4)	6,195.059	16,551.797	10,356.738	167.18%
Grassland management (KP 3.4)	22,035.480	20,465.601	-1,569.879	-7.12%
Total	-27,618.494	-16,531.999	11,086.495	-40.14%

Source: Own calculations

10.3 Impacts on emissions trends and on time-series consistency

10.3.1 Greenhouse-gas inventory

The time-series consistency has improved as a result of the recalculations.

As a result, the trend for total national emissions (not including LULUCF) shows a reduction of about 41.3 % with respect to the current base year.

Especially as a result of the impacts of the coronavirus pandemic, the 2020 figures for pure CO_2 emissions are nearly 10 % below the corresponding values for the previous year.

At minus 1.9 % and minus 2.7 %, respectively, the reductions for methane and nitrous oxide are considerably smaller. By contrast, the emissions for the sum of F gases have decreased considerably, by more than 11 %, although it should be noted that the trends for the individual F gases continue to develop heterogeneously.

10.3.2 KP LULUCF inventory

The consistency of the time series is maintained, in spite of the recalculations that have been carried out. The methodological changes, and data-sources improvements, that have been made have considerably improved the accuracy of the KP-LULUCF inventory.

10.4 Inventory improvements

10.4.1 Greenhouse-gas inventory

The following table summarises the improvements made in GHG-emissions reporting on the basis of the ERT's references and remarks in past reviews under the UNFCCC and the Kyoto Protocol. The table lists only aspects that were not already successfully addressed during the Review.

Table 475: Compilation of the Review recommendations successfully addressed as of the current report

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
0.	In CRF table 6, indirect emissions of CO2 and N2O from the energy and IPPU sectors were reported as “NO”. Furthermore, neither a notation key nor a figure was reported for the indirect emissions of CO2 and N2O from the LULUCF and waste sectors. During the review, Germany explained that it applied the same approach to the calculation of indirect emissions as during the first commitment period of the Kyoto Protocol. The Party stated that the notation keys for indirect emissions would be changed to “NE” in the next submission. Is finding an issue and/or a problem?: Yes. Comparability	Issue has been resolved: CRF-table 6 and chapter 9 of the NIR have been revised according to review recommendation	2018	G.11, Table 6	G7, Table 3 2020; (G.8, Table 3, 2020)	NIR 2022, chap. 9 and CRF-table 6
0.	While the Party reported key categories pursuant to the tier 1 approach in NIR table 6, the table does not clearly segregate categories identified as key by level from those identified as key by trend, because the headings of the columns of the table refer to the level assessment only. The ERT noted that this is not in accordance with the 2006 IPCC Guidelines (vol. 1, tables 4.2–4.3) because the relationship between the level and the trend of each category’s emissions and removals is not systematically and transparently presented. During the review, the Party clarified that an error had been made in the headings for columns 10–12 of NIR table 6, but the data in the table are correct. Is finding an issue/problem?: Not an issue/problem	the mistakes were corrected.	2020	G.9, Table 5		see NIR 2021, chapter 1.5.1, table 6.
0.	The Party reported potential further improvements to individual categories in the sectoral chapters of its NIR (e.g. in section 3.2.12.3, p.158), but not all these potential further improvements were included in NIR table 510 on planned improvements, although sometimes the table is cross-referenced. The ERT noted that this is not in accordance with the UNFCCC Annex I inventory reporting guidelines because information obtained from implementing the QA/QC programme, the inventory review process and other verification activities should be considered in the development and/or revision of the QA/QC plan and the quality objectives. During the review, the Party clarified that data loss had occurred when entering the planned improvements into NIR table 510, but this was not noticed until after the NIR had been finalized. Is finding an issue/problem?: Yes. Convention reporting adherence	Development of a new Checklist for the QSE-Coordinator to ensure that all the needs for category-specific improvements are included in the inventory plan.	2020	G.10, Table 5		-
1.D.1.a.	Gaseous fuels: In CRF table 1s2, the cells for reporting CO2 captured for domestic storage and for storage in other countries were left blank. During the review, Germany clarified that this should be reported as “NO” ERT: Finding is an issue and/or a problem: Yes	Issue has been resolved, by adding the aproprIate notation key	2015, 2016	E.18, Table 5	E.5, 2018; E.3, Table 3, 2020;	CRF table 1.C
2.A.1.	Germany reported that recalculations were made to include dust discharged via the bypass path for the entire time series (NIR, section 4.2.1.5). The ERT noted that the methodology used to estimate bypass dust was not explained in the NIR. During the review, Germany explained that the German Cement Works Association estimates the bypass dust for its members, which results in a similar value to the default EF of the IPCC (2 per cent). The Party stated that in the future, the IPCC default EF would be used. Is finding an issue and/or a problem?: Yes. Transparency	Description has been improved.	2018	I.10, Table 5	I.1, Table 3, 2020;	NIR 2021, 4.2.1.2

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
2.A.4.b.	The Party reported large inter-annual variation in CO2 emissions for subcategory 2.A.4.b (other uses of soda ash) between 2016 and 2017 (–39.6 per cent) and 2017 and 2018 (–65.6 per cent) in CRF table 2(I).A-Hs1, and also reported that emissions decreased from 205.7 kt CO2 in 2016 to 42.7 kt CO2 in 2018. Germany stated in the NIR (section 4.2.4.2.2, p.309) that "at the time the inventory was being prepared, clarification of those figures was still underway…the low values for the years 2017 and 2018 lead to a decreasing trend, one that cannot yet be explained from a technical industry standpoint and that would seem to arise calculatory from the balance-sheet method used". During the review, the Party explained that verification of these figures is still in progress and that it is aiming to make relevant improvements for the next submission. During the review, the ERT determined there were no underestimates of emissions. Is finding an issue/problem?: Yes. Accuracy	Even though waiting until the last possible moment, we do not have the necessary data to restructure the entire soda calculation. Thus, an update was made according to the previous method.	2020	I.16, Table 5		NIR-Ch. 4.2.4.2.3
2.B.2.	Germany reported that emission control technologies are used and "in some cases catalytic decomposition directly following ammonia combustion" occurs (NIR, section 4.3.2.2). During the review, Germany explained that secondary catalytic reduction of N2O and NH3 is used. The ERT noted the reporting and documentation section of the 2006 IPCC Guidelines (volume 3, chapter 3.3.4.2) indicates that it is good practice to document all information required to produce the inventory and that in the case of nitric acid production, the type of abatement technology is an example of specific documentation. Is finding an issue and/or a problem?: Yes. Transparency	The follwing information "During the review, the Party clarified that selective catalytic reduction technology is used to reduce N2O and NH3 emissions, and that one plant has two selective catalytic reductions in a row." is added in the NIR.	2018	I.16, Table 6	I.5, Table 3, 2020;	See NIR 2022, chapt. 4.3.2.2, p. 313
2.B.3.	The 2014 review report contained a recommendation on the methodology used to estimate N2O emissions from adipic acid production (see table 3, ID# I.2). In the 2016 submission, Germany improved the transparency of its reporting on the methodology used to estimate N2O emissions from the three plants in operation (page 318). It is reported that one of the three plants, which started operation in 2002, has been conducting measurements continuously since 2013. However, Germany did not report how the emissions for that plant were estimated during the period 2002–2012, prior to when the measurements started ERT: Finding is an issue and/or a problem: Yes	Resolved	2015, 2016	I.9, Table 5	I.4, 2018; I.8, Table 3, 2020	NIR 2019, chapter 4.3.3.2 and NIR 2021, chapter 4.3.3.3
2.C.2	The Party reported the source of the AD used to estimate CO2 emissions for category 2.C.2 (ferroalloys production) from 1995 onward in its NIR (section 4.4.2.1, p.342), but did not provide information on the AD used for 1990–1994. During the review, the Party clarified that production figures from the Federal Statistical Office were used for 1990–1994, but since 1995, these production figures have not been included in national production statistics. As a result of this situation, data from the British Geological Survey were used for 1995 onward. Is finding an issue/problem?: Yes. Transparency	Resolved	2020	I.17, Table 5		see NIR 2021, chapter 4.4.2.2
2.D.1.(a)	The Party reported emissions of 138.84 kt CO2 and 2.33 kt NMVOC for 2011 in CRF table 2(I)s2. NIR table 213 shows the recalculation made for 2011 resulted in a much higher change to the emissions (33.70 per cent) than the recalculations made for other years, which ranged from –0.37 to +0.48 per cent. During the review, the Party provided the calculation spreadsheet for NMVOC and CO2 emissions from stationary lubricant use. The ERT noted that the NMVOC emissions for 2011 were calculated as 23.33 kt, not 2.33 kt as reported in CRF table 2(I)s2. Germany explained after examining the point raised by the ERT that a transcription error must have occurred with the decimal place in the database and that it would be corrected in the next submission. The ERT noted that this error in NMVOC emissions resulted in an error in CO2 emissions. Is finding an issue/problem?: Yes. Accuracy	Resolved	2020	I.18, Table 5		see NIR 2021, chapter 4.5.1.4

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
2.D.2	The Party reported a CO2 IEF of 2.50 t CO2/t product in CRF table 2(I).A-Hs2 for category 2.D.2 (paraffin wax use), while the NIR (section 4.5.2.1, p.358) provides a value of 2.9467 t CO2/t product. The EF in the NIR is consistent with the default EFs in the 2006 IPCC Guidelines (vol. 2, chap. 1), that is, 40.2 TJ/kt in table 1.2 (default net calorific values) and 73.3 kg/TJ in table 1.4 (default CO2 EFs for combustion), while the EF in CRF table 2(I).A-Hs2 is not consistent with these default values. During the review, the Party clarified that the AD in CRF table 2(I).A-Hs2 for category 2.D.2 include the biogenic fraction (15 per cent) of wax, thus resulting in an artificial IEF for CO2 emissions. Is finding an issue/problem?: Yes. Comparability	Resolved	2020	I.19, Table 5		see NIR 2021, chapter 4.5.2.2
2.E.3	The Party reported in its NIR (section 4.6.3.1, p.374) that “in Germany, use of SF6 in solar technology began in 2003…from 2014 onward, no wafer production with SF6 has taken place in Germany”. For category 2.E.3 (photovoltaics), CRF table 2(II).B-Hs1 reports consumption and emissions of SF6 for 2018 as 0.05 t and 0.002 t, respectively. For 1990–2002 and 2014–2017, consumption and emissions have blank cells. During the review, the Party confirmed the 2018 data from the Federal Statistical Office are incorrect and would be corrected for the next submission, and indicated that the appropriate notation key, “NO”, would be reported for 2018. Is finding an issue/problem?: Yes. Comparability	The value was replaced by the notation key.	2020	I.20, Table 5		Subm 2021, CRF table 2(II)B-Hs1 2018
2.G.3	The Party reported that it made recalculations of N2O emissions for subcategory 2.G.3.a (medical applications) for 1990–2002). CRF table 2(I).A-Hs2 in the 2019 submission reports N2O emissions for 1990–2002 (ranging between 6.81 kt N2O in 1990 to 3.42 kt N2O in 2002), while CRF table 2(I).A-Hs2 in the 2020 submission reports emissions as “C” (confidential) for 1990–2002. There are no recalculations for 2003 onward. During the review, the Party clarified that the export from the database to CRF Reporter did not work, so a lot of IPPU data had to be added to CRF Reporter manually. This led to what is assumed to be human error, and N2O emissions from anaesthetic use, explosives, semiconductor production, and propellant for pressure and aerosol products being reported as confidential. Is finding an issue/problem?: Yes. Accuracy	The missing N2O emissions were added´.	2020	I.21, Table 5		Subm 2021, CRF table 2(I)H-As2
3.	The Party reported the dairy cattle population in its NIR (p.454) and in Haenal et al. (2020, section 3.4.2.2). The population decreased significantly from 1990 to 1991 – by 11.4 per cent – but the reason for this change is not described in the NIR or in Haenal et al. (2020). The Party also reported the IEF for enteric fermentation of swine in CRF table 3.As1. The IEF decreased significantly from 1990 to 1991 – by 16.3 per cent – but the reason for this change is not described in the NIR or in Haenal et al. (2020). During the review, the Party clarified that after German reunification in 1990, the animal populations of dairy cattle and swine decreased due to structural changes resulting from the reunification. Is finding an issue/problem?: Not an issue/problem	Issue has been resolved.	2020	A.6, Table 5		see NIR 2022 chap. 5.3.1.2.3

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
3.A.1.	Germany stated in the agriculture sector methodology report (Haenel et al., 2018, section 4.7.2) that mean annual ME requirement of suckler cows is assumed to be constant at 36,000 MJ per animal, and that a share of 1,620 MJ per animal is consumed with concentrates and the rest is consumed with pasture grass and grass silage. During the review, in response to the ERT's request that performance parameters (e.g. weight, weight gain, milk yield) applied as the basis for ME and DMI of suckling cows be specified, Germany explained that constant ME and DMI values were used and that they were obtained from KTBL (2006). The reference represents data for a typical suckling cow, and is widely used by German farmers for planning purposes. Therefore, the Party considers that the reference correctly represents German agricultural practice and takes energy requirements from all activities into account. The ERT noted that Germany reported, in its supplementary Excel file to Haenel et al. (2018), data on mean percentage time spent on pasture by suckling cows (table AI1005CAT.130). This grazing time has an increasing trend, increasing from 41.5 per cent in 1990 to 47.3 per cent in 2016. In response to a question raised by the ERT on how energy required for activities (e.g. walking, eating from pasture) is considered in the estimation of ME and DMI of suckling cows, as DMI and ME values per head of suckling cow are kept constant to estimate the enteric fermentation CH4 EF over the entire time series, the Party explained that, based on the calculations completed by KTBL (an enquiry was sent to KTBL during the review), the impact of the difference in grazing times between 1990 and 2016 on extra ME requirement is negligible (141 MJ per animal per year) and, hence, it might be accounted for under conservative rounding up, because Germany used, in the inventory, 36,000 MJ per animal per year instead of 35,766 MJ per animal per year as reported by KTBL. Is finding an issue and/or a problem?: Yes. Transparency	Issue has been resolved.	2018	A.11, Table 6	A3, Table 3, 2020;	see NIR 2022 chap.5.1.3.3, Leistungs-, Energie- und Futterdaten (3.A, 3.B), see table 231
3.A.1.	Germany reported in the agriculture sector methodology report (Haenel et al. (2018), p.151) on the methodology applied to estimate ME requirements of heifers, which include the energy required for maintenance and for growth for various weight gains and during pregnancy. The ERT noted that Germany reported, in its supplementary Excel file to Haenel et al. (2018), data on mean percentage time spent on pasture by heifers (table AI1005CAT.69). This grazing time has a slightly increasing trend, increasing from 20.0 per cent in 1990 to 20.7 per cent in 2016. During the review, in response to a question raised by the ERT on how energy required for activities (e.g. walking, eating from pasture) is considered in the estimation of ME of heifers, Germany explained that average ME requirements due to grazing were taken into account, but variations in mean percentage time spent on pasture were not reflected in the estimations of average ME. In addition, the Party explained that is not clear how much grazing time was assumed when deriving the data in table 4.32 of Haenel et al. (2018) (ME requirements as a function of animal weight and weight gain). Moreover, Germany stated that the influence of weight gain and weight on ME requirements is of much more importance than the influence of grazing time, as the change in grazing times of heifers from 20.0 per cent in 1990 to 20.7 per cent in 2016 is small. The Party also stated that data on mean percentage time spent on pasture are considered in the calculation of ME contributions by pasture grass and grass silage, which has a slight impact on the estimations of VS value and Nex rate. Is finding an issue and/or a problem?: Yes. Transparency	Issue has been resolved.	2018	A.12, Table 6	A.4, Table 3, 2020;	see NIR 2022 chapter 5.1.3.3, Leistungs-, Energie- und Futterdaten (3.A, 3.B), see table 231

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
3.B.3.	The Party reported that there are no other manure management systems (free range pigs) in the country in CRF table 3.B(b) and in the NIR (p.464) that "free-range management of swine plays an insignificant role in Germany and it is thus not occurring in Germany". During the review, the Party clarified that, according to the 2010 agriculture census conducted by the Federal Statistical Office, there were approximately 48,800 free range pigs in 2010, equating to 0.2 per cent of all swine housing types. The Party explained that according to expert opinion, this population has not changed because of the strict national requirements for swine housing systems, and further, that free range pigs are not excluded from the inventory but are included in other management systems because total pig numbers are used in the inventory. Is finding an issue/problem?: Yes. Transparency	Issue has been resolved.	2020	A.7, Table 5		see CRF Table3.B(a)s2, and NIR 2022 chapter 5.1.3.6 ff.
3.D.a.2.c + 3.D.b	The Party reported in its NIR (p.509) that the emissions associated with the application of biowaste residues to crops as fertilizer are included under the waste sector. In the waste chapter (on p.709 regarding composting facilities and p.712 regarding digestion plants) the Party reported that EFs for the composting of biowaste include both emissions from the composting itself and emissions from the storage and application of the compost. Furthermore, the Party stated in the NIR (p.709) that "the nitrous oxide emissions following fertilization with compost are very low. They can be neglected, since the nitrogen they include is organically bound and mineralizes very slowly". The ERT noted that the 2006 IPCC Guidelines (vol. 3, chap. 11) recommend that direct and indirect N2O emissions from organic fertilizers applied to managed soils be estimated. The Guidelines provide a default EF of 0.01 kg N2O- N per kg N applied to estimate direct N2O emissions, 0.01 kg N2O-N per kg NH3-N and NOX-N volatilized to estimate indirect N2O emissions, and 0.0075 kg N2O per kg N to estimate leaching and run-off. During the review, the Party confirmed that the EF for the composting of biowaste is based on a country study (Cuhls et al., 2015) and it includes composting as well as the storage of compost and its application onto soils. Germany reported that the emissions from the storage and application of biowaste are 25g N2O per Mg biowaste. Is finding an issue/problem?: Yes. Transparency	Detailed information on the composition of the used EFs for N2O, regarding treatment, application and minerlisation have been added to the NIR, including a comparison with the default factor from IPCC. Addiotionally the questioned statement has been deleted and the sentence adjusted accordingly.	2020	A.8, Table 5		See NIR chap. 7.3.1.2 and 7.3.2.2
4.	The ERT encourages Germany to use the Wetlands Supplement in preparing its annual inventory for CO2 off-site emissions in drained organic soils for future annual submissions. Is finding an issue/problem?: Not an issue/problem	Issue has been resolved.	2020	L.7, Table 5		see NIR 2022 chapter 6.1.2.2.2 and 6.7.2

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
4.A .	The Party reported in its NIR (section 6.4.2.2.8, p.606) that to calculate carbon stock changes between two time points (1987–2002, 2002–2008, 2008–2012 and 2012–2017), the “continuous forest inventory” method was used; that is, for scaling up a national total estimate, only cluster points that were included at both time points were used. The same method has been applied to biomass and DOM carbon pools, although for DOM, the carbon stock data are limited to three points in time (2002, 2008 and 2017). The ERT noted that the total biomass carbon stock change reported for the forest domain under the Convention in CRF table 4.A (forest land remaining forest land and land converted to forest land, with the latter limited to stock gains) and CRF tables 4.B–4.E (forest land converted to other land uses, limited to stock losses) does not match the total biomass carbon stock change reported under the Kyoto Protocol in CRF tables 4(KP-I)A.1 (afforestation and reforestation, limited to stock gains), 4(KP-I)A.2 (deforestation, limited to stock losses) and 4(KP-I)B.1 (FM). The same inconsistency was found for the DOM carbon pool. For instance, for 2017, the total forest-related biomass annual net carbon stock change reported under the Convention is 13,986.504 kt C (forest land remaining forest land, 12,551.962 kt C; land converted to forest land, 1,697.615 kt C; forest land converted to other land uses, –263.073 kt C), while under the Kyoto Protocol the total is 14,591.672 kt C (FM, 12,391.471 kt C; AR, 2,515.870 kt C, deforestation, –315.668). Similarly, for DOM, the total annual net carbon stock change reported for 2017 under the Convention is 845.838 kt C (forest land remaining forest land, 884.969 kt C; land converted to forest land, 105.690 kt C; forest land converted to other land uses, –144.822 kt C) and under the Kyoto Protocol is 925.831 kt C (FM, 873.172 kt C; AR, 197.628 kt C; deforestation, –144.969 kt C). The ERT also noted that the forest definition applied under the Convention does not significantly differ from that applied under the Kyoto Protocol (NIR, p.781) and that carbon stock change estimates under both reporting requirements are based on data from the same database and on the same methodologies for determining land representation (NIR, sections 6.2–6.3) and calculating carbon stock changes (NIR, pp.790–791). Thus, for each carbon pool in each inventory year the total carbon stock change of the forest domain reported under the Convention should match the one reported under the Kyoto Protocol; further, both should match the total carbon stock change calculated by subtracting the total carbon stock determined from an NFI from the total carbon stock of the previous NFI. During the review, the Party did not provide any additional information. Is finding an issue/problem?: Yes. Accuracy	Issue has been resolved.	2020	L.10, Table 5		see NIR 2022 chapter 6.1.2.3.1, 6.1.2.3.2, 6.1.2.3.8, 6.1.2.4, 6.4.2.5.2
4.A .	The Party reported in its NIR (sections 6.2–6.3) that the same data sources and methods were applied to land representation for LULUCF under the Convention as to KP-LULUCF activities under the Kyoto Protocol. The Party also reported that the forest definition applied under the Convention does not significantly differ from that applied under the Kyoto Protocol (NIR, p.781) so lands classified as forest or non-forest under the Convention have the same classification under the Kyoto Protocol. Accordingly, the total area reported as forest land under the Convention should be identical to that reported under the Kyoto Protocol (and vice versa). However, the ERT noted that in every inventory year the total area reported as forest land under the Convention does not match that reported under the Kyoto Protocol. For instance, for 2017, the total forest area reported under the Convention is 10,986.159 kha (forest land remaining forest land, 10,792.496 kha; land converted to forest land, 193.663 kha), while under the Kyoto Protocol the total is 10,965.449 kha (FM, 10,699.156 kha; AR, 266.293 kha). During the review, the Party did not provide any additional information. Is finding an issue/problem?: Yes. Accuracy	Issue has been resolved.	2020	L.11, Table 5		see NIR 2022 chapter 6.1.2.1 and 6.1.2.3, 6.4.2.5.3

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
4.B.	The Party reported short-rotation plantations for wood production under cropland instead of forest land in CRF table 4.B and section 6.1.2.3.4.3 (pp.558–561) of the NIR. In that section, the Party also reported that biomass carbon stock changes in short-rotation plantations for wood production are only reported in the year of conversion of a land to a short-rotation plantation, and the biomass carbon stock net gain is estimated once, as an instantaneous accumulation in the year of conversion only. The ERT noted that this is not in accordance with the 2006 IPCC Guidelines (vol. 4, chap. 1, on land-use categories; chap. 2, on generic methodologies for estimating stock changes in carbon pools; chap. 4, on additional guidance to estimate carbon stock changes in forest land; and chap. 5, on additional guidance to estimate carbon stock changes in cropland) because short-rotation plantations produce wood rather than crops and meet the forest land definition of the 2006 IPCC Guidelines, as well as the thresholds of the German forest definition, so IPCC good practice for estimating forest biomass carbon stock changes applies even if this management system is reported by the Party under cropland. During the review, the Party clarified that lands with short-rotation plantations are considered to be agricultural areas (cropland) and that managing forest land as short-rotation plantations is prohibited by German forest codes and laws. Accordingly, short-rotation plantations are not included in the NFI. Is finding an issue/problem?: Yes. Accuracy	Issue has been resolved.	2020	L.12, Table 5		see NIR 2022 chapter 6.1.2.1 and 6.1.2.3.4, 6.1.2.3.5.5
4.B.1.	The Party reported a 'net zero' biomass carbon stock change in cropland remaining cropland with perennial vegetation under the assumption of long-term equilibrium of such carbon stocks in its NIR (section 6.1.2.3, pp.546–563). The ERT noted that this is not in accordance with the 2006 IPCC Guidelines (vol. 4, chap. 5.2.1.1) because the default method is to multiply the area of perennial woody cropland by a net estimate of biomass accumulation from growth and subtract losses associated with harvesting, gathering or disturbance (according to equation 2.7). Losses are estimated by multiplying a carbon stock value by the area of cropland on which perennial woody crops are harvested. This implies that the IPCC tier 1 methodology assumes continuous accumulation of biomass in perennial crops until the final harvest occurs. During the review, the Party clarified that the rotation times of permanent crops are highly variable and depend on their species (between approximately 3 and 30 years, but usually fewer than 20). Therefore, the age structure of the permanent crops in the 'remaining' category is unknown, as is the stage of growth at which permanent crops change from the transitional to the remaining category. Consequently, the carbon stock is assumed to be in long-term equilibrium, and the age groups of the different cultures in the remaining category are assumed to be uniformly distributed over the long term. However, the ERT notes that national GHG inventories shall report emissions when those actually occur. The methodology applied by Germany, which is based on reporting net zero emissions (the consequence of assuming a constant carbon stock at its long-term equilibrium level), involves counting in any year an amount of future emissions or removals up to an amount that counterbalances the actual emissions and removals occurring in that year. Is finding an issue/problem?: Yes. Completeness	Issue has been resolved.	2020	L.13, Table 5		see NIR 2022 chapter 6.1.2.1

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
4.B.1. + 4.C.1.	The Party reported in its NIR (p.532) that “for mineral soils with no use or name change, in land-use categories 4.B, 4.C, it is assumed that the pertinent carbon inputs into the soil and carbon extractions from the soil are equal in size, so that the systems are in equilibrium”. The increased use of organic fertilizers shown in NIR figure 62 is expected to have caused, across time, a permanent average increase in the soil organic carbon stock of German agricultural land. The ERT noted that assuming equilibrium in SOC in cropland remaining cropland and grassland remaining grassland without consideration of changes in cultural practices and their intensity is not in accordance with the 2006 IPCC Guidelines (vol. 4, chaps. 2, 5 and 6, and equation 2.25) because the IPCC default method differentiates SOC in mineral soils of cropland according to tillage intensity and amount of carbon input, including organic fertilizers, as well as by use type including set-aside, and of grassland according to carbon input and intensity of management. Thus, IPCC good practice requires the estimation of SOC changes associated with changes in those variables. During the review, the Party clarified that no official or representative data regarding the management of agricultural land were available to the inventory compilation team and, therefore, that no quantified comprehensive spatially explicit assessments of the effects of different management measures on SOC content in the cropland remaining cropland and grassland remaining grassland categories can be made yet. Further, the Party stated that the findings (as summarized in the NIR, section 6.5.2.3) of the permanent soil observation system, which examines agricultural areas that are cultivated according to the well-established methods of good agricultural practice, indicate that on average there have been no changes in the SOC of agricultural mineral soils over the last 25 years. Finally, the Party informed the ERT that it is working on a medium-term solution that will provide the capability to implement a new inventory methodology after 2025 by conducting a second nationwide inventory of agriculturally used soils (start: 2021); developing model ensembles, which will be validated by results from the first and second agricultural soil inventory; attempting to gain access to georeferenced agricultural management data for the inventory, in particular from the German Integrated Administration and Control System (which is a difficult process because of German privacy legislation and necessary negotiations with all 16 German federal states); and exploring options of deriving management information from remote sensing data (which would only cover the future and recent past). Acknowledging the future work on the subject as planned by the Party, the ERT notes that the country-specific methodology currently applied requires verification as per paragraph 41 of the UNFCCC Annex I inventory reporting guidelines. Is finding an issue/problem?: Yes. Convention reporting adherence	Issue has been resolved.	2020	L.14, Table 5		see NIR 2022 chapter 6.1.2.1, 6.5.2.2, 6.6.2.2
4.B.2. + 4.C.2.	The Party reported in its NIR (p.530) that biomass carbon stock changes for land-use changes are calculated under the assumption that the entire carbon stock change occurs in the year of the conversion. The ERT noted that this approach is not consistent with conversion to land with perennial biomass, as per good practice set out in the 2006 IPCC Guidelines (vol. 4, chaps. 2, 5 and 6, and equations 2.7 and 2.15), because perennial biomass accumulates over time, not just in the year of conversion. During the review, the Party confirmed that perennial biomass in non-forest land is assumed to accumulate once, in the year of conversion, and to be in long-term equilibrium thereafter. Is finding an issue/problem?: Yes. Accuracy	Issue has been resolved. Description is given in the resp. chapter.	2020	L.15, Table 5		NIR 2022, chapters 6.1.2.1 und 6.1.2.3.4, 6.1.2.3.5.5, 6.5.2.3.2, and 11.3.1.1.1

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in ...
5.B.2.	Germany reported AD as “NO” in the CRF table for this category (5.B). The ERT noted, however, that 677.0 t of livestock manure in 2018 and an estimated 2,373.0 t in 2020 were co-digested with biowaste at digestion plants (NIR, section 7.3.2.1, p.711). The emissions from the livestock component of the plant feedstock were appropriately reported under the agriculture sector in CRF table 3.B(a), column K (NIR 2018, sections 5.1.3.6.5 and 5.1.4) in order to avoid double counting. During the review, the ERT and the Party discussed the appropriate reporting of this category (5.B) with respect to footnote 4 to CRF table 3.B(a), and agreed that the AD should be reported in CRF table 5.B, column B, while the emissions should be reported as “IE” in order to improve the consistency of the NIR and the CRF tables and also to ensure the reporting is in accordance with footnote 4 to CRF table 3.B(a) (i.e. “This category should include all organic waste from sources not covered by municipal solid waste”). Is finding an issue/problem?: Yes. Transparency	The recommendation has been implemented. See CRF Table 5b	2020	W.10, Table 5		table 5b
KP	Germany included SRCs under cropland management activity, since, according to the forest definition provided in the German NFI, they are explicitly not forests and are not covered by German forest law. During the review, the Party clarified that no spatially explicit data for SRCs are available. The ERT notes that, according to the Kyoto Protocol Supplement, it is good practice to continuously follow the management of land subject to cropland management by tracking lands, or through statistical sampling techniques, ensuring that double counting with forest management is avoided. The ERT further notes that it is good practice to document how consistency is achieved with Kyoto Protocol activities ERT: Finding is an issue and/or a problem: Yes	Issue has been resolved. Description is given in the resp. chapter.	2015, 2016	KL.12, Table 5	KL.10+11, 2018; KL.5+6, Table 3, 2020;	NIR 2022, chapters 6.1.2.1 und 6.1.2.3.4, 6.1.2.3.5.5, 6.5.2.3.2, and 11.3.1.1.1 Fertilizers see 6.1.2.3.5.5 Footnote
KP	Germany reports the CSCs under cropland management as “NO” (see ID# L.6 above) ERT: Finding is an issue and/or a problem: Yes	Issue has been resolved.	2015, 2016	KL.13, Table 5	KL.12+13, 2018 ; KL.7+8, Table 3, 2020;	NIR 2022, chapter 6.1.2.1, 6.1.2.3.6, 6.6.1, 6.6.2.2, 11.3.1.1.1
KP-CM	The Party reported short-rotation plantations for wood production under cropland instead of forest land in CRF table 4.B and section 6.1.2.3.4.3 (pp.558–561) of the NIR. In that section, the Party also reported that biomass carbon stock changes in short-rotation plantations for wood production are only reported in the year of conversion of a land to a short-rotation plantation, and the biomass carbon stock net gain is estimated once, as an instantaneous accumulation in the year of conversion only. The ERT noted that this is not in accordance with the Kyoto Protocol Supplement (chap. 1), which requires reporting, and accounting, of annual emissions and removals associated with carbon stock changes in woody biomass, including emissions associated with the removal of tree cover below the forest threshold in land that – although it meets the forest definition – is reported under a non-forest Kyoto Protocol activity. However, the ERT also noted that such an exclusion will not impact the accounting if appropriate methods for estimating annual changes in woody biomass are applied. Is finding an issue/problem?: Yes. Accuracy	Issue has been resolved.	2020	KL.17, Table 5		NIR 2022, chapter 6.1.2.1, 6.1.2.3.4, 6.1.2.3.5.5, 11.3.1.1.1
KP-CM - GM	see ARR 2020 L.14 Is finding an issue/problem?: Yes. KP reporting adherence	Issue has been resolved.	2020	KL.19, Table 5		NIR 2022, chapter 6.1.2.1, 6.1.2.3, 6.5.2.2, 6.6.2.2, 11.3.1.1.1

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
KP-FM	The Party reported in NIR table 553 a projection of the biomass carbon stock changes for 2013–2020, as applied in the technical correction to its FMRL. For 2013, the biomass carbon pool is projected to be a net source of 7,396 kt CO2, while in CRF table 4.A, a net sink is reported of 45,044 kt CO2 for 2008, which is the latest year of the historical period to be used to project the FMRL. The difference between the two figures is 52,440 kt CO2. The ERT noted that Germany, in its FMRL submission, projected an increase in the harvest rate of approximately 24 per cent between 2008 and 2013, or approximately 19 million m3, which can explain no more than half of the projected decrease in the biomass sink (see document FCCC/TAR/2011/DEU). The ERT therefore concludes that the large difference of 52,440 kt CO2 in the annual net carbon stock change within such a short period (four years) is not justified by the modelling of future harvests or by the dynamic in the age–class distribution, given that ageing of forests is minimal within such a short period and, in any case, the increased projected harvest rate is expected to rejuvenate the forest estate. The Party did not provide information – neither in the NIR nor in the FMRL submission – to show that model-based calculations used for constructing a projected FMRL reproduce the data for FM or forest land remaining forest land for the historical period. The ERT noted that this is not in accordance with the good practice set out in the Kyoto Protocol Supplement (pp.2.97–2.98). During the review, the Party did not provide any additional information. Is finding an issue/problem?: Yes. KP reporting adherence	Issue has been resolved. Description is given in the resp. chapter.	2020	KL.13, Table 5		NIR 2022, chapter 11.5.3.4
KP-FM	The Party reported in NIR table 553 a projection of the biomass carbon stock changes for 2013–2020, as applied in the technical correction to its FMRL. For 2013–2018, the biomass carbon pool is projected to be a net source of 7,861 Gg CO2, while in CRF table 4(KP-I)B.1 for the same period, a net sink of –45,470 kt CO2 is reported. The ERT noted that the increase in the harvesting rate between the historical period (2000–2008) and the projected period (2013–2020) is approximately 30 per cent or 23 million m3 (see tables 8–9 of the FMRL submission (available at https://unfccc.int/topics/land-use/workstreams/land-use--land-use-change-and-forestry-lulucf/forest-management-reference-levels), so the projected harvest increase cannot alone justify the projected decrease of 53 Mt CO2 in the forest sink. The ERT also noted that the NIR does not provide information on the main factors generating the accounted quantity (i.e. the difference in net emissions between reporting of FM during the second commitment period and the FMRL); in particular, the NIR does not provide evidence that the lower sink during the second commitment period, as compared with what was assumed in the 'business as usual' scenario, is quantitatively consistent with the observed higher harvest rate, and/or evidence that other major factors are contributing to the difference. This is not in accordance with the good practice set out in the Kyoto Protocol Supplement (p.2.97). During the review, the Party did not provide any additional information. Is finding an issue/problem?: Yes. Transparency	Issue has been resolved.	2020	KL.14, Table 5		NIR 2022, chapter 11.5.3.3
KP-FM	see ARR 2020 L.11 Is finding an issue/problem?: Yes. Completeness	Issue has been resolved.	2020	KL.15, Table 5		NIR 2022, chapter 6.1.2.1, 6.1.2.3, 6.4.2.5.3

CRF	Review Findings	Improvement	Report [year]	Source	Reference	Resolved in …
KP-LULUCF	The Party reported that no indirect or natural GHG emissions sources or sinks were included in the reported estimates of carbon stock changes (NIR, section 11.3.1.3, p.799), although carbon stock changes measured by a comparison of consecutive NFIs do account for any direct and indirect human-induced as well as natural effects. The ERT noted that the reporting is not in accordance with the Kyoto Protocol Supplement because section 11.3.1.3 of the NIR does not provide information on whether indirect and natural GHG emissions and removals have been factored out. The Kyoto Protocol Supplement (section 2.3.7) states that for the purpose of accounting under the Kyoto Protocol, 'factoring out' in the accounting of KP-LULUCF has been addressed through a 'net-net' approach, where the net change in GHG emissions and removals is accounted for by comparing GHG emissions and removals during the commitment period with a benchmark under either a base year or a 'business as usual' scenario, which could also be a scenario in which emissions and removals are assumed to sum to zero. During the review, the Party did not provide any additional information. Is finding an issue/problem?: Yes. KP reporting adherence	Issue has been resolved.	2020	KL.9, Table 5		NIR 2022, chapter 11.3.1.3
KP-LULUCF	see ARR 2020 L.10 and L.12 Is finding an issue/problem?: Yes. Accuracy	Issue has been resolved.	2020	KL.11, Table 5		NIR 2022, chapter 6.1.2.3.1, 6.1.2.3.2, 6.1.2.3.8, 6.1.2.4, 6.4.2.5.2, 11.3.1

All measures are aimed at achieving complete consistency with the UNFCCC report guidelines and the IPCC Guidelines and at preventing any adjustments under the Kyoto Protocol.

The following table summarises information, as provided in the various category chapters of the inventory reports (since 2011), relative to planned improvements. That information is supplemented with details on the resulting required action, the planned deadlines for completing the measures and the current processing status in each case.

Table 476: Compilation of a) the planned improvements completed as of the present report and of b) the planned improvements that are mentioned in NIR category chapters and are still pending

CRF	Planned improvement	Data quality objective	Deadline	STATUS	Comment	Resolved in …	Year of reporting	Reference NIR-chapter
1.	As noted at the beginning of this chapter, it was not possible to complete the planned countryspecific calculation approach. This important step will be completed in connection with the 2021 submission.	The country-specific calculation approach is to be finalized and adopted for the inventory.	[2022]	overdue	The announced development of a country-specific calculation approach is delayed.	2020	19.1.5	1.
1.A.3.d	With regard to inland waterway transport, in cooperation with the responsible modellers (ifeu) and national experts (ZKR: Zentralkommission für die Rheinschifffahrt / CCNR: Central Commission for the Navigation of the Rhine), ways are sought for the exact separate collection of national and international vessels.	National and international ships are to be recorded exactly and separately. The procedure should be developed with ifeu and the ZKR and documented in the NIR and the IB. If needed, the inventory has to be updated.	[2020]	overdue	Germany is continuing to work on that issue.	2017	3.2.10.4.6	1.A.3.d
1.B.2	Several measurement campaigns are currently underway in Germany to determine emission factors for natural gas transmission and distribution pipelines. It is planned to include the findings from the measurement programs in the inventory after completion.	The results from the measurement campaigns are to be included in the inventory.	[2023]	open	Ongoing	2021	3.3.2.6	1.B.2
2.B.7.	Improvements in data quality are planned with the targeted manufacturer agreements, although it is not yet known whether there may be significant impacts on emission levels.	After the manufacturer agreements have been concluded, it must be checked whether they have an impact on emissions. If necessary, the inventory must be revised accordingly.	[2023]	open	Ongoing	2022	4.3.7.6	2.B.7.
2.D.3.(b)	Relevant findings currently available from a research project are to be used for specific evaluation of emission factors.	The emission factors need to be evaluated on the basis of the existing project report.	[2012]	overdue	Germany is continuing to work on that issue.	2012	4.2.6.6	2.D.3.(b)
2.H.2.	Based on an ongoing project, emission factors shall be updated.	Based on the results of the recently launched project, the emission factors used so far need to be updated.	[2023]	open	Ongoing	2021	4.9.2.6	2.H.2.

CRF	Planned improvement	Data quality objective	Deadline	STATUS	Comment	Resolved in …	Year of reporting	Reference NIR-chapter
4.	The regionalization of mineral soil carbon stocks planned for this submission, depending on site-specific parameters, could not yet be implemented for technical reasons; the setup is planned in the short term. Germany will thus implement the corresponding recommendation of the ERT from the 2020 review process.	Data quality objective: see review-recommendation ARR 2020 L.8, Table 5	[2023]	open	Ongoing	2022	6.1.2.1.9	4.
4.	The introduction of regionalized emission factors for mineral soils, depending on site-specific parameters, and their computer-based implementation is planned; implementation is targeted in the short term.	Data quality objective: see review-recommendation ARR 2020 L.8, Table 5	[2023]	open	Ongoing	2022	6.1.4	4.
4.B.	The regionalization of carbon stocks of mineral soils under agricultural land, depending on site-specific parameters, is in progress and will be implemented in the short term. Germany will thus implement the corresponding recommendation of the ERT from the 2020 review process	Data quality objective: see review-recommendation ARR 2020 L.8, Table 5	[2023]	open	Ongoing	2022	6.5.6	4.B.
4.C.	The regionalization of carbon stocks of mineral soils under grassland, depending on site-specific parameters, is in progress and will be implemented in the short term. Germany will thus implement the corresponding recommendation of the ERT from the 2020 review process	Data quality objective: see review-recommendation ARR 2020 L.8, Table 5	[2023]	open	Ongoing	2022	6.6.6	4.C.
4.D.	The regionalization of carbon stocks of mineral soils of terrestrial wetlands, depending on site-specific parameters, is in progress and will be implemented in the short term. Germany will thus implement the corresponding recommendation of the ERT from the 2020 review process	Data quality objective: see review-recommendation ARR 2020 L.8, Table 5	[2023]	open	Ongoing	2022	6.7.6	4.D.
4.E.	The regionalization of mineral soil carbon stocks of settlement areas, depending on site-specific parameters, is in progress and will be implemented with the next submissions. Germany will thus implement the corresponding recommendation of the ERT from the 2020 review process	Data quality objective: see review-recommendation ARR 2020 L.8, Table 5	[2023]	open	Ongoing	2022	6.8.6	4.E.

CRF	Planned improvement	Data quality objective	Deadline	STATUS	Comment	Resolved in ...	Year of reporting	Reference NIR-chapter
5.A.1.	In an international comparison, collection rates of landfill gas, at about 20 %, seem very low. They also seem low in that nearly all German landfills have gas-collection facilities and that the technical characteristics of German landfills would seem to provide a comparatively good basis for high collection rates. This apparent contradiction will need to be cleared up for future reports.	The causes for the high differences between statistical data and estimated amount of landfill gas shall be determined.	[2018]	overdue	Germany is continuing to work on that issue.	2013	8.2.1.6	5.A.1.
5.A.1.	For some years now, there has been increasing evidence in Germany that the formation of landfill gas calculated according to the FOD model of the IPPC and the resulting methane emissions are considerably overestimated compared to the real behaviour of landfills. The Federal Environment Agency has therefore commissioned two research projects to investigate this issue and to determine national values for half-lives, k-values and DOCf-values.	After completion of the current SV project (for the textual and mathematical incorporation of the results from two previously finished Research projects into the NIR), the results are to be transferred to the NIR and the inventory revised.	[2020]	overdue	Germany is continuing to work on that issue.	2019	7.2.1.6	5.A.1.
5.A.1.	For some years now, there have been growing indications in Germany that the IPCC's FÖD model for calculating landfill-gas formation, and the resulting methane emissions, produces significant overestimations with regard to actual landfill behaviour. To address this situation, the Federal Environment Agency has commissioned two research projects aimed at producing national values for the applicable half-lives, k values and DÖCf values.	Two research projects were completed to update the landfill gas formation and resulting methane emissions, calculated using the IPPC's FOD model. As a result, the currently calculated emissions are significantly overestimated compared to real landfill behavior. The values for half-lives, k-values, and DOCf-values, currently used in the FOD model, are to be adjusted accordingly.	[2022]	overdue	The draft results reports are currently coordinated between the Ministry for Environment (BMU) and the Federal Environment Agency (UBA) for official acceptance and publication, the implementation of the results can only take place afterwards.	2020	7.2.1.6	5.A.1.
5.D.1.	In the area of wastewater treatment, only CH_4 emissions from open cesspools and N2O emissions from aeration tanks and from effluent are currently being reported. Other possible treatment steps that could be emissions-relevant – such as sludge treatment – are not reported, since the 2006 IPCC Guidelines do not cover them and since no pertinent data are available to date.	The inventory needs to be adjusted in keeping with the results of the R&D project on "fugitive emissions."	[2020]	overdue	Germany is continuing to work on that issue.	2016	7.5.1.1.1	5.D.1.

CRF	Planned improvement	Data quality objective	Deadline	STATUS	Comment	Resolved in ...	Year of reporting	Reference NIR-chapter
5.D.1.	In a national research project, measurements were carried out for methane and nitrous oxide. Emission factors are to be derived for the municipal wastewater treatment sector on the basis of these measurements. The project has not yet been completed. This is due to delays in the technical evaluation of the project as a result of the pandemic situation and a change of tasks as a result of restructuring in the relevant specialist unit. A final evaluation of the results can only be made after the project has been completed.	If the internal evaluation of the results of the FE project on "fugitive emissions" allows it, the inventory shall be adjusted accordingly.	[2023]	open	Ongoing	2022	7.5.1.1.6 + 7.5.1.3.6	5.D.1.

10.4.2 KP & LULUCF

The LULUCF-sector improvements described for the Convention inventory, in Chapter 10.4.1, are also to be applied to the KP-LULUCF inventory.

10.4.3 Implementing Regulation Article 9: Reporting on implementation of recommendations and adjustments

Table 477: Implementing Regulation Article 9: Reporting on implementation of recommendations and adjustments, Article 9.1

Member State:	Germany			
Reporting year:	UNFCCC Annual Review Report 2020			
CRF category / issue	**Review recommendation**	**Review report / paragraph**	**MS response / status of implementation**	**Chapter/section in the NIR**
0.	The ERT recommends that the Party annually review, and if necessary, update the information in the NIR with respect to the calculation of the commitment period reserve, ensuring that it is calculated based on the most recent information	Germany is continuing to work on that issue.	2015, 2016	G.5, Table 5
0.	The ERT considers that the recommendation has not yet been fully addressed because the Party still uses "IE" to report indirect CO2 emissions from the energy and IPPU sectors, which is not in line with paragraph 29 of the UNFCCC Annex I inventory reporting guidelines. ARR 2018: The ERT recommends that Germany use the notation key "NE" to report indirect CO2 and N2O emissions from the energy, IPPU and waste sectors in CRF table 6, as well as for indirect CO2 emissions from the LULUCF sector, if appropriate. Noting that the Party reports indirect N2O emissions from leaching and run-off under the LULUCF sector in CRF table 4(IV), the ERT recommends that Germany use the notation keys "NE" and "IE" to report indirect N2O emissions from the LULUCF sector in CRF table 6.	Issue has been resolved: CRF-table 6 and chapter 9 of the NIR have been revised according to review recommendation	2018	G.11, Table 6
0.	The ERT encourages Germany to follow tables 4.2–4.3 of the 2006 IPCC Guidelines (vol. 1) for reporting the key category analysis in the NIR.	the mistakes were corrected.	2020	G.9, Table 5
0.	The ERT recommends that Germany improve its QC procedures to ensure that all category-specific issues that are identified as issues that need potential further improvement are included in the table for planned improvements of the inventory (NIR table 510 in the 2020 submission).	Resolved by development of a new Checklist for the QSE-Coordinator to enshure that all the needs for category-specific improvements are included in the inventory plan.	2020	G.10, Table 5
1.A.	The ERT recommends that Germany include in its NIR the main assumptions used to establish the provisional energy balance.	Germany is continuing to work on that issue.	2018	E.7, Table 5
1.A.3.b.	The ERT encourages that Germany improve the transparency of future NIRs by including an explanation of the adjustment made to the CO2 EF for gasoline, which resulted in a CO2 EF that is higher than the IPCC default value and among the highest IEFs reported by Parties for all categories in which gasoline is used.	ongoing	2020	E.5, Table 5
1.AD	The ERT recommends that Germany, when completing CRF table 1.A(d) in future submissions, report estimates of emissions from non-energy uses of fuels and/or use the appropriate notation keys in line with paragraph 37 of the UNFCCC Annex I inventory reporting guidelines (e.g. "NA" instead of "NE" when no emissions are expected from the non-energy use of a fuel).	Germany is continuing to work on that issue.	2020	E.4, Table 5

Member State:	Germany			
Reporting year:	UNFCCC Annual Review Report 2020			
CRF category / issue	**Review recommendation**	**Review report / paragraph**	**MS response / status of implementation**	**Chapter/section in the NIR**
1.D.1.a.	ARR 2020: The ERT considers that the recommendation has not yet been fully addressed because the Party, given the national circumstances described in the NIR, did not report “NO” for CO2 captured for domestic storage and for storage in other countries in CRF table 1s2. The ERT recommends that Germany complete the blank cell for CO2 captured for domestic storage and for storage in other countries using the appropriate notation key	Issue has been resolved, by adding the aproprIate notation key	2015, 2016	E.18, Table 5
2.A.1.	ARR 2020: The ERT considers that the recommendation has not yet been fully addressed because the Party did not include this information in the NIR. The ERT recommends that Germany include in its NIR a description of the methodology used for estimating bypass dust, and that the bypass dust estimate of the German Cement Works Association be used in the future, if deemed suitable by the Party, rather than the default EF of the IPCC for bypass dust.	Description has been improved.	2018	I.10, Table 5
2.A.4.b.	The ERT recommends that Germany either verify the decreasing emission trend and large inter-annual variation in emissions for 2016–2018 for subcategory 2.A.4.b (other uses of soda ash) and justify it in the NIR or recalculate the reported emissions to ensure time-series consistency.	Even though waiting until the last possible moment, we do not have the necessary data to restructure the entire soda calculation. Thus, an update was made according to the previous method.	2020	I.16, Table 5
2.B.2.	The ERT recommends that Germany include in its NIR the type of technology used to control emissions at nitric acid plants.	Resolved: The follwing information "During the review, the Party clarified that selective catalytic reduction technology is used to reduce N2O and NH3 emissions, and that one plant has two selective catalytic reductions in a row." is added in the NIR.	2018	I.16, Table 6
2.B.3.	ARR 2020: The ERT considers that the recommendation has not yet been fully addressed because the Party did not include this information in the correct NIR section on time-series consistency (section 4.3.3.3). The ERT recommends that, for the third plant, which started operation in 2002 but began conducting measurements only in 2013, Germany report on how the N2O emissions were estimated for the period 2002–2012. The ERT further recommends that Germany report on how time-series consistency was ensured, given the use of different methods in the time series	Resolved	2015, 2016	I.9, Table 5
2.C.2	The ERT recommends that Germany include in future NIRs information on the source of AD for 1990–1994 used to estimate CO2 emissions from ferroalloys production.	Resolved	2020	I.17, Table 5
2.C.3.a.	ARR 2020: The ERT considers that the recommendation has not yet been fully addressed because the Party did not include the information on the validation of the EF used from 2009 in the NIR. The ERT recommends that Germany include in the NIR the explanation that the aluminium plant was redesigned, resulting in a reduction in the SF6 EF for secondary aluminium. The ERT also recommends that the Party explain in detail how the change in the EF was justified, whether by confidential measurement results and/or by a measurement protocol, and that the measurement protocol was checked and verified by a third party.	Germany is continuing to work on that issue.	2018	I.20, Table 6
2.D.1.(a)	The ERT recommends that Germany correct in the next submission the error in CO2 and NMVOC emissions from stationary lubricant use for 2011 in CRF table 2(I)s2.	Resolved	2020	I.18, Table 5

Member State:	Germany			
Reporting year:	UNFCCC Annual Review Report 2020			
CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter/section in the NIR
2.D.2	The ERT recommends that Germany include an explanation of the AD used for category 2.D.2 (paraffin wax use) in CRF table 2(I).A-Hs2 (e.g. in the documentation box) to prevent misinterpretation of the reported IEF.	Resolved	2020	I.19, Table 5
2.E.3	The ERT recommends that Germany update CRF table 2(II).B-Hs1 such that the appropriate notation key is reported for all years where SF6 emissions from photovoltaics are not occurring (i.e. 1990–2002 and 2014 onward).	The value was replaced by the notation key.	2020	I.20, Table 5
2.G.3	The ERT recommends that Germany correct in future submissions the error that arose from manual data entry by reporting N2O emissions from anaesthetic use, explosives, semiconductor production, and propellant for pressure and aerosol products rather than reporting these emissions as “C” (confidential) for 1990–2002.	The missing N2O emissions were added´.	2020	I.21, Table 5
3.	The ERT recommends that Germany improve the information on the AD trends by including in the NIR an explanation of how German reunification, which led to structural changes in the country, has impacted the population of dairy cattle (a decrease of 11.4 per cent from 1990 to 1991) and swine (a decrease of 16.3 per cent from 1990 to 1991) and the associated enteric fermentation emissions at the beginning of the reporting period.	Issue has been resolved.	2020	A.6, Table 5
3.A.1.	ARR 2020: The ERT considers that the recommendation has not yet been addressed because the Party did not include in the NIR the performance indicators (e.g. weight, weight gain, milk yield) used by KTBL (2006) to estimate the metabolizable energy value (dry matter intake) or the reason this information was not reported. The Party also did not explain in the NIR how the changes in energy required for activity at pasture contribute to the values of metabolizable energy and dry matter intake of suckling cows. The ERT recommends that Germany improve the transparency of its reporting by including in its NIR, or in a supplementary publication referenced in the NIR (such as Haenel et al. (2018)), more information on the performance indicators (e.g. weight, weight gain, milk yield) used to calculate ME (MJ per animal per year) and DMI (kg dry matter per animal per year) of suckling cows, and explaining how the changes in energy required for activity at pasture contribute to the values of ME and DMI of suckling cows.	Issue has been resolved.	2018	A.11, Table 6
3.A.1.	ARR 2020: During the review, the Party clarified that the model used for estimating energy requirements would be updated for the 2021 submission to include all individual energy contributions, including grazing. Germany also stated that a detailed description of the improved model would be provided in the 2021 update of Haenel et al. (2020). The ERT recommends that Germany improve the transparency of its reporting by including in its NIR, or in a supplementary publication referenced in the NIR (such as Haenel et al. (2018)), an updated explanation of categories of energies taken into consideration in the estimates of ME, including time spent on pasture.	Issue has been resolved.	2018	A.12, Table 6
3.B.3.	The ERT recommends that Germany report free range pigs as “IE” in CRF table 3.B(b) in accordance with the UNFCCC Annex I inventory reporting guidelines, and clarify in its NIR that free range pigs are not excluded from the inventory but that their numbers are captured under other management systems.	Issue has been resolved.	2020	A.7, Table 5

Member State:	Germany			
Reporting year:	UNFCCC Annual Review Report 2020			
CRF category / issue	**Review recommendation**	**Review report / paragraph**	**MS response / status of implementation**	**Chapter/section in the NIR**
3.D.a.2.c + 3.D.b	The ERT recommends that Germany increase the transparency of its reporting by providing detailed information in the next NIR or in supplementary material on how direct and indirect N2O emissions resulting from the application of biowaste onto managed soils are included in the country-specific N2O EF used by the Party and how this EF compares with the default EFs from the 2006 IPCC Guidelines (vol. 3, chap. 11). The ERT also recommends that the Party remove the statement “they can be neglected, since the nitrogen they include is organically bound and mineralizes very slowly” from the NIR (p.709) Die Anforderungen sind über den HB 6593 ebenfalls für 5.B. adressiert. Die gemeinsame Abarbeitung ist zu beachten..	Detailed information on the composition of the used EFs for N2O, regarding treatment, application and minerlisation have been added to the NIR, including a comparison with the default factor from IPCC. Addiotionally the questioned statement has been deleted and the sentence adjusted accordingly.	2020	A.8, Table 5
4(V)	The ERT recommends that Germany use available data on DOM stocks to include them as fuel when calculating CH4 and N2O emissions from biomass burning.	Germany is continuing to work on that issue.	2020	L.16, Table 5
4.	The ERT recommends that Germany ensure that the new reporting system is capable of detecting and reporting SOC changes associated with changes in the use and management of land with different soil types and climate conditions at a minimum. Until the new reporting system is fully implemented, the ERT recommends that the Party apply a method consistent with good practice, as defined by the 2006 IPCC Guidelines (vol. 4, section 2.3.3.1), for estimating SOC changes. For instance, a set of SOCREF values stratified by climate zone and soil type using SOC measurements taken in forest land, and grassland under natural conditions, if any, could be calculated. Thus, if the SOCREF values calculated are within the uncertainty range of the IPCC default values, the IPCC default stock change factors could be applied. Then, the SOC for each combination of land use and management system, as stratified by climate and soil type, could be calculated and formulation B of equation 2.25 from the 2006 IPCC Guidelines (vol. 4, box 2.1) could be applied to estimate the annual net SOC change associated with each change in the use and/or management of land.	Germany is continuing to work on that issue.	2020	L.8, Table 5
4.	Missing categories that may affect completeness: The categories for which estimation methods are included in the 2006 IPCC Guidelines that were reported as “NE” or for which the ERT otherwise determined that there may be an issue with the completeness of the reporting in the Party’s inventory are the following: (a) 4.B.1 cropland remaining cropland – perennial biomass (CO2) (see ID# L.13 in table 5) **--> erledigt**; (b) 4(V) biomass burning – DOM stocks (CH4 and N2O) (see ID# L.16 in table 5; --> **offen**; (c) FM (CO2 and N2O) (see ID# KL.15 in table 5) --> **erledigt**; (d) CM (CO2) (see ID# KL.18 in table 5) --> **begonnen**.	Not completely resolved. Description is given in the resp. chapter.	2020	Annex III
4.	The ERT **encourages** Germany to use the Wetlands Supplement in preparing its annual inventory for CO2 off-site emissions in drained organic soils for future annual submissions.	Issue has been resolved.	2020	L.7, Table 5
4.A .	The ERT recommends that Germany reconcile in each year the total carbon stock change reported under the Convention and under the Kyoto Protocol for each of the biomass and DOM carbon pools. The ERT further recommends that the Party reconcile the total carbon stock change reported for biomass and DOM in any period between two subsequent NFIs with the total carbon stock change calculated across the period as the difference between the total carbon stock of the two subsequent NFIs.	Issue has been resolved.	2020	L.10, Table 5

Member State:	Germany			
Reporting year:	UNFCCC Annual Review Report 2020			
CRF category / issue	**Review recommendation**	**Review report / paragraph**	**MS response / status of implementation**	**Chapter/section in the NIR**
4.A .	The ERT recommends that Germany reconcile in each year the total carbon stock change reported under the Convention and under the Kyoto Protocol for each of the biomass and DOM carbon pools. The ERT further recommends that the Party reconcile the total carbon stock change reported for biomass and DOM in any period between two subsequent NFIs with the total carbon stock change calculated across the period as the difference between the total carbon stock of the two subsequent NFIs.	Issue has been resolved.	2020	L.11, Table 5
4.A .	The ERT recommends that Germany report complete information, including, where practicable, a flow chart that clearly presents in a visual format all steps and data used in the calculation of the SOC change, in order to demonstrate that the calculated SOC change is not biased by changes in forest area over time.	ongoing	2020	L.9, Table 5
4.B.	The ERT recommends that Germany apply good practice, as set out in the 2006 IPCC Guidelines (vol. 4., chaps. 2 and 5), for estimating changes in forest biomass carbon stocks in order to estimate annual emissions and removals associated with biomass carbon stock changes in short-rotation plantations.	Issue has been resolved.	2020	L.12, Table 5
4.B.1.	The ERT recommends that Germany report annual estimates of net carbon stock changes of perennial biomass by applying the tier 1 method from the 2006 IPCC Guidelines (vol. 4, chap. 5.2.1.1) or any other method that is consistent with good practice, including approaches developed by other European Union member States (the ERT notes that the limited availability of relevant data experienced by Germany is also experienced by other European countries).	Issue has been resolved.	2020	L.13, Table 5
4.B.1. + 4.C.1.	The ERT recommends that Germany provide verification of reported estimates by applying the default methodology in the 2006 IPCC Guidelines (vol. 4, chaps. 2, 5 and 6, and equation 2.25) to estimate SOC changes in cropland remaining cropland and grassland remaining grassland associated with changes in land management.	Issue has been resolved.	2020	L.14, Table 5
4.B.2. + 4.C.2.	The ERT recommends that Germany report annual net carbon stock accumulation over time for perennial biomass in land converted to a cropland or grassland subcategory that has vegetation with perennial biomass by applying equation 2.7 or 2.15 from the 2006 IPCC Guidelines (vol. 4) or any other method that is consistent with good practice.	Issue has been resolved. Description is given in the resp. chapter.	2020	L.15, Table 5

Member State:	Germany			
Reporting year:	UNFCCC Annual Review Report 2020			
CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter/section in the NIR
5.A.1.	ARR 2020: Germany indicated during the review that the results of the ongoing research projects to determine country-specific k-values were not available in time to implement them in the 2020 annual submission (NIR, section 7.2.1.6, p.707). While the latest results of the research have been published, they can only be incorporated into the emission inventory report after clarification of review questions with the contractors, QA through peer review and public validation by national experts. These processes are planned for completion in 2020. The Party expects the results from the research projects to be applied in the 2021 submission. The ERT recommends that Germany update the k-values used in the emission estimation as soon as the data from the research projects that will determine national k-values are available. If the results are not available in time for the 2019 annual submission, the ERT recommends that the Party include the status of these projects in the NIR, including a timeline for the implementation of their results in the inventory.	Germany is continuing to work on that issue. The k-Values will be updated when the research projects are finished - probably with emission reporting 2021.	2018	W.11, Table 6
5.B.2.	The ERT recommends that Germany report in future submissions the amount of livestock manure co-digested anaerobically with biowaste at biogas facilities (i.e. the AD) in CRF table 5.B, column B, and report the associated CH4 and N2O emissions in CRF table 5.B as “IE” while indicating in the documentation box to that table that they are reported under the agriculture sector in CRF table 3.B(a) to avoid double counting.	The recommendation has been implemented. See CRF Table 5b	2020	W.10, Table 5
5.D.1.	The ERT recommends that Germany implement the results of the study that will produce better documented EFs as soon as the data are available. If the results are not available in time for the 2019 submission, the ERT recommends that the Party include the status of this study in the NIR, including a timeline for the implementation of its results in the inventory.	Germany is continuing to work on that issue. The research project is not finished and plausibility checks are still in progress.	2018	W.14, Table 6
5.D.1.	The ERT recommends that Germany investigate whether it is reasonable to assume the same MCF for human sewage as for animal manure, noting that there are significant differences between swine and cattle slurry and that the retention time might be different between a septic tank and a slurry tank. Depending on the results of this investigation, the ERT recommends that Germany either assess whether it would be better to use the appropriate MCF values reported in table 10.17 of the 2006 IPCC Guidelines (volume 4) rather than the data that were used in the Revised 1996 IPCC Guidelines or if animal manure is not found to be representative for human sewage, to use the IPCC default MCF.	Rationale for chosing the MCF has been thoroughly explained and verified. Note: The recommendation has already been implemented with the 2021 NIR, but is reattached here to allow consistency in tracking the processing of ARR 2020 results.	2018	W.15, Table 6
KP	The ERT recommends that Germany stratify the cropland management estimates, taking into account the SRCs, on the basis of the methodology provided in the Kyoto Protocol Supplement. The ERT further recommends that the Party include in the NIR detailed information on SRCs, including information on the fertilization occurring in the SRCs and HWP originating from the SRCs, to increase transparency	Issue has been resolved. Description is given in the resp. chapter.	2015, 2016	KL.12, Table 5

Member State:	Germany			
Reporting year:	UNFCCC Annual Review Report 2020			
CRF category / issue	**Review recommendation**	**Review report / paragraph**	**MS response / status of implementation**	**Chapter/section in the NIR**
KP	The ERT recommends that Germany estimate and report the CSCs for woody biomass in accordance with the 2006 IPCC Guidelines and the Kyoto Protocol Supplement, taking into consideration the biomass accumulation from growth and the losses associated with harvest, gathering or disturbance. The ERT further recommends that Germany improve the transparency of its reporting by including in the NIR transparent and verifiable information to demonstrate that the cropland management soil pool is not a net source	Issue has been resolved.	2015, 2016	KL.13, Table 5
KP-CM	The ERT recommends that Germany apply good practice, as set out in the 2006 IPCC Guidelines (vol. 4, chaps. 2 and 5), and the Kyoto Protocol Supplement (as quoted above in chap. 1), for estimating changes in forest biomass carbon stocks in order to estimate annual emissions and removals associated with biomass carbon stock changes in short-rotation plantations.	Issue has been resolved.	2020	KL.17, Table 5
KP-CM	The ERT recommends that Germany consider the issues listed in ID#s L.9 ;, L.10; and L.12 ; under the LULUCF sector (CM) above as also being relevant to KP-LULUCF activities.	Not completely resolved. Description is given in the resp. chapter.	2020	KL.18, Table 5
KP-CM - GM	The ERT recommends that Germany consider the issue listed in ID# L.14 under the LULUCF sector (CM and GM) above as also being relevant to KP-LULUCF activities.	Issue has been resolved.	2020	KL.19, Table 5
KP-Deforestation	The ERT, taking into consideration the inconsistencies in carbon stock change estimates reported under the Convention and under the Kyoto Protocol, as noted in ID#s L.10 and L.11 above, **encourages** Germany to report annual carbon stock change estimates for each carbon pool in the information item of CRF table 4(KP-I)A.2.	ongoing	2020	KL.12, Table 5
KP-FM	The ERT recommends that Germany provide in future submissions information demonstrating that model-based calculations reproduce the data for FM or forest land remaining forest land for the historical period reported in the inventory.	Issue has been resolved. Description is given in the resp. chapter.	2020	KL.13, Table 5
KP-FM	The ERT recommends that Germany provide in its next submission information on the main factors generating the accounted quantity under FM (i.e. the difference in net emissions between reporting of FM during the second commitment period and the FMRL) and on the difference between the projected harvest rate and the actual harvest rate.	Issue has been resolved.	2020	KL.14, Table 5
KP-FM	The ERT recommends that Germany consider the issue listed in ID# L.11 under the LULUCF sector (FM) above as also being relevant to KP-LULUCF activities.	Issue has been resolved.	2020	KL.15, Table 5
KP-FM	The ERT recommends that Germany consider the issue listed in ID# L.9 under the LULUCF sector (FM) above as also being relevant to KP-LULUCF activities.	Germany is continuing to work on that issue.	2020	KL.16, Table 5
KP-LULUCF	The ERT recommends that Germany update the information reported in the NIR on 'factoring out' in accounting for KP-LULUCF by applying guidance provided in section 2.3.7 of the Kyoto Protocol Supplement.	Issue has been resolved.	2020	KL.9, Table 5
KP-LULUCF	The ERT recommends that Germany consider the issue listed in ID# L.8 under the LULUCF sector above as also being relevant to KP-LULUCF activities.	Germany is continuing to work on that issue.	2020	KL.10, Table 5
KP-LULUCF	The ERT recommends that Germany consider the issues listed in ID#s L.10 and L.11 under the LULUCF sector above as also being relevant for AR, deforestation and FM.	Issue has been resolved.	2020	KL.11, Table 5

11 Supplementary information as required pursuant to Article 7 (1) of the Kyoto Protocol

11.1 General information

11.1.1 The definition of forest, and any other criteria

The National Forest Inventory is the main data source used for determination of emissions in the forest sector. Its forest definition, which serves as a basis for the report, inter alia, is described in Chapter 6.2.1.

In keeping with Germany's initial report under the Kyoto Protocol (UNFCCC, 2007), Germany has defined the following specific parameters for its national forest definition:

Table 478: Definition of "forest" in Germany

Parameter	Range	Selected value
Minimum area of land (minimum area of land)	0.05 – 1.00 ha	0.1 ha
Tree crown cover or equivalent stocking level (tree crown cover or equivalent stocking level)	10 – 30 %	10 %
Potential tree height at maturity (potential tree height at maturity)	2 – 5 m	5 m

Within the range defined by the Marrakesh Accords (cf. the above range), these parameters are the ones that come closest to the definition used in the National Forest Inventory. As comparative studies have shown, the differences between different activity-data calculations carried out in accordance with the aforementioned parameters are negligible Tomter et al. (2010).

Pursuant to the Kyoto Protocol (UNFCCC, 1998a), areas are to be assigned to the activities "afforestation" and "deforestation" if they have been afforested / deforested since 1990. These areas remain in these categories until the end of the commitment period. In greenhouse-gas reporting, short-rotation plantations are reported under Cropland.

Germany does not have any forest plantations that have been transferred into another land-use category (non- Forest Land) and are credited under Forest Managament (KP 3.4). All afforestation and deforestation are reported under KP 3.3. As a result, the management form described in Decision 2/CMP.7, Annex, Paragraphs 37–39 does not apply to Germany.

Reforestation requirements apply in Germany (cf. Art. 11 (1) p. 2 Federal Forest Act (BWaldG (2015))), meaning that clear-cut forest areas and thinned forest stands have to be reforested or replenished. Areas that have been afforested since 1990, but temporarily have no forest cover as a result of natural disasters, continue to fall within the definition of forest and must be reforested. No deforestation as a result of natural disasters takes place in Germany.

11.1.2 Elected activities under Article 3 Paragraph 4 of the Kyoto Protocol

In the second commitment period, Germany has to credit the activity *Forest Management* (FM activity pursuant to Article 3 (4) of the Kyoto Protocol. In addition, Germany is reporting emissions from harvested wood products. Germany has not selected the option *natural disturbances*.

Germany has selected the following voluntary activities under Article 3.4 of the Kyoto Protocol:

- Cropland management (CM)
- Grazing land management (GM).

Germany has opted for accounting at the end of the second commitment period.

11.1.3 Description of how the definitions of each activity under Article 3.3, and each elected activity under Article 3.4, have been implemented and applied consistently over time

11.1.3.1 Afforestation, reforestation and deforestation (ARD)

The definitions used by Germany for afforestation, reforestation and deforestation are in accordance with the Marrakesh Accords (MA). Pursuant to the MA, afforestation is defined as "the direct human-induced conversion of land that has not been forested for a period of at 50 years to forested land through planting, seeding and / or the human-induced promotion of natural seed sources[147]." Reforestation differs from afforestation solely with regard to the time since the area was last forested and, pursuant to the IPCC, occurs on land that has not been forest since 31 December 1989[148]. Since the reporting period for Germany begins with base year 1990, and since adequate data for differentiation of land-use forms are available only for the period as of 1970, afforestation and reforestation are considered together in the present context (and hereafter are both referred to as afforestation). Afforestation means the establishment of trees on abandoned land, if the relevant rejuvenation suffices for producing forest in accordance with the national forest definition. In general, the time of afforestation is the time at which the first activity in the relevant regeneration process was carried out. In the case of spontaneous regeneration of trees, the time of afforestation is considered to be the time at which the national criteria for the forest definition have been met, i.e. when the natural forest cover has reached an average age of five years, and a crown cover of at least 50 % (cf. Chapter 6.2.1).

The afforestation category corresponds to the following categories in reporting under the UN Framework Convention on Climate Change:

[147] "Afforestation is the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources." (IPCC KP Supplements (IPCC et al., 2014a))

[148] Original: "Reforestation" is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land. For the first commitment period, Reforestation activities will be limited to Reforestation occurring on those lands that did not contain forest on 31 December 1989. (IPCC KP Supplements (IPCC et al., 2014a))

Table 479: Afforestation in KP and UNFCCC categories

Category in KP reporting	Category pursuant to UNFCCC	
Afforestation under Art. 3.3 KP	4.A.2.1 Cropland / Special crops converted to Forest Land	4.A.2.1.1 Cropland$_{annual}$ converted to Forest Land
		4.A.2.1.2 Hops plantations converted to Forest Land
		4.A.2.1.3 Vineyards converted to Forest Land
		4.A.2.1.4 Fruit plantations converted to Forest Land
		4.A.2.1.5 Tree nurseries converted to Forest Land 4.A.2.1.5 Other crops$_{perennial}$ converted to Forest Land
		4.A.2.1.6 Christmas tree plantations plantations converted to Forest Land
		4.A.2.1.7 Short-rotation plantations plantations converted to Forest Land
	4.A.2.2. Grassland converted to Forest Land	4.A.2.2.1 Grassland (in the strict sense) converted to Forest Land
		4.A.2.2.2 Woody Grassland converted to Forest Land
	4.A.2.3. Wetlands converted to Forest Land	4.A.2.3.1 Wetlands (terrestrial) converted to Forest Land
		4.A.2.3.2 Waters converted to Forest Land
		4.A.2.3.3 Peat extraction areas converted to Forest Land
	4.A.2.4. Settlements converted to Forest Land	
	4.A.2.5. Other land converted to Forest Land	

The IPCC defines deforestation as "the direct human-induced conversion of forested land to non-forested land"[149]. In accordance with the provisions of the IPCC, harvest that is followed by regeneration is not considered deforestation, since harvest is a forest-management activity pursuant to Art. 3.4. This definition also does not include "forest cover loss resulting from natural disturbances, such as wildfires, insect epidemics or wind storms", since "in most cases these areas will regenerate naturally or with human assistance." Such areas also fall within the category of managed land pursuant to Art. 3.4 or, if the areas are afforested land, within the category of afforested land pursuant to Art. 3.3.

Where, since 1990, human activities have however taken place on such areas temporarily without forest cover – activities such as road construction, settlement construction or other forms of land use (management of grassland or wetlands) – with the result that forest regeneration is prevented, then, so the IPCC, the areas must be considered deforested.

The deforestation category corresponds to the following categories in reporting under the UN Framework Convention on Climate Change:

[149] Original "Deforestation" is the direct human-induced conversion of forested land to non-forested land." (IPCC KP Supplements (IPCC et al., 2014a))

Table 480: Deforestation in KP and UNFCCC categories

Category in KP reporting	Category pursuant to UNFCCC	
Deforestation under Art. 3.3 KP	4.B.2.1. Forest Land converted to Cropland / Special crops	4.B.2.1.1 Forest Land converted to $Cropland_{annual}$
		4.B.2.1.2 Forest Land converted to Hops plantations
		4.B.2.1.3 Forest Land converted to Vineyards
		4.B.2.1.4 Forest Land converted to Fruit plantations
		4.B.2.1.5 Forest Land converted to Tree nurseries
		4.B.2.1.6 Forest Land converted to Christmas tree plantations
		4.B.2.1.7 Forest Land converted to Short-rotation plantations
	4.C.2.1. Forest Land converted to Grassland	4.C.2.1.1 Forest Land converted to Grassland (in the strict sense)
		4.C.2.1.2 Forest Land converted to Woody Grassland
	4.D.2.1. Forest Land converted to Wetlands	4.D.2.1.1 Forest Land converted to Wetlands (terrestrial)
		4.D.2.1.2 Forest Land converted to Waters
		4.D.2.1.3 Forest Land converted to Peat extraction
	4.E.2.1. Forest Land converted to Settlements	
	4.F.2.1. Forest Land converted to Other Land	(NO)

NO: not occurring

11.1.3.2 Forest management (FM)

In Germany, all forest areas that have been forest since 1990 are considered managed within the meaning of the Marrakesh Accords[150] and are reported under *forest management*[151] pursuant to Art. 3.4 KP. A detailed pertinent description is presented in Chapter 11.5.1.

Table 481: Forest management in KP and UNFCCC categories

Category in KP reporting	Category pursuant to UNFCCC
Forest management pursuant to Art. 3.4 KP	4.A.1 Forest Land remaining Forest Land

Since every land-use change to forest is considered afforestation, every land-use change from Forest Land to a different land-use category is considered deforestation, and all forest areas not afforested are subject to forest management, there is no possibility that the manner in which the relevant definitions are applied could change over time.

The emissions contribution from harvested wood products in Germany, in terms of greenhouse emissions from sources and removals in sinks, in the land-use sector, was estimated with the

150 Paragraph 1 lit. f of Annex A of Decision 16/CMP.1

151 Original: "'Forest management' is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner." (IPCC KP Supplements (IPCC et al., 2014a))

help of the WoodCarbonMonitor model, via a calculation approach based on wood-product production data. The estimation covers all harvested wood products that are produced in Germany, that consist of wood which originates from trees harvested in Germany and that are used for their material (not energy) value.

11.1.3.3 Cropland management (CM)

Cropland management (CM) is agricultural use of land for cultivation of field crops (such as grain, pulses, root crops) and berries (such as strawberries); of garden land for cultivation of vegetables, fruit and flowers and for culturing of crops; and of special crop areas, for cultivation of certain plants (such as hops, wine grapes, fruit in orchards). Cropland management includes annual crops and permanent crops such as vineyards, orchards, hops, tree nurseries, Christmas trees and short-rotation plantations. Permanent crops do not fall within the German definition of forest.

The definition of cropland management is in keeping with the definition of areas under cropland as used for reporting under the UN Framework Convention on Climate Change (cf. Chapter 6.2 and Table 354 in Chapter 6.3.2.1).

The afforestation category corresponds to the following categories in reporting under the UN Framework Convention on Climate Change:

Table 482: Afforestation in KP and UNFCCC categories

Category in KP reporting	Category pursuant to UNFCCC	
Cropland management pursuant to Art. 3.4 KP	4.B.1 Cropland remaining Cropland	
	4.B.2.2 Grassland converted to Cropland	4.B.2.2.1 Grassland (in the strict sense) converted to Cropland
		4.B.2.2.2 Woody Grassland converted to Cropland
	4.B.2.3 Wetlands converted to Cropland	4.B.2.3.1 Wetlands (terrestrial) converted to Cropland
		4.B.2.3.2 Waters converted to Cropland
		4.B.2.3 Peat extraction converted to Cropland
	4.B.2.4 Settlements converted to Cropland	
	4.B.2.5 Other areas converted to Cropland	
	4.C.2.2.2 Cropland converted to Woody Grassland	
	4.D.2.2 Cropland converted to Wetlands	4.D.2.2.3 Cropland converted to Terrestrial Wetlands
		4.D.2.2.2 Cropland converted to Waters
		4.D.2.1 Cropland converted to Peat extraction
	4.E.2.2 Cropland converted to Settlements	
	4.F.2.2 Cropland converted to Other Land (NO)[2)]	

All areas under cropland management are subject to periodic cultivation measures, and thus the pertinent emissions and removals are anthropogenic.

11.1.3.4 Grazing land management (GM)

Grazing land management (GM) is the use of Grassland (in the strict sense) as meadows, pastures, mountain pastures, rough pastures, heath land, natural grassland, recreational areas or swamps/marshes.

The definition of grazing land management is in keeping with the definition of areas under Grassland (in the strict sense) as used for reporting under the UN Framework Convention on Climate Change (cf. Chapter 6.2 and Table 354 in Chapter 6.3.2.1).

The grazing land management category corresponds to the following categories in reporting under the UN Framework Convention on Climate Change:

Table 483: Grazing land management in KP and UNFCCC categories

<table>
<tr><th>Category in KP reporting</th><th colspan="2">Category pursuant to UNFCCC</th></tr>
<tr><td rowspan="20">Grazing land management pursuant to Art. 3.4 KP</td><td colspan="2">4.C.1.1 Grassland (in the strict sense) remaining as Grassland (in the strict sense)</td></tr>
<tr><td rowspan="7">4.C.2.2 Cropland converted to Grassland (in the strict sense)</td><td>4.C.2.2 Cropland$_{annual}$ to Grassland (in the strict sense)</td></tr>
<tr><td>4.C.2.2 Hops plantations converted to Grassland (in the strict sense)</td></tr>
<tr><td>4.C.2.2 Vineyards converted to Grassland (in the strict sense)</td></tr>
<tr><td>4.C.2.2 Fruit plantations converted to Grassland (in the strict sense)</td></tr>
<tr><td>4.C.2.2 Tree nurseries converted to Grassland (in the strict sense)</td></tr>
<tr><td>4.C.2.2 Christmas tree plantations converted to Grassland (in the strict sense)</td></tr>
<tr><td>4.C.2.2 Short-rotation plantations converted to Grassland (in the strict sense)</td></tr>
<tr><td colspan="2">4.C.1.3 Woody Grassland converted to Grassland (in the strict sense)</td></tr>
<tr><td rowspan="3">4.C.2.3 Wetlands converted to Grassland (in the strict sense)</td><td>4.C.2.3. Terrestrial Wetlands to Grassland (in the strict sense)</td></tr>
<tr><td>4.C.2.3 Waters converted to Grassland (in the strict sense)</td></tr>
<tr><td>4.C.2.3 Peat extraction converted to Grassland (in the strict sense)</td></tr>
<tr><td colspan="2">4.C.2.4 Settlements converted to Grassland (in the strict sense)</td></tr>
<tr><td colspan="2">4.C.2.5 Other land converted to Grassland (in the strict sense)</td></tr>
<tr><td colspan="2">4.C.1.4 Grassland (in the strict sense) converted to Woody Grassland</td></tr>
<tr><td rowspan="3">4.D.2.3 Grassland (in the strict sense) converted to Wetlands</td><td>4.D.2.3.3 Grassland (in the strict sense) converted to Terrestrial Wetlands</td></tr>
<tr><td>4.D.2.2.3 Grassland (in the strict sense) converted to Waters</td></tr>
<tr><td>4.D.2.1 Grassland (in the strict sense) converted to Peat extraction</td></tr>
<tr><td colspan="2">4.E.2.3.1 Grassland (in the strict sense) converted to Settlements</td></tr>
<tr><td colspan="2">4.F.2.3.1 Grassland (in the strict sense) converted to Other Land[2)]</td></tr>
</table>

All areas under grazing land management are subject to periodic cultivation measures, and thus the pertinent emissions and removals are anthropogenic.

11.1.4 Description of precedence conditions and/or hierarchy among Article 3.4 activities, how they have been consistently applied in determining how land was classified

Germany has defined the hierarchy of activities relative to Art. 3.4 of the Kyoto Protocol pursuant to the provisions of the 2013 IPCC KP Supplement (IPCC et al., 2014a). The activity *forest management* is binding, and thus has priority over the voluntary activities *cropland management* and *grazing land management*. In the first commitment period, Germany selected *forest management* voluntarily. The hierarchy makes it possible to carry out consistent reporting for the first and second commitment periods.

Pursuant to the provisions of the 2013 IPCC KP Supplement (IPCC et al., 2014a), forest management (FM) can take place only on lands that meet the definition of forest. The forest areas reported under FM are the forest areas reported, pursuant to the Convention, under *Forest Land remaining Forest Land*, except for areas assigned either to the categories of conversion leading to Forest Land (Convention) or to the category of afforestation (Kyoto Protocol). The total forest area under the Convention and the total forest area under the Kyoto Protocol are the same. All German forest lands are considered managed within the meaning of the provisions of the Marrakesh Accords. The definition of forest management is broadly interpreted (cf. for a detailed discussion Chapter 11.5.1).

Within the group of voluntary activities, allocations to *cropland management* have priority over allocations to *grazing land management*. Agricultural grass within the context of crop rotations is allocated to cropland management. By contrast, permanent land-use changes from cropland to Grassland (in the strict sense), and vice-versa, are reported as activity changes from cropland management to grazing land management, and vice-versa. As a result, the land classifications for cropland management and grazing land management are in keeping with the inventory's classifications of Cropland and Grassland (in the strict sense) under the UNFCCC.

11.2 Land-oriented information

11.2.1 Spatial assessment unit used for determining the area of the units of land under Article 3.3

The method used to derive activity data (areas) is described in Chapter 6.3. It corresponds to Approach 3 pursuant to the IPCC 2006 Guidelines (IPCC, 2006a). The reference area is Germany; it comprises 35,790,122 ha. A detailed description of the land-use classifications used for Forest Land, including afforested and deforested areas, is provided in Chapter 6.2 and Chapter 6.3.

Thanks to the use of a consistent method for derivation of the LUM, the same spatial assessment unit is used for deforestation areas as is used for afforestation areas.

11.2.2 Method used to develop the land-transition matrix

The method used to define forest areas, and to derive areas for the "change" categories, is described in detail in Chapter 6.3. Table 484 provides an overview of land-use changes (LUC) leading to Forest Land (afforestation/reforestation), of land-use changes leading away from Forest Land (deforestation), and of managed areas (forest management). Conversion areas remain in the relevant conversion categories until the end of the 2nd commitment period of the Kyoto Protocol, 2020; for this reason, the annual areas accumulate. In Table 484, the column for the accumulated areas lists those areas as they are reported. An adjacent column shows the corresponding annual areas.

Table 484: Accumulated and annual areas in the categories afforestation, deforestation and forest management

Year	Afforestation/ Reforestation (KP 3.3) [kha]		Deforestation (KP 3.3) [kha]		Forest Management (KP 3.4) [kha]	
	Accumulated areas	Annual areas	Accumulated areas	Annual areas	Accumulated areas	Annual areas
1990	11,727	11,727	1,415	1,415	10,826,682	10,826,682
1995	70,591	11,765	8,575	1,433	10,819,522	10,878,348
2000	129,436	11,772	15,743	1,430	10,812,354	10,930,018
2005	175,712	9,260	58,782	8,604	10,769,315	10,935,767
2010	222,841	9,422	86,016	5,445	10,742,081	10,955,500
2011	229,320	6,479	90,163	6,479	10,737,934	10,960,775
2012	235,793	6,473	94,306	4,143	10,733,791	10,963,111
2013	242,255	6,462	98,453	4,147	10,729,644	10,965,437
2014	248,729	6,474	102,597	4,144	10,725,500	10,967,755
2015	255,195	6,466	106,746	4,149	10,721,351	10,970,080
2016	269,324	14,129	112,523	5,777	10,715,574	10,970,769
2017	283,444	14,120	118,291	5.768	10,709,806	10,979,130
2018	297,572	14,128	124,065	5,774	10,704,032	10,987,476
2019	311,693	14,121	129,836	5,771	10,698,261	10,995,833
2020	325,819	14,126	135,609	5,773	10,692,488	11,004,181

In Table 485, in the interest of transparency, land-use changes (LUC) from Forest Land (deforestation) are broken down by land-use categories.

