CLIMATE CHANGE
29/2023

Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2023

National Inventory Report for the German Greenhouse Gas Inventory 1990 – 2021

German Environment Agency

Umwelt Bundesamt

CLIMATE CHANGE 29/2023

Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2023

National Inventory Report for the German Greenhouse
Gas Inventory 1990 – 2021

Imprint

Publisher
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
buergerservice@uba.de
Internet: www.umweltbundesamt.de

/umweltbundesamt.de
/umweltbundesamt

eport completed in:
April 2023

Edited by:
Section V 1.6 Emission Situation
Dirk Günther (Section Lead), Patrick Gniffke, Yaman Tarakji (support)

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

ISSN 1862-4359

Dessau-Roßlau, June 2023

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 German 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 1.0, based on the CSE database, and with trend tables last revised as of 30 November 2022), is available on the website of the German Environment Agency:
http://www.umweltbundesamt.de/themen/klima-energie/treibhausgas-emissionen

Management of the report as a whole: Dirk Günther, Patrick Gniffke (UBA V 1.6)

Supporting editor: Yaman Tarakji (UBA V 1.6)

For the individual chapters:

Part I: Annual deliveries for the inventories [ip = in part]:

Chapter 1.1	Dirk Günther (UBA V 1.6); Thomas Voigt (UBA V 1.1)
Chapters 1.2.1 & 1.2.2	Dirk Günther (UBA V 1.6)
Chapters 1.3.2, 1.3.3, 1.6 ip	Stephan Schiller (UBA V 1.6)
Chapters 1.3.3.1.8, 1.6.2	Robert Kludt (UBA V 1.6)
Chapters 1.3.2.4, 2, 3.2.1, 3.2.3&5, 3.2.13	Dirk Günther (UBA V 1.6)
Chapter 1.4	Dirk Günther (UBA V 1.6) and the relevant specialised contact persons (Fachliche Ansprechpartner (FAP))
Chapter 1.5	David Kuntze (UBA V 1.6)
Chapters 1.7, 1.8	Kevin Hausmann (UBA V 1.6)
Chapter 3.2	Petra Icha Jens Langenfeld (UBA V 1.5), Marion Dreher (UBA V 1.5), Kristina Juhrich (UBA III 2.1)
Chapter 3.2.2.2	Sabine Gores (Öko-Institut Berlin), Michael Kotzulla (UBA V 1.6), Frank Wetzel (UBA I 2.2)
Chapter 3.2.2.3	Katharina Koppe (UBA I 2.2), Michael Kotzulla (UBA V 1.6)
Chapter 3.4	Michael Kotzulla (UBA V 1.6)
Chapters 3.2.6 – 3.2.8, 3.2.9.7.2	Petra Icha, Jens Langenfeld (UBA V 1.5), Kristina Juhrich (UBA III 2.1)
Chapter 3.2.9.1	Petra Icha (UBA V 1.5), Sebastian Plickert (UBA III 2.2)
Chapters 3.2.9.2 - 3.2.9.3, 3.2.9.5, 3.2.9.7 - 3.2.9.11	Petra Icha (UBA V 1.5)
Chapter 3.2.9.4	Petra Icha (UBA V 1.5), Almut Reichart (UBA III 2.1)
Chapter 3.2.10.1	Sabine Gores (Öko-Institut Berlin), Michael Kotzulla (UBA V 1.6), Frank Wetzel (UBA I 2.2)
Chapters 3.2.10.2 - 3.2.10.4	Gunnar Gohlisch (UBA I 2.2), Michael Kotzulla (UBA V 1.6)
Chapter 3.2.10.5	Kristina Juhrich (UBA III 2.1)
Chapters 3.2.11 + 3.2.13	Christian Liesegang (UBA III 2.1), Detlef Drosihn (UBA V 1.5)
Chapters 3.2.12 + 3.2.14	Michael Kotzulla (UBA V 1.6)
Chapter 3.3.1	Christian Böttcher (UBA V 1.6)
Chapter 3.3.2	Christian Böttcher (UBA V.1.6), Christopher Proske (UBA III 2.1), Karen Pannier (UBA III 2.1); Andreas Bertram (UBA V 1.3); Charlotte Grosse (DBI GuT)
Chapters 4.2.1 - 4.2.2	Maja Bernicke (UBA III 2.2)
Chapter 4.2.3	Sandra Leuthold (UBA III 2.2)
Chapter 4.2.4.1	Til Bolland (UBA III 2.2)

Chapters 4.2.4.2 - 4.2.4.4	Robert Kludt (UBA V 1.6)
Chapters 4.3.1 & 4.3.2	Anna Koska (UBA III 2.1)
Chapter 4.3.3	Jens Reichel (UBA V 1.6), Traute Fiedler (UBA III 2.1)
Chapter 4.3.4	Jens Reichel (UBA V 1.6), Traute Fiedler (UBA III 2.1)
Chapters 4.3.5 - 4.3.6	Anna Koska (UBA III 2.1)
Chapter 4.3.7	Robert Kludt (UBA V 1.6)
Chapters 4.3.8 & 4.3.10	Jens Reichel (UBA V 1.6) , Traute Fiedler (UBA III 2.1), Christian Böttcher (V.1.6)
Chapter 4.3.9	Cornelia Elsner (UBA III 1.4)
Chapter 4.4.1	Sebastian Plickert (UBA III 2.2)
Chapter 4.4.2	Christian Lehmann (UBA III 2.2)
Chapter 4.4.3	Christian Lehmann (UBA III 2.2), Cornelia Elsner (UBA III 1.4), Kerstin Martens (UBA III 1.4)
Chapter 4.4.4	Cornelia Elsner (UBA III 1.4), Kerstin Martens (UBA III 1.4)
Chapters 4.5.1 & 4.5.2	Jens Reichel (UBA V 1.6), Michael Kotzulla (UBA V 1.6)
Chapter 4.5.3	Folke Dettling, Conrad Dorer (UBA III 1.4), David Kuntze (UBA V 1.6)
Chapters 4.5.4 & 4.5.5	Robert Kludt (UBA V 1.6
Chapter 4.5.6	Michael Kotzulla (UBA V 1.6)
Chapter 4.6	Cornelia Elsner (UBA III 1.4), Kerstin Martens (UBA III 1.4)
Chapter 4.7	Kerstin Martens (UBA III 1.4), Cornelia Elsner (UBA III 1.4)
Chapters 4.8.1, 4.8.2 & 4.8.4	Cornelia Elsner (UBA III 1.4), Kerstin Martens (UBA III 1.4)
Chapter 4.8.5	Jens Reichel (UBA V 1.6)
Chapter 4.9.3	Kerstin Martens (UBA III 1.4), Cornelia Elsner (UBA III 1.4)
Chapter 5	Thünen Institute of Climate-Smart Agriculture (TI-AK): Cora Vos, Claus Rösemann, Roland Fuß; Ulrike Döring (UBA V 1.6)
Chapter 6.1	Johann Heinrich von Thünen Institute, Federal Research Institute for Rural Areas, Forestry and Fisheries (TI): Andreas Gensior, Roland Fuß, Karsten Dunger, Wolfgang Stümer; Ulrike Döring (UBA V 1.6)
Chapters 6.2 through 6.3	Johann Heinrich von Thünen Institute (TI): Andreas Gensior, Roland Fuß, Andreas Laggner, Birgit Laggner, Wolfgang Stümer, Sascha Adam, Karsten Dunger; Ulrike Döring (UBA V 1.6)
Chapter 6.4	Thünen Institute of Forest Ecosystems (TI-WO): Wolfgang Stümer, Karsten Dunger, Thomas Riedel, Daniel Ziche, Erik Grüneberg, Nicole Wellbrock, Katja Oehmichen, Sascha Adam; Ulrike Döring (UBA V 1.6)
Chapters 6.5 through 6.9 and 6.11	Thünen Institute of Climate-Smart Agriculture (TI-AK): Andreas Gensior, Roland Fuß, Andreas Laggner; Ulrike Döring (UBA V 1.6)
Chapter 6.10	Thünen Institute of Wood Research (TI-HF): Sebastian Rüter
Chapter 7.2	Wolfgang Butz (UBA III 2.4)
Chapter 7.3	Tim Hermann (UBA III 2.4)
Chapter 7.4.1	Sue-Martina Starke (UBA III 2.4)
Chapter 7.4.2	Robert Kludt (UBA V 1.6)
Chapter 7.5.1	Kai Kessler (UBA III 2.5), Stephan Schiller (UBA V 1.6)
Chapter 7.5.2	Ulrich Gromke (UBA III 2.1)
Chapter 7.6.1	Wolfgang Butz (UBA III 2.4)
Chapter 9	Dirk Günther (UBA V 1.6)
Chapter 10	Michael Kotzulla (UBA V 1.6)