Table 485: Accumulated deforestation areas, by land-use category, in hectares [ha] (CRF 4(KP-I)A.2)

Year	To Forest Land	To Cropland	To Grassland	To Wetlands	To Settlements	To Other Land	Total
1990	NO	0	0	239	1,176	0	1,415
1995	NO	0	0	1,473	7,102	0	8,575
2000	NO	0	0	2,714	13,029	0	15,743
2005	NO	0	0	12,538	46,244	0	58,782
2010	NO	0	0	16,110	69,906	0	86,016
2011	NO	0	0	16,508	73,655	0	90,163
2012	NO	0	0	16,903	77,403	0	94,306
2013	NO	0	0	17,303	81,150	0	98,453
2014	NO	0	0	17,704	84,893	0	102,597
2015	NO	0	0	18,109	88,637	0	106,746
2016	NO	0	0	18,831	93,692	0	112,523
2017	NO	0	0	19,548	98,743	0	118,291
2018	NO	0	0	20,268	103,797	0	124,065
2019	NO	0	0	20,991	108,845	0	129,836
2020	NO	0	0	21,712	113,897	0	135,609

The method used to define cropland and grassland areas, and to derive areas for the conversion categories, is also described in detail in Chapter 6.3. Table 486 provides an overview of Cropland Management areas and Grazing Land Management areas. In the base years, the land-use changes (LUC) in the period 1970 through 1990 are included, except those consisting of land-use changes leading to Forest Land. For purposes of methodological consistency with KP Art. 3.3, those changes have been recorded cumulatively, since 1990, as afforestation. The areas are divided into the categories

- Cropland remaining Cropland and Grassland (in the strict sense) remaining Grassland (in the strict sense)
- Land-use changes leading to Cropland or to Grassland (in the strict sense) (except for Forest Land)
- Land-use changes from Cropland, and from Grassland (in the strict sense), to land-use categories that are not included in other activities under KP Art. 3.3. or 3.4.

In the case of land-use changes from Cropland, and from Grassland (in the strict sense), to land-use categories that are not included in other activities under KP Art. 3.3. or 3.4, and in keeping with the IPCC 2013 KP Supplements (IPCC et al., 2014a), Chapter 2.9.2, relevant areas are determined, and their emissions reported, as follows:

Included Elsewhere (IE) is used in connection with land-use changes from Cropland management or Grazing Land management to the category Afforestation/Reforestation. In addition, IE is used for the litter and dead wood pools, since the total biomass of the plants involved enters into the emission calculation.

Table 486: Overview of Cropland Management areas and Grazing Land Management areas, 1990-2020 (in boldface type: areas of relevance to Kyoto II)

	Cropland Management (CM)			
Year	Cropland remaining Cropland [ha]	∑LUC to Cropland [ha]	∑LUC from Cropland [ha]	∑Cropland Management [ha]
1990	**13,087,052**	**502,120**	**7,830**	**13,597,002**
1995	13,105,472	497,953	46,997	13,650,422
2000	13,120,473	497,201	86,159	13,703,833
2005	12,471,178	764,891	335,980	13,572,049
2010	12,103,629	859,704	476,512	13,439,845
2013	**11,786,558**	**1,047,292**	**563,347**	**13,397,197**
2014	**11,679,858**	**1,110,829**	**592,392**	**13,383,079**
2015	**11,572,633**	**1,174,909**	**621,360**	**13,368,902**
2016	**11,516,349**	**1,200,237**	**634,537**	**13,351,123**
2017	**11,459,119**	**1,226,506**	**647,547**	**13,333,172**
2018	**11,401,680**	**1,252,978**	**660,441**	**13,315,099**
2019	**11,343,477**	**1,280,237**	**673,503**	**13,297,217**
2020	**11,284,943**	**1,307,812**	**686,571**	**13,279,326**

Year	Grazing Land Management (GM) Grazing Land remaining Grazing Land [ha]	∑LUC to Grazing Land [ha]	∑LUC from Grazing Land [ha]	∑Grazing Land Management [ha]
1990	**5,759,300**	**413,336**	**4,430**	**6,177,066**
1995	5,738,496	401,763	26,629	6,166,888
2000	5,709,756	398,084	48,822	6,156,662
2005	5,221,671	1,044,443	264,617	6,530,731
2010	4,996,692	1,325,240	430,475	6,752,407
2013	**4,796,135**	**1,518,366**	**513,759**	**6,828,260**
2014	**4,728,020**	**1,583,995**	**541,343**	**6,853,358**
2015	**4,659,786**	**1,649,719**	**569,053**	**6,878,558**
2016	**4,620,743**	**1,692,027**	**594,526**	**6,907,296**
2017	**4,581,117**	**1,734,888**	**620,004**	**6,936,009**
2018	**4,541,110**	**1,778,167**	**645,540**	**6,964,817**
2019	**4,500,672**	**1,821,839**	**670,919**	**6,993,430**
2020	**4,459,901**	**1,865,849**	**696,279**	**7,022,029**

11.2.3 Maps and/or databases to identify the geographical locations, and the pertinent system of identification codes for the geographical locations

The following data sources were used in determination of activity data:

- The Basic Digital Landscape Model (Basis-Digitales LandschaftsModell; Basis-DLM) for the years 2000, 2005, 2010, 2015 and 2020,
- Map of Germany's organic soils
- The OpenStreetMap dating from 2013 (©OpenStreetMap co-authors)
- Corine Land Cover (CLC) 1990, 2000
- The digital land cover model (Digitales Landbedeckungsmodell) for the year 2012 (LBM12)

Detailed descriptions of the data sources are presented in Chapter 6.3.2.1.

All afforestation and deforestation are accounted for under Article 3.3 and are not listed under forest management, cropland management and grazing land management pursuant to Article 3.4. The changes in areas between the measures pursuant to Article 3.3 and to Article 3.4 are listed in KP table NIR 2. The method for deriving areas uses a sample-based system that records the area for each land-use category and the land-use changes to and from the various land-use categories (cf. Chapter 6.3). The sampling grid used is based on a systematic network with a 100 m x 100 m grid size. Each sample point is assigned, in keeping with its status, to one – or none – of the land-use categories forest management, afforestation, deforestation, cropland management, and grazing land management. In the categories afforestation and deforestation, sample points cannot be shifted into other land-use categories. Each sample point has an area of 1 ha, and each point's geographic position is defined in terms of its coordinates. This identification system ensures that differentiation between a) afforested and deforested areas under KP Article 3.3 and b) forest management, cropland management and grazing land management areas under KP Article 3.4 is unambiguous.

11.3 Activity-specific information

11.3.1 Methods for determination of carbon-stock changes, greenhouse-gas emissions and reduction estimates

11.3.1.1 Description of methodologies and the underlying assumptions used

11.3.1.1.1 Summary

Forest management, afforestation and deforestation

As described in Chapter 11.1.3 , the activities forest management and afforestation in the Kyoto Protocol are equivalent to the UNFCCC categories 4.A.1 Forest Land remaining Forest Land and 4.A.2 Land converted to Forest Land, respectively. For this reason, the methods used are identical to those used for reporting under the Convention. The methods are described in the relevant chapters, as noted below:

- Changes in carbon stocks in above-ground and below-ground biomass: Chapter 6.4.2.2,
- Carbon-stocks change in dead wood: Chapter 6.4.2.3,
- Carbon-stocks change in litter: Chapter 6.4.2.4,
- Carbon-stocks change in mineral soils: Chapter 6.4.2.5,
- CO_2, CH_4 and N_2O emissions from drained organic soils: Chapter 6.4.2.6,
- Direct and indirect N_2O emissions from humus losses connected to land-use changes: Chapter 6.1.2.7 and Chapter 6.1.2.8
- CO_2, CH_4 and N_2O emissions from forest fires: Chapter 6.4.2.7.5,
- Carbon-stocks change in harvested wood products: Chapter 6.10,

In deforestation, carbon losses occur in biomass, dead wood and litter and in mineral and organic soils. In the case of biomass, dead wood and litter, it is assumed that the pertinent losses take the form of emissions in the year of conversion. Emissions from organic soils take place each year on the entire deforested area. For mineral soils, a transition time of 20 years is assumed.

Table 487 provides an overview for 2020 of changes in carbon stocks, greenhouse-gas emissions and areas in the forest-management, afforestation and deforestation categories.

Table 487: Carbon-stock changes and greenhouse-gas emissions as a result of forest management, afforestation and deforestation, for the year 2020

	Forest management	Afforestation	Deforestation
C-stock changes in biomass [kt C] *	8,004.873	35.109	-124.148
C-stock changes in dead wood [kt C] *	1,014.681	0.869	-11.373
C-stock changes in litter [kt C] *	-133.656	152.015	-107.592
C-stock changes in mineral soils [kt C] *	4,279.996	88.543	-18.528
CO_2 from organic soils [kt C] *	-672.720	-65.122	-64.551
N_2O from organic soils [kt N_2O] **	0.698	0.067	0.027
CH_4 from organic soils [kt CH_4] **	1.245	0.118	2.311
Direct and indirect N_2O from decomposition of organic material in mineral soils [kt N_2O] **	0.000	0.052	0.042
CO_2 from forest fires [kt C] *	IE	IE	NO
N_2O from forest fires [kt N_2O] **	0.004	IE	NO
CH_4 from forest fires [kt CH_4] **	0.073	IE	NO
C-stock changes in harvested wood products [kt C] *	2.359.440	IE	NO
Total [kt CO_2-eq.] **	-54,098.446	-725.089	1,274.136
Annual areas [ha]	11,004,181	14,126	5,773
Accumulated areas [ha]	10,692,488	325,819	135,609

* Stock change, positive: Carbon sink; stock change, negative: carbon source

** GHG emissions, positive: GHG source; GHG emissions, negative: GHG sink

Cropland management

Methodologically, the activity Cropland Management corresponds to the UNFCCC categories 4.B.1 and 4.B.2, with the exception of 4.B.2.1 Forest Land converted to Cropland:

- Changes in carbon stocks in above-ground and below-ground biomass: Chapters 6.1.2.3ff and 6.5.2.2,
- Carbon-stocks change in mineral soils: Chapters 6.1.2.1 and 6.5.2.3,
- CO_2, CH_4 and N_2O emissions from drained organic soils: Chapter 6.1.2.1 and Chapter 6.5.2.4,
- Direct and indirect N_2O emissions from humus losses connected to land-use changes: Chapter 6.1.2.7 and Chapter 6.1.2.8 and
- Proof to the effect that cropland under "remaining as" management is not a net source for greenhouse gases: Chapter 6.5.2.3.2

The carbon pools dead wood and litter occur only on Forest Land; they do not occur in cropland management (NO), since land-use changes from Forest Land to Cropland are accounted under deforestation. N_2O emissions from organic soils under cropland are reported not under the cropland management activity pursuant to Art. 3.4, but as part of the agricultural sector (CRF 3.D.a.6). The same applies to N_2O emissions from mineralisation of organic substance of mineral soils in the sub-category Cropland remaining Cropland (CRF 3.D.a.5). In Table 488, therefore, these emissions are listed as "IE".

Pursuant to the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol, Chapter 2.9.2 (IPCC et al., 2014a), emissions from land that was cropland during the base year only, and not during the commitment period, are reported as "0" if the pertinent land has been moved into in a non-elected or non-accountable category (Woody Grassland, Terrestrial Wetlands, Waters, Peat extraction and Settlements). It is good practice to show, for reasons of transparency, what impacts such corrections have on the emissions to be reported, and on accounting in the framework of the Kyoto Protocol (IPCC et al., 2014a); in the present case, such impacts are shown in Table 490 and Table 491.

Since Germany has elected cropland management only for the second commitment period of the Kyoto Protocol, emissions resulting from moving of cropland management into non-Kyoto activities are accounted only for land that underwent the land-use change after 2012. Such emissions have to be reported, because the pertinent land was already reported during the commitment period (Resolution 2/CMP.7, Para. 24 in the Annex (UNFCCC).

The findings in connection with cropland management, with respect to the biomass pool, in the EU Commission's study report "Member State recommendations on reporting systems for cropland & grazing land management emissions & removals" (Ecofys & Environment Agency Austria), and the relevant findings of the IPCC Reviews, have been translated into suitable methods and, in the present submission, completely implemented[152]. The required methodological change with regard to mineral soils[153] is currently undergoing methodological and technical development, and it will be implemented as quickly as possible[154] (cf. Chapter 6.1.3.4).

Table 488 provides an overview for 2020 of carbon-stock changes, and of greenhouse-gas emissions, in connection with cropland management.

[152] ARR 2021: KL.12, KL.13, KL.17, L.12, L.15, Table 5; ARR 2020: KL.5, Kl.6, Table 3; ARR 2018: KL.10, KL.11
[153] ARR 2021; L.8, Table 5
[154] ARR 2021; L. 14

Table 488: Carbon-stock and greenhouse-gas emissions as a result of cropland management, for the year 2020

Sub-categories	C-stock changes in biomass * [kt C]	C-stock changes in mineral soils * [kt C]	CO_2 from organic soils * [kt C]	CH_4 from organic soils ** [kt CH_4]	Direct and indirect N_2O from decomposition of organic material in mineral soils ** [kt N_2O]	Total ** [kt CO_2-eq.]
Cropland remaining Cropland	-3.37	-7.12	-2,061.06	2.83	IE	7,666.34
Total for LUC to Cropland	-264.84	-1,176.11	-1,030.10	2.21	2.17	9,762.87
Total for LUC from Cropland	389.67	-100.94	-32.49	0.30	0.18	-877.41
Total	121.46	-1,284.17	-3,123.65	5.34	2.35	16,551.80

* Stock change, positive: Carbon sink; stock change, negative: carbon source

** GHG emissions, positive: GHG source; GHG emissions, negative: GHG sink

The emissions from cropland management in 2020 are dominated by CO_2 from organic soils. Carbon losses from mineral soils, as a result of transitions from grazing land managment to cropland management, are also significant. As a result of land-use changes from cropland to non-accounted activities (Woody Grassland, Terrestrial Wetlands, Waters, Peat extraction and Settlements), the carbon-stock increases in the biomass pool are considerably larger than the emissions from the soils. With this overcompensation, this sub-category functions as a sink.

In 2020, the net emissions from cropland management were 17% higher than they were in the base year 1990 (cf. Table 488 in Chapter 11.5.2.1), with the result that net emissions of 1,762.04 kt CO_2-eq. have to be accounted in 2020.

Grazing land management:

Methodologically, the activity grazing land management corresponds to the sub-category Grassland (in the strict sense) (4.C.1.1 and land-use changes to Grassland (in the strict sense), except for changes from Forest Land to Grassland (in the strict sense)). The relevant calculation methods are as follows:

- Changes in carbon stocks in above-ground and below-ground biomass: Chapters 6.1.2.3ff and 6.6.2.2,
- Carbon-stocks change in mineral soils: Chapters 6.1.2.1 and 6.6.2.3,
- CO_2, CH_4 and N_2O emissions from drained organic soils: Chapters 6.1.2.1 and 6.6.2.4,
- Direct and indirect N_2O emissions from humus losses connected to land-use changes: Chapter 6.1.2.7 and 6.1.2.8.

The carbon pools dead wood and litter occur only on Forest Land; they do not occur in grazing land management (NO, IE), since land-use changes from Forest Land to Grassland (in the strict sense) are accounted under deforestation.

Table 489 provides an overview for 2020 of carbon-stock changes, and of greenhouse-gas emissions, in connection with grazing land management. N_2O emissions from organic soils under cropland are reported not under the grazing land management activity pursuant to Art. 3.4, but as part of the agricultural sector.

With regard to greenhouse-gas emissions and sinks on land undergoing land-use changes to non-accountable activities, and to implementation of findings from the various Reviews, the statements made with regard to cropland management apply in equal measure to grazing land management.

Table 489: Carbon-stock and greenhouse-gas emissions as a result of grazing land management, for the year 2020

Sub-categories	C-stock changes in biomass * [kt C]	C-stock changes in mineral soils * [kt C]	CO_2 from organic soils * [kt C]	CH_4 from organic soils ** [kt CH_4]	Direct and indirect N_2O from decomposition of organic material in mineral soils ** [kt N_2O]	Total ** [kt CO_2-eq]
Grazing land remaining grazing land	NA	NA	-6,062.75	31.89	NA	23,027.35
Total for LUC to grazing land	-784.03	2,395.83	-1,119.74	6.45	0.004	-1,641.69
Total for LUC from grazing land	669.19	-248.53	-107.39	3.89	0.44	-920.06
Total	-114.84	2,147.30	-7,289.88	42.23	0.44	20,465.60

* Stock change, positive: Carbon sink; stock change, negative: carbon source

** GHG emissions, positive: GHG source; GHG emissions, negative: GHG sink

For the most part, the emissions from grazing land management in 2020 originate in drained organic soils. They are only partly offset (by about 33 %) by mineral soils' sink function following land-use changes. The sub-categories "to grazing land management" and "from grazing land management" function as a sink. In the former case, the carbon-stock increase in mineral soils overcompensates for the emissions from biomass and organic soils; in the latter, the carbon-sink function of the biomass more than offsets the emissions from the soil.

In 2020, the net emissions from grazing land management were 24.5% lower than they were in the base year 1990 (cf. Table 518 in Chapter 11.5.2.2), with the result that a net emissions reduction of -6,652.79 kt CO_2-eq. can be accounted in 2020.

Impacts of the corrections, to be carried out pursuant to the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014a), on reported emissions from cropland and grazing land management and their accounting

Table 490 and Table 491 show the impacts, to be carried out pursuant to the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014a), on the absolute quantities of emissions from cropland and grazing land management in Germany. The emissions from cropland management, in the variant without exclusion of land moved in the period 1990 – 2012, have increased only slightly with respect to the base year; in the variant to be reported, they have increased considerably, since negative emissions, basically, have been set to "0".

In the case of emissions from grazing land management, the emissions of both variants are considerably lower in the commitment period than they were in the base year. The reason for this is that, here as well, in the variant to be reported, the emissions that have had to be set to "0" are mostly negative ones.

Table 491 shows the impacts of the rule-conformal corrections made on accounting of emissions in the framework of the Kyoto Protocol. In sum, a sink that is about 69 % lower results.

Table 490: Emissions [kt CO_2-Eq.] from cropland and grazing land management in Germany, for the base year and the second commitment period of the Kyoto Protocol. The listed emissions include both the reported emissions and the emissions that, pursuant to the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014a), have been reported as "0"

Cropland management	Base year	2013	2014	2015	2016	2017	2018	2019	2020
					[kt CO_2-eq.]				
$Emissions_{reported}$	14,142	18,166	18,168	18,522	17,785	17,455	17,320	16,906	16,552
$Emissions_{set\ to\ 0}$	272	-3,430	-3,023	-2,683	-2,270	-1,846	-1,625	-1,398	-1,143
Grazing land management	**Base year**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
					[kt CO_2-eq.]				
$Emissions_{reported}$	27,118	23,155	22,931	21,969	22,231	21,973	21,278	20,958	20,466
$Emissions_{set\ to\ 0}$	217	-2,270	-2,024	-1,801	-1,603	-1,318	-576	-307	-63

Table 491: Calculation of the emissions [kt CO2-eq.] from cropland and grazing land management, in Germany, to be accounted in the second commitment period of the Kyoto Protocol. The listed emissions include both the reported emissions ($Accounting_{actual}$) and, for comparison purposes, the calculated emissions without exclusion of the emissions that, pursuant to the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014a), are to be reported as "0" (comparative listing: $Accounting_{without\ 0}$)

	$Accounting_{actual}$										Accounting	
	Base year	2013	2014	2015	2016	2017	2018	2019	2020	Total[1]	Quantity[2]	Balance[3]
						[kt CO_2-eq.]						
Cropland management	14,142	18,166	18,168	18,522	17,785	17,455	17,320	16,906	16,552	140,874	**27,739**	**-14,248**
Grazing land management	27,118	23,155	22,931	21,969	22,231	21,973	21,278	20,958	20,466	174,960	**-41,987**	

	Comparative listing: $Accounting_{without\ 0}$										Accounting	
	Base year	2013	2014	2015	2016	2017	2018	2019	2020	Total[1]	Quantity[2]	Balance[3]
						[kt CO_2-eq.]						
Cropland management	14,414	14,736	15,145	15,839	15,516	15,609	15,695	15,508	15,409	123,457	**8.143**	**-45.546**
Grazing land management	27,336	20,885	20,907	20,167	20,628	20,655	20,702	20,651	20,402	164,998	**-53,688**	

1) Sum of emissions of the commitment period 2013-2020

2) Quantity = sum – base year * 8

3) ∑ Quantity

11.3.1.1.2 Biomass

Forest management and afforestation:

Information on methods used for calculating carbon stocks, and carbon-stock changes, in above-ground and below-ground biomass is presented in the following chapters:

- With regard to Forest Land remaining Forest Land, cf. Chapter 6.4.2.2.1.
- For Land converted to Forest Land, cf. Chapter 6.4.2.2.2.

Deforestation:

The carbon-stock changes in biomass on deforestation areas are calculated with the stock-difference method. In the process, only those areas are taken into account that were Forest Land at time 1 and non- Forest Land at time 2 (deforestation areas).

With regard to deforested areas, an individual-tree calculation was carried out on the basis of the 1987 National Forest Inventory (BWI), the BWI 2002, the 2008 Inventory Study, the BWI 2012 and the 2017 Carbon Inventory. For the period between the BWI 1987 and BWI 2002 inventories, only trees in the old German Länder were considered, since the BWI 1987 inventory was carried out only there. The wood-stocks data for the old German Länder were applied to the new German Länder. The emission factors for the decreasing above-ground and below-ground biomass are presented in Table 492. The carbon stocks released upon deforestation are counted, completely, as emissions in the same year. The stocks in the following use classes are listed for the relevant conversion year, on a one-time basis, under "gains" in the CRF table. They are thus taken into account.

Table 492: Emission factors (EF) for biomass in connection with deforestation; positive: carbon removal by sink; negative: carbon emissions

	1990	2000	2010	2015	2016	2017	2018	2019	2020
Above-ground biomass [tC/ha]	-24.53	-24.53	-34.88	-36.06	-36.06	-36.06	-36.06	-36.06	-36.06
Below-ground biomass [tC/ha]	-4.39	-4.39	-4.60	-4.82	-4.82	-4.82	-4.82	-4.82	-4.82

Cropland management:

Information on methods used for calculating carbon stocks, and carbon-stock changes, in above-ground and below-ground biomass is presented in Chapter 6.1.2.3 and Chapter 6.5.2.2, divided into the following categories:

- Permanent crops and perennial crops, stratified into the sub-categories Hops, Orchards, Vineyards, Tree nurseries, Christmas tree plantations and Short-rotation plantations (cf. Chapter 6.1.2.3.4).
- For annual crops, cf. Chapter 6.1.2.3.3. The biomass stocks are calculated from annual cultivation and yield statistics, in a manner consistent with the method used in Chapter 5 (agriculture) to calculate N inputs from crop residues.
- For aggregation of the biomass figures, cf. Chapter 6.5.2.2.1.

The findings in connection with cropland management, with respect to the biomass pool, in the EU Commission's study report "Member State recommendations on reporting systems for cropland & grazing land management emissions & removals" (ECOFYS 2017), and the relevant findings of the IPCC Reviews, have been translated into suitable methods and, in the present submission, completely implemented[155].

Grazing land management:

Information on methods used for calculating carbon stocks, and carbon-stock changes, in above-ground and below-ground biomass is presented in Chapter 6.4.2.2.2.

11.3.1.1.3 Dead wood

Forest management and afforestation:

Information on methods used for calculating carbon stocks and carbon-stock changes in dead wood is presented in the following chapters:

- Forest Land remaining Forest Land, cf. Chapter 6.4.2.3.1.
- Land converted to Forest Land cf. Chapter 6.4.2.3.2.

[155] ARR 2021: KL.12, KL.13, KL.17, L.12, L.15, Table 5; ARR 2020: KL.5, Kl.6, Table 3; ARR 2018: KL.10, KL.11

Deforestation:

The quantities of dead wood on deforestation areas were calculated with data of the BWI 2002, the 2008 Inventory Study (IS08), the BWI 2012 and and the 2017 Carbon Inventory. In the BWI 2002, terrestrial sampling was limited to dead wood with a diameter > 20 cm at its thicker end, for fallen dead wood, or with a DBH > 20 cm, for standing dead wood (Polley, 2001). For other sampling, the boundary used conformed to the provisions for climate reporting, i.e. was > 10 cm.

For dead wood with diameters ranging from 10 to 20 cm, the ratio of the two diameter classes' changes in dead-wood C stocks for the period 2008 through 2012 was used as a basis for the period 2002 through 2008. The mean value for the change in dead-wood C stocks in the period 2002 through 2012 was used as the change in such stocks for the period 1990 through 2002. Table 493 presents the changes in dead-wood C stocks for the different relevant periods and diameter classes. For the period as of the year 2018, the emission factor for the period 2012 through 2017 has been extrapolated. In each case of deforestation, the carbon stocks in dead wood, for the relevant year, were taken into account immediately as carbon emissions.

Table 493: Emission factors (EF) for dead wood

$t\ C\ ha^{-1}\ a^{-1}$	1990 - 2001	2002 - 2007	2008 - 2011	2012 - 2020
EF for dead wood	-1.884	-1.817	-1.481	-1.971

Cropland management and grazing land management:

Dead wood does not occur in connection with cropland management and grazing land management. For this reason, the relevant entries in CRF Table 4(KP-I)B.2 and 4(KP-I)B.3 are given as "NO." Dead wood and tree cuttings are removed from areas with permanent crops. Such measures have already been taken into account in the biomass calculation. For this reason, "IE" (include elsewhere) has been entered for them here.

11.3.1.1.4 Litter

Forest management and afforestation:

Information on methods used for calculating carbon stocks and carbon-stock changes in litter is presented in the following chapters:

- Forest Land remaining Forest Land, cf. Chapter 6.4.2.4.1.
- Land converted to Forest Land cf. Chapter 6.4.2.4.2.

Deforestation:

Calculations relative to the litter ground cover were carried out with the status data of the BZE I and BZE II forest soil inventories. According to the relevant calculations, the average carbon stocks in litter amounted to 19.05 $t\ C\ ha^{-1}$ in 1990 (BZE I) and to 18.83 $t\ C\ ha^{-1}$ in 2006 (BZE II). For the years 1991 through 2005, the stocks were derived by interpolating the status data for the years 1990 and 2006. For the period as of 2007, the stocks were obtained via extrapolation. In each case of deforestation, the carbon stocks in litter, for the relevant year, were taken into account immediately as carbon emissions.

Cropland management and grazing land management:

Litter does not occur in connection with cropland management and grazing land management, and it is included in the relevant biomass pool. For this reason, NO and IE have been entered for it in CRF Table 4(KP-I)B.2 and 4(KP-I)B.3.

11.3.1.1.5 Mineral soils

Forest management:

Information on methods used to calculate carbon stocks and carbon-stock changes in mineral soils of the "Forest Land remaining Forest Land" category is provided in Chapters 6.1.2.1 and 6.4.2.5.1

Afforestation and deforestation:

For each land-use-change category, the carbon-stock changes in mineral soils are calculated as the difference between the carbon stocks of the final land-use category and the carbon stocks of the original land-use category. Pursuant to the IPCC Guidelines (IPCC, 2003, 2006a; IPCC et al., 1997), the total changes are linearly distributed over a period of 20 years. For afforested and deforested areas, the carbon-stock changes in mineral soils were calculated in keeping with the procedures in Table 494 and Chapter 6.1.2.1. For each relevant year, the forest-soil carbon stocks were calculated via linear interpolation of the results of the forest-soil surveys.

A detailed description of the methods used with regard to deforestation leading to Settlements, to the relevant impacts on soil organic carbon stocks, is provided in Chapter 6.1.2.1.6.

Table 494: Implied **emission factors (IEF)** [t C ha^{-1} a^{-1}] **for mineral soils in the source categories afforestation and deforestation (negative = emission, positive = removal)**

[t C ha^{-1} a^{-1}]	KP 3.3 Afforestation/Reforestation	KP 3.3 Deforestation
1990	-0.841	-5.062
1995	-0.452	-0.856
2000	-0.377	-0.479
2005	-0.256	-0.717
2010	-0.101	-0.279
2011	-0.048	-0.186
2012	0.001	-0.174
2013	0.048	-0.164
2014	0.093	-0.155
2015	0.134	-0.145
2016	0.173	-0.214
2017	0.207	-0.196
2018	0.239	-0.179
2019	0.268	-0.164
2020	0.294	-0.150

Cropland management:

In the present report, mineral-soils carbon-stock changes resulting from land use and land-use changes are being calculated with inventory-based emission factors – with emission factors based on results of the Agricultural Soil Inventory (Jacobs et al., 2018); (cf. Chapter 6.1.2.1). Information on methods used to calculate carbon stocks and carbon-stock changes in mineral soils is presented in Chapter 6.1.2.1 and Chapter 6.5.2.3.

For areas remaining as cropland, national measurements show no change in carbon stocks in mineral soils. Proof to the effect that this pool is not a net sink is provided in Chapter 6.5.2.3.2.

In the 2020 Review Process, the ERT recommended that soil organic carbon stocks and nitrogen stocks be regionalised, in keeping with locally relevant soil and site factors (ARR 2020; L.8, Table 5). For technical reasons, it has not yet been possible to act on this recommendation, but plans call for establishment of the necessary means to do so in the near term.

Grazing land management:

In the present report, mineral-soils carbon-stock changes resulting from land use and land-use changes are being calculated with inventory-based emission factors – with emission factors based on results of the Agricultural Soil Inventory (Jacobs et al., 2018); (cf. Chapter 6.1.2.1). Information on methods used to calculate carbon stocks and carbon-stock changes in mineral soils is presented in Chapter 6.1.2.1 and Chapter 6.6.2.3.

For areas remaining as grassland (in the strict sense), no change in carbon stocks in mineral soils, on the basis of national measurements, is listed (cf. Chapter 6.6.2.3). With regard to the regionalisation of soil data, the remarks made in connection with cropland management apply (see above).

11.3.1.1.6 Organic soils

Forest management and afforestation:

Information on methods used for calculating carbon stocks and carbon-stock changes in organic soils is presented in the following chapters:

- Forest Land remaining Forest Land, cf. Chapter 6.4.2.6.1.
- Land converted to Forest Land cf. Chapter 6.4.2.6.2.

Deforestation:

For deforestation areas, the emission factors of sub-categories, and the area-weighted emission factors for deforestation on organic soils, were calculated pursuant to Table 495 and Chapter 6.1.2.2. It is important to remember that these calculations do not yield the carbon-stock difference between Forest Land and the subsequent use; they yield the emissions for the new use, in keeping with drainage intensity.

Table 495: Emission factors for organic soils of deforestation areas in 2020 (negative = loss; positive = sink)

	CO_2 [t ha^{-1}]	N_2O [kg ha^{-1}]	CH_4 [kg ha^{-1}]
Deforestation	18.95	1.354	185.09

Cropland management and grazing land management:

Emission factors for organic soils were derived from spatially explicit data. This was done by differentiating the frequency distribution for depths to water table by uses, and by applying regressions betweens depths to water table and CO_2 emissions. For land-use changes, the emission factor for the new land-use category applies right away. Additional information is presented in the following chapters:

- Derivation of emissions, cf. Chapter 6.1.2.2.
- Methods for Cropland, cf. Chapter 6.5.2.4
- Methods for Grassland (in the strict sense), cf. Chapter 6.6.2.4

11.3.1.1.7 Harvested wood products

In the first commitment period of the Kyoto Protocol, and in accordance with the IPCC 2003 GPG (IPCC, 2003), the contribution from carbon storage in wood products was taken into account as an immediate emission and thus was neither reported nor credited (cf. Chapter 2.8.2, IPCC et al. (2014a)).

As described in detail in Chapter 6.10, for the present reporting year, the emissions contribution made by harvested wood products in Germany, in terms of sources and removals into sinks for greenhouse gases, was determined (as in past years) with the *WoodCarbonMonitor* model (Rüter, 2017), in keeping with the specifications of the IPCC KP Supplement (IPCC et al., 2014a).

First, the availability of activity data, i.e. data on the production of and foreign trade in harvested wood products, was reviewed (cf. Chapter 2.8.1.1, IPCC et al. (2014a)), and the product fractions originating from domestic harvest were calculated. Then, in a second step (cf. Chapter 2.8.1.2, IPCC et al. (2014a)), the carbon contained in those products was allocated, using the procedure described in Chapter 6.10.2.1, to the forest activities listed in the Kyoto Protocol under Article 3, paragraphs 3 and 4. For Germany, the wood harvest can be fully assigned to the two activities *forest management* and *deforestation*. In keeping with the provisions of the IPCC 2013 KP Supplement (IPCC et al., 2014a), harvested wood products from deforestation are taken into account on the basis of instantaneous oxidation. As a result, the annual wood-harvest fractions from the activity forest management $f_{FM}(i)$ can be calculated from the inventory information available for Germany and from Equation 2.8.3 (IPCC et al., 2014a).

Germany has no wood that comes from deforestation areas but not from the actual deforestation events involved (cf. the CRF table). For this reason, "NO" was entered at this point in the CRF table. Wood from the activities afforestation and reforestation, on the other hand, is included in the forest management data, and thus is marked "IE" in the table. The biomass of short-rotation plantations in Germany is used exclusively for energy purposes (cf. category 1.A, Chapter 3.2), and thus that biomass is not reported under "harvested wood products" (HWP).

Further information, and details on the emission factors used and on the calculation carried out for Germany, in keeping with the provisions of the IPCC 2013 KP Supplement (IPCC et al., 2014a), are provided in Chapters 6.10.2.2 and 0. In keeping with these provisions, wood used for energy purposes, and wood in landfills, are taken into account on an immediate-emission basis (cf. Chapter 2.8.2, IPCC et al. (2014a)).

11.3.1.1.8 Other greenhouse-gas emissions

Information relative to calculations of other greenhouse-gas emissions is presented in the following chapters:

Forests:

- Nitrous oxide emissions from nitrogen fertilisers (CRF Table 4(KP-II)1); cf. Chapter 6.4.2.7.1
- Drainage and rewetting of organic and mineral soils (CRF Table 4(KP-II)2); cf. Chapter 6.4.2.7.2
- Direct nitrous oxide emissions from nitrogen mineralization and immobilization (CRF Table 4(KP-II)3); cf. Chapter 6.4.2.7.3
- Indirect nitrous oxide emissions from cultivated soils (CRF Table 4(KP-II)3); cf. Chapter 6.4.2.7.4
- Forest fires (CRF Table 4(KP-II)4); cf. Chapter 6.4.2.7.5

Cropland management and grazing land management:

- Drainage and rewetting of organic and mineral soils (CRF Table 4(KP-II)2); cf. Chapters 6.1.2.6, 6.5.2.4, 6.6.2.4
- Direct nitrous oxide emissions from nitrogen mineralization and immobilization (CRF Table 4(KP-II)3); cf. Chapter 6.1.2.7
- Indirect nitrous oxide emissions from cultivated soils (CRF Table 4(KP-II)3); cf. Chapter 6.1.2.8

For purposes of Kyoto reporting, the direct and indirect nitrous oxide emissions are combined, and the pertinent joint emission factor is reported in CRF Table 4(KP-II)3. In the agricultural sector, N_2O emissions from organic soils under cropland management or grazing land management are reported in the sub-category Cultivation of histosols (CRF 3.D.a.6), as are direct and indirect nitrous oxide emissions from mineralisation of organic substance of mineral soils in the remaining category Cropland management (CRF 3.D.a.5).

11.3.1.2 Justification when omitting any carbon pool or of greenhouse-gas emissions / removals from activities under Article 3.3 and elected activities under Article 3.4

No fertilization of forest areas, with mineral fertilizers, takes place in Germany. For this reason, the CRF Table 4(KP-II)1 spaces labelled as "Direct N_2O emissions from N fertilization" have been marked "NO" (not occurring).

Dead wood and litter do not occur in connection with cropland management and grassland management (NO; not occurring).

Emissions from mineral soils in the Cropland and Grassland "remaining as" categories are not taken into account, because such soils are not a net source for greenhouse gases. Proof of this is provided in Chapter 6.5.2.3.2 and Chapter 6.6.2.3.

11.3.1.3 Information on whether or not indirect and natural greenhouse gases and removals have been factored out

In calculation of greenhouse gases under KP 3.3 and 3.4, the following processes were not excluded via calculation:

- Increased carbon-dioxide concentrations above the pre-industrial level
- Indirect nitrogen deposition
- Dynamic effects of the age structure as a result of activities prior to 1 January 1990.

For the preparation of the FMRL, the existing age-class distribution was taken into account, as a starting point for the projection, in creation of the benchmark for the accounting via net-net approach, as called for by the Supplement.

11.3.1.4 Changes in data and methods since the previous submission (recalculations)

The key inventory-improvement measures that were carried out for the present submission, and that led to recalculations, are as follows:

- The sampling network for determining land use and land-use changes has been adjusted (cf. Chapter 6.3.1ff).
- Changed emission factors for biomass. For Forest Land remaining Forest Land, annual EF for biomass were introduced in the 2021 submission. In the present submission, the logging data used for derivation of the annual figures are consistent with the data used for derivation of harvested wood products (cf. also Chapter 6.4.2.2 and Chapter 6.10).
- For dead wood, the afforestation data from the 2017 Carbon Inventory were corrected.
- Implementation of a new method for calculating emissions from organic soils as a function of depth to water table (Chapter 6.1.2.2 ff);
- Modification of the method for determining the areas of drainage ditches for organic soils (Chapter 6.1.2.2.1);
- Introduction of a new method for calculating mineral-soil emission factors for land-use changes from/to Settlements and, in a related measure, introduction of new emission factors for carbon (cf. Chapter 6.1.2.1.6);

In the following tables, the 2022 submission and the 2021 submission are compared with regard to activity data (AD) and emissions (EM):

- AD afforestation, deforestation and forest management Table 496
- AD cropland management Table 497
- AD grassland management Table 498
- EM afforestation Table 499
- EM deforestation Table 500
- EM forest management Table 501
- EM Land converted to cropland management Table 502
- EM cropland management Table 503
- EM land converted to grassland management Table 504
- EM grassland management Table 505
- EF dead wood for afforestation, deforestation and forest management Table 506
- EF biomass for forest management Table 497

Table 496: Comparison of the 2021 and 2022 submissions with regard to activity data for Forest Land (kha)

Source category	Submission	Sub-category / Pool	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.3 Afforestation /Reforestation	Mineral soil	2021	11.4	68.3	125.2	166.3	207.9	237.6	251.2	264.7	278.3	291.8
		2022	11.4	68.8	126.1	167.2	208.7	238.2	250.8	263.5	276.1	288.7
		Absolute difference	0.08	0.52	0.93	0.91	0.80	0.60	-0.33	-1.28	-2.22	-3.17
		in %	1%	1%	1%	1%	0%	0%	0%	0%	-1%	-1%
	Organic soil	2021	0.3	1.7	3.2	8.4	14.0	16.8	18.6	20.3	22.0	23.7
		2022	0.3	1.8	3.3	8.5	14.2	17.0	18.5	20.0	21.5	23.0
		Absolute difference	0.01	0.06	0.13	0.13	0.16	0.14	-0.08	-0.29	-0.51	-0.73
		in %	4%	4%	4%	2%	1%	1%	0%	-1%	-2%	-3%
KP 3.3 Deforestation	Mineral soil	2021	1.4	8.4	15.5	52.4	77.7	98.5	104.7	110.8	117.0	123.1
		2022	1.4	8.4	15.5	52.1	77.0	96.6	101.9	107.2	112.5	117.8
		Absolute difference	-0.01	-0.01	-0.03	-0.40	-0.74	-1.89	-2.75	-3.61	-4.46	-5.32
		in %	-0.01	0.00	0.00	-0.01	-0.01	-0.02	-0.03	-0.03	-0.04	-0.05
	Organic soil	2021	0.02	0.14	0.27	6.72	9.07	10.14	10.65	11.16	11.67	12.17
		2022	0.02	0.15	0.29	6.73	9.05	10.11	10.59	11.06	11.54	12.01
		Absolute difference	0.00	0.01	0.02	0.01	-0.02	-0.03	-0.07	-0.10	-0.14	-0.16
		in %	9%	5%	7%	0%	0%	0%	-1%	-1%	-1%	-1%
KP 3.4 Forest Management	Mineral soil	2021	10,561.1	10,554.1	10,547.0	10,510.1	10,484.8	10,464.0	10,457.8	10,451.7	10,445.5	10,439.4
		2022	10,560.7	10,553.7	10,546.7	10,510.1	10,485.2	10,465.5	10,460.2	10,454.9	10,449.6	10,444.3
		Absolute difference	-0.38	-0.38	-0.35	0.01	0.36	1.51	2.37	3.23	4.08	4.93
		in %	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Organic soil	2021	265.5	265.4	265.2	258.8	256.4	255.4	254.8	254.3	253.8	253.3
		2022	265.9	265.8	265.7	259.2	256.9	255.9	255.4	254.9	254.4	254.0
		Absolute difference	0.46	0.46	0.44	0.46	0.48	0.50	0.53	0.57	0.60	0.63
		in %	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 497: Comparison of the 2021 and 2022 submissions with regard to activity data for cropland management (kha)

Source category	Submission	Sub-category / Pool	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.4 to Cropland Management	Mineral soil	2021	478.2	478.3	478.5	785.6	930.4	1,268.8	1,312.3	1,355.7	1,399.2	1,442.6
		2022	478.1	475.1	474.6	698.3	774.8	1,059.7	1,085.7	1,112.5	1,139.5	1,167.3
		Absolute difference	-0.11	-3.26	-3.92	-87.34	-155.56	-209.07	-226.54	-243.21	-259.67	-275.37
		in %	0%	-1%	-1%	-13%	-20%	-20%	-21%	-22%	-23%	-24%
	Organic soil	2021	24.0	24.1	24.2	71.4	96.2	134.6	139.9	145.3	150.6	155.9
		2022	24.0	22.9	22.6	66.6	84.9	115.2	114.5	114.0	113.5	113.0
		Absolute difference	-0.02	-1.21	-1.56	-4.84	-11.36	-19.44	-25.43	-31.29	-37.12	-42.93
		in %	0%	-5%	-7%	-7%	-13%	-17%	-22%	-27%	-33%	-38%
KP 3.4 Cropland Management	Mineral soil	2021	12,778.6	12,799.5	12,820.4	12,120.7	11,701.3	11,130.9	11,058.9	10,986.9	10,914.9	10,843.0
		2022	12,775.5	12,799.5	12,820.9	12,204.2	11,852.9	11,336.0	11,283.2	11,229.6	11,175.7	11,121.2
		Absolute difference	-3.09	-0.03	0.49	83.47	151.58	205.12	224.28	242.65	260.82	278.22
		in %	0%	0%	0%	1%	1%	2%	2%	2%	2%	3%
	Organic soil	2021	311.7	304.9	298.2	262.2	239.5	217.4	207.7	198.0	188.4	178.7
		2022	311.6	306.0	299.6	267.0	250.7	236.6	233.2	229.6	225.9	222.3
		Absolute difference	-0.07	1.11	1.45	4.74	11.18	19.26	25.47	31.52	37.55	43.57
		in %	0%	0%	0%	2%	4%	8%	11%	14%	17%	20%

Table 498: Comparison of the 2021 and 2022 submissions with regard to activity data for grassland management (kha)

Source category	Submission	Sub-category / Pool	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.4 to Grazing Land Management	Mineral soil	2021	353.9	354.1	354.3	997.9	1,387.8	1,901.1	1,982.4	2,063.6	2,144.9	2,226.1
		2022	353.8	342.6	339.0	945.9	1,215.4	1,533.9	1,570.1	1,606.8	1,643.9	1,681.2
		Absolute difference	-0.18	-11.56	-15.32	-51.99	-172.39	-367.20	-412.27	-456.85	-501.00	-544.94
		in %	0%	-3%	-5%	-5%	-14%	-24%	-26%	-28%	-30%	-32%
	Organic soil	2021	59.6	59.6	59.8	103.9	123.7	138.3	148.1	157.8	167.5	177.2
		2022	59.6	59.2	59.1	98.5	109.8	115.8	121.9	128.1	134.3	140.6
		Absolute difference	0.02	-0.46	-0.66	-5.43	-13.81	-22.55	-26.13	-29.66	-33.19	-36.53
		in %	0%	-1%	-1%	-6%	-13%	-19%	-21%	-23%	-25%	-26%
KP 3.4 Grazing Land Management	Mineral soil	2021	4,845.4	4,804.2	4,763.0	4,292.2	3,972.3	3,473.5	3,393.3	3,313.1	3,233.0	3.152.8
		2022	4,840.5	4,810.8	4,773.5	4,337.7	4,136.8	3,831.7	3,797.2	3,762.2	3,726.9	3,691.3
		Absolute difference	-4.89	6.58	10.46	45.52	164.48	358.23	403.92	449.11	493.89	538.43
		in %	0%	0%	0%	1%	4%	9%	11%	12%	13%	15%
	Organic soil	2021	919.3	927.7	936.1	879.1	846.7	806.3	798.0	789.8	781.5	773.3
		2022	918.8	927.7	936.3	883.9	859.9	828.1	823.5	818.9	814.2	809.4
		Absolute difference	-0.52	-0.01	0.20	4.88	13.17	21.84	25.50	29.10	32.72	36.14
		in %	0%	0%	0%	1%	2%	3%	3%	4%	4%	4%

Table 499: Comparison of the 2021 and 2022 submissions with regard to data on emissions from afforestation

Source category	GHG [kt]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.3 Afforestation/ Reforestation	C	2021	-183.93	-144.61	-39.03	5.47	171.76	273.38	67.85	102.89	137.81	172.15
		2022	-142.23	-127.67	-69.15	-136.93	412.86	218.19	117.55	141.36	158.86	183.63
		Absolute difference	41.70	16.94	-30.12	-142.39	241.11	-55.19	49.69	38.47	21.04	11.48
		in %	-29.3%	-13.3%	43.6%	104.0%	58.4%	-25.3%	42.3%	27.2%	13.2%	6.3%
	CH_4	2021	0.001	0.009	0.017	0.040	0.065	0.078	0.085	0.096	0.104	0.113
		2022	0.002	0.009	0.017	0.039	0.065	0.079	0.087	0.096	0.103	0.111
		Absolute difference	0.000	0.000	0.000	-0.001	0.000	0.001	0.001	0.000	-0.001	-0.002
		in %	11.0%	-4.1%	0.3%	-2.3%	0.0%	1.7%	1.5%	0.3%	-1.0%	-1.8%
	N_2O	2021	0.012	0.060	0.099	0.135	0.166	0.169	0.180	0.190	0.201	0.213
		2022	0.021	0.090	0.154	0.192	0.211	0.168	0.166	0.164	0.162	0.160
		Absolute difference	0.009	0.031	0.055	0.056	0.045	-0.001	-0.014	-0.026	-0.039	-0.053
		in %	44.1%	33.9%	35.8%	29.4%	21.3%	-0.8%	-8.3%	-16.0%	-24.2%	-33.0%

Table 500: Comparison of the 2021 and 2022 submissions with regard to data on emissions from deforestation

Source category	GHG [kt]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.3 Deforestation	C	2021	-56.36	-59.16	-62.36	-468.35	-342.93	-296.91	-426.63	-429.03	-431.47	-433.49
		2022	-77.67	-69.21	-52.86	-501.08	-253.71	-178.60	-301.24	-312.87	-322.75	-323.74
		Absolute difference	-21.31	-10.05	9.49	-32.73	89.22	118.30	125.39	116.16	108.72	109.75
		in %	27.4%	14.5%	-18.0%	6.5%	-35.2%	-66.2%	-41.6%	-37.1%	-33.7%	-33.9%
	CH_4	2021	0.0013	0.009	0.016	0.362	1.149	1.315	1.423	1.484	1.541	1.598
		2022	0.0036	0.027	0.057	1.191	1.600	1.841	1.932	2.030	2.126	2.225
		Absolute difference	0.0023	0.018	0.041	0.829	0.451	0.526	0.509	0.546	0.586	0.626
		in %	63.5%	68.0%	72.0%	69.6%	28.2%	28.6%	26.3%	26.9%	27.5%	28.2%
	N_2O	2021	0.0002	0.0018	0.003	0.034	0.034	0.033	0.043	0.044	0.045	0.046
		2022	0.0064	0.0095	0.010	0.059	0.049	0.044	0.055	0.056	0.057	0.058
		Absolute difference	0.0062	0.0078	0.007	0.025	0.015	0.011	0.012	0.012	0.012	0.012
		in %	96.9%	81.6%	67.0%	42.0%	30.7%	24.4%	22.0%	21.2%	20.5%	20.0%

Table 501: Comparison of the 2021 and 2022 submissions with regard to data on emissions from forest management

Source category	GHG [kt]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.4 Forest Management	C	2021	6,215.84	22,038.27	17,118.47	9,231.92	13,426.17	16,904.04	17,409.60	17,321.68	15,862.52	15,675.02
		2022	5,528.15	19,747.15	14,241.03	9,664.84	13,539.51	16,648.34	17,406.61	17,112.35	15,190.70	14,273.63
		Absolute difference	-687.69	-2,291.12	-2,877.44	432.93	113.34	-255.70	-2.99	-209.34	-671.82	-1,401.39
		in %	-12.4%	-11.6%	-20.2%	4.5%	0.8%	-1.5%	0.0%	-1.2%	-4.4%	-9.8%
	CH_4	2021	1.304	1.304	1.303	1.274	1.263	1.258	1.255	1.252	1.249	1.246
		2022	1.306	1.305	1.304	1.273	1.261	1.256	1.254	1.252	1.249	1.247
		Absolute difference	0.001	0.001	0.001	-0.001	-0.001	-0.002	-0.002	0.000	0.000	0.001
		in %	0.1%	0.1%	0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%	0.0%	0.1%
	N_2O	2021	1.806	1.805	1.804	1.761	1.745	1.737	1.734	1.731	1.727	1.724
		2022	1.151	1.151	1.150	1.122	1.112	1.108	1.106	1.104	1.101	1.099
		Absolute difference	-0.654	-0.654	-0.654	-0.638	-0.633	-0.629	-0.628	-0.627	-0.626	-0.624
		in %	-56.8%	-56.8%	-56.9%	-56.9%	-56.9%	-56.8%	-56.8%	-56.8%	-56.8%	-56.8%

Table 502: Comparison of the 2021 and 2022 submissions with regard to data on emissions from land conversions to cropland management

Source category	GHG [kt]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.4 to Cropland Management	C	2021	-764.68	-751.02	-739.56	-1,447.52	-1,764.60	-2,325.97	-2,603.28	-2,659.90	-2,883.70	-2,890.37
		2022	-835.28	-914.37	-901.77	-1,792.05	-1,760.60	-2,343.22	-2,386.47	-2,386.70	-2,477.21	-2,461.33
		Absolute difference	-70.60	-163.35	-162.21	-344.52	4.00	-17.25	216.81	273.21	406.49	429.04
		in %	8.5%	17.9%	18.0%	19.2%	-0.2%	0.7%	-9.1%	-11.4%	-16.4%	-17.4%
	CH_4	2021	0.467	0.395	0.362	2.040	2.524	3.444	3.051	3.186	3.326	3.491
		2022	0.462	0.384	0.356	1.284	1.828	2.367	2.421	2.448	2.411	2.336
		Absolute difference	-0.004	-0.011	-0.007	-0.756	-0.696	-1.077	-0.630	-0.738	-0.915	-1.155
		in %	-1.0%	-2.9%	-1.8%	-58.9%	-38.1%	-45.5%	-26.0%	-30.1%	-37.9%	-49.4%
	N_2O	2021	0.392	0.388	0.386	0.721	0.848	1.178	1.209	1.242	1.276	1.312
		2022	0.784	0.771	0.765	1.283	1.413	1.967	2.000	2.038	2.079	2.124
		Absolute difference	0.392	0.382	0.379	0.562	0.565	0.788	0.791	0.796	0.803	0.811
		in %	50.0%	49.6%	49.5%	43.8%	40.0%	40.1%	39.5%	39.1%	38.6%	38.2%

Table 503: Comparison of the 2021 and 2022 submissions with regard to data on emissions from cropland management

Source category	GHG [kt]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.4 Cropland Management	C	2021	-2,895.12	-2,846.44	-2,801.20	-2,468.92	-2,262.04	-2,043.11	-1,945.13	-1,854.94	-1,763.83	-1,673.81
		2022	-2,918.09	-2,888.09	-2,840.97	-2,537.92	-2,380.05	-2,232.92	-2,216.22	-2,183.20	-2,144.09	-2,106.80
		Absolute difference	-22.97	-41.65	-39.77	-69.00	-118.01	-189.81	-271.09	-328.26	-380.26	-432.99
		in %	0.8%	1.4%	1.4%	2.7%	5.0%	8.5%	12.2%	15.0%	17.7%	20.6%
	CH_4	2021	5.379	5.003	4.607	3.819	3.284	2.910	2.760	2.596	2.446	2.310
		2022	5.367	5.009	4.613	3.882	3.438	3.171	3.151	3.101	3.025	2.936
		Absolute difference	-0.011	0.006	0.006	0.063	0.154	0.261	0.392	0.505	0.579	0.626
		in %	-0.2%	0.1%	0.1%	1.6%	4.5%	8.2%	12.4%	16.3%	19.2%	21.3%

Table 504: Comparison of the 2021 and 2022 submissions with regard to data on emissions from land conversions to grassland management

Source category	GHG [kt]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.4 to Grazing Land Management	C	2021	-25.54	-37.59	-47.69	-38.08	719.66	1,277.18	1,057.09	1,037.12	1,167.30	1,113.93
		2022	-60.13	-149.94	-165.18	-598.14	341.07	789.02	597.00	542.45	591.59	523.20
		Absolute difference	-34.59	-112.35	-117.49	-560.06	-378.59	-488.16	-460.09	-494.68	-575.70	-590.73
		in %	57.5%	74.9%	71.1%	93.6%	-111.0%	-61.9%	-77.1%	-91.2%	-97.3%	-112.9%
	CH_4	2021	2.774	2.728	2.652	4.453	6.363	7.301	7.910	8.158	8.390	8.568
		2022	2.409	2.333	2.249	4.694	5.258	5.609	5.681	5.782	5.953	6.169
		Absolute difference	-0.365	-0.395	-0.403	0.242	-1.105	-1.692	-2.229	-2.375	-2.436	-2.398
		in %	-15.1%	-17.0%	-17.9%	5.1%	-21.0%	-30.2%	-39.2%	-41.1%	-40.9%	-38.9%
	N_2O	2021	0.0002	0.0003	0.0003	0.002	0.002	0.002	0.002	0.002	0.003	0.003
		2022	0.0005	0.0005	0.0005	0.003	0.004	0.004	0.004	0.004	0.004	0.004
		Absolute difference	0.0002	0.0002	0.0002	0.002	0.002	0.001	0.001	0.001	0.001	0.001
		in %	47.2%	45.9%	46.1%	46.8%	42.8%	37.8%	37.1%	36.8%	36.0%	35.2%

Table 505: Comparison of the 2021 and 2022 submissions with regard to data on emissions from grassland management

Source category	GHG [kt]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
KP 3.4 Grazing Land Management	C	2021	-7,027.01	-7,082.76	-7,137.61	-6,662.37	-6,359.79	-6,017.23	-5,954.11	-5,890.92	-5,827.57	-5,764.08
		2022	-7,099.66	-7,159.96	-7,217.04	-6,772.92	-6,530.52	-6,249.30	-6,212.95	-6,176.14	-6,139.18	-6,100.82
		Absolute difference	-72.66	-77.20	-79.43	-110.56	-170.74	-232.07	-258.84	-285.22	-311.61	-336.74
		in %	1.0%	1.1%	1.1%	1.6%	2.6%	3.7%	4.2%	4.6%	5.1%	5.5%
	CH_4	2021	39.472	39.968	40.481	38.556	38.461	37.692	37.264	36.842	36.424	36.020
		2022	32.218	32.683	33.155	31.955	32.748	32.845	32.653	32.456	32.277	32.100
		Absolute difference	-7.254	-7.285	-7.326	-6.600	-5.713	-4.847	-4.611	-4.385	-4.147	-3.920
		in %	-22.5%	-22.3%	-22.1%	-20.7%	-17.4%	-14.8%	-14.1%	-13.5%	-12.8%	-12.2%

Table 506: Comparison of the 2021 and 2022 submissions with regard to emission factors for dead wood (tC/ha)

CRF No.		Sub-category / Pool	1990-2001	2002-2007	2008-2011	2012-2019
KP 3.4	Forest Land remaining Forest Land	2021	-0.04	-0.10	0.19	-0.09
		2022	-0.04	-0.10	0.19	-0.09
		Difference	0.00	0.00	0.00	0.00
KP 3.3	Afforestation/Reforestation	2021	-0.03	-0.03	-0.23	-0.003
		2022	-0.03	-0.03	-0.23	-0.003
		Difference	0.00	0.00	0.00	0.000
	Deforestation	2021	1.88	1.82	1.48	1.97
		2022	1.88	1.82	1.48	1.97
		Difference	0.00	0.00	0.00	0.00

Table 507: Comparison of the 2021 and 2022 submissions with regard to emission factors for biomass in forest management (tC/ha)

Sub-category / Pool	Forest Land remaining Forest Land Above-ground biomass		Below-ground biomass	
Submission	2021	2022	2021	2022
1990	-0.19	-0.14	-0.02	-0.01
1991	-1.47	-1.58	-0.14	-0.15
1992	-1.61	-1.71	-0.15	-0.16
1993	-1.60	-1.70	-0.15	-0.16
1994	-1.36	-1.50	-0.13	-0.14
1995	-1.53	-1.34	-0.15	-0.13
1996	-1.40	-1.42	-0.13	-0.13
1997	-1.38	-1.37	-0.13	-0.13
1998	-1.39	-1.35	-0.13	-0.13
1999	-1.40	-1.39	-0.13	-0.13
2000	-1.12	-0.87	-0.11	-0.08
2001	-1.27	-1.34	-0.12	-0.13
2002	-0.46	-0.39	-0.12	-0.10
2003	-0.42	-0.42	-0.11	-0.11
2004	-0.39	-0.39	-0.10	-0.10
2005	-0.35	-0.38	-0.09	-0.10
2006	-0.33	-0.35	-0.08	-0.09
2007	-0.25	-0.26	-0.07	-0.07
2008	-0.97	-0.97	-0.13	-0.13
2009	-1.12	-1.11	-0.15	-0.15
2010	-0.98	-0.99	-0.13	-0.14
2011	-0.96	-0.96	-0.13	-0.13
2012	-0.93	-0.92	-0.16	-0.16
2013	-0.95	-1.00	-0.17	-0.18
2014	-1.01	-0.98	-0.18	-0.18
2015	-0.98	-0.96	-0.17	-0.17
2016	-1.02	-1.02	-0.18	-0.18
2017	-1.02	-1.00	-0.18	-0.18
2018	-0.90	-0.85	-0.16	-0.15
2019	-0.89	-0.78	-0.16	-0.14

11.3.1.5 Estimation of uncertainties

The uncertainties for activities pursuant to Article 3.3 Afforestation/Deforestation and 3.4 Forest Management, Cropland Management and Grazing Land Management of the Kyoto Protocol (KP) were determined in keeping with the provisions of the 2006 IPCC Guidelines (IPCC, 2006a). The uncertainty statistics given for a normal distribution include the 95 % confidence interval, ± half of the 95 % confidence interval and 1.96 x the standard error, in % of the mean. For asymmetric distributions – in the present context, usually consisting of data sets with a logarithmic normal distribution – the relevant deviations are described as upper and lower bounds, expressed as % values of the pertinent position scale. The propagation of uncertainties was calculated via a conservative approach in which the distance between the extreme value of the sloping axis section and the position scale is defined as half of the 95 % confidence interval.

Table 508 shows the results of uncertainties calculation for all categories and sub-categories of the KP 3.3/3.4 inventory (except for harvested wood products, cf. Chapter 11.3.1.5.3). The total uncertainty is ± 20.26 %.

Further information relative to uncertainties is provided as follows: for estimation of land-use-change areas, in Chapter 11.3.1.5.3; for above-ground and below-ground biomass and dead wood, in Chapter 11.3.1.5.1; for litter and mineral soils, in Chapter 11.3.1.5.2; and summarised for the LULUCF sector overall, in Chapter 6.1.2.10.

Table 508: Uncertainties for greenhouse-gas reporting for Kyoto Protocol activities in Articles 3.3 and 3.4

Category	Sub-category / Pool	Gas	Base year emissions [CO_2-eq.] kt a^{-1}	Year 2020 emissions [CO_2-eq.] kt a^{-1}	Combined uncertainty, maximum value %	Contribution to Variance by Category in Year 2020 %
KP 3.3 Afforestation/Reforestation	Mineral soils	CO_2	35.25	324.66	5.0	0.0
	Organic soils	CO_2	2.83	238.78	16.4	0.0
	Organic soils	CH_4	0.04	2.96	63.1	0.0
	Organic soils	N_2O	0.38	31.58	67.2	0.0
	Above-ground biomass	CO_2	317.85	353.16	40.4	0.0
	Below-ground biomass	CO_2	187.49	224.42	63.5	0.0
	Litter	CO_2	20.42	557.39	297.6	2.0
	Deadwood	CO_2	1.48	3.19	74.6	0.0
	SOM	N_2O	5.86	15.56	132.9	0.0
KP 3.3 Deforestation	Mineral soils	CO_2	25.84	67.94	20.4	0.0
	Organic soils	CO_2	0.53	236.69	78.3	0.0
	Organic soils	CH_4	0.09	57.78	83.7	0.0
	Organic soils	N_2O	0.03	7.92	261.2	0.0
	Above-ground biomass	CO_2	127.29	453.05	32.2	0.0
	Below-ground biomass	CO_2	22.79	2.16	33.0	0.0
	Litter	CO_2	98.58	394.50	6.9	0.0
	Dead wood	CO_2	9.78	41.70	46.1	0.0
	SOM	N_2O	1.90	12.40	172.9	0.0
KP 3.4 Forest Management	Mineral soils	CO_2	14,879.68	15,693.32	52.6	49.1
	Organic soils	CO_2	2,588.15	2,466.91	24.2	0.3
	Organic soils	CH_4	32.66	31.10	110.0	0.0
	Organic soils	N_2O	343.03	327.07	120.4	0.1
	Above-ground biomass	CO_2	5,953.11	24,910.46	10.4	4.8
	Below-ground biomass	CO_2	622.73	4,432.87	14.0	0.3
	Litter	CO_2	97.89	489.94	470.4	3.8
	Dead wood	CO_2	1,459.13	3,719.50	24.8	0.6
	Forest fires	CH_4	6.77	1.81	81.7	0.0
	Forest fires	N_2O	4.46	1.20	56.3	0.0
	SOM	N_2O	0.00	1.00	0.0	0.0
KP 3.4 to Cropland Management	Mineral soils	CO_2	1,349.04	4,312.40	2.1	0.0
	Organic soils	CO_2	804.35	3,777.02	40.6	1.7
	Organic soils	CH_4	11.55	55.16	83.8	0.0
	Above-ground biomass	CO_2	531.89	327.74	248.3	1.5
	Below-ground biomass	CO_2	377.42	643.33	30.6	0.0

Category	Sub-category / Pool	Gas	Base year emissions [CO_2-eq.] kt a^{-1}	Year 2020 emissions [CO_2-eq.] kt a^{-1}	Combined uncertainty, maximum value %	Contribution to Variance by Category in Year 2020 %
KP 3.4 Cropland Management	Mineral soils	CO_2	84.97	26.09	5.2	0.0
	Organic soils	CO_2	10,554.77	7,557.24	42.6	7.5
	Organic soils	CH_4	134.18	70.64	90.1	0.0
	Above-ground biomass	CO_2	35.58	17.28	260.9	6.3
	Below-ground biomass	CO_2	24.33	4.91	9.2	0.0
KP 3.4 total Cropland Management	SOM	N_2O	233.76	647.21	10.3	0.0
KP 3.4 to Grazing Land Management	Mineral soils	CO_2	1,937.86	8,784.71	2.0	0.0
	Organic soils	CO_2	1,654.18	4,105.71	70.9	6.1
	Organic soils	CH_4	60.22	161.31	326.2	0.2
	Above-ground biomass	CO_2	400.89	2,253.96	292.1	0.6
	Below-ground biomass	CO_2	103.29	620.82	51.7	1.0
KP 3.4 Grazing Land Management	Mineral soils	CO_2	0.00	0.00	2.2	0.0
	Organic soils	CO_2	26,032.10	22,230.10	89.2	283.6
	Organic soils	CH_4	805.44	797.25	442.0	9.0
	Above-ground biomass	CO_2	0.00	0.00	382.6	30.1
	Below-ground biomass	CO_2	0.00	0.00	36.2	0.0
KP 3.4 total Grazing Land Management	SOM	N_2O	0.14	1.22	50.8	0.0
	Uncertainty total ARD / FM / CM / GM [%]:				**20.26**	

11.3.1.5.1 Estimation of uncertainties in emission factors for biomass and dead wood

Table 509 shows the uncertainties that result for the calculation of carbon-stock changes in living biomass, as carried out in keeping with the information provided in Chapter 6.4.3.2.

It was not possible to derive emission factors for KP Afforestation/Reforestation and KP Deforestation for the new German Länder for the period 1993 – 2002, since the Datenspeicher Wald forest database does not contain the data necessary for such derivation. Consequently, the emission factors for the old German Länder have been used for that period.

Table 509: Total error for estimation of C-stock changes in biomass for the National Forest Inventory inventory periods 1987–2002, 2002–2008, 2008–2012 and 2012–2017 (RMSE% – root mean square error percent)

RMSE%	1987-2002	1993-2002	2002-2008	2008-2012	2012-2017
	Old German Länder	New German Länder	Germany as a whole		
Afforestation (KP 3.3)	22.99	-	45.57	23.48	35.95
Deforestation (KP 3.3)	17.42	-	22.70	23.29	27.18
Forest Management (KP 3.4)	8.76	10.05	22.17	9.52	9.10

Table 510 shows the uncertainties that result, on the basis of the information provided in Chapter 6.4.3.2, for the calculation of C-stock changes in dead wood.

Table 510: Total error for estimation of C-stock changes in dead wood for the National Forest Inventory inventory periods 2008–2012 and 2012–2017 (RMSE% - root mean square error percent)

RMSE%	2008-2012	2012-2017
Afforestation (KP 3.3)	45.50	117.84
Deforestation (KP 3.3)	50.80	52.30
Forest Management (KP 3.4)	27.80	24.77

The total-error calculation for purposes of reporting under the Kyoto Protocol is presented in Table 508 in Chapter 11.3.1.5.

11.3.1.5.2 Estimation of uncertainties in emission factors for mineral soils and litter

Table 511 shows the uncertainties that result for the emission factors for mineral soils and litter, as determined in keeping with the information provided in Chapter 6.4.3.3.

Table 511: Error budget for the emission factors for mineral soils and litter; se = standard deviation of the mean value; C 90, C 06 = laboratory error in carbon-stocks determination, BZE I and BZE II; FE = error in determination of the fine-earth fraction

LULUCF category	Sub-category / Pool	Emission factor					
		se [%]	C 90 [%]	C 06 [%]	FE [%]	error total [%]	Uncertainty [%]
KP Forest Management	Litter	105.9	111.2	73.4		168.9	337.8
KP Forest Management	Mineral soil	9.0	14.1	13.6	12.2	26.7	53.4

11.3.1.5.3 Estimation of uncertainties for harvested wood products

Pursuant to information in the IPCC 2013 KP Supplement (IPCC et al., 2014a) Guidelines, the uncertainties for the activity data for harvested wood products amount to -25/+5%. For the emission factors, the standard values listed in Table 2.8.2 of the IPCC 2013 KP Supplement (IPCC et al., 2014a) Guidelines are used. Those values include no uncertainties. Due to the lack of uncertainties, no error calculation can be carried out for harvested wood products.

11.3.1.6 Information on other methodological issues

In this chapter, the individual-pools results in the present submission are compared with those of other countries. As described in Chapter 6.4.4.3, any comparison of Germany with other countries can only serve the purpose of general categorization. A range of different methods and approaches have been used, especially in connection with the definition of Forest Land and with selection of activities under Article 3.4. All countries that can be usefully compared to Germany report forest management as a mandatory category pursuant to Article 3.4. To date, only Germany, Denmark and the UK have committed to reporting in the reporting-optional categories Cropland Management and Grazing Land Management. As a result, no comparison with other countries has been carried out for these two activities.

The comparison data for the carbon-stock changes of other countries are obtained from the national inventory reports of countries neighbouring Germany and the UK. The emission factors have been obtained from the countries' 2021 submissions to the UN Climate Secretariat, and they are oriented to the 2019 inventory year. The comparisons, which are broken down by pools, are found in the following tables: for biomass, in Table 512; for dead wood and litter, in Table 513; for mineral and organic soils, in Table 514.

Table 512: Carbon-stock changes in living biomass (for 2019)

Country	Afforestation		Deforestation		Forest management	
[t C ha^{-1}]	Above-ground	Below-ground	Above-ground	Below-ground	Above-ground	Below-ground
Belgium	1.00	0.20	-3.46	-0.64	0.63	0.07
Denmark	0.95	0.23	-2.75	-0.51	0.43	0.09
France	1.18	0.48	-1.53	-0.42	0.35	0.15
UK	1.38	0.46	-2.60	IE,NA	0.43	0.13
Netherlands	3.15	0.45	-2.81	-0.38	0.85	0.15
Austria	0.98	0.27	-0.61	-0.15	0.25	0.03
Poland	0.75	0.22	-1.14	-0.26	0.77	0.20
Switzerland	0.88	0.40	-2.06	-0.63	0.49	0.10
Czech Republic	1.15	0.22	-1.72	-0.37	-1.34	-0.29
Germany	0.16	-0.06	-1.34	-0.07	0.89	0.16

Source: (UNFCCC)

Table 513: Carbon-stock changes in dead wood and litter (for 2019)

Country	Afforestation		Deforestation		Forest management	
[t C ha^{-1}]	Dead wood	Litter	Dead wood	Litter	Dead wood	Litter
Belgium	NO,NA	NO,NA	-0.19	-0.05	NO,NA	NO,NA
Denmark	0.41	0.02	-0.57	-0.05	0.45	0.07
France	0.02	0.16	-0.03	-0.20	-0.02	0.00
UK	0.15	0.07	IE,NA	-0.87	0.31	0.03
Netherlands	0.10	NO,NE	-0.08	-1.05	0.06	NO
Austria	0.02	0.74	0.00	-0.48	0.06	NO,NE,IE,NA
Poland	NO,NA	NO,NA	-0.03	-0.30	NO,NA	NO,NA
Switzerland	0.03	-0.02	-0.14	-0.48	-0.04	0.04
Czech Republic	0.03	0.43	-0.07	-0.22	-0.01	NO,IE
Germany	0.00	0.47	-0.10	-0.92	0.09	-0.01

Source: (UNFCCC)

Table 514: Carbon-stock changes in mineral and organic soils (for 2019)

Country	Afforestation		Deforestation		Forest management	
[t C ha^{-1}]	Mineral soil	Organic soil	Mineral soil	Organic soil	Mineral soil	Organic soil
Belgium	0.49	NO,NA	-1.11	NO,NA	NO,NA	NO,NA
Denmark	0.18	-1.30	-0.39	-8.40	NO,NA	-1.30
France	0.04	NO,IE	-0.71	NO,IE	0.00	IE
UK	-0.62	-1.27	-1.63	0.95	0.46	0.30
Netherlands	0.01	-1.01	0.09	-2.36	NO	-0.92
Austria	0.43	NO,NA	-0.37	NO,NA	-0.18	NO,NA
Poland	-0.09	-0.68	-1.87	1.00	0.10	-0.68
Switzerland	0.68	-0.08	-0.97	-4.50	0.00	-0.08
Czech Republic	0.22	NO	-0.13	NO,NA	NO,NE	NO
Germany	0.19	-2.57	-0.35	-5.08	0.41	-2.57

Source: (UNFCCC)

11.3.1.7 The year of the onset of an activity, if after 2013

Table 515 shows the area sizes for KP 3.3 activities that began after 2013. The activity Forest Management (KP.3.4) is included only for those areas that have been forest since 1990. As the table indicates, there are no areas on which forest management began after 2013.

Table 515: Relevant area sizes for activities that began after 2013.

KP 3.3 Activity	Year of onset						
	2014	2015	2016	2017	2018	2019	2020
Afforestation / Reforestation [ha]	6,474	6,466	14,129	14,120	14,128	14,121	14,126
Deforestation [ha]	4,144	4,149	5,777	5,768	5,774	5,771	5,773

11.4 Article 3.3

11.4.1 Information that demonstrates that activities under Article 3.3 began on or after 1 January 1990 and before 31 December 2020 and are directly human-induced

As described in Chapter 6.3, the procedure for determining land-use changes from and to Forest Land identifies area changes as of 1970, while the methods used for purposes of reporting under the Kyoto Protocol take account only of changes since 1990. As of the 2014 Submission, submissions take account of the results of the third National Forest Inventory, for which the reference year is 2012. Those results provide the database for the initial year of the second commitment period. All included activities in this context fall within the period 1 January 1990 to 31 December 2020.

While each land-use change from and to Forest Land is recorded primarily via the National Forest Inventory (Bundeswaldinventur; BWI), such changes are also recorded in additional data sets. The relevant sampling points form a grid that covers all of Germany. Via repeated surveying of the sample points, all changes can be mapped on a large scale. If a point is mapped as forest that was mapped as non-forest in the previous inventory, it represents a specific area of afforestation. The BWI differentiates between afforestation via planting / sowing and afforestation via natural rejuvenation. However, an area afforested via natural rejuvenation is classified as *afforested* only when the relevant stand has an average age of five years and crown cover of at least 50 % (cf. Chapter 6.2.1).

Agricultural land can change from (managed) cropland to unmanaged land and, via spontaneous establishment of trees (natural rejuvenation), into Forest Land. Pursuant to the IPCC 2013 KP Supplements (IPCC et al., 2014a), this type of afforestation may be accounted only if it is "directly human-induced". "It is good practice to provide documentation that all afforestation and reforestation activities included (…) are directly human-induced. Relevant documentation includes forest management records or other documentation that demonstrates that a decision had been taken to replant or to allow forest regeneration by other means."[156] German law requires a "permit from the competent authority under the law of the Länder" (Art. 10 (1) Federal Forest Act (BWaldG)) for each afforestation. Pursuant to Para. 2, no permit is required only in those cases in which, for the area to be afforested, "afforestation has been mandated in a legally binding way, on the basis of other public legal provisions, or the requirements of regional planning and Land (state) planning are not affected". Germany is a densely populated, intensively managed country in which all areas nation-wide are subject to land-use plans. In addition, Germany has different planning levels, ranging from large-scale planning (e.g. regional planning) to specific small-scale planning (e.g. landscape plans, operational plans for forest management). Preparation of, and compliance with, plans is monitored by the relevant competent authorities in each case, including authorities of the Federal Government, of the Länder and of individual municipalities. Thus it may be assumed that all afforested areas fulfill the "directly human-induced" requirement, since the act of permission, as well as the act of mandating in a legally binding manner and the preparation and establishment of regional and landscape plans all presuppose active decisions by humans.

11.4.2 Information about a Scheme for differentiation between a) harvest or forest disturbance that is followed by reforestation, and b) deforestation

Pursuant to Art. 11 (1) Federal Forests Act (BWaldG), "forests (…) (should) be properly and sustainably managed, in the framework of their defined purposes. Länder laws are to be enacted that set forth obligations for all forest owners whereby clear-cut or degraded forest areas

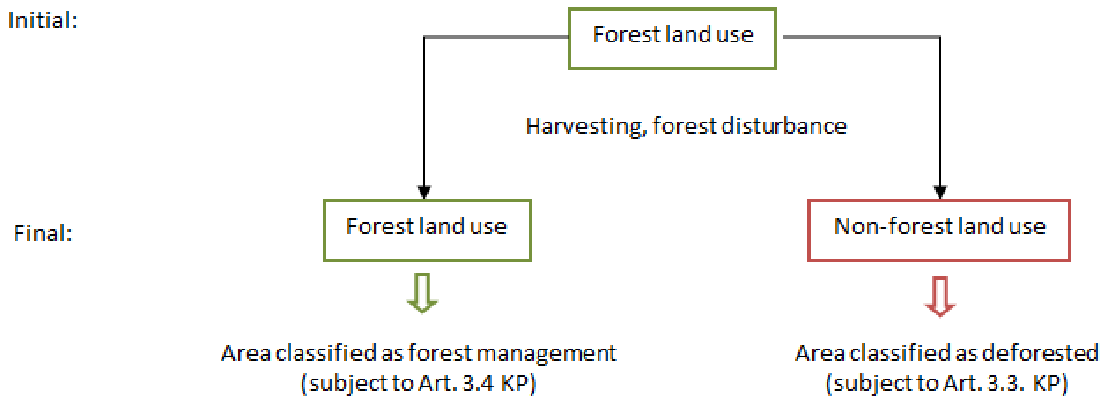
13. are to be reforested, or
14. replenished, in cases in which natural regrowth remains incomplete,

within a reasonable period of time, unless conversion to another type of use has been approved or is otherwise permitted."

In general, reforestation is called for on all forest areas that are to remain in use as Forest Land. That is a legal requirement, and it is the customary practice in the German forestry sector. Forest land that is temporarily unstocked thus continues to fall within the scope of required reporting on forest management pursuant to Art. 3.4 KP. The situation is different in cases in which Forest Land becomes unstocked and planning calls for subsequent use of the land to fall within the category "non-Forest Land". Such land is to be considered deforested land, with the relevant deforestation directly human-induced, regardless of whether the deforestation was caused by humans or by natural disturbances.

[156] Vgl. IPCC 2014, Section 2.5.2

Figure 92: Scheme for differentiation between a) harvest or forest disturbance that is followed by reforestation, and b) deforestation



11.4.3 Information about the size and geographic location of forest areas that have lost forest cover but which are not yet classified as deforested

Forest management routinely generates small unstocked areas (bare areas) in forests. Pursuant to the data of the BWI 2012, such areas total about 41,742 ha and account for 0.36 % of the total forest area. As explained above in Chapter 11.4.2, such areas continue to fall within the national forest definition and continue to figure in calculations relative to carbon stocks and their changes.

11.4.4 Information about natural disturbances under Article 3.3

As explained in Chapter 11.1.2, Germany has not selected the natural disturbances option. Natural disturbances that occur are not considered separately; instead, they enter into the change calculations for the relevant pools.

11.4.5 Information about harvested wood products under Article 3.3

As described in detail in Chapter 6.10, the emissions contribution made by harvested wood products in Germany, in terms of sources and removals into sinks for greenhouse gases, was determined with the *WoodCarbonMonitor* model (Rüter), in keeping with the specifications of the IPCC KP Supplement (IPCC et al., 2014a).

For Germany, the wood harvest can be fully assigned to the two activities forest management and deforestation. Wood products from deforestation (Article 3.3) are accounted for, pursuant to the provisions of the IPCC KP Supplements (IPCC et al., 2014a), on the basis of instantaneous oxidation.

11.5 Article 3.4

11.5.1 Information that demonstrates that activities under Article 3.4 have occurred since 1 January 1990 and are human-induced

11.5.1.1 Forest management

Since an integrated procedure is used for surveying Forest Lands, land-use changes and the carbon-stock changes caused by relevant activities, the statements made in Chapter 11.4.1 apply mutatis mutandis for the activity "forest management".

Pursuant to Art. 1 No. 1 Federal Forest Act (BWaldG), "forests are to be preserved, to be enlarged as necessary and to be properly and sustainably managed, in light of their economic value (utility function) and of their importance with regard to the environment, especially the long-term vitality of natural systems and cycles, and with regard to climate, water cycles, air quality, soil fertility, landscape beauty, agrarian structures and infrastructure and the population's needs for rest and recreation (protection and recreation functions)."

Forests are thus assigned three key basic functions, namely utility, conservation and recreation functions, in light of which they are to be preserved and properly and sustainably managed. In addition, Art. 11 (1) p. 1 BWaldG sets forth that "forests (…) (should) be properly and sustainably managed, in the framework of their defined purposes." While that formulation does not mean that forests "must" be managed, and thus it does not establish a general obligation, it is important to note that it does not use "may" phrasing, which would rule out any obligation. The wording chosen thus clearly reveals a basic orientation – namely, that forests should be managed. An obligation to manage forest lands thus applies to all of Germany.[157]

In the interest of protecting forests' three basic functions, forests, pursuant to Art. 1 No. 1 in conjunction with Art. 11 (1) p.1 BWaldG, should be protected and properly and sustainably managed. The aim of proper forest management as set forth by the Marrakesh Accords (MA) thus agrees with the requirements set forth by the Federal Forest Act (BWaldG). In both cases, management is oriented to the aim of ensuring that the forest can continue to fulfill its functions in perpetuity.

The Marrakesh Accords define forest management as "a system of practices". That indicates that management involves actions / measures. A forest area that is left untouched, and for which no measures are taken, is thus not a managed forest area. For a forest area to qualify as "unmanaged", however, no human activities may take place in it, i.e. no active human interventions may be permitted in it (equivalent to MCPFE conservation category 1.1). Forest areas meeting those criteria are "practically non-existent" in Germany (BMELV, 2009). In 2007, forest conservation areas in which permitted human interventions are restricted to a minimum, i.e. fully protected areas (MCPFE conservation category 1.2), accounted for 1.1% of Germany's total forest area, and were tending to be enlarged (BMELV, 2009). The primary focus with regard to such forest areas is on biotope and species conservation (for example, protected forests, natural forest reserves, core zones of national parks and biosphere reserves). Certain types of interventions are expressly permitted, however (for example, measures to control wildfires, hoofed game, diseases or insect calamities[158]). For protected forests, as for all protected areas, concepts are to be prepared that set forth / define / describe the object/focus of protection, the protection purpose, the necessary requirements and prohibitions for achieving the protection purpose and the necessary relevant care, management, development and restoration measures[159] (for example, in ordinances or guidelines on protected areas; cf. for example, Art. 23 (2) State Forest Act (LWaldG) of Mecklenburg – West Pomerania). In addition, some 23% of Germany's forest area consists of protected areas whose conservation purpose is actively assured via management measures (MCPFE conservation category 1.3); 56 % consist of forests whose primary purpose is to conserve landscapes and specific natural elements (MCPFE conservation category 2); and 34 % have the primary purpose of providing protective functions (MCPFE conservation category 3). In MCPFE conservation categories 1.3 through 3, management is to be aligned with the relevant conservation purpose. Such categories thus fulfill the criteria

[157] Häusler and Scherer-Lorenzen (2002) speak of an obligation, for all forest owners, "to carry out sustainable, proper management"; the citation appears in: Nachhaltige Forstwirtschaft in Deutschland im Spiegel des ganzheitlichen Ansatzes der Biodiversitätskonvention. BfN – Skripten 62, p. 5 and 15.

[158] In addition, environmentally compatible measures to develop forests for recreational purposes and for nature-compatible research are permitted.

[159] Cf. for example, Art. 22 (1) Federal Nature Conservation Act (BnatSchG).

for forest management. Human activities for protecting conservation areas are also certainly allowed in MCPFE category 1.2. Pursuant to the 2006 IPCC Guidelines (IPCC, 2006a), such areas thus fulfill forest-management criteria in accordance with Art. 3.4 KP: "For example forested national parks (…) where these parks are managed to fulfil relevant ecological (including biodiversity) and social functions, and are subject to forest management activities such as fire suppression, a country may choose to include these forested national parks as lands subject to forest management."[160] It should be noted that the aforementioned area shares in the different forest-conservation categories cannot simply be summed, since they overlap to some extent; in some cases, the same forest area will have been repeatedly included (BMELV, 2009).

Much of Germany's forest land is subject to planning. According to estimates of the BMEL, forest-management plans (economic plans, operational plans or reports) are in place for about ¾ of the country's forested area (BMELV, 2009). In addition to such operational plans, in many cases forest landscape plans (forest framework plans) are also prepared for forests, in the framework of landscape planning[161]. The aim of forest framework planning is to "safeguard the forest functions necessary for the development of ecological and economic conditions pursuant to Art. 1 No. 1 (BWaldG)". That accords precisely with the aim prescribed by the IPCC Good Practice Guidance (IPCC, 2003) with respect to forest management. To that end, measures may be, or must be, prescribed (cf. for example, Art. 6 (3) No. 4 p. 2 BWaldG old version; Art. 6 (1) No. 2 Bavarian Forest Act (BayWaldG); Art. 9 (4) State Forest Act (LWaldG) of Mecklenburg – West Pomerania; Art. 6 p. 2 Forest and Landscape Act of the State of Lower Saxony (NWaldLG); Art. 7 (1) State Forest Act for the State of North Rhine – Westphalia (LFoG NRW); Art. 6 (2) Forest Act of the State of Saxony-Anhalt (WaldG Sachsen-Anhalt)[162]). In some cases, requirements explicitly call for such planning to serve as a guideline for management, inter alia (cf. Art. 8 (3) LFoG NRW).

All in all, it must thus be considered confirmed that all forests in Germany are managed in accordance with forest-management criteria as set forth by the Marrakesh Accords and by the IPCC 3013 KP Supplements (IPCC et al., 2014a).

A compilation of excerpts from state forest acts, relative to requirements for forest management and for forest framework planning, is provided by Steuk (2010). A pertinent summary is presented in Table 516.

[160] IPCC KP Supplements (2014) Chapter 2.7.2 and IPCC 2006 Guidelines, Chapter 2, Volume 4

[161] Until 2005, the Federal Forest Act (BWaldG) required the preparation of forest framework plans. Because the Länder differ widely in their planning structures, those provisions were eliminated, however. Cf. BMELV (2009) Waldbericht der Bundesregierung (Forest Report of the Federal Government), p. 28.

[162] For definition of measures in operational plans, cf. Art. 5 (6) p. 3 State Forest Act (LWaldG) of Schleswig-Holstein.

Table 516: Overview of obligations relative to forest management, preparation of plans and use of forest framework plans, as set forth by the forest acts of the Länder

State (Land)	Forest-management obligations			Obligations to prepare plans (economic plans, operational plans, operational reports or other specialised forest-management plans)			Obligations to prepare forest framework plans
	State forest	Municipal forest	Private forest	State forest	Municipal forest	Private forest	
Baden-Württemberg	X	X	X	X	X	(X)	(X)
Bavaria	X	X	X	X	[X]		(X)
Berlin	X	X	X				X
Brandenburg							X
Bremen	X	X	X				
Hamburg	X	X	X				X
Hesse	X	X	X	X	X	[X]	
Mecklenburg – West Pomerania	X	X	X				X
Lower Saxony	X	X	X	[X]	[X]		X
North Rhine – Westphalia	X	X	X		X		X
Rhineland-Palatinate	X	X	X	[X]	[X]	[X]	X
Saarland	X	X	X	X	X	(X)	X
Saxony	X	X	X	X	X		(X)
Saxony-Anhalt	X	X	X	X	X		X
Schleswig-Holstein				[X]	[X]		
Thuringia	X	X	X	X	X	[X]	X

Legend:

X Binding requirement (includes "should" requirements)

[X] Requirement is binding only under certain conditions (for example, conditions pertaining to minimum size)

(X) Optional guideline / not binding (a "can" requirement)

11.5.1.2 Cropland management and grazing land management

All areas under cropland management and grazing land management are subject to periodic cultivation measures (carried out once or several times per year), and thus the pertinent emissions and removals are anthropogenic.

11.5.2 Information relative to cropland management and grazing land management for the base year

11.5.2.1 Cropland management

The emissions from cropland management in 1990 are dominated by CO_2 from organic soils. Carbon losses from mineral soils, as a result of conversions to Cropland, are also significant (Table 517). The emission pattern is very similar to that seen in 2020, apart from the following exception: In 1990, biomass still functioned as a minor source (cf. Table 488 in Chapter 11.3.1.1.1).

Table 517: Carbon-stock and greenhouse-gas emissions as a result of cropland management, in the base year 1990

Sub-categories	C-stock changes		CO_2 from organic soils [1]	CH_4 from organic soils [2]	Direct and indirect N_2O from decomposition of organic material in mineral soils [2]	Total [2] [3]
	Biomass [1]	Mineral soils [1]				
	[kt C]	[kt C]	[kt C]	[kt CH_4]	[kt N_2O]	[kt CO_2-eq]
Cropland remaining Cropland	-16.34	-23.17	-2,878.57	5.37	IE	10.833.84
Total for LUC to Cropland	-248.00	-367.92	-219.37	0.46	0.78	3,308.01
Total for LUC from Cropland	0	0	0	0	0	0
Total	-264.34	-391.09	-3,097.94	5.83	0.78	14.141.85

1) Stock change, positive: carbon removal by sink; negative: carbon source

2) GHG emissions, positive: GHG source; negative: GHG sink

3) Not including N_2O emissions from organic soils; they are reported as part of the agricultural sector

Emissions and removals from land-use changes from cropland to other land-use categories are taken into account under Art. 3.3 (afforestation) and Art. 3.4 (grazing land management). With regard to greenhouse-gas emissions and removals on land undergoing land-use changes to non-accountable activities (Woody Grassland, Terrestrial Wetlands, Waters, Peat extraction and Settlements), and to implementation of findings from the various Reviews, the statements made in Chapter 11.3.1.1.1 with regard to cropland management apply in equal measure. For this reason, emissions from land that, as a result of land-use changes in the period 1990 – 2012, moves to non-elected or non-accountable activities (Woody Grassland, Terrestrial Wetlands, Waters, Peat extraction and Settlements), are reported as "0" (Table 517), in keeping with the IPCC 2013 KP Supplements, Chapter 2.9.2 (IPCC 2014) (cf. Chapter 11.3.1.1.1).

N_2O emissions from organic soils under cropland management are reported in the agriculture sector, in the sub-category Cultivation of histosols (CRF 3.D.a.6). Direct and indirect N_2O emissions resulting from mineralisation of organic soil substance of mineral soils in the category Cropland remaining as Cropland also have to be reported in the agriculture sector (CRF 3.D.a.5); in Table 517, therefore, they are marked as "IE".

11.5.2.2 Grazing land management

Emissions and removals from land-use changes from grazing land management to other land-use categories are taken into account under Art. 3.3 (afforestation) and Art. 3.4 (grazing land management). With regard to greenhouse-gas emissions and removals on land undergoing land-use changes to non-accountable activities (Woody Grassland, Terrestrial Wetlands, Waters, Peat extraction and Settlements), and to implementation of findings from the various Reviews, the statements made in Chapter 11.3.1.1.1 with regard to cropland management apply in equal measure to grazing land management. For this reason, emissions from land that, as a result of land-use changes in the period 1990 – 2012, moves to non-elected or non-accountable activities (Woody Grassland, Terrestrial Wetlands, Waters, Peat extraction and Settlements), are reported as "0" (Table 518), in keeping with the IPCC 2013 KP Supplements, Chapter 2.10.2 (IPCC 2014) (cf. Chapter 11.3.1.1.1).

N_2O emissions from organic soils under grazing land management are reported in the agricultural sector, in the sub-category Cultivation of histosols (CRF 3.D.a.6).

As Table 518 shows, the emissions in 1990 from grazing land management are dominated by CO_2 from organic soils. The carbon sink in mineral soils, resulting from land-use changes to grazing land management, only slightly offsets the pertinent emissions.

Table 518: Carbon-stock and greenhouse-gas emissions as a result of grazing land management, in the base year 1990

Sub-categories	C-stock changes Biomass [1) [kt C]	C-stock changes Mineral soils [1) [kt C]	CO_2 from organic soils [1) [kt C]	CH_4 from organic soils [2) [kt CH_4]	Direct and indirect N_2O from decomposition of organic material in mineral soils [2) [kt N_2O]	Total [2) 3) [kt CO_2-eq]
Grazing land remaining grazing land	NA	NA	-7,099.66	32.22	NA	26.837.54
Total for LUC to grazing land	-137.50	528.51	-451.14	2.41	0.0005	280.85
Total for LUC from grazing land	0	0	0	0	0	0
Total	-137.50	528.51	-7,550.80	34.63	0.0005	27,118.39

1) Stock change, positive: carbon removal by sink; negative: carbon source

2) GHG emissions, positive: GHG source; negative: GHG sink

3) Not including N_2O emissions from organic soils; they are reported as part of the agricultural sector

11.5.3 Information relating to Forest Management

11.5.3.1 Definition of forest management

As explained above in Chapter 11.5.1, the law requires German forests to be managed properly and sustainably. National provisions on forest management are set forth in the Federal Forest Act (BWaldG). In addition, the Länder have their own Land (state) forest acts in place that further detail the provisions of the Federal Forest Act. A comparison of Germany's national provisions with the relevant international definition shows broad agreement.

International definition pursuant to the Marrakesh Accords[163]*:*

"'Forest management' is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner."

Translation: "'Forest management' is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner."

National definitions pursuant to state forest acts (Landeswaldgesetze - LWaldG):

Pursuant to Art. 1 No. 1 Federal Forest Act (BWaldG), the purpose of the Act is, in particular, "to conserve forest for the sake of its economic value (utility function) and for the sake of its (…) (conservation and recreation function), to increase it, if necessary, and to assure its proper management for the long term". Pursuant to Art. 11 (1) p. 1 BWaldG, forests are to be "managed properly and sustainably, in the framework of their defined purposes." In keeping with the Federal Government's restricted legislative competence in this regard, the Federal Government simply provides a framework that the Länder implement and detail with regard to specific applications (cf. Art. 5 and Art. 11 (1) p. 2 BWaldG). As a result, the Länder define what is to be understood by "proper and sustainable forest management". A compilation of relevant sections of Länder forest acts is provided by Steuk (2010).

The forest-management requirements pursuant to Länder forest acts are comparable to those set forth by international forest legislation. The requirement that forests are to be managed sustainably, with a view to fulfilling ecological (including biological diversity), economic and

[163] Paragraph 1 lit. f of Annex A of Decision 16/CMP.1

social functions[164], is found in all Länder forest acts. In Germany, ecological, economic and social functions are often referred to as "conservation, utility and recreation" functions[165] (cf. Table 519). Where the ecological, economic and social functions that are to be served by management are not referred to explicitly as such in Länder laws, the laws add the phrase "within the framework of its [their] defined purposes"[166]. Forests are thus to be managed sustainably, within the framework of their defined purposes. This orientation is found in Art. 1 BWaldG (purpose of the act), which appears verbatim in every Land forest act. In addition, Art. 1 No. 1 BWaldG sets forth that forests are to be protected especially "in light of their economic value (utility function) and their (...) (conservation and recreation functions)". The aim of protecting economic, ecological and social functions is thus found in all such laws. Furthermore, both the Federal Forest Act and the forest acts of the Länder warrant the sustainability of forest management.

Table 519: Comparison of forest functions pursuant to the Federal Forest Act and the IPCC

Forest functions pursuant to BWaldG	Forest functions pursuant to MA
Utility function	Economic functions
Conservation function	Ecological functions
Recreation function	Social functions

11.5.3.2 Conversion of Natural Forest to Planted Forest

Within the meaning of the Kyoto Protocol, all German forests are defined as part of the Planted Forest (cf. Annex 4A.1, Chapter 4, Volume 4, IPCC (2006a)). In this context, this definition includes all managed forests, plantations, planted stocks and forest areas that have been set aside for protection in keeping with a management plan (cf. Chapter 11.5.1.1). Forest areas not subject to a management concept do not occur in Germany. Also, Germany has no primary forest (or, no primary-forest areas of relevant size) that meet the definition for such forest (Krismann & Hennenberg, 2012).

For the aforementioned reasons, Germany has no conversion of Natural Forest to Planted Forest.

11.5.3.3 Forest Management Reference Levels (FMRL)

Pursuant to resolution 2/CMP.6 (Cancun Agreements), for the second commitment period of the Kyoto Protocol, anthropogenic greenhouse-gas emissions from sources and sinks that result from forest management under Article 3.4 are to be accounted against the Forest Management Reference Levels (FMRL). In each case, the FMRL contains a value that projects the average annual net emissions from forest management, in the second commitment period, from historic data and political decisions.

Pursuant to the KP Supplement, Chapter 2.7.5.2, Box 2.7.3, approach 1a has been selected for the calculation. This approach comprises a modelled projection under a "business-as-usual" scenario. In the process, data from forest inventories are combined with the projected future wood harvest, to make it possible to use the WEHAM model to project future forest management.

For Germany, an FMRL of -22,418 kt CO_2-eq. per year has been reported. The documents submitted in 2011 relative to the FMRL, and the pertinent review report, are provided on the

[164] Cf. Art. 4 No. 1 BayWaldG; Art. 1a LFoG NRW; a similar meaning also is seen in Art. 6 (1) LWaldG RLP; and a similar meaning is seen in Art. 18 (1) in conjunction with Art. 19 (1) p. 2 ThürWaldG.

[165] Cf. Art. 1 No. 1 BWaldG; Art.13 LWaldG BW; Art. 11 (2) No. 1 LWaldG B; Art. 4 (2) LWaldG Bbg; Art.5 (1) BremWaldG, Art. 6 (1) HeFoG; Art. 6 (1) No. 1 LWaldG MV; Art. 11 (1) NWaldLG; Art. 5 (1) LWaldG SH.

[166] Cf. Art. 6 (1) LWaldG Ha; Art. 11 (1) LWaldG SL; Art. 17 SächsWaldG; Art. 4 (1) WaldG LSA; Art. 18 (1) ThürWaldG.

UNFCCC website [167]. Those documents include a description of the methods used to obtain the FMRL.

Figures on wood-harvest records for the period 1999 through 2008 are provided in Chapter 6.4.2.2.1. The wood harvest in the commitment period 2013 through 2020 is described in the submitted document "Submission of information on forest management reference levels by Germany". The further information called for in the FMRL review – including requested information on WEHAM – has been published in the background paper "The German Reference Level for FM" (IPCC, 2014). In addition, information on WEHAM, and the data and assumptions (including wood harvest data) used in connection with it, is also provided in {Schmitz et al. (2016)}, Bösch et al. (2016) and {Rock et al. (2013)}.

11.5.3.4 Technical correction of the FMRL

The IPCC KP Supplements (IPCC et al., 2014a) require a technical correction of the FMRL if methodological changes result in calculation of the time series, if new or corrected historical data become available or if pools are included in current reporting that could not be taken into account in the original FMRL calculation.

With regard to carbon stocks in living biomass, the previous FMRL, which was reported to the UNFCCC Secretariat and the EU in 2011, is based on data of the 2008 Inventory Study and, for the projection, on the forest management scenario of the WEHAM forest development and wood-production model. For the pools dead biomass (litter, dead wood) and soils, and for emissions from fertilisation, drainage and combustion of biomass (forest fires), country-specific emission factors either were not available or were not recorded. Carbon in harvested wood products (HWP) was not accounted for in a manner consistent with decision 2/CMP.7 and the KP Supplement adopted following the submission of the FMRL. Consequently, the reference level used to date does not contain all source categories and other emissions that are reported relative to KP 3.4, pursuant to the current rules for GHG reporting, and that thus are part of the pertinent accounting. Additional recommendations relative to corrections are provided in the "Report of the technical assessment of the FMRL submission of Germany submitted in 2011" (FCCC/TAR/2011/DEU). For this reason, Germany carried out a technical correction of the FMRL in the 2019 submission.

Since the 2019 submission, additional methodological improvements, and data updates, have been carried out that entail changes in time series prior to 2009. For example, an expanded method has been introduced for preparation of the land-use matrix (LUM). For harvested wood products, the activity data (FAO data) for the period as of 1995 have been updated. In addition, in summer 2021 the IPCC carried out a review of the FMRL and the technical correction (KP-LULUCF FM, CP2 checklist for all KP Parties). The recommended changes have been taken into account; they also necessitate a technical correction. All of the pertinent changes are summarised in Table 538. As a result of these developments, a technical correction of the FMRL has been provided in the present 2022 submission.

All of the data derived and listed below are based on results of the 2022 submission.

[167] UNFCCC AWG-KP: Forest management reference levels http://unfccc.int/bodies/awg-kp/items/5896.php

Table 520: Improvements and changes in the greenhouse-gas inventory, since 2011, that necessitate a technical correction of the Forest Management Reference Level

Storage/GHG source	Relevant change	Need for a technical correction
Activity data	Expanded method for derivation of the LUM	Changes in the activity data rows
Living biomass in forest	BWI 2012	New WEHAM-model run, with the data from the 2012 National Forest Inventory (BWI 2012), but with the policies of the period prior to 2009[168]; this necessitates a recalculation of HWP
	New parameters for growth function	
	New biomass functions	
Soil / litter	Forest soil survey (Bodenzustandserhebung (BZE) Wald) (country-specific emission factors)	Adjustment to GHG-inventory methods and factors
Dead wood	BWI 2012 (complete survey; adjusted survey threshold)	
HWP	BWI 2012 (projection of wood harvest)	New run of the WEHAM model
	No wood from deforestation	Methodological specifications from the IPCC KP Supplement not available until 2014
	New available and conversion factors	
Other	minor changes	Minor adjustments possible

For the technical correction, the FMRL for the reported pools and sources was calculated with the methods given in Table 521. In the process, a distinction was made between activity data (AD) and emission factors (EF). For the EF, and in keeping with a conservative estimation approach, either the average value or the trend has been used (cf. also Krug et al. (2011)). The time frame chosen in this connection, 1999-2008, is the same as was used for the preparation of the FMRL; i.e., it has not changed.

Table 521: Methods for the technical correction of the FMRL by pools and sources

Pool / source	Area (AD) / Emission factor (EF)	GHG	Method, FMRL – technical correction (2013-2020)
Mineral soil	AD	C	Change from 2012 carried forward
Organic soil	AD	C / CH_4 / N_2O	Change from 2012 carried forward
Mineral soil	EF	C	Average value, 1999-2008
Organic soil	EF	C	Average value, 1999-2008
Organic soil	EF	CH_4	Average value, 1999-2008
Organic soil	EF	N_2O	Average value, 1999-2008
Above-ground biomass	EF	C	Modelling with WEHAM 2012; run 23
Below-ground biomass	EF	C	Modelling with WEHAM 2012; run 23
Litter	EF	C	Average value, 1999-2008
Dead wood	EF	C	Average value, 1999-2008
Forest fires / wildfires	AD	CO_2 / CH_4 / N_2O	Average value, 1999-2008
Forest fires / wildfires	**EF**	CO2	Trend 1999-2008
Forest fires / wildfires	EF	CH_4	Trend 1999-2008
Forest fires / wildfires	EF	N_2O	Trend 1999-2008
HWP	**AD /EF**	C	Modelling with WoodCarbonMonitor (including WEHAM 2012; run 23)

The resulting emissions projections for the period 2013 through 2020 are summarised in Table 522. Additional details relative to the data and methods used, with regard to pools and sources, are provided in the following sub-chapters.

168 Cf. FCCC/TAR/2011/DEU

Table 522: Emissions projections by pools/sources, for the period from 2013 through 2020

Sub-category / Pool	GHG	Units	2013	2014	2015	2016	2017	2018	2019	2020
Mineral soil	CO_2	kt CO_2-eq.	-15,745	-15,739	-15,733	-15,725	-15,717	-15,709	-15,701	-15.693
Organic soil	CO_2	kt CO_2-eq.	2,494	2,492	2,490	2,485	2,481	2,476	2,471	2,467
Organic soil	CH_4	kt CO_2-eq.	31	31	31	31	31	31	31	31
Organic soil	N_2O	kt CO_2-eq.	331	330	330	329	329	328	328	327
Above-ground biomass	CO_2	kt CO_2-eq.	6,669	6,667	6,664	6,660	6,657	9,833	9,828	9,823
Below-ground biomass	CO_2	kt CO_2-eq.	787	787	787	786	786	502	502	502
Litter	CO_2	kt CO_2-eq.	492	492	491	491	491	491	490	490
Dead wood	CO_2	kt CO_2-eq.	-1,977	-1,976	-1,975	-1,974	-1,973	-1,972	-1,971	-1,970
Forest fires / wildfires	CH_4	kt CO_2-eq.	2	2	2	2	2	2	2	2
Forest fires / wildfires	N_2O	kt CO_2-eq.	1	1	1	1	1	1	1	1
Forest fires / wildfires	CO_2	kt CO_2-eq.	25	25	26	26	26	26	26	26
SOM_mineral soil	N_2O	kt CO_2-eq.	0	0	0	0	0	0	0	0
Mineral soil	N_2O	kt CO_2-eq.	NO	NO	NO	NO	NO	NO	NO	NO
Mineral fertiliser	N_2O	kt CO_2-eq.	NO	NO	NO	NO	NO	NO	NO	NO
Harvested wood products (HWP)	CO_2	kt CO_2-eq.	-12,007	-11,436	-10,963	-10,562	-10,213	-9,903	-8,675	-8,523
Total	All	kt CO_2-eq.	-18,896	-18,324	-17,850	-17,449	-17,101	-13,894	-12,667	-12,518

For the technical correction of the FMRL, the new FMRL has to be calculated. It is obtained as the sum of all emissions for the period 2013-2020, as listed in Table 522, divided by the relevant number of years. The difference between the old and the new FMRL serves as the value for the technical correction. The results are shown in Table 523.

Table 523: Results of the technical correction of the Forest Management Reference Level

	Total, 2013-2020 [kt CO_2-eq.]	Average value, 2013-2020 [kt CO_2-eq.]
FMRL new	-128.699	-16.087
FMRL old	-179.344	-22.418
Technical correction		6.331

AD for mineral and organic soils

The derivation of the applicable areas is described in detail in Chapter 6.3. A distinction is made between the areas with mineral soils and those with organic soils. For the projection of the land areas for the period from 2013 through 2020, it is assumed that the areas will continue to develop in keeping with the changes that have occurred in the last few years. In the report, the area changes for the period 2013-2016 are shown in Table 360 in Chapter 6.3.5. The same annual changes are assumed to apply for the projection period 2013 through 2020.

EF for mineral soils and litter

The carbon stocks in mineral soils and litter are calculated with data from the Forest Soil Inventory (cf. Chapter 6.4.2.4 and Chapter 6.4.2.5). In keeping with the 2022 report, the same EF are used, and thereby an average emission factor for the period 1999 through 2008 is calculated.

EF for organic soils

CO_2, N_2O and CH_4 emissions from organic forest soils are reported. Reporting also covers methane emissions from drainage ditches, as well as carbon losses in connection with dissolved organic carbon (DOC)(cf. also Chapter 6.1.2.2). For the projection for the period 2013 through 2020, in the FMRL framework, the trends for all three greenhouse gases for the period 1999 through 2008 are carried forward.

EF for biomass

The living biomass data are determined for the FMRL with the WEHAM model. On the basis of the National Forest Inventory, the WEHAM forest development and wood production model estimates how forests will develop, in light of a given outset situation, and how much raw wood they can be expected to produce. On that basis, the carbon content in above-ground and below-ground biomass is then estimated (cf. also Chapter 6.4.2.2). The outset data consist of the data from the 2012 National Forest Inventory and, for the management scenarios, the data from 2003 (archive: WEHAM 2012; run 23). This is in keeping with the requirement, set forth by the IPCC 2013 KP Supplement (IPCC et al., 2014a), to the effect that no post-2009 policies be used in the projection. The wood harvest projected via the model run, and the actual wood harvest for the commitment period, are shown in Table 524. As the comparison shows, the wood harvest projected on the basis of the policies prior to 2009 is considerably larger than the actual wood harvest (cf. also Chapter 11.5.3.7). Further information about WEHAM is provided in {Krug et al. (2011)}, (Bösch et al.), {Schmitz et al. (2016)} and {Rock et al. (2013)}.

Table 524: Wood harvest projected with WEHAM (potential quantity of raw timber), and actual wood harvest in the commitment period 2013-2020

Year	Potential quantity of raw timber, WEHAM [m^3]	Actual wood harvest [m^3]
2013	111,725,742	88,437,913
2014	111,725,742	90,311,720
2015	111,725,742	92,359,096
2016	111,725,742	86,775,816
2017	111,725,742	88,860,454
2018	109,617,402	102,818,969
2019	109,617,402	109,460,301
2020	109,617,402	122,413,960

EF for litter

In the Yasso model, litter data are estimated together with mineral soils data, as described in the sub-chapter on mineral soils. Results for litter are not given separately; they are given together with results for mineral soils. For this reason, notation key IE (included elsewhere) has been entered in Table 522.

EF for dead wood

Carbon stocks in dead wood are calculated on the basis of the data of the National Forest Inventories (cf. Chapter 6.4.2.3). On this basis, for the projection as of 2013 it is assumed that the dead-wood C stocks do not change significantly, and an average emission factor for the period 1999 through 2008 is calculated.

AD and EF for forest fires

The derivation of forest-fire emissions is described in Chapter 6.4.2.7.5. As a result of Germany's prevailing climate conditions, and of the country's measures to prevent forest fires, forest fires tend to occur rather rarely. It is assumed that no basic changes in forest-fire events will occur in future. For this reason, the following are used for the period as of 2013: a) the average forest-fire burn area of the period 1999 through 2008, and b) for the emission factors of the greenhouse gases CO_2, N_2O and CH_4, the trend of the period 1999 through 2008.

AD and EF for harvested wood products

The reference value for the carbon stocks in harvested wood products is calculated with the WoodCarbonMonitor computer model. Taking account of various outset data items and various methods, the model calculates the carbon stocks in harvested wood products for the period 2013 through 2020. Logging statistics are a key set of input data. They are also derived with WEHAM (cf. the sub-chapter on biomass). A comprehensive description of the model used in provided in Rüter (2017).

11.5.3.5 Determination of the FM CAP

The FM CAP is determined in keeping with DEC 6/CMP.9, paragraph 12. This means that the relevant calculation is based on those base-year emissions that were reported in the annual report, on the national greenhouse-gas inventory, that was due on 15 April 2015, and that the calculation is adopted for the second commitment period (351,007.813 kt CO_2 eq.).

11.5.3.6 Information pertaining to accounting pursuant to the Kyoto Protocol

A comparison of the emissions given in the Forest Management Reverence Level (FMRL) with those reported in greenhouse-gas reporting (GHG) shows that removals are smaller in the FMRL, for all years, than in the reporting (cf. Table 525). In accounting, this leads to credits. This is due primarily to the projected biomass. The political framework prior to 2009 provided for a large wood harvest that was tied to a strong demand for wood. This framework has been adopted in the WEHAM model and used for model projections into the future. The results show a carbon loss in biomass. In actuality, the political framework has changed, however. This has led to reduced wood harvesting, and carbon has been stored in the biomass. Since the quantities of wood that are removed have an impact on quantities of harvested wood products, the FMRL and the reporting also differ in terms of the emissions they show. On the other hand, the effect is a contrary one – the FMRL shows greater carbon storage than the reporting does. Relatively large differences are also seen in the dead wood pool. In the FMRL, a smaller quantity of dead wood is assumed, as a result of high utilisation levels and nearly complete wood removal. With regard to all other pools, the FMRL and the reporting either do not differ, or differ only very slightly.

Table 525: Comparison of emissions [kt CO2-eq.] as shown in the Forest Management Reverence Level (FMRL) and in greenhouse-gas reporting (GHG), broken down by pools, and for the commitment period 2013-2020

	Sub-category / Pool	2013	2014	2015	2016	2017	2018	2019	2020
FMRL	Mineral soil	-15,745	-15,739	-15,733	-15,725	-15,717	-15,709	-15,701	-15,693
GHG	Mineral soil	-15,745	-15,739	-15,733	-15,725	-15,717	-15,709	-15,701	-15,693
FMRL	Organic soil	2,856	2,854	2,851	2,846	2,841	2,835	2,830	2,825
GHG	Organic soil	2,856	2,854	2,851	2,846	2,841	2,835	2,830	2,825
FMRL	Biomass	7,456	7,454	7,451	7,447	7,443	10,336	10,330	10,325
GHG	Biomass	-46,572	-45,610	-44,561	-47,347	-46,273	-39,232	-35,874	-29,351
FMRL	Litter	492	492	491	491	491	491	490	490
GHG	Litter	492	492	491	491	491	491	490	490
FMRL	Dead wood	-1,977	-1,976	-1,975	-1,974	-1,973	-1,972	-1,971	-1,970
GHG	Dead wood	-3,733	-3,732	-3,731	-3,729	-3,727	-3,725	-3,723	-3,720
FMRL	Wildfires	29	29	29	29	29	29	29	29
GHG	Wildfires[169]	2	1	4	2	3	19	22	3
FMRL	Harvested wood products	-12,007	-11,436	-10,963	-10,562	-10,213	-9,903	-8,675	-8,523
GHG	Harvested wood products	-2,712	-3,289	-2,229	-2,303	-3,138	-8,651	-6,067	-8,651
FMRL	Total	-18,896	-18,324	-17,850	-17,449	-17,101	-13,894	-12,667	-12,518
GHG	Total	-65,411	-65,023	-62,904	-65,762	-65,517	-63,953	-58,001	-54,095

[169] Not including CO_2 emissions; they are included in the biomass

11.5.3.7 Information about natural disturbances under Article 3.4

As explained in Chapter 11.1.2, Germany has not selected the natural disturbances option. Natural disturbances that occur are not considered separately; instead, they enter into the change calculations for the relevant pools.

11.5.3.8 Information about harvested wood products under Article 3.4

As described in detail in Chapter 6.10, the emissions contribution made by harvested wood products in Germany, in terms of sources and removals into sinks for greenhouse gases, was determined with the WoodCarbonMonitor model (Rüter), in keeping with the specifications of the IPCC KP Supplement (IPCC et al., 2014a).

First, the availability of activity data, i.e. data on the production of and foreign trade in harvested wood products, was reviewed (cf. Chapter 2.8.1.1, IPCC et al. (2014a)), and the product fractions originating from domestic harvest were calculated. Then, in a second step (cf. Chapter 2.8.1.2, IPCC et al. (2014a)), the carbon contained in those products was allocated, using the procedure described in Chapter 6.10.2.1, to the forest activities listed in the Kyoto Protocol under Article 3, paragraphs 3 and 4. For Germany, the wood harvest can be fully assigned to the two activities forest management and deforestation. In keeping with the provisions of the IPCC 2013 KP Supplement (IPCC et al., 2014a), harvested wood products from deforestation are taken into account on the basis of instantaneous oxidation. As a result, the annual wood-harvest fractions from the activity forest management fFM(i) can be calculated from the inventory information available for Germany and from Equation 2.8.3 (IPCC et al., 2014a).

Further information, and details on the emission factors used and on the calculation carried out for Germany, in keeping with the provisions of the IPCC 2013 KP Supplement (IPCC et al., 2014a), are provided in Chapters 6.10.2.2 and 0.

Pursuant to paragraph 2(g) (letters iii and iv) of Annex II of resolution 2/CMP.8, it is determined that the contribution of carbon storage in harvested wood products was taken into account, in the first commitment period of the Kyoto Protocol, and in accordance with the IPCC 2003 GPG (IPCC), as an "instantaneous oxidation" and thus was neither reported nor accounted (cf. also in this regard the remarks made in Chapter 2.8.2 (IPCC et al., 2014a)).

For this reason, no contribution of harvested wood products to greenhouse-gas emissions and removals by sinks has been taken into account prior to the beginning of the second commitment period. Pursuant to Chapter 2.8.3 of the KP Supplement (IPCC et al., 2014a), the annual initial value of carbon storage was calculated, for the first time, for the 2013 report year, pursuant to the IPCC Guidelines (Equation 2.8.6) with t0 = 1990 (cf. Chapter 6.10.2.3).

11.6 Other information

11.6.1 Key-category analysis for Article 3.3 activities and any elected activities under Article 3.4

In connection with analysis for the UNFCCC inventory, key-category analysis was also carried out for activities pursuant to Article 3.3 and for selected activities pursuant to 3.4. The results are presented in tabular form in Chapter 1.5.2 of this report. The procedures, foundations and methods used to obtain those results are described in the same chapter.

11.6.2 Managed wetlands pursuant to (EU)2018/841

The data presented below (Table 526) were reported in the framework of reporting on managed wetlands pursuant to EU Regulation (EU) 2018/841 (in keeping with Article 7 (4)).

Table 526 For 2020 overall, the table shows an emissions decrease with respect to the reference period, since the emissions increase in the categories "managed wetlands" and "from managed wetlands" is more than offset by the emissions decrease in the sub-category "to managed wetlands."

Table 526: CO_2, N_2O and CH_4 emissions [kt CO_2-eq.] resulting from wetlands management in 2020, compiled pursuant to (EU) 2018/841, Art. 7 (4)

Managed wetlands (remaining category)					
Sub-category / Pool	GHG	Units	Reference period 2005-2009 (1)	Report year 2020 (2)	Balance (2) - (1)
Mineral soil	CO_2	kt CO_2-eq.	-0.15	-0.4	-0.25
Organic soil	CO_2	kt CO_2-eq.	1,422.77	1,398.37	-24.4
Organic soil	CH_4	kt CO_2-eq.	291.37	316.76	25.39
Organic soil	N_2O	kt CO_2-eq.	31.12	28.67	-2.45
Above-ground biomass	CO_2	kt CO_2-eq.	1.86	-11.9	-13.76
Below-ground biomass	CO_2	kt CO_2-eq.	0.51	-5.75	-6.26
SOM mineral soils, indirect	N_2O	kt CO_2-eq.	0	0	0
SOM mineral soils, direct	N_2O	kt CO_2-eq.	0	0	0
Peat off-site	CO_2	kt CO_2-eq.	2,181.94	2,212.98	31.04
∑	**CO_2**	**kt CO_2-eq.**	**3,606.93**	**3,593.29**	**-13.64**
∑	**CH_4**	**kt CO_2-eq.**	**291.37**	**316.76**	**25.39**
∑	**N_2O**	**kt CO_2-eq.**	**31.12**	**28.67**	**-2.45**
Total	**∑**	**kt CO_2-eq.**	**3,929.41**	**3,938.72**	**9.31**
to managed wetlands					
Sub-category / Pool	**GHG**	**Units**	**2005-2009 (1)**	**2020 (2)**	**(2) - (1)**
Mineral soil	CO_2	kt CO_2-eq.	-5.07	-5.59	-0.51
Organic soil	CO_2	kt CO_2-eq.	189.50	202.77	13.27
Organic soil	CH_4	kt CO_2-eq.	53.16	93.58	40.42
Organic soil	N_2O	kt CO_2-eq.	3.09	3.80	0.71
Above-ground biomass	CO_2	kt CO_2-eq.	222.32	72.25	-150.06
Below-ground biomass	CO_2	kt CO_2-eq.	80.36	36.51	-43.85
SOM mineral soils, indirect	N_2O	kt CO_2-eq.	0.00	0.00	0.00
SOM mineral soils, direct	N_2O	kt CO_2-eq.	0.00	0.00	0.00
∑	CO_2	kt CO_2-eq.	487.10	305.95	-181.16
∑	CH_4	kt CO_2-eq.	53.16	93.58	40.42
∑	N_2O	kt CO_2-eq.	3.09	3.80	0.71
Total	**∑**	**kt CO_2-eq.**	**543.35**	**403.33**	**-140.03**
from managed wetlands					
Sub-category / Pool	**GHG**	**Units**	**2005-2009 (1)**	**2020 (2)**	**(2) - (1)**
Mineral soil	CO_2	kt CO_2-eq.	4.07	4.25	0.18
Organic soil	CO_2	kt CO_2-eq.	24.19	40.76	16.56
Organic soil	CH_4	kt CO_2-eq.	1.55	1.33	-0.22
Organic soil	N_2O	kt CO_2-eq.	2.38	3.74	1.36
Above-ground biomass	CO_2	kt CO_2-eq.	-86.77	-69.78	16.99
Below-ground biomass	CO_2	kt CO_2-eq.	-30.56	-20.51	10.06
SOM mineral soils, indirect	N_2O	kt CO_2-eq.	0.09	0.09	0.00
SOM mineral soils, direct	N_2O	kt CO_2-eq.	0.39	0.40	0.00
∑	CO_2	kt CO_2-eq.	-89.07	-45.28	43.79
∑	CH_4	kt CO_2-eq.	1.55	1.33	-0.22
∑	N_2O	kt CO_2-eq.	2.87	4.23	1.36
Total	**∑**	**kt CO_2-eq.**	**-84.65**	**-39.72**	**44.93**

11.7 Information relative to Article 6 (JI & CDM projects / management of ERU)

Pursuant to Section 5 (1) Sentence 1 of the Project Mechanisms Act[170] (Projekt-Mechanismen-Gesetz; ProMechG), no projects in the area of LULUCF may be approved that are to take place in Germany.

[170] ProMechG http://www.gesetze-im-internet.de/promechg/__5.html

The impermissability results from Section 5 in conjunction with the concept of emissions reduction pursuant to Art. 2 No. 5 ProMechG, which states that "emission reduction" "means the reduction of emissions from sources; this shall not include the increased removal of greenhouse gases by sinks in the areas of land use, changes in land use and forestry." Furthermore, JI projects are hindered in that use of JI in Germany ended at the end of 2012; cf. Section 5 (3) ProMechG.

12 Information relative to accounting for Kyoto units

12.1 Background information

Chapter 11 and 13 include information on the German emission trading registry. The accounting on Kyoto units and the public availability of information is described in chapter 11. Any significant changes in the national registry are reported in chapter 13.

12.2 Summary of information reported in the SEF tables

According to decision 15/CMP.1, annex, part 1, section E each Party must include information on its aggregate holdings and transactions of Kyoto units in its annual report. The information has to be reported in the Standard Electronic Format (SEF), which is an agreed format, embodied in a special report, for reporting on Kyoto units.

The SEF for 2021 was generated on 10 January 2022 with the Union Registry software in version 13.5.2, provided by the EU commission on 1 December 2021 and the SEF application version 3.8.3, provided by the Secretariat on 26 January 2018. The German SEF for 2021 contains the information required in paragraph 11 of the annex to decision 15/CMP.1 and adheres to the guidelines of the SEF. The SEF has been submitted to the UNFCCC Secretariat electronically.

12.3 Discrepancies and Notifications

15/CMP.1 annex I.E paragraph 12 List of discrepant transactions	No discrepant transactions occurred in 2021.
15/CMP.1 annex I.E paragraph 13 and 14 List of CDM notifications	No CDM notifications occurred in 2021.
15/CMP.1 annex I.E paragraph 15 List of non-replacements	No non-replacements occurred in 2021.
15/CMP.1 annex I.E paragraph 16 List of invalid units	No invalid units exist as at 31 December 2021.
15/CMP.1 annex I.E paragraph 17 Actions and changes to address discrepancies	No actions were taken or changes made to address discrepancies for the period under review.

12.4 Publicly accessible information

13/CMP.1 annex II paragraph 45 Account information	In line with the data protection requirements of Regulation (EC) No 45/2001 and the GDPR Regulation (EU) 2016/679 and in accordance with Article 77 of Commission Regulation (EU) No 2019/1122, the information on account representatives, account holdings, account numbers, all transactions made and carbon unit identifiers, held in the EUTL, the Union Registry and any other KP registry (required by paragraph 45) is considered confidential. The most up-to-date account information may be accessed via: **https://unionregistry.ec.europa.eu/euregistry/DE/public/reports/publicReports.xhtml**
13/CMP.1 annex II paragraph 46 Joint implemention project information	The complete documentation of the JI projects is presented in the German JI project database which is accessible at the following URL. The database also contains already registered but not yet approved JI projects. https://jicdm.dehst.de/promechg/pages/project1.aspx A complete list of ERU issuance years is available at: https://www.dehst.de/SharedDocs/downloads/EN/project-mechanisms/ERU_table.pdf In 2021, no ERU were converted from AAU and no ERU converted from RMU were issued.
13/CMP.1 annex II paragraph 47 Unit holding and transaction information	The information requested in (a), (d), (f) and (l) is classifed as confidential due to Article 77 of Commission Regulation (EU) No 2019/1122 as well as national data protection law and therefore not publicly available. Transactions of units within the most recent five year period are also classified as confidential, therefore the transactions provided are only those completed more than five years in the past. The information requested in (b), (c), (e), (g), (h), (i), (j) and (k) is publicly available at https://unionregistry.ec.europa.eu/euregistry/DE/public/reports/publicReports.xhtml .
13/CMP.1 annex II paragraph 48 Authorized legal entities information	The following legal entities are authorized by the Member State to hold Kyoto units:

	Legal entities authorised by Germany to hold units
AAU	Federal Government only
ERU	Each account holder
CER	Each account holder
RMU	Federal Government only
tCER	Federal Government only
lCER	Federal Government only

12.5 Calculation of the Commitment Period Reserve

Germany's Commitment Period Reserve (CPR) is calculated as 90 percent of Germany's assigned amount (3,592,699,888 tonnes CO_2 equivalent) calculated pursuant to Article 3 paragraphs 7 and 8 of the Kyoto Protocol. The initial CPR of the current commitment period did not change and is still 3,233,429,900 tonnes CO_2 equivalent (or AAU).

In accordance to Article 88 of Commission Regulation (EU) No 2019/1122 in line with Article 4 paragraph 4 Commission Regulation (EU) No 389/2013 the Union registry has to prepare for keeping the CPR. If a transfer proposal would result in an infringement of the CPR, the registry should reject it internally.

The German registry did not violate the CPR during the reported year.

12.6 KP-LULUCF accounting

The Kyoto Protocol accounting under the second commitment period started with the entering into force of the Doha amendment. Germany chose to account over the entire commitment period for emissions and removals from activities under Article 3, paragraphs 3 and 4, of the Kyoto Protocol. Table 527 contains data as submitted under the Kyoto Protocol. More information is given in NIR chapter 11 and the respective NIR chapters of the LULUCF sector.

Table 527: Information on accounting for activities under Articles 3.3 and 3.4 of the Kyoto Protocol

GREENHOUSE GAS SOURCE AND SINK ACTIVITIES	NET EMISSIONS/REMOVALS											
	Base Year	2013	2014	2015	2016	2017	2018	2019	2020	Total	Accounting parameters	Accounting quantity
	(kt CO2 eq)											
A. Article 3.3 activities												
A.1. Afforestation/reforestation		-621.69	-684.72	-747.93	-379.32	-467.04	-531.62	-622.84	-725.09	-4,780.25		-4,780.25
A.2. Deforestation		623.22	669.06	716.20	1,171.56	1,217.06	1,256.09	1,262.57	1,274.14	8,189.90		8,189.90
B. Article 3.4 activities												
B.1. Forest management										-500,721.28		-372,022.61
Net emissions/removals		-65,412.57	-65,023.52	-62,907.79	-65,764.11	-65,519.90	-63,972.15	-58,022.80	-54,098.45	-500,721.28		
Forest management reference level (FMRL)											-22,418.00	
Technical corrections to FMRL											6,330.67	
Forest management cap											351,007.81	-351.007.81
B.2. Cropland management	14,141.85	18,165.94	18,168.11	18,521.90	17,785.30	17,454.87	17,320.19	16,906.17	16,551.80	140,874.29		27,739.50
B.3. Grazing Land Management (GM)	27,118.39	23,154.96	22,930.67	21,968.59	22,231.26	21,973.40	21,277.58	20,958.23	20,465.60	174,960.29		-41,986.82

13 Information on changes in the national system

Following the 2016 In-Country Review, the institutional consolidation of the National System, pursuant to the requirements for the 2nd commitment period of the Kyoto Protocol, as set forth in the Revised UNFCC Reporting Guidelines, and in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, may be considered completed. The emphasis in the present reporting period was thus on safeguarding existing data streams.

In July 2018, the Wirtschaftsvereinigung Stahl German steel industry association informed the Single National Entity that it would be unable to provide data for 2017 on the basis of the cooperation agreement in force. The Single National Entity and the Federal Ministry for Economic Affairs and Energy (BMWi) thereupon took measures to restore the relevant data stream.

In early summer 2019, Wirtschaftsvereinigung Stahl again provided data – in this case, for the years 2017 and 2018 – to the Single National Entity. This made it possible to close the previous year's data gap in source categories 1.A.2 and 2.C.1.
No other changes in the institutionalisation of the National System were made in 2019 and 2020.

14 Information on changes in the national registries

The following changes to the national registry of Germany have occurred in 2021. Note that the 2021 SIAR confirms that previous recommendations have been implemented and included in the annual report.

15/CMP.1 annex II.E paragraph 32.(a) Change of name or contact	No change in the name or digital contact information of the registry administrator occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(b) Change regarding cooperation arrangement	There was a change in the cooperation arrangement occurred during the reported period as the United Kingdom of Great Britain and Northern Ireland no longer operate their registry in a consolidated manner within the Consolidated System of EU registries, CS EUR.
15/CMP.1 annex II.E paragraph 32.(c) Change to database structure or the capacity of national registry	There have been 6 new EUCR releases (versions 12.4, 13.0.2, 13.2.1, 13.3.3 , 13.5.1 and 13.5.2) after version 11.5 (the production version at the time of the last Chapter 14 submission). No changes were applied to the database, whose model is provided in Annex A. No change was required to the application backup plan or to the disaster recovery plan. No change to the capacity of the national registry occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards	The changes that have been introduced with versions 12.4, 13.0.2, 13.2.1, 13.3.3, 13.5.1 and 13.5.2 compared with version 11.5 of the national registry are presented in Annex B. It is to be noted that each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and are carried out prior to the relevant major release of the version to Production (see Annex B). No other change in the registry's conformance to the technical standards occurred for the reported period.
15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures	No change of discrepancies procedures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(f) Change regarding security	No changes regarding security occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(g)	No change to the list of publicly available information occurred during the reporting period.

Change to list of publicly available information	
15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address	No change to the registry internet address during the reported period.
15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures	No change of data integrity measures occurred during the reporting period.
15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results	No change during the reported period.
1/CMP.8 paragraph 23 PPSR account	The PPSR account was opened on 6.10.2020 in the Union Registry.
Annual Review report Previous Expert Review Team recommendations	The last available report (FCCC/ARR/2020/DEU published 29.4.2021) recommends in G.3, that the value used for the CPR should be consistent with the value agreed in the report to facilitate the calculation of the assigned amount (FCCC/IRR/2016/DEU). This has been addressed in 12.5.

15 Information regarding minimisation of negative impacts pursuant to Article 3 (14)

Most of the measures that would be carried out in Germany would not be expected to have direct effects on developing countries. In the case of other measures, the expected effects are largely considered to be positive. Such effects, for example, would include establishment of technical and administrative structures for climate protection.

Almost all of the possible indirect effects are also considered to be positive. Such effects would include beneficial impacts on energy supplies and prices in co-operating countries. Detailed descriptions of the individual measures were provided in the 2016 NIR. The areas covered by the measures include promotion of use of biofuels, reduction of subsidies for hard coal, policies and measures at the EU level – especially EU emissions trading – and support for developing countries in energy-supply diversification. To date, no changes have been made with respect to these reported measures.

16 Other information

This chapter is currently not required.

17 Annex 1: Key categories within the German greenhouse-gas inventory

Pursuant to the *2006 IPCC Guidelines*, the parties to the UN Framework Convention on Climate Change and to the Kyoto Protocol are required to calculate and publish emissions data annually.

These emissions inventories must be readily comprehensible (transparency); must be calculated in a consistent manner in the time series since 1990 (consistency); must be evaluated uniformly at the international level via application of the prescribed calculation methods (comparability); must contain all the relevant emission sources and sinks in the reporting country (completeness); must be evaluated with regard to error; and must undergo ongoing internal and external quality management (accuracy).

To facilitate concentrating the many and detailed activities and resources required for this purpose on the inventory's principal categories, the IPCC has introduced the term "key category." Key categories are categories which are highlighted in the national inventory system because their emissions have a significant influence on total emissions of direct greenhouse gases, either in terms of absolute emissions, or as a contribution to the emissions trend over time, or in both ways.

Chapter 4 of the 2006 IPCC Guidelines describes the methods to be applied for identifying key categories. These methods include inventory analysis for one year (Approach 1, Level Assessment), time-series analysis of inventory data (Approach 1, Trend Assessment), detailed analysis of inventory data with error evaluation (Approach 2, Trend Assessment with consideration of uncertainties) and assessment of qualitative criteria (pursuant to Chapter 4.3.3 of 2006 IPCC GL, Vol. 4, Ch. 1)

Approach 1 analyses must always be carried out using two procedures. In a first procedure, only emissions from sources are evaluated, and storage in sinks is not considered. In a second procedure, emissions storage in sinks is then included (without any consideration of whether it is positive or negative). As would be expected, the two results differ. Pursuant to the 2006 IPCC GL, both results must be taken into account in identification of key categories.

For identified key categories, the Parties are then required to use highly detailed calculation methods (Tier 2 or higher; the relevant methods are also specified in the 2006 IPCC GL). Should direct use of such methods prove impossible, for whatever reason (e.g. data are not available for the required input variables, etc.), Parties are required to prove that the methods applied nationally achieve at least a comparable degree of accuracy in the calculation result. Such proof, as well as the key-category analysis performed overall, must be outlined in the national inventory report to be prepared annually.

17.1 Description of the methods for identifying key categories

The results of key-category analysis via the two Approach 1 procedures (Level and Trend), the Approach 2 procedure and assessment in terms of qualitative criteria, are presented in Table 6 in Chapter 1.5. In this context, we call attention to the description of the underlying methods in the *2006 IPCC GL* (IPCC (2006a): Vol. 1).

17.1.1 Approach 1 procedures

Level analysis has the purpose of identifying those source categories responsible for 95 % of total national emissions (as CO_2-equivalent emissions), in the Kyoto Protocol's base year and in the current year; those sources are then defined as key categories (●). Calculations were performed using formula 4.1 from the 2006 IPCC Guidelines (IPCC (2006a): Vol. 1).

Trend analysis identifies as key categories (●) those categories which have made an especially significant contribution to changes in total GHG emissions in the most recent year, in terms of the development of their contribution since the base year. In this respect, it is irrelevant whether such changes have led to a reduction or an increase in total emissions. Calculations were performed using formula 4.2 from the 2006 IPCC Guidelines (IPCC (2006a): Vol. 1).

The following table presents a complete list of all of the sub-categories covered by the analysis.

Table 528: Key categories for Germany pursuant to the Approach 1 method (complete list)

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2020	Level 2020 + LULUCF	Trend 2020	Trend 2020 + LULUCF	KCA decision
1 A 1 a, Public Electricity and Heat Production	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 1 a, Public Electricity and Heat Production		CH_4	-	-	-	-	●	●	●	●	L/T
1 A 1 a, Public Electricity and Heat Production		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 1 b, Petroleum Refining	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 1 b, Petroleum Refining		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 1 b, Petroleum Refining		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 1 c, Manufacture of Solid Fuels and Other Energy	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 1 c, Manufacture of Solid Fuels and Other Energy		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 1 c, Manufacture of Solid Fuels and Other Energy		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 2 a, Iron and steel	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 2 a, Iron and steel		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 2 a, Iron and steel		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 2 b, Non-ferrous metals	fossil fuels	CO_2	-	-	-	-	-	-	-	-	-/-
1 A 2 b, Non-ferrous metals		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 2 b, Non-ferrous metals		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 2 d, Pulp, Paper and Print	fossil fuels	CO_2	-	-	-	-	-	-	-	-	-/-
1 A 2 d, Pulp, Paper and Print		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 2 d, Pulp, Paper and Print		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 2 e, Food Processing, Beverages and Tobacco	fossil fuels	CO_2	-	-	-	-	-	-	●	●	-/T
1 A 2 e, Food Processing, Beverages and Tobacco		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 2 e, Food Processing, Beverages and Tobacco		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 2 f, Non-Metallic Minerals	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 2 f, Non-Metallic Minerals		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 2 f, Non-Metallic Minerals		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 2 g, Other	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 2 g, Other		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 2 g, Other		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 3 a, Domestic Aviation	fossil fuels	CO_2	-	-	-	-	-	-	-	-	-/-
1 A 3 a, Domestic Aviation		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 3 a, Domestic Aviation		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 3 b, Road Transport	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 3 b, Road Transport		CH_4	-	-	-	-	-	-	●	-	-/T
1 A 3 b, Road Transport		N_2O	-	-	-	-	-	-	●	●	-/T

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2020	Level 2020 + LULUCF	Trend 2020	Trend 2020 + LULUCF	KCA decision
1 A 3 c, Railways	fossil fuels	CO_2	●	●	●	●	-	-	●	●	L/T
1 A 3 c, Railways		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 3 c, Railways		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 3 d, Domestic Navigation	fossil fuels	CO_2	-	●	-	●	-	-	-	-	L/-
1 A 3 d, Domestic Navigation		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 3 d, Domestic Navigation		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 3 e, Other Transportation	fossil fuels	CO_2	-	-	-	-	-	-	-	-	-/-
1 A 3 e, Other Transportation		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 3 e, Other Transportation		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 4 a, Commercial/Institutional	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 4 a, Commercial/Institutional		CH_4	-	-	-	-	-	-	●	●	-/T
1 A 4 a, Commercial/Institutional		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 4 b, Residential	fossil fuels	CO_2	●	●	●	●	●	●	●	●	L/T
1 A 4 b, Residential		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 4 b, Residential		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 4 c, Agriculture/Forestry/Fishing	fossil fuels	CO_2	●	●	●	●	●	●	-	-	L/-
1 A 4 c, Agriculture/Forestry/Fishing		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 4 c, Agriculture/Forestry/Fishing		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 5, Other: Military	fossil fuels	CO_2	●	●	●	●	-	-	●	●	L/T
1 A 5, Other: Military		CH_4	-	-	-	-	-	-	-	-	-/-
1 A 5, Other: Military		N_2O	-	-	-	-	-	-	-	-	-/-
1 B 1, Solid Fuels	fossil fuels	CO_2	-	-	-	-	-	-	-	-	-/-
1 B 1, Solid Fuels		CH_4	●	●	●	●	-	-	●	●	L/T
1 B 2 a, Oil		CO_2	-	-	-	-	-	-	-	-	-/-
1 B 2 a, Oil		CH_4	-	-	-	-	-	-	-	-	-/-
1 B 2 a, Oil		N_2O	-	-	-	-	-	-	-	-	-/-
1 B 2 b, Natural Gas		CO_2	-	-	-	-	-	-	-	-	-/-
1 B 2 b, Natural Gas		CH_4	●	●	●	●	●	●	-	-	L/-
1 B 2 c, Venting and Flaring		CO_2	-	-	-	-	-	-	-	-	-/-
1 B 2 c, Venting and Flaring		CH_4	-	-	-	-	-	-	-	-	-/-
1 B 2 c, Venting and Flaring		N_2O	-	-	-	-	-	-	-	-	-/-
2 A 1, Cement Production		CO_2	●	●	●	●	●	●	●	●	L/T
2 A 2, Lime Production		CO_2	●	●	●	●	●	●	●	●	L/T
2 A 3, Glass Production		CO_2	-	-	-	-	-	-	-	-	-/-
2 A 4, Other Process Uses of Carbonates		CO_2	-	-	-	-	-	-	-	-	-/-
2 B 1, Ammonia Production		CO_2	●	●	●	●	●	●	-	●	L/T
2 B 2, Nitric Acid Production		N_2O	●	●	●	●	-	-	●	●	L/T
2 B 3, Adipic Acid Production		N_2O	●	●	●	●	-	-	●	●	L/T
2 B 5, Carbide Production		CO_2	-	-	-	-	-	-	-	-	-/-
2 B 7, Soda Ash Production		CO_2	-	-	-	-	-	-	-	-	-/-
2 B 8, Petrochemical and Carbon Black Production		CO_2	-	-	-	-	-	-	-	-	-/-
2 B 8, Petrochemical and Carbon Black Production		CH_4	-	-	-	-	-	-	-	-	-/-

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2020	Level 2020 + LULUCF	Trend 2020	Trend 2020 + LULUCF	KCA decision
2 B 9 a, By-product Emissions		HFC-23	●	●	●	●	-	-	●	●	L/T
2 B 9 b, Fugitive Emissions		SF_6	-	-	-	-	-	-	-	-	-/-
2 B 9 b, Fugitive Emissions		HFC-134a	-	-	-	-	-	-	-	-	-/-
2 B 9 b, Fugitive Emissions		HFC-227ea	-	-	-	-	-	-	-	-	-/-
2 B 9 b, Fugitive Emissions		CF_4	-	-	-	-	-	-	-	-	-/-
2 B 10, Other		CH_4	-	-	-	-	-	-	-	-	-/-
2 B 10, Other		N_2O	-	-	-	-	-	-	-	-	-/-
2 C 1, Iron and Steel Production		CO_2	●	●	●	●	●	●	●	●	L/T
2 C 1, Iron and Steel Production		CH_4	-	-	-	-	-	-	-	-	-/-
2 C 1, Iron and Steel Production		N_2O	-	-	-	-	-	-	-	-	-/-
2 C 2, Ferroalloys Production		CO_2	-	-	-	-	-	-	-	-	-/-
2 C 2, Ferroalloys Production		CH_4	-	-	-	-	-	-	-	-	-/-
2 C 3, Aluminium Production		CO_2	-	-	-	-	-	-	-	-	-/-
2 C 3, Aluminium Production		SF_6	-	-	-	-	-	-	-	-	-/-
2 C 3, Aluminium Production		CF_4	-	-	-	-	-	-	●	●	-/T
2 C 3, Aluminium Production		C_2F_6	-	-	-	-	-	-	-	-	-/-
2 C 4, Magnesium Production		SF_6	-	-	-	-	-	-	-	-	-/-
2 C 4, Magnesium Production		HFC-134a	-	-	-	-	-	-	-	-	-/-
2 C 5, Lead Production		CO_2	-	-	-	-	-	-	-	-	-/-
2 C 6, Zinc Production		CO_2	-	-	-	-	-	-	-	-	-/-
2 D 1, Lubricant Use		CO_2	-	-	-	-	-	-	-	-	-/-
2 D 2, Paraffin Wax Use		CO_2	-	-	-	-	-	-	-	-	-/-
2 D 2, Paraffin Wax Use		N_2O	-	-	-	-	-	-	-	-	-/-
2 D 3, Other		CO_2	-	-	-	-	-	-	-	-	-/-
2 E, Electronics Industry		SF_6	-	-	-	-	-	-	-	-	-/-
2 E, Electronics Industry		NF_3	-	-	-	-	-	-	-	-	-/-
2 E, Electronics Industry		HFC-23	-	-	-	-	-	-	-	-	-/-
2 E, Electronics Industry		HFC-32	-	-	-	-	-	-	-	-	-/-
2 E, Electronics Industry		CF_4	-	-	-	-	-	-	-	-	-/-
2 E, Electronics Industry		C_2F_6	-	-	-	-	-	-	-	-	-/-
2 E, Electronics Industry		C_3F_8	-	-	-	-	-	-	-	-	-/-
2 E, Electronics Industry		$c\text{-}C_4F_8$	-	-	-	-	-	-	-	-	-/-
2 E, Electronics Industry		C_6F_{14}	-	-	-	-	-	-	-	-	-/-

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2020	Level 2020 + LULUCF	Trend 2020	Trend 2020 + LULUCF	KCA decision
2 F, Product Uses as Substitutes for ODS		HFC-23	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		HFC-32	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		HFC-43-10mee	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		HFC-125	-	-	-	-	●	●	●	●	L/T
2 F, Product Uses as Substitutes for ODS		HFC-134a	-	-	-	-	●	●	●	●	L/T
2 F, Product Uses as Substitutes for ODS		HFC-143a	-	-	-	-	-	-	●	●	-/T
2 F, Product Uses as Substitutes for ODS		HFC-152a	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		HFC-227ea	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		HFC-236fa	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		HFC-245fa	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		HFC-365mfc	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		C_2F_6	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		C_3F_8	-	-	-	-	-	-	-	-	-/-
2 F, Product Uses as Substitutes for ODS		C_6F_{14}	-	-	-	-	-	-	-	-	-/-
2 G, Other Product Manufacture and Use		CH_4	-	-	-	-	-	-	-	-	-/-
2 G, Other Product Manufacture and Use		N_2O	-	-	-	-	-	-	●	●	-/T
2 G, Other Product Manufacture and Use		SF_6	●	●	●	●	●	●	●	●	L/T
2 G, Other Product Manufacture and Use		HFC-134a	-	-	-	-	-	-	-	-	-/-
2 G, Other Product Manufacture and Use		HFC-245fa	-	-	-	-	-	-	-	-	-/-
2 G, Other Product Manufacture and Use		HFC-365mfc	-	-	-	-	-	-	-	-	-/-
2 G, Other Product Manufacture and Use		$C_{10}F_{18}$	-	-	-	-	-	-	-	-	-/-
3 A, Enteric Fermentation	Dairy cows	CH_4	●	●	●	●	●	●	●	●	L/T
3 A, Enteric Fermentation	non-dairy cattle	CH_4	●	●	●	●	●	●	●	●	L/T
3 A, Enteric Fermentation	other animals	CH_4	-	-	-	-	-	-	-	-	-/-
3 B, Manure Management	Dairy cows	CH_4	-	-	-	-	●	●	●	●	L/T
3 B, Manure Management	non-dairy cattle	CH_4	-	-	-	-	-	-	-	-	-/-
3 B, Manure Management	swine	CH_4	●	●	●	●	●	●	●	●	L/T
3 B, Manure Management	other animals	CH_4	-	-	-	-	-	-	-	-	-/-
3 B, Manure Management	Dairy cows	N_2O	-	-	-	-	-	-	-	-	-/-
3 B, Manure Management	non-dairy cattle	N_2O	-	-	-	-	-	-	-	-	-/-
3 B, Manure Management	swine	N_2O	-	-	-	-	-	-	-	-	-/-
3 B, Manure Management	other animals	N_2O	-	-	-	-	-	-	-	-	-/-
3 B, Manure Management	deposition	N_2O	-	-	-	-	-	-	-	-	-/-
3 D, Agricultural Soils		N_2O	●	●	●	●	●	●	●	●	L/T
3 G, Liming		CO_2	-	-	-	-	-	-	-	●	-/T
3 H, Urea Application		CO_2	-	-	-	-	-	-	-	-	-/-

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2020	Level 2020 + LULUCF	Trend 2020	Trend 2020 + LULUCF	KCA decision
3 I, Other carbon-containing fertilisers		CO_2	-	-	-	-	-	-	-	-	-/-
3 J, Other		CH_4	-	-	-	-	-	-	●	●	-/T
3 J, Other		N_2O	-	-	-	-	-	-	-	-	-/-
4 A , Forest Land		CO_2		●		●		●		●	L/T
4 A , Forest Land		CH_4		-		-		-		-	-/-
4 A , Forest Land		N_2O		-		-		-		-	-/-
4 B, Cropland		CO_2		●		●		●		●	L/T
4 B, Cropland		CH_4		-		-		-		-	-/-
4 B, Cropland		N_2O		-		-		-		-	-/-
4 C, Grassland		CO_2		●		●		●		●	L/T
4 C, Grassland		CH_4		-		-		-		-	-/-
4 C, Grassland		N_2O		-		-		-		-	-/-
4 D, Wetlands		CO_2		●		●		●		●	L/T
4 D, Wetlands		CH_4		-		-		-		-	-/-
4 D, Wetlands		N_2O		-		-		-		-	-/-
4 E, Settlements		CO_2		-		-		-		-	-/-
4 E, Settlements		CH_4		-		-		-		-	-/-
4 E, Settlements		N_2O		-		-		-		-	-/-
4 G, Harvested Wood Products		CO_2		-		-		●		●	L/T
5 A, Solid Waste Disposal		CH_4	●	●	●	●	●	●	●	●	L/T
5 B, Biological Treatment of Solid Waste		CH_4	-	-	-	-	-	-	●	●	-/T
5 B, Biological Treatment of Solid Waste		N_2O	-	-	-	-	-	-	-	-	-/-
5 D 1, Domestic Wastewater		CH_4	-	-	-	-	-	-	●	●	-/T
5 D 1, Domestic Wastewater		N_2O	-	-	-	-	-	-	-	-	-/-
5 D 2, Industrial Wastewater		CH_4	-	-	-	-	-	-	-	-	-/-
5 D 2, Industrial Wastewater		N_2O	-	-	-	-	-	-	-	-	-/-
5 E, Other		CH_4	-	-	-	-	-	-	-	-	-/-
5 E, Other		N_2O	-	-	-	-	-	-	-	-	-/-

17.1.2 Approach 2 procedure

Key-category analysis using the Approach 2 procedure is based on the results of current uncertainties determination in accordance with Approach 1. In the present case, the results have provided extensive confirmation of the results of the Approach 1 key-category analyses. The categories listed in Table 8, Chapter 1.5.1, also have to be considered, however.

17.1.3 Assessment with qualitative criteria

Germany assesses key categories with help of qualitative criteria. The criteria to be applied are listed in Criteria 4.3.3 of the 2006 IPCC Guidelines (IPCC (2006a): Vol. 1). The criteria allow assessment on the basis of use of emissions-reduction equipment, of expected disproportionate emissions increases, of a high level of uncertainty or of unexpectedly lower or higher emissions in a given category. The criteria may be used as a basis for defining additional categories as key categories.

In the category adipic acid production (2.B.3), a redundant waste-gas-treatment system was installed. In light of that installation, the category has been classified as a key category, on the basis of qualitative criteria. 2.B.3 is already a key category, however, in terms of Approach 1 Level and Trend assessment. SF_6 emissions from soundproof windows are reported in 2.G.2. Even though such a trend cannot yet be recognized, it is clear that SF_6 emissions must be expected to increase sharply in coming years as disposal of old windows increases. For that reason – i.e. on the basis of qualitative criteria – the category has already been identified as a key category. That classification leads to no change, however, since 2.G is already a key category, according to Approach 1 Level and Trend, for SF_6. Qualitative assessment on the basis of large uncertainties is not required, since Germany carries out Approach 2 key-category analysis for the entire inventory every year. No unexpectedly low or high emissions have been seen in the inventory.

Use of qualitative criteria has not identified any additional key categories in Germany.

Germany uses all recommended procedures for identifying and evaluating categories. The IPCC Guidelines mandate that 95% of emissions from sources / removals in sinks be classified in key categories. The key categories that Germany has identified comprise emission-causing activities that account for about 98 % of the total inventory. This high percentage results from Germany's practice of identifying key categories by combining the results of all analysis procedures and evaluations.

17.1.4 Key-category analysis for Kyoto reporting

The following CRF Table NIR.3 summarises information relative to key-category analysis for Kyoto reporting.

Table 529: KP CRF Table NIR.3: Summary Overview for Key Categories for Land Use, Land-Use Change and Forestry Activities under the Kyoto Protocol

KEY CATEGORIES OF EMISSIONS AND REMOVALS	Gas	CRITERIA USED FOR KEY CATEGORY IDENTIFICATION			Comments [4]
		Associated category in UNFCCC inventory[1] is key (indicate which category)	Category contribution is greater than the smallest category considered key in the UNFCCC inventory[2] (including LULUCF)	Other[3]	
Specify key categories according to the national level of disaggregation used[1]					
Afforestation and Reforestation					
CO_2	CO_2	Land converted to Forest Land	Yes	High expected growth.	The value is very close to the value in the smallest category considered key in the UNFCCC inventory. The value has increased about tenfold since 1990.
Deforestation					
CO_2	CO_2	Land converted to Cropland	Yes	None	No comment
Forest Management					
CO_2	CO_2	Forest Land remaining Forest Land	Yes	None	No comment
Cropland management					
CO_2	CO_2	Cropland remaining Cropland, Land converted to Cropland	Yes	None	No comment
Grazing Land Management					
CO_2	CO_2	Grassland remaining Grassland	Yes	None	No comment

(1) See section 2.3.6 of the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol.

(2) If the emissions or removals of the category exceed the emissions of the smallest category identified as key in the UNFCCC inventory (including LULUCF), Parties should indicate YES. If not, Parties should indicate NO.

(3) This should include qualitative assessment as per section 4.3.3 of the 2006 IPCC Guidelines or any other criteria.

(4) Indicate the criteria (level, trend of both) identifying the category as key.

18 Annex 2: Detailed discussion of the methodology and data for calculating CO_2 Emissions from combustion of fuels

18.1 The Energy Balance for the Federal Republic of Germany

The basis for determination of energy-related emissions is the Energy Balance of the Federal Republic of Germany, which is prepared by the Working Group on Energy Balances (AG Energiebilanzen – AGEB) under commission to the Federal Ministry for Economic Affairs and Energy (BMWi). The most important data source for the Energy Balance is the *Federal Statistical Office (Statistisches Bundesamt). Data on renewable energy sources are determined by the Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat).* Additional data, supplementing those provided by the aformentioned data sources, are provided by associations of the German energy industry, and by German research institutes. In the Federal Republic of Germany, energy statistics are published by numerous other agencies, and their statistics can differ in terms of their presentation, scope, methods and aggregation.

The complete Energy Balances for the years since 1990 are available on the Internet at:

http://www.ag-energiebilanzen.de/index.php?article_id=7&clang=0

The AGEB's website presents a foreword for the Energy Balances, in German and English, that describes the structure of the Energy Balance.

The members of the Working Group on Energy Balances (AGEB) include (as of: April 2021):

- Bundesverband der deutschen Energie- and Wasserwirtschaft e.V. (BDEW) (Association of the German Energy and Water Industry), Berlin
- Deutscher Braunkohlen-Industrie-Verein e.V. (DEBRIV) (Federal German association of lignite-producing companies and their affiliated organisations), Cologne,
- Deutsches Institut für Wirtschaftsforschung (DIW) (German Institute for Economic Research), Berlin,
- EEFA GmbH, Münster
- Association of the German Petroleum Industry (MWV), Berlin,
- Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI) (Rhine-Westphalian Institute for Economic Research), Essen.
- Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), Stuttgart

The work of the Working Group on Energy Balances (AGEB) is also supported by the German Coal Importer Association (Verein der Kohlenimporteure e.V.); the Branchenverband Steinkohle und Nachbergbau e. V. (bs|n; German hard-coal and post-mining industry association); the Energieeffizienzverband für Wärme, Kälte und KWK e.V. (AGFW; Association for energy efficiency in heating, cooling and CHP systems); and the Association of Industrial Energy and Power Producers (VIK). Since the 1994 balance year, overall responsibility for preparation of Energy Balances has lain with the German Institute of Economic Research (DIW; Berlin); since 2002, the DIW has carried out relevant work in co-operation with EEFA (Energy Environment Forecast Analysis GmbH).

Official statistics are the most important source. The surveys of the Federal Statistical Office that were used are listed in Table 532: Federal Statistical Office surveys used in preparation of Energy Balances for the Federal Republic of Germany. The final Energy Balance continues to include data of the following associations: German Association of Energy and Water Industries (BDEW), German Atomic Forum (DAtF), Gesamtverband Steinkohle association of the German hard-coal-mining industry (GVSt), DEBRIV Federal German association of lignite-producing companies and their affiliated organisations and Association of the German Petroleum Industry (MWV).

In a number of categories, furthermore, experts personally provide relevant data – in categories, for example, such as non-energy-related consumption by the chemical industry.

Furthermore, the Federal Ministry for Economic Affairs and Energy (BMWi) has mandated the following: as of balance year 2018, the AGEB will be able to directly incorporate, within the Energy Balances, Energy-Balance-relevant data on renewable energies that have been prepared by the Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), under the direction of the Federal Environment Agency (UBA). The data in question include provisional data on renewable energy sources that enter into the estimated Energy Balance and into the evaluation tables.

18.2 Structure of the Energy Balances

The Energy Balances, which are structured in matrix form, provide an overview of the interconnections within the energy sector. As a result, they not only provide information about consumption of energy resources in the various source categories, they also show the relevant flows of such resources, from production to use in the various production, transformation and consumption areas. The ***production balance*** shows:

- domestic production,
- imports,
- removals from stocks,
- exports,
- international marine bunkers,
- additions to stocks,

of energy resources, and it summarises them under ***primary energy consumption***. The primary Energy Balance provides the basis for calculations under the IPCC reference procedure (Plinke & Schonert, 2000). The ***usage balance*** provides a key basis for preparation of emissions inventories. The usage balance can also be used for determination of primary energy consumption. It comprises:

- the transformation balance
- flaring and line losses
- non-energy-related consumption, and
- final energy consumption.

Differences between the production and usage balances are compensated for in the position "Statistical differences".

The ***transformation balance***, part of the usage balance, shows what energy resources are transformed into other, "secondary" resources. The transformation production shows the results of such transformation. Energy transformation can involve conversions of substances – such as conversion of crude oil (conversion input) into petroleum products (conversion output) – or conversions of energy – such as combustion of hard coal (conversion input) – in power stations, for production of electrical energy (conversion output). The energy consumption in the transformation sector shows how much energy was needed for operation of transformation systems (the transformation sector's own consumption). The transformation balance is divided into a total of 12 different sectors.

Non-energy-related consumption, as a component of the consumption balance, is shown as a total, without allocation to industrial sectors. Data on non-energy-related consumption, broken down by industrial sectors, are regularly provided to the Federal Environment Agency (UBA) in the framework of an additional table included with the Energy Balance for Germany. It describes which energy resources are used as raw materials (e.g. in the chemicals industry, transformation of energy resources into plastics).

The breakdown of final energy consumption (broken down by energy sources / fuels and sectors) shows the extent to which energy, in the various final consumer sectors, is transformed into the forms it which it is ultimately needed (such as power, light, indoor heat and process heat) (***final energy consumption***). The breakdown covers the areas of industry – sub-divided into 14 sectors – transport, households, commercial use, trade, services and other consumers (including agriculture).

The energy flow in the Energy Balances is depicted for 30 energy resources. These energy resources can be allocated to the following main groups:

- hard coal,
- lignite,
- petroleum (including LPG and refinery gas),
- gases (coke-oven and blast furnace gas, natural gas and firedamp, and excluding landfill gas and the gases in the previous category),
- Renewable energies (including renewable waste and, as of 2013, sewage sludge),
- Other energy sources (non-renewable waste, waste heat),
- electrical power and other energy resources.

- Energy Balances for Germany as a whole are available for the years as of 1990 (AGEB, 2003)

As of the year 2000, the energy-resource structure in the area of renewable energies / waste was changed: hydroelectric and windpower systems, and photovoltaic systems, were combined, and waste/biomass was divided into renewable and non-renewable fractions. Since 2003, non-renewable waste and waste heat are also listed under final-energy consumption within the Energy Balance.

In the Energy Balance, fuels / energy resources are listed in *natural units*, including tonnes (t) for solid and liquid fuels, cubic metres (m^3) for gases (except for natural gas), kilowatt hours (kWh) for electrical power and natural gas, and joules (J) for waste, renewable energy sources, nuclear power and district heating. In order to render the data comparable, and to allow them to be added up, all values are converted into joules (J), via suitable conversion factors. With respect to gases, the Energy Balance differs from gas statistics in that it views all gases in terms of their net calorific value H_i – and not of their gross calorific value, H_s.

To date, Energy Balances through 2018 have been published. On an annual basis, the Working Group on Energy Balances (AGEB) provides the Federal Environment Agency with an updated, complete, provisional Energy Balance for year x-1, for purposes of inventory preparation. This procedure, which takes place at the end of June, is oriented to the need for currentness in emissions reporting.

18.3 Methodological issues: Energy-related activity rates

Essentially, the inventories for air pollutants and greenhouse gases prepared by the Federal Environment Agency are based on the Energy Balances for Germany prepared by the Working Group on Energy Balances (AGEB). The data required for emissions calculation can be read directly from Energy Balance lines 11, 12, 15, 16, 40, 60, 65 and 68. For natural gas and light heating oil, EB line 14 is also used in calculation.

In a few cases, the special requirements pertaining to emissions calculation, and the need to assure the completeness of data, necessitate a departure from the above-described system, and additional data have to be added:

- The emissions-relevant fuel inputs for lignite drying have to be calculated out of EB line 10. A precise description of category 1.A.1.c is provided in Chapter 3.2.8.2.
- Natural gas inputs in compressors, for the years 1995-2002, can be read directly from the Energy Balance (EB line 33). For the years 1990-1994, and for the period as of 2003, the values have to be calculated outside of the Energy Balance. The method is described in the Chapter for category 1.A.3.e.
- For systematic reasons, and for reasons having to do with a focus on energy production, the Energy Balance does not list incinerated waste quantities completely for all relevant years. In this area as well, therefore, the lacking data have to be added from waste statistics. Relevant explanations are provided in Chapter for category 1.A.1.a and in the Chapter for category 1.A.2.g Other (stationary).
- Firewood use in the categories commercial and institutional is not listed in the Energy Balance through 2012 and has to be added. The method is described in Chapter for category 1.A.4.

In the Energy Balance, inputs of reducing agents, in pig-iron production, are listed in part as energy-related consumption, in EB line 54, and in part as transformation inputs, in EB line 17 (top-gas equivalent). Use of the related blast-furnace gas for energy production is listed in the relevant Energy Balance lines, 11, 12, 15, 33 and 54. To prevent double counting, the reducing-agent inputs from blast furnaces, as listed in EB line 54, and the relevant top-gas equivalent, are not reported.

18.4 Uncertainties, time-series consistency and quality assurance in the Energy Balance

While the Act on Energy Statistics (which entered into force in 2003) improved the relevant basic data foundations somewhat, the dynamic development of the energy sector soon necessitated an amendment of that Act. The amendment of the Act on Energy Statistics of 6 March 2017 (Federal Law Gazette (BGBl) I p. 392) introduces improvements in statistical coverage, updates of the survey groups involved and a number of new aspects to be surveyed. In addition, the survey periodicity has changed – in part, in favour of monthly surveys. The first survey covers survey year 2018.

The data structures of the Energy Balance are adjusted on an ongoing basis, in order to enhance data availability to the best possible extent.

These changes are made at relatively large intervals and are documented by the Working Group on Energy Balances (AGEB) in each case:

- Explanations relative to revision of the Energy Balances 2003 – 2006 [171]
- Remarks regarding changes in the Energy Balances 2003 through 2007 [172]
- Revision of the Energy Balances 2003 through 2009 [173]

[171] http://www.ag-energiebilanzen.de/#revision_der_eb_2003_bis_2006
[172] http://www.ag-energiebilanzen.de/#aktualisierungen_der_energiebilanzen_2003_bis
[173] http://www.ag-energiebilanzen.de/#revision_der_energiebilanzen_2003_bis_2009_05

- Methodological changes in the 2012 Energy Balance [174]
- Explanations relative to the Energy Balances (updated as of November 2015) [175]

In October 2021, the AGEB prepared a report, in compliance with its contract, on "Germany's Energy Balance – required revision" ("Revisionsbedarf in der Energiebilanz Deutschland"). In all likelihood, the next revision of the time series will be carried out in 2022, when this report has been evaluated.

18.4.1 Quality report of the Working Group on Energy Balances (AGEB) regarding preparation of Energy Balances for the Federal Republic of Germany

In 2012, the Working Group on Energy Balances (AGEB) began regularly submitting joint quality reports, to the Federal Environment Agency (UBA), that document its quality-assurance measures in preparation of Energy Balances. The new contract, covering the Energy Balances for the period 2019-2021, will have new aspects that will enter into preparation of Energy Balances as of 2020. One such new aspect, an additional quality-assurance measure, calls for Energy Balances to be prepared and provided in time-series form. This will improve detection of year-to-year discontinuities during data compilation.

The following section presents the content of the current reports, in their original wording (marked with a different typeface).

18.4.1.1.1 Background

In the framework of greenhouse-gas reporting, the National Co-ordinating Committee for the National System of Emissions Inventories has established minimum requirements pertaining to quality control and quality assurance (QC/QA). Those requirements are to be fulfilled on all levels of inventory preparation. One of the most important data sets for determination of greenhouse-gas emissions consists of the Energy Balances for the Federal Republic of Germany, which the Working Group on Energy Balances (AGEB) has been commissioned to prepare. The German Institute for Economic Research (DIW Berlin), the EEFA research institute (Münster) and the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW; Stuttgart) support the AGEB in its work, as sub-contractors. All persons working on Energy Balances are required to comply with minimum requirements pertaining to QC/QA, in areas such as transparency, consistency, comparability, completeness and accuracy.

To document its data sources and quality-assurance measures in preparation of Energy Balances, the Working Group on Energy Balances (AGEB) herewith submits its current quality report to the Federal Environment Agency (UBA). It focuses especially on the 2019 Energy Balance.

18.4.1.1.2 Work-sharing in preparation of Energy Balances

The DIW Berlin is responsible for preparing Energy Balances for the following energy areas:

- Natural gas, petroleum gas,
- Non-renewable waste, waste heat (50 % settlement waste, by agreement with ZSW and AGEE-Stat)
- Nuclear power,
- Crude oil, and
- Petroleum products (gasoline; naphtha; jet fuels; diesel fuel; light heating oil; heavy heating oil; petroleum coke; LP gas; refinery gas; other petroleum products)

[174] http://www.ag-energiebilanzen.de/#methodische_aenderungen_der_eb_2012
[175] http://www.ag-energiebilanzen.de/index.php?article_id=29&fileName=vorwort.pdf

Also in the framework of its Energy Balance work, the DIW Berlin coordinates the quarterly estimates of primary energy consumption for the Federal Republic of Germany, and it prepares estimates for the energy area "Other".

The Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) processes the area of renewable energies for the Energy Balances. The data concerned include data on:

- Hydroelectric power, wind power on land and at sea, and photovoltaics,
- Biomass (solid, liquid, biofuels, biogas, sewage gas, landfill gas) and renewable waste (settlement waste)
- Other renewable energy sources (solar-thermal, deep geothermal, near-surface geothermal).

Figures on renewable energies are calculated and published on the basis of the relevant data, in consultation with the office of the Working Group on Renewable Energy Statistics (GS AGEE-Stat).

The tasks of the EEFA research institute include preparing complete Energy Balances for the following fuels:

- Hard coal, hard-coal coke, hard-coal briquettes and other hard-coal products,
- Lignite (raw), lignite briquettes, other lignite products and hard lignite, and
- Coking-plant gas and city gas, blast furnace gas and basic oxygen furnace gas, and mine gas.
- Electricity and
- District heat (Fernwärme).

Since Energy Balance year 2009, estimate balances have been prepared in the framework of work for the evaluation tables. They incorporate data from Statistik-Nr. 066 (Erhebung über die Elektrizitäts- und Wärmeerzeugung der Stromerzeugungsanlagen der allgemeinen Versorgung; Survey of electricity and heat generation of public-sector electricity generation systems) of the Federal Statistical Office (StBA), and association data – for example, of the German Association of Energy and Water Industries (BDEW). In addition, data from the *Official Mineral Oil Statistics (AMS)* of the Federal Office of Economics and Export Control (BAFA) are used.

At that early stage in Energy-Balance preparation, important official data sources, such as surveys relative to energy consumption of industrial sectors, are normally not yet available. The pertinent data gaps are closed with the help of estimates. It is thus clear that an estimated Energy Balance cannot fulfill the strict requirements pertaining to data quality that the final Energy Balance meets, a work published with a time lag of somewhat less than one year.

18.4.1.1.3 Quality of the data sources used

The following *data of the Federal Statistical Office (StBA)* are used in the preparation of the Energy Balances for the Federal Republic of Germany:

- Annual survey (No. 060) of energy use by manufacturing, mining and quarrying companies,
- Monthly survey (No. 061E) of coal imports,
- Annual survey (No. 062) of heat and electricity generation from geothermal energy,
- Annual survey (No. 063) of production of biofuels,
- Annual survey (No. 064) of generation and use of heat and of heating-network operations,
- Monthly survey (No. 066K) of electricity and heat generation for the public supply,
- Annual survey (No 067) of electricity and heat generation by manufacturing, mining and quarrying companies,
- Monthly survey (No. 068) of the gas supply,
- Annual survey (No. 070) of electricity feed-in, and electricity demand, as recorded by electricity grid operators,

- Annual survey (No. 073) of production, use and supply of sewage gas,
- Annual survey (No. 075) of supply of LP gas,
- Annual survey (No. 082) of gas sales and income in the gas-supply sector,
- Energiesteuerstatistik (energy taxation statistics), Fachserie 14, Reihe 9.3).

The data of the Federal Statistical Office (StBA) are subject to official quality requirements. The quality reports of the Federal Statistical Office are available on the Internet:

https://www.destatis.de/DE/Methoden/Qualitaet/Qualitaetsberichte/Energie/einfuehrung.html [176], last checked on 1 February 2021.

In addition, data from the *Official Mineral Oil Statistics (AM)* of the Federal Office of Economics and Export Control (BAFA) are used:

https://www.bafa.de/SharedDocs/Downloads/DE/Energie/Mineraloel/moel_amtliche_daten_2019_dezember, last checked on 1 February 2021.

The AMS, which are published monthly and annually, are a closed, consistent system covering all petroleum production and consumption in Germany. The statistical basis for the AMS consists of the Integrated Mineral Oil Report (Integrierte Mineralölbericht – IM), which is prepared monthly, on the basis of the Act on mineral oil data (Mineralöldatengesetz), with input from companies operating in Germany's petroleum market. The Federal Office of Economics and Export Control (BAFA) reports the pertinent production and consumption data, together with the relevant data of the Federal Statistical Office, to IEA and Eurostat, which publish internationally comparable energy balances. The calorific values for crude oil inputs, and the petroleum products, that are covered by these reports are cross-checked against the national Energy Balance. For the Energy Balance's section on petroleum, both AMS data and data of the Federal Statistical Office are used.

As of January 2018, the Mineral Oil Statistics of the Federal Office of Economics and Export Control (BAFA) underwent changes that led to discontinuities in the time series. The pertinent changes are explained in the following:

"1) Inclusion of companies with olefin plants in the group of reporting companies

In a comparison with the previous year, the expansion of the group of reporting companies, to include companies with olefin plants, has impacts on domestic deliveries, and on reuse, in connection with the following products:

- Naphtha: Reduction of domestic deliveries / increases in the area of recycled products

- Liquefied petroleum gas: Reduction of domestic deliveries / increases in the area of recycled products

- Gasoline components: Increases in gross refinery production / domestic deliveries

2) Domestic deliveries of semi-finished products

As of recently, companies are now being permitted to list gasoline components, middle- distillate components and high-voltage components as domestic deliveries. Previously, in order to be able to list semi-finished products as domestic deliveries, companies had been required to reclassify such products as marketable products (e.g. gasoline components as naphtha)."

With regard to domestic sales of petroleum products, BAFA has no figures on the degree to which semi-finished products were reclassified as marketable products prior to 2018. As one can infer from

[176] On its website, the Federal Statistical Office publishes only quality reports conforming to the new Energy Statistics Act (EnStatG) of 2017. Quality reports in keeping with the old EnStatG are no longer available online.

the figures for 2018, products are still being reclassified, but the fraction of reclassified products has decreased sharply in comparison to its levels in previous years.

In the Energy Balance, this is apparent in connection with the figures for naphtha for the period as of 2017. In this area, conversion inputs at refineries (petroleum processing) increased from 60 thousand tonnes (2015) and 124 thousand tonnes (2016) to 1,309 thousand tonnes (2017) and 2,012 thousand tonnes (2018).

In the area of LP gas, this effect does not become apparent until 2018. In this area, conversion inputs at refineries jumped sharply, from 71 thousand tonnes in 2017 to 595 thousand tonnes in the following year.

https://www.bafa.de/DE/Energie/Rohstoffe/Mineraloelstatistik/mineraloel_node.html, last checked on 1 February 2021.

In addition, the Official Mineral Oil Statistics (AMS) show a change in Table 6j (1000 t) in the area of international marine bunkers. A review of the years 2016 through 2018 shows the following shifts in the area of energy sources / fuels:

2016: diesel fuel (DK) 999, heavy fuel oil (HS) 1855, other petroleum products (AMP) 1

2017: DK 230, light fuel oil (HEL) 632, HS 1457, AMP 1

2018: HEL 734, HS 981.

For the 2018 Energy Balance, this means that international marine bunkers are no longer listed for diesel fuel and HS; as of that year they are listed only for HEL and HS.

In addition to the available official data, *association data* are also used. The *Statistik der Kohlenwirtschaft* coal statistics play a special role among the association statistics. The data used for the Energy Balance include the following:

For hard coal:

- Statistics on domestic sales, broken down by types of hard coal and consumer groups (discontinued as of reporting year 2019), and
- Statistics on production, use in transformation sectors and changes in stocks (form 4a) (discontinued as of reporting year 2019).

For lignite:

- Data on extraction, production of lignite products, producers' own consumption and sales (form 5), and information from production reports,
- Data on domestic sales / use, broken down by Länder and consumer groups,

The coal-statistics data available in Germany have a semi-official status, and they are very precise and reliable. For more than 60 years, the Statistik der Kohlenwirtschaft coal-sector-statistics association has served as a liaison between coal-sector companies and official producers of statistics. Official coal statistics in this area are based on surveys carried out by the Statistik der Kohlenwirtschaft association. A large portion of the coal data is made publicly accessible on the website http://www.kohlenstatistik.de. The transparency this provides also attests to the reliability and accuracy of these data sources. The Act on Energy Statistics (Energiestatistikgesetz) has no separate paragraph relative to surveys on the domestic coal sector; its refers instead explicitly to the functioning system of coal statistics.