Part II: Supplementary information as required pursuant to Article 7 (1) of the Kyoto Protocol

Chapters 11	German Emissions Trading Authority (DEHSt):
Annexes:	
Annex 1	Christian Mielke (UBA V 1.6)
Annex 2	Marion Dreher (UBA V 1.5),
Annex 2, Chapter 15.7	Kristina Juhrich (UBA III 2.1), Christian Böttcher (UBA V 1.6)
Annex 3	Authors in keeping with specialised responsibility in Chapters 3-15
Annex 3, Chapter 16.1.2	Michael Kotzulla (V 1.6)
Annex 3, Chapter 16	Johann Heinrich von Thünen Institute (TI): Cora Vos, Claus Rösemann, Roland Fuß
Annex 4	Michael Kotzulla (UBA V 1.6)
Annex 5	Robert Kludt (UBA V 1.6)
Annex 6	Dirk Günther (UBA V 1.6), Authors in keeping with specialised responsibility
Annex 6, Chapter 19.1.2	Stephan Schiller (UBA V 1.6)
Annex 6, Chapter 19.1.3	Kevin Hausmann (UBA V 1.6)
Annex 6, Chapters 19.1.4 & 5	Christian Mielke (UBA V 1.6)
Annex 6, Chapter 19.4	Michael Kotzulla (UBA V 1.6)
Annex 7	Kevin Hausmann (UBA V 1.6)

Contents

List of Figures

List of Tables

List of Abbreviations

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
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
BMUB	cf. BMUV
BMU	cf. BMUV
BMEL	Federal Ministry of Food and Agriculture

BMELV	cf. BMEL
BMVEL	cf. BMEL
BMVG	Federal Ministry of Defence
BMWA	cf. BMWi
BMWK	Federal Ministry for Economic Affairs and Climate Action
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")
SCR	Selective Catalytic Reduction
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. Global Warming Potentials (GWP) as specified in IPCC Assessment Report 5 (IPCC AR5) are used.

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**1A1c Manufacture of Solid Fuels and Other Energy Industries**	**All fuels**	**CO_2**	**65,289.1**	**5.1 %**	**8,645.5**	**1.1 %**	**-86.8 %**
-/-	1A1c Manufacture of Solid Fuels and Other Energy Industries	All fuels	N_2O	103.0	0.0 %	139.8	0.0 %	35.7 %
-/-	1A1c Manufacture of Solid Fuels and Other Energy Industries	All fuels	CH_4	586.2	0.1 %	114.0	0.0 %	-80.6 %

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
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. For determination of their National Determinated Contribution, the EU countries have been making use of the joint fulfillment option under the Paris Agreement and the UN Framework Convention on Climate Change They have been doing so via European regulations, most recently EU Regulation 2018/842[1] and its Implementing Regulation 2020/2126[2]. Current European implementation, via regulations, has made the pertinent requirements 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.

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).

In its Chapters 1 to 10, the **NIR** 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. Subsequently, it describes the national inventory arrangements that, pursuant to Paragraph 20 of COP decision 24/CP.19, are designed to support 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.

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.

[1] REGULATION (EU) 2018/842 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013

[2] COMMISSION IMPLEMENTING DECISION (EU) 2020/2126 of 16 December 2020 on setting out the annual emission allocations of the Member States for the period from 2021 to 2030 pursuant to Regulation (EU) 2018/842 of the European Parliament and of the Council

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**.

Annexes 1 through 7, in **Chapters 14-20**, 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 21**.