For natural gas, associated gas:

- Data on flaring losses are obtained using the implied net calorific value given by the Federal association of the natural gas, oil and geothermal energy industry (BVEG, the former WEG oil and gas industry association). The 2019 Statistical Report (Statistischer Bericht 2019) (page 22) introduced a change in the breakdown of flaring losses into the categores of "routine", "safety-relevant" and "non-routine".
- Data on transports are provided by Zukunft Erdgas (formerly known as "Erdgas mobil"), via the German Association of Energy and Water Industries (BDEW). Data from energy tax statistics are expected to become available for this sector in May 2021; only then will it be possible to enter these data in the 2019 Natural Gas Balance (Erdgasbilanz 2019) (for 2019: 1800 GWh Ho Zukunft Erdgas (Ho = gross calorific value (GCV); Zukunft Erdgas is an initiative of gas-industry companies); for comparison, here are the values for 2018: 1600 GWh Ho and 1839.058 GWh Ho Energy tax statistics of 19 June 2020).
- As a result of the change in the statistical report of the Federal association of the natural gas, oil and geothermal energy industry (BVEG), own consumption is now listed as process-related own consumption, i.e. including processing losses, measuring differences and flaring losses. For purposes of preparation of Energy Balances, the BVEG has provided actual-own-consumption figures for the years 2018 through 2020.

The following *additional sources* are also used:

- With regard to wood consumption in the Residential sector, results from the relevant survey by RWI/forsa are carried forward.
- Since 2013, wood consumption in the Commercial and Institutional sector has been determined as a remainder. The basis for this work consists of data on total energy-wood production in Germany, data obtained through surveys and calculations of the Johann Heinrich von Thünen Institute (Federal Research Institute for Rural Areas, Forestry and Fisheries).
- Data on wind energy yields on land and at sea, and on electricity production via photovoltaics, are derived from the quantities certified by auditors of transmission system operators (TSO), relative to electricity feed-in and relevant compensation, pursuant to the Renewable Energy Sources Act (EEG).
- In the framework of monitoring under the CHP act (Kraft-Wärme-Kopplungsgesetz), the Öko-Institut e.V. Institute for Applied Ecology estimates inputs of natural gas, and light fuel oil, for electricity and heat generation in compact gas-/oil- fired CHP systems that are not covered by official statistics.
- Model calculations are used in the areas of feed-in of biomass-based electricity into the grid, of solar-thermal energy and of use of environmental heat.

In addition to quality, the important aspects of the available data, relative to preparation of Energy Balances, include their multi-year availability and their standardised, consistent presentations of time series. Such aspects play a critically important role in ensuring that the procedures and methods used for preparation of Energy Balances generate data that can be consistently integrated, without structural discontinuities, in the basic scheme for the Balances. Both the relevant official sources and the coal statistics data have a long tradition. Where breaks in time series cannot be avoided, as a result of reviews or changes in statistical foundations (for example in the Act on Energy Statistics), such breaks are documented in the sources used for preparation of Energy Balances. This ensures that methods are always properly adjusted.

18.4.1.1.4 Transparency of methods and procedures

The Act on Energy Statistics (Energiestatistikgesetz – (EnStatG) entered into force on 1 January 2003. That act consolidates official energy statistics, from different legal frameworks, and adapts them to users' changed information requirements. Since the act's entry into force, the Federal Statistical Office has also collected and provided data for the areas heat market, combined heat / power generation (CHP) and renewable energy sources. As a result of the restructuring, the Federal Statistical Office, in addition to providing data on electricity and heat generation from combined heat / power generation (CHP), also provides data on all fuel inputs for CHP, for both the general public supply and industry (broken down by energy sources).

Such changes in the available statistics have made it necessary to adjust the methods used for the Energy Balances – especially for their descriptions of industrial final energy consumption. As a consequence of the described expansion in the data supply, separate data on fuel inputs as of 2003 for industrial electricity generation – i.e. for electricity-only generation – are now available.

The Federal Statistical Office does not collect data on breakdowns of fuel inputs by "electricity" and "heat" in industrial and public-supply combined heat / power generation (CHP) systems; such statistics are collected by the Working Group on Energy Balances (AGEB) and estimated by institutes it commissions. The "Finnish" method used for such purposes is based on Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004. That method is precisely defined, mathematically, and it is explained in the forewords to the Energy Balances. Currently, it is also explained in the brochure "Energie in Zahlen – Arbeit und Leistungen der AG Energiebilanzen" ("Energy in figures – the work and services of the Working Group on Energy Balances"), p. 10, 11 f.

With regard to quality assurance, the Finnish method makes calculations relative to power/heat production for the public supply and for industry logical and transparent. The necessary pertinent assumptions, such as the reference efficiencies of non-CHP generation as provided in the documentation for the Energy Balances, are stated in the process. In sum, although Energy Balance preparation is a process that makes use of frequently complex transformational methods, its results can still be highly transparent and unambiguous. As a result, all Energy Balance entry fields can always be traced back to their primary statistical foundations.

Primary data provided by official or association sources – regardless of its quality – can seldom simply be "plugged into" the Energy Balance without undergoing the statistical processing normally used to prepare the Energy Balances. Description of relevant complex energy flows, using matrices that conform to the formal parameters and methodological specifications for the Energy Balances, and on the basis of statistical raw data, requires numerous transformation steps, recalculations and reallocations. What is more, in some (few) areas of the Energy Balance primary statistics are no longer available, and thus data gaps have to be closed through use of formal estimation methods, applied in accordance with the requirements of each relevant individual case.[177]

18.4.1.1.5 Checking and verification of results

Measures for quality assurance and control cover the following areas:

- Assurance of data quality / transparency of methods and procedures,

[177] Outlook: The amended Act on Energy Statistics (Energiestatistikgesetz – (EnStatG) entered into force on 10 March 2017. The amended version of the act suitably addresses changed requirements for energy data at the national and international levels. In addition, it adapts energy statistics to the changed framework now seen in the energy sector. Furthermore, it closes a number of data gaps, especially in the areas of renewable energies, combined heat / power generation (CHP) and heat generation. The amended EnStatG has been applied to monthly surveys in the period as of reporting month January 2018.

- Mechanisms for checking and critically reviewing the Energy Balances, measures that assure the Balances' correctness, completeness and consistency,
- Measures for documentation and archiving, designed to ensure the Balances' clarity and reproducibility,
- Expert responsibility for preparation of Energy Balances.

Critical discussion, verification and checking of results take place on various levels:

- The annual Energy Balance is prepared independently by several experts, in a process that includes cross-checking of work.
- The involved experts mutually check their work and review it, on the basis of control figures (such as changes emerging year-to-year comparisons, implied calorific values, utilisation levels), for plausibility.
- The time-series consistency is regularly verified. Where a time series shows implausible jumps that cannot be attributed to transfer or calculation errors, and that must be tied to developments in the underlying primary statistics, the problem is discussed constructively with the relevant data-supplying institution (such as the Federal Statistical Office). In preparation of the 2018 Energy Balance, for example, it was seen in the Statistik 064 statistics, with respect to the fuels natural gas, petroleum gas, and light fuel oil, that plants' case numbers had increased, while their fuel inputs had remained at about the same level. This was due to a change of perspective from companies to plants (cf. Table 1 in this regard).
- The Energy Balances are cross-checked against the data provided to IEA/Eurostat.
- In addition, the AGEB member associations carry out supporting checks.
- Furthermore, at early stages data and results are exchanged and discussed with responsible experts of the Federal Environment Agency (UBA), also in consultation with AGEE-Stat.
- Statistical questions pertaining to the Energy Balance are also discussed by the "Working Group on methods" ("Arbeitskreis Methodik" – AKM) within the Federal Ministry for Economic Affairs and Energy (BMWi).

Only when the completed Energy Balance has successfully passed through all controlling bodies is it published on the AGEB's website and are provisional Energy Balance data provided to the Federal Environment Agency for further processing within the system for the national greenhouse-gas inventory.

With a view to effective prevention of errors in data calculation and estimation for the Energy Balances, the annual balances are prepared via standardised procedures. To that end, a broad range of instruments has been developed that automate proven estimation procedures, and formal calculation methods, within the context of Energy Balance preparation. This approach, which often permits simple entry of statistical raw data into the suitable calculation tools, largely eliminates calculation and transformation errors. What is more, its use of consistent, standardised methods plays an important role in assuring time-series consistency.

18.4.1.1.6 Documentation and archiving

DIW Berlin, the EEFA research institute and the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) keep careful, detailed documentation relative to the annual Energy Balances. The documentation covers every Energy Balance entry, lists the statistical sources and surveys used and precisely describes the calculation methods and procedures used. The purpose of the documentation is to ensure that all steps can be retraced, both by Energy Balance staff and by the Federal Ministry for Economic Affairs and Energy (BMWi) and the Federal Environment Agency. Furthermore, regular updating of the documentation contributes to data quality and helps to assure consistency in time series and methods.

All statistical data, calculation methods and estimation procedures used in preparation of Energy Balances for the Federal Republic of Germany are archived. The pertinent electronic data are backed up at DIW Berlin and at ZSW – both automatically, by central data systems, on dedicated server space, and manually, at regular intervals. For electronic archiving, the EEFA institute uses portable media (CD-ROMs, DVD), external drives and network-based server systems. Data back-ups are carried out both automatically and manually (at regular intervals).

18.4.1.1.7 Qualified staff

For execution of the service project "Preparation of Energy Balances for the Federal Republic of Germany" ("Erstellen von Energiebilanzen für die Bundesrepublik Deutschland"), DIW Berlin, the EEFA research institute and ZSW rely on experienced staff with solid backgrounds in the areas of statistics, economics and the energy sector.

18.4.1.1.8 Explanations regarding the currentness and availability of data for preparation of Energy Balances

Official statistics

The final annual data from the monthly survey 066 (monthly survey of electricity and heat generation for the public supply), for 2019, became available in May 2020. Other annual surveys became available as follows: 064 (heat generation), November 2020; 067 (electricity generation systems of industry), October 2020; 070 (electricity feed-in), November 2020; and 073 (sewage gas), November 2020. No. 082 became available in November 2020. The results of survey 062 (geothermal energy) became available in September 2020, while the results of survey 063 (biofuels) became available in October 2020. The results of surveys 066 (electricity generation systems for the public supply) and 067 (electricity generation systems for industry) have to be converted via the "Finnish" method. Calculations, checking procedures and processes of consultation with the German Association of Energy and Water Industries (BDEW), the Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), and the Energy Environment Forecast and Analysis (EEFA) institute take at least two weeks. The results of survey 060 (energy use by industry), which account for a significant part of the Energy Balances, became available in October 2020. Calculations for individual sectors, plausibility checks, checking requests submitted to the Federal Statistical Office (which has to forward the requests to the Länder) and consultations with participating associations are subject to certain time lags.

As a result of such time constraints, and in a procedure that began with report year 2009, an estimated Energy Balance is now prepared in July of each year. Under the current agreement, an estimated Energy Balance is to be prepared in June of each year, and the evaluation tables, into which the updated estimated Energy Balance, with updated data on renewable energies, is entered, is to be prepared in September. In each case, the updated estimated Energy Balance includes the available official data from survey 066. The remaining data are first estimated and agreed on in cooperation with the AGEB member associations.

The following table presents an overview of publication times for statistics used in the Energy Balance for the Federal Republic of Germany:

Table 530: Data for the year 2019:

Surveying institution	Statistics no.	Publication date
Federal Statistical Office	060	Oct. 2020
	062	End of Sept. 2020
	063	Oct. 2020
	064	Nov. 2020
	066	May 2020
	067	Oct. 2020
	070	Nov. 2020
	073	Nov. 2020
	075	Feb. 2021
	082	Nov. 2020
BAFA	Official Mineral Oil Statistics (Amtliche Mineralölstatistik)	July 9, 2020

Table 531: Data for the year 2018:

Surveying institution	Statistics no.	Publication date
Federal Statistical Office	Energy tax 2019, Tab. 2.3 Natural gas	June 19, 2020

Association statistics

Data from associations (see above), which become available early, enter into the final Energy Balance. Data of the Federal association of the natural gas, oil and geothermal energy industry (BVEG) are used in the area of flaring losses, while data of Zukunft Erdgas (formerly, "Erdgas mobil") are used in the area of transports of natural gas and associated gas.

Because quarterly estimates of primary energy consumption in Germany are carried out, provisional data in the relevant areas also become available quickly. The BDEW provides important provisional data, dated as of August, that are also of relevance to final energy consumption as recorded in the estimate Balance. Every summer, that organisation publishes data under the heading "The German energy market – facts and figures on the gas, electricity and district-heating sectors" ("Energiemarkt Deutschland – Zahlen und Fakten zur Gas-, Strom- und Fernwärmeversorgung"). In addition, the estimated Balance incorporates BDEW data on gross electricity generation, data of Statistik der Kohlenwirtschaft coal-industry statistics, data of the Association of the German Petroleum Industry (MWV) and data of the Deutsche Atomforum nuclear-energy association.

Other data

For the final Energy Balance, data on electricity generation from wind energy, photovoltaics and geothermal energy are used that are based on the quantities certified by auditors of transmission system operators (TSO), relative to electricity feed-in and relevant compensation, pursuant to the Renewable Energy Sources Act (EEG). Those data become available in August of each year.

The figures on electricity generation from biomass, and on biomass-fuel inputs in decentralised CHP systems, are based on calculations of the Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat). With regard to wood consumption in the Residential and Commercial / Institutional sectors, figures of AGEE-Stat were used. Data in the areas of solar thermal energy and environmental heat are based on model calculations of AGEE-Stat.

Figures for electricity generation and fuel inputs in small CHP systems fired with natural gas and HEL (< 1 MW) were calculated with data the BHKW (compact combined heat-and-power (CHP) generating systems) database of the Öko-Institut e.V. Institute for Applied Ecology. The same data are used for reporting in the IEA/Eurostat context.

Data on use of petroleum coke in metallurgical coking plants are provided for the Federal balance by the relevant German Länder, on the basis of an agreement between the Working Group on Energy Balances (AGEB) and the Länder working group on Energy Balances (Länderarbeitskreis Energiebilanzen). Via BAFA, these data also enter into the Joint Annual Questionnaire of IEA/Eurostat.

Table 532: Federal Statistical Office surveys used in preparation of Energy Balances for the Federal Republic of Germany

Survey	No.	Survey period	Currentness, pursuant to quality report	Type of data	Group surveyed	Units surveyed
Annual survey of energy use by manufacturing, mining and quarrying companies	060	Annually	End of the following year	Electricity purchases and generation; electricity sales and consumption Purchases of heat; heat consumption and sales Fuel sales and stocks, by fuel Average lower net calorific value	Sections B "Mining and quarrying" and C "Manufacturing"	Producing companies (currently, at least 40,000) with at least 20 employees Exception: Plants of manufacturing sector companies with workforces of 10 or more persons, in various industrial sectors
Survey on coal imports	061E	Monthly, annually	end of April of the following year	Coal imports	Companies that import lignite, lignite products, hard coal, hard-coal coke and hard-coal briquettes	Exhaustive survey (but does not include units located abroad)
Annual survey of heat and electricity generation from geothermal energy	062	Annually	About 9 weeks after the end of the reporting period	Type and output of installations, and heat and/or electricity generation; type and output of installations, use and provision of heat and/or electricity from deep geothermal energy; provision by energy utilities and own installations	All operators of systems for use of deep geothermal energy	The survey is aimed at all operators of plants for use of deep geothermal energy
Annual survey of production of biofuels	063	Annually	About 9 weeks after the end of the reporting period	Type and capacity of plants; input materials for production of biofuels; production and imports from abroad; domestic and international sales of biofuels	All operators of systems for production of biofuels	The survey is aimed at all operators of plants for production of biofuels.
Annual survey of generation and use of heat and of heating-network operations	064	Annually	End of the following year	A Figures in keeping with installations for the heating plant. Output, heat generation, fuel inputs and fuel stocks at year's end; summary of all installations, with outputs and heat generation, fuel inputs and fuel stocks at year's end B Figures only for heat-driven CHP plants: Output, own consumption, fuel inputs and fuel stocks at year's end; heat and electricity generation; summary for all German Länder; output, own consumption, fuel inputs and fuel stocks at year's end; heat and electricity generation C Figures only for storage systems, storage capacity in storage systems D Figures for heat networks E Heat balance		All operators of heating plants with installed rated capacity of 1 MWth, all operators of installations for grid-connected heat supply, including heat-driven CHP installations, and third parties that use such installations.
Monthly survey of electricity and heat generation for the public supply	066K	Monthly; annually	70 days after the end of the reference month end of April of the following year	A Number, net nominal capacity, and electricity and heat generation by generating unit B Fuel inputs, fuel stocks, and electricity and heat generation by the installation, in the report month C Sales of heat in the report month D Storage systems	Operators of plants for generation of electricity, including CHP systems, with net nominal capacity of at least 1 MWel in each case; and electricity-storage systems with a storage capacity of at least 1 MWh.	Quantity- and performance-based data on power stations of utilities with net nominal capacity of at least 1 MW, and on systems for storage of electricity with installed net nominal capacity of at least 1 MWel or with storage capacity of at least 1 MWh. All operators of systems for generation and storage of electricity, including CHP systems.
Annual survey of electricity and heat generation by manufacturing, mining and quarrying companies	067	Annually	9 weeks after the end of the reporting period	A Number, net nominal capacity, and electricity and heat generation, broken down by generating units; and bottleneck capacity by type of installation; primary energy savings B Fuel inputs, fuel stocks, and electricity and heat generation by the installation, in the report year	Sections B "Mining and quarrying" and C "Manufacturing"	Operators of electricity-generation installations, including CHP systems, that are for self-supply and that have installed net nominal capacity of at least 1 MWel.
Monthly survey of gas supply	068	Monthly	42 days after the end of the reference month	A Production and own consumption of natural gas (upper net calorific value) B Feed-in and withdrawal of natural gas, biogas; own consumption C Storage changes and fill levels		All operators of installations for production of natural gas, or for transport of natural gas and biogas via long-distance pipelines, and all operators of storage facilities for natural gas
Annual survey of electricity feed-in, and electricity demand, as recorded by electricity grid operators,	070	Annually	12 weeks after the end of the reporting period	A Grid utilisation charges for customers with special contracts B Grid feed-in, by fuels C Removals from the grid D CHP systems with net nominal capacity of less than 1 MW Total for all German Länder, A - D		All operators of electricity grids for the public supply
Annual survey of production, use and supply of sewage gas	073	Annually	8 weeks after the end of the reporting period	A Production, use and supply of sewage gas B Use of sewage sludge, at wastewater treatment plants, for generation of electricity and heat C Installed capacity of installations for generation of electricity and heat D Electricity and heat generation from sewage gas E Electricity and heat generation from sewage sludge		All operators of installations that produce sewage gas, or that use sewage sludge to generate electricity and heat

Survey	No.	Survey period	Currentness, pursuant to quality report	Type of data	Group surveyed	Units surveyed
Annual survey of deliveries of LP gas	075	Annually	8 weeks after the end of the reporting period	Deliveries of LP gas to end consumers and resellers; deliveries overall and by German Länder		Companies that annually supply at least 100 tonnes of LP gas to end consumers
Annual survey of gas sales and income in the gas-supply sector	082	Annually	National results normally become available 12 months after the end of the period covered by the report	A Extraction or production of gas: Natural gas extraction, or extraction/production of other gases; own consumption and losses; contractual imports and exports, by country of origin and destination; sales of gas (and relevant revenue) to end consumers in all German Länder Supply and exports of gas, and relevant revenue Gas production, by gas production, by gas types Deliveries of gas, and relevant revenue, by German Länder		All operators of systems in the gas supply sector

Link to the nomenclature for classification of industrial sectors (Nomenklatur der Wirtschaftszweige; WZ 2008): https://www.destatis.de/DE/Methoden/Klassifikationen/Gueter-Wirtschaftsklassifikationen/klassifikation-wz-2008.html

Link to the quality reports on energy statistics, including questionnaires: https://www.destatis.de/DE/Methoden/Qualitaet/Qualitaetsberichte/Energie/einfuehrung.html [178]

[178] On its website, the Federal Statistical Office publishes only quality reports conforming to the new Energy Statistics Act (EnStatG) of 2017. Quality reports in keeping with the old EnStatG are no longer available online.

18.5 REGULAR COMPARISONS OF ENERGY BALANCES

18.5.1 Comparison of the 2019 Energy Balance with the 2018 Energy Balance

The AGEB normally publishes the final Energy Balances in the spring of the next calendar year but one. In the interest of early provision of data, as of 2009 an estimated Energy Balance is prepared, in the summer of the following year, and along with the evaluation tables. In part, the estimated Energy Balance is based on different data sources (cf. the quality reports of DIW and EEFA).

In such comparisons, both absolute and relative discrepancies are calculated, to make it possible to identify any significant discrepancies between final and provisional Energy Balances. Such significant discrepancies have to be individually explained. Positions with discrepancies are analysed, by Energy Balance lines and Energy Balance columns, in light of a combination of the criteria "discrepancies in TJ" and "discrepancies in %". Discrepancies of 10,000 TJ and 20 % are used as thresholds.

With these criteria, the comparison of the 2019 Energy Balance with the 2018 Energy Balance yields 51 positions (including sum fields). These are shown in the overview below and explained in the following.

The differences shown here correspond to the statistical changes with respect to the previous year. The general reasons for such differences include economic trends, structural changes, changes in prices, weather-related effects and special developments such as the decision to discontinue use of nuclear power. Such general trends in energy consumption and its determining factors in 2019, in comparison to the corresponding aspects in 2018, are discussed in the annual reports of the Working Group on Energy Balances (AG Energiebilanzen; 2012).[179]

The comparison of the Energy Balances serves the primary purpose of checking and documenting the plausibility of noticeable changes. In some Balance positions, changes determined via the aforementioned criteria are simply not unusual, however. For example, this applies to changes in stocks, which by nature differ significantly from year to year.

[179] AG Energiebilanzen (Working Group on Energy Balances): Energieverbrauch in Deutschland im Jahr 2019 weiter rückläufig (energy consumption in Germany continued its decrease in 2019). March 2020. www.ag-energiebilanzen.de.

Table 533: Overview: Positions of note in the comparison of the 2018 Energy Balance with the 2017 Energy Balance

EB column	EB line	TJ	%	Explanatory remarks:
Hard coal	Domestic production	-75,404	-100.0	Termination of hard coal mining
Hard coal	Removals from stocks	-90,974		Not comparable
Hard coal	Additions to stocks	54,172		Not comparable
Hard coal	DOMESTIC PRIMARY ENERGY CONSUMPTION	-328,119	-23.7	Total
Hard coal	Thermal power stations for the public supply	-195,087	-30.3	According to statistics
Hard coal	DOMESTIC ENERGY SUPPLY, PURSUANT TO TRANSFORMATION BALANCE	-103,589	-40.4	Total
Hard coal	Statistical differences	98,448	-412.5	Not comparable
Coke	DOMESTIC PRIMARY ENERGY CONSUMPTION	-14,743	-35.0	Total
Lignite	Domestic production	-316,500	-21.0	According to statistics
Lignite	Domestic energy production	-322,060	-21.3	Total
Lignite	DOMESTIC PRIMARY ENERGY CONSUMPTION	-322,060	-21.3	Total
Lignite	Thermal power stations for the public supply	-293,102	-22.6	According to statistics
Lignite	Total transformation inputs	-310,634	-20.9	Total
Petroleum	Removals from stocks	-21,966	-100.0	Not comparable
Petroleum	Additions to stocks	22,291		Not comparable
Gasoline fuels	Imports	30,553	29.5	AMS T5b S4 Z2+Z3+Z13
Gasoline fuels	Domestic energy production	30,553	29.5	Total
Gasoline fuels	Additions to stocks	11,753		AMS T6j S6+S7 Z2+Z3+Z13
Gasoline fuels	DOMESTIC PRIMARY ENERGY CONSUMPTION	27,368	-24.7	Total
Gasoline fuels	Manufacture of refined petroleum products	-84,712	-54.3	AMS T5j S3 Z2+Z3+Z13
Gasoline fuels	Total transformation inputs	-84,712	-54.3	Total
Gasoline fuels	NON-ENERGY-RELATED CONSUMPTION	145,365		T7j S2+6 Z3 chem. processing of gasoline components
Diesel	Additions to stocks	-10,329	-57.4	AMS T6j S6 + S7 Z4
Diesel	DOMESTIC PRIMARY ENERGY CONSUMPTION	75,579	23.1	Total
HEL	Removals from stocks	-29,584	-100.0	AMS T6j S6 7 Z5 + Z6
HEL	Manufacture of refined petroleum products	16,788	27.4	AMS T5j S3 Z5 + Z6
HEL	Total transformation inputs	16,297	22.8	Total
HEL	Statistical differences	-14,806	80.5	Not comparable
HS	Imports	-20,820	-24.1	AMS T5b S4 Z7 + Z8
HS	Domestic energy production	-20,820	-24.1	Total
HS	Bunker fuels	-12,611	-31.9	AMS T6j S4 Z7 + Z8
LP gas	NON-ENERGY-RELATED CONSUMPTION	17,822	23.2	AMS T7j S2 Z9
Natural gas	Imports	-5,760,527	-100.0	ME Gas, cross-checking of natural-gas balance, Federal Statistical Office
Natural gas	Removals from stocks	5,570,651		ME Gas, cross-checking of natural-gas balance, Federal Statistical Office
Natural gas	Additions to stocks	85,544	120.3	ME Gas, cross-checking of natural-gas balance, Federal Statistical Office
Natural gas	Statistical differences	-63,733	565.0	Not comparable
Electricity	Imports	30,233	26.5	According to statistics
Electricity	Domestic energy production	30,233	26.5	Total
Electricity	DOMESTIC PRIMARY ENERGY CONSUMPTION	57,841	-33.0	Total

EB column	EB line	TJ	%	Explanatory remarks:
District heating	Flaring and line losses	-11,450	-21.9	According to statistics
District heating	Commercial and institutional, and other consumers	14,769	62.9	Residual value
PET	Imports	-5,853,236	-50.7	Total
PET	Removals from stocks	5,452,139	4,561.8	Total
PET	Additions to stocks	162,017	227.8	Total
PET	Statistical differences	40,560	-93.1	Total
SET	Removals from stocks	-31,030	-75.7	Total
SET	DOMESTIC PRIMARY ENERGY CONSUMPTION	127,568	22.9	Total
Total	**Imports**	**-5,758,574**	**-42.9**	**Total**
Total	**Removals from stocks**	**5,421,109**		**Total**
Total	**Additions to stocks**	**171,740**	**177.3**	**Total**
Total	**Statistical differences**	**43,370**	**-51.6**	**Total**

18.6 Energy-Data Action Plan for inventory improvement

Also since 2012, the Federal Environment Agency, working in cooperation with the Federal Ministry for Economic Affairs and Energy (BMWi), the Working Group on Energy Balances (AGEB) and the Federal Statistical Office, prepares an "energy-data action plan for inventory improvement" that outlines actions to be taken to address the criticism that emerges from inventory reviews. This fulfills the action-plan requirement set forth in Paragraph 39 of the 2011 review report (FCCC/ARR/2011/DEU).

Table 534: Energy-Data Action Plan for inventory improvement

No.	Issue	Responsibility	Responsibility for execution	Reference (paragraph)	Quotation from 2011 review report (FCCC/ARR/2011/DEU)	Instrument for implementation / publication	Activity for improvement	Result planned / achieved	Time perspective	Remark
1	Energy-Data Action Plan for inventory improvement	Federal Ministry for Economic Affairs and Energy (BMWi) / UBA / AGEB / Federal Statistical Office	UBA	39	*address review relevant issues in an action plan in the 2011 submission. […] The ERT reiterates the recommendation of the previous review report that Germany prepare a plan for the remaining abovementioned issues, and to report on it and on any progress achieved in its next annual submission*	Action plan; NIR	The pertinent action plan is being prepared, for the first time, for the 2013 inventory report	A coordinated Energy-Data Action Plan for inventory improvement is available for the 2012 inventory review process and will be updated annually	Ongoing	
2.1	Deadline compliance of the final Energy Balance	BMWi/AGEB/Federal Statistical Office/Statistical offices of the Länder	BMWi	39	*timeliness of reporting […]*	Process analysis, energy data; NIR	For the 2013 inventory report, a process analysis is presented. Inter alia, it covers reporting channels (these are described more precisely than in the past), the efforts made to shorten such channels and the relevant success achieved.	Process analysis, describing applicable reporting channels more precisely than in the past, and describing efforts made to shorten such channels and the relevant success achieved, enables review experts to determine that Germany has made use of all available possibilities for optimisation; The status of such work is documented in the NIR 2013	Completed	
2.2	Deadline compliance of	BMWi/AGEB/Federal Statistical	BMWi/AGEB (not for official	137	*In the course of the review, the ERT formulated a number*	Process analysis, energy data; NIR	Organisational improvements in	In future, official statistics are to be transmitted at an		

No.	Issue	Responsibility	Responsibility for execution	Reference (paragraph)	Quotation from 2011 review report (FCCC/ARR/2011/DEU)	Instrument for implementation / publication	Activity for improvement	Result planned / achieved	Time perspective	Remark
	the final Energy Balance	Office/Statistical offices of the Länder	data)/Federal Statistical Office and statistical offices of the Länder (for official data);		*of recommendations relating to the transparency of background and methodological information (e.g. in the energy[...] sectors), justification and documentation of recalculations (e.g. in the energy[...] sectors)[...] The key sectoral recommendations are that Germany: [...] (b) Improve the timeliness of reporting of the NEB (energy);*		the statistical offices of the Länder. In rapporteurs' meetings with the Länder, the Federal Statistical Office discusses possibilities and ways of improving the cooperation.	earlier time than has been the case to date.		
3.1	Discrepancies between provisional and final EB	BMWi/AGEB/Federal Statistical Office/Statistical offices of the Länder	AGEB; UBA	39	*significant differences between the preliminary and final NEB*	QC report; NIR	Energy data consistency analysis (EDKA)	Identification and clarification of discrepancies, along with differentiation and addressing of a) Informational deficits b) Documentation requirements c) Data problems d) Methodological changes	Ongoing	
3.2	Discrepancies between provisional and final EB	AGEB	AGEB	39	*significant differences between the preliminary and final NEB*	QC	The AGEB is working to reduce estimation errors. The contract for preparation of the Energy Balances for the years 2018 through 2020, which is currently in the tendering process, will stipulate that the existing estimation procedures and transition models are to be continually	AGEB reports on plausibility checks The AGEB reviews new procedures and methods for preparing the estimated Energy Balance. Specific proposals in this regard have been made (cf. the report of the EEFA research institute regarding approaches in estimation and modelling for the preparation of provisional Energy Balances.	Ongoing	

No.	Issue	Responsibility	Responsibility for execution	Reference (paragraph)	Quotation from 2011 review report (FCCC/ARR/2011/DEU)	Instrument for implementation / publication	Activity for improvement	Result planned / achieved	Time perspective	Remark
							optimised and recorded in writing.			
3.3	Discrepancies between provisional and final EB	AGEB, UBA	UBA	39	*significant differences between the preliminary and final NEB*	Inventory description	In the framework of work on the inventory and the 2015 National Inventory Report (NIR), discrepancies are described, and the results are presented in a "differences discussion".	The status of this work is documented in the 2015 inventory description: Documentation, revision of data for earlier years, reduction of estimation errors	Ongoing since 2012	
4	Complex National System	Federal Ministry of Economics and Technology (BMWi) / UBA / AGEB	UBA	39	*The previous review report noted several issues related to Germany's NEB (such as [...] the complexity of the NEB compiling process that may contribute to the problems with regard to timeliness and quality.*	NaSE	Exchange regarding the results of the inventory review and derivation of requirements for action;	Energy-data workshop on 16 Nov. 2010 Energy-data workshop on 5 August 2011 Energy-data workshop on 27 April 2012 Energy-data workshop on 7 August 2012 2013 Energy-data workshop on 7 May 2013 2014 Energy-data workshop on 5 June 2014 2016 Energy-data workshop on 3 May 2016		
5	Quality assurance	EEFA / German Institute for Economic Research (DIW) / Federal Statistical Office / AGEB / UBA	AGEB / UBA	39	*lack of QA/QC procedures in place for some data sources used to compile the NEB*	NIR	Joint AGEB quality report in the new Annex 2 of the NIR 2012 and in subsequent inventory reports	the NEB is subject to QA/QC procedures in accordance with the national system	Ongoing since 2012	
6.1	Discrepancies between EB and IEA data	BMWi, AGEB, persons responsible for questionnaires	BMWi	39	*low comparability with the IEA data*		To be jointly defined in the framework of the action plan	Introduction of a transition procedure for assuring compatibility between the Energy Balance and surveys in the areas of electricity and heat (cf. in this regard	Completed or ongoing	

No.	Issue	Responsibility	Responsibility for execution	Reference (paragraph)	Quotation from 2011 review report (FCCC/ARR/2011/DEU)	Instrument for implementation / publication	Activity for improvement	Result planned / achieved	Time perspective	Remark
								the report of the EEFA research institute to the AGEB and the Federal Ministry for Economic Affairs and Energy (BMWi). The transition has been successfully carried out as part of comprehensive revision of the questionnaires. Efforts to minimize discrepancies are being continued in other areas of the surveys and the Energy Balance. AGEB reports on plausibility checks Revision of the questionnaire for 2003-2011. Planned revision of the NEB	Completed Spring 2014	
6.2	Discrepancies between EB and IEA data	BMWi, AGEB, persons responsible for questionnaires	BMWi	45	*The ERT also noted differences between the inventory data and the corresponding IEA data (e.g. for solid fuels exports, the data show differences of over 60 per cent in some recent years […] Germany has provided some explanations for the divergences and informed the ERT that it is continuing to investigate these differences. The ERT considers that the differences cause no underestimation of emissions, but reiterates the recommendation of the previous review report that Germany explain the reasons for these differences between*		To be jointly defined in the framework of the action plan	See 6.1		

No.	Issue	Responsibility	Responsibility for execution	Reference (paragraph)	Quotation from 2011 review report (FCCC/ARR/2011/DEU)	Instrument for implementation / publication	Activity for improvement	Result planned / achieved	Time perspective	Remark
					its inventory data and the corresponding IEA data in its next annual submission.					
6.3	Discrepancies between EB and IEA data	BMWi, Working Group on Energy Balances (AG Energiebilanzen)	BMWi		*The ERT also noted differences between the inventory data and the corresponding IEA data (e.g. for solid fuels exports, the data show differences of over 60 per cent in some recent years […] Germany has provided some explanations for the divergences and informed the ERT that it is continuing to investigate these differences. The ERT considers that the differences cause no underestimation of emissions, but reiterates the recommendation of the previous review report that Germany explain the reasons for these differences between its inventory data and the corresponding IEA data in its next annual submission.*		Study on reduction of discrepancies between national and international energy statistics	Since the Member States' NECPs must lend themselves to comparison, they draw to a large extent on Eurostat data. In the interest of preventing inconsistencies, the existing discrepancies between national and international energy data (IEA, Eurostat) are to be minimised. For this reason, a study was commissioned for the purposes of a) producing a complete picture of the existing data discrepancies and their causes and b) developing strategies for reducing the discrepancies. The results of the study are now available. The tender for the contract for preparation of the Energy Balances for the years 2018 through 2020 takes account of the findings of the discrepancies study. As of the final 2020 EB, an evaluation is to be carried out with the aim of preventing the occurrence of unjustified new discrepancies to the greatest possible extent.	End of 2018 Beginning of 2022	
7.1	Improvement of the balance sheet for gases	BMWi / Federal Statistical Office	Federal Statistical Office	39	*significant amount of flaring/losses of natural gas in*	NIR, EB	Meeting involving all participating energy experts;	The significant amount of flaring/losses of natural gas are taken into account	Apr 12	Completed

No.	Issue	Responsibility	Responsibility for execution	Reference (paragraph)	Quotation from 2011 review report (FCCC/ARR/2011/DEU)	Instrument for implementation / publication	Activity for improvement	Result planned / achieved	Time perspective	Remark
		/ DIW / UBA / and others			*the NEB that were not transparently accounted for*		review and adjustment of the data source			
7.2	Improvement of the balance sheet for gases	BMWi / Federal Statistical Office / DIW / UBA / and others	Federal Statistical Office	39	*significant amount of flaring/losses of natural gas in the NEB that were not transparently accounted for*	NIR, EB	Updating of the gas balance sheets in the positions relative to flaring losses, and in positions relative to production, foreign trade, changes in stocks, non-energy-related consumption and energy-related consumption, in the Energy Balances for 2005 and for subsequent years	The significant amount of flaring/losses of natural gas are taken into account with regard to the time series Revision of the NEB	Completed	

18.7 Uncertainties in the activity data for stationary combustion systems

See NIR 2007, Chapter 13.6.

18.8 CO_2 emissions

The CO_2 emission factors have been completely revised for the 2015 report. For the first time, such work was able to draw extensively on data from emissions trading. Emissions trading data were available on relevant calorific values, emission factors, fuel quantities and data quality. The data were subjected to thorough quality control. For example, only factors on level 3 or 4 (measurement) entered into the calculations. In addition, emission factors were replaced if it was clear that they had simply been taken from lists. In emissions trading, some substance flows are not unambiguously named, and this can lead to erroneous material allocations in solid fuels categories. With regard to coal, it was possible to identify such misallocations, via the pertinent net calorific values, and then carry out the necessary resorting. Lignite and hard coal can be clearly differentiated via net calorific values. Annually weighted average values were calculated from the quality-checked data. To make it possible to determine whether the resulting factors are representative, the underlying fuel quantities were compared with the corresponding quantities in the Energy Balance. In addition, every effort was made to achieve the greatest possible consistency between net calorific values and emission factors.

Other data sources, in addition to the data from emissions trading, were evaluated as well. Furthermore, archive data were reviewed and measurements of our own were carried out. The recalculations through 1990 were carried out with widely differing procedures, chosen in each case in accordance with the specific subject area. This was done with a view to assuring time-series consistency and to obtaining the most realistic solutions possible. The task of finding well-documented archive data for the year 1990 presented a special challenge, since the documents from that period are available only in paper form and are housed at various different institutions. What is more, data are seldom kept for a period of longer than 20 years.

Since no reliable and representative data are available on the carbon content remaining in ash, an oxidation factor of 1 has been assumed. That figure is also the default value in the 2006 IPCC Guidelines (IPCC, 2006a).

18.8.1 Hard coal

For hard coal, an inter-sectoral emission factor has been calculated. In the present case, this ensures that the total emissions are determined as precisely as possible. One exception in this case consists of the coking coal for the iron and steel industry, which differs considerably from steam coal. Another exception consists of the anthracite coal used in the residential sector and in other small combustion plants; that coal has considerably higher calorific values and carbon-content levels.

For the other types of hard coal, emissions trading data from the years 2005 – 2014 were evaluated. For each type, there are substance flows that can be correlated with specific areas of origin. This makes it possible to determine origin-specific CO_2 emission factors and calorific values. Apart from the coal for which origin-specific data are available, there are quantities of mixed coal, and of coal of uncertain origin, to consider. CO_2 emission factors and calorific values were determined for all individual coal fractions (Germany, South Africa, Australia, Indonesia, Columbia, Norway, Poland, Czech Republic, Russia, the U.S. and Venezuela). In addition, weighted averages were calculated for the other hard-coal types for which specific values cannot be obtained. Two different methods for recalculating the emission factors for hard coal were reviewed. On the one hand, a weighted average for each year was calculated with the help of the data on the various individual areas of origin and the import-flow figures from hard-coal statistics. On the other, a weighted average was formed from all of the emission factors reported and checked in the emissions trading framework. The following figure shows the results of this comparison:

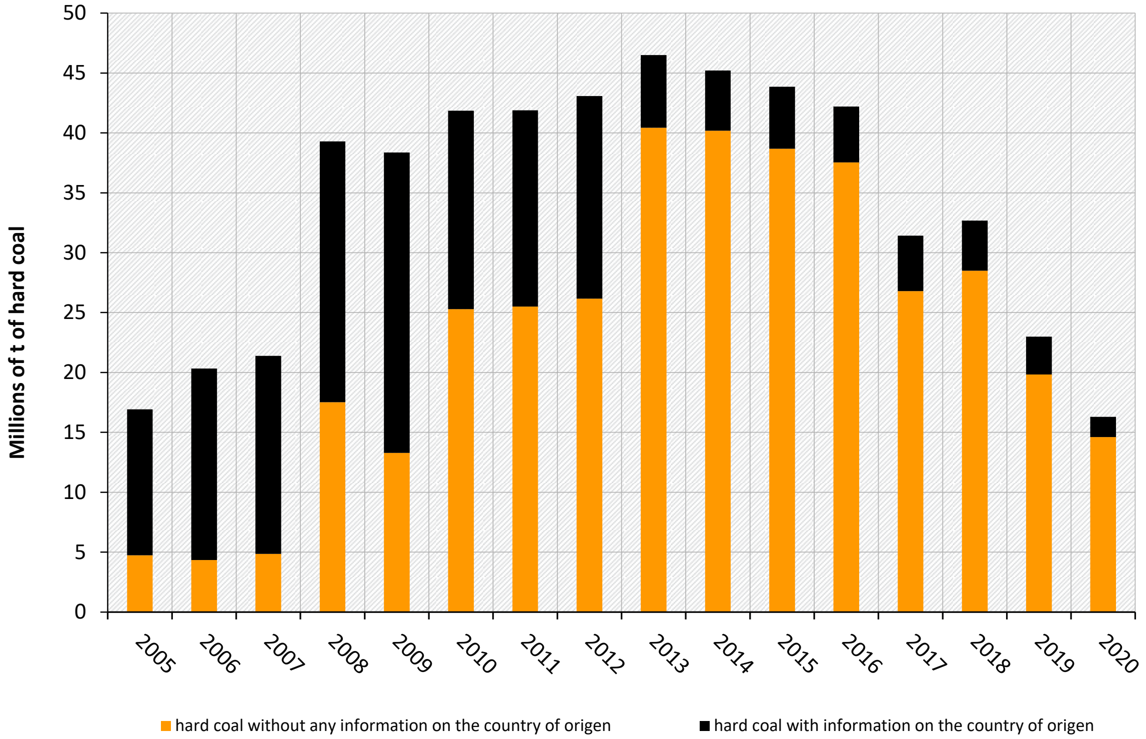
Table 535: Comparison of CO_2 emission factors for hard coal

[t CO2/TJ]	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Calculation via imports	93.874	93.976	93.865	93.924	93.993	94.003	94.181	93.652	93.276	93.888
Weighted EF from all ETS data	93.606	93.940	93.792	94.317	94.121	94.032	94.228	93.675	93.363	93.560
Difference	**0.29%**	**0.04%**	**0.08%**	**-0.42%**	**-0.14%**	**-0.03%**	**-0.05%**	**-0.02%**	**-0.09%**	**0.35%**

Since the differences are very small in most years, as of the year 2006 the weighted emission factors for all hard coal reported in the emissions trading framework (apart from that in the iron and steel sector) can be used – regardless of the area of origin involved. For the recalculation through 1990, the origin-specific emission factors calculated from emissions trading data are combined with the relevant import flows. This produces a consistent time series.

The following figure shows the evaluatable hard-coal quantities for which emission factors and calorific values were available that were measured in the emissions trading framework.

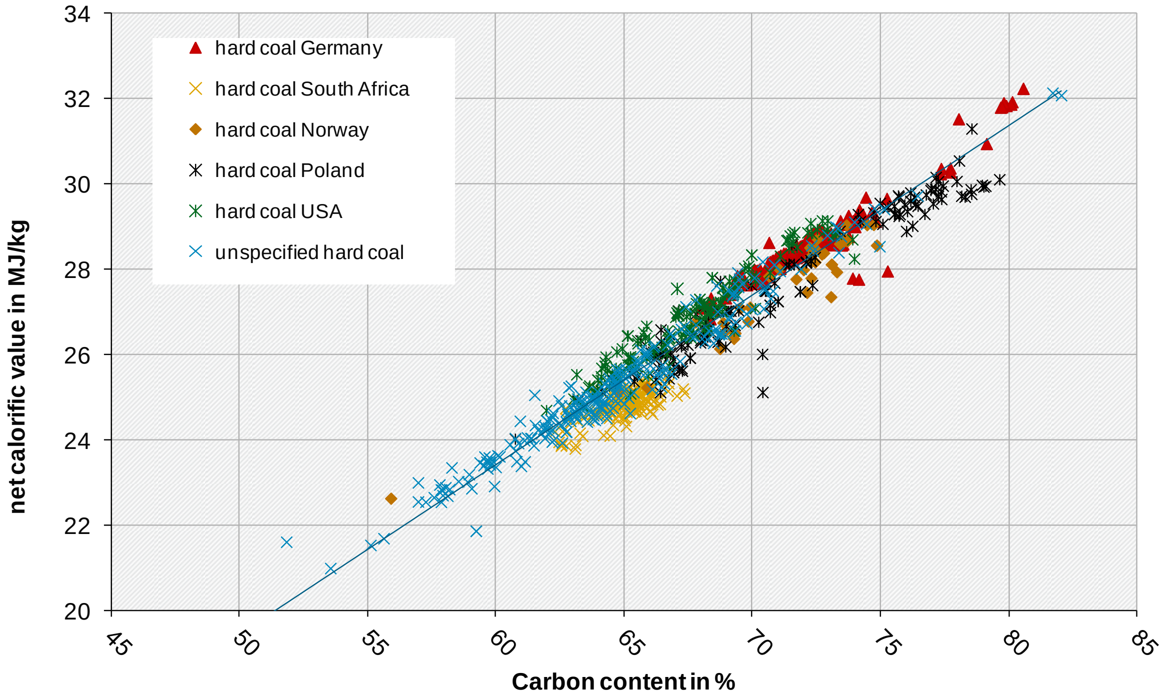
Figure 93: Hard-coal quantities for which emission factors and calorific values measured in the emissions trading framework are available



It emerges that the quality of the values increases – especially so as of the year 2008 – due to changes in regulations. Furthermore, the quantity of hard coal that can be clearly allocated to a specific mining area decreases noticeably. For this reason, the most sensible approach, from a technical standpoint, is to form a weighted average for all hard coal, regardless of area of origin. This is the only way to ensure that the emission factors are representative.

All in all, very thorough quality checks were conducted, and numerous evaluations were carried out. As the following figure illustrates, it is possible to develop fairly clear origin profiles, and there is a clear relationship between carbon content and net calorific value.

Figure 94: Relationship between carbon content and calorific values, for various qualities of hard coal



Most types of hard coal have a carbon content (with respect to the original substance) of between 60 and 75 %. The average, depending on the year concerned, lies between 65 and 66 %. The hard coal in the lower range, with a carbon content as low as 56 %, and a net calorific value of no more than 22 MJ/kg, can be referred to as "high-ballast coal". The hard coal in the upper range, as of a net calorific value of about 30 MJ/kg, is of coking-coal quality. The highest carbon-content levels are found in anthracite.

The figure does not include values for the **coking coal** used in Germany. Coking coal was evaluated separately, due to its special characteristics. In addition, no evaluatable net calorific values are reported, with regard to coal in the emissions trading framework, for the iron and steel industry. As a result, only weight-based emission factors have been determined for that area. Consequently, the coal quantities in that area have also been recorded in terms of tonnes. Since the available statistics give virtually no pertinent calorific-value figures, it seems useful to calculate with natural units. With the help of intensive discussions with the responsible experts of the German Emissions Trading Authority (DEHSt), it proved possible to determine representative emission factors for the hard coal used in the iron and steel industry. From the same data set, it was possible to generate emission factors for **hard-coal coke, hard-coal tar and benzene**.

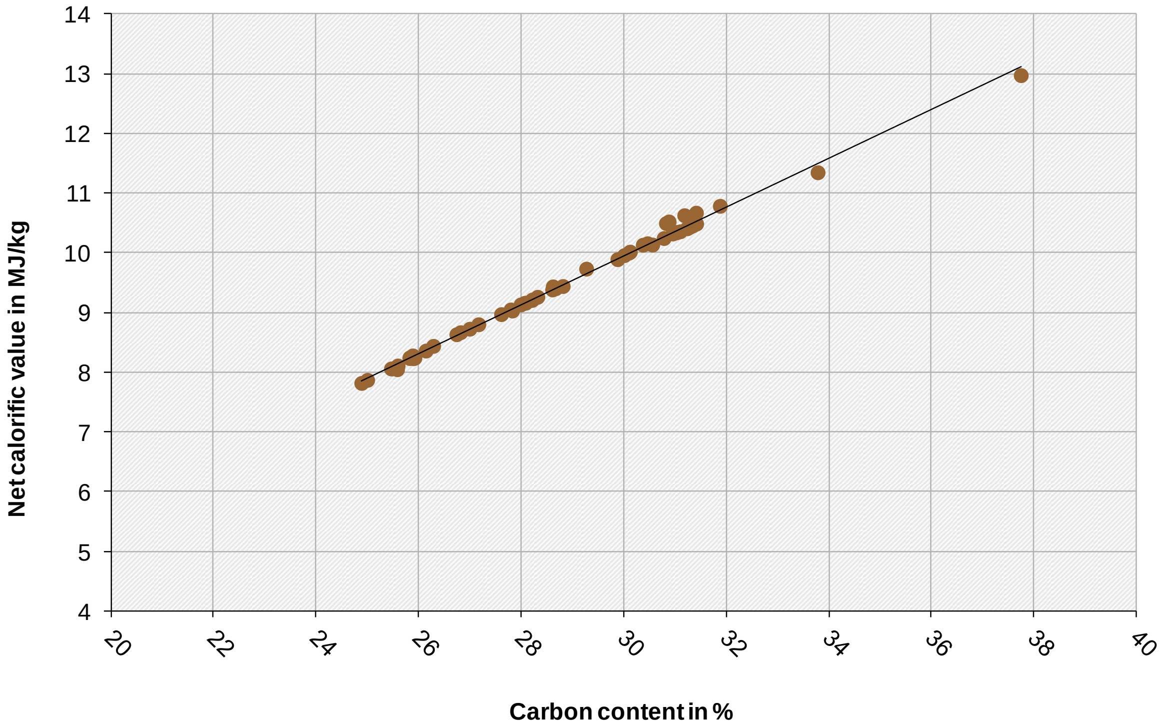
With regard to **hard-coal coke**, an average, energy-based CO_2 emission factor was calculated, for all other industrial sectors, from the emissions trading data for the years 2005 – 2013. The emission factors for the subsequent years differ only slightly, and thus calculations can continue to use the average value.

Since emissions trading statistics do not cover the **hard-coal briquettes** used in small combustion plants, we carried out our own analyses for that area, in the framework of a project. The resulting values have been entered back through the year 1990, since no representative values are available for the base year.

18.8.2 Lignite

The raw lignite used for electricity generation for the public grid can be allocated, via lignite statistics, to specific coalfields. For the period as of the year 2005, the CO_2 emission factors are determined from emissions trading data. The carbon content figures (with respect to the original substance) are also available in mining-district-specific form. The following figure provides an illustrative example:

Figure 95: Relationship between carbon content and net calorific values, illustrated with the example of crude-lignite quality



The variances in sulphur content are larger in lignite than they are in hard coal. Since sulphur content has a noticeable effect on net calorific value and, thus, on the relationship between carbon content and net calorific value, lignite has to be evaluated mining-district-specifically. As Figure 95 shows, there is a clear correlation between net calorific value and carbon content. Consequently, for each relevant year the carbon content, and the energy-related CO_2 emission factor, can be calculated, via a resulting formula, from the net calorific value as known for that year. This makes it possible to recalculate the figures back through 1990 – and thus to form a consistent time series. Some uncertainties do remain, however, since it is likely that a number of small mines were in operation in 1990 that produced coal with other sulphur-content levels. That supposition can no longer be checked, however. Hardly any carbon analyses were carried out in 1990, because carbon content was not an issue at that time. Only a few individual analyses were carried out, and their results are not necessarily representative. For example, only net-calorific-value data are available for lignite from the state of Hesse (Hessische Braunkohle), which was mined until 2003. For recalculation purposes, a mid-level sulphur content was assumed, a level between those found in the Mitteldeutsch ("central German") and Rhenish coalfields. That coal is of little relevance in terms of quantity, however. Between 1991 and 1992, the applicable emission factor changed sharply, because two power stations in that district went offline during that period, and they had been fired for some time with low-quality coal.

For raw-lignite inputs in district heating stations, a weighted emission factor is calculated from lignite inputs for the public electricity supply. For industry and the residential, institutional and commercial (small consumers) sectors, a weighted emission factor was calculated, from sales statistics of the DEBRIV Federal German association of lignite-producing companies and their affiliated organisations, that reflects the distribution of the relevant coalfields.

The emission factors for **lignite briquettes** were determined on the basis of emissions trading data for the period as of 2005. From those data, mining-district-specific averages, for each specific year, were formed. Then a weighted average was calculated from those averages, with the help of DEBRIV sales statistics. The emissions trading data cannot be used directly, since they do not completely reflect and cover the areas being reported on. The residential, institutional and commercial sectors do not take part in emissions trading. To ensure that the fuel-quality figures are the same, the ETS-based data evaluations were compared with our own analyses for briquettes in the residential sector. The two data sets show good agreement. While lignite briquettes are a standardized product, for which certain quality requirements apply, mining-district-specific differences still occur, in the form of carbon-content and sulphur-content variances in the raw lignite used. The recalculation back to 1990 proved to be considerably more complicated than the calculation for raw lignite. From the ETS data for the period 2005 – 2013, it was possible to calculate an average CO_2 emission factor only for Rhenish lignite briquettes. That factor can also be used for the years 1990 – 2004. In the new German Länder, a great many briquette factories were closed in the early 1990s. This considerably changed fuel quality levels in that region. No briquettes are now produced from central German (Mitteldeutsch) lignite. Consequently, no current relevant measurements are available. For this reason, we had to rely on archive data in this area. Data from analyses carried out by Mohry in 1986, and data from the 1986 "Jahresbericht der Kohleindustrie der DDR" ("annual report on the coal industry of the GDR") were available. It emerged that the carbon content previously assumed for central German (Mitteldeutsch) briquettes was too high, by a considerable amount. In calculation of the average values, care was taken to ensure that the resulting emission factors agreed with the net calorific values published by DEBRIV. As a result, it was possible to calculate an annual CO_2 emission factor for each coalfield. From those factors, it was then possible, with the help of DEBRIV sales statistics, to calculate weighted annual CO_2 emission factors.

Data on **lignite dust and fluidised-bed coal** are easier to obtain, since emissions trading data are available from all relevant coalfields. For the recalculations through 1990, average values from the years 2005, and 2008 – 2013, were used, depending on data quality. In an approach similar to that used for raw lignite and briquettes, a weighted CO_2 emission factor was calculated for lignite dust and fluidised-bed coal with the help of DEBRIV sales statistics. As of the year 2005, the CO_2 emission factors from emissions trading are entered directly into the calculation. Then, via the customary procedure, weighted factors are calculated with the help of mining-district-specific sales statistics.

Lignite coke is currently being produced in only one coalfield. In general, hearth furnace coke is used primarily for its properties as a material. Since fuel quality in this category fluctuates very little, an average was formed from the ETS data for the period 2008 – 2013 and then used for recalculations back through 1990. For the new German Länder, only one data source was available. That source consists of analyses carried out by the Ingenieurschule für Bergbau und Energetik "Ernst Thälmann" (the "Ernst Thälmann" school of engineering, specialising in mining and energy technology), located in Senftenberg. It seems plausible, however, that the coke studied in those analyses, in comparison to Rhenish coke, had a considerably lower carbon content and considerably higher ash and sulphur content. Consequently, the emission factor calculated for the new German Länder is lower.

The emission factor determined for 2014, from emissions trading data, at 109.317 t CO_2/TJ, is very close to the average value calculated for 2005 – 2013, 109.578 t CO_2/TJ.

The data set from the Ingenieursschule für Bergbau und Energetik "Ernst Thälmann" in Senftenberg also included analyses for **air-dried peat**. The net calorific value given agrees with the corresponding value used in the Energy Balance. The values for the **lignite tar oil** used in refineries in the new German Länder come from the same data source.

No data were available for the **lignite tar** used in the new German Länder. As an alternative, analysis data from the research report Vertrag Nr. (contract no.) 7220-EB/106 (DEBRIV 1980) were used. Lignite tar has not been used since 1991.

The ETS data can be used to generate CO_2 emission factors for **meta-lignite** for the period as of 2008. At present, only very small quantities of meta-lignite are used in Germany. To make it possible to calculate the applicable emission factors for the period back through 1990, the relevant carbon / net calorific value relationship was determined from the available ETS data. It was then possible, with the help of the net calorific values known from the DEBRIV lignite statistics, to produce a consistent time series.

18.8.3 Petroleum

Crude oil and **naphtha** are not used in combustion systems in Germany. For this reason, the emissions trading data do not include any carbon-content figures for these raw materials. In addition, no analysis values are available from other sources. For this reason, the default values from the 2006 Guidelines have been used. The relevant factors have been used only for the Reference Approach and for the transformation balance for refineries. Default values have also been used for **avgas** and **lubricants**.

For calculation of the CO_2 emission factors for **gasoline**, research report 502-1 of the German Society for Petroleum and Coal Science and Technology (DGMK), "Zusammensetzung von Ottokraftstoffen aus deutschen Raffinerien" ("composition of gasolines produced by German refineries") (DGMK, 2002) was comprehensively evaluated. That study studied the components of the fuels involved in great detail. As a result, data are available on the average concentrations of 113 individual substances, and of 16 substance groups, in the categories regular gasoline, super (premium) and super plus (premium plus), for all German refineries. Via the carbon-content levels in the substances listed, and the pertinent concentrations, it was possible to calculate weighted carbon-content levels for each of the 3 grades of gasoline involved. This was because it was possible to calculate weight-based emission factors from carbon content. The following table presents the average values and fluctuation ranges ranges for the CO_2 factors:

Table 536: Composition of, and emission factors for, gasoline

		average CO_2 EF	Minimum	Maximum	Units
Regular gasoline		**3.183**	**3.160**	**3.206**	**t CO_2/ t**
Super (premium)		**3.185**	**3.152**	**3.211**	**t CO_2/ t**
Super plus (premium plus)		**3.141**	**3.102**	**3.176**	**t CO_2/ t**
With the following composition:					
Regular gasoline	Kerosenes	45.30	52.06	41.64	%
	Aromatic compounds	37.14	28.68	48.12	%
	Oxygen compounds	0.30	0.32	0.19	%
Super (premium)	Kerosenes	40.23	23.32	32.22	%
	Aromatic compounds	43.44	47.99	46.30	%
	Oxygen compounds	2.54	11.52	0.01	%
Super plus (premium plus)	Kerosenes	33.95	41.60	33.29	%
	Aromatic compounds	44.33	34.43	49.19	%
	Oxygen compounds	10.49	13.44	6.80	%

The naphthenes and olefins in the gasolines, while worthy of mention as additional components, have virtually no influence on CO_2 factors. In the case of regular gasoline, levels of aromatic compounds are the main factor that affects the size of CO_2 emission factors. On average, aromatic compounds tend to have higher carbon-content levels than kerosenes do. The levels of aromatic compounds found in a gasoline depend primarily on whether the refinery that produces the gasoline also produces basic chemical compounds. Where refineries do produce such compounds, efforts are made to make the highest possible fractions of aromatic compounds available for chemical production processes. The levels of aromatic compounds found in premium-grade gasolines fluctuate only very slightly. The CO_2 factors for such gasolines are determined primarily by the gasolines' content of oxygen compounds (MTBE). In the case of super plus (premium plus) grades, the levels of aromatic compounds and of oxygen compounds both play a role.

A weighted CO_2 emission factor has been calculated from the figures on annual sales of regular gasoline (Normalbenzin), premium (Super) and premium plus (Super Plus) (Official Mineral Oil Statistics). No figures for the new German Länder are available for the year 1990. For this reason, the breakdown by individual fuel qualities for the year 1991 has been applied to 1990. In the interest of consistency, an energy-related CO_2 emission factor has been calculated from the calculated weight-based emission factor and the lower net calorific value listed in the Energy Balance. So-calculated emission factors hardly fluctuate at all over the years concerned. The only year in which the emission factor changed more significantly was 2011, when the factor was unusually low. When the "E10" fuel was introduced (with a 10% biofuel fraction in premium grade fuel), greater quantities of Super Plus (premium plus) were sold.

The basis for calculation of the emission factor for **diesel fuel** is research report (Forschungsbericht) 583 of the German Society for Petroleum and Coal Science and Technology (DGMK): "Zusammensetzung von Dieselkraftstoffen aus Deutschen Raffinerien 1999-2002" ("Composition of diesel fuels from German refineries, 1999-2002"). For that study, winter and summer samples from 13 refineries were studied. From the analysis results, an average value for the fuel quality in summer and an average value for the fuel quality in winter were calculated. In Germany, the availability of "winter diesel" is regulated by law. The law requires filling stations to offer winter diesel from 15 November to 28 February. In addition, a transition phase has to be taken into account, and thus a usage period of about 4 months can be expected for winter diesel. Consequently, diesel-powered vehicles operate with summer diesel for 8 months. Via this distribution, a weighted emission factor was calculated from the analysis results relative to summer and winter diesel.

The CO_2 emission factors for **light fuel oil, petroleum coke, heavy fuel oil** and **other petroleum products** have been calculated from emissions trading data. The relevant average values for the years 2005 – 2013 have been applied to the years back through 1990. As of 2005 (or 2008, as relevant), year-specific, weighted average values from emissions trading will be used for petroleum coke, heating oil (heavy) and other petroleum products. It is difficult to draw a precise line between heavy fuel oil and other petroleum products. In keeping with Mineral Oil Statistics (Mineralölstatistik), "other petroleum products" have been defined as residual substances from refineries, and the pertinent emission factor has been calculated accordingly.

For **refinery gas**, a weight-based CO_2 emission factor has been calculated from the ETS data. Since the annual fluctuations for such gas are small, the same factor, formed from the average values for the years 2005 – 2013, has been used for all years. While the lower net calorific values given in the context of emissions trading show only slight annual fluctuations, the calorific values used in the Energy Balance vary significantly, in some cases, and show discrepancies with the ETS data. The refinery-gas quantities reported in the Energy Balance come from the Mineral Oil Statistics. Those values agree well with the ETS data. In the interest of consistency, the lower net calorific values used in the Energy Balance were chosen for inventory preparation. The pertinent emission factor has been adjusted accordingly.

For determination of the CO_2 emission factors for **LP gas**, first the applicable carbon content levels for butane and propane were calculated via molar masses. The pertinent fractions for the two components are published in the annual report of the German Liquid Petroleum Gas Association (Deutscher Verband Flüssiggas e.V.). The data through 1990 have also been provided by that association. Via the applicable fractions for the two components, a weighted emission factor years was calculated, and then that factor was divided by the lower net calorific value used in the Energy Balance. The LP gas emission factors published in the NIR apply only to energy-related consumption. The data for material-related use differ, since the relevant mixtures contain more butane than propane on average. Gas for energy-related use tends to contain more propane than butane. Unfortunately, the ratios between the two fuels are no longer available as of reported year 2017. For this reason, the existing butane-to-propane ratio will be carried forward in future. This is not expected to have a major impact. The fractions for the two fuels varied only insignificantly over the years.

18.8.4 Gases

Some gaseous fuels are allocated to the solid fuels category, in keeping with a) the IPCC fuel definitions and b) the Guidelines' emphasis on the fact that they originate in solid fuels or are produced from such fuels. This approach is taken for coke oven gas, town gas, blast furnace gas and basic oxygen furnace gas. The other relevant produced gases are allocated to the liquid fuels category, since those gases are produced primarily by the chemical industry, in non-energy-related consumption of naphtha and other petroleum products. These allocations play a necessary role in enabling the Reference Approach to achieve useful results.

For determination of CO_2 emission factors for **coke oven gas, blast furnace gas, basic oxygen furnace gas** and **petroleum gas**, emissions trading data are used. For the recalculations back through 1990, average values were calculated from the ETS data for the period 2005 – 2013 and then used for the years 1990 – 2004. In energy statistics, blast furnace gas and basic oxygen furnace gas are reported only as a gas mixture. For this reason, a weighted emission factor for such mixtures has been calculated from the individually determined emission factors for the two gases and from produced quantities of blast furnace gas and basic oxygen furnace gas. In all likelihood, the mixing ratios of such mixtures vary throughout the different specific areas in which the mixtures are used. Emissions trading data only partially cover combustion of blast furnace gas and basic oxygen furnace gas, but the calculation method used here ensures that the total emissions of such gases are still calculated correctly.

Until 1996, town gas was still used in Germany. In in the Energy Balance, it is combined with coke oven gas. The applicable fractions of **coke oven gas and town gas** cannot be determined on the usage side (the situation is similar to that for combustion of blast furnace gas and basic oxygen furnace gas). For this reason, here as a well a weighted emission factor is calculated – in this case from the produced quantities of coke oven gas and town gas. The values for **town gas** have been obtained from the firms of GASAG and DBI Gas- und Umwelttechnik GmbH Leipzig. Detailed analyses are available for the years 1989 through 1991. The different gases have been mixed so as to yield mixtures with fairly constant town-gas quality. DBI Gas- und Umwelttechnik GmbH Leipzig has also provided information regarding the mixing ratios in which the gas fractions are combined to produce summer-quality and winter-quality grades. The emission factors have been weighted accordingly. The figures for **fuel gas**, which is used exclusively in the new German Länder, have been obtained from a data set provided by the Ingenieurschule für Bergbau und Energetik "Ernst Thälmann" (the "Ernst Thälmann" school of engineering, specialising in mining and energy technology), located in Senftenberg. The term "fuel gas" has not been clearly defined. Since that gas has been used primarily in mine-mouth power plants, it may be assumed to be lignite-based. Such gases can vary widely in composition, however. Consequently, the applicable emission factors can also vary widely. They lie within the range 118.6 – 131 t CO_2/TJ. To ensure that the base-year emissions are not overestimated, a conservative approach is applied, and the lowest emission factor is used. The 1989 annual report for the energy sector (Energiewirtschaftlicher Jahresbericht 1989) gives a net calorific value of 5.3 MJ/Nm^3 for "other gas", a figure that points to a higher emission factor. Since coke oven gas, town gas and fuel gas are reported in combined form in the Energy Balance, the net calorific values for those individual gases can no longer be determined.

Other produced gases are used primarily in the chemical industry. The category to which that term refers includes both a) gases with high calorific values and with large hydrogen fractions and b) flare gases with low calorific values and with large nitrogen fractions. The pertinent emission factor has been calculated from emissions trading data for the chemical industry. In the process, an average value for the years 2008 – 2013 was formed. Although the calorific-value figures given in energy statistics differ considerably from those used in emissions trading, the applicable cubic-metre quantities listed in the two contexts show good agreement. Consequently, an emission factor based on those natural units (cubic metres) was calculated for this category. In the interest of consistency, the net calorific value used in energy statistics has been used for calculations for inventory preparation. An analysis of the energy consumption in large combustion plants has shown that the generated electricity quantities were considerably larger than had been previously thought. As a result of this discrepancy, a decision has been made calling for use of a different net calorific value in future calculations. The CO_2 emission factor will decrease as a result.

For **mine gas**, a methane content figure was calculated with the help of the methane-utilization data provided by the Gesamtverband Steinkohle (GVSt) hard-coal-mining association and the total methane quantities listed (in cubic metres) in the Energy Balance. A CO_2 emission factor was then calculated via the corresponding gas composition. Statistical differences result in some years, and thus calculations are carried out with the lowest methane-content figure, in the interest of applying a conservative approach.

Since the **natural gas** quantities recorded in the emissions trading context are not representative, and since default emission factors are often used in this category, the firm of DBI Gas- und Umwelttechnik GmbH Leipzig carried out its own analyses in the framework of the project "Messungen der Erdgasqualität an verschiedenen Stellen im Netz zur Ableitung bzw. Verifizierung von durchschnittlichen Emissionsfaktoren und Heizwerte von Erdgas" (2014; measurements of natural gas quality at various locations within the network, for purposes of derivation and verification of average emission factors and net calorific values for natural gas). In that effort, measurements were carried out at 32 locations throughout Germany. The measurement points were selected so as to ensure that all important imported gases and the country's own in-country production were taken into account. In addition, a mixture distributed in Germany was analysed. Alternative measuring sites were found for selected border handover points at which measures proved unfeasible. Within the relevant gas-quality ranges, the CO_2 emission factors fluctuate only very slightly. And the values fluctuate very little overall. In an approach similar to that used for other fuels, no sector-specific emission factors were determined for natural gas. As it is, the data do not allow determination of such factors. It thus seemed advisable, and more feasible, to determine weighted emission factors at the national level. They were calculated on the basis of the measurements carried out, of import flows and of the country's own production. Since 2015, it has no longer been possible to use this calculation method, since large quantities of imports are subject to confidentiality. As a result, for the period as of 2015, the weighted average values calculated from emissions trading data have been used, even though such average values are not fully representative of the actual situation. In previous years, the different factors were very similar.

18.8.5 Waste and special fuels

For **waste**, a carbon content pursuant to VDI 3460 is assumed. Energy statistics serve as the data source for the calorific values. The data for **special fuels** were obtained from the project "Einsatz von Sekundärbrennstoffen" ("use of secondary fuels"; Lechtenböhmer et al. (2006c), FKZ 204 42 203/02). These data still need to be reviewed, with the help of emissions trading data, and corrected as necessary. In general, it is difficult to compare data on fuels with relevant biomass fractions with ETS data, since the emission factors for such fuels do not always take account of the biomass fractions. What is more, the terms used in the ETS context are not always unambiguous. And since the net calorific values of special fuels vary considerably more strongly than those of conventional fuels do, net calorific values cannot be used for unambiguous identification of special fuels. All of these factors considerably complicate such comparisons. While for conventional fuels inter-sectoral emission factors are determined in most cases, for special fuels the factors have to be calculated sector-specifically.

For a few special fuels, emissions trading data have already been evaluated. This applies to **waste oil** and **waste plastics**. The relevant values are used in the carbon balance for the iron and steel industry. The emission factor for **waste tyres** has been calculated from ETS data from the year 2010.

18.8.6 Biomass fuels

The emission factors for the biomass fuels that are used as **substitute fuels** in industry have also been obtained via the project "Einsatz von Sekundärbrennstoffen" ("use of secondary fuels"; Lechtenböhmer et al. (2006c), FKZ 204 42 203/02). The CO_2 emission factors for **wood** have been obtained from the research report "Effiziente Bereitstellung aktueller Emissionsdaten für die Luftreinhaltung" ("Efficient provision of current emissions data for purposes of air quality control"; (Struschka et al., 2008)).

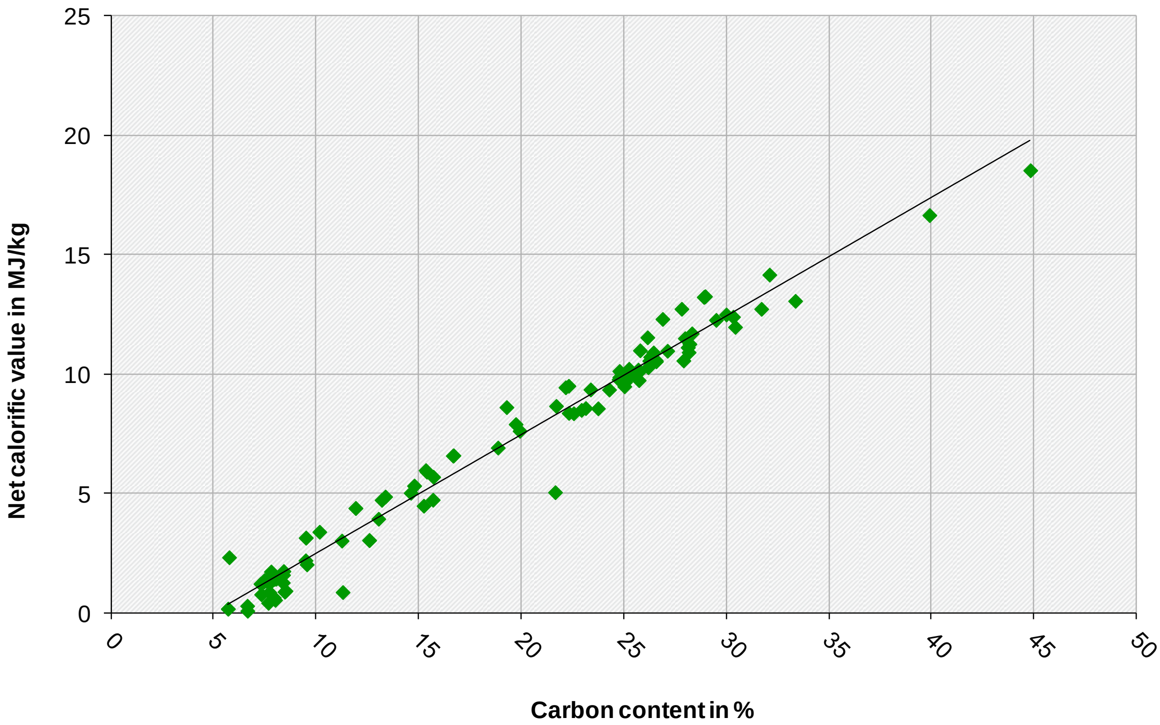
With regard to **black liquor** from wood pulp production, emission factors for spent sulphate liquor and for spent sulphite liquor were calculated on the basis of operator information relative to liquor composition. A weighted mean is formed annually by applying those two values to the produced quantities of sulphite and sulphate wood pulp.

The process for calculation of the CO_2 emission factors for **biogas, landfill gas** and **sewage gas** began with evaluation of relevant net calorific values from energy statistics. Averages of those calorific values were then calculated for each category from the values for the years 2009 – 2011. Then, corresponding methane quantities were determined from each such average calorific value. Apart from methane, these gases consist mainly of carbon dioxide and a small nitrogen fraction. As a result, the net calorific value is determined via the methane content. The biogases also contain other hydrocarbons, in fractions totalling about 1 %. A CO_2 emission factor was then calculated via this known gas composition.

The emission factor for **bioethanol** was calculated on the basis of the number of carbon atoms, and of the molar mass, of ethanol. The relevant net calorific value is published by the Bundesverband der Deutschen Bioethanolwirtschaft German bioethanol industry association. For **bodiesel**, we did not carry out any analyses of our own. For this reason, the default emission factor given in the 2006 IPCC Guidelines (IPCC, 2006a) has been used.

For determination of the CO_2 emission factors for **sewage sludge, waste wood and animal meal**, data from emissions trading were evaluated. For animal meal and waste wood, a median was formed from data on carbon content and net calorific value available for the period 2005 through 2014. For sewage sludge, data from municipal waste-management companies were also included in the evaluation. Since sewage sludges are used both in their original condition and in a dry condition, the spectrum of net calorific values ranges from < 1 MJ/kg to 18 MJ/kg. Consequently, the standard deviation for the CO_2 emission factors is so high that it would not be useful to form an average or median. Since the carbon content correlates very well with the net calorific value, a suitable formula can be derived from the graphic representation (cf. the following figure).

Figure 96: Relationship between carbon content and calorific values, for various sewage sludges



As a result, the pertinent carbon content and emission factors can be calculated with the help of the net calorific values, as given in energy statistics, for co-incineration and for mono-incineration.

18.8.7 List of carbon dioxide emission factors derived for energy & industrial processes

The following tables provide an overview of the carbon dioxide emission factors used in the inventory.

Table 537: CO_2 emission factors derived for emissions reporting for the period as of 1990; energy

Fuel-based emission factors	Units	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Coal																				
Hard coal																				
Raw hard coal (power stations, industry)	t CO_2/TJ	93.1	93.1	93.5	93.9	93.9	93.8	94.3	94.1	94.0	94.2	93.7	93.4	93.6	93.5	93.6	93.4	93.1	93.7	93.6
Hard-coal briquettes	t CO_2/TJ	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9	95.9
Hard-coal coke (not including that for the iron & steel industry)	t CO_2/TJ	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.1	108.3	108.1	107.5	108.3
Hard-coal coke for the iron & steel industry	t CO_2/ t	3.29	3.26	3.23	3.19	3.18	3.16	3.17	3.17	3.18	3.17	3.17	3.20	3.19	3.17	3.17	3.18	3.18	3.18	3.19
Anthracite (heat market for households, commerce, trade, services)	t CO_2/TJ	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6	97.6
Ballast hard coal, *old German Länder*	t CO_2/TJ	95.2																		
Coking coal, *Germany*	t CO_2/ t	2.96	2.93	2.90	2.87	2.86	2.86	2.85	2.85	2.86	2.85	2.86	2.85	2.89	2.90	2.88	2.87	2.88	2.89	2.89
Hard coal for the iron & steel industry	t CO_2/ t	2.92	2.92	2.92	2.95	2.99	2.96	2.91	2.86	2.89	2.89	2.91	2.96	2.97	2.90	2.88	2.94	2.90	2.93	2.94
Other hard-coal products	t CO_2/ t	3.30	3.30	3.30	3.30	3.30	3.30	3.27	3.29	3.29	3.30	3.30	3.32	3.32	3.32	3.32	3.33	3.32	3.31	3.32
Hard-coal tar	t CO_2/ t	3.27	3.27	3.27	3.28	3.28	3.28	3.24	3.26	3.27	3.27	3.28	3.31	3.31	3.30	3.31	3.31	3.31	3.30	3.31
Benzene	t CO_2/ t	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.37	3.37	3.37	3.37	3.38

Fuel-based emission factors	**Units**	**1990**	**1995**	**2000**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Lignite																				
Raw lignite																				
Public district heating stations, *Germany*	t CO_2/TJ		111.7	110.8	111.1	111.2	111.3	111.5	111.4	110.7	110.7	111.0	110.7	110.9	111.0	111.2	111.4	110.8	110.6	110.7
Old German Länder	*t CO_2/TJ*	113.8																		
New German Länder	*t CO_2/TJ*	110.0																		
Industry, commercial and institutional and residential ("small consumers"), *Germany*	t CO_2/TJ		106.0	109.8	108.2	107.3	107.4	106.5	106.1	106.3	106.0	105.0	105.1	103.8	104.0	105.8	106.2	106.4	106.5	106.0
Old German Länder	*t CO_2/TJ*	114.7																		
New German Länder	*t CO_2/TJ*	107.7																		
Public power stations; coalfield:																				
Rheinland	t CO_2/TJ	114.8	113.9	113.1	113.2	113.5	113.5	113.8	113.6	113.3	113.3	113.2	113.0	113.1	113.1	113.0	113.0	112.7	112.9	113.3
Helmstedt	t CO_2/TJ	98.7	98.7	98.7	98.7	98.7	98.7	95.2	97.3	96.7	101.7	97.9	103.3	101.1	99.5	97.9	NO	NO	NO	NO
Hesse	t CO_2/TJ	112.2	103.2	103.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lausitz	t CO_2/TJ	111.2	111.3	111.5	111.2	111.3	111.3	112.2	112.0	110.6	109.9	111.0	110.3	111.2	110.9	111.3	111.5	110.6	109.9	110.2
Mitteldeutschland	t CO_2/TJ	105.7	103.9	102.9	104.0	103.9	103.5	103.4	103.3	103.4	103.4	102.8	102.9	102.8	102.9	103.9	104.3	104.2	104.2	103.6
Lignite briquettes, Germany	t CO_2/TJ		98.3	99.0	99.3	99.0	99.6	99.8	99.4	99.0	99.3	99.3	99.1	99.6	99.4	99.5	99.3	99.0	99.0	99.2
Old German Länder	*t CO_2/TJ*	99.5																		
New German Länder	*t CO_2/TJ*	96.6																		
Lignite tar, *New German Länder*	t CO_2/TJ	82.9																		
Lignite tar oil, *New German Länder*		78.6																		
Lignite dust and fluidised bed coal, Germany	t CO_2/TJ		97.6	98.1	98.1	98.1	97.9	98.0	97.8	98.0	98.1	98.0	98.0	98.1	98.0	98.1	98.1	97.5	97.5	97.5
Old German Länder	*t CO_2/TJ*	98.3																		
New German Länder	*t CO_2/TJ*	96.1																		
Lignite coke, *Germany*	t CO_2/TJ		109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6	109.6
Old German Länder	*t CO_2/TJ*	109.6																		
New German Länder	*t CO_2/TJ*	100.2																		
Peat, *old German Länder, Germany*		101.8	101.8	101.8	101.8	101.8	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Meta-lignite ("hard lignite")	t CO_2/TJ	96.4	96.4	96.5	NO	96.6	95.7	96.7	95.5	94.9	94.8	94.9	94.2	95.6	94.5	94.8	94.6	95.1	94.7	94.4

Fuel-based emission factors	Units	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Petroleum																				
Crude oil [4)]	t CO_2/TJ	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3
Gasoline	t CO_2/t	3.181	3.182	3.183	3.183	3.183	3.183	3.184	3.184	3.184	3.180	3.182	3.183	3.183	3.183	3.183	3.183	3.183	3.183	
Naphtha, *Germany*[4)]	t CO_2/TJ		73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3
Old German Länder[4)]	*t CO_2/TJ*	73.3																		
New German Länder[4)]	*t CO_2/TJ*	73.3																		
Kerosene[4)]	t CO_2/TJ	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3
Avgas[4)]	t CO_2/TJ	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Diesel fuel, *Germany*	t CO_2/TJ		74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0
Old German Länder	*t CO_2/TJ*	74.0																		
New German Länder	*t CO_2/TJ*	74.0																		
Light heating oil, *Germany*	t CO_2/TJ		74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0
Old German Länder	*t CO_2/TJ*	74.0																		
New German Länder	*t CO_2/TJ*	74.0																		
Heavy fuel oil	t CO_2/TJ	79.8	79.8	79.8	79.6	79.7	79.8	80.1	79.0	79.7	79.9	80.1	80.0	81.3	80.9	81.6	80.8	79.9	79.4	79.7
Petroleum	t CO_2/TJ	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0
Petroleum coke (not including coke burn-off in catalyst regeneration)	t CO_2/TJ	94.8	94.8	94.8	94.8	94.8	94.8	95.0	94.2	94.6	95.4	94.7	95.1	95.7	97.6	103.8	104.3	104.0	104.3	103.4
LP gas, *Germany (energy-related consumption)*	t CO_2/TJ		65.3	64.4	65.3	65.4	66.6	65.2	65.3	65.3	65.4	65.4	65.4	65.5	66.3	66.3	66.3	66.3	66.3	66.3
Old German Länder	*t CO_2/TJ*	65.6																		
New German Länder	*t CO_2/TJ*	65.6																		
Refinery gas, *Germany*	t CO_2/TJ		56.9	56.7	57.0	57.1	57.6	57.9	62.2	65.4	61.3	62.3	61.3	62.0	62.4	53.3	70.4	58.0	58.0	58.0
Old German Länder	*t CO_2/TJ*	54.6																		
New German Länder	*t CO_2/TJ*	54.6																		
Other petroleum products, *Germany*	t CO_2/TJ		82.1	82.1	82.1	82.1	82.1	82.1	82.5	82.5	82.8	82.9	82.6	82.7	82.3	80.9	83.0	80.4	80.1	80.4
Old German Länder	*t CO_2/TJ*	82.1																		
New German Länder	*t CO_2/TJ*	82.1																		
Lubricants[4)]		73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3	73.3
Gases																				
Coke oven gas, *Deutschland*	t CO_2/TJ		41.0	41.0	40.7	41.1	40.6	40.9	41.1	40.3	41.6	41.2	41.8	41.2	41.3	41.1	40.7	40.9	40.8	41.0
Old German Länder	*t CO_2/TJ*	41.0																		
New German Länder	*t CO_2/TJ*	43.6																		
Coking-plant and city gas, *Germany*	t CO_2/TJ		42.6																	
Old German Länder	*t CO_2/TJ*	43.2																		
New German Länder	*t CO_2/TJ*	58.3																		
Blast furnace gas and basic oxygen furnace gas, *Germany*	t CO_2/TJ		257.1	258.7	252.9	256.6	249.4	257.5	265.9	259.7	264.7	263.5	259.5	256.8	261.3	256.7	258.6	259.6	259.2	256.4
Old German Länder	*t CO_2/TJ*	264.6																		
New German Länder	*t CO_2/TJ*	264.6																		
Fuel gas, *New German Länder*	t CO_2/TJ	118.4																		
Other produced gases, *Germany*	t CO_2/1000 m^3	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77

Fuel-based emission factors	Units	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Natural gases																				
Natural gas, *Germany*	t CO_2/TJ		55.8	55.8	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.8	55.8	55.7	55.7	55.8
Old German Länder	*t CO_2/TJ*	55.7																		
New German Länder	*t CO_2/TJ*	55.5																		
Petroleum gas	t CO_2/TJ	61.9	61.9	61.9	61.9	61.9	61.9	61.7	61.9	61.4	61.5	61.5	63.2	62.0	61.6	61.9	62.5	63.6	62.2	61.0
Pit gas	t CO_2/TJ	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1	68.1
Waste 2)																				
Household waste / municipal waste	t CO_2/TJ	109.6	96.9	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5	91.5
Industrial waste, *Germany*	t CO_2/TJ		71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1	71.1
Old German Länder	*t CO_2/TJ*	73.9																		
New German Länder	*t CO_2/TJ*	74.9																		
Special waste, Germany	t CO_2/TJ		83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0
Special fuels[1]																				
Used oil	t CO_2/TJ	75.7	75.7	75.7	75.7	75.7	75.7	74.6	76.8	75.9	75.9	77.3	75.6	75.5	75.3	76.3	75.4	75.1	77.6	76.9
Waste plastics	t CO_2/TJ	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9	80.9
Waste tyres	t CO_2/TJ	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4	88.4
Bleaching clay	t CO_2/TJ	NO	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2
Sewage sludge (2 MJ/kg)	t CO_2/TJ	NO	NO	NO	168.9	168.9	168.9	168.9	168.9	168.9	168.9	168.9	168.9	168.9	168.9	168.9	168.9	168.9	168.9	168.9
Sewage sludge (4 MJ/kg)	t CO_2/TJ	NO	NO	NO	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4	120.4
Sewage sludge (6 MJ/kg)	t CO_2/TJ	NO	NO	NO	104.2	104.2	104.2	104.2	104.2	104.2	104.2	104.2	104.2	104.2	104.2	104.2	104.2	104.2	104.2	104.2
Sewage sludge (8 MJ/kg)	t CO_2/TJ	NO	NO	NO	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1	96.1
Sewage sludge (10 MJ/kg)	t CO_2/TJ	NO	NO	NO	91.3	91.3	91.3	91.3	91.3	91.3	91.3	91.3	91.3	91.3	91.3	91.3	91.3	91.3	91.3	91.3
Solvents (waste)	t CO_2/TJ	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2	74.2
Biomass fuels[3]																				
Spent liquors from pulp production	t CO_2/TJ	121.1	121.1	110.3	104.8	99.2	98.6	98.1	97.6	98.3	98.0	98.2	97.9	97.5	97.8	97.9	97.4	97.8	97.5	
Fibre/de-inking residues	t CO_2/TJ	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9	54.9
Firewood, untreated	t CO_2/TJ	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1	102.1
Waste wood, wood scraps (industry)	t CO_2/TJ	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8	107.8
Waste wood, wood scraps (commercial/institutional)	t CO_2/TJ	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4	101.4
Bark	t CO_2/TJ	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6
Animal meals and fats	t CO_2/TJ	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8	85.8
Biogas	t CO_2/TJ	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6
Landfill gas	t CO_2/TJ	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4	111.4
Sewage gas	t CO_2/TJ	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9	104.9
Bioethanol	t CO_2/TJ	NO	NO	NO	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6
Biodiesel[4]	t CO_2/TJ	NO	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8	70.8

Fuel-based emission factors	**Units**	**1990**	**1995**	**2000**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Other factors, units [kg/t]																				
Flue-gas desulphurisation	kg/t	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0	440.0

1) Designations of fuels as defined for the inventory data can diverge from other standards, and they are listed as such, and given EF as such, only in the inventory.