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)

With the Kyoto Protocol's entry into force, in February 2005, the international community of nations became obligated 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.

[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]

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. With a 34.3% reduction by 2020, Germany also exceeded that goal.

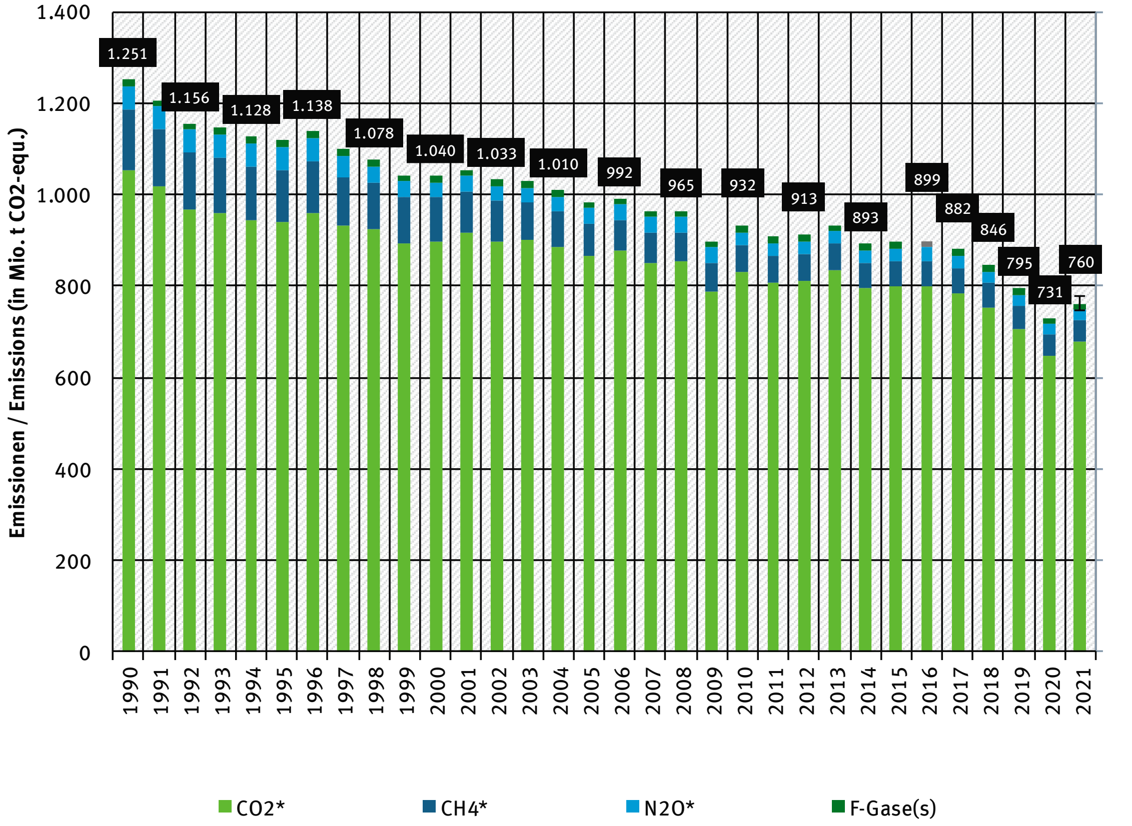
0.2 Summary overview of emissions of greenhouse gases and their removals in sinks (ES.2)

In the first commitment period, lasting from 2008 through 2012, Germany completely fulfilled its obligations within the framework of the aforementioned European burden-sharing, with regard to the base-year emissions determined in 2007 for the first commitment period[7], 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 exhibited a markedly decreasing trend (cf. Chapter 2.1). In 2021, emissions did increase again, however.

[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

[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 %.

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



* without LULUCF; Tier-2 uncertainties without LULUCF (cf. Chapter 1.7.1.2)

The individual greenhouse gases[9] 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 19.3.

In 2021, with an 89.3 % 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 5.0 percentage points since 1990. Methane (CH_4) emissions, caused predominantly by animal husbandry, fuel distribution and landfills, accounted for a 6.0 % share. Emissions of nitrous oxide (N_2O), caused primarily by agriculture, industrial processes and burning of fossil fuels, contributed 3.3 % of greenhouse-gas releases. Fluorinated greenhouse gases ("F gases") contributed about 1.5 % 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 19.3.

---

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

[9] Except where noted otherwise, all greenhouse-gas emissions expressed in terms of carbon dioxide equivalents have been calculated using the global warming potentials (GWP) given in the 5th Assessment Report of the IPCC.

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

Emissions Trends	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
						(kt CO2e)										
CO_2 emissions (without LULUCF)	**1,054,741**	**939,897**	**898,938**	**865,471**	**831,130**	**807,614**	**812,816**	**833,804**	**794,739**	**798,085**	**801,745**	**785,986**	**754,811**	**707,491**	**647,252**	**678,799**
Net CO_2 emissions/removals	1,083,501	909,585	891,603	865,778	820,839	791,170	787,704	809,946	778,062	779,213	780,350	767,606	739,346	692,963	643,742	675,066
CH_4 (without LULUCF)	**132,606**	**115,632**	**96,046**	**72,574**	**60,100**	**58,551**	**58,893**	**57,899**	**56,368**	**55,895**	**54,178**	**53,339**	**51,098**	**48,261**	**47,051**	**45,688**
CH_4 (including LULUCF)	138,936	121,955	102,370	78,999	66,607	65,061	65,409	64,421	62,898	62,436	60,719	59,883	57,762	54,832	53,613	52,255
N_2O (without LULUCF)	**51,554**	**49,111**	**32,472**	**33,367**	**27,449**	**27,458**	**27,584**	**27,718**	**28,202**	**28,155**	**28,019**	**27,548**	**26,383**	**25,669**	**24,922**	**24,767**
N_2O (including LULUCF)	52,440	49,981	33,332	34,466	28,576	28,582	28,712	28,841	29,350	29,314	29,145	28,679	27,526	26,805	26,068	25,931
F gases, sum (CO_2 equi.) 1995 base year	**12,324**	**16,021**	**12,735**	**13,576**	**13,701**	**13,880**	**14,056**	**14,085**	**14,085**	**14,523**	**14,619**	**14,710**	**13,879**	**13,212**	**11,697**	**11,104**
Total Emissions without LULUCF (CO_2 equi.)	**1,251,225**	**1,120,661**	**1,040,192**	**984,987**	**932,379**	**907,502**	**913,348**	**933,505**	**893,394**	**896,658**	**898,560**	**881,583**	**846,171**	**794,634**	**730,923**	**760,358**
Total Emissions/Removals with LULUCF (CO_2 equi.)	1,287,200	1,097,542	1,040,041	992,819	929,723	898,693	895,881	917,293	884,395	885,486	884,832	870,878	838,514	787,811	735,120	764,356
Emission source and sink categories	**1990**	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2018**	**2020**	**2021**
						(kt CO2e)										
1. Energy	**1,044,156**	**922,578**	**872,552**	**832,819**	**800,320**	**776,304**	**783,203**	**803,522**	**762,833**	**767,815**	**768,841**	**748,982**	**718,460**	**671,198**	**613,329**	**642,351**
2. Industry	**93,227**	**94,758**	**76,658**	**74,091**	**61,850**	**61,816**	**60,925**	**60,750**	**60,674**	**59,700**	**61,518**	**65,453**	**62,549**	**59,534**	**55,140**	**57,180**
3. Agriculture	**72,632**	**63,189**	**62,732**	**59,623**	**59,355**	**59,394**	**60,052**	**60,852**	**62,108**	**61,967**	**61,546**	**60,867**	**59,265**	**58,525**	**57,552**	**56,333**
4. Land-Use Change and Forestry	**35,976**	**-23,118**	**-151**	**7,832**	**-2,656**	**-8,809**	**-17,467**	**-16,213**	**-8,999**	**-11,172**	**-13,727**	**-10,705**	**-7,657**	**-6,822**	**4,197**	**3,998**
CO_2 (net emissions)	28,760	-30,312	-7,335	307	-10,290	-16,444	-25,111	-23,859	-16,677	-18,872	-21,395	-18,380	-15,465	-14,529	-3,511	-3,733
N_2O + CH_4	7,215	7,194	7,183	7,525	7,635	7,634	7,644	7,646	7,677	7,700	7,667	7,675	7,808	7,707	7,708	7,731
5. Waste	**41,209**	**40,136**	**28,250**	**18,454**	**10,853**	**9,987**	**9,167**	**8,381**	**7,780**	**7,175**	**6,655**	**6,281**	**5,897**	**5,377**	**4,901**	**4,494**