2) Annual changes in EF as a result of varying fractions for combustion systems and plants' own systems. 1990 through 1994 – for each year, separately for old German Länder / new German Länder

3) Listed for selected fuels; calculated CO_2 emissions are reported only as memo items, and do not enter into the total inventory quantities; biomass fractions from special fuels (see above) are not listed separately, because their CO_2 EF are not differentiated.

4) Default values

Remark: **The information and FAQ provided by the German Emissions Trading Authority (DEHSt) must be taken into account in any use of substance data from the NIR in the context of the ETS.**

Table 538: Emission factors for CO_2 as of 1990, as derived for emissions reporting: industrial processes

Units [kg CO_2 / t (raw material or product)]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2.A.1 Production of cement clinkers	530.00	530.00	530.00	530.00	530.00	530.00	530.00	530.00	530.00	530.00	530.00	530.00	530.00	530.00	530.00
2.A.2 Production of burnt lime	746.00	746.00	746.00	746.00	746.00	746.00	746.00	746.00	746.00	746.00	746.00	746.00	746.00	746.00	746.00
2.A.2 Production of dolomite lime	867.00	867.00	867.00	867.00	867.00	867.00	867.00	867.00	867.00	867.00	867.00	867.00	867.00	867.00	867.00
2.A.3 Production of container glass	193.00	193.00	193.00	193.00	193.00	193.00	193.00	193.00	193.00	193.00	193.00	193.00	193.00	193.00	193.00
2.A.3 Production of flat glass	208.00	208.00	208.00	208.00	208.00	208.00	208.00	208.00	208.00	208.00	208.00	208.00	208.00	208.00	208.00
2.A.3 Production of household and table glassware	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00	120.00
2.A.3 Production of special glass	113.00	113.00	113.00	113.00	113.00	113.00	113.00	113.00	113.00	113.00	113.00	113.00	113.00	113.00	113.00
2.A.3 Production of glass fibres	198.00	198.00	198.00	198.00	198.00	198.00	198.00	198.00	198.00	198.00	198.00	198.00	198.00	198.00	198.00
2.A.3 Production of rock wool	299.00	299.00	299.00	299.00	299.00	299.00	299.00	299.00	299.00	299.00	299.00	299.00	299.00	299.00	299.00
2.A.3 Production of glass[1)]	118.94	115.64	112.76	115.53	115.70	113.75	116.30	118.54	119.58	123.88	123.51	116.88	118.09	117.41	116.54
2.A.4.a Production of ceramics[2)]	71.79	74.91	69.47	61.53	59.20	58.76	58.42	58.30	56.43	54.74	55.56	54.79	53.46	53.75	53.23
2.A.4.b Use of soda ash	415.00	415.00	415.00	415.00	415.00	415.00	415.00	415.00	415.00	415.00	415.00	415.00	415.00	415.00	415.00
2.B.1 Production of ammonia[3)]	2227.63	2246.17	2160.68	2190.69	2171.33	2091.96	2195.60	2107.36	1654.47	1507.97	1415.79	1396.84	1372.08	1382.85	1380.36
2.B.5 Production of calcium carbide	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
2.B.7 Production of soda ash	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
2.B.8 Petrochemicals	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
2.B.8.f Production of carbon black	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960	1,960
2.C.1 Production of electrical steel	8.50	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
2.C.1 Production of oxygen steel; limestone input	440.00	440.00	440.00	440.00	440.00	440.00	440.00	440.00	440.00	440.00	440.00	440.00	440.00	440.00	440.00
2.C.2 Ferroalloys production	1.500.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00	110.00
2.C.3 Production of primary aluminium	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00	1367.00
2.C.5 Production of refined lead (D)		371.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00
2.C.5 Production of refined lead (old German Länder)	434.00														
2.C.5 Production of refined lead (new German Länder)	200.00														
2.C.6 Zinc production: primary and resmelted zinc	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00	1720.00

C = Confidential data

ABL/NBL/D: Reference to old German Länder / new German Länder / Germany as a whole

1) 2.A.3 for all glass types: CO2-EF = (EM total, including inputs of used glass) / activity data

2) 2.A.4.a for all products: CO2-EF = EM total / activity data

3) 2.B.1: CO2-EF = (EM - Recovery amount) / activity data

Remark: The information and FAQ provided by the German Emissions Trading Authority (DEHSt) must be taken into account in any use of substance data from the NIR in the context of the ETS.

18.9 Analysis of CO_2 emissions from non-energy-related use of fuels

The great majority of the coal, oil and gas that Germany uses is used for energy-related purposes. The remainder of the coal, oil and gas is used as feedstock for production processes. This consumption enters into the balance as "non-energy use" (NEU).

In the German Energy Balance, this consumption is listed separately, in line 43. The chemical industry is the leading user of fossil fuels for non-energy-related purposes. It uses fossil fuels in steam crackers, in reforming processes, in synthetic-gas production and in the produciton of graphite electrodes. For cracking and reforming, the most important downstream products are ethylene, propylene, 1,3-butadiene, benzene, toluene and xylenes; for production of synthetic gases, the most important such products are ammonia and methanol. Bitumen, lubricants and paraffin waxes are produced in refineries. Bitumen is used in a range of applications, including road surfaces and bitumen sheeting for roofs. Lubricants are used in road vehicles and machines (inter alia). Without suitable adjustments, the consumption figures listed in Energy Balance line 43 cannot be compared with the CO_2 and NMVOC emissions from use of fossil fuels, in non-energy-related uses, that are reported in the inventory under industrial processes. The reason is that for the industrial processes, only emissions from production or use of products are taken into account, while line 43 takes account of entire feedstocks, thereby including both product-specific emissions and the carbon quantities stored in products. The latter account for far and away the largest share of the feedstocks. Another important difference is that calculation of emissions from product use takes account of imported and exported quantities. In the interest of complete accounting, the carbon quantities stored in the relevant fossil fuel products were taken into account in Table 540 (see below). The correlation between material-related applications and products and the various relevant fuels is oriented to Table 1.3 from Volume 3 of the 2006 IPCC GL, and is based on information provided by relevant associations, producers and experts. In some cases, we had to make our own estimates of the applicable correlation with individual fuels.

The produced quantities of the products listed in the table have been obtained from data reported by the Federal Statistical Office and by the Federal Office of Economics and Export Control (BAFA) and have been converted into CO_2 equivalents. For petrochemical products, the conversion was made on the basis of a) the specific carbon content pursuant to Table 3.10 in Volume 3 of the 2006 IPCC-GL (IPCC, 2006a) and b) the molar mass of CO_2. The pertinent CO_2 equivalent emissions were split among the three feedstocks used in Germany (naphta, LP gas and other petroleum products), in keeping with (internal) data provided by associations.

In the case of carbon black, the product is assumed to consist of pure carbon. That carbon was also converted into CO_2 equivalents.

The production quantities for bitumen, lubricants and paraffin waxes were obtained from the Official Mineral Oil Statistics, and they are based on gross refinery production. The production quantities have been converted into CO_2 equivalents with the help of the following IPCC standard values (Table 1.2 and Table 1.4 from Vol. 2 of the 2006 IPCC GL).

Table 539: IPCC standard values for EF & lower net calorific value

	EF t CO_2/TJ	Lower net calorific value TJ/kt
Bitumen	80.6	40.2
Paraffin wax	73.3	40.2
Lubricating oil	73.3	40.2

For the year 2019, the last year for which a final Energy Balance is available (processing status as of 25 February 2021), the sum of the carbon from the pertinent emissions and of the carbon stored in products amounts to 107 % of the non-energy-related consumption given in line 43 of the Energy Balance. Consequently, the relevant material-related use can clearly be shown to include the quantities listed in the Energy Balance as non-energy-related consumption. No gaps in determination of non-energy-related CO_2 emissions are apparent in the inventory.

Table 540: Verification of the completeness of reported data on CO_2 from non-energy-related use of fossil fuels

			Coal			Petroleum					Gas	
Year	**2019**	**Units**	**Hard coal + hard-coal coke**	**Lignite + lignite products**	**Total, solid fuels**	**Raw benzene (naphtha)**	**Petrol coke**	**LPG**	**Other petroleum products**	**Total, liquid fuels**	**Natural gas**	**Total, gas**
A: Listed NEU quantity (Energy Balance line 43)		TJ	3,096	13,972	17,067.6	384,344	6,728	94,718	248,259	734,049.0	143,999	143,999.0
B: Carbon content		kg C/GJ	29.4	30.1		20.0	28.4	18.1	22.3		15.2	
C: Total input as feedstock / non-energy use		kt C	90.9	421.0	511.9	7,683.4	191.3	1,713.5	5,548.3	15,136.6	2,190.5	2,190.5
D: Total input as feedstock / non-energy use		**kt CO_2**	**333.2**	**1,543.7**	**1,876.9**	**28,172.5**	**701.5**	**6,283.0**	**20,343.9**	**55,501.0**	**8,031.9**	**8,031.9**
E: Implied oxidised carbon fraction		**%**	**141%**			**103%**	**100%**	**93%**	**131%**	**112%**	**89%**	**89%**

			Coal			Petroleum					Gas	
Year	**2019**	**Units**	**Hard coal + hard-coal coke**	**Lignite + lignite products**	**Total, solid fuels**	**Raw benzene (naphtha)**	**Petrol coke**	**LPG**	**Other petroleum products**	**Total, liquid fuels**	**Natural gas**	**Total, gas**
	AD [kt]	**EM [kt CO_2]**	**Activity data + emissions (C in Gg CO_2)**			**Activity data + emissions (C in Gg CO_2)**						
F: Total reported fossil IPPU CO_2		**6,995**	**469**			**29,119**	**702**	**5,824**	**26,682**	**62,326**	**7,155**	**7,155**
2 Industrial processes		**6,995**	**469**			**29,119**	**702**	**5,824**	**5,544**	**41,188**	**7,155**	**7,155**
2B: Chemical industry		**5,832**				**29,119**	**8**	**5,824**	**5,544**	**40,494**	**7,155**	**7,155**
2B1: Ammonia production	2,948	5,233									5,233	5,233
2B5: Carbide production												
2B6: Titanium dioxide production	C	8					8			8		
2B8: Petrochemical industry (1)		NE										
Methanol												
Ethylene	*1,398*										*1,922*	1,922
Propylene	*4,524*					*10,650*		*2,130*	*1,420*	*14,200*		
Butene and 1,3-Butadiene	*3,439*					*8,098*		*1,620*	*1,080*	*10,798*		
Benzene	*2,111*					*5,155*		*1,031*	*687*	*6,874*		
Toluene	*1,514*					*3,842*		*768*	*512*	*5,123*		
Xylene	*547*					*1,373*		*275*	*183*	*1,830*		
Carbon black												
2C: Metal industry	*301*	*591*							*1,661*	*1,661*		
2C1: Iron and steel production (2)		1,164	**469**				**694**			**694**		
2C2: Production of ferroalloys		IE										
2C3: Primary aluminium production	54	6	6									
2C5: Lead production (2)	508	694					694			694		
2C6: Zinc production (2)	C	IE										

Year	2019	Units	Coal: Hard coal + hard-coal coke	Lignite + lignite products	Total, solid fuels	Petroleum: Raw benzene (naphtha)	Petrol coke	LPG	Other petroleum products	Total, liquid fuels	Gas: Natural gas	Total, gas
	AD [kt]	EM [kt CO_2]	Activity data + emissions (C in Gg CO_2)			Activity data + emissions (C in Gg CO_2)						
2D: Non-energy-related products from fuels and solvents (1)									***21,138***	**21,138**		
Lubricants	*2,460*								*7,252*	*7,252*		
Waxes, paraffins, vaseline, etc.	*219*								*646*	*646*		
Bitumen	*4,083*								*13,240*	*13,240*		
Solvents and other product use (3)	IE	IE				IE						

(1) To ensure that a complete carbon balance is obtained, a departure is made here from the report format used for the categories in the inventory. For this reason, the production quantities listed here cannot be compared with the inventory figures in 2.B.8 and 2.D. The emissions given in the table refer to complete transformation of products into CO_2 – instead of, as in the inventory categories – to emissions from production or use.

(2) For reasons of confidentiality, these data are reported in aggregated form.

(3) Since over 90% of solvents from basic chemicals are produced in steam crackers, it is assumed that carbon emitted from NMVOCs comes from products of such crackers.

19 Annex 3: Other detailed methodological descriptions for individual source or sink categories, including KP-LULUCF activities

19.1 Other detailed methodological descriptions for the source category "Energy" (1)

19.1.1 Revision of the activity rates for stationary combustion systems of the new German Länder for the year 1990 and for subsequent years (1.A.1 and 1.A.2)

Problems with the GDR's official statistics in 1990, the year of German reunification, along with the creation of a standardised system of official statistics for all of Germany, had a noticeable effect on the quality of figures, as reported in past inventories, for activity rates of stationary combustion systems of the new German Länder for the year 1990 (and for subsequent years). For this reason, these figures have been revised, completed and corrected as necessary and suitably recorded. This work was carried out by the Institute for Energy and Environment (Institut für Energetik und Umwelt gGmbH; IE gGmbH), in the research project "Base year and update" ("Basisjahr und Aktualisierung"; (Zander and Merten (2006): FKZ 20541115). For a detailed description of the procedure for revising the activity data for stationary combustion systems, see the 2010 NIR.

19.1.2 Energy industry (1.A.1)

19.1.2.1 Methodological aspects of determination of emission factors (Chapter 3.2.6.2)

This section of the Annex describes the main steps carried out in the research projects Rentz et al. (2002) and Fichtner et al. (2011) for determination of emission factors. (This description does not apply to the CO_2 emission factors whose determination is described in Annex 2 (Chapter 18.8).)

Determination of emission factors requires detailed analysis of all operational facilities with regard to technologies used and design-specific emission behaviour. Three overarching categories are formed: large combustion systems, combustion systems within the scope of application of the Technical Instructions on Air Quality Control (TA Luft) and gas turbines. Existing plants are classified in terms of emissions-relevant characteristics, and the pertinent emission factors are determined. These so-called "technology-specific" factors can then be aggregated in an adequate manner. This database also provides the basis for estimating future emissions (changes in the overall make-up of the entire group of facilities, in terms of percentage shares for various facility types). This procedure thus consists of the following steps:

1. Characterisation of the technology-specific emissions behaviour of combustion systems.
   In a first step, the combustion and emissions-reduction technologies used in Germany are briefly described, and the relevant emissions-determining factors are explained. On the basis of this characterisation, emission factors are derived for the various different relevant technologies, differentiated by size class and fuel type. The chosen classification is also oriented to applicable provisions under immissions-control law, an orientation that permits derived emission factors to be compared with limits applicable now or in the future.
2. Analysis of the relevant category structure
   Emissions calculations must be carried out using emission factors that have the same references as the pertinent energy-input data. The latter (data) are broken down by categories that are derived from the national energy balance – cf. Chapter 3.2 – and are

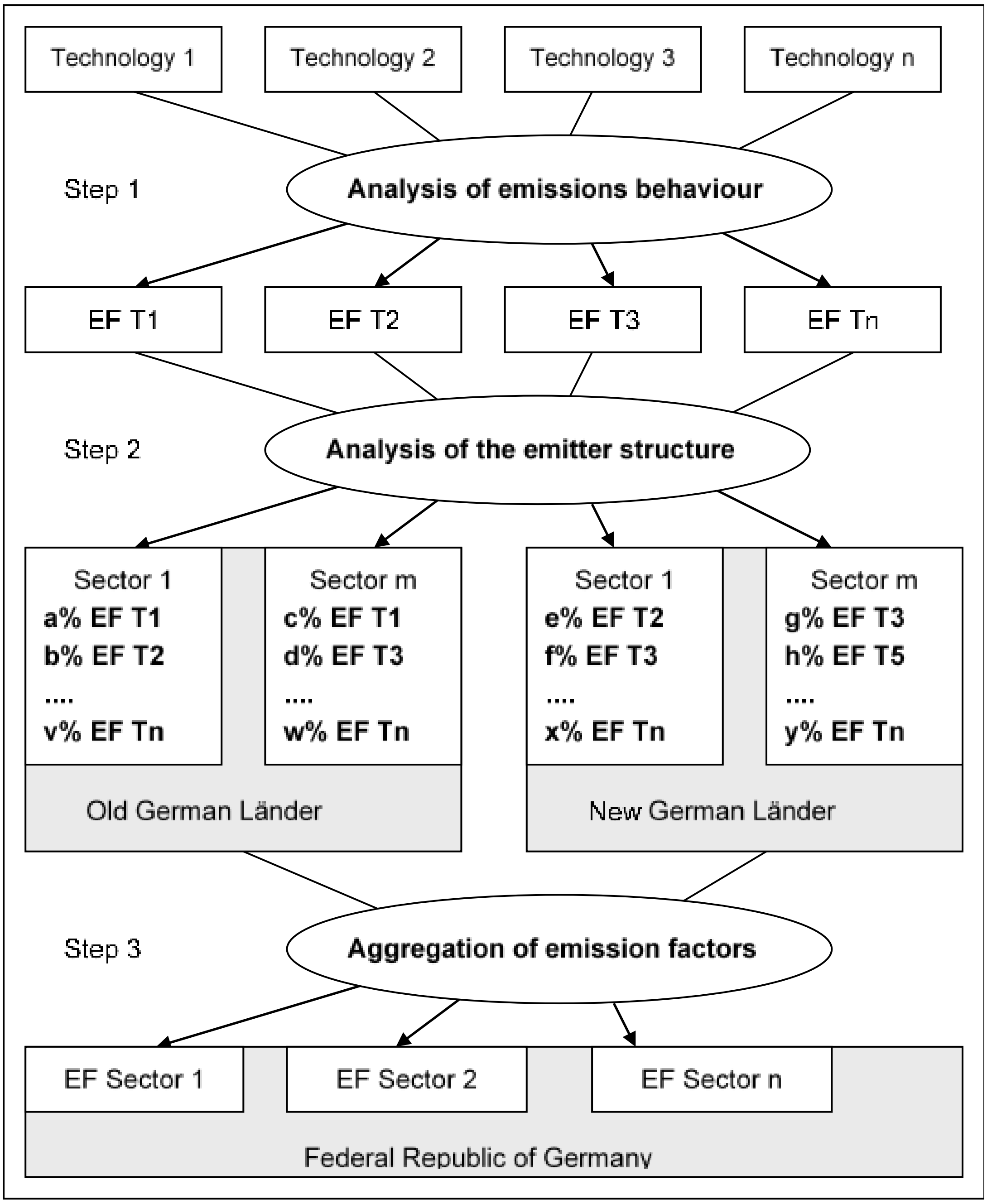
not based on the combustion technologies used. The project has defined and analysed the following categories: Public electricity and heat production (CRF 1.A.1a), Industrial power stations (CRF 1.A.1c for mining-sector power stations; otherwise CRF 1.A.2), District-heating stations (CRF 1.A.1a), Refinery power stations (CRF 1.A.1b), Industrial combustion systems (CRF 1.A.1c and 1.A.2) and Residential and Institutional and commercial (small consumers) (CRF 1.A.4 and 1.A.5).
In the analysis, the various technologies' contributions to total energy use must be determined. The most important data sources for this include the power-station database of the DFIU (now the KIT), relevant statistics, communications of industry associations (VGB, VDEW, VIK), operator information and technical publications. Furthermore, excerpts of emissions declarations from the years 1996 and 2004, as provided by some Länder authorities, were also evaluated in the present context.

3. Aggregation of emission factors
   On the basis of the percentage contributions for the various technologies – which were determined separately for the old and new Länder – the technology-specific emission factors are aggregated to form category-specific factors. Finally, factors for Germany as a whole are formed. The category-specific factors are sub-divided in accordance with the categories "large combustion systems", "TA Luft combustion systems" and "gas turbines", as well as by fuel type. The aggregated emission factors are formed first for the reference year 1995 (Rentz et al., 2002) and for the reference year 2004 (Fichtner et al., 2011).
4. Projections are made for the years 2000 and 2010 (Rentz et al., 2002) and for the years 2010 and 2020 (Fichtner et al., 2011). Technology-specific emission factors are defined for the purpose of describing ongoing technical progress. These are derived from characterisation of modern technologies. An increasing contribution of low-emissions technologies to total relevant activity, thus, can be represented by suitably changing the percentage shares for the technologies under consideration. The framework for such carrying forward consists of the relevant applicable provisions under immissions-control law. For the reference year 2010, it is assumed that requirements from the amended Technical Instructions on Air Quality Control (TA Luft) from 2002 and the EU Large Combustion Plants Directive of 2001 have been implemented; for the reference year 2020, we assume that the requirements of Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions have been implemented.

The above-described methods, beginning with characterisation of the emissions behaviour of relevant combustion technologies and gradually leading to aggregated factors at various regional and category-specific levels, make it possible to represent the required factors transparently.

The chosen methods for deriving emission factors for a given reference year are shown in Figure 97 below.

Figure 97: Methods for calculating emission factors



The origins and quality of the data are described in detail in the project reports Rentz et al. (2002) and Fichtner et al. (2011). A large part of the data has been taken from the emissions declarations of the German Länder (states) Baden-Württemberg, Brandenburg, North Rhine – Westphalia and Thuringia for 1996, and from the emissions declarations of all Länder (except for Berlin) for the year 2004. The annual pollutant-load data included in those data are based, depending on the pollutant in question, on measurements from continuous monitoring, on individual measurements or on calculations based on physical laws, mass balances or emission factors. In the following, the emissions declarations of the state of Baden-Württemberg are used to show, by way of illustration, what data-determination methods tend to be used for the various types of combustion systems and substances in question. Such analysis makes it possible to classify the quality of the underlying data with regard to the derived technology-specific emission factors. At the same time, the description illustrates the data-evaluation procedure.

Where a sufficient amount of data for a source category is available, the relevant value range is characterised via the median and the percentile is characterised at 25 % and 75 %[180]. This produces a robust estimate that, unlike characterisation via the mean value, is not distorted by extreme values. In general, percentiles at 5 % and 95 % are also listed, to describe the distribution of values. Similar percentile evaluations were also carried out for the emissions declarations of the other Federal Länder.

In the following, a distinction is made between measured data (either continuous measurements or individual measurements) and data based on calculations or emission factors. In evaluation, therefore, individual data items are first classified as either "measurements" (M) or "assumptions" (A). This general overview, in turn, is divided into the categories of large combustion systems, TA Luft combustion systems and gas turbines. These are then further subdivided, with regard to declaration obligations, into facilities subject to abbreviated (K) or complete (V) declarations. For each of the three groups of systems, evaluation and derivation of emission factors is carried out, using the sample data from Baden-Württemberg and with classification by "measurements" and "assumptions".

Table 541 provides an overview of the facility types considered, grouped on the basis of their numbers under the 4th Ordinance Implementing the Federal Immission Control Act (BImSchV) and of the type of declaration concerned.

Table 541: Facility types pursuant to Annex of 4th BImSchV (4th Ordinance on Execution of the Federal Immission Control Act)

Index	**Large combustion systems (Großfeuerungsanlagen)**		**Type of declaration required**
1 01 1	Power stations	≥ 50 MW for solid, liquid and gaseous fuels	V
1 02A 1	Combustion systems	≥ 50 MW for solid and liquid fuels	V
1 02B 1	Combustion systems	≥ 50 MW for gaseous fuels	V
Index	**TA Luft installations**		**Type of declaration required**
1 02A 2	Combustion systems heating oil EL)	1 - < 50 MW, solid and liquid fuels (except for	V
1 02B 2	Combustion systems	5 - < 50 MW heating oil EL	K
1 02C 2	Combustion systems	10 - < 50 MW for natural gas	K
	Combustion systems installations	10 - < 50 MW, except for natural gas	V
1 03 1	Combustion systems	> 1 MW, other fuels	V
Index	**Gas turbine systems**		**Type of declaration required**
1 05 1	Gas turbines	≥ 50 MW for natural gas	K
	Gas turbines	≥ 50 MW, except for natural gas installations	V
1 05 2	Gas turbines	< 50 MW for natural gas	K
	Gas turbines	< 50 MW, except for natural gas installations	V

180 For the entire value range of a variable X, the sum-frequency distribution can be used to estimate what percentage of all units considered will have a maximal value of x. That value is referred to as a *quantile* or, when percentage values are being considered, as a *percentile*. The best-known percentile, the one that separates the lower half of all values from the upper half, is the 50th percentile, the so-called *median*. The 25th and 75th percentiles cut off the upper and lower quarters of the distribution. They are thus also referred to as upper and lower *quartiles* or as the first and third *quartile* (with the median being a sort of second quartile).

In the analyses, emissions data are differentiated by combustion technologies. Table 542 provides an overview of this technology classification based on types. Categories 110 to 118 apply mainly to solid fuels, while 120 to 125 apply to liquid fuels and 130 to 132 apply to gaseous fuels.

Table 542: Classification of sources by type of combustion system

Technology	
Type	**Meaning**
110	Combustion systems for solid fuels / waste
111	Filled-shaft combustion systems
112	Combustion with throw feed
113	Combustion systems with pneumatic feed
114	Under-thrust combustion
115	Combustion with mechanically moved grids
116	Dust incineration with dry-ash ventilation
117	Dust incineration with wet-ash ventilation
118	Fluidised-bed combustion
120	Combustion systems for liquid fuels / waste
121	With evaporative burner
122	With pressure-atomising burner
123	With steam-atomising burner
124	With rotation-atomising burner
125	With air-atomising burner
130	Combustion systems for gaseous fuels / waste
131	With atmospheric gas burner
132	With gas-blower burner
141	Multiple-substance combustion systems
142	Mixed combustion
815	Gas turbines

19.1.2.2 CO_2 emissions from flue-gas desulphurisation (CRF 1.A.1, Limestone balance)

In the framework of the research project "limestone balance" ("Kalksteinbilanz"; Lechtenböhmer et al. (2006c), FKZ 20541217/02), data for CO_2 emissions from flue-gas desulphurisation were determined for the category Electricity and heat production in public power stations (cf. 3.2.6.2). Flue-gas desulphurisation systems have the task of converting sulphur dioxide in combustion gases, via chemical and physical processes, into substances that are less harmful. Limestone is commonly used as a reagent in flue-gas desulphurisation. Desulphurisation systems are tailored to the applicable requirements under immissions-control law and to the economic value of the resulting residual substances (plaster). The predominant process used in electricity generating plants is limestone scrubbing. Some 87 % of all power stations in Germany, in terms of installed output, use this process (Rentz et al., 2002).

Desulphurisation with $CaCO_3$ consists of several sub-reactions. For stoichiometric calculation of limestone inputs in the limestone-scrubbing process, the relevant chemical gross-reaction equation for the process is used (Strauß, 1998):

$$CaCO_3 + SO_2 + 1/2O_2 + 2H_2O \Longrightarrow CaSO_4.2H_2O + CO_2$$

This equation can be used to derive the limestone/plaster molar mass ratio. Such derivation shows that 581.39 kilograms of limestone are used per produced tonne of plaster. Plaster-production figures thus can be used to obtain the theoretically maximal limestone inputs for flue-gas desulphurisation in hard-coal-fired and lignite-fired power stations. The plaster-production figures do not indicate whether limestone or lime has been used, however. This problem was resolved with the help of statistics of the German Lime Association (BV Kalk) relative to sales of burnt and unburnt lime for the air-quality-control sector. Using the above reaction equation, the pertinent process-related CO_2 emissions can be determined from the mass relationship between $CaCO_3$ and CO_2. The results of the calculation are shown in the following table. The take account of the figures on gypsum production in all years since 1990; in 2020, the figures on gypsum production were updated for the years 2009, 2010, 2012, 2013, 2017, 2018 and 2019 (VGB Powertech E.V. 2021). No association data are yet available for the year 2020. For the year 2020, therefore, we estimated the gypsum production, on the basis of an assumed proportionality between annual electricity production and gypsum production. In light of the 2019 data on gypsum production in hard-coal-fired and lignite-fired power stations, and of the quantities of electricity produced by those power stations in 2019 and 2020, such an assumption is justified. This procedure was chosen because the annual electricity production from both hard coal (-26.09%) and lignite (-10.27%) decreased sharply in 2020.

Table 543: CO_2 emissions from flue-gas desulphurisation in public power stations

Year CRF 1.A.1	1990	1991	1992	1993	1994 Figures in kt	1995	1996	1997	1998	1999
CO_2 from flue-gas desulphurisation in public power stations	618	652	629	662	616	683	867	878	1,005	966
Year CRF 1.A.1	**2001**	**2001**	**2002**	**2003**	**2004 Figures in kt**	**2005**	**2006**	**2007**	**2008**	**2009**
CO_2 from flue-gas desulphurisation in public power stations	1,135	1,069	1,094	1,156	1,162	1,142	1,076	1,017	985	952
Year CRF 1.A.1	**2010**	**2011**	**2012**	**2013**	**2014 Figures in kt**	**2015**	**2016**	**2017**	**2018**	**2019**
CO_2 from flue-gas desulphurisation in public power stations	919	1,028	1,052	1,030	974	989	921	979	936	769
Year CRF 1.A.1	**2020**				**Figures in kt**					
CO_2 from flue-gas desulphurisation in public power stations	646									

Source: Calculation on the basis of of the "limestone balance" project (Lechtenböhmer et al. (2006c), FKZ 20541217/02); updated in 2008 (cf. NIR 2009)

In the inventory, these CO_2 emissions were assigned to emissions from use of solid fuels, because such use is the reason for operation of the flue-gas desulphurisation systems and for the systems' CO_2 emissions. Pursuant to expert estimates of the group carrying out the pertinent research, the uncertainty for limestone use and, thus, the uncertainty for related CO_2 emissions, is +/- 10 %.

19.1.3 Transport (1.A.3)

19.1.3.1 Transport – Civil aviation (1.A.3.a)

19.1.3.1.1 Derivation of additional emission factors (1.A.3.a)

Kerosene

Emissions of *sulphur dioxide* depend directly on the sulphur content of the jet kerosene being used. That, in turn, is subject to regional and chronological fluctuations. IPCC (2006a) gives an EF of 1 kg SO_2/t kerosene, which is based on a sulphur content of 0.05 % by weight. According to current information of the Fachausschuss für Mineralöl- und Brennstoff-Normung[181] (FAM; technical committee for petroleum and fuels standardisation), jet kerosene in Germany typically has a total sulphur content of about 0.01 % by weight, i.e. one-fifth of the content given by the IPCC. The 2009 inventory report uses a sulphur-content figure of 0.021 % by weight for jet kerosene, on the basis of measurements from the year 1998 (Döpelheuer, 2002). It seems plausible that the emission factor would decrease over time as a result of improved procedures and reduced maximum permitted levels. Consequently, a linear reduction is included here between the framework years 1990 (1.08 g SO_2 / kg kerosene), 1998 (0.4 g) and 2009 (0.2 g). In addition, it is assumed that all of the sulphur in the fuel is converted into sulphur dioxide. Because the emission factor depends directly and solely on the sulphur content of the jet kerosene, this emission factor is used for both flight phases.

NO_X and *CO emissions* are calculated with the help of implied emission factors based on TREMOD-AV calculations. Those results, in turn, are based on aircraft-type-specific and operational-state-specific emission factors taken largely from the EMEP/EEA database. Adjusted emission factors have to be used in some cases, when specific aircraft types cannot be directly allocated to the proper categories, even with the help of data on technically similar aircraft types. Those emission factors were determined via emissions functions, in the context of regression calculations, that calculate the emission factor for each engine type as a function of take-off weight. The basis for those functions consisted of the emission factors for existing aircraft types pursuant to Knörr et al. (2012).

In each case, the *NMVOC* emission factors are obtained from the difference between the emission factor for hydrocarbons and that for methane.

Avgas

In an approach similar to that used for kerosene, all emission factors – except for that for carbon dioxide, for which the IPCC default value has been used – have been taken from the TREMOD AV model.

Within that model, the *NMVOC* emission factors are obtained from the difference between the emission factor for hydrocarbons and that for methane.

Table 544: Emission factors for avgas, 2018

	1.A.3.a		1.D.1.a	
	LTO	Cruise	LTO	Cruise
CO_2	70,000			
CH_4	165	0.00	137	0.00
N_2O	2.30			
SO_2	0.46			
NO_X	92.0	143	56.0	82.2
NMVOC	660	579	548	467
CO	17,028	21,025	22,827	29,108

Source: (Gores, 2021)

[181] Personal e-mail communication with Dr. Feuerhelm, FAM Hamburg, 9 June 2009

Table 545: Overview of emission factors for kerosene; in kg/TJ

	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1.A.3.a – Overarching																						
CO_2																						73,256
SO_2	19.7	19.5	19.5	19.5	19.5	19.5	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6
National, LTO																						
CH_4	7.09	7.23	7.63	7.87	8.11	8.30	8.23	8.11	8.48	8.60	8.66	8.30	8.07	7.99	8.00	8.71	9.25	9.23	9.11	9.58	9.78	10.8
N_2O	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81
NO_X	295	324	287	288	283	277	279	277	276	281	290	300	304	309	312	311	310	312	321	322	316	308
NMVOC	28.4	28.9	30.5	31.5	32.4	33.2	32.9	32.4	33.9	34.4	34.7	33.2	32.3	31.9	32.0	34.9	37.0	36.9	36.5	38.3	39.1	43.2
CO	212	211	275	277	285	294	291	291	292	286	280	266	260	254	252	260	265	265	252	255	262	276
National, cruise																						
CH_4																						0.00
N_2O	2.34	2.33	2.33	2.33	2.33	2.33	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34
NO_X	337	375	348	345	342	339	341	340	341	347	358	368	374	376	381	383	381	386	397	400	396	390
NMVOC	14.4	16.0	16.6	16.8	17.9	18.4	18.6	18.9	19.9	20.4	20.6	20.3	19.9	19.9	20.2	21.7	22.7	22.0	17.7	18.1	17.7	19.2
CO	147	149	186	190	204	211	206	203	203	203	204	202	197	197	201	212	219	214	154	151	152	155
International, LTO																						
CH_4	14.9	9.03	6.42	6.19	6.01	5.93	5.80	5.72	5.71	5.62	5.50	5.29	5.31	5.19	5.12	5.08	4.97	5.12	5.06	5.19	5.36	5.17
N_2O	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30	2.30
NO_X	297	306	303	305	306	311	318	324	325	330	331	338	342	345	346	349	353	352	357	358	355	357
NMVOC	59.7	36.1	25.7	24.8	24.0	23.7	23.2	22.9	22.9	22.5	22.0	21.2	21.2	20.8	20.5	20.3	19.9	20.5	20.2	20.8	21.4	20.7
CO	249	227	236	234	234	230	227	219	217	211	209	203	203	199	199	197	194	196	192	192	195	192
International, cruise																						
CH_4																						0.00
N_2O	2.34	2.33	2.33	2.33	2.33	2.33	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34
NO_X	313	317	329	329	330	333	335	338	338	342	343	346	352	354	360	362	362	366	370	372	373	375
NMVOC	13.3	8.96	5.98	5.66	5.51	5.54	5.38	5.27	5.15	5.02	4.89	4.77	4.66	4.53	4.39	4.39	4.71	4.35	4.17	4.23	4.32	4.25
CO	73.8	61.6	47.7	46.8	46.2	45.7	43.8	42.4	41.5	40.6	39.7	38.6	37.8	37.3	37.0	36.8	40.1	36.2	34.2	34.2	34.7	34.6

Source: (Gores, 2021)

[a] pursuant to IPCC (2006a): Volume 2, Chapter 3.6, Table 3.6.5: Methane emissions during cruise flight are negligibly low.

19.1.3.1.2 Detailed overview of the uncertainties underlying the pertinent activity data and emission factors (1.A.3.a)

Table 546: Overview of the applicable partial uncertainties for activity rates and emission factors

Individual components		Partial uncertainties		AD (kerosene & avgas)		SF (LTO / cruise)		AD (kerosene) LTO and cruise		EM(CO_2) LTO and cruise		EM (CH_4) LTO and cruise		EM (N_2O) LTO and cruise		Source / reason for assumptions
		%		Total	n / i	n	i	n	i	n	i	n	i	n	i	
AD of AGEB and BAFA		-5	5	x	x											Öko-Institut / DIW 2007 Here, the higher uncertainties of the Energy Balance are used. The uncertainties for the BAFA data are +3, -1% (conservatively estimated, using the approach for the uncertainties of mineral-oil statistics, which are based on BAFA data.)
Split factor, national/international																Results, since v42, from the TREMOD calculations relative to national air traffic in relation to the Energy Balance. No longer an influencing variable in its own right.
Kerosene consumption	n & i	-5.0	5					x	x							Calculated
Data of the Federal Statistical Office relative to aircraft movements	n	-0.1	0.1			x										Aviation statistics are based on the Transport statistics act (Verkehrsstatistikgesetz - VerkStatG). The data specified by Arts. 12, 13 VerkStatG are recorded. Pursuant to that act, all civil aviation craft, including aircraft, helicopters, airships, motorised gliders, sailplanes and manned balloons, are to be included in relevant surveys, as long as airports/airfields in Germany are involved.
	i	0	0.1				x									
Real-distance surcharge	n & i	-3	3			x	x									The data of the Federal Statistical Office are oriented to great-circle distances. A detour factor for cruise flight has been used, as a means of estimating the distances actually flown (cf. IFEU and Öko-Institut 2010).
Allocation of kerosene consumption data to aircraft types	n	-5	5			x										Aircraft types pursuant to the Federal Statistical Office are assigned emission factors from the EMEP-EEA database. There are four different quality levels for such assignment: a) direct, b) via similar types, c) via regression functions depending on take-off weight, and d) lump-sum EF.
	i	-5	5				x									
LTO/cruise split	n	-6	6					x								Calculated
	i	-6	6						x							Calculated
Kerosene consumption LTO and cruise	n	-8	8							x		x		x		Calculated
	i	-8	8								x		x		x	Calculated
emission factors	CO_2	5	5							x	x					IPCC 2006, p.3.69; low uncertainty, since the EF depends only on the C content of the fuel.
	CH_4	-57	100									x	x			IPCC 2006, p.3.69; depends on technology and is thus subject to large uncertainty in combination via the Tier 1 approach
	N_2O	-70	150											x	x	IPCC 2006, p.3.69; depends on technology and is thus subject to large uncertainty in combination via the Tier 1 approach
The total uncertainty is above				+5%	+5%	+6%	+6%	+8%	+8%	+9%	+9%	+58%	+58%	+70%	+70%	
The total uncertainty is below				-5%	-5%	+6%	-6%	-8%	-8%	-9%	-9%	-100%	-100%	-150%	-150%	

n = national share; i = international share

Source: (Gores, 2021)

19.1.3.2 Derivation of activity rates for road transport (1.A.3.b)

19.1.3.2.1 Harmonisation with the Energy Balance

The basis for CSE data collection for the road-transport sector consists of energy consumption data provided by the Working Group on Energy Balances (AGEB). For each year, the sum of the activity rates for the various individual structural elements must be equivalent to the Energy Balance data, in terajoules (TJ). The relevant basic Energy Balance data are shown in Table 547 below.

Table 547: Energy inputs in road transports, since 1990

	Gasoline	Diesel fuel	Biofuels [a]	CNG, LPG and	Petroleum	Lubricants [b]
Energy inputs pursuant to Energy Balances 1990-2020 (last revision: 10/2021), in TJ						
1990	1,330,479	735,920	0	138	0	2,495
1991	1,332,285	785,174	0	137	0	1,668
1992	1,344,129	853,502	0	229	0	1,275
1993	1,350,617	907,787	0	184	473	857
1994	1,276,637	932,060	0	184	559	586
1995	1,299,982	964,013	1,504	138	610	447
1996	1,299,879	964,580	2,046	115	638	365
1997	1,297,487	979,586	3,652	106	357	261
1998	1,300,463	1,022,794	4,081	106	637	202
1999	1,300,602	1,097,036	5,370	100	637	113
2000	1,237,055	1,108,105	12,276	94	414	81
2001	1,199,318	1,097,416	16,740	98	471	73
2002	1,166,381	1,105,842	20,460	607	472	75
2003	1,108,989	1,078,352	29,948	694	0	71
2004	1,072,720	1,110,931	40,042	1,887	0	73
2005	992,377	1,078,620	78,897	5,484	0	77
2006	930,834	1,082,042	143,881	9,051	0	76
2007	892,982	1,073,987	155,752	14,787	0	79
2008	854,002	1,102,624	126,181	22,796	0	80
2009	829,227	1,114,939	113,765	32,285	0	86
2010	791,416	1,168,063	120,129	30,591	0	81
2011	787,803	1,197,252	115,828	32,384	0	80
2012	742,000	1,223,718	120,513	32,438	0	76
2013	741,150	1,283,637	109,358	30,508	0	77
2014	744,661	1,296,828	113,957	28,983	0	77
2015	708,672	1,348,789	105,764	26,420	0	77
2016	709,179	1,393,481	106,054	22,705	0	77
2017	719,580	1,425,424	108,049	21,316	0	77
2018	692,694	1,377,104	112,594	21,514	0	76
2019	699,835	1,390,837	111,781	21,147	0	76
2020	629,926	1,241,557	135,073	22,708	0	78

Sources: Evaluation tables of the Energy Balances, "Mineralöl-Zahlen" ("Petroleum Data") of the Association of the German Petroleum Industry (MWV, 2020b) and "Amtliche Mineralöldaten" ("Official Mineral Oil Statistics") (BAFA, 2021).

[a] Biodiesel, biogasoline and biogas; [b] as a component of 1:50 two-stroke fuel mixtures

The Energy Balance is also used to model transport-quantity structures in TREMOD. For example, the German Economic Institute (DIW) carries out a fuel-consumption calculation in order to derive total mileage travelled Heilwig (2002). Some of the results of the calculation, for automobile transports, are entered into TREMOD. The DIW uses a fuel-consumption calculation in order to determine total domestic mileage; TREMOD uses some other sources and assumptions to estimate total domestic mileage – especially for goods transports (cf. the detailed description in Knörr et al. (2002)). This estimate also takes the basic figures of the Energy Balance into account.

On the other hand, due to the many dependencies and uncertainties in the model, and to the basic data that must be taken into account, no feasible means is available for comparing mileage and energy consumption, for each year and each vehicle layer, in such a manner that the results yield the Energy Balance sum and the mileage and mean energy consumption figures in the time series are plausible. For this reason, the TREMOD results for the energy consumption are corrected, at the end of the process, in such a manner that the total for each reference year corresponds to the relevant figure in the Energy Balance.

Since TREMOD calculates energy consumption in tonnes, the results first have to be converted into TJ. This is done with the net calorific values provided by the Working Group on Energy Balances (AGEB) (cf. Table 548).

Table 548: Mean net calorific values for gasoline and diesel fuel

Validity period	Gasoline	Diesel fuel
1990-1992	43.543 MJ/kg	42.704 MJ/kg
since 1993	43.543 MJ/kg	42.960 MJ/kg
since 2014	42.280 MJ/kg	

Source: Working Group on Energy Balances (AGEB)

The correction factors are derived in TREMOD separately for the various vehicle categories, as follows:

- Firstly, a correction factor for gasoline is derived from the calculated gasoline consumption for all vehicle categories and from gasoline sales pursuant to the Energy Balance.
- The correction factor for gasoline is then also used to bring fuel consumption of vehicles with diesel engines, among automobiles and other vehicles ≤ 3.5 t (light duty vehicles (LNF), and of motor homes and motorcycles (MZR)), into line with the Energy Balance.
- The difference between the corrected diesel-fuel consumption of automobiles and of other vehicles ≤ 3.5 t and the Energy Balance is then allocated to heavy duty vehicles and buses.
- The correction factor for heavy duty vehicles and buses is then calculated from their energy consumption, as calculated in accordance with the domestic principle, and from the pertinent difference, as calculated for this group, with respect to the Energy Balance.

The following table summarises the correction factors used.

Table 549: Correction factors for harmonisation with the Energy Balance

	Gasoline fuels[a]	Diesel fuels [a]	
	automobiles, light utility vehicles, motor- cycles	*automobiles, light utility vehicles,*	*heavy utility vehicles, Buses*
1990	1.046	1.046	1.035
1995	1.012	1.012	0.992
2000	0.967	0.967	1.021
2005	0.917	0.917	0.838
2006	0.895	0.895	0.877
2007	0.882	0.882	0.833
2008	0.881	0.881	0.828
2009	0.870	0.870	0.867
2010	0.858	0.858	0.910
2011	0.867	0.867	0.891
2012	0.846	0.846	0.950
2013	0.867	0.867	0.960
2014	0.883	0.883	0.910
2015	0.880	0.880	0.927
2016	0.892	0.892	0.928
2017	0.905	0.905	0.928
2018	0.873	0.873	0.900
2019	0.870	0.870	0.915
2020	0.892	0.892	0.921

[a] In each case, including biogenic admixtures
Source: (Knörr et al., 2021c)

19.1.3.2.2 Allocation of biofuels, petroleum, natural gas and LP gas to the structural elements

The Energy Balance includes data on biomass and other fuels, broken down by individual vehicle categories. Those data are allocated as follows:

- The figures for biodiesel and bioethanol are divided in accordance with the various vehicle categories' shares of consumption of the corresponding fossil fuels.
- Petroleum is allocated to buses (on roads outside urban areas) in keeping with the buses' percentage shares of consumption of conventional diesel fuel.

19.1.3.2.3 Activity rate for evaporation

The activity rate for evaporation emissions is set as total gasoline consumption, on *municipal roads (= city)*; the corresponding figure for mopeds is the *total consumption*. The values corrected to the Energy Balance are used.

19.1.3.3 Derivation of emission factors

19.1.3.3.1 Emission factors from TREMOD

In the Central System of Emissions (CSE), implied emission factors, in [kg/TJ] or [kg/t], generated from more-specific TREMOD data, are given for the categories *engine type* and *evaporation*. For gasoline and diesel fuel, those values can be derived directly from TREMOD. To that end, emissions in [t] and energy consumption in [TJ] (converted from the results "energy consumption in t", using the net calorific values pursuant to Table 548) are derived from the TREMOD results and allocated to the relevant structural elements. The implied emission factors (IEF) result as the quotient of specific emissions in [t] divided by the specific energy consumption in [TJ].

$$IEF\ [kg\ per\ TJ]_{\ inventory} = EM\ [kg]_{\ specific,TREMOD} \div AR\ [TJ]_{\ specif.consumption,TREMOD}$$

A similar procedure is used for the implied emission factors for evaporation:

$$IEF\ [kg\ per\ t]_{\ inventory} = EM\ [kg]_{\ specific,TREMOD} \div AR\ [t]_{\ specif.consumption,TREMOD}$$

In general, TREMOD data that have not been corrected in accordance with the Energy Balance are used for this derivation. Use of the so-corrected figures for emissions and energy consumption would lead to the same results, however, since the correction factor cancels out when the IEF is calculated.

$$EM_{corr.} \div AR_{corr.} = EM_{TREMOD} \div AR_{TREMOD}$$

19.1.3.3.2 Emission factors for biodiesel, bioethanol, petroleum, natural gas and LP gas

In all cases, the emission factors for biodiesel and petroleum are set to the same values as those for conventional diesel fuel. The emission factors for bioethanol are set to the same values as those for conventional gasoline.

Exceptions:

- The EF(CO_2) used for biodiesel, 70.8 t/TJ, is a default pursuant to the IPCC (2006a): Volume 2, Chapter 2 – Stationary Combustion, p. 2.20, Tab. 2.4.
- The EF (SO_2) for petroleum is set to 24 kg/TJ for those years in which diesel fuel has a higher value. In all other years, the lower value for diesel fuel is used.

The emission factors for LP gas and natural gas, like those for diesel fuel and gasoline, are taken from the "Handbook for emission factors of road transports 4.1" ("Handbuch für Emissionsfaktoren des Straßenverkehrs 3.1"; (Keller et al., 2017)).

19.1.4 CO_2 emissions from lubricant co-incineration in two-stroke gasoline engines

The German greenhouse-gas inventory covers CO_2 emissions from co-incineration of lubricants for all mobile sources. In keeping with emissions reporting requirements, emissions from two-stroke gasoline engines are allocated directly to the pertinent emission sources, since in those cases lubricants are seen as part of the relevant two-stroke fuel mixtures. On the other hand, all co-incineration emissions not caused by two-stroke engines are reported under CRF 2.D.1 (product use). (Cf. Chapter 4.5.1)

For the entire time series as of 1990, it is assumed, as a simplification, that the two-stroke fuel mixture used in Germany consists of 49 parts gasoline and one part lubricants (mixture of 1:50). Since the 1980s, this mixing ratio has been the standard for most vehicles with two-stroke engines. No reliable usage data are available on motors that use mixtures of 1:100 (newer mobile devices such as chainsaws, lawnmowers, etc.).

Mopeds and small motorcycles are now virtually the only types of *vehicles with two-stroke engines* that are found on German roads. Until the end of the 1990s, the automobile and utility vehicle fleet included a fraction of vehicles with two-stroke engines produced in the former GDR.

TREMOD contains pertinent separate sets of consumption data for automobiles and light utility vehicles (through 1999) and for two-wheel vehicles.

TREMOD MM contains current figures on use of *mobile devices with two-stroke engines* for both the Residential (1.A.4.b ii) and Forestry (1.A.4.c ii) sectors.

The figures on gasoline consumption in road transports and by mobile sources in the Commercial and Institutional, and Residential, sectors agree with the corresponding figures in the Energy Balance.

To obtain a complete picture of the fuel consumption that must be assigned to two-stroke engines, the relevant quantities of lubricants added to fuel have been calculated, in accordance with the mixing ratio of 1:50. On the basis of an r_V 2 % fraction by volume, the fraction r_E applying to the pertinent energy quantity in terajoules has to be determined, via the relationship of the two components' average densities (ρ) and net calorific values (H_i):

$$r_{E\%} = r_{V\%} \times \frac{\rho_{lubricants}}{\rho_{fuel}} \times \frac{\mathrm{H_{i_{lubricants}}}}{\mathrm{H_{i_{fuel}}}}$$

$$r_{E\%} = 2\ \% \times \frac{0.875\ \frac{\mathrm{kg}}{\mathrm{l}}}{0.750\ \frac{\mathrm{kg}}{\mathrm{l}}} \times \frac{40.000\ \frac{\mathrm{kJ}}{\mathrm{kg}}}{43.543\ \frac{\mathrm{kJ}}{\mathrm{kg}}} = 2.1435\ \%$$

The lubricant quantities in [TJ] that are co-combusted as part of two-stroke fuel mixtures are then calculated from the annual energy inputs in [TJ] that are assigned to two-stroke engines and the pertinent fraction r_E.

The CO_2 emissions from lubricant co-incineration in two-stroke engines in road transports can thus be listed separately (cf. Chapters 3.2.10.2 & 19.1.3.2). In the CRF tables, this is done under CRF *1.A.3.b v – Other (please specify): CO_2 from lubricant co-incineration in 2-stroke road vehicles.*

In the category of mobile machines and devices, no separate lubricant quantities are calculated in terajoules. Instead, in a simplification the energy inputs applying to these two-stroke engines are upwardly corrected by 2.1435 %. The CO_2 emissions from lubricant co-incineration in two-stroke engines in mobile machines and devices are thus included in the total emissions of the relevant sectors (cf. Chapter 3.2.12). Consequently, the emissions are also not listed separately within the CRF tables.

Emission factors

To make it possible to show CO_2 emissions from combusted two-stroke fuel mixtures in the inventory, weighted implied emission factors were formed for the entire time series. These consist of a 49/50ths fraction based on the year-specific EF(CO_2) for gasoline ((or the Tier 1 EF for bioethanol) and a 1/50th fraction based on the default value 73,300 kg CO_2/TJ for lubricants pursuant to (IPCC, 2006a): Volume 2, Chapter 2 – *Stationary Combustion*, page 2.20, Table 2.4.

These IEF, which include 2 % by vol. for lubricants, are thus slightly higher than the values used for the relevant pure fuels (gasoline, bioethanol).

Table 550: Derivation of the EF(CO_2) for two-stroke fuel mixtures, in kg/TJ

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Gasoline	73,069	73,075	73,094	73,103	73,119	75,287	75,285	75,285	75,285	75,284	75,276
Biogasoline						71,607					
Lubricants [a]						73,300					
Two-stroke mix											
fossil	73,074	73,079	73,098	73,107	73,123	75,247	75,245	75,245	75,245	75,244	75,237
biogenic						71,641					

Source: Own calculations

[a] Default emission factor pursuant to IPCC (2006a): Volume 2, Chapter 2 – *Stationary Combustion*, page 2.20, Table 2.4

Table 551: CO_2 from lubricants co-incinerated in two-stroke gasoline engines, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
1.A.3.b	183	32.8	5.90	5.64	5.97	5.65	5.67	5.65	5.54	5.59	5.72
1.A.4.b ii	2.35	1.91	1.34	1.15	1.31	1.50	1.48	1.47	1.46	1.45	1.39
1.A.4.c ii	4.52	4.39	4.86	4.46	2.38	2.63	2.49	2.51	2.82	2.68	3.35
Total	**190**	**39.1**	**12.1**	**11.2**	**9.65**	**9.78**	**9.65**	**9.63**	**9.82**	**9.72**	**10.5**

Source: Own calculations, based on (Knörr et al., 2021b; Knörr et al., 2021c)

Recalculations with respect to the 2021 Submission

The fuel consumption figures for road vehicles with two-stroke engines have been recalculated, for all years since 2015. Also, the gasoline-consumption figures for two-stroke vehicles in 1.A.4.b ii have been revised.

This has led to the adjustments shown below in the quantities of co-combusted lubricants.

Table 552: Revised quantities of co-combusted lubricants, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
2022 Submission	2,589	534	165	154	132	132	130	130	133	131
2021 Submission	2,588	531	163	152	132	132	131	130	136	137
Absolute change	0.87	2.03	2.27	1.21	0.08	-0.16	-0.29	-0.44	-3.11	-5.89
Relative change	0.03%	0.38%	1.39%	0.79%	0.06%	-0.12%	-0.22%	-0.34%	-2.29%	-4.30%

Source: Own calculations

Table 553: Revised carbon dioxide emissions, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019
2022 Submission	190	39.1	12.1	11.2	9.65	9.78	9.65	9.63	9.82	9.72
2021 Submission	190	38.9	11.9	11.2	9.65	9.79	9.67	9.66	10.0	10.1
Absolute change	0.06	0.15	0.17	0.09	0.01	-0.01	-0.02	-0.03	-0.22	-0.43
Relative change	0.03%	0.38%	1.39%	0.79%	0.06%	-0.12%	-0.22%	-0.34%	-2.20%	-4.21%

Source: Own calculations

Carbon dioxide from lubricant co-combustion in four-stroke gasoline engines, and in other engines in vehicles and in mobile machinery and equipment, on the other hand, is reported separately under CRF 2.D.1, as emissions from product use. (Cf. Chapter 4.5.1)

19.1.5 Calculation of the fossil fractions of biofuels used, as well as of the carbon dioxide emissions resulting from their use

In the present report, the fossil fractions of biofuels used, and of the carbon dioxide emissions resulting from their use, are being recorded and reported in the German greenhouse-gas inventory for the first time.

Unfortunately in this connection, it was not possible, for reasons of capacity, to prepare and implement an approach based on country-specific and year-specific data on time. For this reason, a proxy approach, which is described in detail below, has been used instead in the present submission.

Methodological issues

In the future, annual statistical data on the composition of domestically sold biofuels are to be used in this area, in the framework of a country-specific approach. At present, the CO_2 emissions resulting, in the various source categories, from use of biodiesel and biogasoline are used as a basis for the relevant calculations.

Table 554: CO_2 emissions resulting from use of biodiesel and biogasoline, in kilotonnes

	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019	2020
Carbon dioxide from biogasoline											
1.A.2.g vii	0	0	0	0.34	2.11	7.87	10.4	10.7	10.3	10.4	9.07
1.A.3.b	0	0	0	84.1	501	2,236	2,246	2,250	2,215	2,273	2,201
1.A.4.b ii	0	0	0	0.18	1.18	9.35	13.1	13.2	12.8	13.6	13.1
1.A.4.c ii	0	0	0	0.12	0.79	6.97	10.2	10.2	9.93	10.6	10.2
1.A.5.b	0	0	0	0.23	1.49	4.34	5.22	4.95	4.83	5.78	5.28
Subtotal	0	0	0	85.0	506	2,265	2,285	2,289	2,253	2,313	2,239
Carbon dioxide from biodiesel											
1.A.1.c	0	0.00	26.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.A.2.g vii	0	0	0	92.8	162	207	169	170	176	177	175
1.A.3.b	0	108	882	2,787	5,162	6,396	5,259	5,263	5,419	5,697	5,636
1.A.3.c	0	0	0	12.5	28.4	67.8	51.4	51.6	42.9	38.8	43.3
1.A.4.a ii	0	0	0	14.8	26.7	31.3	22.5	23.1	23.7	23.7	23.1
1.A.4.c ii	0.00	0.00	0.00	99.7	182	242	201	202	210	216	215
1.A.5.b	0.00	0.00	0.00	2.33	15.2	5.31	2.24	2.17	1.57	1.15	1.13
Subtotal	**0.00**	**108**	**908**	**3,009**	**5,577**	**6,949**	**5,705**	**5,712**	**5,872**	**6,154**	**6,094**
TOTAL QUANTITY	**0.00**	**108**	**908**	**3,094**	**6,083**	**9,214**	**7,990**	**8,001**	**8,125**	**8,467**	**8,332**

Source: Own calculations

In a next step, the fossil fractions of these emissions are calculated. To this end, the following conservative assumptions are made:

- 100 % of the biodiesel is produced from fatty acid methyl ester (FAME).
- 5.50 % of the carbon contained in the FAME used is of fossil origin.[182]
- 90 % of the biogasoline is produced from bioethanol, and 10 % is produced from ethyl tertiary butyl ether (ETBE).
- 66.67 % of the carbon contained in the ETBE used is of fossil origin.[183]

With these assumptions, the following percentage shares of fossil carbon in the biodiesel and biogasoline used result:

- 5.50 % of the carbon contained in the biodiesel used in Germany is of fossil origin.
- 6.66 % of the carbon contained in the biogasoline used in Germany is of fossil origin.

On the basis of the total emissions shown above, the carbon dioxide quantities shown in Table 2 result. These quantities are allocated to the total national emissions.

Table 555: CO_2 emissions from fossil fractions of biofuels used, in kilotonnes

	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019	2020
Fossil carbon dioxide from biogasoline											
1.A.2.g vii	0.00	0.00	0.02	0.14	0.52	0.70	0.71	0.69	0.69	0.60	0.69
1.A.3.b	0.00	0.00	5.46	32.5	146	147	147	145	149	144	137
1.A.4.b ii	0.00	0.00	0.01	0.08	0.62	0.88	0.88	0.85	0.91	0.87	0.87
1.A.4.c ii	0.00	0.00	0.02	0.10	0.29	0.35	0.33	0.32	0.39	0.35	0.46
1.A.5.b	0.00	0.00	0.03	0.22	0.88	0.68	0.61	0.50	0.49	0.47	0.39
Subtotal	**0.00**	**0.00**	**5.54**	**33.1**	**148**	**149**	**150**	**147**	**151**	**146**	**140**

[182] WG I – Note on fossil carbon content in biofuels; Calculating the fossil fuel content of biofuels that replace fossil diesel (biodiesel)

[183] WG I – Note on fossil carbon content in biofuels; Table 1 – Carbon content and fossil fraction of carbon content of biogasoline

	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019	2020
Fossil carbon dioxide from biodiesel											
1.A.1.c	0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.A.2.g vii	0.00	0.00	5.11	8.93	11.4	9.31	9.35	9.67	9.75	9.65	14.22
1.A.3.b	5.86	47.80	151	281	349	287	288	296	312	308	402
1.A.3.c	0.00	0.00	0.69	1.56	3.73	2.83	2.84	2.36	2.13	2.38	3.28
1.A.4.a ii	0.00	0.00	0.81	1.47	1.72	1.24	1.27	1.30	1.30	1.27	1.84
1.A.4.c ii	0.00	0.00	5.48	10.0	13.3	11.0	11.1	11.6	11.9	11.8	17.7
1.A.5.b	0.00	0.00	0.13	0.83	0.29	0.12	0.12	0.09	0.06	0.06	0.04
Subtotal	**5.86**	**49.3**	**164**	**304**	**379**	**312**	**312**	**321**	**337**	**334**	**439**
TOTAL QUANTITY	**5.86**	**49.3**	**169**	**337**	**527**	**461**	**462**	**468**	**488**	**480**	**578**

Source: Own calculations

Table 556: CO_2 emissions from fossil fractions of biofuels used, in kilotonnes

	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019	2020
1.A.2.g vii – Mobile combustion in manufacturing industries and construction											
from biogasoline	0.00	0.00	0.02	0.14	0.52	0.70	0.71	0.69	0.69	0.60	0.69
from biodiesel	0.00	0.00	5.11	8.93	11.4	9.3	9.3	9.7	9.8	9.6	14.2
Total quantity, 1.A.2.g vii	0.00	0.00	5.13	9.07	11.9	10.0	10.1	10.4	10.4	10.3	14.9
1.A.3.b – Road transportation											
from biogasoline	0.00	0.00	5.46	32.5	146	147	147	145	149	144	137
from biodiesel	5.86	47.8	151	281	349	287	288	296	312	308	402
Total quantity, 1.A.3.b	**5.86**	**47.8**	**157**	**313**	**495**	**434**	**435**	**441**	**460**	**453**	**539**
of which: automobiles	1.85	14.3	66.0	148	288	272	274	277	286	279	301
of which: light duty vehicles	0.42	4.20	14.3	27.5	32.6	28.4	29.4	31.4	34.1	34.3	47.4
of which: heavy duty vehicles (including buses)	3.59	29.3	76.5	137	170	130	127	129	136	136	187
of which: motorcycles	0.00	0.00	0.12	0.75	3.50	3.66	3.73	3.69	3.78	3.66	3.95
1.A.3.c – Railways											
from biodiesel	0.00	0.00	0.69	1.56	3.73	2.83	2.84	2.36	2.13	2.38	3.28
1.A.4 – Vehicles and mobile machinery in the Commercial / Institutional sector, agriculture and forestry											
from biogasoline											
1.A.4.b ii	0.00	0.00	0.01	0.08	0.62	0.88	0.88	0.85	0.91	0.87	0.87
1.A.4.c ii	0.00	0.00	0.02	0.10	0.29	0.35	0.33	0.32	0.39	0.35	0.46
Subtotal	**0.00**	**0.00**	**0.03**	**0.18**	**0.91**	**1.22**	**1.21**	**1.17**	**1.29**	**1.22**	**1.34**
from biodiesel											
1.A.4.a ii	0.00	0.00	0.81	1.47	1.72	1.24	1.27	1.30	1.30	1.27	1.84
1.A.4.c ii	0.00	0.00	5.48	10.03	13.32	11.04	11.13	11.55	11.86	11.82	17.72
Subtotal	**0.00**	**0.00**	**6.30**	**11.50**	**15.04**	**12.28**	**12.39**	**12.86**	**13.16**	**13.10**	**19.56**
Total quantity, 1.A.4	**0.00**	**0.00**	**6.33**	**11.67**	**15.95**	**13.50**	**13.60**	**14.03**	**14.46**	**14.32**	**20.90**
1.A.5.b – Military transports											
from biogasoline	0.00	0.00	0.03	0.22	0.88	0.68	0.61	0.50	0.49	0.47	0.39
from biodiesel	0.00	0.00	0.13	0.83	0.29	0.12	0.12	0.09	0.06	0.06	0.04
Total quantity, 1.A.5.b	**0.00**	**0.00**	**0.16**	**1.06**	**1.18**	**0.80**	**0.73**	**0.58**	**0.56**	**0.53**	**0.43**

Source: Own calculations

Uncertainties and time-series consistency

The uncertainties used as a basis in the present context are in keeping with the figures given, in the various source categories, for the biofuels actually used. These uncertainties are used consistently throughout the entire time series.

Specific quality assurance / control and verification

General quality control and quality assurance, covering a scope wider than the biofuels actually used in the various source categories, was not carried out. Such quality control and quality assurance will not be carried until the pertinent country-specific method has been successfully implemented.

Specific recalculations

With respect to the 2021 submission, recalculations were carried out to take account of corrections, within the individual CRF categories, of input quantities for biofuels. The recalculations are not described in detail here, however.

The adjustments in the activity data lead to revised fossil-based carbon-dioxide quantities from combustion of biodiesel and biogasoline.

Table 557: Revised indirect CO_2 emissions from biofuels, in kilotonnes

	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019
2022 Submission	0.00	5.86	49.3	169	337	527	461	462	468	488
2021 Submission	0.00	5.97	50.0	171	341	534	466	467	473	492
Absolute change	0.00	-0.11	-0.70	-1.95	-4.05	-6.17	-4.94	-4.75	-4.54	-4.43
Relative change		-1.84%	-1.40%	-1.14%	-1.19%	-1.16%	-1.06%	-1.02%	-0.96%	-0.90%

Source: Own calculations

Planned improvements

Currently, no improvements are planned, apart from annual revision of the underlying models.

Chapter 10.4, Inventory Improvements (Table 476), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 475 in the same chapter.

19.2 Other detailed methodological descriptions for the category "industrial processes" (2)

This chapter is currently not required.

19.3 Other detailed methodological descriptions for the category "Agriculture" (3)

19.3.1 Calculation of the emissions for additional animal categories

The CRF tables in IPCC (2006a Vol 4) call for reporting of emissions for additional animal categories that are not included in Chapter 5:

- Deer,
- Rabbits,
- Reindeer,
- Ostriches,
- Fur-bearing animals.

No reindeer are kept in Germany. In the following, the GHG emissions from the other four categories are calculated, by way of example, and using Tier 1 methods, for one year. Table 558 summarises the results of these calculations. These data serve as the basis for concluding that the relevant emissions are insignificant and thus do not have to be reported in the NIR; cf. Chapter 21.

Table 558: Total GHG emissions of deer, rabbits, ostriches and fur-bearing animals

	CH_4 [kt a^{-1}]	N_2O [kt a^{-1}]	CO_{2eq} [kt a^{-1}]
Total	**5.635**	**0.108**	**172.91**
Deer	5.348	0.085	159.11
Rabbits	0.194	0.011	7.98
Ostriches	0.043	0.003	1.83
Fur-bearing animals (mink)	0.050	0.009	3.99

19.3.1.1 Animal-place figures

In Germany, no official counts are taken of populations of deer, rabbits, ostriches and fur-bearing animals. Table 559 presents estimates of the Federal Statistical Office concerning the average animal populations (Federal Statistical Office, Section G 105, C. Schreiner, personal communication, 2012). These figures are interpreted as numbers of continuously occupied animal places – i.e. average animal populations (AAP) (cf. Chapter 5.1.3.2). The FAO also provides figures for rabbits, but those figures are far lower than the national figures. For this reason, the approach used here may be considered a conservative one.

Table 559: Average annual animal populations, pursuant to estimates of the Federal Statistical Office

	Population	Source
Deer	264,500	Landesverbände für landwirtschaftliche Wildtierhaltung (state associations for agricultural husbandry of wild animals); survey conducted in the period 2008/2009
Rabbits	440,000	Bundesverband deutscher Kaninchenfleisch- und –wollerzeuger e.V. (national association of German producers of rabbit meat and rabbit fur)
Ostriches	7,632	Tierseuchenkasse (animal diseases fund; 2012)
Fur-bearing animals (mink)	63,500	Länderabfrage zur Haltung von Pelztieren (State survey on husbandry of fur-bearing animals; last revision March 2012)

19.3.1.2 CH_4 emissions from enteric fermentation

No CH_4 emissions from enteric fermentation are calculated for ostriches, since IPCC (2006a Vol 4) does not specify any methods for such calculation. The emissions for the categories deer, rabbits and fur-bearing animals are calculated by multiplying the relevant numbers of animals by the pertinent emission factors.

For deer, the CH_4 default emission factor in IPCC (2006a Vol 4, 10.28, Table 10.10) is used (20 kg pl^{-1} a^{-1}).

IPCC (2006a Vol 4) does not provide an emission factor for rabbits. Pursuant to footnote 1 to Table 10.10 on p. 10.28 in IPCC (2006a Vol 4), the emission factor can be approximated by selecting an emission factor for an animal with a similar digestive system and then scaling that emission factor using the ratio of the weights of the animals raised to the 0.75 power. For such estimation, the horse was chosen as the comparison animal, since it is neither a ruminant (cattle, sheep, goats) nor an omnivore (swine). Pursuant to IPCC (2006a Vol 4, 10.28, Table 10.10), a horse weight of 550 kg per animal should be used for the calculation. The specified weight for rabbits is 3.0 kg (final live weight of a fattening rabbit, pursuant to LfL Bayern (2006) (Bavarian state office for agriculture)). From the CH_4 emission factor for horses (18 kg pl^{-1} a^{-1}, IPCC (2006a Vol 4, 10.28, Table 10.10)), one then obtains a CH_4 emission factor of 0.36 kg pl^{-1} a^{-1} for rabbits.

For fur-bearing animals, we have adopted the CH_4 emission factor used by other countries (Estonia, Iceland, Latvia, Lithuania, Norway; the 2017 NIR applies in each case), 0.1 kg pl^{-1} a^{-1}.

Table 560 shows, by way of example, the annual emissions from enteric fermentation calculated for deer, rabbits and fur-bearing animals.

Table 560: CH_4 emissions from enteric fermentation for deer, rabbits and fur-bearing animals

	EF [kg pl^{-1} a^{-1}]	CH_4 [kt a^{-1}]	CO_{2eq} [kt a^{-1}]
Total		5.45	136.37
Deer	20.00	5.29	132.25
Rabbits	0.36	0.16	3.96
Fur-bearing animals (mink)	0.10	0.0064	0.16

19.3.1.3 CH_4 emissions from manure management

The default emission factors in IPCC (2006a Vol 4, 10.83, Table 10A-9) are used. The resulting emissions are shown in Table 561.

Table 561: CH_4 emissions from manure management for deer, rabbits, ostriches and fur-bearing animals

	EF [kg pl^{-1} a^{-1}]	CH_4 [kt a^{-1}]	CO_{2eq} [kt a^{-1}]
Total		**0.180**	**4.50**
Deer	0.22	0.058	1.45
Rabbits	0.08	0.035	0.88
Ostriches	5.67	0.043	1.08
Fur-bearing animals (mink)	0.68	0.043	1.08

19.3.1.4 N_2O emissions from manure management

To calculate N_2O emissions from manure management, one must know the relevant N excretions. It is also useful to know how the relevant animal population is divided among the applicable housing systems. The latter factor is not known for deer, rabbits, ostriches and fur-bearing animals in Germany. As a simplification, therefore, year-round free-range management is assumed for deer, while year-round housing in solid-manure-based stable systems is assumed for rabbits, fur-bearing animals and ostriches. With regard to the N excretions, cf. Chapter 19.3.1.4.1. The resulting N_2O emissions are listed in Chapter 19.3.1.4.2.

19.3.1.4.1 N excretions

Neither IPCC (2006a Vol 4) nor EMEP/EEA (2019) specifies a default value for the N excretions of deer. The German calculations have been carried out with the value used by Denmark (16 kg pl^{-1} a^{-1}; UNFCCC (2021b)), since it can be assumed that the average N excretions of deer in Denmark do not differ significantly from those of deer in Germany.

For rabbits, IPCC (2006a Vol 4, 10.59, Table 10.19) specifies a default N-excretion value of 8.1 kg pl^{-1} a^{-1}. That value seems unrealistically high, since it is of the same order of magnitude as the total weight gain per animal place and year. Assuming about four rounds of fattening per year (n_{round}, derived from a 87-day duration of fattening pursuant to LfL Bayern (2006) (Bavarian state office for agriculture)) and a final live weight of about 3 kg $animal^{-1}$ (cf. also LfL Bayern), the weight gain works out to about 12 kg pl^{-1} a^{-1}. For this reason, the N excretions of rabbits are estimated on the basis of the relevant N balance for the animals; cf. Equation 64:

Equation 64: Calculation of the N excretions of rabbits (N balance)

$$N_{\text{excr, rabbit}} = n_{\text{round}} \cdot \Delta w_{\text{round}} \cdot (x_{\text{N}} \cdot x_{\text{XP, feed}} \cdot x_{\text{feed}} - x_{\text{N, ret}})$$

Where

$N_{excr, rabbit}$	N excretions (in kg $place^{-1}$ a^{-1})
n_{round}	Number of fattening rounds per year (in rounds a^{-1})
Δw_{round}	Weight gain per fattening round (in kg $round^{-1}$ $place^{-1}$)
x_N	N content of raw protein (1 / 6.25 kg kg^{-1})

$x_{XP, feed}$	Raw protein content of feed (fresh matter) (in kg kg^{-1})
x_{feed}	Feed input (fresh matter) per kg of weight gain (in kg kg^{-1})
$x_{N, ret}$	Specific N retention (kg kg^{-1})

In a conservative approach, and as a simplifying approximation, Δw_{round} is considered to be equal to the end weight after fattening (see above). The raw protein content of the feed, $x_{XP,feed}$, pursuant to Beduco NV (2020), is about 0.17 kg kg^{-1}. The feed input x_{feed} is about 3.5 kg kg^{-1} (LfL Bayern, 2006). Pursuant to DLG (2005), p.12, $x_{n,ret}$ = 0.03 kg kg^{-1}. Equation 64 then yields an N-excretion value of 0.8 kg pl^{-1} a^{-1}.

For ostriches, neither IPCC (2006a Vol 4) nor EMEP/EEA (2019) specifies default values for N excretions. For the German calculations in this category, we again use the relevant Danish value (UNFCCC, 2021b): 15.6 kg pl^{-1} a^{-1}.

For mink, IPCC (2006a Vol 4, 10.59, Table 10.19) specifies a default N-excretion value of 4.59 kg pl^{-1} a^{-1}.

19.3.1.4.2 Direct N_2O emissions from manure management

For rabbits, fur-bearing animals and ostriches, the direct N_2O emissions from manure management are obtained by multiplying the relevant animal-place figures by the annual N excretions per place, the relevant N_2O-N emission factor (0.005 kg kg^{-1} for rabbits and fur-bearing animals, and 0.001 kg kg^{-1} for ostriches; cf. Chapter 5.3.4.2.2) and the molar ratio of N_2O to N (44/28). No N_2O emissions occur in the area of manure management for deer, since free-range management may be considered equivalent to "grazing" in this regard. The resulting emissions are reported together with the direct N_2O emissions from soils; cf. Chapter 19.3.1.6.

Table 562: Direct N_2O emissions from manure management for deer, rabbits, ostriches and fur-bearing animals

	N_{excr} [kg pl^{-1} a^{-1}]	N_2O [kt a^{-1}]	CO_{2eq} [kt a^{-1}]
Total		**0.005**	**1.56**
Deer	16	NO	NO
Rabbits	0.8	0.003	0.82
Ostriches	15.6	0.0002	0.06
Fur-bearing animals (mink)	4.59	0.002	0.68

19.3.1.5 Indirect N_2O emissions from manure management

As for other animals (cf. Chapter 5.3.1), indirect N_2O emissions from leaching / surface runoff are not calculated. The following section describes the calculation of indirect N_2O emissions from deposition of reactive nitrogen from NH_3 and NO emissions from housing and storage. Due to a lack of relevant data, nitrogen inputs from bedding material cannot be taken into account.

First, the NH_3 and NO emissions from housing and storage are determined. The procedure for calculating the NO emissions is similar to that for calculating direct N_2O emissions from housing and storage (cf. Chapter 19.3.1.4.2). As was the case for the other animals (cf. Chapter 5.3.4.2.2), the emission factor is set to ten percent of the N_2O emission factor: 0.0013 kg kg^{-1} for rabbits and fur-bearing animals, and 0.0001 kg kg^{-1} for ostriches.

The NH_3 emissions from housing are calculated by multiplying the excreted quantity of TAN (total ammoniacal nitrogen) by the relevant emission factor. The applicable TAN quantity is obtained as the product of N excretions and the excretions' relative TAN content. The NH_3 emissions from storage are proportional to the TAN quantity that remains following deduction of N losses due to NH_3 emissions from housing. The pertinent proportionality factor is the emission factor for storage. No data on TAN content and emission factors are available for rabbits and ostriches. For this reason, the relevant default values for horses and geese in EMEP/EEA (2019-3B-31) have been used for those animals. The data ultimately used are listed in Table 563, with the emission factors given in kg NH_3-N per kg of TAN. For deer, the calculation is not required, since deer are assumed to remain outdoors year-round.

Table 563: Input data for calculation of NH_3 emissions (emission factors [EF] in kg NH_3-N per kg TAN)

	TAN content [%]	EF housing [kg kg^{-1}]	EF storage [kg kg^{-1}]	Remarks
Rabbits	60	0.22	0.35	Default for horses, EMEP/EEA (2019-3B-31)
Ostriches	70	0.57	0.16	Default for geese, EMEP/EEA (2019-3B-31)
Fur-bearing animals (mink)	60	0.27	0.09	Default, EMEP/EEA (2019-3B-31)

The resulting deposition of reactive nitrogen (N_{reac}), and the then-resulting indirect N_2O emissions, are given in Table 564. Pursuant to IPCC (2006a Vol 4, 11.24, Table 11.3), the emission factor EF_4 = 0.01 kg N_2O-N per kg N_{reac} has been used.

Table 564: Indirect N_2O emissions from deposition of reactive nitrogen from NH_3 and NO emissions from housing and storage

	N_{reac}[kt a^{-1}]	N_2O [kt a^{-1}]	CO_{2eq} [kt a^{-1}]
Total	**0.2164**	**0.00340**	**1.01**
Rabbits	0.0000	0.00000	0.00
Ostriches	0.1043	0.00164	0.49
Fur-bearing animals (mink)	0.0533	0.00084	0.25

19.3.1.6 Direct N_2O emissions from agricultural soils

Application of manure of rabbits, ostriches and fur-bearing animals, and free-range husbandry of deer, leads to direct N_2O emissions from agricultural soils.

The emissions from manure application are calculated by multiplying the N quantity that remains, following N losses (as NH_3, N_2O, NO and N_2) from housing and storage, by the IPCC default emission factor EF_1 (0.01 kg N_2O-N per kg N, IPCC (2006a Vol 4, 11.11, Table 11.1)) and the molar ratio 44/28.

The N_2O emissions caused by deer are obtained by multiplying the number of animals by the TAN excretions, the N_2O-N emission factor for grazing and the molar ratio 44/28. The applicable TAN quantity is obtained as the product of N excretions and the excretions' relative TAN content. Since the latter factor is unknown, the relevant value for sheep pursuant to EMEP/EEA (2019-3B-31) (50 %) is used. In keeping with IPCC (2006a Vol 4, 11.11, Table 11.1), the emission factor used is the $EF_{3PRP,SO}$ for sheep and other animals (0.01 kg N_2O-N per kg N excretions).

Table 565 shows the pertinent emissions, along with the N quantities used to obtain them, via multiplication by the relevant emission factors and the molar ratio 44/28.

Table 565: Direct N_2O emissions from soils as a result of free-range husbandry of deer and of application of manure of rabbits, ostriches and fur-bearing animals.

	N [kt a^{-1}]	N_2O [kt a^{-1}]	CO_{2eq} [kt a^{-1}]
Total	**4.765**	**0.0749**	**22.31**
Deer	4.232	0.0665	19.82
Rabbits	0.241	0.0038	1.13
Ostriches	0.065	0.0010	0.31
Fur-bearing animals (mink)	0.227	0.0036	1.06

19.3.1.7 Indirect N_2O emissions from agricultural soils

To calculate the indirect emissions from deposition of reactive nitrogen, one must know the NH_3-N emissions from free-range husbandry of deer and from manure application, along with the relevant NO-N emissions. Table 567 shows the emission factors that are used to calculate the NH_3 emissions.

Table 566: Parameters for calculation of indirect N_2O emissions from deposition of reactive nitrogen as a result of free-range husbandry and of application (emission factors [EF] in kg NH_3-N per kg TAN)

	EF_{NH3-N} Free-range	EF_{NH3-N} application	Remarks
Deer	0.09		Default for sheep, EMEP/EEA (2019-3B-31)
Rabbits		0.90	Default for horses, EMEP/EEA (2019-3B-31)
Ostriches		0.45	Default for geese, EMEP/EEA (2019-3B-31)
Fur-bearing animals (mink)		0.90	Default for horses, EMEP/EEA (2019-3B-31)

In a procedure similar to that described in Chapter5.3.4.2.2, the NO-N emissions from free-range husbandry of deer, and from application of manure of rabbits, ostriches and fur-bearing animals are calculated with the emission factor derived by Stehfest and Bouwman (2006), 0.012 kg NO-N per kg of available nitrogen.

The resulting deposition of reactive nitrogen (N_{reac}), and the then-resulting indirect N_2O emissions, are given in Table 567. In keeping with IPCC (2006a Vol 4, 11.24, Table 11.3), the emission factor EF_4 = 0.01 kg N_2O-N per kg N_{reac} has been used.

Table 567: Indirect N_2O emissions from deposition of reactive nitrogen (N_{reac}) from NH_3 and NO emissions from free-range husbandry of deer and from manure application

	N_{reac}[kt a^{-1}]	N_2O [kt a^{-1}]	CO_{2eq} [kt a^{-1}]
Total	**0.456**	**0.0072**	**2.13**
Deer	0.241	0.0038	1.13
Rabbits	0.096	0.0015	0.45
Ostriches	0.014	0.0002	0.07
Fur-bearing animals (mink)	0.104	0.0016	0.49

The indirect emissions from leaching / surface runoff are calculated by multiplying the N quantity applied to the soil ($N_{applied}$) by $FRAC_{Leach}$ (0.3 kg kg^{-1} pursuant to IPCC (2006a Vol 4, 11.24, Table 11.3)) and the emission factor EF_5 = 0.0075 kg N_2O-N (kg N leaching/runoff)$^{-1}$ pursuant to IPCC (2006a Vol 4, 11.24, Table 11.3).

Table 568: Indirect N_2O emissions from the soil as a result of leaching / surface runoff

	$N_{applied}$ [kt a^{-1}]	N_2O [kt a^{-1}]	CO_{2eq} [kt a^{-1}]
Total	**4.765**	**0.0168**	**5.02**
Deer	4.232	0.0150	4.46
Rabbits	0.241	0.0009	0.25
Ostriches	0.065	0.0002	0.07
Fur-bearing animals (mink)	0.227	0.0008	0.24

19.3.2 Distributions of housing, storage and application procedures, and of grazing data (CRF 3.B, 3.D)

Table 569 through Table 572 show the applicable distributions, aggregated at the national level (and rounded to whole-number percentages), of housing, storage and application procedures. They also include data on grazing. Buffalo, and mules and asses, are not listed separately in the following tables, because buffalo data are reported together with cattle data, and data for mules and asses are reported together with data for horses (cf. Chapter 5.1.3.2.2).

The relevant emissions were calculated not with the data shown in Table 569 through Table 572, but with the data underlying those data. Those underlying data have state-level (German-Länder-level) resolution. Cf. Chapter 3.4.3 in Vos et al. (2022). The tables also include information relative to emission factors (including that for NH_3). For further details, cf. chapters 3.4.4, 4.2.2, 5.2.2, 6.2.2, 7.2.2, 8.2.2 and 8.3.8.3 in Vos et al. (2022).