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

GHG Emission Fractions	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
						(%)										
CO_2 emissions (without LULUCF)	84.30	83.87	86.42	87.87	89.14	88.99	88.99	89.32	88.96	89.01	89.23	89.16	89.20	89.03	88.55	89.27
CH_4 (without LULUCF)	10.60	10.32	9.23	7.37	6.45	6.45	6.45	6.20	6.31	6.23	6.03	6.05	6.04	6.07	6.44	6.01
N_2O (without LULUCF)	4.12	4.38	3.12	3.39	2.94	3.03	3.02	2.97	3.16	3.14	3.12	3.12	3.12	3.23	3.41	3.26
F gases, sum	0.98	1.43	1.22	1.38	1.47	1.53	1.54	1.51	1.58	1.62	1.63	1.67	1.64	1.66	1.60	1.46
GHG Emission Fractions for Categories (without LULUCF)	**1990**	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**		**2020**	**2021**
						(%)										
1. Energy	83.45	82.32	83.88	84.55	85.84	85.54	85.75	86.08	85.39	85.63	85.56	84.96	84.91	84.47	83.91	84.48
2. Industry	7.45	8.46	7.37	7.52	6.63	6.81	6.67	6.51	6.79	6.66	6.85	7.42	7.39	7.49	7.54	7.52
3. Agriculture	5.80	5.64	6.03	6.05	6.37	6.54	6.57	6.52	6.95	6.91	6.85	6.90	7.00	7.37	7.87	7.41
5. Waste	3.29	3.58	2.72	1.87	1.16	1.10	1.00	0.90	0.87	0.80	0.74	0.71	0.70	0.68	0.67	0.59

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

0.3 Summary of emissions estimates, and of trends for source and sink groups (ES.3)

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.

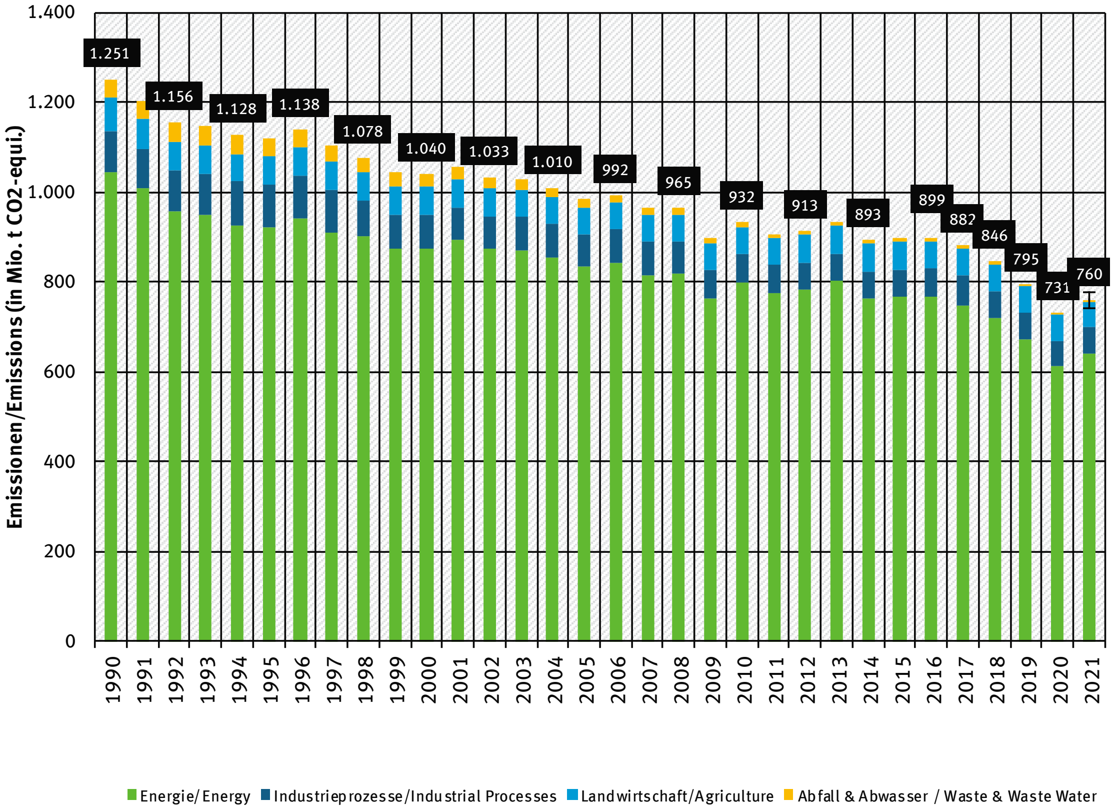
On the whole, greenhouse-gas emissions decreased by 39.2 % in 2021[10]. Considerations of the various components involved confirm this trend, to varying degrees. The relevant emissions changes for the most important greenhouse gases in terms of quantity were as follows: -35.6 % for carbon dioxide (CO_2), -65.5 % for methane (CH_4) and -52.0 % for nitrous oxide (N_2O). The corresponding trends for the so-called "F" gases, which contribute about 1.5 % 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 30.7 % since 1995, however.

With respect to the previous year, 2020, total emissions increased by 4.0 %. That increase was the largest seen since the year 1990.

Most prominently, CO_2 emissions from electricity generation increased sharply. **Emissions from public** hard-coal-fired and lignite-fired power stations increased particularly markedly, as a result of higher coal use for power generation. On the other hand, use of natural gas, which has lower emissions than coal does, decreased in the second half of the year, as a result of gas-price increases. The primary reason for the increased use of hard coal and lignite for electricity generation is that renewables-based electricity generation decreased considerably with respect to the previous year. The decrease in electricity generation from wind energy was especially marked.

[10] 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[11,]

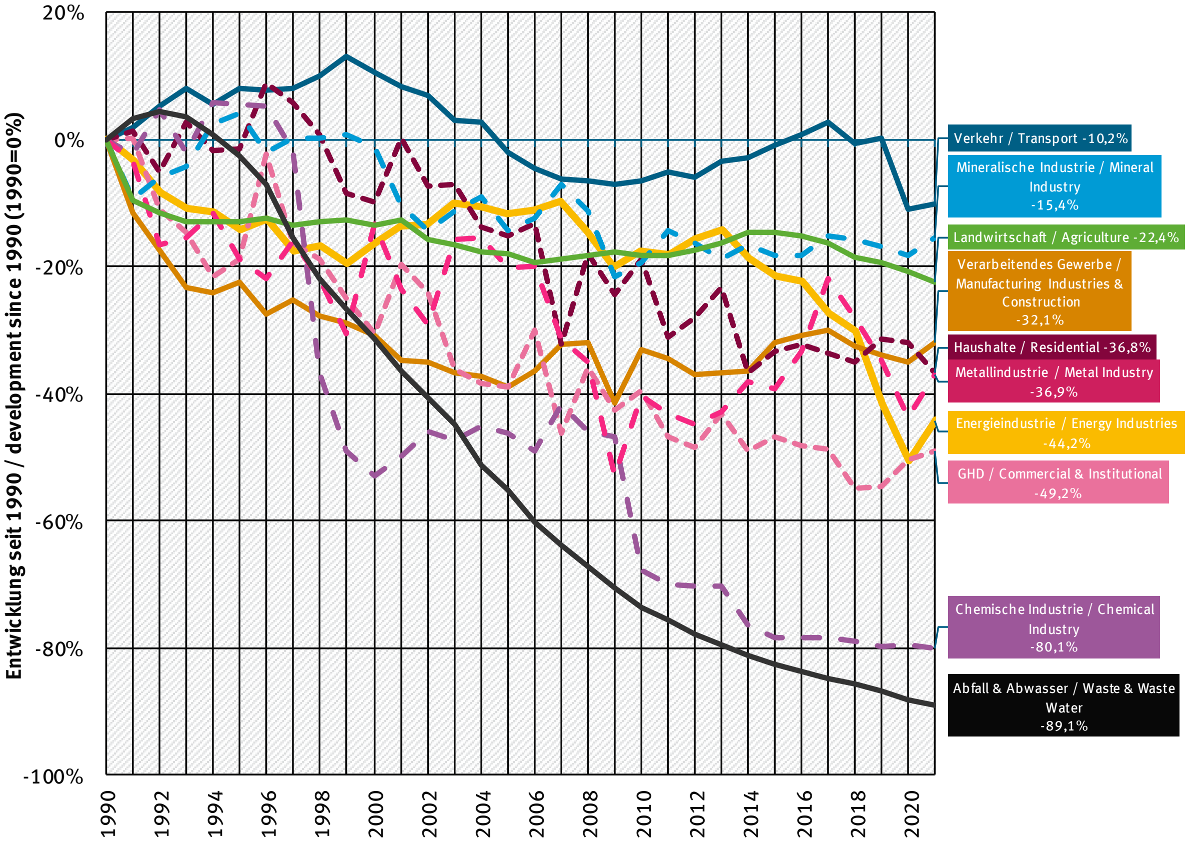


Without LULUCF; Tier-2 uncertainties without LULUCF (cf. Chapter 1.7.1.2)

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, especially 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.

[11] * 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[12,]



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

1 Introduction

1.1 Background information on greenhouse-gas inventories and climate change

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 51 %. 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 417 ppm (Global Carbon Project, 2022). In the same period, the concentration of methane (CH_4) in the atmosphere increased by a factor of 2.5, to 1895.6 nmol/mol, and the concentration of nitrous oxide (N_2O) increased to a level of 334.3 nmol/mol (UBA, 2022). 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 .

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[13]. 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 (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

[13] 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.

%, with respect to the base year, by 2020. Via the European Effort Sharing Decision[14], 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 have been 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. Previously, Germany was obligated to reduce its emissions to 451.33 million tonnes of CO_2-equivalents, by 2020.

As of 2021, the European Union's reduction commitment for the period through 2030, as set forth in its Nationally Determined Contribution (NDC), has been divided, via the European Effort Sharing Regulation, among the 27 Member States, along with Norway and Iceland. Under this regulation, Germany is now obligated to reduce its emissions to 300.57 million tonnes of CO_2-equivalents by 2030[15].