Table 569: Frequency distributions of animal housing procedures (in %), and pertinent litter quantities and NH_3 emission factors

livestock category	housing type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	bedding material (straw) kg place d-1	NH3-N EF for housing, kg NH3-N per kg TAN in excreta
Dairy cows	tied systems, straw based	31	31	31	31	15	15	15	15	13	13	13	12	12	12	11	11	10	10	10	9	9	8	8	7	7	6	5	5	4	4	3	5.0	0.066
	tied systems, slurry based	39	39	39	39	36	36	36	36	34	34	33	31	30	28	27	25	24	23	21	20	18	17	16	15	14	13	12	11	10	9	9		0.066
	loose housing, straw based	2	2	2	2	3	3	3	3	3	3	4	4	5	5	6	6	7	7	8	8	9	8	8	8	8	7	7	7	6	6	6	5.0	0.197
	loose housing, slurry based	28	28	28	28	46	46	46	46	49	49	50	52	53	55	56	57	59	60	61	63	64	65	67	68	70	71	73	74	76	77	78		0.197
	loose housing, deep bedding	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	3	3	4	4	4	8.0	0.197
	time spent on pastures (in % of year)	20	21	21	21	16	16	16	15	15	15	13	12	12	12	12	11	11	11	11	11	10	10	10	10	9	9	9	8	8	8	7		
male beef cattle	tied systems, straw based	4	4	4	4	2	2	2	2	2	2	2	3	3	4	4	5	5	5	6	6	7	6	6	6	5	5	4	4	3	3	3	2.0	0.066
	tied systems, slurry based	7	7	7	7	4	4	4	4	4	4	4	5	5	6	7	7	8	8	9	9	10	9	9	8	8	7	7	6	6	5	4		0.066
	loose housing, slurry based	85	85	85	85	89	89	89	89	91	91	87	84	80	77	74	70	67	63	60	56	53	53	54	54	55	55	56	56	56	57	57		0.197
	loose housing, sloped floor	4	4	4	4	4	4	4	4	3	3	5	8	10	12	14	17	19	21	23	25	28	27	26	24	23	22	21	20	19	18	17	2.5	0.213
	Loose housing, deep bedding, straw based	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2	3	3	4	6	8	9	11	12	14	16	17	19	5.0	0.197
	time spent on pastures (in % of year)	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	4	4	4	4	5	6	6	7	8	9	9	10	11		
female beef cattle	tied systems, straw based	9	9	9	9	9	9	9	9	9	9	9	9	10	10	10	10	10	11	11	11	11	11	10	9	9	8	7	7	6	6	5	2.0	0.066
	tied systems, slurry based	16	16	16	16	18	18	18	18	18	18	18	17	16	16	15	15	14	13	13	12	11	11	11	10	10	10	9	9	8	8	8		0.066
	loose housing, slurry based	48	48	48	48	50	50	50	50	50	50	50	49	48	48	47	46	46	45	44	44	43	44	44	45	46	47	48	48	49	50	51		0.197
	loose housing, straw based	28	28	28	28	23	23	23	23	22	22	23	24	25	26	26	27	28	29	30	30	31	30	28	27	26	24	23	22	20	19	18	3.0	0.197
	Loose housing, deep bedding, straw based	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	3	3	3	5	6	8	10	11	13	14	16	18	19	6.0	0.197
	time spent on pastures (in % of year)	20	20	19	19	19	19	20	20	19	19	20	19	19	19	19	19	19	20	17	17	17	18	17	17	17	17	16	16	16	15	15		
dairy heifers	tied systems, straw based	8	8	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	10	10	10	10	9	9	8	8	7	7	6	5	5	4	2.0	0.066
	tied systems, slurry based	17	17	17	17	17	17	17	17	17	17	16	15	15	14	13	13	12	11	11	10	9	9	9	8	8	8	7	7	7	6	6		0.066
	loose housing, slurry based	49	49	49	49	49	49	49	49	49	49	49	48	48	47	47	46	46	45	45	44	44	45	45	46	47	48	48	49	50	51	51		0.197
	loose housing, straw based	26	26	26	26	26	26	26	26	26	26	26	27	28	28	29	30	31	31	32	33	33	32	31	29	28	26	25	23	22	20	19	3.0	0.197

livestock category	housing type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	bedding material (straw) kg place d^{-1}	NH3-N EF for housing, kg NH3-N per kg TAN in excreta
	Loose housing, deep bedding, straw based	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	2	3	3	3	5	7	8	10	12	13	15	16	18	20	6.0	0.197
	time spent on pastures (in % of year)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	19	19	19	18	18	18	17	17		
calves	tied systems, straw based	50	50	50	50	50	50	50	50	50	50	50	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0.066
	loose housing, deep bedding	50	50	50	50	50	50	50	50	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	2.5	0.197
	time spent on pastures (in % of year)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
suckler cows	tied systems, straw based	10	10	10	10	8	8	8	8	7	7	8	8	9	9	10	10	11	11	11	12	12	12	11	11	10	9	9	8	8	7	7	5.0	0.066
	tied systems, slurry based	3	3	3	3	3	3	3	3	2	2	3	3	3	3	3	4	4	4	4	4	5	4	4	4	4	4	4	4	4	3	3		0.066
	loose housing, slurry based	7	7	7	7	6	6	6	6	6	6	6	7	8	9	10	10	11	12	13	14	14	15	15	15	15	15	15	15	15	15	15		0.197
	Loose housing, straw based	0	0	0	0	0	0	0	0	0	0	4	9	13	18	22	27	31	36	40	44	49	48	46	45	43	42	41	39	38	37	35	8.0	0.197
	loose housing, deep bedding	80	80	80	80	83	83	83	83	85	85	79	73	67	61	55	49	43	37	32	26	20	22	24	26	28	30	32	34	35	37	39	8.0	0.197
	time spent on pastures (in % of year)	43	42	43	43	43	43	44	44	45	45	45	45	45	45	46	46	46	47	47	47	48	49	50	50	51	52	53	54	55	56	56		
mature males > 2 years	tied systems, straw based	15	15	15	15	15	15	15	15	14	14	14	14	14	14	14	14	14	13	13	13	13	12	12	11	10	10	9	8	7	7	6	5.0	0.066
	tied systems, slurry based	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	7	7	7	7	7	7	6	6	6	5	5	5	4	4	4		0.066
	loose housing, slurry based	34	34	34	34	35	35	35	35	36	36	35	35	34	34	33	33	32	32	31	30	30	30	30	30	30	30	30	30	30	30	30		0.197
	loose housing, straw based	43	43	43	43	42	42	42	42	41	41	41	40	40	40	39	39	39	38	38	37	37	36	35	34	33	32	31	30	29	28	27	5.0	0.197
	Loose housing, deep bedding, straw based	0	0	0	0	0	0	0	0	0	0	1	2	4	5	6	7	8	10	11	12	13	15	17	19	21	23	25	27	29	31	33	8.0	0.197
	time spent on pastures (in % of year)	35	33	33	34	33	33	33	32	33	33	32	32	32	32	32	33	33	33	34	34	34	35	36	37	38	39	41	42	43	44	45		
fattening pigs	fully slatted floor, slurry	49	49	49	49	57	57	57	57	62	62	63	64	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	79	80	81		0.3
	partly slatted floor, slurry	40	40	40	40	34	34	34	34	31	31	31	30	29	28	27	26	26	25	24	23	22	21	21	20	19	19	18	17	16	16	15		0.3
	plane floor with bedding	8	8	8	8	6	6	6	6	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	3	3	3	3	2	2	0.3	0.4
	deep bedding, closed insulated	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1.0	0.4
	Deep bedding, free ventilated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1.0	0.35
	time spent on pastures (in % of year)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		

livestock category	housing type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	bedding material (straw) kg place d^{-1}	NH3-N EF for housing, kg NH3-N per kg TAN in excreta
weaners	fully slatted floor, slurry	45	45	45	45	57	57	57	57	62	62	63	64	64	65	66	67	68	68	69	70	71	72	73	74	75	76	76	77	78	79	80		0.3
	partly slatted floor, slurry	41	41	41	41	33	33	33	33	28	28	28	27	27	26	26	25	25	24	24	23	23	22	21	21	20	19	18	18	17	16	16		0.3
	plane floor with bedding	10	10	10	10	7	7	7	7	6	6	6	6	6	6	6	6	5	5	5	5	5	5	4	4	4	4	3	3	3	3	2	0.15	0.4
	deep bedding, closed insulated	4	4	4	4	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	0.2	0.4
	Deep bedding, free ventilated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0.2	0.35
	time spent on pastures (in % of year)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
sows	straw based	42	42	42	42	26	26	26	26	24	24	23	22	22	21	20	19	18	17	16	15	14	14	13	12	12	11	10	10	9	8	8	0.5	0.34
	slurry based	58	58	58	58	74	74	74	74	76	76	77	78	78	79	80	81	82	83	84	85	86	86	87	88	88	89	90	90	91	92	92		0.34
	time spent on pastures (in % of year)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
boars	straw based	32	32	32	32	23	23	23	23	21	21	21	21	20	20	19	19	18	18	17	17	16	15	15	14	13	12	11	10	9	9	8	0.5	0.34
	slurry based	68	68	68	68	77	77	77	77	79	79	79	79	80	80	81	81	82	82	83	83	84	85	85	86	87	88	89	90	91	91	92		0.34
	time spent on pastures (in % of year)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
laying hens	cages; ≥2010: small group housing systems	95	95	95	95	95	94	92	90	89	88	87	85	84	81	77	73	70	68	62	38	18	14	13	11	11	10	10	9	9	7	6		*)
	floor management, aviary	4	4	4	4	4	5	5	7	7	7	7	7	7	9	12	14	15	17	22	45	63	64	64	64	64	64	63	65	62	62	62	0.5 kg per place and year	*)
	free range, organic farming	1	1	1	1	1	2	2	4	4	5	7	8	9	10	11	13	14	15	16	18	19	22	23	24	26	26	27	26	29	30	32	0.5 kg per place and year	*)
broilers	floor management	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	1.4 kg per place and year	0.09 kg per kg of total N excreted
pullets	floor management	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.75 kg per place and year	0.09 kg per kg of total N excreted
ducks	floor management	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	22 kg per place and year	0.16 kg per kg of total N excreted
geese	floor management	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100		0.57
turkeys, female	floor management	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	10.3 kg per place and year	0,222 kg per kg of total N excreted
turkeys, male	floor management	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	10.3 kg per place and year	0,222 kg per kg of total N excreted
horses	straw based system	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	8.0/ 5.0	0.22
	time spent on pastures (in % of year)	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21		

livestock category	housing type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	bedding material (straw) kg place d^{-1}	NH3-N EF for housing, kg NH3-N per kg TAN in excreta
sheep without lambs	straw based system	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.4	0.22
	time spent on pastures (in % of year)	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	56	55	55		
lambs	straw based system	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.16	0.22
	time spent on pastures (in % of year)	57	57	58	58	57	57	58	57	57	57	57	57	57	57	57	57	57	57	57	57	55	55	55	55	55	55	55	55	56	55	55		
goats	straw based system	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.4	0.22
	time spent on pastures (in % of year)	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34		

*) s. Table 572: Laying hens, housing-specific partial NH_3 emission factors

Table 570: Frequency distributions of storage systems (in %); quantities of digested energy crops; and pertinent emission factors

livestock category	storage type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system (leachate / urine)	N_2O EF for storage kg N_2O-N per kg N in storage system	N_2O EF for storage kg N_2O-N per kg N in storage system (leachate / urine)	CH_4 MCF for storage % of Bo < 10 °C	maximum CH_4 producing capacity (Bo) m^3 CH4 per kg VS
cattle, untreated slurry	open tank (% of total untreated slurry)	1	1	1	1	1	1	1	1	1	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	0.150		0.000		17.0	0.23
	solid cover (% of total untreated slurry)	23	23	23	23	22	22	22	22	22	22	23	23	24	25	25	26	27	28	28	29	30	29	28	27	26	25	25	24	23	22	21	0.015		0.005		17.0	0.23
	natural crust (% of total untreated slurry)	33	33	33	33	41	41	41	41	41	41	40	39	37	36	35	34	33	32	31	30	29	30	30	31	31	32	32	33	33	34	34	0.045		0.005		10.0	0.23
	plastic film (% of total untreated slurry)	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	0.023		0.000		17.0	0.23
	artificial crust (chaff) (% of total untreated slurry)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0.030		0.000		17.0	0.23
	storage below	42	42	42	42	36	36	36	36	36	36	36	35	35	35	34	34	34	33	33	32	32	32	32	31	31	31	30	30	30	29	29	0.045		0.002		17.0	0.23

livestock category	storage type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system (leachate / urine)	N_2O EF for storage kg N_2O-N per kg N in storage system	N_2O EF for storage kg N_2O-N per kg N in storage system (leachate / urine)	CH_4 MCF for storage % of Bo < 10 °C	maximum CH_4 producing capacity (Bo) m³ CH4 per kg VS
	animal confinements > 1 month (% of total untreated slurry)																																					
cattle, digestion of slurry	% of total cattle slurry	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	4	7	10	12	15	18	23	24	26	27	28	27	28	27	26	26						
cattle, digestion of solid manure	% of total solid manure of cattle	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	3	3	4	4	5	5	5	5	5	5	5	6						
cattle, storage of digestates	gas tight storage (% of slurry)	0	1	2	3	4	5	5	6	7	8	9	10	11	12	14	15	20	25	30	35	41	46	57	59	61	62	62	62	62	63	63	0.000		0.000		2.683	0.23
cattle, storage of digestates	open tank (% of slurry)	100	99	98	97	96	95	95	94	93	92	91	90	89	88	86	85	80	75	70	65	59	54	43	41	39	38	38	38	38	37	37	0.045		0.005		3.090	0.23
cattle, storage of digestates	gas tight storage (% of solid manure)	0	1	2	3	4	5	5	6	7	8	9	10	11	12	14	15	20	25	30	35	41	46	57	59	61	62	62	62	62	63	63	0.000		0.000		1.198	0.23
cattle, storage of digestates	open tank (% of solid manure)	100	99	98	97	96	95	95	94	93	92	91	90	89	88	86	85	80	75	70	65	59	54	43	41	39	38	38	38	38	37	37	0.045		0.005		1.611	0.23
dairy cows, solid manure	heap (% of total solid manure)	100	100	100	100	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	97	94	91	88	85	82	79	75	71	67	0.600	0.013	0.005	0.005	2.0	0.23
Dairy cows, solid manure	Deep bedding (% of total solid manure)	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	6	9	12	15	18	21	25	29	33	0.600		0.010		17.0	0.23
male beef cattle, solid manure	heap (% of total solid manure)	45	45	45	45	37	37	37	37	35	35	29	25	23	22	21	20	20	19	19	18	18	17	16	15	14	12	11	10	9	8	7	0.600	0.013	0.005	0.005	2.0	0.23
	sloped floor (% of total solid manure)	53	53	53	53	57	57	57	57	58	58	65	68	70	71	72	73	73	73	74	74	74	71	68	65	62	59	56	53	50	47	44	0.600		0.010	0.005	17.0	0.23
	Deep bedding (% of total solid manure)	3	3	3	3	5	5	5	5	6	6	7	7	7	7	7	7	7	7	7	7	7	12	16	20	24	29	33	37	41	45	49	0.600		0.010		17.0	0.23
female beef cattle,	heap (% of total	100	100	100	100	100	100	100	100	100	100	99	98	98	97	96	96	95	94	94	93	93	89	86	82	78	74	70	66	62	58	54	0.600	0.013	0.005	0.005	2.0	0.23

livestock category	storage type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system (leachate / urine)	N_2O EF for storage kg N_2O-N per kg N in storage system	N_2O EF for storage kg N_2O-N per kg N in storage system (leachate / urine)	CH_4 MCF for storage % of Bo < 10 °C	maximum CH_4 producing capacity (Bo) m^3 CH4 per kg VS
solid manure	solid manure) Deep bedding (% of total solid manure)	0	0	0	0	0	0	0	0	0	0	1	2	2	3	4	4	5	6	6	7	7	11	14	18	22	26	30	34	38	42	46	0.600		0.010		17.0	0.23
dairy heifers, solid manure	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	99	98	98	97	96	95	95	94	94	93	93	89	86	82	78	74	70	67	63	58	54	0.600	0.013	0.005	0.005	2.0	0.23
	Deep bedding (% of total solid manure)	0	0	0	0	0	0	0	0	0	0	1	2	2	3	4	5	5	6	6	7	7	11	14	18	22	26	30	33	37	42	46	0.600		0.010		17.0	0.23
calves, solid manure	heap (% of total solid manure)	50	50	50	50	50	50	50	50	50	50	50	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.600	0.013	0.005	0.005	2.0	0.23
	deep bedding (% of total solid manure)	50	50	50	50	50	50	50	50	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.600		0.010		17.0	0.23
suckler cows, solid manure	heap (% of total solid manure)	11	11	11	11	9	9	9	9	8	8	14	19	25	31	37	43	49	55	62	69	76	73	71	68	66	64	61	59	56	54	51	0.600	0.013	0.005	0.005	2.0	0.23
	deep bedding (% of total solid manure)	89	89	89	89	91	91	91	91	92	92	86	81	75	69	63	57	51	45	38	31	24	27	29	32	34	36	39	41	44	46	49	0.600		0.010		17.0	0.23
mature males, solid	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	98	96	94	92	90	88	86	84	83	81	79	76	73	70	67	64	61	58	55	53	50	0.600	0.013	0.005	0.005	2.0	0.23
	Deep bedding (% of total solid manure)	0	0	0	0	0	0	0	0	0	0	2	4	6	8	10	12	14	16	17	19	21	24	27	30	33	36	39	42	45	47	50	0.600		0.010		17.0	0.23

livestock category	storage type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system (leachate / urine)	N_2O EF for storage, kg N_2O-N per kg N in storage system	N_2O EF for storage, kg N_2O-N per kg N in storage system (leachate / urine)	CH_4 MCF for storage, % of Bo < 10 °C	maximum CH_4 producing capacity (Bo), m^3 CH4 per kg VS
pigs, untreated slurry	open tank (% of total untreated slurry)	47	47	47	47	27	27	27	27	27	27	25	23	22	20	18	17	15	13	12	10	8	9	9	9	10	10	10	11	11	11	12	0.150		0.000		25.0	0.30
	solid cover (% of total untreated slurry)	18	18	18	18	22	22	22	22	22	22	22	22	21	21	21	20	20	20	19	19	19	18	18	18	18	18	17	17	17	17	17	0.015		0.005		25.0	0.30
	natural crust (% of total untreated slurry)	3	3	3	3	13	13	13	13	13	13	14	16	17	18	20	21	23	24	25	27	28	27	27	26	25	24	23	22	21	20	20	0.105		0.005		15.0	0.30
	plastic film (% of total untreated slurry)	0	0	0	0	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	8	8	9	9	9	10	10	10	0.023		0.000		25.0	0.30
	artificial crust (chaff) (% of total untreated slurry)	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	0.030		0.000		25.0	0.30
	storage below animal confinements > 1 month (% of total untreated slurry)	32	32	32	32	31	31	31	31	32	32	32	32	32	33	33	33	33	33	34	34	34	35	35	35	36	36	36	37	37	38	38	0.105		0.002		25.0	0.30
pigs, digested slurry	% of total pig slurry	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	3	4	5	6	8	10	12	13	15	15	16	16	16	16	15	15						
pigs, storage of digestates	gas tight storage (% of digestates)	0	1	2	3	4	5	5	6	7	8	9	10	11	12	14	15	20	25	30	35	41	46	57	59	61	62	62	62	62	63	63	0.000		0.000		3.475	0.30
pigs, storage of digestates	open tank (% of digestates)	100	99	98	97	96	95	95	94	93	92	91	90	89	88	86	85	80	75	70	65	59	54	43	41	39	38	38	38	38	37	37	0.045		0.005		3.879	0.30
fattening pigs / weaners, solid manure	heap (% of total solid manure)	75	75	75	75	70	70	70	70	69	69	69	70	70	71	71	71	72	72	73	73	74	73	72	71	70	68	67	65	64	62	60	0.600	0.030	0.005	0.005	3.0	0.30
	deep bedding (% of total solid manure)	25	25	25	25	30	30	30	30	31	31	31	30	30	29	29	29	28	28	27	27	26	27	28	29	30	32	33	35	36	38	40	0.600		0.010		25.0	0.30
sows / boars,	heap (% of total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.600	0.030	0.005	0.005	3.0	0.30

livestock category	storage type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system (leachate / urine)	N_2O EF for storage kg N_2O-N per kg N in storage system	N_2O EF for storage kg N_2O-N per kg N in storage system (leachate / urine)	CH_4 MCF for storage % of Bo < 10 °C	maximum CH_4 producing capacity (Bo) m^3 CH4 per kg VS
solid manure	solid manure)																																					
laying hens	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.140		0.001		1.5	0.39
broilers	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.170		0.001		1.5	0.36
pullets	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.170		0.001		1.5	0.39
ducks	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.240		0.001		1.5	0.36
geese	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.160		0.001		1.5	0.36
turkeys, female	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.240		0.001		1.5	0.36
turkeys, male	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.240		0.001		1.5	0.36
poultry, digested solid manure		0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	3	4	5	6	8	10	11	12	13	14	14	14	14	14	14	14						
poultry, storage of digestates	gas tight storage (% of digestates)	0	1	2	3	4	5	5	6	7	8	9	10	11	12	14	15	20	25	30	35	41	46	57	59	61	62	62	62	62	63	63	0.000		0.000		1.149	0.36 / 0.39 (see animal-specific values above)
poultry, storage of digestates	open tank (% of digestates)	100	99	98	97	96	95	95	94	93	92	91	90	89	88	86	85	80	75	70	65	59	54	43	41	39	38	38	38	38	37	37	0.045		0.005		1.562	0.36 / 0.39 (see animal-specific values above)
horses	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.350		0.005		2.0	0.30
sheep	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.320		0.005		2.0	0.19
goats	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0.280		0.005		2.0	0.18

livestock category	storage type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system	NH_3-N EF for storage, kg NH_3-N per kg TAN in storage system (leachate / urine)	N_2O EF for storage kg N_2O-N per kg N in storage system	N_2O EF for storage kg N_2O-N per kg N in storage system (leachate / urine)	CH_4 MCF for storage % of Bo < 10 °C	maximum CH_4 producing capacity (Bo) m^3 CH4 per kg VS
digestion of energy crops	amount of energy crops digested (1000 kt fresh matter)	0.01	0.02	0.03	0.04	0.05	0.12	0.20	0.25	0.57	0.65	1.0	1.5	2.1	2.5	3.3	8.9	12.4	16.9	19.7	25.3	31.8	39.7	43.5	52.6	55.1	57.2	56.9	55.9	55.1	55.1	55.1						
	gas tight storage (% of digestates)	0	1	2	3	4	5	6	7	8	8	9	10	11	13	14	16	21	26	32	37	42	48	59	62	64	65	65	65	65	65	65	0.000		0.000		1.0	0.36
	open tank (% of digestates)	100	99	98	97	96	95	94	93	92	92	91	90	89	87	86	84	79	74	68	63	58	52	41	38	36	35	35	35	35	35	35	0.045		0.005		1,414	0.36

*) digestion of slurry, solid manure, poultry manure and energy crops: MCFs are overall values for the system "pre-storage (if existent) + digester + storage of digestates"

Table 571: Frequency distributions of application procedures (in %), and pertinent emission factors

livestock category	application type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for application, kg NH_3-N per kg TAN applied
cattle, untreated slurry	broadcast, without incorporation	11	11	11	11	2	2	2	2	2	2	2	2	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.50
	broadcast, incorporation < 1 h	3	3	3	3	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	7	9	11	11	10	10	10	10	0.10
	broadcast, incorporation < 4h	0	0	0	0	2	2	2	2	2	2	3	3	4	5	6	7	7	8	9	10	11	11	17	14	11	7	6	6	5	4	3	0.26
	broadcast, incorporation < 6h	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.35
	broadcast, incorporation < 8h	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	3	3	4	4	5	5	5	0	0	0	0	0	0	0	0	0	0.40
	broadcast, incorporation < 12h	0	0	0	0	20	20	20	20	22	22	20	18	16	14	12	11	9	7	5	3	1	1	0	0	0	0	0	0	0	0	0	0.43
	broadcast, incorporation < 24h	32	32	32	32	9	9	9	9	9	9	8	8	7	6	5	4	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0.46
	broadcast, incorporation < 48h	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.50
	broadcast, vegetation	0	0	0	0	0	0	0	0	0	0	2	3	5	6	8	9	11	13	14	16	17	17	17	16	16	15	13	11	10	8	6	0.50

livestock category	application type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for application, kg NH_3-N per kg TAN applied
	broadcast, grassland	44	44	44	44	42	42	42	42	41	41	41	42	42	43	43	44	44	45	45	46	46	46	46	47	47	48	46	45	43	41	40	0.60
	trailing hose, without incorporation	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.46
	trailing hose, incorporation < 1 h	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	0.04
	trailing hose, incorporation < 4h	0	0	0	0	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	0.15
	trailing hose, incorporation < 6h	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.20
	trailing hose, incorporation < 8h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0.24
	trailing hose, incorporation < 12h	0	0	0	0	9	9	9	9	9	9	8	7	6	6	5	4	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0.30
	trailing hose, incorporation < 24h	1	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.39
	trailing hose, incorporation < 48h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.46
	trailing hose, vegetation	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	3	3	3	4	4	4	3	3	3	3	4	4	4	5	0.35
	trailing hose, short vegetation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.46
	trailing hose, grassland	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	4	4	0.54
	trailing shoe, incorporation < 1 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	3	4	4	0.04
	trailing shoe, incorporation < 4 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0.15
	trailing shoe, incorporation < 8 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.24
	trailing shoe, incorporation < 12 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.30
	trailing shoe, grassland	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	4	5	8	11	13	16	19	0.36
	injection (open slot)	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	2	2	2	2	2	3	3	3	0.24
	grubber and injection	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	3	3	0.04
cattle, solid manure	broadcast, without incorporation	14	14	14	14	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	0.90
	broadcast, incorporation < 1 h	5	5	5	5	11	11	11	11	12	12	12	12	12	12	12	13	13	13	13	13	13	13	14	14	14	14	14	15	15	15	15	0.09

livestock category	application type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for application, kg NH_3-N per kg TAN applied
	broadcast, incorporation < 4h	0	0	0	0	9	9	9	9	9	9	10	11	12	14	15	16	17	19	20	21	22	24	25	26	27	29	30	31	32	34	35	0.45
	broadcast, incorporation < 12h	11	11	11	11	28	28	28	28	29	29	29	28	28	28	28	28	28	27	27	27	27	27	27	26	26	26	24	22	20	17	15	0.81
	broadcast, incorporation < 24h	43	43	43	43	24	24	24	24	25	25	23	22	20	19	17	16	14	12	11	9	8	6	5	3	2	0	0	0	0	0	0	0.90
	broadcast, incorporation < 48h	7	7	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.90
	broadcast, vegetation/grassland	20	20	20	20	25	25	25	25	23	23	24	24	24	25	25	25	26	26	26	27	27	27	28	28	28	29	29	30	30	31	31	0.90
pigs, untreated slurry	broadcast, without incorporation	7	7	7	7	4	4	4	4	4	4	4	3	3	3	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0.25
	broadcast, incorporation < 1 h	4	4	4	4	8	8	8	8	8	8	8	8	7	7	7	7	7	6	6	6	6	6	6	6	7	8	7	6	5	4	4	0.04
	broadcast, incorporation < 4h	0	0	0	0	1	1	1	1	1	1	2	2	3	4	5	5	6	7	8	8	9	9	15	11	8	5	4	3	3	2	1	0.09
	broadcast, incorporation < 6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11
	broadcast, incorporation < 8h	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	3	3	4	4	5	5	0	0	0	0	0	0	0	0	0	0.13
	broadcast, incorporation < 12h	0	0	0	0	29	29	29	29	28	28	25	23	21	18	16	13	11	8	6	3	1	1	0	0	0	0	0	0	0	0	0	0.16
	broadcast, incorporation < 24h	50	50	50	50	4	4	4	4	4	4	3	3	3	2	2	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0.21
	broadcast, incorporation < 48h	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25
	broadcast, vegetation	30	30	30	30	22	22	22	22	23	23	23	23	23	23	23	23	23	23	22	22	22	22	22	21	20	19	16	13	10	7	4	0.25
	broadcast, grassland	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	3	3	3	3	3	3	3	3	2	2	2	2	2	2	0.30
	trailing hose, without incorporation	0	0	0	0	2	2	2	2	2	2	2	2	2	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18
	trailing hose, incorporation < 1 h	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	6	7	9	9	9	9	9	9	0.02
	trailing hose, incorporation < 4h	0	0	0	0	1	1	1	1	1	1	2	2	3	3	4	4	5	5	5	6	6	6	10	8	6	4	4	4	3	3	3	0.06
	trailing hose, incorporation < 6h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.08

livestock category	application type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for application, kg NH_3-N per kg TAN applied
	trailing hose, incorporation < 8h	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	3	3	3	3	0	0	0	0	0	0	0	0	0	0.0925
	trailing hose, incorporation < 12h	0	0	0	0	10	10	10	10	10	10	9	8	7	7	6	5	4	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0.11
	trailing hose, incorporation < 24h	4	4	4	4	2	2	2	2	2	2	2	2	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14
	trailing hose, incorporation < 48h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17
	trailing hose, vegetation	0	0	0	0	0	0	0	0	0	0	3	6	8	11	14	17	20	22	25	28	31	31	31	32	34	35	36	37	37	38	38	0.125
	trailing hose, short vegetation	1	1	1	1	8	8	8	8	9	9	8	7	6	6	5	4	3	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0.175
	trailing hose, grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	0.21
	trailing shoe, incorporation < 1 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	3	3	4	5	0.02
	trailing shoe, incorporation < 4 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	0.06
	trailing shoe, incorporation < 8 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0925
	trailing shoe, incorporation < 12 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.11
	trailing shoe, grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2	3	5	8	10	13	16	19	0.12
	injection (open slot)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	3	4	4	4	4	4	4	0.06
	grubber and injection	0	0	0	0	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	5	5	6	6	6	7	7	0.02
pigs, solid manure	broadcast, without incorporation	36	36	36	36	29	29	29	29	31	31	30	28	26	24	22	20	18	17	15	13	11	9	7	6	4	2	2	3	4	4	5	0.90
	broadcast, incorporation < 1 h	4	4	4	4	15	15	15	15	15	15	15	15	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	17	17	18	18	0.09
	broadcast, incorporation < 4h	0	0	0	0	2	2	2	2	2	2	4	6	8	10	12	14	16	19	21	23	25	27	29	31	33	36	36	36	37	37	37	0.45
	broadcast, incorporation < 12h	0	0	0	0	20	20	20	20	21	21	21	21	21	21	22	22	22	22	22	22	22	23	23	23	23	23	20	17	15	12	9	0.81
	broadcast, incorporation < 24h	53	53	53	53	33	33	33	33	31	31	29	27	25	23	21	19	17	15	13	12	10	8	6	4	2	0	0	0	0	0	0	0.90
	broadcast, incorporation < 48h	8	8	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.90
	broadcast, vegetation	0	0	0	0	0	0	0	0	0	0	1	3	4	6	7	9	10	12	13	15	16	18	19	21	22	24	25	26	28	29	31	0.90

livestock category	application type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for application, kg NH_3-N per kg TAN applied
cattle and pigs, leachate	broadcast, without incorporation	50	50	50	50	50	50	50	50	50	50	45	41	36	32	27	23	18	14	9	5	0	0	0	0	0	0	0	0	0	0	0	0.20
	broadcast, incorporation < 1 h	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3	4	5	5	5	5	5	5	5	0.02
	broadcast, incorporation < 4h	0	0	0	0	0	0	0	0	0	0	1	1	2	3	4	4	5	6	7	7	8	8	19	15	12	9	7	6	4	3	2	0.07
	broadcast, incorporation < 8h	0	0	0	0	0	0	0	0	0	0	1	1	2	3	4	4	5	6	6	7	8	8	0	0	0	0	0	0	0	0	0	0.116
	broadcast, incorporation < 12h	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	2	3	3	3	0	0	0	0	0	0	0	0	0	0.144
	broadcast, vegetation	0	0	0	0	0	0	0	0	0	0	1	3	4	6	7	8	10	11	13	14	15	15	15	15	14	13	11	9	7	5	3	0.20
	broadcast, grassland	50	50	50	50	50	50	50	50	50	50	50	49	49	49	49	48	48	48	48	47	47	47	47	48	48	49	41	32	23	15	6	0.20
	trailing hose, without incorporation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.18
	trailing hose, incorporation < 1 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	3	4	6	7	8	0.01
	trailing hose, incorporation < 4h	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	4	3	3	2	2	3	3	3	3	0.05
	trailing hose, incorporation < 8h	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0.09
	trailing hose, incorporation < 12h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0.12
	trailing hose, vegetation	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	3	3	4	4	4	4	6	7	9	11	12	14	15	17	0.10
	trailing hose, grassland	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	0.14
	trailing shoe, incorporation < 1 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	4	5	6	0.01
	trailing shoe, incorporation < 4 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	0.05
	trailing shoe, incorporation < 8 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09
	trailing shoe, incorporation < 12 h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.12
	trailing shoe, grassland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	4	7	10	13	17	20	0.08
	injection (open slot)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	4	6	7	9	0.04
	grubber and injection	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	2	3	3	3	3	3	3	3	2	2	5	7	10	13	16	0.01

livestock category	application type	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	NH_3-N EF for application, kg NH_3-N per kg TAN applied
laying hens, solid manure	broadcast, without incorporation	8	8	8	8	5	5	5	5	8	8	9	10	11	11	12	13	14	14	15	16	16	17	18	19	19	20	22	24	26	27	29	0.90
	broadcast, incorporation < 1 h	0	0	0	0	0	0	0	0	0	0	1	3	4	5	7	8	9	11	12	14	15	16	18	19	20	22	23	24	26	27	28	0.00
	broadcast, incorporation < 4h	0	0	0	0	0	0	0	0	0	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	46	44	42	40	38	0.18
	broadcast, incorporation < 12h	0	0	0	0	11	11	11	11	21	21	21	20	19	19	18	17	17	16	15	14	14	13	12	12	11	10	9	8	7	5	4	0.40
	broadcast, incorporation < 24h	92	92	92	92	84	84	84	84	70	70	66	61	57	53	48	44	39	35	31	26	22	18	13	9	4	0	0	0	0	0	0	0.45
poultry, except laying hens, solid manure	broadcast, without incorporation	0	0	0	0	0	0	0	0	0	0	1	2	4	5	6	7	8	9	11	12	13	14	15	16	18	19	21	23	25	27	29	0.90
	broadcast, incorporation < 1 h	0	0	0	0	0	0	0	0	0	0	1	3	4	6	7	8	10	11	13	14	15	17	18	20	21	22	24	25	26	28	29	0.00
	broadcast, incorporation < 4h	0	0	0	0	0	0	0	0	0	0	3	6	9	12	15	18	22	25	28	31	34	37	40	43	46	49	47	45	43	41	39	0.18
	broadcast, incorporation < 12h	0	0	0	0	0	0	0	0	0	0	1	1	2	2	3	4	4	5	5	6	6	7	8	8	9	9	8	7	6	5	3	0.40
	broadcast, incorporation < 24h	100	100	100	100	100	100	100	100	100	100	94	88	81	75	69	63	56	50	44	38	31	25	19	13	6	0	0	0	0	0	0	0.45

Table 572: Laying hens, housing-specific partial NH_3 emission factors

[in kg NH_3-N per excreted kg N]	≤ 2000	2001 - 2009	≥2010
cage housing; as of 2010: small-group housing	0.164		0.066
floor management, aviary	0.351	linear interpolation	0.090
intensive outdoor management, free-range management, organic production	0.099		

19.4 Other detailed methodological descriptions for the source/sink category "Land-use change and forestry" (4)

This chapter is currently not required.

19.5 Other detailed methodological descriptions for the category "Waste and wastewater" (6)

This chapter is currently not required.

20 Annex 4: The CO_2 Reference Approach, and comparison with the Sectoral Approach

General information

In general, the Reference Approach briefly described in Chapter 3.2.1.1 is to be suitable for all reporting countries. Such generalization and abstraction cannot help but lead to considerable discrepancies with the Sectoral Approach.

On the whole, the Sectoral Approach supports calculations that are considerably more differentiated and precise, with results that – especially at a detailed level – differ (sharply, in some cases) from those produced by the Reference Approach.

Efforts to eliminate errors in transfer of country-specific activity data into the Reference Approach structure have gotten underway in recent years. At the level of maximum aggregation, this work, which is being continued with the present submission, has brought the results achieved with the two calculation approaches into excellent agreement (cf. Chapter 3.2.1.1). On the other hand, a number of discrepancies at the *fuel* and *fuel-group* levels still persist. While these can be explained – at least in part – as the result of country-specific circumstances, it has not yet been possible to eliminate them in a satisfactory manner.

The Reference Approach will thus continue to offer room for further improvements. Notably, the comparability of the two approaches would benefit from extensive flexibilization of data management in the CRF Reporter, as well as from review, and any necessary revision, of the input data and calculation approaches used for the area of non-energy-related consumption.

20.1 Comparing the results: The Sectoral Approach and the Reference Approach

The following section compares results obtained in calculating CO_2 emissions via the Sectoral Approach with results obtained via the Reference Approach.

CRF report table 1.A(c) compares results obtained with the Sectoral Approach with results obtained with the Reference Approach. Since the non-energy-related consumption (NEV) of the fuels considered occurs elsewhere (industrial processes and product use), the quantities that must be assigned to such consumption, pursuant to the Energy Balances, are deducted from the Reference Approach. In addition to lubricants, bitumen and naphtha, this procedure is also applied to diesel fuel, light and heavy fuel oil, LP gas, petroleum coke and other mineral oils, hard coal and lignite, coke and natural gas.

For the year 2020, this approach yields a non-energy-related consumption of about 1060 petajoules (cf. CRF Table 1.A(d), the sum of cells D27, D38 and D42).

For peat, which is listed separately, identical emission factors and input quantities are used in 1.AA and 1.AB. For this reason, Table 1.A(c) shows no discrepancies in this area.

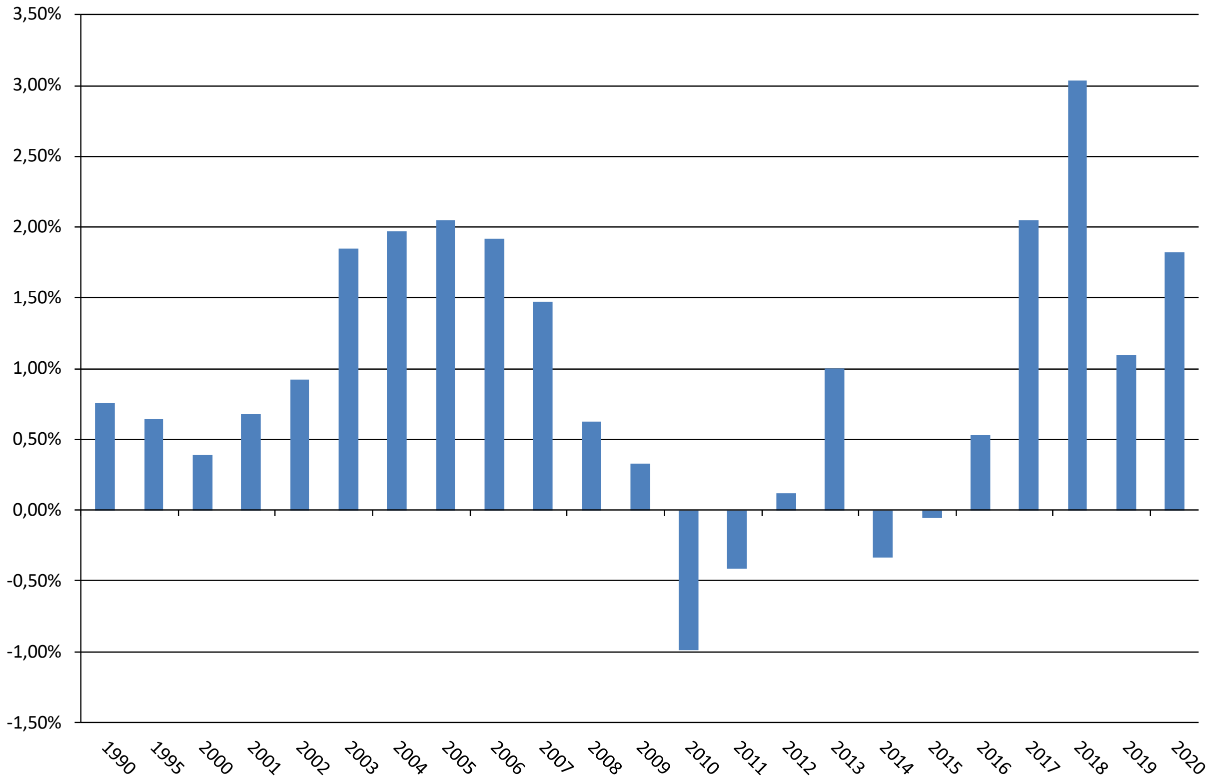
The following tables present further sample results of the comparison between the Sectoral Approach and the Reference Approach. For 2020, the Reference Approach yields fuel inputs that are 1.77 % higher and reference emissions that are 2.64 % lower (cf. Chapter 3.2.1.1).

Throughout the period as of 1990, most all of the fuel inputs listed under the Reference Approach (less the quantities used for non-energy-related purposes) are higher than those listed under the Sectoral Approach. The years 2010, 2011, 2014 and 2015 are exceptions in this regard.

Table 573: Comparison of the energy inputs determined via the Sectoral Approach and the Reference Approach (not including NEV), in terajoules

Year	1.AA	*1.AB (including non-energy-related consumption)*	1.AB (excluding non-energy-related consumption)	1.AB (excluding non-energy-related consumption) minus 1.AA	
1990	11,673	12,917	11,761	88	0.76%
1995	10,926	12,114	10,996	70	0.64%
2000	10,553	11,841	10,594	41	0.39%
2001	10,835	12,092	10,908	74	0.68%
2002	10,614	11,895	10,711	98	0.92%
2003	10,607	12,000	10,803	196	1.85%
2004	10,416	11,824	10,621	205	1.97%
2005	10,204	11,686	10,413	209	2.05%
2006	10,340	11,769	10,538	199	1.92%
2007	9,926	11,235	10,072	146	1.47%
2008	10,094	11,294	10,158	63	0.63%
2009	9,448	10,525	9,479	31	0.33%
2010	9,898	10,955	9,800	-98	**-0.99%**
2011	9,505	10,608	9,466	-39	-0.41%
2012	9,562	10,661	9,574	11	0.12%
2013	9,793	10,978	9,891	98	1.00%
2014	9,239	10,325	9,208	-31	-0.34%
2015	9,316	10,395	9,310	-5	-0.06%
2016	9,510	10,663	9,560	50	0.53%
2017	9,301	10,647	9,491	190	2.04%
2018	8,996	10,229	9,270	273	**3.04%**
2019	8,603	9,758	8,698	94	1.10%
2020	7,871	9,074	8,010	139	1.77%

Figure 98: Percentage discrepancies between annual total activity data under the Reference Approach and the corresponding total quantities under the Sectoral Approach



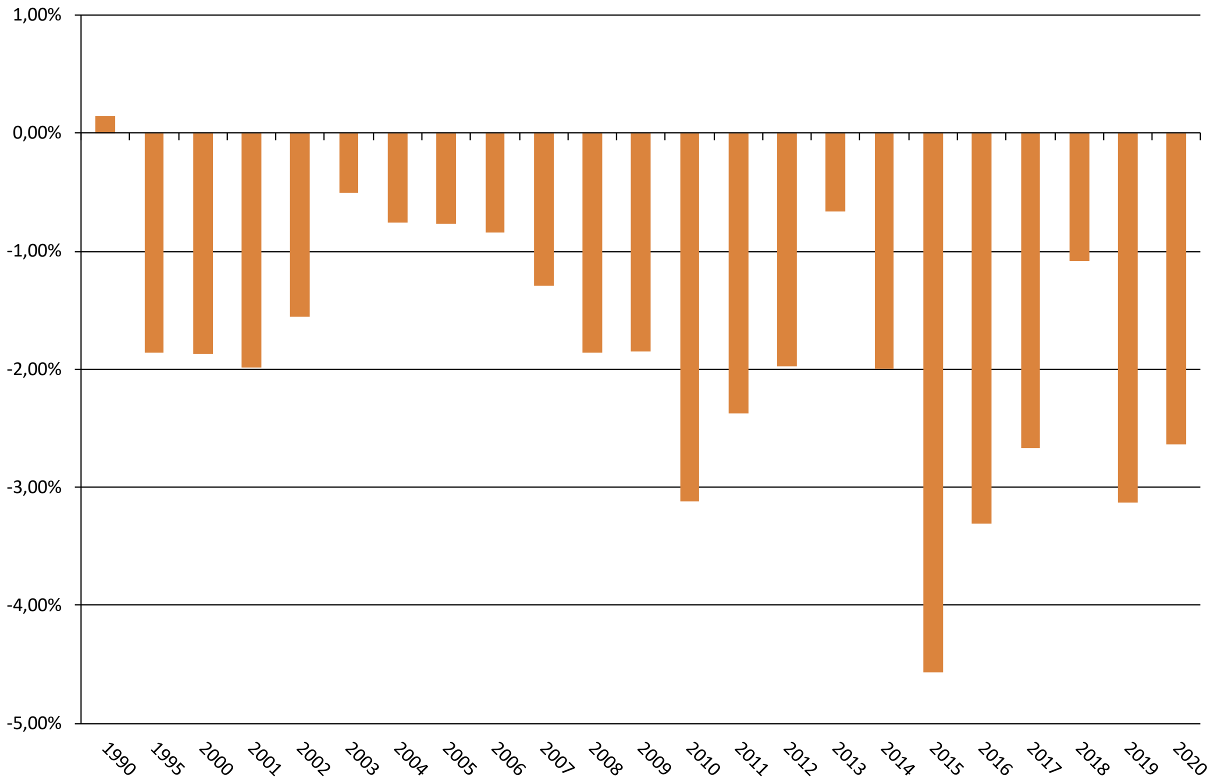
The situation is turned around for the carbon dioxide emissions calculated with the Reference Approach: In almost all cases, they tend to be lower than those calculated with the Sectoral Approach. The values for the year 1990 are the sole exceptions in this regard (cf. Chapter 3.2.1.1).

Table 574: Comparison of the CO_2 emissions determined via the Sectoral Approach and the Reference Approach (not including non-energy-related consumption), in kilotonnes

	1.AA	1.AB (excluding non-energy-related consumption)	1.AB (excluding non-energy-related consumption) minus 1.AA	
1990	985,253	986,690	1,437	0.15%
1995	877,638	861,349	-16,289	-1.86%
2000	836,208	820,600	-15,607	-1.87%
2001	858,980	841,966	-17,014	-1.98%
2002	844,301	831,160	-13,142	-1.56%
2003	841,061	836,841	-4,221	-0.50%
2004	827,085	820,793	-6,293	-0.76%
2005	808,723	802,509	-6,213	-0.77%
2006	819,850	812,953	-6,897	-0.84%
2007	794,600	784,351	-10,248	-1.29%
2008	800,218	785,308	-14,910	-1.86%
2009	744,232	730,512	-13,720	-1.84%
2010	781,485	757,149	-24,336	-3.11%
2011	757,628	739,642	-17,986	-2.37%
2012	763,103	748,026	-15,078	-1.98%
2013	780,791	775,608	-5,182	-0.66%
2014	741,946	727,174	-14,771	-1.99%

2015	746,783	712,664	-34,119	-4.57%
2016	749,812	724,989	-24,824	-3.31%
2017	731,410	711,915	-19,495	-2.67%
2018	702,521	694,896	-7,624	-1.09%
2019	657,691	637,101	-20,591	-3.13%
2020	593,070	577,426	-15,644	-2.64%

Figure 99: Percentage discrepancies between the annual carbon dioxide emissions as calculated with the Reference Approach and as calculated with the Sectoral Approach



21 Annex 5: Assessment of completeness, and of potentially excluded sources and sinks of greenhouse gas emissions

The following two tables show the sources for greenhouse gases that have not yet been directly reported in Germany's greenhouse-gas inventories to date. This refers to emissions for which the necessary bases for calculation are not available or which could be determined only at great effort. At the same time, the emissions need to conform to the negligibility criteria given in the definition of the notation keys "NE." The necessary estimates for such conformance are also listed.

In addition, a summary is provided of CRF Table 9(a), which lists emissions reported as "IE" at other locations in the inventory.

Additional information is presented in Chapter 1.8.

Table 575: Overview, for completeness, of sources and sinks whose emissions are not estimated (NE)

Emissions 2020			
kt CO_2-eq.	**National total (without LULUCF)**	**728,738**	
kt CO_2-eq.	thereof 0.1 %	729	
kt CO_2-eq.	thereof 0.05 %	364	
Category code	**Category description**	**Assumption for estimated emission (in kt CO2 equiv)**	**Reference to NIR**
1.B.2.d	Geothermal Energy	< 1	see NIR 3.3.2.4
2.A.4.c	Non-metallurgical magnesium production	< 100	see NIR Chapter 4.2.4.3.2
2.B.4.a	Caprolactam	< 17.9	see NIR Chapter 4.3.4.2
2.B.6	Titanium dioxide production	< 300	see NIR chapter 4.3.6
2.D.3	Asphalt – asphalt roofing	0.2	see NIR Chapter 4.5.4.2
2.D.3	Asphalt – road paving	2.5	see NIR Chapter 4.5.5.2
3.A.4	Deer	132	see NIR Chapter 19.3.1
3.A.4	Rabbits	3.96	see NIR Chapter 19.3.1
3.A.4	Fur-bearing animals	0.16	see NIR Chapter 19.3.1
3.B(a).4	Deer	1.45	see NIR Chapter 19.3.1
3.B(a).4	Fur-bearing animals	1.08	see NIR Chapter 19.3.1
3.B(a).4	Rabbits	0.88	see NIR Chapter 19.3.1
3.B(a).4	Ostriches	1.08	see NIR Chapter 19.3.1
3.B(b).4	Fur-bearing animals	0.68	see NIR Chapter 19.3.1
3.B(b).4	Rabbits	0.82	see NIR Chapter 19.3.1
3.B(b).4	Ostriches	0.06	see NIR Chapter 19.3.1
3.B(b).5	Indirect emissions	1.01	see NIR Chapter 19.3.1
3.D	Other animals	29.48	The entries for other animals are not shown in CRF Reporter under 3 D., see NIR Chapter 19.3.1
5.A	Flaring	0.51	see NIR Chapter 7.2.1.2.9
5.E.	accidental fires (buildings, cars ...)	< 100	see NIR Chapter 7.6
Sum		**695**	

Table 576: Overview, for completeness, of sources and sinks that are reported elsewhere (included elswhere, IE)

For reasons of consistency and space, this table is now included only in Table 9 of the CRF tables.

22 Annex 6: Additional information to be considered as part of the NIR submission (where relevant) or other useful reference information

22.1 Additional information relative to inventory preparation and to the National System

22.1.1 Definitions in the "National System" principles paper on emissions reporting

In the "National System" principles paper on emissions reporting, state secretaries of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB); Federal Ministry of the Interior (BMI); Federal Ministry of Defence (BMVg); Federal Ministry of Finance (BMF); Federal Ministry for Economic Affairs and Energy (BMWi); Federal Ministry of Transport, Building and Urban Affairs (BMVBS) and Federal Ministry of Food and Agriculture (BMEL) defined responsibilities pertaining to the various relevant source and sink categories and to the necessary financing for 2008. The agreement reads as follows:

BMUB, BMI, BMVg, BMF, BMWi, BMVBS, BMEL *Berlin, 5 June 2007*

"National System" principles paper on emissions reporting

The state secretaries of the ministries concerned have determined as follows, by common consent, with regard to the issue of the "National System" for emissions reporting pursuant to Art. 5(1) Kyoto Protocol:

1. *The Federal Environment Agency, Section I 4.6[184] "Emissions Situation", is the responsible "Single national entity" (national co-ordinating agency) for reporting pursuant to the UN Framework Convention on Climate Change and the Kyoto Protocol. A country's Single National Entity is responsible for preparing the country's national inventory, working for continual improvement of the inventory, supporting those persons involved in the national system and preparing decisions of the Co-ordinating Committee.*

2. *A Co-ordinating Committee, representing all affected departments, has been established to deal with all questions arising in the framework of the National System, and to be responsible for official discussion and approval of the inventories and the reports required pursuant to Articles 5, 7 and 8 of the Kyoto Protocol. The Committee shall support all pertinent processes in this framework and, in particular, it shall clarify any pertinent uncertainties – for example, in connection with definition of individual emission factors.*

   In particular, the Committee shall define key source and sink categories, and the minimum requirements pertaining to quality control and quality assurance for data collection and processing and to the annual quality control and quality assurance plan.

   As necessary, the Committee may specify the methods to be used for calculating emissions in the various categories and for calculating storage in sink categories. The Committee is chaired by the BMU. The Committee shall meet whenever at least one department sees a need for such a meeting. Subordinate authorities and other institutions involved in inventory preparation may be included in meetings as necessary.

3. *For preparation of the national inventory, such data shall be used, for calculations of emissions and reductions, as are required pursuant to the provisions of Art. 3 (1) of decision 280/2004/EC and of Art. 2 (1) of the Ground rules for calculating emissions in source categories and storage in sink categories. Inventories shall be prepared on an annual basis. In addition, quality assurance in keeping with the*

[184] Author's remark: currently, I 2.6.

requirements of Art. 12 of the rules shall be carried out. Furthermore, reliable documentation and archiving shall be required.

Existing data-transfer arrangements, such as those made on the basis of voluntary agreements or legal provisions, should not be fundamentally changed; they should only be completed and improved as necessary in order to provide a reliable database. For this reason, the aforementioned responsibilities do not necessarily include data collection and forwarding. With regard to division of responsibilities between BMU/UBA, BMVBS and BMWI, attention is called especially to Annex 1.

The responsibilities for ensuring proper data delivery to the Single National Entity, and for quality control, documentation and data archiving, shall be distributed as follows among the various relevant departments:

a) For category 1 (Energy) – with the exception of categories 1.A.3 (Transport) und 1.A.5a (Energy: other), where emissions sources of the German Federal Armed Forces (Bundeswehr) are concerned – the Federal Ministry for Economic Affairs and Energy (BMWi) has responsibility.

b) For categories 2 (Production processes) and 3 (Use of solvents and other products), the Federal Ministry for Economic Affairs and Energy (BMWi) has responsibility.

c) For category 1.A.3 (Transport), the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) has responsibility.

d) For category 1.A.5a (Energy: other), where emissions sources of the German Federal Armed Forces (Bundeswehr) are concerned – the Federal Ministry of Defence (BMVg) has responsibility. Where data are subject to secrecy provisions, the Federal Environment Agency shall take the relevant secrecy requirements into account.

e) For source and sink categories 4 (Agriculture) and 5 (Land use, land-use changes and forestry), the Federal Ministry of Food and Agriculture (BMEL) has responsibility.

f) For category 6 (Waste) and category 7, and well as for issues related to greenhouse-gas emissions from biomass combustion, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) has responsibility.

g) The Federal Ministry of Food and Agriculture (BMEL) is also responsible for preparing tables in the standardised reporting format pursuant to Art. 2 (2) letter a of Decision 2005/166/EC (implementation rules) in source and sink categories 4 and 5.

In addition, the relevant authorities, as determined by the pertinent statistics regulations, are responsible for tasks relative to official statistics, including data delivery, quality assurance and data documentation and archiving. Co-operation between a) the statistical offices of the Federal Government and the Länder and b) the agencies concerned with reporting is co-ordinated via the Federal Statistical Office. In the process, secrecy requirements pertaining to statistics are to be observed.

4. *The responsible departments shall clarify, in the short term, how proper data provision is to be permanently assured, to the extent such clarification has not already been completed. In particular, this requirement shall apply to agreements, ordinances or laws needed for institutionalisation of the National System. In general, for purposes of emissions reporting, voluntary agreements with associations and/or individual companies shall have the same status as pertinent legal provisions. In addition, as agreed in the co-ordination discussion on 12 September 2006, the Federal Environment Agency and the Federal Statistical Office shall determine what data can be provided, for reporting purposes, from the official statistical system, as well as what additional data should be collected via the official statistical system. The various relevant departments, the Federal Environment Agency and the Federal Statistical Office shall send their pertinent proposals to the BMU by 15 July 2007.*

5. *By 31 July 2007, the BMU shall invite participating departments to co-ordinate pertinent proposals and to establish a schedule for implementing the required instruments. The responsible departments, and the Federal Government, shall arrange for the establishment of the required instruments as quickly as possible.*

6. *Where additional funding is required for execution of the responsibilities mentioned under 3., such funding shall be provided from proceeds from sale of AAUs, via an expansion of the state secretaries' agreement of 22 December 2006 relative to Article 3.4 of the Kyoto Protocol.*

   To this end, a budget item for relevant income shall be established within Individual Plan 16 (Einzelplan 16) as of the 2008 fiscal year. Following review by the Federal Ministry of Finance (BMF), the additional requirements requiring financing shall be listed as expenditures within the departments' individual budgets. The departments' additional requirements in this regard must be submitted to the BMF by 6 June 2007.

   Should additional budget funding be required in coming years, in addition to the additional requirements determined in connection with the 2008 budget, then suitable relevant amounts of additional AAUs shall be sold in subsequent years.

[…]

Annex: Division of responsibilities between BMU/UBA, BMVBS and BMWI

The BMU, BMVBS and BMWi have agreed that the existing emissions-reporting structures are to be retained and that the Federal Environment Agency (UBA) shall continue to perform its existing tasks with regard to the categories 1, 1.A.3, 2 and 3. The BMVBS and the BMWi shall ensure that any gaps in the data for those categories for which they are responsible are closed.

Specifically:

BMWi:

With regard to category 1: The inventories in this area shall be prepared by the Federal Environment Agency, on a basis that shall include energy data provided by the agency contracted by the BMWi for preparation of energy balances, as well as on the basis of additional relevant statistics and association information.

With regard to category 2: The inventories in this area shall be produced by the Federal Environment Agency on the basis of data that shall include data from statistics of the manufacturing sector (Produzierendes Gewerbe – ProdGewStatG) and from communications of relevant associations / individual companies.

With regard to category 3: The inventories in this area shall be produced by the Federal Environment Agency on the basis of data that shall include data from statistics of the manufacturing sector (Produzierendes Gewerbe – ProdGewStatG), from foreign trade statistics and from communications of relevant associations / individual companies.

Existing requirements for further optimisation shall be clarified, in the short term, by BMWi, BMU and UBA, working in co-ordination. Where data optimisation is required via changes in existing surveys based on the Environmental Statistics Act (UStatG) or on the 13th Ordinance on the Execution of the Federal Immission Control Act (13. BimSchV), the BMU shall be responsible. The Federal Environment Agency shall assume responsibility for recording and archiving data received by the Federal Environment Agency.

BMVBS:

Emissions relative to category 1.A.3 (Transport) shall be calculated by the Federal Environment Agency, using the TREMOD model. The BMVBS shall provide data/calculations as needed to close data gaps and determine emissions relative to international air transports or shall ensure that such data/calculations are provided by third parties. At present, emissions from ship transports may be calculated from Energy Balance data, using *default emission factors. The Federal Environment Agency shall assume responsibility for recording and archiving data received by the Federal Environment Agency.*

22.1.2 Additional information about the Quality System of Emissions Inventories

22.1.2.1 Minimum requirements pertaining to a system for quality control and assurance

As described above in the main section, the requirements pertaining to the system for quality control and quality assurance (QC/QA system) and to measures for quality control and quality assurance are defined primarily by Chapter 8 of the *IPCC Good Practice Guidance*.

From those provisions, the Federal Environment Agency has derived its own "General minimum requirements pertaining to quality control and quality assurance in connection with greenhouse-gas-emissions reporting" ("Allgemeine Mindestanforderungen an die Qualitätskontrolle und Qualitätssicherung bei der Treibhausgasemissionsberichterstattung"; last revision: November 2007). These are described below.

22.1.2.1.1 Introduction

Representatives of the departments participating in the co-ordinating committee for the National System of Emissions Inventories define the general minimum requirements, which are described in the present document, for quality control and quality assurance (QC/QA) in reporting on greenhouse-gas emissions. Such minimum requirements serve as the basis for collection, processing and forwarding of, and reporting on, all data that support the process of reporting on greenhouse-gas emissions.

These minimum QC/QA requirements must be adhered to on all levels of inventory preparation. In many cases, relevant efforts can draw on existing processes and systems, such as the quality standards for public statistics. Annex 1 of the present document describes, by way of example, implementation of the minimum QC/QA requirements and the QC/QA system within the Federal Environment Agency. All participating institutions are required to submit suitable descriptions of their implementation of these minimum requirements; such descriptions are to be published with the inventory report in the framework of reporting in 2009. On request, the Federal Environment Agency supports participating ministries in preparing QC/QA systems in their relevant areas of responsibility.

22.1.2.1.2 System for quality control and quality assurance

The *rules (Commission Decision 2005/166/EC) implementing Decision 280/2004/EC* require national greenhouse-gas inventories to conform to the QC/QA requirements of the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (IPCC Good Practice Guidance) and the *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC Good Practice Guidance for LULUCF).

The *IPCC Good Practice Guidance* specifies that QC/QA systems must be introduced, with the aim of enhancing transparency, consistency, comparability, completeness and precision of national emissions inventories and, especially, that such inventories must fulfill requirements pertaining to "good inventory practice". A QC/QA system comprises the following:

- An agency responsible for co-ordinating QC/QA activities
- Development and implementation of a QC/QA plan
- General QC procedures
- Category-specific QC procedures
- QA procedures and
- Reporting procedures
- Documentation and archiving procedures

QC/QA measures can conflict with requirements for punctuality and cost-effectiveness. Available time, and available staffing and financial resources, should thus be taken into account in any QC/QA-system development. In good practice, more stringent data-quality requirements are applied to key categories. For other categories, not all category-specific QC procedures have to be implemented. In addition, not all measures have to be carried out on an annual basis; for example, data-collection methods have to be reviewed only once in detail. Thereafter, it suffices to carry out periodic controls to determine whether the prerequisites for application of relevant methods are still being fulfilled. Data uncertainty is another factor that enters into requirements pertaining to QC/QA measures. In order to reduce an inventory's overall uncertainty, those categories that have high levels of uncertainty should be reviewed in detail.

22.1.2.1.3 Agency responsible for co-ordinating QC/QA activities

As the Single National Entity (national co-ordinating agency), the Federal Environment Agency is responsible for the QC/QA system for the national greenhouse-gas inventory. In this function, it has established the position of co-ordinator for the Quality System for Emissions Inventories (QSE). In good practice, each company and organisation involved in inventory preparation appoints a QC/QA co-ordinator and notifies the QSE co-ordinator of such appointment.

A QC/QA co-ordinator has responsibility for ensuring that a relevant QC/QA system is developed and implemented. Such implementation should be suitably institutionalised – for example, by means of an in-house directive or association agreement.

In order to ensure that the Single National Entity can efficiently carry out its supporting tasks, the persons responsible for the following additional functions should be announced (by name) to the QSE co-ordinator:

Responsible expert (Fachverantwortlicher) – Person responsible for data collection, data entry and pertinent calculation, in keeping with the prescribed methods, as well as for carrying out QC measures and preparing a relevant textual contribution for the National Inventory Report.

Quality control manager (Qualitätskontrollverantwortlicher) – Person responsible for checking and approving data and report sections (the QC/QA co-ordinator may also perform this function).

22.1.2.1.4 QC/QA plan

The purpose of the QC/QA plan is to ensure that QC/QA measures are properly organised and executed. It includes a description of all required QC/QA measures and a schedule for implementation of such measures. The QC/QA plan also defines the primary emphases of such measures. The criteria for selection of categories for detailed review include the following:

- The category's relevance (key category yes/no, uncertainties high/low)
- The time of the last detailed QC/QA measure for the source category, and the results of such measure
- Changes in methods or the pertinent database
- Results of annual inventory review in keeping with the UN Framework Convention on Climate Change and the Kyoto Protocol
- Available resources for execution of QC/QA measures

Good practice calls for establishing a QC/QA plan and then reviewing and updating it each year after the latest inventory has been prepared.

On the basis of the results of annual inventory review, and of the results of QC/QA measures of which it is aware, the Single National Entity prepares an improvement plan for the entire inventory. On this basis, in turn, it derives proposals for a binding inventory plan for the next report year. Such proposals are then submitted to the co-ordinating committee for approval. The QC/QA co-ordinator, working in co-operation with the QSE co-ordinator in the Single National Entity, defines the procedures, scheduling and scope for inclusion of his institution's QC/QA measures in the inventory plan for the overall inventory.

22.1.2.1.5 General quality control

Pursuant to the definition used by the IPCC (Chapter 8.1 *Good Practice Guidance*), quality control (QC) comprises a system of routine specialised measures for measuring and checking the quality of inventories in preparation.

Consequently, a QC system should achieve the following:

- Facilitate routine, standardised checks in the interest of data integrity, correctness and completeness;
- Identify and eliminate errors and omissions;
- List and archive inventory material and record all QC activities.

Table 8.1 of the *IPCC Good Practice Guidance* includes a complete list of general QC measures. Requirements pertaining to general, Tier-1 QC procedures can be derived from the requirements mentioned in Chapter 8.6 of the *IPCC Good Practice Guidance*. Typical general quality control measures in activity-rate determination include checking data for transfer errors, checking data for completeness, checking formulae for combining data and carrying out plausibility checks with the help of external data sources and earlier calculations. Suppliers of emissions calculations have to carry out additional QC measures – for example, checking formulae for emissions calculation.

Required quality controls should be recorded in checklists. Such lists should include at least the checking measures carried out, the results of checking, any pertinent corrections made and the name of the person(s) responsible for the measures. Annex 2 of the present document includes a sample checklist of the Federal Environment Agency.

Not all quality controls have to be carried out on an annual basis; some may be implemented at longer regular intervals. This applies especially to aspects of data collection that do not change from year to year. Requirements pertaining to the frequency and completeness of QC measures are more stringent for key categories than for other categories. It should be ensured that all categories undergo detailed quality control at least periodically.

22.1.2.1.6 Category-specific quality control

Available resources permitting, particularly relevant categories (such as key categories), in addition to undergoing Tier 1 procedures, should undergo Tier 2 quality control with regard to determination of activity rates, emissions and uncertainties (cf. Chapter 8.7 *Good Practice Guidance*). The chapters of the IPCC Good Practice Guidance that pertain to the various individual categories (Chapter 5) include additional information relative to category-specific QC measures. Such guidelines must be observed in preparation of any QC/QA plan. :

Where combined **activity data** from secondary sources are used, good practice calls for evaluating pertinent QC measures in connection with preparation of such secondary sources. If the level of such measures is adequate, it suffices to call attention to this fact in the documentation. Where secondary sources do not fulfill minimum requirements pertaining to quality control, suitable QC/QA checks should be carried out by the institution that uses the data. Results of subsequent QC/QA checks should enter into determination of uncertainties for activity rates. In addition, wherever possible, a range of different sources should be compared for purposes of determining data quality.

In use of facility-specific activity data, it is good practice to review the methods and QC/QA standards applied to data collection. Where such methods and standards do not meet minimum requirements, the advisability of using the data should be reconsidered and the uncertainties should be adjusted as necessary.

With regard to **emissions data**, it is good practice to review the emission factors that have been used. Such efforts include using national emission factors for key categories and reviewing the validity of IPCC standard factors under the applicable national circumstances. Where emissions data are obtained via direct measurements, it is good practice to review the relevant measurement methods and the quality standards applied. Emissions data and emission factors should be reviewed in light of data from previous years, and from independent sources, and any resulting discrepancies should be explained.

Quality control for uncertainties includes checking to determine whether calculations are free of errors and whether documentation for reproduction of results is adequate. In use of experts' assessments, the pertinent experts' qualifications and estimation methods should be reviewed and documented.

22.1.2.1.7 Quality assurance procedures

While the primary aim of quality control is to ensure that methods are correctly applied, the primary purpose of quality assurance is to examine methods as such and improve them as necessary.

Pursuant to the relevant IPCC definition (Chapter 8.1 Good Practice Guidance), measures for **quality assurance** (QA) are based *"on a planned system of reviews by persons who are not directly involved in preparing the inventory. Such reviews – which are best carried out by independent third parties – should be applied to completed inventories, after QC procedures have been carried out. Such measures accomplish the following:*

- Verify that data-quality criteria are fulfilled,
- Ensure that the inventory takes account of the best available estimates of emissions and sinks, in keeping with the latest scientific findings and available data, and
- Promote the efficiency of the QC system".

The required instrument for quality assurance is the peer review. While use of audits is encouraged, audits are not required.

22.1.2.1.8 Reporting procedures

The Single National Entity is responsible for initiating and co-ordinating reporting and carrying out relevant overall organisation. Provision of data and reports by third parties must conform to applicable requirements pertaining to the scope, form and scheduling of/for such provision.

22.1.2.1.9 Documentation and archiving

As a general requirement, all data and information used for inventory calculation must be documented (i.e. recorded) and archived, for each report year. The purpose of such documentation (i.e. recording) is to make it possible to completely reconstruct all emissions calculations after the fact. The general requirements pertaining to documentation and archiving for the entire process of preparation of greenhouse-gas inventories are described in Chapter 8.10.1 of the *IPCC Good Practice Guidance*.

Consequently, data providers have the obligation to keep records of the following information relative to data they supply to the Federal Environment Agency, for purposes of inventory calculations:

Data providers:

- Publication / source of activity data, with detailed referencing of the relevant Table numbers and names, and of the relevant pages in the original sources;
- Survey contents (definitions of the surveyed characteristics, delimitations used, survey units used) and survey methods;
- The legal foundations and ordinances on which surveys are based;
- Chronological and spatial comparability with previous-year data, and any changes with regard to definitions, scopes of validity, cut-off points, sources of activity rates or data-collection methods;
- Any revision of previously published data;
- The accuracy or quantitative error of activity data, methods used to estimate errors and the names of experts who have carried out error estimation.
- Secrecy and data protection: suitable notification with regard to any individual data items that are considered secret.

Such materials should be provided to the Federal Environment Agency on an annual basis, together with pertinent data, and they are centrally archived by the Federal Environment Agency.

Quality control (QC)

The records kept in the framework of quality control should include the names of the persons responsible for managing and carrying out relevant actions, the types of quality control carried out, the dates on which quality control measures were carried out, the pertinent results, and the corrections and modifications triggered by quality control measures. In each case, record-keeping and archiving for quality control measures are carried out internally, by the institution supplying the pertinent data. A general description of regularly executed quality control measures is provided to the Federal Environment Agency for purposes of the national inventory report and inventory review.

Providers of emissions calculations

For providers of emissions calculations, the minimum requirements pertaining to record-keeping also include the following:

- Description of the pertinent calculation methods and reasons why the methods were selected;
- Assumptions and criteria pertaining to selection of activity data and emission factors;
- Documentation pertaining to emission factors and their sources, with detailed references to the relevant numbers and pages in original sources;
- Calculation models;
- Calculation files, calculation software.

Points 1-4 are recorded and archieved along with descriptions provided for the national inventory report. Separate documentation pertaining to calculation models must be provided, in keeping with general scientific practice, and along with internal documentation in the form of manuals or guides. Data suppliers archive calculation files and calculation software, and keep pertinent records, on an internal basis. Such materials should be provided to the Federal Environment Agency as necessary in the framework of inventory review.

Quality assurance

In addition to carrying out quality control measures, providers of emissions calculations are obligated to carry out quality assurance. The records kept in the framework of quality assurance should include the names of the persons responsible for managing and carrying out relevant actions, the types of quality assurance carried out, the dates on which quality assurance measures were carried out, the pertinent results, and the corrections and modifications triggered by quality assurance measures. In addition, records should be kept of category-specific quality controls.

In each case, record-keeping and archiving relative to pertinent quality assurance are carried out internally, by the relevant data-supplying institution. In addition, pertinent quality assurance measures are summarised in the national inventory report.

Confidential data / secrecy

In general, confidential data must be designated as such when they are provided, to ensure that the proper precautions are taken when they are used.

In inventory review, general obligations apply whereby confidential data must be disclosed in cases in which inventory reviewers consider such disclosure to be necessary to ensure that emissions calculations are transparent and clear. The extent to which such disclosure actually must involve disclosure of individual data items should be clarified on a case-by-case basis with the institution providing the data.

22.1.2.1.10 Annex 1: Minimum requirements pertaining to quality control and quality assurance in emissions reporting in the Federal Environment Agency

22.1.2.1.10.1 Introduction

The general minimum requirements, as approved by the co-ordinating committee for the National System of Emissions Inventories, pertaining to quality control and quality assurance (QC/QA) in reporting on greenhouse-gas emissions apply to all participants. These requirements are the basis for collecting, processing, forwarding and reporting of/on all data that support reporting on greenhouse-gas emissions. They are thus binding for all working groups involved, in the Federal Environment Agency, in fulfillment of this reporting task.

22.1.2.1.10.2 System for quality control and quality assurance

In addition to the general minimum requirements, approved by the co-ordinating committee for the National System of Emissions Inventories, pertaining to quality control and quality assurance (QC/QA) in reporting on greenhouse-gas emissions, the specific provisions of in-house directive (Hausanordnung) No. 11/2005 also apply at the Federal Environment Agency. Pursuant to that directive, the pertinent procedure defined in the QSE manual is binding for all Federal Environment Agency personnel involved in emissions reporting (Rules of procedure of the Federal Environment Agency (Geschäftsordnung des Umweltbundesamtes), Volume II, Numeral XV).

The in-house directive fully implements the requirements of Chapter 8 of the *IPCC Good Practice Guidance*. Suitable UBA-specific instruments have been established to ensure effective identification and execution of measures for continual inventory improvement (improvement plan and inventory plan; cf. 22.1.2.1.10.3). That work has led to the development of the Quality System for Emissions Inventories (QSE), via which the points mentioned in Chapter 22.1.2.1.2 have been implemented.

22.1.2.1.10.2.1 Agency responsible for co-ordinating QC/QA activities in the Federal Environment Agency

Pursuant to in-house directive No. 11/2005, section FG V 1.6, "Emissions Situation", is the "Single National Entity" (SNE) within the Federal Environment Agency. In the Federal Environment Agency's organisational diagramme, the so-defined SNE is thus included in the Federal Environment Agency’s group of "focal points" and liaison offices for international organisations. In addition, this assignment of responsibility was confirmed by the relevant ministries via a state secretaries' resolution of 5 June 2007.

The roles and responsibilities of the Single National Entity, and of the specialised departments participating in emissions reporting, are described in Chapter 3.2, "Roles and responsibilities", of the QSE manual. The Single National Entity is responsible for updating and managing the QSE manual and its appendices and annexes. In carrying out this responsibility, the SNE is assisted by the contact persons named to it by the relevant specialised departments. The version of the QSE manual and its co-applicable documents published on the Single National Entity's intranet is the binding version of these materials.

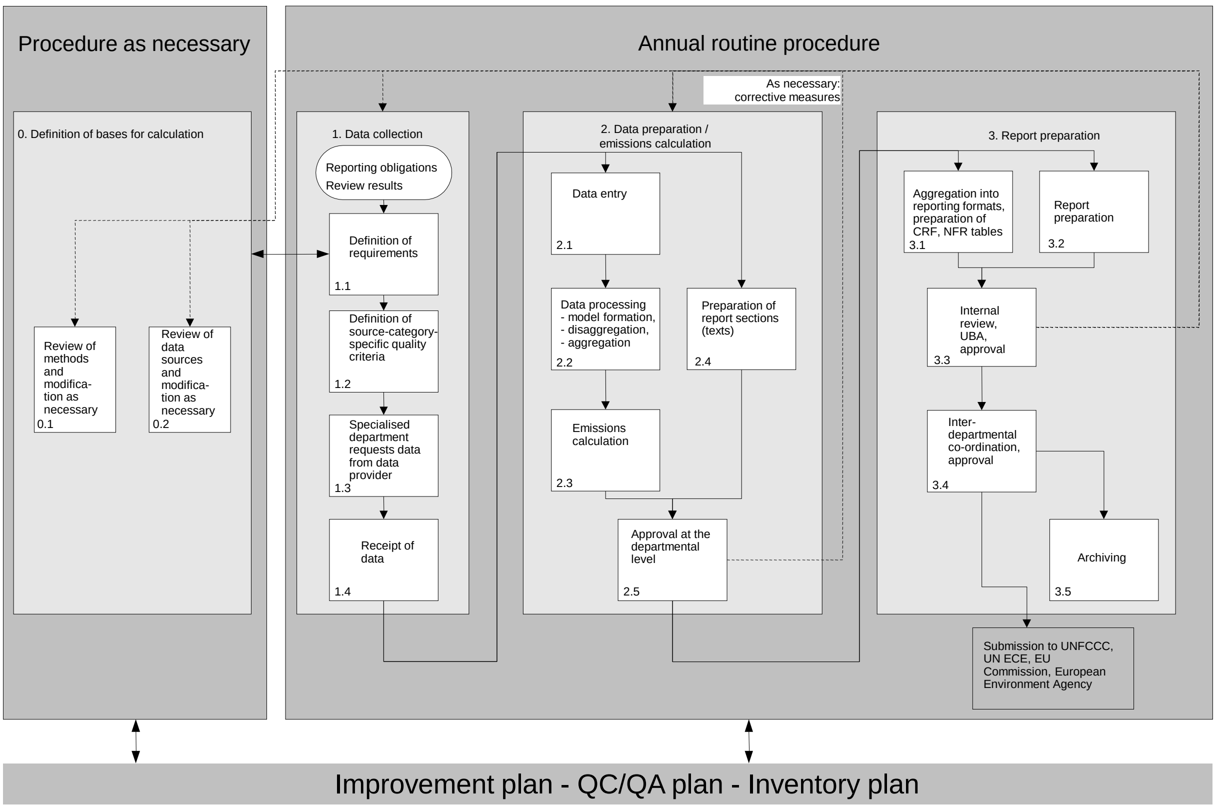
22.1.2.1.10.2.2 Reporting procedures

In many cases, complex activities comprise numerous different, but related and cumulative, activities (processes) that lead to the production of a single product. To manage such processes effectively, one must strive to understand the manner in which the processes function (or should function), to describe such functioning in logical, realistic ways (activities, dependencies, responsibilities, and many more) and to interrelate the processes in a useful way.

In practice, workflows of complex processes cannot always be fit smoothly into the hierarchical, traditional structures of companies and institutions. The required processes are often diametrally opposed to such structures, since they have to cut across different organisational units. To organise interrelated work processes in a manner oriented to production of the desired product, one must look outside of rigid hierarchies and redefine the processes with a view to improvement.

For this reason, emissions reporting was first described as a process that, via a number of interrelated activities, leads to a product (NIR and inventories) (cf. Figure 100). Additional relevant information is provided in the QSE manual, Chapter 4.3.

Figure 100: Overview of the overall emissions-reporting process



Via a role concept, suitable responsibilities have been assigned to cover the activities within the main processes and sub-processes shown. Each responsibility thus involves execution of pertinent processes. To understand this approach, it is useful to consider the situation in which many different people carry out the same basic activities even though they work in different work units and on different categories. In the present case, this situation was approached by defining a certain group of persons (persons with a specific role – for example, responsible experts). That group was then seen to be subordinate to another group of persons (with a different role – for example, specialised contact persons) that ensures that the first group observes and fulfills the requirements pertaining to its work. In addition, a QSE co-ordinator was appointed, in keeping with relevant requirements of the IPCC (cf. Chapter 22.1.2.1.2), to ensure that the system is refined and improved as necessary.

Overall, a comprehensive role concept was developed that addresses the many different requirements applying to the Federal Environment Agency in its task as Single National Entity. The roles involved include the following:

1. **Responsible expert at the operational level (FV)**
   - Main responsibilities: data collection, data entry, calculations with prescribed methods, execution of QC measures, preparation of the NIR text

2. **Quality control manager (QKV)**
   - Is the superior for the FV
   - Main responsibilities: checking and approving data and report sections

3. **Specialised contact person (FAP)**
   - Member of the Single National Entity's staff
   - Main responsibilities: providing category-specific support for involved experts (inventory work and report preparation) and quality control / quality assurance relative to pertinent categories in the NIR and CSE.

4. **Co-ordinator for the national inventory report (NIRK)**
   - Member of the Single National Entity's staff
   - Main responsibilities: co-ordination of supporting textual work, preparation of the NIR from the various relevant contributions, overarching QC and QA for the NIR

5. **CSE co-ordinator (ZSEK)**
   - Member of the Single National Entity's staff
   - Main responsibilities: maintenance of databases, emissions calculation and aggregation, overarching QC and QA in connection with data entries and calculations for the inventory

6. **QSE co-ordinator (QSEK)**
   - Member of the Single National Entity's staff
   - Main responsibilities: maintenance and refinement of the QSE (system, checklists, improvement plan, inventory plan, QC/QA plan and QSE manual)

7. **NaSE co-ordinator (NaSEK)**
   - Member of the Single National Entity's staff
   - Main responsibilities: schedule-conformal, requirements-conformal reporting, providing for involvement of national institutions, establishing/recording legal agreements

As a rule, each of the above-described roles will have tasks in several different main and sub-processes of emissions reporting.

22.1.2.1.10.3 QC plan, QA plan and inventory plan

To ensure that all potential improvements identified during the course of inventory work are systematically implemented, identified improvements must be listed in a co-ordinated way. In the process, identified potential improvements should be listed together with all relevant information (origin of the potential improvement, category, pertinent responsibility, priority, etc.) needed for efficient further processing. Planning and arrangements for implementing identified potential improvements (required actions / corrective measures, deadlines, etc.) should then be made on the basis of such information.

In the interest of proper control and record-keeping in the framework of the NaSE and the QSE (cf. Figure 101), procedures have been defined for processing identified potential improvements for their systematic management and further use. The overall aim is to answer the central question of WHO should do WHAT, HOW, WHEN and WHY:

WHO: This provides the reference to the role concept: A certain person xy is responsible – for example, in the role of responsible expert (FV)

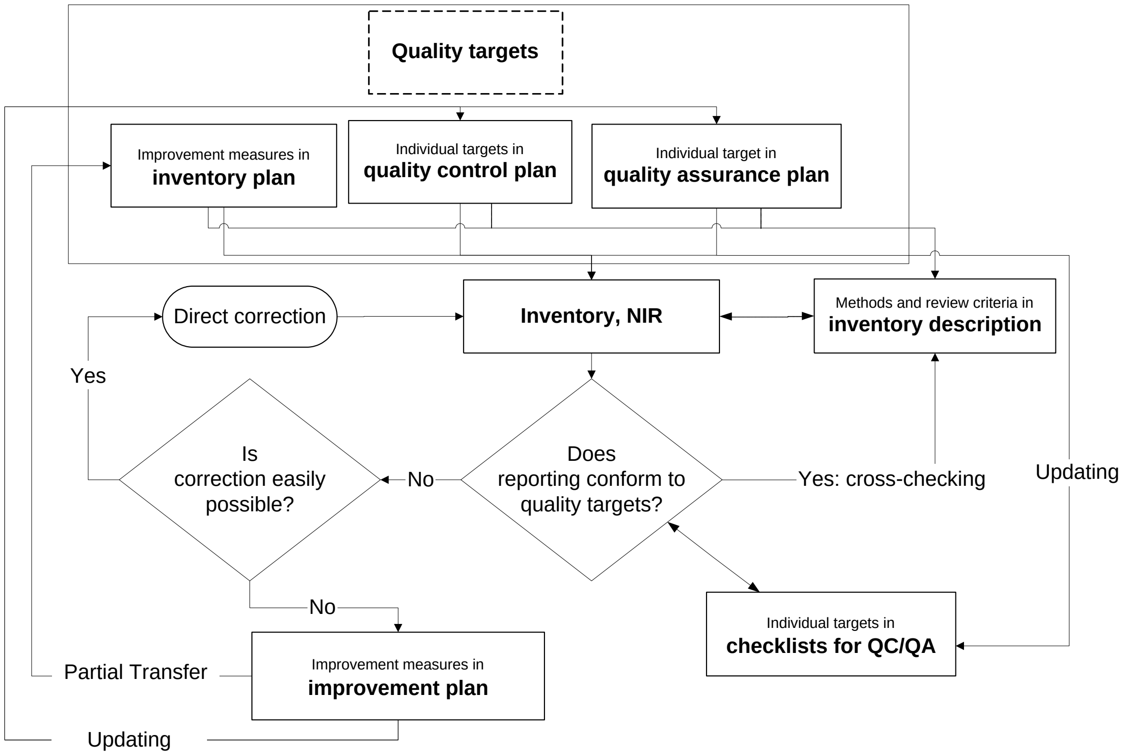
WHAT: This provides the reference to the object that is to be improved – for example, the CO_2 calculation in category xy needs to be improved

HOW: This provides the reference to the aim that is to be achieved – for example, a certain improvement, pursuant to an inventory plan or checklist.

WHEN: This provides the reference to the time by which the improvement must be completed, pursuant to the inventory plan

WHY: This provides the reference to the origin of the necessary action – for example, the improvement must be carried out as a result of a recommendation via the UNFCCC review process

Figure 101: Control and documentation in the framework of the NaSE and the QSE



The **quality targets** have been derived from the general quality aims of the IPCC Good Practice Guidance (transparency, consistency, accuracy, comparability, completeness). In addition, operational individual objectives, relative to quality control and quality assurance, for the various categories, have to be derived from comparison of the requirements from the *IPCC Good Practice Guidance*, the results of independent inventory review (UNFCCC and EU) and assessment of inventory realities.

In an **improvement plan**, all potential improvements and criticisms resulting from independent inventory review are collected and assigned potential corrective measures. The Single National Entity categorises the corrective measures, prioritises them and then, via consultations with the relevant responsible experts, integrates them as necessary within the **inventory plan**. There, they are linked with deadlines and responsibilities. As an annex to the NIR, the inventory plan undergoes a co-ordination and release process in the Federal Environment Agency and in the co-ordinating committee. It is thus a binding set of specifications for improvements to be carried out in future.

In the interest of transparent, effective control and execution of inventory-improvement measures, such measures, in keeping with the *IPCC Good Practice Guidance* (Chapter 8.5) are defined role-specifically, as well as category-specifically as necessary, in the **quality control plan / quality assurance plan (QC/QA plan)**. The QC plan is oriented solely to quality control aims for the inventory. In the QA plan, quality assurance objectives may be focused on the inventory, the reporting process or the QSE itself. Furthermore, the quality assurance plan includes scheduling of quality assurance measures to be performed by external third parties.

The **checklists for quality control and quality assurance** list all individual objectives in the emissions-reporting process, in keeping with the pertinent quality control and quality assurance plans. The checklists, which are designed to facilitate review of achievement of individual objectives, are made available to all persons responsible for quality control and quality assurance. The checklists are used to record execution of measures for quality control and quality assurance. Where individual objectives are not achieved and direct correction is not possible, a pertinent entry must be made in the improvement plan (see above).

22.1.2.1.10.4 Procedures for general and category-specific quality control

From the requirements set forth in the IPCC Good Practice Guidance, the Federal Environment Agency has developed a checklist concept via which quality requirements are formulated as specific targets. Every effort should be made to achieve such targets. When a target is achieved, such achievement is noted and described in the checklists. The possible entries for such records include "yes" (the target was achieved), "not relevant" (the target as formulated does not correspond to the special situation for the category in question; this answer is seldom a viable option) and "no" (it was not possible to achieve the target).

Each checklist includes a general section that reflects all Tier 1 QC requirements from IPCC Good Practice Guidance and that is used in connection with every instance of reporting. In addition, each checklist contains a category-specific section (Tier 2) that provides concrete objectives for the relevant key category area.

Checklists are provided only for the first five roles within the role concept. Where different roles are responsible for different main and sub- processes of emissions reporting (cf. Chapter 22.1.2.1.10.2.2), pertinent checklists will also be oriented to several different main and sub-processes of emissions reporting. They thus represent a cross-section of emissions reporting. The checklists of the FV and the FAP include a basic common set of goals. The FAP are responsible for checking the work of the FV, and such checking is most effective when both roles are oriented to the same goals.

22.1.2.1.10.5 Quality assurance procedures

In the role concept, procedures are designed to ensure that quality assurance is always supported by a "four-eyes" principle. The specialised contact persons (FAP) have the task of ensuring that the emissions calculations and textual work of the responsible experts (FV) are of the proper quality.

In its section on "Expert Peer Review", the IPCC notes that the (above-described) formal procedure selected by the Federal Environment Agency can complement, but not replace, expert peer review (Good Practice Guidance; Chapter 8.8). In one solution found for addressing the justified call for inclusion of external experts, within the framework of available resources, detailed review of specific issues is carried out by external third parties via research projects and studies. In general, the two sides involved (i.e. FV and FAP) jointly manage the process of commissioning third parties. In another means found for addressing the need for third-party inclusion, workshops on the National System are held at irregular intervals. For such workshops, national experts are invited to come to the Federal Environment Agency for discussion with Federal Environment Agency experts (FV) on current inventory issues relative to selected categories.

No audits have been carried out in the Federal Environment Agency to date, and none are planned at present. According to the Good Practice Guidance, audits are not absolutely required.

22.1.2.1.10.6 Documentation and archiving

Standardised record-keeping and archiving procedures are to be used in preparation of German greenhouse-gas inventories. At the same time, it is important to differentiate between the central record-keeping and archiving carried out by the Single National Entity and the non-central record-keeping and archiving carried out by the specialised departments of the Federal Environment Agency and of other institutions.

Record-keeping procedures for data and context information vary in accordance with specific requirements. In their information storage, they overlap to some degree, with such overlapping consisting partly of redundancies and partly of storage of similar items at differing levels of detail. On a regular basis, consistency must be ensured for both types of overlapping.

To ensure that all of the Federal Environment Agency's working units use basically consistent procedures, the specifications applying to the instruments used in such procedures – including both general specifications and specifications developed especially for emissions reporting – must be complied with. For purposes of "documentation" (i.e. record-keeping), the Federal Environment Agency has access to the instruments described in Table 577. The specifications pertaining to each type of document / record must be observed. Where no special specifications apply, the provisions from the "General minimum requirements for quality control and quality assurance in reporting on greenhouse-gas emissions" ("Allgemeine Mindestanforderungen an die Qualitätskontrolle und Qualitätssicherung bei der Treibhausgasemissionsberichterstattung") apply.

Table 577: Documentation / record-keeping instruments at the Federal Environment Agency

Instrument	Specifications
Publicly available	
National inventory (CRF tables, CRF-Reporter)	Annex 2, QSE manual: instructions for carrying out recalculations in the CRF tables
National Inventory Report	Annex 3, QSE manual: specifications for preparing report sections in the context of the National System
Publication	Rules of procedure of the Federal Environment Agency: Point 6.2 Publications
Published manuals, guides	For IT descriptions: procedural model of the Federal Environment Agency; otherwise: no special specifications
Centralised, and internally available, at the Single National Entity	
CSE database	Annex 5, QSE manual: specifications for data recording within the CSE
Inventory description	Annex 4, QSE manual: requirements pertaining to documentation (record-keeping) and archiving
De-centralised, and internally available	
Files of the central registry	Rules of procedure of the Federal Environment Agency: Point 4.2.10 Handling of files
Reference files	no special specifications
Internal manuals, guides	For IT descriptions: procedural model of the Federal Environment Agency; otherwise: no special specifications

An integrated documentation / record-keeping concept defines what key content should be stored in the aforementioned documentation instruments. It also defines how a suitable referencing system is to be used to ensure consistency and transparency throughout all such instruments (cf. Annex 4, QSE manual).

22.1.2.1.11 Annex 2: Example of a general checklist for the responsible-expert role

The example presented below (last revision: CHKL 2010) includes only the relevant requirements. Detailed information has been removed in the interest of clarity.

Table 578: General checklist for responsible experts

Process No.	Sub-process name	Individual goal	Optional goal

Main process: 0. Definition of bases for calculation

Process No.	Sub-process name	Individual goal	Optional goal
0.1	Review of methods, and modification as necessary	The calculation method is in conformance with current key-category analysis.	
0.1	Review of methods, and modification as necessary	The calculation method has been selected in accordance with, or accords with, the pertinent decision tree of the IPCC Good Practice Guidance.	Departures from the decision tree of the IPCC Good Practice Guidance have been properly explained, in keeping with logical and pertinent specialised criteria, and have been duly documented.
0.1	Review of methods, and modification as necessary	The calculation method has been selected in keeping with requirements from the inventory plan.	Departures from the inventory plan have been properly explained, in keeping with logical and pertinent specialised criteria, and have been duly documented.
0.1	Review of methods, and modification as necessary	The selected calculation method can be applied to the entire time series as of 1990, or is already being consistently applied.	In cases of changes of methods in the time series, recalculation pursuant to the QSE manual (Annex 2), and proper pertinent documentation, are assured.
0.1	Review of methods, and modification as necessary	Departures from the objectives required via 0.1.01-0.1.04 have been properly explained, in keeping with logical and pertinent specialised criteria, and have been duly documented.	
0.2	Review of data sources, and modification as necessary	Have new data sources been used?	
0.2	Review of data sources, and modification as necessary	The data source(s) is / are / will be available throughout the long term (for example, on the basis of legal provisions, long-term agreements [> 3 years], etc.).	
0.2	Review of data sources, and modification as necessary	One / several complete time series as of 1990 are available in the data source(s).	Gaps in the data available for time series as of 1990 have been properly and logically explained, and have been duly documented.
0.2	Review of data sources, and modification as necessary	One / several complete time series as of 1990 are available in the data source(s).	A suitable procedure (interpolation/ extrapolation) has been chosen for dealing with data gaps, in conformance with IPCC Good Practice Guidance (Chap. 7.3.2.2), and the procedure has been logically documented. Note: Continued use of the same value is not extrapolation !
0.2	Review of data sources, and modification as necessary	One / several complete time series as of 1990 are available in the data source(s).	Following closure of data gaps, time-series recalculation has been carried out as necessary, pursuant to QSE manual (Annex 2), and such recalculation has been documented and substantiated in the NIR and CRF.
0.2	Review of data sources, and modification as necessary	The data source(s) completely cover the category.	The incomplete coverage has been addressed in an extrapolation and has been taken into account in the uncertainties calculation. All steps have been documented and justified clearly and logically.
0.2	Review of data sources, and modification as necessary	Uncertainties information (amount and distribution) is available for the data source(s).	
0.2	Review of data sources, and modification as necessary	The EF and the AR agree in terms of the manner in which they are tailored to the source category.	In the case of discrepancies between the EF and AR, other data sources can establish agreement between the two values. Alternatively, the lack of agreement

			has been taken into account in an extrapolation, and in the uncertainties calculation, and the entire process has been properly and logically documented.
0.2	Review of data sources, and modification as necessary	The procedures for calculating outset data are clearly described.	
0.2	Review of data sources, and modification as necessary	The data source(s) have been selected in keeping with requirements from the inventory plan.	Any discrepancies have been clearly and logically justified and documented.
0.2	Review of data sources, and modification as necessary	The assumptions and criteria upon which the relevant data source(s) have been selected have been clearly and logically documented.	
0.2	Review of data sources, and modification as necessary	The data provider has carried out routine quality controls of the data source(s). For one-time projects, one-time quality controls have been carried out. Execution of the controls has been duly documented.	
0.2	Review of data sources, and modification as necessary	In use of one/more new data sources, a recalculation pursuant to the QSE manual (Annex 2) was carried out on the basis of this/these other data source(s).	
0.2	Review of data sources, and modification as necessary	In use of IPCC default EF, the manner in which the EF were generated has been reviewed in light of national circumstances, and the EF may be used for Germany. The result of such review has been duly documented.	For IPCC default values that do not fit with national circumstances, the discrepances have been taken into account in the uncertainties and documented.
0.2	Review of data sources, and modification as necessary	In use of EF other than the IPCC default EF, use of such EF has been clearly and logically justified and substantiated. Note: Use of other EF is permissible only when such EF permit more precise calculation of country-specific emissions.	
0.2	Review of data sources, and modification as necessary	The AR used have been compared with other data sources (for example, EU-ETS, IEA, EPER, etc.), and the result has been duly documented.	
		Main process: 1. Data collection	
1.1	Definition of requirements	The requirements pertaining to data reflect the information and indications from the inventory plan and the inventory reviews (for example, S&A Report, Centralized Review).	
Process No.	**Sub-process name**	**Individual goal**	**Optional goal**
1.3	The relevant specialised department requests the data from the pertinent data provider(s)	The requirements pertaining to QC and data formats have been forwarded to the data suppliers and/or contracting entities, and such forwarding has been duly documented. Note: Where data suppliers are involved via NaSE agreements, this objective has been achieved.	The data supplier (for example, an association) carries out its own routine quality controls, and the results have been duly documented.
1.4	Receipt of data	The data provider or contracting entity has carried out the required quality controls and made proper records of such action.	The data supplier (for example, an association) carries out its own routine quality controls, and the results have been duly documented.
1.4	Receipt of data	The received data are complete, without any gaps.	All data gaps in the time series as of 1990 have been closed, in accordance with the IPCC Good Practice Guidance, via extrapolation/interpolation (Chapter 7.3.2.2) and duly documented and justified. Note: Continued use of the same value is not extrapolation

1.4	Receipt of data	The data received are consistent with the previous year's data, and they have been properly described.	Any marked discrepancies with the previous year's data have been duly documented and justified.
1.4	Receipt of data	The order of magnitude of the received data is in line with that of comparable data from other sources (such as ETS data, IEA, EPER, etc.). The result of the review has been duly documented.	The reasons for any discrepancies have been clearly and logically explained and duly documented.
1.4	Receipt of data	The methods/assumptions on which the uncertainties determinations are based have been clearly and logically documented.	Where it was not possible to derive assumptions, expert assessment was carried out, and the relevant expert's quantification was clearly and logically documented.
1.4	Receipt of data	The uncertainties determinations are complete and plausible.	
Main process: 2. Data preparation / emissions calculation			
2.1	Data entry (preferably into the CSE)	All of the EF have been entered into the CSE.	
2.1	Data entry (preferably into the CSE)	The documentation for the EF data source(s) is complete and conforms to the requirements of the QSE manual (Annexes 3, 4 and 5).	
2.1	Data entry (preferably into the CSE)	Development of the EF within the time series has been plausibly explained and, in the case of unusual effects (such as changes in order of magnitude), has been clearly and logically explained and documented.	Implausible EF have been corrected.
2.1	Data entry (preferably into the CSE)	All of the AR have been entered into the CSE.	
2.1	Data entry (preferably into the CSE)	The documentation for the AR data source(s) is complete and conforms to the requirements of the QSE manual (Annexes 3, 4 and 5).	

Process No.	Sub-process name	Individual goal	Optional goal
2.1	Data entry (preferably into the CSE)	Development of the AR within the time series has been plausibly explained and, in the case of unusual effects (such as changes in order of magnitude), has been clearly and logically explained and documented.	Implausible discrepancies have been corrected.
2.1	Data entry (preferably into the CSE)	Following entry of all data into the CSE, all entered figures, units and conversion factors have been checked for correctness and confirmed.	
2.1	Data entry (preferably into the CSE)	All of the uncertainties have been entered into the CSE and have been documented in keeping with the requirements of the QSE manual (Annexes 3, 4 and 5).	
2.2	Data preparation (model formation, disaggregation, aggregation)	The inventory description includes an adequate description of pertinent models, with regard to organisation, structure, calculation procedures, assumptions, etc..	
2.3	Emissions calculation	The current inventory calculations have been checked against calculations from previous reports.	Where any significant changes or obvious deviations from an expected trend have occurred, the pertinent calculation, and the data used in calculation, have been reviewed, and any persisting discrepancies have been properly, clearly and logically explained and duly documented.

2.3	Emissions calculation	The results of emissions calculation for current / previous reports have been checked against other data sources for Germany, especially ETS data, and found to be comparable. The result has been duly documented.	Where comparability has not been found, or no comparison was carried out, the pertinent reasons have been properly, clearly and logically explained.
2.3	Emissions calculation	The national Implied EF (cf. S&A Report I) from the previous report is comparable with the Implied EF of other countries (same order of magnitude).	Extreme Implied EF have been properly, clearly and logically explained, and duly documented, in the NIR, or reference to an existing explanation has been made.
2.4	Preparation of report sections (texts)	The category has been completely and logically described, for the NIR, in terms of the required six sub-chapters for the NIR ("Category description", "Methodological issues", etc.).	
2.5	Approval by the relevant experts	The values of AR, EF and ED, of their uncertainties, are up to date in the NIR and congruent with the pertinent values in the CSE.	
2.5	Approval by the relevant experts	Documentation of the origins for AR, EF and ED data, and for their uncertainties, are up to date in the NIR and congruent with the pertinent values in the CSE.	Lacking or incomplete documentation of data origin has been properly, clearly and logically explained and duly documented.

22.1.3 The database system for emissions – Central System of Emissions

Since 1998, the Federal Environment Agency has maintained and managed an IT tool for inventory preparation: the *Central System of Emissions (CSE)*, an integrated national database. The CSE implements the diverse requirements pertaining to emissions calculation and reporting, and it automates key steps in such work. It supports the processes of inventory planning and reporting (for example, by carrying out emissions calculations and recalculations, and relevant error analysis); inventory management (for example, by carrying out archiving and annual data evaluation); and quality management at the data level (cf. UBA 2003a, Projekthandbuch Decor (Decor project handbook)). The CSE makes it possible to fulfill the key requirements of transparency, consistency, completeness, comparability and accuracy at the data level.

Data documentation plays a central role in the CSE. The CSE stores such information as who is responsible for handling specific tasks; data sources and calculation procedures; and uncertainties in time-series values. The times at which changes are made, and the persons by whom they are made, are also recorded. The system has a history-management function that archives deleted items and can restore them as necessary. This makes it possible to trace back and reconstruct data, and it enables third parties to carry out independent reviews. The system also provides mechanisms that support quality assurance at the data level (e.g. components for detecting uncertainties and checking plausibility). Above all, transparency is accommodated by ensuring that data are recorded within the same structure in which they are provided, and that all processing and transformations into a reporting format take place first in the CSE itself, and thus remain open to examination. In addition, the CSE manages detailed technology-specific activity data and emission factors that can be processed, via calculation rules (calculation methods), into aggregated, category-specific values for the various reporting formats. Aggregation of individual CSE time series for the CRF report lines, for example, is described in Annex 3 and Chapter 3ff – in each case, with regard to individual categories. In addition to aggregation and model formation for calculations, the CSE also supports scenario and forecast calculations and use of the reference approach.

Data exchange within the framework of the National System – i.e. within the Federal Environment Agency and with third parties – is also organised via the Central System of Emissions. Such processes involve both direct data entry and imports of aggregated values, from existing databases and via a standard interface (for example, TREMOD, for transport data; and GAS-EM, for agricultural data). Ideally, inventory data should be entered into the CSE directly by the relevant responsible experts or should be imported, by the CSE administrator, via the import interface. This applies to in-house UBA employees as well as to external parties involved in the National System. To this end, a range of measures have been implemented:

- Provision of a *standardised import format for the CSE* in 2002 has facilitated the direct import of data from other emissions-relevant databases.
- In September 2002, participating technical experts from the Federal Environment Agency were given direct access to the CSE via the Federal Environment Agency intranet.
- Since November 2002, training courses on CSE procedures have been held on an annual basis for involved Federal Environment Agency staff.
- Since 2005, qualitative and quantitative information about data uncertainties has also been included in the CSE.
- Since 2006, reporting obligations under the Geneva Convention on Long-Range Transboundary Air Pollution and EU legislation (such as the NEC directive) have been fulfilled via the CSE.
- Since 2008, data providers and experts outside of the Federal Environment Agency, and project partners, can work interactively with the CSE via remote access.

22.1.4 Verification of the German Greenhouse Gas Inventory

22.1.4.1 Introduction

In 2021 4 independent sets of data were used. They were selected amongst the criteria given in the 2019 refinements of the IPCC guidelines for verification (Romano *et al.*, 2019). Here the IPCC lists several data sources that may serve as independent verification datasets. The most prominent dataset amongst the options listed under 6.10.1 of the 2019 refinements are the Emission Database for Global Atmospheric Research (EDGAR) of the JRC (Crippa *et al.*, 2019). We chose this dataset for verification as it is widely used amongst the atmospheric research community and is for example used in the compilation of the Copernicus Atmospheric Monitoring Service data products for methane (Seegers, Houweling and Tokaya, 2020) and CO_2 (Chevallier, 2020). EDGAR is also compiled by data sources (Crippa *et al.*, 2021)) that are listed in the IPCC refinements under 6.10.1, therefore, EDGAR represents a prime synergetic dataset that has to be included in any verification work.

Another important source of data that is explicitly mentioned is data from inverse modelling, discussed in the IPCC refinements in chapter 6.10.2. Under 6.10.2.5 CAMS data is explicitly mentioned as a potential source of verification data. Therefore, the CAMS global inversion data from the Copernicus Atmospheric Datastore is used for verification, which is available for N_2O (Thompson, 2021), CO_2 (Chevallier, 2020) and CH_4 (Crippa *et al.*, 2021).

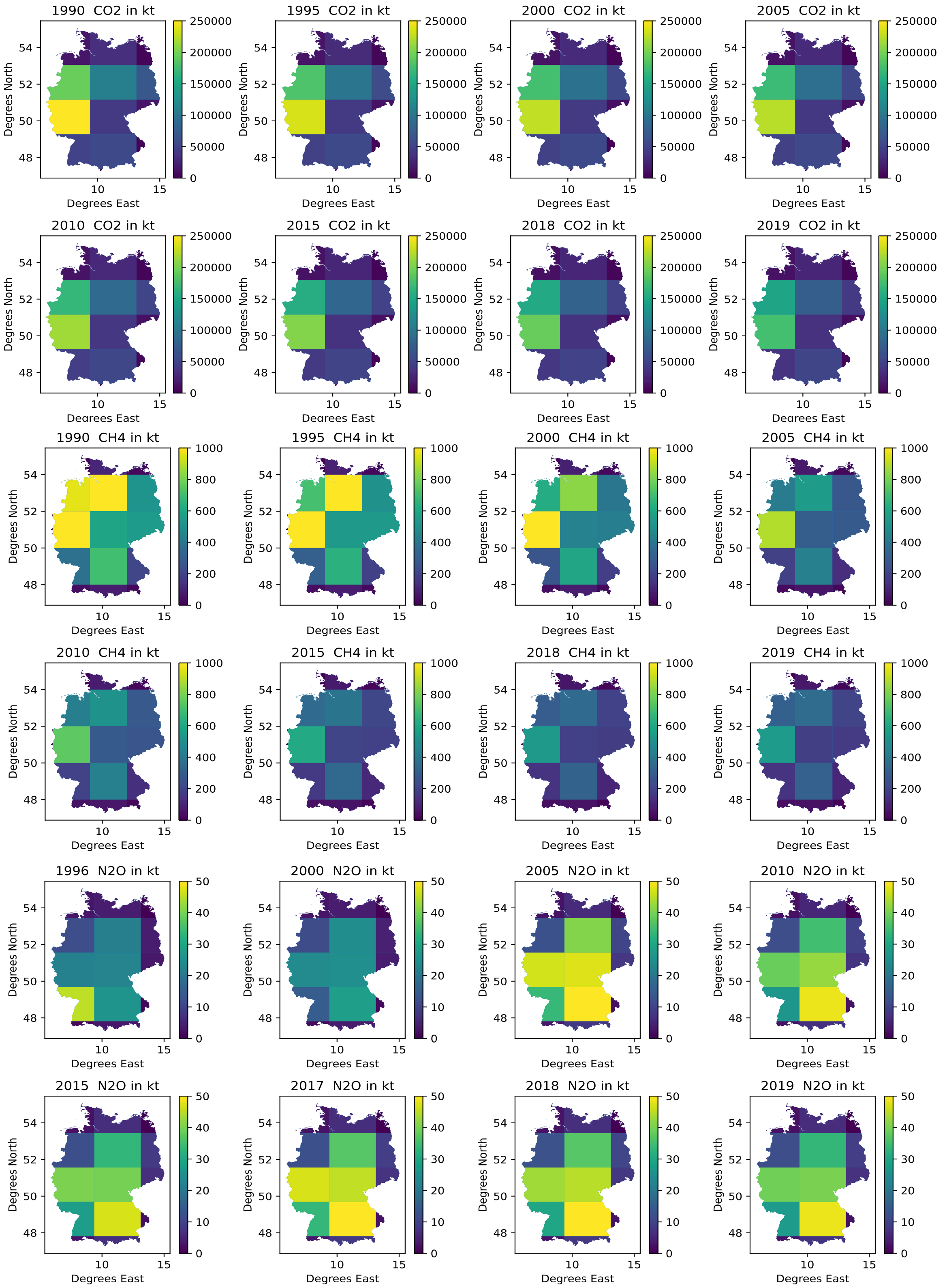
The last two independent sources of data that will be used for verification are not explicitly listed by the IPCC 2019 refinements (Romano *et al.*, 2019). These are the database of the Pollution Release and Transfer Register (PRTR) (Umweltbundesamt, 2022) and the data from the European Emission Trade System (ETS), provided by the European Environment Agency (EEA, 2022). Details of the German PRTR data as well as the database may be found under: https://thru.de/thrude/. Details with respect to the ETS data may be found in the European topic center report compiled by (Graichen, Cludius and Gores, 2019). These four diverse and independent datasets are ideal for a verification of the German inventory according to the IPCC Refinements of 2019 (Romano *et al.*, 2019). Data for all of the three major Green House Gases (GHG) N_2O, CH_4 and CO_2 for all the sectors (including LULUCF/AFOLU) were compared with the four datasets in order to verify the temporal trends in diagrams and by standard mathematical similarity operators such as the Pearson and Spearman-Rank correlations, which are widely used to compute similarity between two mathematical vectors.

The main aim of this chapter is to offer qualitative and semi-quantitative comparisons of the national totals for the three major GHGs methane, nitrous-oxide and CO_2 to independent sources of GHG data. The specific focus is set on the verification of temporal trends in the yearly national totals of the three above named GHGs in kt or Gt of CO_2 equivalent. Direct sectoral comparisons has not been considered as the verification data exhibit very different levels of disaggregation (from none, as in case of the CAMS data product, up until very detailed, as in case of EDGAR).

22.1.4.2 Methods and Materials

The four sets of data each require their own analysis tools that have been developed for this verification work. Whilst the EDGAR database is available for modelling activities in yearly gridded format, it is also available as tabulated document presenting only the national totals. The PRTR- database, in form of an sql-database file offers all the national reported data on large point sources, whilst the CAMS data is available in monthly slices in netcdf-Format. The ETS data is available as a csv file for download hosted at the EEA.

Figure 102: Time Slice Emission data for Germany from the CAMS data store



22.1.4.2.1 The EDGAR Inventory

The EDGAR Inventory Data and its methodology for previous versions of the EDGAR GHG Database has been described in detail in (Crippa et al., 2019). An update of this report is currently in preparation. EDGAR strives to support all countries of the world with emission inventory data. In the process EDGAR is compiled in a consistent, homogeneous and transparent manner (Crippa et al., 2021). This is of high benefit for e.g. all developing countries, who do not yet have consistent inventory data. In addition, the gridded emission data of EDGAR is highly appreciated in the inverse modelling community, who rely on globally consistent gridded emission data for their model runs. Calculation of the CAMS CO_2 and CH_4 inversion optimized data product require the usage of EDGAR data as stated in (Seegers, Houweling and Tokaya, 2020) and (Chevallier, 2020). The yearly national total data from the tabulated EDGAR files (Crippa et al., 2021) will be used in the following for the here presented verification work for CO_2, N_2O and CH_4.

22.1.4.2.2 The CAMS Global Inversion-Optimized Greenhouse Gas Data

The CAMS global inversion optimized GHG data is a compilation of data, which are produced by three different processing chains. The CH_4 production chain is described in (Seegers, Houweling and Tokaya, 2020). Data processing for the compilation of the N_2O data is detailed in (Thompson, 2021), whilst (Chevallier, 2020), describes the data for the CO_2 product. Figure 102 shows the data from the three processing chains, clipped to the extent of Germany. The spatial resolution of the data differs from 3.75° longitude x 1.875° latitude (Thompson, 2021) to 3° longitude x 2° latitude for the methane data product (Seegers, Houweling and Tokaya, 2020). For the verification of the data three different inversion runs can be selected from the application programming interface of CAMS. These are based either on no additional input (time series from 1991 till 2020), surface air samples (time series from 1979-2020), spaceborne data (time series from 2015 onwards), or a combination of surface air samples (time series from 1979 to 2020) and spaceborne data (time series from 2009 to 2019). The longest time series option (surface air sample) was chosen, for the data comparison work presented here to enable the longest trend comparison possible for all three GHGs. Please note that the CAMS time series data for N_2O only starts from 1996 onwards whilst the comparisons for CO_2 and CH_4 use the full timespan from 1990 till 2018.

22.1.4.2.3 The Pollution Release and Transfer Register

The PRTR database is offered as an SQL-Database file at the domain thru.de by the Umweltbundesamt in Germany. It is comprised of reported data for large emission sources in Germany. The PRTR reporting is based on the European Union Regulation No 166/2006 on the establishment of a PRTR register. To access the PRTR database and extract annual data for the three GHGs a modified Python script was used, which is based on the PRTR reporting tool (Hausmann, Zagorski and Mielke, 2021). Figure 103 shows the data of the PRTR point sources reported in the PRTR database file to illustrate points of high point-source emission activity. Currently the database offers PRTR data from 2007 till 2018.

22.1.4.2.4 The European Emission Trade Data

The ETS database is hosted by the EEA (EEA/EuTL (2021)), which also provides a webtool for the display, download and analysis of the data. The data lists the different sectors, which are part of the ETS system, with their respective CO_2 emission equivalents. More details on the database and an in-depth analysis can be found in (Graichen, Cludius and Gores, 2019).

22.1.4.3 Analysis

The analysis of the data requires an overlapping time-period with the GHG totals of Germanys national inventory. Therefore, the time-period from 1990-2018 was considered as time frame for the comparisons considering the temporal coverage of the three comparison data sets. The available data was, where applicable (the CAMS and the PRTR data), plotted for a visual comparison shown in Figure 102 and Figure 103 to visually identify potential spatial patterns and to highlight the spatial density or sparsity of the data in question. The pearson and the spearman-rank correlation were computed for the individual temporal verification datasets to the national inventory data in the overlapping time periods visible in Figure 104. These two mathematical similarity measures were computed, in order to quantify the similarity between the temporal trends visible in Figure 104, for trend verification purposes. The results are shown in Table 579.

22.1.4.3.1 The EDGAR Inventory

EDGAR data was extracted from the national totals spread-sheets, offered as download from the JRC (Crippa et al., 2021). The national totals for Germany were converted to kt CO_2 equivalent for a better comparison of the data to the national inventory. For this the same GWP factors for CH_4 and NO_2 were used as in case of Germanys national inventory report (25 for methane and 298 for nitrous oxide). Figure 104Table 579 shows the EDGAR data in orange, whilst the national inventory data is plotted as thick blue line.

22.1.4.3.2 The CAMS Global Inversion-Optimized Greenhouse Gas Data

The CAMS inversion optimized GHG data was aggregated to the spatial scale of Germany using a spatial vector data file symbolizing the country area of Germany (Patterson and Kelso, 2022), which was intersected with the CAMS data, enabling the cropping of the data pixels. Then the equal earth projection (Šavrič, Patterson and Jenny, 2019) was used to calculate the area of each cell in-order to convert the CAMS flux data to mass per pixel and month. These were then summed up for all twelve months of the respective year to yield the total for the respective gas and year. The data is shown as green line in Figure 104.

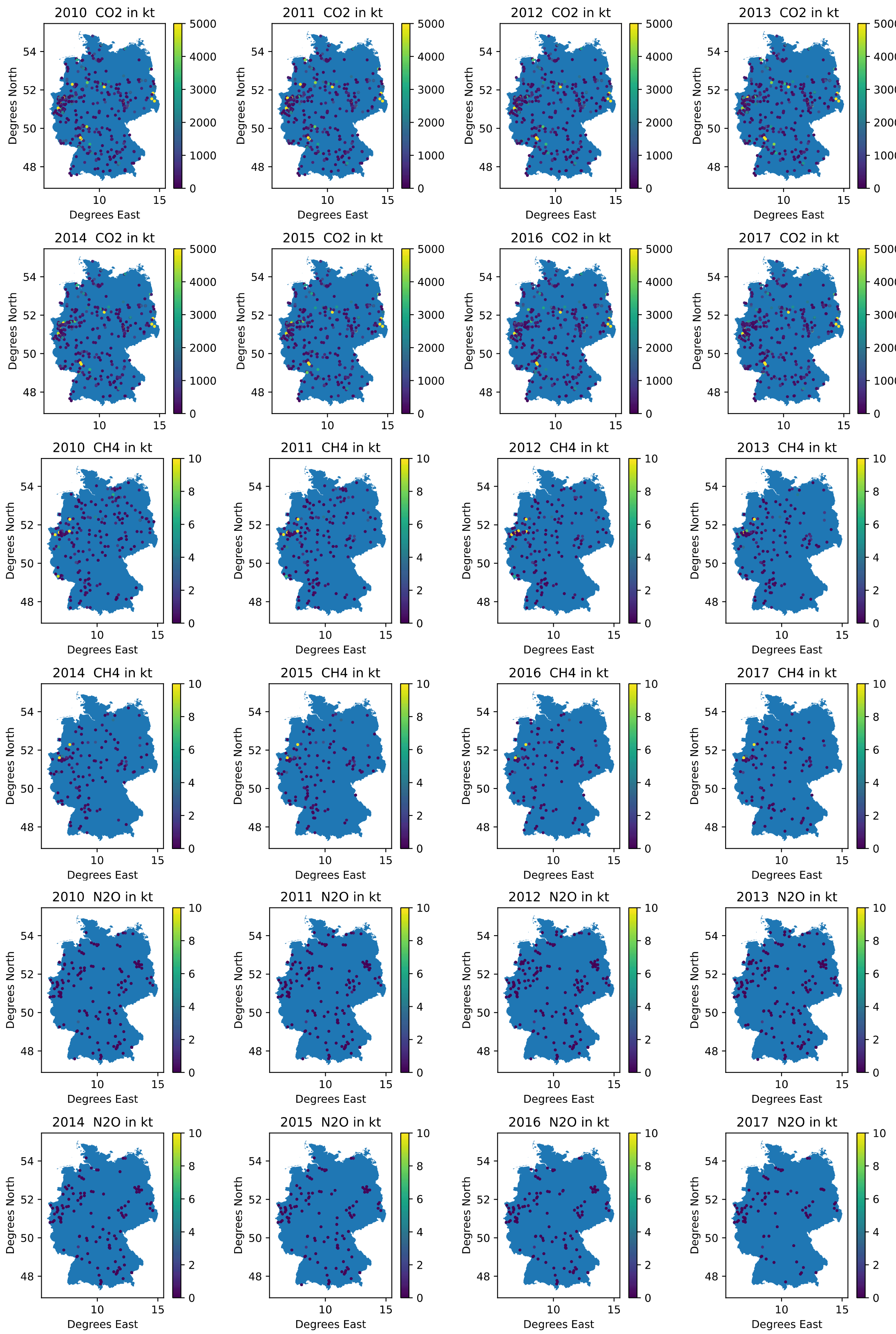
22.1.4.3.3 The Pollution Release and Transfer Register

The PRTR database was queried for data reported from large point-sources. These data contain the longitude and latitude coordinates of each point source, which offers the possibility of spatially displaying the data, as shown in Figure 103 for visualisation. The yearly sums, plotted as red line in Figure 104, were directly extracted from the database file.

22.1.4.3.4 The European Emission Trade Data

The data of the ETS system, hosted by the EEA (EEA, 2022), are filtered for the total verified Emissions of all sectors and plotted against the sum of N_2O and CO_2 of all the other datasets as shown in the leftmost bottom diagram of Figure 104. As data from the ETS system does not cover methane the ETS data is only compared to the sum of the respective gases CO_2 equivalent in Table 579.

Figure 103: Time Slice Emission data for Germany from the EPRTR data store



22.1.4.4 Results and Discussion

The trend data in Figure 104 shows very different patterns for each of the three GHG, which is also visible in Table 579. Overall the EDGAR data shows the highest trend similarity to the national GHG total with correlation scores above 0.9, whilst the CAMS data shows large similarity to the national CH_4 total only in case of CH_4 and CO_2. The biggest disagreement is between the CAMS N_2O trend and the national totals for N_2O with rather small correlation values for the pearson correlation and the spearman rank correlation.

Table 579: Correlation Scores for the three datasets to the German inventory totals

CO_2	PRTR	CAMS	EDGAR	ETS
Pearson	0.354	0.98	0.919	NaN
Spearman-Rank	-0.779	0.979	0.929	NaN
CH_4	**PRTR**	**CAMS**	**EDGAR**	**ETS**
Pearson	0.986	0.966	0.994	NaN
Spearman-Rank	0.986	0.933	0.999	NaN
N_2O	**PRTR**	**CAMS**	**EDGAR**	**ETS**
Pearson	0.984	-0.398	0.975	NaN
Spearman-Rank	0.475	-0.273	0.878	NaN
CO_2 and N_2O	**PRTR**	**CAMS**	**EDGAR**	**ETS**
Pearson	0.447	0.85	0.93	0.84
Spearman-Rank	0.22	0.81	0.97	0.79

22.1.4.4.1 The EDGAR Inventory

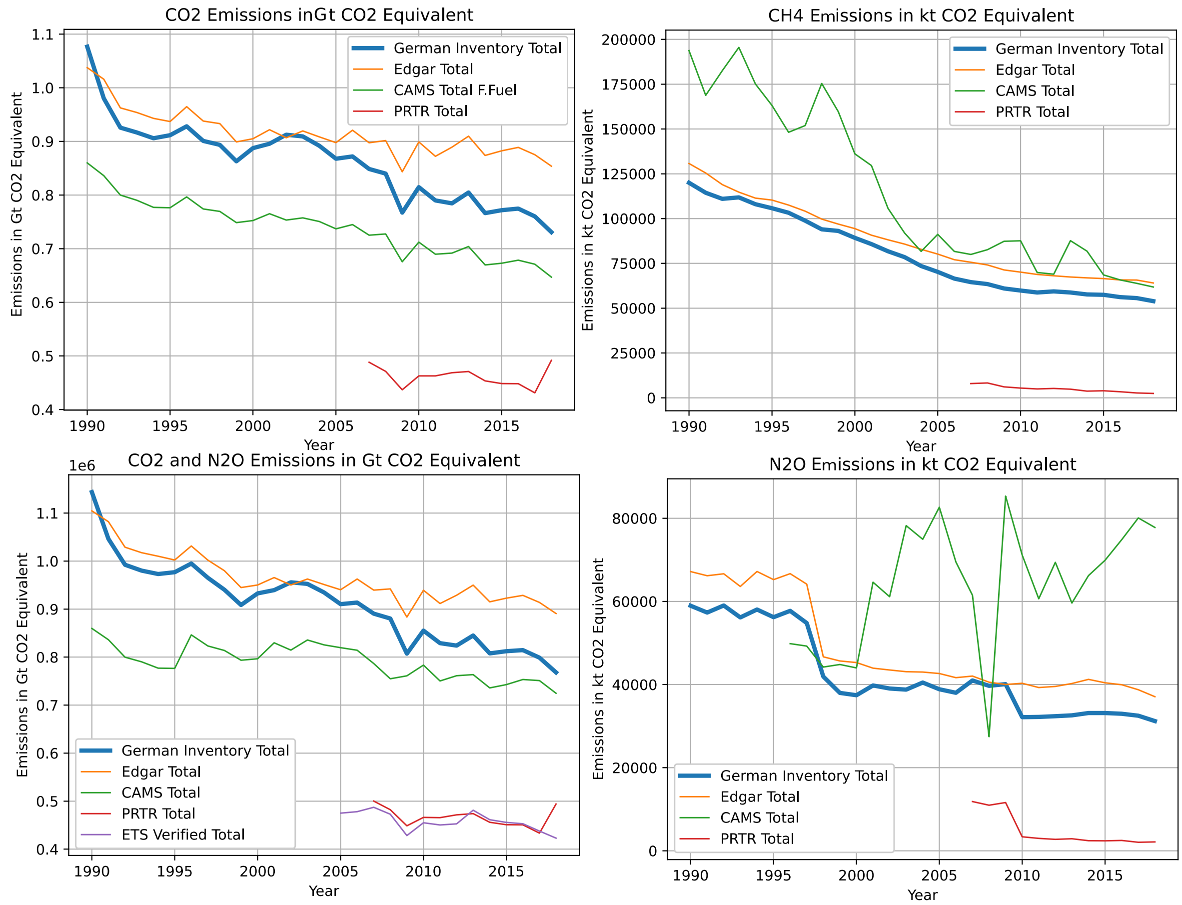
The EDGAR inventory usually is in good agreement with the national inventory data with high correlation values to the national inventory totals, as shown in Table 579 and as visible by the orange line, which is always in close agreement with the reported national totals (thick blue line) in Figure 104. Overall, the EDGAR data shows slightly higher emission values, which is to be expected if different data sources are used to compile a worldwide consistent emission database.

22.1.4.4.2 The CAMS Global Inversion-Optimized Greenhouse Gas Data

The CAMS inversion optimized datasets show anticorrelation for N_2O, with the trends shown in the green curve of Figure 104 not matching the general trend of the inventory data in blue or the EDGAR data in orange. In addition, temporal gradients are starkly amplified in the CAMS N_2O data, if compared to the inventory data. E.g. the dip during the financial crisis in Europe around 2008. The trend between the bottom-up inventories and CAMS data is in good agreement for CO_2 and CH_4 as shown in Figure 104, with correlation scores close to 0.99. Here the bottom-up inventories show an almost exactly the similar trend as the CAMS data, especially in case of the CO_2 CAMS data. This is remarkable considering the coarse spatial resolution of the CAMS data product and the research that is carried out to further refine CO_2 data modelling for inventory verification. Currently there are several big research projects underway to offer a consistent CO_2 monitoring system at a finer spatial and temporal resolution. Good examples are the European project COCO2, which will offer high quality CO_2 monitoring data over Europe. Methane data from CAMS, as shown in Figure 104, shows a good agreement of the trend to the inventory data, as also visible by the high correlation scores in Table 579. The green curve in Figure 104 is starting at higher emission values for the 1990s but is approaching EDGAR values in the early 2000s and is even showing close agreement to the national inventory data of Germany in the last years of the time series. N_2O data from CAMS shows a strong oscillation, if compared to the national inventory and EDGAR data. Therefore, anticorrelation values are rather seen in table

Table 579. Remarkable is the large dip around 2008, which shows a strong contrast in the data if compared to the bottom-up inventories.

Figure 104: Trend plots for CO_2 CH_4 and N_2O emission totals over the years 1990-2018



22.1.4.4.3 The Pollution Release and Transfer Register

The PRTR data matches the trends of the reported national GHG gases quite well, as highlighted in Table 579. Here we see quite consistent correlation scores for methane and nitrous oxides. The low correlation values for CO_2 are due to an increase in CO_2 emissions in the PRTR data, compared to the overall decline of CO_2 in the national totals. The strong decline in the nitrous oxides of the national totals is mirrored by the PRTR data, showing the stop of N_2O emissions from large point sources represented by the PRTR database.

22.1.4.4.4 The European Emission Trade Data

The data from the ETS verified totals for Germany fits quite well to the overall trends in the inventory data with correlation scores around 0.8 for both spearman-rank and pearson correlations as shown in Table 579. This shows that the temporal trend of the combined N_2O and CO_2 emissions of Germanys national inventory is in agreement with the external ETS data.

22.2 Supplementary information as required pursuant to Article 7 (1) of the Kyoto Protocol

22.2.1 KP-LULUCF

The CRF tables are reported separately.

22.2.2 Standard Electronic Format (SEF) Tables

22.2.2.1 Standard Electronic Format for the reported year 2020 (Commitment Period 2)

Report type	RREG1
Registry	DE
Reported year	2021
Submission year	2022
CP	2
Version	1
Status	FINAL
Validity	VALID

Party	Germany
Submission year	2022
Reported year	2021
Commitment period	2

Table 1. Total quantities of Kyoto Protocol units by account type at beginning of reported year

	Account type	Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Party holding accounts	NO	NO	NO	4.269.200	NO	NO
2	Entity holding accounts	NO	30.612	NO	1.702.300	NO	NO
3	Retirement account	NO	NO	NO	NO	NO	NO
4	Previous period surplus reserve account	NO					
5	Article 3.3/3.4 net source cancellation accounts	NO	NO	NO	NO		
6	Non-compliance cancellation account	NO	NO	NO	NO		
7	Voluntary cancellation account	NO	NO	NO	9.071.153	NO	NO
8	Cancellation account for remaining units after carry-over	NO	NO	NO	NO	NO	NO
9	Article 3.1 ter and quater ambition increase cancellation account	NO					
10	Article 3.7 ter cancellation account	NO					
11	tCER cancellation account for expiry					NO	
12	lCER cancellation account for expiry						NO
13	lCER cancellation account for reversal of storage						NO
14	lCER cancellation account for non-submission of certification report						NO
15	tCER replacement account for expiry	NO	NO	NO	NO	NO	
16	lCER replacement account for expiry	NO	NO	NO	NO		
17	lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
18	lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
	Total	NO	30.612	NO	15.042.653	NO	NO

Party	Germany
Submission year	2022
Reported year	2021
Commitment period	2

Table 2 (a). Annual internal transactions

	Transaction type	Additions						Subtractions					
		Unit type						Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
	Article 6 issuance and conversion												
1	Party-verified projects		NO					NO		NO			
2	Independently verified projects		NO					NO		NO			
	Article 3.3 and 3.4 issuance or cancellation												
3	3.3 Afforestation and reforestation			NO				NO	NO	NO	NO		
4	3.3 Deforestation			NO				NO	NO	NO	NO		
5	3.4 Forest management			NO				NO	NO	NO	NO		
6	3.4 Cropland management			NO				NO	NO	NO	NO		
7	3.4 Grazing land management			NO				NO	NO	NO	NO		
8	3.4 Revegetation			NO				NO	NO	NO	NO		
9	3.4 Wetlands drainage and management			NO				NO	NO	NO	NO		
	Article 12 afforestation and reforestation												
10	Replacement of expired tCERs							NO	NO	NO	NO	NO	
11	Replacement of expired lCERs							NO	NO	NO	NO		
12	Replacement for reversal of storage							NO	NO	NO	NO		NO
13	Cancellation for reversal of storage												NO
14	Replacement for non-submission of certification report							NO	NO	NO	NO		NO
15	Cancellation for non-submission of certification report												NO
	Other cancelation												
16	Voluntary cancellation							NO	NO	NO	3.245.865	NO	NO
17	Article 3.1 ter and quater ambition increase cancellation							NO					
	Sub-total		NO	NO				NO	NO	NO	3.245.865	NO	NO

	Transaction type	Retirement					
		Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Retirement	NO	NO	NO	NO	NO	NO
2	Retirement from PPSR	NO					
	Total	NO	NO	NO	NO	NO	NO

Party	Germany
Submission year	2022
Reported year	2021
Commitment period	2

Table 2 (b). Total annual external transactions

		Additions						Subtractions					
		Unit type						Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
	Total transfers and acquisitions												
1	AU	NO	NO	NO	605.571	NO	NO	NO	NO	NO	688.613	NO	NO
2	CDM	NO	NO	NO	14.829.382	NO	NO	NO	NO	NO	NO	NO	NO
3	CH	NO	NO	NO	570.050	NO	NO	NO	NO	NO	4.701.981	NO	NO
4	ES	NO	NO	NO	658.600	NO	NO	NO	2.200	NO	11.363	NO	NO
5	EU	NO	NO	NO	3.473.439	NO	NO	NO	NO	NO	1.546.023	NO	NO
6	GB	NO	NO	NO	37.732	NO	NO	NO	NO	NO	NO	NO	NO
7	NL	NO	NO	NO	1.676.504	NO	NO	NO	NO	NO	3.306.844	NO	NO
8	NO	NO	NO	NO	30.429	NO	NO	NO	NO	NO	12.000	NO	NO
9	SE	NO	NO	NO	21.566	NO	NO	NO	NO	NO	3.416	NO	NO
10	SI	NO	NO	NO	1.510.000	NO	NO	NO	NO	NO	1.605.699	NO	NO
11	FR	NO	NO	NO	NO	NO	NO	NO	NO	NO	1.200.087	NO	NO
12	MT	NO	NO	NO	NO	NO	NO	NO	NO	NO	155	NO	NO
	Sub-total	NO	NO	NO	23.413.273	NO	NO	NO	2.200	NO	13.076.181	NO	NO

Table 2 (c). Annual transactions between PPSR accounts

		Additions						Subtractions					
		Unit type						Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
	Transfers and acquisitions between PPSR accounts												
	Sub-total	NO						NO					

Table 2 (d). Share of proceeds transactions under decision 1/CMP.8, paragraph 21 - Adaptation fund

		Amount transferred or converted						Amount contributed as SoP to the adaptation fund					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	First international transfers of AAUs	NO						NO					
2	Issuance of ERU from party-verified projects		NO						NO				
3	Issuance of independently verified ERUs		NO						NO				

Table 2 (e). Total annual transactions

1	**Total (Sum of sub-totals in table 2a and table 2b)**	NO	NO	NO	23.413.273	NO	NO	NO	2.200	NO	16.322.046	NO	NO

Party	Germany
Submission year	2022
Reported year	2021
Commitment period	2

Table 3. Annual expiry, cancellation and replacement

	Transaction or event type	Requirement to replace or cancel			Replacement						Cancellation					
		Unit type			Unit type						Unit type					
		tCERs	lCERs	CERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
	Temporary CERs															
1	Expired in retirement and replacement accounts	NO			NO	NO	NO	NO	NO							
2	Expired in holding accounts	NO													NO	
	Long-term CERs															
3	Expired in retirement and replacement accounts		NO		NO	NO	NO	NO								
4	Expired in holding accounts		NO													NO
5	Subject to reversal of storage		NO		NO	NO	NO	NO		NO						NO
6	Subject to non-submission of certification Report		NO		NO	NO	NO	NO		NO						NO
	Carbon Capture and Storage CERs															
7	Subject to net reversal of storage			NO							NO	NO	NO	NO		
8	Subject to non-submission of certification report			NO							NO	NO	NO	NO		
	Total	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Party	Germany
Submission year	2022
Reported year	2021
Commitment period	2

Table 4. Total quantities of Kyoto Protocol units by account type at end of reported year

	Account type	Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Party holding accounts	3.592.699.888	NO	NO	4.269.200	NO	NO
2	Entity holding accounts	NO	28.412	NO	8.793.527	NO	NO
3	Retirement account	NO	NO	NO	NO	NO	NO
4	Previous period surplus reserve account	NO					
5	Article 3.3/3.4 net source cancellation accounts	NO	NO	NO	NO		
6	Non-compliance cancellation account	NO	NO	NO	NO		
7	Voluntary cancellation account	NO	NO	NO	12.317.018	NO	NO
8	Cancellation account for remaining units after carry-over	NO	NO	NO	NO	NO	NO
9	Article 3.1 ter and quater ambition increase cancellation account	NO					
10	Article 3.7 ter cancellation account	NO					
11	tCER cancellation account for expiry					NO	
12	lCER cancellation account for expiry						NO
13	lCER cancellation account for reversal of storage						NO
14	lCER cancellation account for non-submission of certification report						NO
15	tCER replacement account for expiry	NO	NO	NO	NO	NO	
16	lCER replacement account for expiry	NO	NO	NO	NO		
17	lCER replacement account for reversal of storage	NO	NO	NO	NO		NO
18	lCER replacement account for non-submission of certification report	NO	NO	NO	NO		NO
	Total	3.592.699.888	28.412	NO	25.379.745	NO	NO

Party	Germany
Submission year	2022
Reported year	2021
Commitment period	2

Table 5 (a). Summary information on additions and subtractions

		Additions						Subtractions					
		Unit type						Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Assigned amount units issued	3.592.699.888											
2	Article 3 paragraph 7 ter cancellations							NO					
3	Cancellation following increase in ambition							NO					
4	Cancellation of remaining units after carry over							NO	NO	NO	NO	NO	NO
5	Non-compliance cancellation							NO	NO	NO	NO		
6	Carry-over		NO		NO				NO		NO		
7	Carry-over to PPSR	NO						NO					
	Total	3.592.699.888	NO		NO			NO	NO	NO	NO	NO	NO

Table 5 (b). Summary information on annual transactions

		Additions						Subtractions					
		Unit type						Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Year 1 (2013)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2	Year 2 (2014)	NO	NO	NO	1.761.325	NO	NO	NO	NO	NO	151.074	NO	NO
3	Year 3 (2015)	NO	NO	NO	4.556.137	NO	NO	NO	NO	NO	5.639.465	NO	NO
4	Year 4 (2016)	NO	NO	NO	2.367.730	NO	NO	NO	NO	NO	2.351.699	NO	NO
5	Year 5 (2017)	NO	28.999	NO	3.763.731	NO	NO	NO	NO	NO	2.737.210	NO	NO
6	Year 6 (2018)	NO	1	NO	7.368.752	NO	NO	NO	NO	NO	4.784.889	NO	NO
7	Year 7 (2019)	NO	1.612	NO	12.538.235	NO	NO	NO	NO	NO	10.316.344	NO	NO
8	Year 8 (2020)	NO	NO	NO	17.953.086	NO	NO	NO	NO	NO	18.356.815	NO	NO
9	Year 2021	NO	NO	NO	23.413.273	NO	NO	NO	2.200	NO	16.322.046	NO	NO
10	Year 2022	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
11	Year 2023	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	Total	NO	30.612	NO	73.722.269	NO	NO	NO	2.200	NO	60.659.542	NO	NO

Table 5 (c). Summary information on annual transactions between PPSR accounts

		Additions						Subtractions					
		Unit type						Unit type					
		AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Year 1 (2013)	NO						NO					
2	Year 2 (2014)	NO						NO					
3	Year 3 (2015)	NO						NO					
4	Year 4 (2016)	NO						NO					
5	Year 5 (2017)	NO						NO					
6	Year 6 (2018)	NO						NO					
7	Year 7 (2019)	NO						NO					
8	Year 8 (2020)	NO						NO					
9	Year 2021	NO						NO					
10	Year 2022	NO						NO					
11	Year 2023	NO						NO					
	Total	NO						NO					

Table 5 (d). Summary information on expiry, cancellation and replacement

		Requirement to replace or cancel			Replacement						Cancellation					
		Unit type			Unit type						Unit type					
		tCERs	lCERs	CERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Year 1 (2013)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2	Year 2 (2014)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3	Year 3 (2015)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4	Year 4 (2016)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
5	Year 5 (2017)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
6	Year 6 (2018)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
7	Year 7 (2019)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
8	Year 8 (2020)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
9	Year 2021	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
10	Year 2022	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
11	Year 2023	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	Total	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

Table 5 (e). Summary information on retirement

		Retirement					
		Unit type					
	Year	AAUs	ERUs	RMUs	CERs	tCERs	lCERs
1	Year 1 (2013)	NO	NO	NO	NO	NO	NO
2	Year 2 (2014)	NO	NO	NO	NO	NO	NO
3	Year 3 (2015)	NO	NO	NO	NO	NO	NO
4	Year 4 (2016)	NO	NO	NO	NO	NO	NO
5	Year 5 (2017)	NO	NO	NO	NO	NO	NO
6	Year 6 (2018)	NO	NO	NO	NO	NO	NO
7	Year 7 (2019)	NO	NO	NO	NO	NO	NO
8	Year 8 (2020)	NO	NO	NO	NO	NO	NO
9	Year 2021	NO	NO	NO	NO	NO	NO
10	Year 2022	NO	NO	NO	NO	NO	NO
11	Year 2023	NO	NO	NO	NO	NO	NO
	Total	NO	NO	NO	NO	NO	NO

Party	Germany
Submission year	2022
Reported year	2021
Commitment period	2

Table 6 (a). Memo item: Corrective transactions relating to additions and subtractions

	Additions						Subtractions					
	Unit type						Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs

Table 6 (b). Memo item: Corrective transactions relating to replacement

	Requirement for replacement		Replacement					
	Unit type		Unit type					
	tCERs	lCERs	AAUs	ERUs	RMUs	CERs	tCERs	lCERs

Table 6 (c). Memo item: Corrective transactions relating to retirement

	Retirement					
	Unit type					
	AAUs	ERUs	RMUs	CERs	tCERs	lCERs

22.2.2.2 Discrepant transactions

No discrepant transactions occurred in 2021.

22.2.3 Detailed information about the National System, and about changes within the National System

All of this information has been provided in the preceding chapters.

22.2.4 Further detailed information about the National Registries and about accounting of Kyoto units

The required documents are confidential and accessible for assessors only.

22.3 Additional information about greenhouse-gas trends

Here, we provide the detailed tables relative to the trend discussion presented in Chapters 0.2 and 1.

Table 580: Emissions trends in Germany, by greenhouse gas and category

GHG emissions / sinks, in CO_2 equivalents (kt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CO_2 emissions (without LULUCF)	**1,051,979**	**1,013,824**	**965,542**	**955,820**	**939,492**	**938,614**	**958,700**	**930,870**	**922,812**	**895,352**	**899,352**	**916,144**	**899,450**	**900,628**	**886,637**
Net CO_2 emissions/removals	1,076,570	980,147	925,747	916,569	905,828	911,628	928,195	900,956	893,700	862,890	887,392	895,674	912,355	909,298	891,763
CH_4 (with LULUCF)	**118,555**	**112,965**	**109,571**	**110,368**	**106,615**	**104,350**	**101,812**	**97,433**	**92,585**	**91,717**	**87,798**	**84,298**	**80,305**	**76,954**	**71,989**
CH_4 (without LULUCF)	119,996	114,403	111,026	111,808	108,053	105,785	103,250	98,867	94,018	93,150	89,232	85,756	81,791	78,476	73,543
N_2O (with LULUCF)	**57,989**	**56,342**	**58,034**	**55,169**	**57,079**	**55,250**	**56,762**	**53,827**	**40,978**	**37,054**	**36,483**	**38,530**	**37,767**	**37,496**	**39,154**
N_2O (without LULUCF)	58,960	57,326	59,025	56,146	58,050	56,211	57,721	54,780	41,926	37,993	37,419	39,763	39,032	38,789	40,475
F gases, total	**13,395**	**12,835**	**13,307**	**16,094**	**16,496**	**17,092**	**16,089**	**16,284**	**16,803**	**15,077**	**13,293**	**14,027**	**14,151**	**13,548**	**13,988**
Total emissions, without LULUCF	**1,241,919**	**1,195,966**	**1,146,454**	**1,137,451**	**1,119,682**	**1,115,305**	**1,133,363**	**1,098,413**	**1,073,178**	**1,039,200**	**1,036,926**	**1,052,999**	**1,031,673**	**1,028,626**	**1,011,769**
Total emissions / removals, with LULUCF	1,268,922	1,164,710	1,109,105	1,100,617	1,088,427	1,090,716	1,105,255	1,070,886	1,046,448	1,009,111	1,027,337	1,035,220	1,047,329	1,040,111	1,019,768

GHG emissions / sinks, in CO_2 equivalents (kt)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO_2 emissions (without LULUCF)	**866,303**	**877,939**	**851,223**	**854,508**	**789,900**	**832,541**	**808,912**	**813,693**	**831,208**	**792,255**	**795,557**	**800,340**	**785,616**	**754,408**	**707,150**
Net CO_2 emissions/removals	867,709	871,894	848,510	839,901	767,094	814,811	789,854	784,512	804,688	766,386	771,823	774,608	760,212	730,929	688,886
CH_4 (with LULUCF)	**68,701**	**64,914**	**62,899**	**61,777**	**59,335**	**58,140**	**57,051**	**57,597**	**56,966**	**55,847**	**55,627**	**54,366**	**53,798**	**52,007**	**49,944**
CH_4 (without LULUCF)	70,292	66,532	64,543	63,450	61,037	59,867	58,792	59,355	58,741	57,639	57,438	56,186	55,629	53,953	51,814
N_2O (with LULUCF)	**37,522**	**36,769**	**39,709**	**38,418**	**38,817**	**30,841**	**30,855**	**31,001**	**31,172**	**31,705**	**31,655**	**31,521**	**31,028**	**29,716**	**28,948**
N_2O (without LULUCF)	38,873	38,021	40,969	39,695	40,110	32,150	32,195	32,376	32,582	33,152	33,142	32,967	32,489	31,199	30,450
F gases, total	**14,184**	**14,117**	**14,209**	**14,232**	**14,689**	**14,246**	**14,426**	**14,609**	**14,642**	**14,657**	**15,116**	**15,215**	**15,288**	**14,411**	**13,692**
Total emissions, without LULUCF	**986,709**	**993,739**	**968,040**	**968,935**	**902,742**	**935,768**	**911,244**	**916,901**	**933,987**	**894,465**	**897,954**	**901,442**	**885,729**	**850,542**	**799,734**
Total emissions / removals, with LULUCF	991,058	990,565	968,231	957,277	882,931	921,074	895,267	890,853	910,653	871,834	877,519	878,975	863,618	830,492	784,842

GHG emissions / sinks, in CO_2 equivalents (kt)	2020
CO_2 emissions (without LULUCF)	**639,381**
Net CO_2 emissions/removals	624,731
CH_4 (with LULUCF)	**49,015**
CH_4 (without LULUCF)	50,889
N_2O (with LULUCF)	**28,182**
N_2O (without LULUCF)	29,694
F gases, total	**12,159**
Total emissions, without LULUCF	**728,738**
Total emissions / removals, with LULUCF	717,473

GHG emissions / sinks, by source and sink categories, in CO_2 equivalents (kt)	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
1. Energy	**1,036,444**	**999,444**	**950,536**	**941,487**	**919,035**	**917,379**	**938,271**	**906,869**	**897,143**	**872,657**	**869,647**	**890,067**	**873,670**	**868,846**	**852,116**
2. Industrial processes	**96,891**	**93,168**	**93,393**	**94,580**	**100,355**	**98,600**	**96,661**	**96,933**	**83,088**	**75,009**	**77,895**	**74,533**	**73,115**	**76,980**	**78,882**
3. Agriculture	**70,581**	**63,953**	**62,532**	**61,558**	**61,253**	**61,252**	**61,798**	**60,910**	**61,373**	**61,589**	**60,997**	**61,673**	**59,542**	**58,961**	**58,233**
4. Land use, land-use changes & forestry	**27,003**	**-31,256**	**-37,350**	**-36,834**	**-31,255**	**-24,590**	**-28,108**	**-27,527**	**-26,730**	**-30,090**	**-9,589**	**-17,780**	**15,656**	**11,485**	**7,999**
CO_2	24,591	-33,677	-39,795	-39,251	-33,664	-26,986	-30,505	-29,914	-29,112	-32,462	-11,959	-20,471	12,905	8,670	5,126
N_2O & CH_4	2,412	2,422	2,445	2,417	2,410	2,396	2,397	2,387	2,382	2,373	2,370	2,691	2,751	2,815	2,874
5. Waste	**38,003**	**39,402**	**39,994**	**39,827**	**39,040**	**38,074**	**36,633**	**33,701**	**31,574**	**29,944**	**28,388**	**26,727**	**25,345**	**23,839**	**22,538**

GHG emissions / sinks, by source and sink categories, in CO_2 equivalents (kt)	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
1. Energy	**831,839**	**841,629**	**815,512**	**821,054**	**763,153**	**800,987**	**777,237**	**783,914**	**801,247**	**761,165**	**766,393**	**768,977**	**750,503**	**720,389**	**673,836**
2. Industrial processes	**75,602**	**75,767**	**76,938**	**73,193**	**65,758**	**62,559**	**62,485**	**61,569**	**61,319**	**61,194**	**60,229**	**62,076**	**65,933**	**62,967**	**59,790**
3. Agriculture	**58,081**	**56,994**	**57,549**	**57,877**	**58,243**	**57,761**	**57,844**	**58,511**	**59,271**	**60,547**	**60,388**	**59,993**	**59,311**	**57,634**	**56,912**
4. Land use, land-use changes & forestry	**4,348**	**-3,174**	**192**	**-11,658**	**-19,811**	**-14,694**	**-15,976**	**-26,048**	**-23,334**	**-22,631**	**-20,435**	**-22,467**	**-22,111**	**-20,050**	**-14,892**
CO_2	1,406	-6,045	-2,713	-14,607	-22,806	-17,730	-19,058	-29,181	-26,520	-25,870	-23,733	-25,732	-25,404	-23,479	-18,264
N_2O & CH_4	2,942	2,871	2,905	2,950	2,994	3,036	3,081	3,133	3,185	3,239	3,298	3,266	3,293	3,430	3,372
5. Waste	**21,188**	**19,349**	**18,041**	**16,811**	**15,589**	**14,461**	**13,677**	**12,907**	**12,150**	**11,558**	**10,943**	**10,396**	**9,982**	**9,552**	**9,196**

GHG emissions / sinks, by source and sink categories, in CO_2 equivalents (kt)	**2020**
1. Energy	**608,399**
2. Industrial processes	**55,473**
3. Agriculture	**56,095**
4. Land use, land-use changes & forestry	**-11,265**
CO_2	-14,650
N_2O & CH_4	3,385
5. Waste	**8,770**

Table 581: Contributions to emissions trends in Germany, by greenhouse gas and category

GHG emissions / sinks; shares for greenhouse gases* (%)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CO_2 emissions*	84.71	84.77	84.22	84.03	83.91	84.16	84.59	84.75	85.99	86.16	86.73	87.00	87.18	87.56	87.63	87.80	88.35	87.93	88.19	87.50	88.97	88.77	88.74	89.00	88.57	88.60	88.78	88.70	88.70	88.42	87.74
CH_4*	9.55	9.45	9.56	9.70	9.52	9.36	8.98	8.87	8.63	8.83	8.47	8.01	7.78	7.48	7.12	6.96	6.53	6.50	6.38	6.57	6.21	6.26	6.28	6.10	6.24	6.19	6.03	6.07	6.11	6.25	6.73
N_2O*	4.67	4.71	5.06	4.85	5.10	4.95	5.01	4.90	3.82	3.57	3.52	3.66	3.66	3.65	3.87	3.80	3.70	4.10	3.96	4.30	3.30	3.39	3.38	3.34	3.54	3.53	3.50	3.50	3.49	3.62	3.87
F gases, total	1.08	1.07	1.16	1.41	1.47	1.53	1.42	1.48	1.57	1.45	1.28	1.33	1.37	1.32	1.38	1.44	1.42	1.47	1.47	1.63	1.52	1.58	1.59	1.57	1.64	1.68	1.69	1.73	1.69	1.71	1.67
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

GHG emissions / sinks; shares for categories* (%)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1. Energy	83.46	83.57	82.91	82.77	82.08	82.25	82.79	82.56	83.60	83.97	83.87	84.53	84.68	84.47	84.22	84.30	84.69	84.24	84.74	84.54	85.60	85.29	85.50	85.79	85.10	85.35	85.31	84.73	84.70	84.26	83.49
2. Industrial processes	7.80	7.79	8.15	8.32	8.96	8.84	8.53	8.82	7.74	7.22	7.51	7.08	7.09	7.48	7.80	7.66	7.62	7.95	7.55	7.28	6.69	6.86	6.71	6.57	6.84	6.71	6.89	7.44	7.40	7.48	7.61
4. Agriculture	5.68	5.35	5.45	5.41	5.47	5.49	5.45	5.55	5.72	5.93	5.88	5.86	5.77	5.73	5.76	5.89	5.74	5.94	5.97	6.45	6.17	6.35	6.38	6.35	6.77	6.73	6.66	6.70	6.78	7.12	7.70
5. Waste	3.06	3.29	3.49	3.50	3.49	3.41	3.23	3.07	2.94	2.88	2.74	2.54	2.46	2.32	2.23	2.15	1.95	1.86	1.73	1.73	1.55	1.50	1.41	1.30	1.29	1.22	1.15	1.13	1.12	1.15	1.20
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

* Not including emissions from Land Use, Land Use Change and Forestry (LULUCF).

Table 582: Emissions of direct and indirect greenhouse gases and SO_2 in Germany since 1990

Emissions development (kt)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CO_2 emissions (without LULUCF)	**1,051,979**	**1,013,824**	**965,542**	**955,820**	**939,492**	**938,614**	**958,700**	**930,870**	**922,812**	**895,352**	**899,352**	**916,144**	**899,450**	**900,628**	**886,637**
Net CO_2 emissions / removals	1,076,570	980,147	925,747	916,569	905,828	911,628	928,195	900,956	893,700	862,890	887,392	895,674	912,355	909,298	891,763
CH_4 (without LULUCF)	**4,742**	**4,519**	**4,383**	**4,415**	**4,265**	**4,174**	**4,072**	**3,897**	**3,703**	**3,669**	**3,512**	**3,372**	**3,212**	**3,078**	**2,880**
CH_4 (with LULUCF)	4,800	4,576	4,441	4,472	4,322	4,231	4,130	3,955	3,761	3,726	3,569	3,430	3,272	3,139	2,942
N_2O (without LULUCF)	**195**	**189**	**195**	**185**	**192**	**185**	**190**	**181**	**138**	**124**	**122**	**129**	**127**	**126**	**131**
N_2O (with LULUCF)	198	192	198	188	195	189	194	184	141	127	126	133	131	130	136
F gases, total (CO_2-equivalents)	**13,395**	**12,835**	**13,307**	**16,094**	**16,496**	**17,092**	**16,089**	**16,284**	**16,803**	**15,077**	**13,293**	**14,027**	**14,151**	**13,548**	**13,988**
NO_x	**2,839**	**2,618**	**2,472**	**2,371**	**2,244**	**2,186**	**2,104**	**2,031**	**2,003**	**1,969**	**1,893**	**1,837**	**1,775**	**1,729**	**1,682**
SO_2	**5,460**	**3,964**	**3,237**	**2,902**	**2,416**	**1,742**	**1,476**	**1,225**	**977**	**798**	**643**	**622**	**559**	**531**	**491**
NMVOC	**3,892**	**3,380**	**3,067**	**2,884**	**2,469**	**2,342**	**2,244**	**2,190**	**2,133**	**1,971**	**1,806**	**1,711**	**1,619**	**1,538**	**1,535**
CO	**13,081**	**10,840**	**9,345**	**8,454**	**7,451**	**7,100**	**6,542**	**6,313**	**5,810**	**5,407**	**5,084**	**4,892**	**4,597**	**4,273**	**4,061**

Emissions development (kt)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO_2 emissions (without LULUCF)	**866,303**	**877,939**	**851,223**	**854,508**	**789,900**	**832,541**	**808,912**	**813,693**	**831,208**	**792,255**	**795,557**	**800,340**	**785,616**	**754,408**	**707,150**
Net CO_2 emissions / removals	867,709	871,894	848,510	839,901	767,094	814,811	789,854	784,512	804,688	766,386	771,823	774,608	760,212	730,929	688,886
CH_4 (without LULUCF)	**2,748**	**2,597**	**2,516**	**2,471**	**2,373**	**2,326**	**2,282**	**2,304**	**2,279**	**2,234**	**2,225**	**2,175**	**2,152**	**2,080**	**1,998**
CH_4 (with LULUCF)	2,812	2,661	2,582	2,538	2,441	2,395	2,352	2,374	2,350	2,306	2,298	2,247	2,225	2,158	2,073
N_2O (without LULUCF)	**126**	**123**	**133**	**129**	**130**	**103**	**104**	**104**	**105**	**106**	**106**	**106**	**104**	**100**	**97**
N_2O (with LULUCF)	130	128	137	133	135	108	108	109	109	111	111	111	109	105	102
F gases, total (CO_2-equivalents)	**14,184**	**14,117**	**14,209**	**14,232**	**14,689**	**14,246**	**14,426**	**14,609**	**14,642**	**14,657**	**15,116**	**15,215**	**15,288**	**14,411**	**13,692**
NO_x	**1,632**	**1,641**	**1,591**	**1,528**	**1,433**	**1,445**	**1,419**	**1,411**	**1,410**	**1,365**	**1,342**	**1,315**	**1,264**	**1,179**	**1,106**
SO_2	**473**	**474**	**457**	**450**	**392**	**403**	**387**	**368**	**357**	**335**	**334**	**309**	**301**	**289**	**259**
NMVOC	**1,487**	**1,484**	**1,421**	**1,359**	**1,245**	**1,362**	**1,272**	**1,257**	**1,212**	**1,174**	**1,147**	**1,141**	**1,145**	**1,099**	**1,072**
CO	**3,837**	**3,809**	**3,770**	**3,748**	**3,207**	**3,513**	**3,429**	**3,175**	**3,134**	**2,965**	**3,069**	**2,946**	**2,961**	**2,852**	**2,753**

Emissions development (kt)	2020
CO_2 emissions (without LULUCF)	**639,381**
Net CO_2 emissions / removals	624,731
CH_4 (without LULUCF)	**1,961**
CH_4 (with LULUCF)	2,036
N_2O (without LULUCF)	**95**
N_2O (with LULUCF)	100
F gases, total (CO_2-equivalents)	**12,159**
NO_x	**978**
SO_2	**233**
NMVOC	**1,036**
CO	**2,455**

Table 583: Changes in emissions of direct and indirect greenhouse gases and SO_2 in Germany, since 1990/1995

Emissions trend Trend with respect to 1990/1995 (%)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CO_2 emissions (without LULUCF)		**-3.6**	**-8.2**	**-9.1**	**-10.7**	**-10.8**	**-8.9**	**-11.5**	**-12.3**	**-14.9**	**-14.5**	**-12.9**	**-14.5**	**-14.4**	**-15.7**
Net CO_2 emissions / removals		-9.0	-14.0	-14.9	-15.9	-15.3	-13.8	-16.3	-17.0	-19.8	-17.6	-16.8	-15.3	-15.5	-17.2
CH_4 (without LULUCF)		**-4.7**	**-7.6**	**-6.9**	**-10.1**	**-12.0**	**-14.1**	**-17.8**	**-21.9**	**-22.6**	**-25.9**	**-28.9**	**-32.3**	**-35.1**	**-39.3**
N_2O (without LULUCF)		**-2.8**	**+0.1**	**-4.9**	**-1.6**	**-4.7**	**-2.1**	**-7.2**	**-29.3**	**-36.1**	**-37.1**	**-33.6**	**-34.9**	**-35.3**	**-32.5**
F gases, total							**-5.9**	**-4.7**	**-1.7**	**-11.8**	**-22.2**	**-17.9**	**-17.2**	**-20.7**	**-18.2**
Total emissions, without LULUCF		**-3.7**	**-7.7**	**-8.4**	**-9.8**	**-10.2**	**-8.7**	**-11.6**	**-13.6**	**-16.3**	**-16.5**	**-15.2**	**-16.9**	**-17.2**	**-18.5**
Total emissions / removals, with LULUCF		-8.2	-12.6	-13.3	-14.2	-14.0	-12.9	-15.6	-17.5	-20.5	-19.0	-18.4	-17.5	-18.0	-19.6
Total emissions, without LULUCF, with respect to base year*		*-4.0*	*-8.0*	*-8.7*	*-10.1*	*-10.5*	*-9.0*	*-11.8*	*-13.8*	*-16.6*	*-16.8*	*-15.5*	*-17.2*	*-17.4*	*-18.8*
NO_x		**-7.8**	**-12.9**	**-16.5**	**-21.0**	**-23.0**	**-25.9**	**-28.5**	**-29.4**	**-30.6**	**-33.3**	**-35.3**	**-37.5**	**-39.1**	**-40.8**
SO_2		**-27.4**	**-40.7**	**-46.9**	**-55.7**	**-68.1**	**-73.0**	**-77.6**	**-82.1**	**-85.4**	**-88.2**	**-88.6**	**-89.8**	**-90.3**	**-91.0**
NMVOC		**-13.1**	**-21.2**	**-25.9**	**-36.6**	**-39.8**	**-42.3**	**-43.7**	**-45.2**	**-49.4**	**-53.6**	**-56.0**	**-58.4**	**-60.5**	**-60.6**
CO		**-17.1**	**-28.6**	**-35.4**	**-43.0**	**-45.7**	**-50.0**	**-51.7**	**-55.6**	**-58.7**	**-61.1**	**-62.6**	**-64.9**	**-67.3**	**-69.0**

Emissions trend Trend with respect to 1990/1995 (%)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO_2 emissions (without LULUCF)	**-17.7**	**-16.5**	**-19.1**	**-18.8**	**-24.9**	**-20.9**	**-23.1**	**-22.7**	**-21.0**	**-24.7**	**-24.4**	**-23.9**	**-25.3**	**-28.3**	**-32.8**
Net CO_2 emissions / removals	-19.4	-19.0	-21.2	-22.0	-28.7	-24.3	-26.6	-27.1	-25.3	-28.8	-28.3	-28.0	-29.4	-32.1	-36.0
CH_4 (without LULUCF)	**-42.1**	**-45.2**	**-46.9**	**-47.9**	**-50.0**	**-51.0**	**-51.9**	**-51.4**	**-51.9**	**-52.9**	**-53.1**	**-54.1**	**-54.6**	**-56.1**	**-57.9**
N_2O (without LULUCF)	**-35.3**	**-36.6**	**-31.5**	**-33.7**	**-33.1**	**-46.8**	**-46.8**	**-46.5**	**-46.2**	**-45.3**	**-45.4**	**-45.6**	**-46.5**	**-48.8**	**-50.1**
F gases, total	**-17.0**	**-17.4**	**-16.9**	**-16.7**	**-14.1**	**-16.6**	**-15.6**	**-14.5**	**-14.3**	**-14.2**	**-11.6**	**-11.0**	**-10.6**	**-15.7**	**-19.9**
Total emissions, without LULUCF	**-20.5**	**-20.0**	**-22.1**	**-22.0**	**-27.3**	**-24.7**	**-26.6**	**-26.2**	**-24.8**	**-28.0**	**-27.7**	**-27.4**	**-28.7**	**-31.5**	**-35.6**
Total emissions / removals, with LULUCF	-21.9	-21.9	-23.7	-24.6	-30.4	-27.4	-29.4	-29.8	-28.2	-31.3	-30.8	-30.7	-31.9	-34.6	-38.1
Total emissions, without LULUCF, with respect to base year*	*-20.8*	*-20.2*	*-22.3*	*-22.2*	*-27.5*	*-24.9*	*-26.8*	*-26.4*	*-25.0*	*-28.2*	*-27.9*	*-27.6*	*-28.9*	*-31.7*	*-35.8*
NO_x	**-42.5**	**-42.2**	**-44.0**	**-46.2**	**-49.5**	**-49.1**	**-50.0**	**-50.3**	**-50.3**	**-51.9**	**-52.7**	**-53.7**	**-55.5**	**-58.5**	**-61.1**
SO_2	**-91.3**	**-91.3**	**-91.6**	**-91.8**	**-92.8**	**-92.6**	**-92.9**	**-93.3**	**-93.5**	**-93.9**	**-93.9**	**-94.3**	**-94.5**	**-94.7**	**-95.2**
NMVOC	**-61.8**	**-61.9**	**-63.5**	**-65.1**	**-68.0**	**-65.0**	**-67.3**	**-67.7**	**-68.9**	**-69.8**	**-70.5**	**-70.7**	**-70.6**	**-71.8**	**-72.5**
CO	**-70.7**	**-70.9**	**-71.2**	**-71.3**	**-75.5**	**-73.1**	**-73.8**	**-75.7**	**-76.0**	**-77.3**	**-76.5**	**-77.5**	**-77.4**	**-78.2**	**-79.0**

Emissions trend Trend with respect to 1990/1995 (%)	2020
CO_2 emissions (without LULUCF)	**-39.2**
Net CO_2 emissions / removals	-42.0
CH_4 (without LULUCF)	**-58.7**
N_2O (without LULUCF)	**-51.4**
F gases, total	**-28.9**
Total emissions, without LULUCF	**-41.3**
Total emissions / removals, with LULUCF	-43.5
Total emissions, without LULUCF, with respect to base year*	*-41.5*
NO_X	**-65.6**
SO_2	**-95.7**
NMVOC	**-73.4**
CO	**-81.2**

* The base year for CO_2, CH_4 & N_2O is 1990; the base year for HFC, PFC, SF_6 & NF_3 is 1995

Table 584: Changes in emissions of direct and indirect greenhouse gases and SO_2 in Germany, since the relevant previous year

Emissions trend Emissions trend with respect to the previous year in each case (%)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
CO_2 emissions (without LULUCF)		**-3.6**	**-4.8**	**-1.0**	**-1.7**	**-0.1**	**+2.1**	**-2.9**	**-0.9**	**-3.0**	**+0.4**	**+1.9**	**-1.8**	**+0.1**	**-1.6**
Net CO_2 emissions / removals		-9.0	-5.6	-1.0	-1.2	+0.6	+1.8	-2.9	-0.8	-3.4	+2.8	+0.9	+1.9	-0.3	-1.9
CH_4 (without LULUCF)		**-4.7**	**-3.0**	**+0.7**	**-3.4**	**-2.1**	**-2.4**	**-4.3**	**-5.0**	**-0.9**	**-4.3**	**-4.0**	**-4.7**	**-4.2**	**-6.5**
N_2O (without LULUCF)		**-2.8**	**+3.0**	**-4.9**	**+3.5**	**-3.2**	**+2.7**	**-5.2**	**-23.9**	**-9.6**	**-1.5**	**+5.6**	**-2.0**	**-0.7**	**+4.4**
F gases, total							**-5.9**	**+1.2**	**+3.2**	**-10.3**	**-11.8**	**+5.5**	**+0.9**	**-4.3**	**+3.2**
Total emissions, without LULUCF		**-3.7**	**-4.1**	**-0.8**	**-1.6**	**-0.4**	**+1.6**	**-3.1**	**-2.3**	**-3.2**	**-0.2**	**+1.6**	**-2.0**	**-0.3**	**-1.6**
Total emissions / removals, with LULUCF		-8.2	-4.8	-0.8	-1.1	+0.2	+1.3	-3.1	-2.3	-3.6	+1.8	+0.8	+1.2	-0.7	-2.0
NO_X		**-7.8**	**-5.6**	**-4.1**	**-5.4**	**-2.6**	**-3.8**	**-3.5**	**-1.4**	**-1.7**	**-3.9**	**-3.0**	**-3.4**	**-2.6**	**-2.7**
SO_2		**-27.4**	**-18.3**	**-10.3**	**-16.7**	**-27.9**	**-15.3**	**-17.0**	**-20.2**	**-18.4**	**-19.4**	**-3.2**	**-10.1**	**-4.9**	**-7.5**
NMVOC		**-13.1**	**-9.3**	**-5.9**	**-14.4**	**-5.2**	**-4.2**	**-2.4**	**-2.6**	**-7.6**	**-8.4**	**-5.3**	**-5.4**	**-5.0**	**-0.2**
CO		**-17.1**	**-13.8**	**-9.5**	**-11.9**	**-4.7**	**-7.9**	**-3.5**	**-8.0**	**-6.9**	**-6.0**	**-3.8**	**-6.0**	**-7.0**	**-5.0**

Emissions trend Emissions trend with respect to the previous year in each case (%)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO_2 emissions (without LULUCF)	**-2.3**	**+1.3**	**-3.0**	**+0.4**	**-7.6**	**+5.4**	**-2.8**	**+0.6**	**+2.2**	**-4.7**	**+0.4**	**+0.6**	**-1.8**	**-4.0**	**-6.3**
Net CO_2 emissions / removals	-2.7	+0.5	-2.7	-1.0	-8.7	+6.2	-3.1	-0.7	+2.6	-4.8	+0.7	+0.4	-1.9	-3.9	-5.8
CH_4 (without LULUCF)	**-4.6**	**-5.5**	**-3.1**	**-1.8**	**-4.0**	**-2.0**	**-1.9**	**+1.0**	**-1.1**	**-2.0**	**-0.4**	**-2.3**	**-1.0**	**-3.3**	**-4.0**
N_2O (without LULUCF)	**-4.2**	**-2.0**	**+8.0**	**-3.2**	**+1.0**	**-20.5**	**+0.0**	**+0.5**	**+0.6**	**+1.7**	**-0.2**	**-0.4**	**-1.6**	**-4.2**	**-2.6**
F gases, total	**+1.4**	**-0.5**	**+0.7**	**+0.2**	**+3.2**	**-3.0**	**+1.3**	**+1.3**	**+0.2**	**+0.1**	**+3.1**	**+0.7**	**+0.5**	**-5.7**	**-5.0**
Total emissions, without LULUCF	**-2.5**	**+0.7**	**-2.6**	**+0.1**	**-6.8**	**+3.7**	**-2.6**	**+0.6**	**+1.9**	**-4.2**	**+0.4**	**+0.4**	**-1.7**	**-4.0**	**-6.0**
Total emissions / removals, with LULUCF	-2.8	-0.0	-2.3	-1.1	-7.8	+4.3	-2.8	-0.5	+2.2	-4.3	+0.7	+0.2	-1.7	-3.8	-5.5
NO_x	**-3.0**	**+0.6**	**-3.1**	**-3.9**	**-6.2**	**+0.9**	**-1.8**	**-0.6**	**-0.1**	**-3.2**	**-1.6**	**-2.1**	**-3.9**	**-6.7**	**-6.3**
SO_2	**-3.8**	**+0.3**	**-3.7**	**-1.3**	**-12.9**	**+2.6**	**-4.0**	**-4.7**	**-3.2**	**-6.0**	**-0.4**	**-7.3**	**-2.8**	**-3.8**	**-10.4**
NMVOC	**-3.1**	**-0.2**	**-4.2**	**-4.4**	**-8.4**	**+9.3**	**-6.5**	**-1.2**	**-3.5**	**-3.2**	**-2.2**	**-0.6**	**+0.4**	**-4.1**	**-2.4**
CO	**-5.5**	**-0.7**	**-1.0**	**-0.6**	**-14.4**	**+9.5**	**-2.4**	**-7.4**	**-1.3**	**-5.4**	**+3.5**	**-4.0**	**+0.5**	**-3.7**	**-3.5**

Emissions trend Emissions trend with respect to the previous year in each case (%)	2020
CO_2 emissions (without LULUCF)	**-9.6**
Net CO_2 emissions / removals	-9.3
CH_4 (without LULUCF)	**-1.9**
N_2O (without LULUCF)	**-2.6**
F gases, total	**-11.2**
Total emissions, without LULUCF	**-8.9**
Total emissions / removals, with LULUCF	-8.6
NO_x	**-11.6**
SO_2	**-10.4**
NMVOC	**-3.4**
CO	**-10.8**

Table 585: Changes in emissions in Germany, by categories, since 1990 / since the relevant previous year

Emissions change with respect to 1990 (%)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1. Energy		-3.6%	-8.3%	-9.2%	-11.3%	-11.5%	-9.5%	-12.5%	-13.4%	-15.8%	-16.1%	-14.1%	-15.7%	-16.2%	-17.8%	-19.7%	-18.8%	-21.3%	-20.8%	-26.4%
2. Industrial processes		-3.8%	-3.6%	-2.4%	3.6%	1.8%	-0.2%	0.0%	-14.2%	-22.6%	-19.6%	-23.1%	-24.5%	-20.6%	-18.6%	-22.0%	-21.8%	-20.6%	-24.5%	-32.1%
3. Agriculture		-9.4%	-11.4%	-12.8%	-13.2%	-13.2%	-12.4%	-13.7%	-13.0%	-12.7%	-13.6%	-12.6%	-15.6%	-16.5%	-17.5%	-17.7%	-19.3%	-18.5%	-18.0%	-17.5%
5. Waste		3.7%	5.2%	4.8%	2.7%	0.2%	-3.6%	-11.3%	-16.9%	-21.2%	-25.3%	-29.7%	-33.3%	-37.3%	-40.7%	-44.2%	-49.1%	-52.5%	-55.8%	-59.0%

Emissions change with respect to 1990 (%)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1. Energy	-22.7%	-25.0%	-24.4%	-22.7%	-26.6%	-26.1%	-25.8%	-27.6%	-30.5%	-35.0%	-41.3%
2. Industrial processes	-35.4%	-35.5%	-36.5%	-36.7%	-36.8%	-37.8%	-35.9%	-32.0%	-35.0%	-38.3%	-42.7%
3. Agriculture	-18.2%	-18.0%	-17.1%	-16.0%	-14.2%	-14.4%	-15.0%	-16.0%	-18.3%	-19.4%	-20.5%
5. Waste	-61.9%	-64.0%	-66.0%	-68.0%	-69.6%	-71.2%	-72.6%	-73.7%	-74.9%	-75.8%	-76.9%

Emissions change, in each case with respect to the previous year; change in %	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1. Energy		-3.6%	-4.9%	-1.0%	-2.4%	-0.2%	2.3%	-3.3%	-1.1%	-2.7%	-0.3%	2.3%	-1.8%	-0.6%	-1.9%	-2.4%	1.2%	-3.1%	0.7%	-7.1%
2. Industrial processes		-3.8%	0.2%	1.3%	6.1%	-1.7%	-2.0%	0.3%	-14.3%	-9.7%	3.8%	-4.3%	-1.9%	5.3%	2.5%	-4.2%	0.2%	1.5%	-4.9%	-10.2%
3. Agriculture		-9.4%	-2.2%	-1.6%	-0.5%	0.0%	0.9%	-1.4%	0.8%	0.4%	-1.0%	1.1%	-3.5%	-1.0%	-1.2%	-0.3%	-1.9%	1.0%	0.6%	0.6%
5. Waste		3.7%	1.5%	-0.4%	-2.0%	-2.5%	-3.8%	-8.0%	-6.3%	-5.2%	-5.2%	-5.8%	-5.2%	-5.9%	-5.5%	-6.0%	-8.7%	-6.8%	-6.8%	-7.3%

Emissions change, in each case with respect to the previous year; change in %	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1. Energy	5.0%	-3.0%	0.9%	2.2%	-5.0%	0.7%	0.3%	-2.4%	-4.0%	-6.5%	-9.7%
2. Industrial processes	-4.9%	-0.1%	-1.5%	-0.4%	-0.2%	-1.6%	3.1%	6.2%	-4.5%	-5.0%	-7.2%
3. Agriculture	-0.8%	0.1%	1.2%	1.3%	2.2%	-0.3%	-0.7%	-1.1%	-2.8%	-1.3%	-1.4%
5. Waste	-7.2%	-5.4%	-5.6%	-5.9%	-4.9%	-5.3%	-5.0%	-4.0%	-4.3%	-3.7%	-4.6%

22.4 Recalculations: detailed consideration on the basis of CRF Table 8

The following tables provide a numerical overview of the revised emissions figures for the years 1990 and 2019, pursuant to CRF tables 8s1 through 8s4 of the current CRF submission. For remarks regarding the recalculations shown, please refer to Chapter 10.1 of the present report and to the relevant category-specific chapters.

22.4.1 Overview for report year 1990

Table 586: Revised carbon dioxide emissions, 1990

	Submission 2021	Submission 2022	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
		[kt]			[%]	
National total emissions and removals	**1,074,783.44**	**1,076,569.85**	**1,786.41**	**0.166**	**0.144**	**0.141**
1. Energy	**989,590.09**	**989,092.98**	**-497.11**	**-0.050**	**-0.040**	**-0.039**
A. Combustion of fuels	985,749.63	985,252.52	-497.11	-0.050	-0.040	-0.039
1. Energy generation	423,905.78	423,905.78	0.00	0.000	0.000	0.000
2. Manufacturing	185,165.00	185,165.00	0.00	0.000	0.000	0.000
3. Transport	161,927.06	161,503.89	-423.17	-0.261	-0.034	-0.033
4. Other sectors	202,954.29	202,924.95	-29.34	-0.014	-0.002	-0.002
5. Other	11,797.50	11,752.90	-44.60	-0.378	-0.004	-0.004
B. Fugitive emissions from fuels	3,840.46	3,840.46	0.00	0.000	0.000	0.000
1. Solid fuels	1,832.80	1,832.80	0.00	0.000	0.000	0.000
2. Oil and natural gas	2,007.65	2,007.65	0.00	0.000	0.000	0.000
C. Transport and storage of CO_2	NO	NA				
2. Industrial processes & product use	**59,694.71**	**59,694.09**	**-0.62**	**-0.001**	**0.0000**	**0.0000**
A. Mineral industry	23,522.38	23,522.38	0.00	0.000	0.000	0.000
B. Chemical industry	8,109.38	8,109.38	0.00	0.000	0.000	0.000
C. Metal production	25,079.88	25,079.88	0.00	0.000	0.000	0.000
D. Non-energy-related Fuel use and solvent use	2,983.07	2,982.45	-0.62	-0.021	0.000	0.000
3. Agriculture	**3,192.03**	**3,192.03**	**0.00**	**0.000**	**0.000**	**0.000**
G. Liming	2,200.53	2,200.53	0.00	0.000	0.000	0.000
H. Urea application	481.05	481.05	0.00	0.000	0.000	0.000
I. Other C-containing fertilisers	510.45	510.45	0.00	0.000	0.000	0.000
J. Other	NO,NA	NO,NA				
4. Land use, land-use changes, forestry	**22,306.60**	**24,590.75**	**2,284.15**	**10.240**		**0.180**
A. Forest land	-22,065.98	-19,707.07	2,358.91	-10.690		0.186
B. Cropland	13,511.10	13,762.36	251.26	1.860		0.020
C. Grassland	26,094.43	26,383.49	289.06	1.108		0.023
D. Wetlands	3,668.32	3,705.75	37.43	1.020		0.003
E. Settlements	2,429.08	1,776.57	-652.51	-26.862		-0.051
F. Other land	NO	NO				
G. Harvested wood products	-1,330.35	-1,330.35	0.00	0.000		0.000
H. Other	NO,IE,NA	NO,IE,NA				
5. Waste & wastewater	**NO,NE,NA**	**NO,NE,NA**				
6. Other	**NA**	**NA**				
Reported as memo items:						
International transports	**18,326.09**	**19,032.74**	**706.65**	**3.856**	**0.057**	**0.056**
International air transports	11,920.74	11,922.23	1.49	0.012	0.000	0.000
International sea transports	6,405.35	7,110.51	705.16	11.009	0.057	0.056
Multilateral operations	IE, NE	NE				
CO_2 from biomass	22,101.38	22,101.38	0.00	0.000	0.000	0.000

Table 587: Revised methane emissions, 1990

	Submission 2021	Submission 2022	Change		Impacts on total national emissions *Without LULUCF*	Impacts on total national emissions *including LULUCF*
	[kt CO_2-eq.]				[%]	
National total emissions and removals	**119,467.24**	**119,996.41**	**529.17**	**0.44**	**0.043**	**0.042**
1. Energy	**40,426.61**	**40,382.00**	**-44.61**	**-0.11**	**-0.004**	**-0.004**
A. Combustion of fuels	6,572.74	6,587.64	14.90	0.23	0.001	0.001
1. Energy generation	280.21	280.21	0.00	0.00	0.000	0.000
2. Manufacturing	251.63	251.63	0.00	0.00	0.000	0.000
3. Transport	1,573.97	1,588.62	14.65	0.93	0.001	0.001
4. Other sectors	4,187.49	4,187.75	0.26	0.01	0.000	0.000
5. Other	279.43	279.42	-0.01	0.00	0.000	0.000
B. Fugitive emissions from fuels	33,853.87	33,794.37	-59.51	-0.18	-0.005	-0.005
1. Solid fuels	25,553.44	25,553.44	0.00	0.00	0.000	0.000
2. Oil and natural gas	8,300.44	8,240.93	-59.51	-0.72	-0.005	-0.005
2. Industrial processes & product use	**351.46**	**410.97**	**59.51**	**16.93**	**0.005**	**0.005**
3. Agriculture	**40,231.34**	**40,964.31**	**732.97**	**1.82**	**0.059**	**0.058**
4. Land use, land-use change and forestry	**1,659.79**	**1,441.09**	**-218.70**	**-13.18**		**-0.017**
A. Forest land	39.43	39.47	0.04	0.10		0.000
B. Cropland	146.13	145.74	-0.39	-0.27		0.000
C. Grassland	1,063.20	872.79	-190.41	-17.91		-0.015
D. Wetlands	363.06	335.07	-27.99	-7.71		-0.002
E. Settlements	47.97	48.03	0.06	0.13		0.000
5. Waste & wastewater	**36,798.04**	**36,798.04**	**0.00**	**0.00**	**0.000**	**0.000**
A. Landfilling of solid waste	34,200.20	34,200.20	0.00	0.00	0.000	0.000
B. Biological treatment of solid waste	25.34	25.34	0.00	0.00	0.000	0.000
D. Wastewater treatment	2,572.50	2,572.50	0.00	0.00	0.000	0.000
6. Other	NO	NA				
Reported only as memo items:						
International transports	6.59	6.97	0.38	5.81	0.000	0.000
International air transports	5.02	5.00	-0.02	-0.49	0.000	0.000
International sea transports	1.56	1.97	0.41	26.03	0.000	0.000
Multilateral operations	IE, NE	**IE, NE**				

Table 588: Revised nitrous oxide emissions, 1990

	Submission 2021	Submission 2022	Change		Impacts on total national emissions *Without LULUCF*	Impacts on total national emissions *including LULUCF*
	[kt CO_2-eq.]				[%]	
National total emissions and removals	**65,792.46**	**58,960.11**	**-6,832.35**	**-10.38**	**-0.550**	**-0.538**
1. Energy	**6,981.79**	**6,968.73**	**-13.06**	**-0.19**	**-0.001**	**-0.001**
A. Combustion of fuels	6,979.52	6,966.37	-13.15	-0.19	-0.001	-0.001
1. Energy generation	3,167.08	3,167.08	0.00	0.00	0.000	0.000
2. Manufacturing	1,350.36	1,350.36	0.00	0.00	0.000	0.000
3. Transport	1,423.08	1,410.78	-12.30	-0.86	-0.001	-0.001
4. Other sectors	977.67	977.26	-0.41	-0.04	0.000	0.000
5. Other	61.33	60.89	-0.44	-0.72	0.000	0.000
B. Fugitive emissions from fuels	2.27	2.36	0.10	4.20	0.000	0.000
2. Oil and natural gas	NO,NA	NO,NA				
2. Industrial processes & product use	**23,391.86**	**23,390.92**	**-0.95**	**0.00**	**0.000**	**0.000**
3. Agriculture	**33,086.12**	**26,424.71**	**-6,661.41**	**-20.13**	**-0.536**	**-0.525**
B. Manure management	3,623.02	3,656.06	33.04	0.91	0.003	0.003
D. Agricultural soils	29,462.98	22,768.53	-6,694.45	-22.72	-0.539	-0.528
J. Other	0.12	0.12	0.00	0.00	0.000	0.000
4. Land use, land-use change and forestry	**895.25**	**970.73**	**75.48**	**8.43**		**0.006**
A. Forest land	442.62	443.53	0.91	0.21		0.000
B. Cropland	190.82	190.82	0.00	0.00		0.000
C. Grassland	64.96	65.22	0.26	0.40		0.000
D. Wetlands	34.10	34.10	0.00	0.00		0.000
E. Settlements	19.30	20.36	1.07	5.53		0.000
H. Other	0.00	0.00	0.00	0.00		

	Submission 2021	Submission 2022	Change		Impacts on total national emissions: *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
5. Waste & wastewater	**1,437.43**	**1,205.02**	**-232.41**	**-16.17**	**-0.019**	**-0.018**
B. Biological treatment of solid waste	15.97	15.97	0.00	0.00	0.000	0.000
D. Wastewater treatment	1,421.47	1,189.05	-232.41	-16.35	-0.019	-0.018
6. Other	**NA**	**NA**				
Reported as memo items:						
International transports	196.64	204.70	8.06	4.10	0.001	0.001
International air transports	112.64	112.65	0.01	0.01	0.000	0.000
International sea transports	84.01	92.05	8.04	9.57	0.001	0.001
Multilateral operations	**IE, NE**	**IE, NE**				
Indirect N_2O	**NO,IE**	**NE,IE**				

Table 589: Revised HFC emissions, 1990

	Submission 2021	Submission 2022	Change		Impacts on total national emissions: *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
Total national emissions	**50.32**	**50.32**	**0.00**	**0.000**	**0.00**	**0.00**
2.E.1. Electronics industry	50.32	50.32	0.00	0.000	0.00	0.00

Table 590: Revised PFC emissions, 1990

	Submission 2021	Submission 2022	Change		Impacts on total national emissions: *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
Total national emissions	**3,060.23**	**3,069.55**	**9.32**	**0.30**	**0.0008**	**0.0007**
2.C.3. Aluminium production	2,888.66	2,888.66	0.00	0.00	0.00	0.00
2.E.1. Electronics industry	171.58	171.58	0.00	0.00	0.00	0.00
2.E.4. Heat transfer fluids	IE,NA	9.32	9.32		0.0008	0.0007

Table 591: Revised SF_6 emissions, 1990

	Submission 2021	Submission 2022	Change		Impacts on total national emissions: *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
Total national emissions	**4,428.00**	**4,428.00**	**0.00**	**0.00**	**0.000**	**0.000**
2.B.9. Production of PFC & SF_6	114.00	114.00	0.00	0.00	0.000	0.000
2.C.4. Magnesium production	180.12	180.12	0.00	0.00	0.000	0.000
2.E.1. Electronics industry	84.36	84.36	0.00	0.00	0.000	0.000
2.G.1. Electrical equipments	867.84	867.84	0.00	0.00	0.000	0.000
2.G.2. SF_6 and PFC from other product use	3,181.68	3,181.68	0.00	0.00	0.000	0.000

Table 592: Revised *unspecified-mix* emissions, 1990

	Submission 2021	Submission 2022	Change		Impacts on total national emissions: *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
Total national emissions	**5,850.00**	**5,850.00**	**0.00**	**0.00**	**0.00**	**0.00**
2.B.9. Production of PFC & SF_6	5,567.08	5,567.08	0.00	0.00	0.00	0.00
2.H. Other	282.92	282.92	0.00	0.00	0.00	0.00

Table 593: Revised NF_3 emissions, 1990

	Submission 2021	Submission 2022	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
		[kt CO_2-eq.]			[%]	
Total national emissions	**6.88**	**6.88**	**0.00**	**0.000**	**0.000**	**0.000**
2.E.1. Electronics industry	6.88	6.88	0.00	0.000	0.000	0.000

22.4.2 Overview for report year 2019

Table 594: Revised carbon dioxide emissions, 2019

	Submission 2021	Submission 2022	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
		[kt CO_2-eq.]			[%]	
National total emissions and removals	**691,622.62**	**688,886.21**	**-2.736.41**	**-0.40**	**-0.342**	**-0.349**
1. Energy	**662,682.69**	**659,719.64**	**-2,963.06**	**-0.45**	-0.371	-0.378
A. Combustion of fuels	660,686.94	657,691.28	-2,995.66	-0.45	-0.375	-0.382
1. Energy generation	244,822.18	246,152.23	1,330.05	0.54	0.166	0.169
2. Manufacturing	124,313.51	122,407.08	-1,906.43	-1.53	-0.238	-0.243
3. Transport	163,495.65	163,259.72	-235.93	-0.14	-0.030	-0.030
4. Other sectors	127,138.50	124,984.32	-2,154.18	-1.69	-0.269	-0.274
5. Other	917.10	887.93	-29.18	-3.18	-0.004	-0.004
B. Fugitive emissions from fuels	1,995.75	2,028.36	32.61	1.63	0.004	0.004
1. Solid fuels	614.61	647.17	32.55	5.30	0.004	0.004
2. Oil and natural gas	1,381.14	1,381.19	0.06	0.00	0.000	0.000
C. Transport and storage of CO_2	NO	NO				
2. Industrial processes & product use	**45,924.02**	**44,699.51**	**-1,224.51**	**-2.67**	**-0.153**	**-0.156**
A. Mineral industry	19,412.68	19,412.68	0.00	0.00	0.000	0.000
B. Chemical industry	5,316.95	5,316.95	0.00	0.00	0.000	0.000
C. Metal production	19,167.39	18,023.86	-1,143.53	-5.97	-0.143	-0.146
D. Non-energy-related fuel use & solvent use	2,027.00	1,946.01	-80.98	-4.00	-0.010	-0.010
3. Agriculture	**2,821.10**	**2,730.80**	**-90.30**	**-3.20**	**-0.011**	**-0.012**
4. Land use, land-use change and forestry	**-19,805.19**	**-18,263.74**	**1,541.45**	**-7.78**		**0.196**
A. Forest land	-57,454.13	-52,777.52	4,676.61	-8.14		0.596
B. Cropland	16,336.74	16,748.90	412.15	2.52		0.053
C. Grassland	17,006.82	18,590.78	1,583.96	9.31		0.202
D. Wetlands	4,333.77	4,308.83	-24.95	-0.58		-0.003
E. Settlements	4,122.12	932.21	-3,189.91	-77.39		-0.406
G. Harvested wood products	-4,150.51	-6,066.94	-1,916.42	46.17		-0.244
5. Waste & wastewater	**NO,NE,NA**	**NO,NE,NA**				
6. Other	**NO**	**NA**				
Reported as memo items:						
International transports	33,101.99	33,229.12	127.13	0.38	0.016	0.016
International air transports	29,633.20	29,622.24	-10.96	-0.04	-0.001	-0.001
International sea transports	3,468.79	3,606.88	138.09	3.98	0.017	0.018
Multilateral operations	IE, NE	IE, NE				
CO_2 from biomass	103,596.69	105,735.88	2,139.19	2.06	0.267	0.273
collected CO_2	**NO**	**NO**				
Long-term C storage in landfills	**NA**	**NA**				
Indirect CO_2	**NO,NE,IE**	**NO,NE,IE**				

Table 595: Revised methane emissions, 2019

	Submission 2021	Submission 2022	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
National total emissions and removals	**51,146.21**	**51,814.26**	**668.05**	**1.31**	**0.084**	**0.085**
1. Energy	9,518.69	8,983.48	-535.21	-5.62	-0.067	-0.068
A. Combustion of fuels	4,378.18	3,918.39	-459.79	-10.50	-0.057	-0.059
1. Energy generation	2,800.74	2,319.97	-480.77	-17.17	-0.060	-0.061
2. Manufacturing	292.64	289.25	-3.39	-1.16	0.000	0.000
3. Transport	237.40	233.31	-4.09	-1.72	-0.001	-0.001
4. Other sectors	1,046.26	1,074.50	28.23	2.70	0.004	0.004
5. Other	1.14	1.37	0.23	20.28	0.000	0.000
B. Fugitive emissions from fuels	5,140.51	5,065.08	-75.43	-1.47	-0.009	-0.010
1. Solid fuels	153.35	154.62	1.27	0.83	0.000	0.000
2. Oil and natural gas	4,987.16	4,910.46	-76.69	-1.54	-0.010	-0.010
2. Industrial processes & product use	**503.13**	**565.01**	**61.88**	**12.30**	**0.008**	**0.008**
B. Chemical industry	465.62	525.48	59.86	12.86	0.007	0.008
C. Metal production	6.57	6.58	0.02	0.25	0.000	0.000
G. Other product use	30.95	32.95	2.00	6.45	0.000	0.000
3. Agriculture	**30,859.04**	**31,997.11**	**1,138.08**	**3.69**	**0.142**	**0.145**
A. Enteric fermentation	23,709.82	24,237.94	528.12	2.23	0.066	0.067
B. Manure management	5,833.70	6,446.25	612.55	10.50	0.077	0.078
J. Other	1,315.52	1,312.93	-2.59	-0.20	0.000	0.000
4. Land use, land-use change and forestry	**1,875.16**	**1,870.21**	**-4.96**	**-0.26**		**-0.001**
A. Forest land	47.24	47.18	-0.06	-0.13		0.000
B. Cropland	135.19	131.80	-3.39	-2.50		0.000
C. Grassland	1,116.91	961.01	-155.90	-13.96		-0.020
D. Wetlands	506.25	664.27	158.01	31.21		0.020
E. Settlements	69.57	65.94	-3.62	-5.21		0.000
5. Waste & wastewater	**8,390.19**	**8,398.45**	**8.26**	**0.10**	**0.001**	**0.001**
A. Landfilling of solid waste	7,189.33	7,186.58	-2.75	-0.04	0.000	0.000
B. Biological treatment of solid waste	701.44	712.43	11.00	1.57	0.001	0.001
C. Waste incineration	497.00	497.00	0.00	0.00	0.000	0.000
E. Other	2.43	2.44	0.02	0.69	0.000	0.000
6. Other	**NO**	**NA**				
Reported only as memo items:						
International transports	**5.17**	**4.92**	**-0.25**	**-4.83**	**0.000**	**0.000**
International air transports	4.30	4.04	-0.26	-5.96	0.000	0.000
International sea transports	0.87	0.88	0.01	0.76	0.000	0.000
Multilateral operations	IE, NE	IE, NE				

Table 596: Revised nitrous oxide emissions, 2019

	Submission 2021	Submission 2022	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
Total national emissions	**36,587.99**	**30,450.06**	**-6,137.93**	**-16.78**	**-0.767**	**-0.782**
1. Energy	5,159.79	5,132.43	-27.36	-0.53	-0.003	-0.003
A. Combustion of fuels	5,158.79	5,131.43	-27.37	-0.53	-0.003	-0.003
1. Energy generation	2,072.64	2.067.20	-5.44	-0.26	-0.001	-0.001
2. Manufacturing	831.05	815.59	-15.46	-1.86	-0.002	-0.002
3. Transport	1,799.78	1,791.17	-8.61	-0.48	-0.001	-0.001
4. Other sectors	451.16	453.65	2.49	0.55	0.000	0.000
5. Other	4.16	3.83	-0.34	-8.10	0.000	0.000
B. Fugitive emissions from fuels	1.00	1.00	0.00	0.39	0.000	0.000
2. Oil and natural gas	1.00	1.00	0.00	0.39	0.000	0.000
2. Industrial processes & product use	**950.95**	**834.10**	**-116.84**	**-12.29**	**-0.015**	**-0.015**
B. Chemical industry	565.98	562.61	-3.36	-0.59	0.000	0.000
C. Metal production	14.76	14.00	-0.76	-5.17	0.000	0.000
D. Non-energy-related fuel use & solvent use	1.23	1.23	0.00	0.06	0.000	0.000
G. Other product use	368.99	256.27	-112.72	-30.55	-0.014	-0.014

	Submission 2021	Submission 2022	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
3. Agriculture	**28,158.78**	**22,184.02**	**-5,974.76**	**-21.22**	**-0.747**	**-0.761**
B. Manure management	2,937.27	2,937.08	-0.19	-0.01	0.000	0.000
D. Agricultural soils	24,963.97	18,994.17	-5,969.79	-23.91	-0.746	-0.761
J. Other	257.54	252.76	-4.78	-1.86	-0.001	-0.001
4. Land use, land-use changes, forestry	**1,466.08**	**1,501.60**	**35.52**	**2.42**		**0.005**
A. Forest land	381.46	380.83	-0.63	-0.16		0.000
B. Cropland	524.16	515.39	-8.77	-1.67		-0.001
C. Grassland	104.41	103.54	-0.87	-0.84		0.000
D. Wetlands	41.99	42.14	0.15	0.36		0.000
E. Settlements	147.15	133.28	-13.87	-9.43		-0.002
H. Other	95.30	160.41	65.11	68.32		0.008
5. Waste & wastewater	**852.38**	**797.90**	**-54.48**	**-6.39**	**-0.007**	**-0.007**
B. Biological treatment of solid waste	306.19	310.01	3.82	1.25	0.000	0.000
D. Wastewater treatment	512.62	454.08	-58.53	-11.42	-0.007	-0.007
E. Other	33.58	33.81	0.23	0.69	0.000	0.000
6. Other	**NO**	**NA**				
Reported as memo items:						
International transports	**325.76**	**327.47**	**1.71**	**0.52**	**0.000**	**0.000**
International air transports	279.36	279.23	-0.13	-0.05	0.000	0.000
International sea transports	46.40	48.24	1.83	3.95	0.000	0.000
Multilateral operations	**NE**	**NE**				
Indirect N_2O	**NO,IE**	**NE,IE**				

Table 597: Revised HFC emissions, 2019

	Submission 2021	Submission 2022	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
Total national emissions	**9,611.81**	**9,324.53**	**-287.28**	**-2.99**	**-0.036**	**-0.037**
2.B.9. Production of PFC & SF_6	IE	IE				
2.C.4. Magnesium production	10.37	10.37	0.00	0.00	0.000	0.000
2.E.1. Electronics industry	14.69	14.69	0.00	0.00	0.000	0.000
2.F.1. Air-conditioning and refrigeration systems	8,536.36	8,424.61	-111.75	-1.31	-0.014	-0.014
2.F.2. Foam production	581.21	404.94	-176.27	-30.33	-0.022	-0.022
2.F.3. Fire extinguishers	105.38	105.46	0.08	0.08	0.000	0.000
2.F.4. Aerosols	352.72	352.72	0.00	0.00	0.000	0.000
2.F.5. Solvents	IE	IE				
2.G.4. Other	11.08	11.74	0.65	5.90	0.000	0.000

Table 598: Revised PFC emissions, 2019

	Submission 2021	Submission 2022	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
		[kt CO_2-eq.]			[%]	
Total national emissions	**231.76**	**231.88**	**0.12**	**0.05**	**0.000**	**0.000**
2.B.9. Production of PFC & SF_6	IE	IE				
2.C.3. Aluminium production	90.61	90.61	0.00	0.00	0.000	0.000
2.E.1. Electronics industry	136.97	136.97	0.00	0.00	0.000	0.000
2.F.1. Air-conditioning and refrigeration systems	4.18	4.30	0.12	2.89	0.000	0.000
2.F.5. Solvents	IE	IE				
2.G.2. SF_6 and PFC from other product use	IE,NA	IE				

Table 599: Revised SF_6 emissions, 2019

	Submission 2021	Submission 2022	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
	[kt CO_2-eq.]			[%]		
Total national emissions	**3,919.33**	**3,919.33**	**0.00**	**0.00**	**0.000**	**0.000**
2.B.9. Production of PFC & SF_6	1.06	1.06	0.00	0.00	0.000	0.000
2.C.4. Magnesium production	23.35	23.35	0.00	0.00	0.000	0.000
2.E.1. Electronics industry	262.78	262.78	0.00	0.00	0.000	0.000
2.G.1. Electrical equipments	**3,919.33**	**3,919.33**	**0.00**	**0.00**	**0.000**	**0.000**
2.G.2. SF_6 and PFC from other product use	1.06	1.06	0.00	0.00	0.000	0.000

Table 600: Revised *unspecified-mix* emissions, 2019

	Submission 2021	Submission 2022	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
	[kt CO_2-eq.]			[%]		
Total national emissions	**203.92**	**204.84**	**0.92**	**0.449**	**0.000**	**0.000**
2.B.9. Production of PFC & SF_6	47.26	47.26	0.00	0.000	0.000	0.000
2.H. Other	156.67	157.58	0.92	0.585	0.000	0.000

Table 601: Revised NF_3 emissions, 2019

	Submission 2020	Submission 2021	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
	[kt CO_2-eq.]			[%]		
Total national emissions	**10.96**	**10.96**	**0.00**	**0.00**	**0.000**	**0.000**
2.E.1. Electronics industry	10.96	10.96	0.00	0.00	0.000	0.000

23 Annex 7: Uncertainties by categories

The uncertainties for the German greenhouse-gas inventories have been determined completely, for all categories. In each case, they have been determined for the base year, for 2020 and for the relevant trend. In Germany, uncertainties are calculated, each year, pursuant to both the Tier 1 and Tier 2 methods.

The results of this year's uncertainties analysis are shown, in keeping with the specifications given in Tables 3.4 and 3.5 of the 2006 IPCC Guidelines (IPCC, 2006a), in Table 602 and Table 603.

Table 602: Uncertainties by sectors (approach 1; error propagation pursuant to Table 3.4 of the 2006 IPCC Guidelines)

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year *x* emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data Note A	Input data Note A	$\sqrt{E^2 + F^2}$	$\frac{(G * D)^2}{(\sum D)^2}$	Note B	$\lvert\frac{D}{\sum C}\rvert$	$I * F$ Note C	$J * E *$ Note D	$\sqrt{2} K^2 + L^2$
		t CO_2 equivalent	t CO_2 equivalent	%	%	%		%	%	%	%	%
Sum	GHG	1,272,617.93	717,472.61			3.56						3.95
1 A 1 a, Public Electricity and Heat Production	CO_2	338,451.16	180,749.02	3.25	1.19	3.46	0.57	0.02	0.14	0.66	0.24	0.50
1 A 1 a, Public Electricity and Heat Production	CH_4	172.17	2,211.84	8.33	56.14	56.75	0.02	0.00	0.00	0.02	0.14	0.02
1 A 1 a, Public Electricity and Heat Production	N_2O	2,407.46	1,596.45	3.04	17.77	18.02	0.00	0.00	0.00	0.01	0.03	0.00
1 A 1 b, Petroleum Refining	CO_2	20,165.56	18,553.09	3.14	4.63	5.60	0.02	0.00	0.01	0.07	0.10	0.01
1 A 1 b, Petroleum Refining	CH_4	16.06	14.27	2.50	18.33	18.50	0.00	0.00	0.00	0.00	0.00	0.00
1 A 1 b, Petroleum Refining	N_2O	100.39	57.67	2.74	31.69	31.81	0.00	0.00	0.00	0.00	0.00	0.00
1 A 1 c, Manufacture of Solid Fuels and Other Energy	CO_2	65,289.06	9,010.32	4.22	3.10	5.24	0.00	0.01	0.01	0.04	0.03	0.00
1 A 1 c, Manufacture of Solid Fuels and Other Energy	CH_4	91.98	129.57	22.96	114.78	117.05	0.00	0.00	0.00	0.00	0.02	0.00
1 A 1 c, Manufacture of Solid Fuels and Other Energy	N_2O	659.23	153.28	5.03	21.93	22.50	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 a, Iron and steel	CO_2	35,269.33	32,589.67	5.14	3.69	6.32	0.06	0.01	0.03	0.19	0.14	0.05
1 A 2 a, Iron and steel	CH_4	62.45	54.80	8.14	24.41	25.73	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 a, Iron and steel	N_2O	155.10	97.72	4.60	33.67	33.98	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 b, Non-ferrous metals	CO_2	1,629.22	1,487.49	10.98	0.95	11.03	0.00	0.00	0.00	0.02	0.00	0.00
1 A 2 b, Non-ferrous metals	CH_4	1.39	1.66	11.03	68.92	69.80	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 b, Non-ferrous metals	N_2O	17.14	7.91	9.96	62.52	63.31	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 d, Pulp, Paper and Print	CO_2	3.65	7.80	5.22	2.24	5.68	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 d, Pulp, Paper and Print	CH_4	0.65	2.57	4.01	42.99	43.17	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 d, Pulp, Paper and Print	N_2O	2.81	11.05	4.01	51.22	51.38	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 e, Food Processing, Beverages and Tobacco	CO_2	2,015.91	241.42	4.86	1.40	5.06	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 e, Food Processing, Beverages and Tobacco	CH_4	4.48	0.18	5.26	35.78	36.17	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 e, Food Processing, Beverages and Tobacco	N_2O	24.65	2.24	4.83	52.38	52.60	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 f, Non-Metallic Minerals	CO_2	18,507.38	12,586.90	3.58	0.92	3.70	0.00	0.00	0.01	0.05	0.01	0.00
1 A 2 f, Non-Metallic Minerals	CH_4	50.28	14.90	3.24	22.44	22.67	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 f, Non-Metallic Minerals	N_2O	205.26	117.10	2.91	27.45	27.61	0.00	0.00	0.00	0.00	0.00	0.00

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year *x* emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data Note A	Input data Note A	$\sqrt{E^2+F^2}$	$\frac{(G*D)^2}{(\sum D)^2}$	Note B	$\lvert\frac{D}{\sum C}\rvert$	*I * F* Note C	*J * E ** Note D	$\sqrt{2}\,K^2+L^2$
		t CO_2 equivalent	t CO_2 equivalent	%	%	%		%	%	%	%	%
1 A 2 g, Other	CO_2	127,739.52	68,423.36	0.00	3.40	3.40	0.08	0.01	0.05	0.00	0.26	0.07
1 A 2 g, Other	CH_4	132.37	197.84	3.03	30.72	30.87	0.00	0.00	0.00	0.00	0.01	0.00
1 A 2 g, Other	N_2O	945.39	543.70	2.91	15.00	15.28	0.00	0.00	0.00	0.00	0.01	0.00
1 A 3 a, Domestic Aviation	CO_2	2,410.94	1,037.78	7.65	3.82	8.55	0.00	0.00	0.00	0.01	0.00	0.00
1 A 3 a, Domestic Aviation	CH_4	2.63	1.50	9.47	93.45	93.93	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 a, Domestic Aviation	N_2O	24.31	10.41	7.45	111.69	111.94	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 b, Road Transport	CO_2	151,886.32	141,282.74	0.00	4.79	4.79	0.67	0.02	0.11	0.00	0.76	0.58
1 A 3 b, Road Transport	CH_4	1,561.13	208.64	4.53	14.48	15.17	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 b, Road Transport	N_2O	1,343.46	1,642.22	6.49	16.52	17.75	0.00	0.00	0.00	0.01	0.03	0.00
1 A 3 c, Railways	CO_2	3,122.15	783.08	0.00	10.04	10.04	0.00	0.00	0.00	0.00	0.01	0.00
1 A 3 c, Railways	CH_4	17.61	0.26	8.54	28.83	30.07	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 c, Railways	N_2O	7.66	1.97	8.73	64.85	65.43	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 d, Domestic Navigation	CO_2	3,001.22	1,392.69	25.28	2.09	25.36	0.00	0.00	0.00	0.04	0.00	0.00
1 A 3 d, Domestic Navigation	CH_4	1.94	0.54	30.71	27.81	41.43	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 d, Domestic Navigation	N_2O	20.87	11.66	12.64	101.22	102.00	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 e, Other Transportation	CO_2	1,083.27	767.52	2.80	0.93	2.95	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 e, Other Transportation	CH_4	5.31	3.76	2.80	69.89	69.95	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 e, Other Transportation	N_2O	14.49	6.70	2.90	48.30	48.39	0.00	0.00	0.00	0.00	0.00	0.00
1 A 4 a, Commercial/Institutional	CO_2	64,111.32	27,615.78	0.00	8.30	8.30	0.08	0.01	0.02	0.00	0.26	0.07
1 A 4 a, Commercial/Institutional	CH_4	1,461.71	83.17	14.73	100.18	101.26	0.00	0.00	0.00	0.00	0.01	0.00
1 A 4 a, Commercial/Institutional	N_2O	147.44	89.08	6.87	71.23	71.56	0.00	0.00	0.00	0.00	0.01	0.00
1 A 4 b, Residential	CO_2	128,635.75	89,770.76	0.00	8.50	8.50	0.85	0.00	0.07	0.00	0.86	0.74
1 A 4 b, Residential	CH_4	2,484.67	785.86	14.22	132.69	133.45	0.02	0.00	0.00	0.01	0.12	0.01
1 A 4 b, Residential	N_2O	768.85	290.19	8.87	84.01	84.48	0.00	0.00	0.00	0.00	0.03	0.00
1 A 4 c, Agriculture/Forestry/Fishing	CO_2	10,177.88	6,027.12	0.00	12.71	12.71	0.01	0.00	0.00	0.00	0.09	0.01
1 A 4 c, Agriculture/Forestry/Fishing	CH_4	241.36	171.66	8.10	51.74	52.37	0.00	0.00	0.00	0.00	0.01	0.00
1 A 4 c, Agriculture/Forestry/Fishing	N_2O	60.97	67.57	12.99	92.33	93.24	0.00	0.00	0.00	0.00	0.01	0.00

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year *x* emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data Note A	Input data Note A	$\sqrt{E^2+F^2}$	$\frac{(G*D)^2}{(\sum D)^2}$	Note B	$\lvert\frac{D}{\sum C}\rvert$	$I*F$ Note C	$J*E*$ Note D	$\sqrt{2}\,K^2+L^2$
		t CO_2 equivalent	t CO_2 equivalent	%	%	%		%	%	%	%	%
1 A 5, Other: Military	CO_2	11,752.90	743.34	0.00	5.57	5.57	0.00	0.00	0.00	0.00	0.00	0.00
1 A 5, Other: Military	CH_4	279.42	1.33	4.18	44.22	44.41	0.00	0.00	0.00	0.00	0.00	0.00
1 A 5, Other: Military	N_2O	60.89	3.18	3.38	87.22	87.28	0.00	0.00	0.00	0.00	0.00	0.00
1 B 1, Solid Fuels	CO_2	1,832.80	629.55	0.00	36.14	36.14	0.00	0.00	0.00	0.00	0.03	0.00
1 B 1, Solid Fuels	CH_4	25,553.44	136.68	0.00	25.34	25.34	0.00	0.01	0.00	0.00	0.00	0.00
1 B 2 a, Oil	CO_2	477.63	393.26	0.00	24.90	24.90	0.00	0.00	0.00	0.00	0.01	0.00
1 B 2 a, Oil	CH_4	241.85	17.00	0.00	17.80	17.80	0.00	0.00	0.00	0.00	0.00	0.00
1 B 2 a, Oil	N_2O	0.32	0.25	0.00	30.00	30.00	0.00	0.00	0.00	0.00	0.00	0.00
1 B 2 b, Natural Gas	CO_2	986.51	470.81	0.00	22.28	22.28	0.00	0.00	0.00	0.00	0.01	0.00
1 B 2 b, Natural Gas	CH_4	7,997.44	4,764.96	0.00	15.12	15.12	0.01	0.00	0.00	0.00	0.08	0.01
1 B 2 c, Venting and Flaring	CO_2	543.52	321.31	0.00	138.70	138.70	0.00	0.00	0.00	0.00	0.05	0.00
1 B 2 c, Venting and Flaring	CH_4	1.65	0.54	0.00	133.13	133.13	0.00	0.00	0.00	0.00	0.00	0.00
1 B 2 c, Venting and Flaring	N_2O	2.04	0.69	0.00	68.26	68.26	0.00	0.00	0.00	0.00	0.00	0.00
2 A 1, Cement Production	CO_2	15,297.27	13,357.49	2.50	2.00	3.20	0.00	0.00	0.01	0.04	0.03	0.00
2 A 2, Lime Production	CO_2	5,986.62	4,180.89	2.40	10.61	10.88	0.00	0.00	0.00	0.01	0.05	0.00
2 A 3, Glass Production	CO_2	780.48	857.26	3.12	11.14	11.57	0.00	0.00	0.00	0.00	0.01	0.00
2 A 4, Other Process Uses of Carbonates	CO_2	1,458.01	647.77	5.67	12.99	14.17	0.00	0.00	0.00	0.00	0.01	0.00
2 B 1, Ammonia Production	CO_2	6,025.00	4,133.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
2 B 2, Nitric Acid Production	N_2O	3,257.50	377.79	0.56	2.19	2.26	0.00	0.00	0.00	0.00	0.00	0.00
2 B 3, Adipic Acid Production	N_2O	18,076.68	189.11	2.00	6.00	6.32	0.00	0.01	0.00	0.00	0.00	0.00
2 B 5, Carbide Production	CO_2	443.16	4.49	10.00	10.00	14.14	0.00	0.00	0.00	0.00	0.00	0.00
2 B 7, Soda Ash Production	CO_2	667.25	360.96	0.00	2.50	2.50	0.00	0.00	0.00	0.00	0.00	0.00
2 B 8, Petrochemical and Carbon Black Production	CO_2	973.97	792.94	10.88	14.03	17.76	0.00	0.00	0.00	0.01	0.01	0.00
2 B 8, Petrochemical and Carbon Black Production	CH_4	333.69	503.42	15.30	16.50	22.50	0.00	0.00	0.00	0.01	0.01	0.00
2 B 9 a, By-product Emissions	HFC-23	C	C	0.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
2 B 9 b, Fugitive Emissions	SF_6	159.60	0.89	0.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
2 B 9 b, Fugitive Emissions	HFC-134a	C	C	0.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
2 B 9 b, Fugitive Emissions	HFC-227ea	C	C	0.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
2 B 9 b, Fugitive Emissions	CF_4	C	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year *x* emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data Note A	Input data Note A	$\sqrt{E^2+F^2}$	$\frac{(G*D)^2}{(\sum D)^2}$	Note B	$\lvert\frac{D}{\sum C}\rvert$	I * F Note C	J * E * Note D	$\sqrt{2\,K^2+L^2}$
		t CO_2 equivalent	t CO_2 equivalent	%	%	%		%	%	%	%	%
2 B 10, Other	CH_4	59.51	59.48	0.00	38.73	38.73	0.00	0.00	0.00	0.00	0.00	0.00
2 B 10, Other	N_2O	C	C	20.00	62.00	65.15	0.00	0.00	0.00	0.00	0.00	0.00
2 C 1, Iron and Steel Production	CO_2	22,810.29	14,538.07	0.00	9.52	9.52	0.03	0.00	0.01	0.00	0.16	0.02
2 C 1, Iron and Steel Production	CH_4	4.67	4.37	0.00	68.68	68.68	0.00	0.00	0.00	0.00	0.00	0.00
2 C 1, Iron and Steel Production	N_2O	26.54	11.96	8.62	71.72	72.23	0.00	0.00	0.00	0.00	0.00	0.00
2 C 2, Ferroalloys Production	CO_2	429.00	5.92	50.00	7.00	50.49	0.00	0.00	0.00	0.00	0.00	0.00
2 C 2, Ferroalloys Production	CH_4	8.58	1.61	50.00	50.00	70.71	0.00	0.00	0.00	0.00	0.00	0.00
2 C 3, Aluminium Production	CO_2	1,011.92	723.22	1.00	50.00	50.01	0.00	0.00	0.00	0.00	0.04	0.00
2 C 3, Aluminium Production	SF_6	C	C	0.00	50.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00
2 C 3, Aluminium Production	CF_4	1,544.51	63.98	0.00	15.00	15.00	0.00	0.00	0.00	0.00	0.00	0.00
2 C 3, Aluminium Production	C_2F_6	256.20	12.72	0.00	15.03	15.03	0.00	0.00	0.00	0.00	0.00	0.00
2 C 4, Magnesium Production	SF_6	C	C	0.00	30.04	30.04	0.00	0.00	0.00	0.00	0.00	0.00
2 C 4, Magnesium Production	HFC-134a	0.00	8.26	0.00	35.00	35.00	0.00	0.00	0.00	0.00	0.00	0.00
2 C 5, Lead Production	CO_2	157.87	73.59	4.96	35.44	35.79	0.00	0.00	0.00	0.00	0.00	0.00
2 C 6, Zinc Production	CO_2	670.80	284.30	0.00	41.52	41.52	0.00	0.00	0.00	0.00	0.01	0.00
2 D 1, Lubricant Use	CO_2	188.65	182.44	0.00	39.80	39.80	0.00	0.00	0.00	0.00	0.01	0.00
2 D 2, Paraffin Wax Use	CO_2	242.70	452.49	0.00	70.71	70.71	0.00	0.00	0.00	0.00	0.04	0.00
2 D 2, Paraffin Wax Use	N_2O	0.70	1.30	0.00	60.57	60.57	0.00	0.00	0.00	0.00	0.00	0.00
2 D 3, Other	CO_2	2,551.10	1,291.75	0.00	9.45	9.45	0.00	0.00	0.00	0.00	0.01	0.00
2 E, Electronics Industry	SF_6	47.28	27.18	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	NF_3	5.29	10.80	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	HFC-23	17.11	14.05	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	HFC-32	0.00	0.00	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	CF_4	102.61	65.77	0.00	13.65	13.65	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	C_2F_6	162.48	42.92	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	C_3F_8	0.00	12.19	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	$c\text{-}C_4F_8$	0.00	5.73	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	C_6F_{14}	25.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year *x* emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data Note A	Input data Note A	$\sqrt{E^2 + F^2}$	$\frac{(G * D)^2}{(\sum D)^2}$	Note B	$\lvert\frac{D}{\sum C}\rvert$	$I * F$ Note C	$J * E *$ Note D	$\sqrt{2} K^2 + L^2$
		t CO_2 equivalent	t CO_2 equivalent	%	%	%		%	%	%	%	%
2 F, Product Uses as Substitutes for ODS	HFC-23	16.25	61.73	0.00	14.14	14.14	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	HFC-32	0.76	215.78	0.00	7.65	7.65	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	HFC-43-10mee	C	C	0.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	HFC-125	149.88	2,079.39	0.00	6.55	6.55	0.00	0.00	0.00	0.00	0.02	0.00
2 F, Product Uses as Substitutes for ODS	HFC-134a	2,268.24	4,760.20	0.00	5.81	5.81	0.00	0.00	0.00	0.00	0.03	0.00
2 F, Product Uses as Substitutes for ODS	HFC-143a	71.33	1,257.47	0.00	9.91	9.91	0.00	0.00	0.00	0.00	0.01	0.00
2 F, Product Uses as Substitutes for ODS	HFC-152a	90.07	31.09	0.00	2.80	2.80	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	HFC-227ea	0.65	87.19	0.00	3.58	3.58	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	HFC-236fa	C	C	0.00	10.03	10.03	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	HFC-245fa	C	C	0.00	8.27	8.27	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	HFC-365mfc	C	C	0.00	8.92	8.92	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	C_2F_6	0.00	2.69	0.00	21.17	21.17	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	C_3F_8	19.91	1.26	0.00	19.07	19.07	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	C_6F_{14}	C	C	0.00	20.00	20.00	0.00	0.00	0.00	0.00	0.00	0.00
2 G, Other Product Manufacture and Use	CH_4	4.53	23.33	20.00	20.00	28.28	0.00	0.00	0.00	0.00	0.00	0.00
2 G, Other Product Manufacture and Use	N_2O	C	C	0.00	47.80	47.80	0.00	0.00	0.00	0.00	0.01	0.00
2 G, Other Product Manufacture and Use	SF_6	C	C	0.00	9.40	9.40	0.00	0.00	0.00	0.00	0.03	0.00
2 G, Other Product Manufacture and Use	HFC-134a	0.00	0.20	0.00	22.36	22.36	0.00	0.00	0.00	0.00	0.00	0.00
2 G, Other Product Manufacture and Use	HFC-245fa	0.00	13.33	0.00	21.09	21.09	0.00	0.00	0.00	0.00	0.00	0.00
2 G, Other Product Manufacture and Use	HFC-365mfc	0.00	0.70	0.00	22.36	22.36	0.00	0.00	0.00	0.00	0.00	0.00
2 G, Other Product Manufacture and Use	$C_{10}F_{18}$	C	C	0.00	24.92	24.92	0.00	0.00	0.00	0.00	0.00	0.00
3 A, Enteric Fermentation	CH_4	17,718.25	13,802.74	4.00	20.00	20.40	0.12	0.00	0.01	0.06	0.31	0.10
3 A, Enteric Fermentation	CH_4	14,016.97	8,938.37	2.17	10.86	11.08	0.01	0.00	0.01	0.02	0.11	0.01
3 A, Enteric Fermentation	CH_4	1,426.47	1,126.31	3.48	12.41	12.89	0.00	0.00	0.00	0.00	0.02	0.00

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	**Gas**	**Base year emissions or removals**	**Year *x* emissions or removals**	**Activity data uncertainty**	**Emission factor / estimation parameter uncertainty**	**Combined uncertainty**	**Contribution to Variance by Category in Year x**	**Type A sensitivity**	**Type B sensitivity**	**Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty**	**Uncertainty in trend in national emissions introduced by activity data uncertainty**	**Uncertainty introduced into the trend in total national emissions**
		Input data	**Input data**	**Input data Note A**	**Input data Note A**	$\sqrt{E^2+F^2}$	$\frac{(G*D)^2}{(\sum D)^2}$	Note B	$\lvert\frac{D}{\sum C}\rvert$	***I * F*** **Note C**	***J * E **** **Note D**	$\sqrt{2}\ K^2+L^2$
		t CO_2 equivalent	**t CO_2 equivalent**	**%**	**%**	**%**		**%**	**%**	**%**	**%**	**%**
3 B, Manure Management	CH_4	2,195.74	2,278.12	4.00	20.00	20.40	0.00	0.00	0.00	0.01	0.05	0.00
3 B, Manure Management	CH_4	2,396.23	1,413.97	2.25	11.24	11.46	0.00	0.00	0.00	0.00	0.02	0.00
3 B, Manure Management	CH_4	3,059.44	2,583.34	3.27	16.34	16.67	0.00	0.00	0.00	0.01	0.05	0.00
3 B, Manure Management	CH_4	150.93	195.27	4.70	10.34	11.35	0.00	0.00	0.00	0.00	0.00	0.00
3 B, Manure Management	N_2O	955.79	720.96	4.00	100.00	100.08	0.01	0.00	0.00	0.00	0.08	0.01
3 B, Manure Management	N_2O	982.87	721.15	2.08	52.03	52.07	0.00	0.00	0.00	0.00	0.04	0.00
3 B, Manure Management	N_2O	400.81	367.80	3.14	78.53	78.59	0.00	0.00	0.00	0.00	0.03	0.00
3 B, Manure Management	N_2O	126.91	135.66	4.99	49.81	50.06	0.00	0.00	0.00	0.00	0.01	0.00
3 B, Manure Management	N_2O	1,189.68	962.86	40.00	400.00	402.00	0.22	0.00	0.00	0.04	0.43	0.19
3 D, Agricultural Soils	N_2O	22,768.53	18,673.22	32.12	70.49	77.47	3.06	0.00	0.01	0.68	1.48	2.66
3 G, Liming	CO_2	2,200.53	1,963.28	3.59	2.94	4.64	0.00	0.00	0.00	0.01	0.01	0.00
3 H, Urea Application	CO_2	481.05	456.65	1.00	1.00	1.41	0.00	0.00	0.00	0.00	0.00	0.00
3 I, Other carbon-containing fertilisers	CO_2	510.45	189.68	3.00	3.00	4.24	0.00	0.00	0.00	0.00	0.00	0.00
3 J, Other	CH_4	0.28	1.312.93	10.00	20.00	22.36	0.00	0.00	0.00	0.01	0.03	0.00
3 J, Other	N_2O	0.12	252.76	9.52	97.10	97.57	0.00	0.00	0.00	0.00	0.03	0.00
4 A , Forest Land	CO_2	-19,707.07	-46,252.00	0.00	17.09	17.09	0.91	0.00	0.04	0.00	1.04	1.08
4 A , Forest Land	CH_4	39.47	35.87	0.00	96.91	96.91	0.00	0.00	0.00	0.00	0.00	0.00
4 A , Forest Land	N_2O	465.04	375.40	0.00	106.49	106.49	0.00	0.00	0.00	0.00	0.05	0.00
4 B, Cropland	CO_2	13,762.36	16,656.04	0.00	19.93	19.93	0.16	0.01	0.01	0.00	0.40	0.16
4 B, Cropland	CH_4	145.74	125.81	0.00	62.51	62.51	0.00	0.00	0.00	0.00	0.01	0.00
4 B, Cropland	N_2O	233.76	645.63	0.00	169.32	169.32	0.02	0.00	0.00	0.00	0.12	0.02
4 C, Grassland	CO_2	26,383.49	18,068.74	0.00	46.67	46.67	1.04	0.00	0.03	0.00	2.27	5.14
4 C, Grassland	CH_4	872.79	962.64	0.00	368.98	368.98	0.18	0.00	0.00	0.00	0.40	0.16
4 C, Grassland	N_2O	66.89	122.45	0.00	128.90	128.90	0.00	0.00	0.00	0.00	0.02	0.00
4 D, Wetlands	CO_2	3,705.75	4,452.15	0.00	33.04	33.04	0.03	0.00	0.00	0.00	0.18	0.03
4 D, Wetlands	CH_4	335.07	683.70	0.00	54.27	54.27	0.00	0.00	0.00	0.00	0.04	0.00
4 D, Wetlands	N_2O	34.10	42.36	0.00	165.65	165.65	0.00	0.00	0.00	0.00	0.01	0.00

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year *x* emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year x	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data Note A	Input data Note A	$\sqrt{E^2+F^2}$	$\frac{(G*D)^2}{(\sum D)^2}$	Note B	$\lvert\frac{D}{\sum C}\rvert$	*I * F* Note C	*J * E ** Note D	$\sqrt{2}\ K^2+L^2$
		t CO_2 equivalent	t CO_2 equivalent	%	%	%		%	%	%	%	%
4 E, Settlements	CO_2	1,776.57	1,075.87	0.00	18.62	18.62	0.00	0.00	0.01	0.00	0.18	0.03
4 E, Settlements	CH_4	48.03	65.27	0.00	60.89	60.89	0.00	0.00	0.00	0.00	0.00	0.00
4 E, Settlements	N_2O	170.94	326.29	0.00	142.34	142.34	0.00	0.00	0.00	0.00	0.05	0.00
4 G, Harvested Wood Products	CO_2	-1,330.35	-8,651.28	0.00	29.85	29.85	0.10	0.01	0.01	0.00	0.32	0.10
5 A, Solid Waste Disposal	CH_4	34,200.20	6,769.63	0.00	50.00	50.00	0.17	0.01	0.01	0.00	0.38	0.15
5 B, Biological Treatment of Solid Waste	CH_4	25.34	713.72	1.43	200.47	200.48	0.03	0.00	0.00	0.00	0.16	0.03
5 B, Biological Treatment of Solid Waste	N_2O	15.97	309.87	1.46	163.01	163.01	0.00	0.00	0.00	0.00	0.06	0.00
5 D 1, Domestic Wastewater	CH_4	2,563.25	435.53	3.17	23.92	24.13	0.00	0.00	0.00	0.00	0.01	0.00
5 D 1, Domestic Wastewater	N_2O	1,157.46	431.67	33.24	3,889.93	3,890.07	4.12	0.00	0.00	0.02	1.89	3.59
5 D 2, Industrial Wastewater	CH_4	9.25	47.23	0.00	50.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00
5 D 2, Industrial Wastewater	N_2O	31.59	26.80	50.00	300.00	304.14	0.00	0.00	0.00	0.00	0.01	0.00
5 E, Other	CH_4	0.00	2.43	2.00	20.00	20.10	0.00	0.00	0.00	0.00	0.00	0.00
5 E, Other	N_2O	0.00	33.57	2.00	20.00	20.10	0.00	0.00	0.00	0.00	0.00	0.00

Table 603: Uncertainties by sectors (approach 2; Monte Carlo simulation pursuant to Table 3.5 of the 2006 IPCC Guidelines)

A1	A2	B	C	D	E-	E+	F-	F+	G-	G+	H	I	J-	J+
IPCC category	Qualifier	gas	Base year emissions or removals	Emissions or removals 2020	Activity data uncertainty		Emission factor uncertainty		Combined uncertainty		Contribution to variance 2020		Inventory trend in national emissions for 2020; increase with respect to base year	
			t CO_2 equivalent	t CO_2 equivalent	-%	+%	-%	+%	-%	+%	fraction	% of base year	-%	+%
Sum		**GHG**	**1,272,617.93**	**717,472.61**					**3.18**	**3.45**		**-43.62**	**9.01**	**9.45**
1 A 1 a, Public Electricity and Heat Production	fossil fuels	CO_2	338,451.16	180,749.02	7.49	7.77	2.64	2.64	3.39	3.45	0.07	-46.60	8.44	8.80
1 A 1 a, Public Electricity and Heat Production	fossil fuels	CH_4	172.17	2,211.84	29.68	44.50	48.70	117.17	28.91	39.92	0.00	1,184.70	48.44	65.40
1 A 1 a, Public Electricity and Heat Production	fossil fuels	N_2O	2,407.46	1,596.45	25.53	24.35	50.02	45.87	20.74	20.81	0.00	-33.69	103.95	145.08
1 A 1 b, Petroleum Refining	fossil fuels	CO_2	20,165.56	18,553.09	10.18	10.66	9.81	10.90	5.39	5.53	0.00	-8.00	108.91	115.57
1 A 1 b, Petroleum Refining	fossil fuels	CH_4	16.06	14.27	39.68	39.57	30.07	53.40	19.55	19.71	0.00	-11.16	304.91	375.06
1 A 1 b, Petroleum Refining	fossil fuels	N_2O	100.39	57.67	58.57	53.07	33.42	35.49	35.31	35.93	0.00	-42.55	483.90	671.42
1 A 1 c, Manufacture of Solid Fuels and Other Energy	fossil fuels	CO_2	65,289.06	9,010.32	11.55	12.22	11.01	11.42	5.17	5.25	0.00	-86.20	2.11	2.18
1 A 1 c, Manufacture of Solid Fuels and Other Energy	fossil fuels	CH_4	91.98	129.57	31.49	41.69	59.17	126.58	50.33	87.36	0.00	40.87	1,692.14	3,103.75
1 A 1 c, Manufacture of Solid Fuels and Other Energy	fossil fuels	N_2O	659.23	153.28	18.30	22.03	45.70	53.00	26.04	26.67	0.00	-76.75	23.59	28.70
1 A 2 a, Iron and steel	fossil fuels	CO_2	35,269.33	32,589.67	13.27	14.54	10.57	10.95	5.92	6.37	0.01	-7.60	490.30	522.83
1 A 2 a, Iron and steel	fossil fuels	CH_4	62.45	54.80	11.22	10.49	32.23	34.37	24.83	25.08	0.00	-12.26	348.00	479.42
1 A 2 a, Iron and steel	fossil fuels	N_2O	155.10	97.72	39.17	35.26	72.36	95.12	36.37	36.64	0.00	-37.00	322.20	501.75
1 A 2 b, Non-ferrous metals	fossil fuels	CO_2	1,629.22	1,487.49	9.80	10.44	1.37	1.36	8.32	8.81	0.00	-8.70	25.99	28.12
1 A 2 b, Non-ferrous metals	fossil fuels	CH_4	1.39	1.66	20.70	14.32	67.58	75.51	68.86	71.27	0.00	19.60	815.93	1,737.33
1 A 2 b, Non-ferrous metals	fossil fuels	N_2O	17.14	7.91	35.47	22.40	55.36	58.36	63.51	65.07	0.00	-53.85	112.01	196.98
1 A 2 d, Pulp, Paper and Print	fossil fuels	CO_2	3.65	7.80	8.65	8.83	3.04	3.17	5.62	5.73	0.00	113.96	65.06	68.65
1 A 2 d, Pulp, Paper and Print	fossil fuels	CH_4	0.65	2.57	43.66	42.93	55.65	65.59	48.30	48.39	0.00	293.75	90.75	129.30
1 A 2 d, Pulp, Paper and Print	fossil fuels	N_2O	2.81	11.05	10.69	11.37	10.19	11.80	6.91	7.43	0.00	293.75	14.74	15.85
1 A 2 e, Food Processing, Beverages and Tobacco	fossil fuels	CO_2	2,015.91	241.42	5.94	6.87	3.15	3.29	3.53	3.64	0.00	-88.02	0.71	0.74
1 A 2 e, Food Processing, Beverages and Tobacco	fossil fuels	CH_4	4.48	0.18	28.46	35.69	40.82	48.39	37.01	37.58	0.00	-95.93	5.10	8.20
1 A 2 e, Food Processing, Beverages and Tobacco	fossil fuels	N_2O	24.65	2.24	22.32	23.76	52.07	65.60	39.53	44.35	0.00	-90.90	8.30	15.58
1 A 2 f, Non-Metallic Minerals	fossil fuels	CO_2	18,507.38	12,586.90	11.82	13.68	2.01	2.09	2.81	2.89	0.00	-31.99	9.50	9.66
1 A 2 f, Non-Metallic Minerals	fossil fuels	CH_4	50.28	14.90	42.67	53.02	33.88	35.34	25.88	25.94	0.00	-70.36	184.71	247.61
1 A 2 f, Non-Metallic Minerals	fossil fuels	N_2O	205.26	117.10	27.64	39.06	35.24	41.23	23.30	23.94	0.00	-42.95	82.66	123.99
1 A 2 g, Other	fossil fuels	CO_2	127,739.52	68,423.36	15.16	17.12	3.64	4.00	2.75	2.88	0.01	-46.44	12.71	13.18
1 A 2 g, Other	fossil fuels	CH_4	132.37	197.84	40.56	50.42	66.95	158.84	18.15	22.28	0.00	49.45	82.69	103.56
1 A 2 g, Other	fossil fuels	N_2O	945.39	543.70	40.40	48.96	28.71	30.16	12.55	12.91	0.00	-42.49	84.57	96.43

A1	A2	B	C	D	E-	E+	F-	F+	G-	G+	H	I	J-	J+
IPCC category	**Qualifier**	**gas**	**Base year emissions or removals**	**Emissions or removals 2020**	**Activity data uncertainty**		**Emission factor uncertainty**		**Combined uncertainty**		**Contribution to variance 2020**		**Inventory trend in national emissions for 2020; increase with respect to base year**	
			t CO_2 equivalent	**t CO_2 equivalent**	**-%**	**+%**	**-%**	**+%**	**-%**	**+%**	**fraction**	**% of base year**	**-%**	**+%**
1 A 3 a, Domestic Aviation	fossil fuels	CO_2	2,410.94	1,037.78	12.59	12.88	5.45	5.73	8.52	8.68	0.00	-56.96	10.92	11.78
1 A 3 a, Domestic Aviation	fossil fuels	CH_4	2.63	1.50	15.03	13.03	53.50	137.66	53.85	93.09	0.00	-42.73	351.24	700.21
1 A 3 a, Domestic Aviation	fossil fuels	N_2O	24.31	10.41	40.11	36.36	63.57	143.68	57.76	108.41	0.00	-57.19	95.55	207.46
1 A 3 b, Road Transport	fossil fuels	CO_2	151,886.32	141,282.74	37.69	45.81	7.92	8.97	4.83	4.83	0.08	-6.98	43.59	47.47
1 A 3 b, Road Transport	fossil fuels	CH_4	1,561.13	208.64	28.98	45.00	63.16	151.74	12.69	14.88	0.00	-86.63	15.19	18.61
1 A 3 b, Road Transport	fossil fuels	N_2O	1,343.46	1,642.22	42.16	59.29	32.09	60.11	13.80	16.12	0.00	22.24	771.58	1,005.40
1 A 3 c, Railways	fossil fuels	CO_2	3,122.15	783.08	10.38	10.45	3.23	3.20	9.95	10.23	0.00	-74.92	6.27	6.97
1 A 3 c, Railways	fossil fuels	CH_4	17.61	0.26	13.78	13.36	54.16	93.85	29.62	30.47	0.00	-98.50	0.91	1.19
1 A 3 c, Railways	fossil fuels	N_2O	7.66	1.97	15.48	14.51	39.50	63.52	37.43	54.67	0.00	-74.26	27.52	43.79
1 A 3 d, Domestic Navigation	fossil fuels	CO_2	3,001.22	1,392.69	22.74	44.00	2.95	4.25	25.43	25.45	0.00	-53.60	52.61	80.34
1 A 3 d, Domestic Navigation	fossil fuels	CH_4	1.94	0.54	33.99	53.57	34.11	43.73	38.82	44.62	0.00	-72.02	32.99	57.76
1 A 3 d, Domestic Navigation	fossil fuels	N_2O	20.87	11.66	11.13	13.21	47.99	74.73	33.72	44.78	0.00	-44.13	136.74	202.54
1 A 3 e, Other Transportation	fossil fuels	CO_2	1,083.27	767.52	1.21	1.75	1.08	1.07	1.50	1.79	0.00	-29.15	2.80	2.98
1 A 3 e, Other Transportation	fossil fuels	CH_4	5.31	3.76	6.81	4.69	43.52	64.67	39.56	56.58	0.00	-29.34	71.41	111.43
1 A 3 e, Other Transportation	fossil fuels	N_2O	14.49	6.70	4.63	3.17	51.51	51.91	48.21	48.48	0.00	-53.73	37.54	61.48
1 A 4 a, Commercial/Institutional	fossil fuels	CO_2	64,111.32	27,615.78	10.27	11.15	1.54	1.58	5.63	5.73	0.00	-56.93	8.93	9.59
1 A 4 a, Commercial/Institutional	fossil fuels	CH_4	1.461.71	83.17	42.66	50.22	47.49	103.41	35.10	51.01	0.00	-94.31	35.47	67.46
1 A 4 a, Commercial/Institutional	fossil fuels	N_2O	147.44	89.08	41.61	48.16	38.08	57.75	29.35	33.90	0.00	-39.58	44.76	60.83
1 A 4 b, Residential	fossil fuels	CO_2	128,635.75	89,770.76	8.89	10.01	1.44	1.63	6.29	6.45	0.06	-30.21	20.66	22.06
1 A 4 b, Residential	fossil fuels	CH_4	2,484.67	785.86	20.31	21.53	45.09	67.81	40.25	56.53	0.00	-68.37	395.87	634.88
1 A 4 b, Residential	fossil fuels	N_2O	768.85	290.19	27.02	41.44	52.99	76.94	34.19	39.07	0.00	-62.26	73.81	103.47
1 A 4 c, Agriculture/Forestry/Fishing	fossil fuels	CO_2	10,177.88	6,027.12	27.31	27.81	7.91	7.29	12.71	12.73	0.00	-40.78	58.82	63.40
1 A 4 c, Agriculture/Forestry/Fishing	fossil fuels	CH_4	241.36	171.66	22.50	24.68	46.81	81.44	30.38	42.44	0.00	-28.88	70.10	101.47
1 A 4 c, Agriculture/Forestry/Fishing	fossil fuels	N_2O	60.97	67.57	33.14	35.21	46.90	77.14	29.14	40.33	0.00	10.82	187.81	266.84
1 A 5, Other: Military	fossil fuels	CO_2	11.752.90	743.34	9.34	10.51	2.65	2.85	3.91	4.05	0.00	-93.68	1.16	1.21
1 A 5, Other: Military	fossil fuels	CH_4	279.42	1.33	24.71	52.36	61.92	85.34	44.25	44.38	0.00	-99.52	5.59	8.01
1 A 5, Other: Military	fossil fuels	N_2O	60.89	3.18	26.36	26.68	66.21	199.21	41.04	77.00	0.00	-94.78	7.53	13.50
1 B 1, Solid Fuels	fossil fuels	CO_2	1,832.80	629.55	3.02	2.99	25.03	30.84	32.06	32.49	0.00	-65.65	89.35	126.44
1 B 1, Solid Fuels	fossil fuels	CH_4	25,553.44	136.68	25.18	24.10	33.45	40.61	27.09	27.01	0.00	-99.47	1.29	2.18
1 B 2 a, Oil		CO_2	477.63	393.26	35.64	46.82	30.81	31.33	26.06	28.17	0.00	-17.66	263.83	348.96
1 B 2 a, Oil		CH_4	241.85	17.00	10.99	11.14	21.23	21.40	17.78	19.08	0.00	-92.97	3.04	3.52
1 B 2 a, Oil		N_2O	0.32	0.25	0.00	0.00	0.00	0.00	29.63	30.03	0.00	-21.55	308.14	427.05
1 B 2 b, Natural Gas		CO_2	986.51	470.81	26.10	33.35	34.26	37.77	22.33	22.25	0.00	-52.27	20.50	26.53
1 B 2 b, Natural Gas		CH_4	7,997.44	4,764.96	24.49	29.97	54.19	67.67	17.99	21.01	0.00	-40.42	23.00	27.47
1 B 2 c, Venting and Flaring		CO_2	543.52	321.31	3.00	3.00	10.02	10.02	15.50	15.52	0.00	-40.88	62.52	74.51
1 B 2 c, Venting and Flaring		CH_4	1.65	0.54	0.00	0.00	0.00	0.00	19.15	19.19	0.00	-66.95	31.59	41.43
1 B 2 c, Venting and Flaring		N_2O	2.04	0.69	3.00	3.00	25.03	25.03	68.19	69.30	0.00	-66.18	103.48	167.18

A1	A2	B	C	D	E-	E+	F-	F+	G-	G+	H	I	J-	J+
IPCC category	**Qualifier**	**gas**	**Base year emissions or removals**	**Emissions or removals 2020**	**Activity data uncertainty**		**Emission factor uncertainty**		**Combined uncertainty**		**Contribution to variance 2020**		**Inventory trend in national emissions for 2020; increase with respect to base year**	
			t CO_2 equivalent	**t CO_2 equivalent**	**-%**	**+%**	**-%**	**+%**	**-%**	**+%**	**fraction**	**% of base year**	**-%**	**+%**
2 A 1, Cement Production		CO_2	15,297.27	13,357.49	2.49	2.49	1.99	2.00	3.18	3.21	0.00	-12.68	27.01	28.23
2 A 2, Lime Production		CO_2	5,986.62	4,180.89	2.66	2.68	7.35	5.93	7.17	6.09	0.00	-30.16	19.90	21.22
2 A 3, Glass Production		CO_2	780.48	857.26	8.86	10.27	24.62	29.43	11.38	11.61	0.00	9.84	628.24	703.71
2 A 4, Other Process Uses of Carbonates		CO_2	1.458.01	647.77	9.17	8.83	9.78	11.23	13.52	13.91	0.00	-55.57	10.33	12.60
2 B 1, Ammonia Production		CO_2	6,025.00	4,133.00	0.00	0.00	0.00	0.00	1.00	0.99	0.00	-31.40	2.44	2.45
2 B 2, Nitric Acid Production		N_2O	3,257.50	377.79	1.69	1.70	4.01	4.17	2.26	2.26	0.00	-88.40	0.41	0.42
2 B 3, Adipic Acid Production		N_2O	18,076.68	189.11	1.99	1.99	6.01	5.93	6.30	6.33	0.00	-98.95	0.08	0.09
2 B 5, Carbide Production		CO_2	443.16	4.49	10.00	9.94	10.03	10.05	13.80	14.56	0.00	-98.99	3.95	4.60
2 B 7, Soda Ash Production		CO_2	667.25	360.96	0.00	0.00	0.00	0.00	2.49	2.49	0.00	-45.90	7.14	7.35
2 B 8, Petrochemical and Carbon Black Production		CO_2	973.97	792.94	46.36	58.92	22.33	23.56	17.34	18.56	0.00	-18.59	243.91	296.10
2 B 8, Petrochemical and Carbon Black Production		CH_4	333.69	503.42	25.81	27.17	14.25	15.80	19.63	20.19	0.00	50.86	159.66	195.98
2 B 9 a, By-product Emissions		HFC-23	C	C	0.00	0.00	0.00	0.00	3.01	2.98	0.00	-99.96	0.00	0.00
2 B 9 b, Fugitive Emissions		SF_6	159.60	0.89	0.00	0.00	0.00	0.00	2.98	2.97	0.00	-99.44	0.02	0.02
2 B 9 b, Fugitive Emissions		HFC-134a	C	C	0.00	0.00	0.00	0.00	3.02	3.01	0.00	-45.74	4.99	5.12
2 B 9 b, Fugitive Emissions		HFC-227ea	C	C	0.00	0.00	0.00	0.00	3.00	3.02	0.00		0.00	0.00
2 B 9 b, Fugitive Emissions		CF_4	C	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00
2 B 10, Other		CH_4	59.51	59.48	0.00	0.00	0.00	0.00	39.10	39.02	0.00	-0.05	5,846.08	8,946.84
2 B 10, Other		N_2O	C	C	20.03	20.00	62.30	62.02	62.94	68.22	0.00	0.00	461.19	962.71
2 C 1, Iron and Steel Production		CO_2	22,810.29	14,538.07	20.87	23.10	8.35	8.42	9.31	9.70	0.00	-36.27	37.46	40.54
2 C 1, Iron and Steel Production		CH_4	4.67	4.37	1.01	1.01	77.49	80.01	67.80	67.52	0.00	-6.38	163.90	293.49
2 C 1, Iron and Steel Production		N_2O	26.54	11.96	15.33	11.73	71.99	76.15	71.78	74.25	0.00	-54.94	526.46	1,242.41
2 C 2, Ferroalloys Production		CO_2	429.00	5.92	50.22	50.29	6.96	6.96	50.44	51.20	0.00	-98.62	474.25	135.81
2 C 2, Ferroalloys Production		CH_4	8.58	1.61	50.22	50.29	49.77	49.73	62.62	80.69	0.00	-81.19	362.84	235.32
2 C 3, Aluminium Production		CO_2	1.011.92	723.22	0.98	1.01	49.41	49.95	49.42	49.95	0.00	-28.53	59,827.87	108,529.78
2 C 3, Aluminium Production		SF_6	C	C	0.00	0.00	0.00	0.00	9.89	10.81	0.00	-63.76	7.92	8.89
2 C 3, Aluminium Production		CF_4	1.544.51	63.98	0.00	0.00	0.00	0.00	14.97	14.84	0.00	-95.86	0.86	1.01
2 C 3, Aluminium Production		C_2F_6	256.20	12.72	0.00	0.00	0.00	0.00	15.01	15.15	0.00	-95.03	1.04	1.22
2 C 4, Magnesium Production		SF_6	C	C	0.00	0.00	0.00	0.00	17.33	11.00	0.00	-73.15	7.90	9.39
2 C 4, Magnesium Production		HFC-134a	0.00	8.26	0.00	0.00	0.00	0.00	20.66	12.96	0.00		0.00	0.00
2 C 5, Lead Production		CO_2	157.87	73.59	10.80	18.40	34.95	40.41	35.37	36.05	0.00	-53.39	82.08	120.62
2 C 6, Zinc Production		CO_2	670.80	284.30	0.00	0.00	0.00	0.00	41.24	41.43	0.00	-57.62	46.27	70.89
2 D 1, Lubricant Use		CO_2	188.65	182.44	24.64	24.87	49.75	49.87	37.20	42.69	0.00	-3.29	1,033.96	1,527.45
2 D 2, Paraffin Wax Use		CO_2	242.70	452.49	0.00	0.00	0.00	0.00	71.32	71.05	0.00	86.44	190.39	451.75
2 D 2, Paraffin Wax Use		N_2O	0.70	1.30	0.00	0.00	0.00	0.00	60.39	61.08	0.00	86.44	202.14	522.99
2 D 3, Other		CO_2	2,551.10	1,291.75	19.93	19.97	10.06	10.10	9.40	9.49	0.00	-49.37	21.29	23.24

A1	A2	B	C	D	E-	E+	F-	F+	G-	G+	H	I	J-	J+
IPCC category	**Qualifier**	**gas**	**Base year emissions or removals**	**Emissions or removals 2020**	**Activity data uncertainty**		**Emission factor uncertainty**		**Combined uncertainty**		**Contribution to variance 2020**		**Inventory trend in national emissions for 2020; increase with respect to base year**	
			t CO_2 equivalent	**t CO_2 equivalent**	**-%**	**+%**	**-%**	**+%**	**-%**	**+%**	**fraction**	**% of base year**	**-%**	**+%**
2 E, Electronics Industry		SF_6	47.28	27.18	0.00	0.00	0.00	0.00	7.05	7.34	0.00	-42.52	13.32	14.38
2 E, Electronics Industry		NF_3	5.29	10.80	0.00	0.00	0.00	0.00	7.03	7.35	0.00	104.20	19.12	20.67
2 E, Electronics Industry		HFC-23	17.11	14.05	0.00	0.00	0.00	0.00	7.01	7.42	0.00	-17.92	45.14	48.76
2 E, Electronics Industry		HFC-32	0.00	0.00	0.00	0.00	0.00	0.00	7.00	7.40	0.00		0.00	0.00
2 E, Electronics Industry		CF_4	102.61	65.77	0.00	0.00	0.00	0.00	6.55	6.75	0.00	-35.91	16.22	17.25
2 E, Electronics Industry		C_2F_6	162.48	42.92	0.00	0.00	0.00	0.00	6.96	7.38	0.00	-73.59	3.53	3.79
2 E, Electronics Industry		C_3F_8	0.00	12.19	0.00	0.00	0.00	0.00	6.98	7.40	0.00		0.00	0.00
2 E, Electronics Industry		$c\text{-}C_4F_8$	0.00	5.73	0.00	0.00	0.00	0.00	7.03	7.37	0.00		0.00	0.00
2 E, Electronics Industry		C_6F_{14}	25.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-100.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS		HFC-23	16.25	61.73	0.00	0.00	0.00	0.00	14.26	14.16	0.00	279.80	27.36	33.06
2 F, Product Uses as Substitutes for ODS		HFC-32	0.76	215.78	0.00	0.00	0.00	0.00	7.62	7.64	0.00	28,443.85	13.53	15.82
2 F, Product Uses as Substitutes for ODS		HFC-43-10mee	C	C	0.00	0.00	0.00	0.00	2.01	2.01	0.00		0.00	0.00
2 F, Product Uses as Substitutes for ODS		HFC-125	149.88	2,079.39	0.00	0.00	0.00	0.00	6.59	6.55	0.00	1,287.39	16.90	21.06
2 F, Product Uses as Substitutes for ODS		HFC-134a	2,268.24	4,760.20	0.00	0.00	0.00	0.00	5.85	5.84	0.00	109.86	18.30	20.55
2 F, Product Uses as Substitutes for ODS		HFC-143a	71.33	1,257.47	0.00	0.00	0.00	0.00	9.92	9.91	0.00	1,662.92	14.51	16.25
2 F, Product Uses as Substitutes for ODS		HFC-152a	90.07	31.09	0.00	0.00	0.00	0.00	2.79	2.81	0.00	-65.49	6.27	7.51
2 F, Product Uses as Substitutes for ODS		HFC-227ea	0.65	87.19	0.00	0.00	0.00	0.00	3.61	3.59	0.00	13,383.97	17.88	23.48
2 F, Product Uses as Substitutes for ODS		HFC-236fa	C	C	0.00	0.00	0.00	0.00	10.05	10.05	0.00		0.00	0.00
2 F, Product Uses as Substitutes for ODS		HFC-245fa	C	C	0.00	0.00	0.00	0.00	8.18	8.27	0.00		0.00	0.00
2 F, Product Uses as Substitutes for ODS		HFC-365mfc	C	C	0.00	0.00	0.00	0.00	8.83	8.90	0.00		0.00	0.00
2 F, Product Uses as Substitutes for ODS		C_2F_6	0.00	2.69	0.00	0.00	0.00	0.00	21.12	21.04	0.00		0.00	0.00
2 F, Product Uses as Substitutes for ODS		C_3F_8	19.91	1.26	0.00	0.00	0.00	0.00	19.07	19.01	0.00	-93.68	1.86	2.42
2 F, Product Uses as Substitutes for ODS		C_6F_{14}	C	C	0.00	0.00	0.00	0.00	19.87	19.72	0.00		0.00	0.00
2 G, Other Product Manufacture and Use		CH_4	4.53	23.33	20.08	20.05	20.21	20.07	26.53	30.06	0.00	415.20	66.94	89.48
2 G, Other Product Manufacture and Use		N_2O	C	C	89.74	110.55	43.60	67.79	47.50	47.42	0.00	-90.10	8.54	14.37
2 G, Other Product Manufacture and Use		SF_6	C	C	0.00	0.00	0.00	0.00	9.40	9.38	0.00	-54.76	25.89	27.03
2 G, Other Product Manufacture and Use		HFC-134a	0.00	0.20	0.00	0.00	0.00	0.00	22.51	22.31	0.00		0.00	0.00
2 G, Other Product Manufacture and Use		HFC-245fa	0.00	13.33	0.00	0.00	0.00	0.00	21.07	20.74	0.00		0.00	0.00
2 G, Other Product Manufacture and Use		HFC-365mfc	0.00	0.70	0.00	0.00	0.00	0.00	22.34	22.26	0.00		0.00	0.00
2 G, Other Product Manufacture and Use		$C_{10}F_{18}$	C	C	0.00	0.00	0.00	0.00	24.97	24.94	0.00		0.00	0.00
3 A, Enteric Fermentation	Dairy cows	CH_4	17,718.25	13,802.74	4.00	3.96	20.07	20.02	20.31	20.48	0.01	-22.10	209.90	259.47
3 A, Enteric Fermentation	non-dairy cattle	CH_4	14,016.97	8,938.37	11.32	11.87	13.14	14.36	10.98	11.02	0.00	-36.23	43.37	48.84
3 A, Enteric Fermentation	other animals	CH_4	1,426.47	1,126.31	16.50	16.60	34.31	43.74	12.80	12.95	0.00	-21.04	120.37	140.61

A1	A2	B	C	D	E-	E+	F-	F+	G-	G+	H	I	J-	J+
IPCC category	**Qualifier**	**gas**	**Base year emissions or removals**	**Emissions or removals 2020**	**Activity data uncertainty**		**Emission factor uncertainty**		**Combined uncertainty**		**Contribution to variance 2020**		**Inventory trend in national emissions for 2020; increase with respect to base year**	
			t CO_2 equivalent	**t CO_2 equivalent**	**-%**	**+%**	**-%**	**+%**	**-%**	**+%**	**fraction**	**% of base year**	**-%**	**+%**
3 B, Manure Management	Dairy cows	CH_4	2,195.74	2,278.12	4.00	4.00	19.96	20.15	20.25	20.64	0.00	3.75	452.04	561.16
3 B, Manure Management	non-dairy cattle	CH_4	2,396.23	1,413.97	10.15	10.82	17.66	19.91	11.40	11.42	0.00	-40.99	36.96	41.49
3 B, Manure Management	swine	CH_4	3,059.44	2,583.34	7.16	6.72	20.92	22.23	16.65	16.85	0.00	-15.56	796.49	944.41
3 B, Manure Management	other animals	CH_4	150.93	195.27	14.74	16.27	49.46	59.57	11.25	11.35	0.00	29.38	76.55	89.29
3 B, Manure Management	Dairy cows	N_2O	955.79	720.96	4.00	4.00	57.30	99.76	57.37	100.03	0.00	-24.57	8,240.95	18,093.72
3 B, Manure Management	non-dairy cattle	N_2O	982.87	721.15	30.64	42.58	44.63	94.04	34.00	49.04	0.00	-26.63	307.22	466.28
3 B, Manure Management	swine	N_2O	400.81	367.80	27.85	20.17	52.07	97.18	46.37	76.70	0.00	-8.23	685.77	1,253.43
3 B, Manure Management	other animals	N_2O	126.91	135.66	45.80	58.91	77.50	171.40	32.82	46.79	0.00	6.89	1,247.29	1,893.76
3 B, Manure Management	deposition	N_2O	1,189.68	962.86	40.02	40.44	94.83	402.68	95.19	405.87	0.02	-19.07	131.51	747.19
3 D, Agricultural Soils		N_2O	22,768.53	18,673.22	77.35	160.93	75.76	334.48	35.90	81.84	0.24	-17.99	3.315.01	5.777.91
3 G, Liming		CO_2	2,200.53	1,963.28	3.55	3.40	3.53	3.39	4.38	4.56	0.00	-10.78	43.23	34.37
3 H, Urea Application		CO_2	481.05	456.65	1.01	0.99	1.01	1.00	1.42	1.41	0.00	-5.07	485.54	493.55
3 I, Other carbon-containing fertilisers		CO_2	510.45	189.68	2.99	3.00	2.99	2.99	4.19	4.27	0.00	-62.84	5.59	5.82
3 J, Other		CH_4	0.28	1.312.93	9.97	10.07	19.92	19.91	21.76	23.11	0.00	475,758.23	28.42	35.99
3 J, Other		N_2O	0.12	252.76	95.16	387.93	60.73	105.45	56.33	97.75	0.00	202,928.66	70.46	152.15
4 A , Forest Land		CO_2	-19,707.07	-46,252.00	0.00	0.00	0.00	0.00	19.90	19.95	0.15	134.70	43.85	49.25
4 A , Forest Land		CH_4	39.47	35.87	0.00	0.00	0.00	0.00	66.00	154.27	0.00	-9.12	314.90	863.97
4 A , Forest Land		N_2O	465.04	375.40	0.00	0.00	0.00	0.00	83.21	81.88	0.00	-19.28	1,045.75	2,635.12
4 B, Cropland		CO_2	13,762.36	16,656.04	0.00	0.00	0.00	0.00	14.46	12.54	0.01	21.03	120.17	163.93
4 B, Cropland		CH_4	145.74	125.81	0.00	0.00	0.00	0.00	42.79	65.58	0.00	-13.68	1,219.95	2,225.46
4 B, Cropland		N_2O	233.76	645.63	0.00	0.00	0.00	0.00	56.45	120.88	0.00	176.20	104.91	240.19
4 C, Grassland		CO_2	26,383.49	18,068.74	0.00	0.00	0.00	0.00	91.69	76.55	0.26	-31.51	226.92	454.47
4 C, Grassland		CH_4	872.79	962.64	0.00	0.00	0.00	0.00	50.62	91.04	0.00	10.30	324.68	672.01
4 C, Grassland		N_2O	66.89	122.45	0.00	0.00	0.00	0.00	46.34	91.65	0.00	83.06	118.68	705.00
4 D, Wetlands		CO_2	3,705.75	4,452.15	0.00	0.00	0.00	0.00	43.85	116.52	0.03	20.14	282.93	562.33
4 D, Wetlands		CH_4	335.07	683.70	0.00	0.00	0.00	0.00	57.32	234.08	0.00	104.05	111.63	398.55
4 D, Wetlands		N_2O	34.10	42.36	0.00	0.00	0.00	0.00	8.90	8.99	0.00	24.25	86.05	107.42
4 E, Settlements		CO_2	1,776.57	1,075.87	0.00	0.00	0.00	0.00	250.53	177.62	0.01	-39.44	330.68	313.71
4 E, Settlements		CH_4	48.03	65.27	0.00	0.00	0.00	0.00	41.39	67.12	0.00	35.89	167.74	327.50
4 E, Settlements		N_2O	170.94	326.29	0.00	0.00	0.00	0.00	51.48	130.26	0.00	90.88	136.25	315.38
4 G, Harvested Wood Products		CO_2	-1,330.35	-8,651.28	0.00	0.00	0.00	0.00	32.42	32.22	0.01	550.30	53.88	68.67
5 A, Solid Waste Disposal		CH_4	34,200.20	6,769.63	0.00	0.00	0.00	0.00	32.34	22.42	0.01	-80.21	9.30	13.01
5 B, Biological Treatment of Solid Waste		CH_4	25.34	713.72	11.06	33.35	71.12	210.41	60.93	119.13	0.00	2,716.57	98.17	255.62
5 B, Biological Treatment of Solid Waste		N_2O	15.97	309.87	14.51	17.13	37.59	70.95	33.52	46.97	0.00	1,840.87	79.57	133.58

A1	A2	B	C	D	E-	E+	F-	F+	G-	G+	H	I	J-	J+
IPCC category	**Qualifier**	**gas**	**Base year emissions or removals**	**Emissions or removals 2020**	**Activity data uncertainty**		**Emission factor uncertainty**		**Combined uncertainty**		**Contribution to variance 2020**		**Inventory trend in national emissions for 2020; increase with respect to base year**	
			t CO_2 equivalent	**t CO_2 equivalent**	**-%**	**+%**	**-%**	**+%**	**-%**	**+%**	**fraction**	**% of base year**	**-%**	**+%**
5 D 1, Domestic Wastewater		CH_4	2,563.25	435.53	30.21	29.97	36.06	35.81	43.14	50.75	0.00	-83.01	3.21	5.29
5 D 1, Domestic Wastewater		N_2O	1,157.46	431.67	86.38	140.53	96.92	368.03	77.75	249.39	0.00	-62.71	681.70	2,731.47
5 D 2, Industrial Wastewater		CH_4	9.25	47.23	0.00	0.00	0.00	0.00	49.82	50.52	0.00	410.48	83.76	152.68
5 D 2, Industrial Wastewater		N_2O	31.59	26.80	50.11	49.97	99.89	597.03	99.90	594.11	0.00	-15.15	100.71	236.43
5 E, Other		CH_4	0.00	2.43	2.01	2.00	20.11	20.09	20.16	20.28	0.00		36.76	45.86
5 E, Other		N_2O	0.00	33.57	2.02	2.01	19.93	20.04	20.02	20.17	0.00		61.00	215.75

Uncertainties for categories have been determined successively, within the framework of UBA sections' data deliveries for current emissions reporting. In addition, external experts have carried out additional uncertainties determination, in research projects, for categories for which no uncertainties information, or incomplete information, has been available to date. The results of such uncertainties analysis have been integrated within the current report.

The uncertainties in the categories Agriculture and LULUCF are estimated by experts of the Thünen Institute (TI).

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