The effectiveness and success of the Paris Agreement in reducing global greenhouse gas emissions – like the effectiveness and success of Kyoto Protocol in this regard – depend on two key factors: Whether its Parties abide by the rules of the Agreement, make their promised contributions, and set even more ambitious goals; 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.

1.2 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 institutional arrangements for preparation of greenhouse-gas inventories. As was the case in the years through 2020, the national institutional arrangements established in Germany in this regard fulfill the provisions of Article 5.1 of the Kyoto Protocol, the requirements of Decision 24/CP.19, and the provisions of the European Governance Regulation for the Energy Union and Climate Action.[16]

The national institutionalisation serves the purpose of inventory preparation in accordance with 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 institutionalisation (establishment of a National System pursuant to Art. 5.1 of the Kyoto Protocol) was completed by 2011, 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 German 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 then-existing National System was adapted to the requirements applying under the second commitment period of the Kyoto Protocol and expanded.

---

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

[15] REGULATION (EU) 2018/842 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013

[16] REGULATION (EU) 2018/1999 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the Governance of the Energy Union and Climate Action

The requirements-conformal institutionalisation and function of the National System has been repeatedly 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 arrangements made for preparation of greenhouse-gas inventories

At the ministerial level, the National System was established in 2007, under the leadership of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), via an agreement of 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 then Federal Ministry of Food and Agriculture (BMEL), the then Federal Ministry for Economic Affairs and Energy (BMWi), the then Federal Ministry of Transport and Digital Infrastructure (BMVI), the then 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 were included 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 institutions and data streams. Where the data streams are incomplete, the pertinent 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).

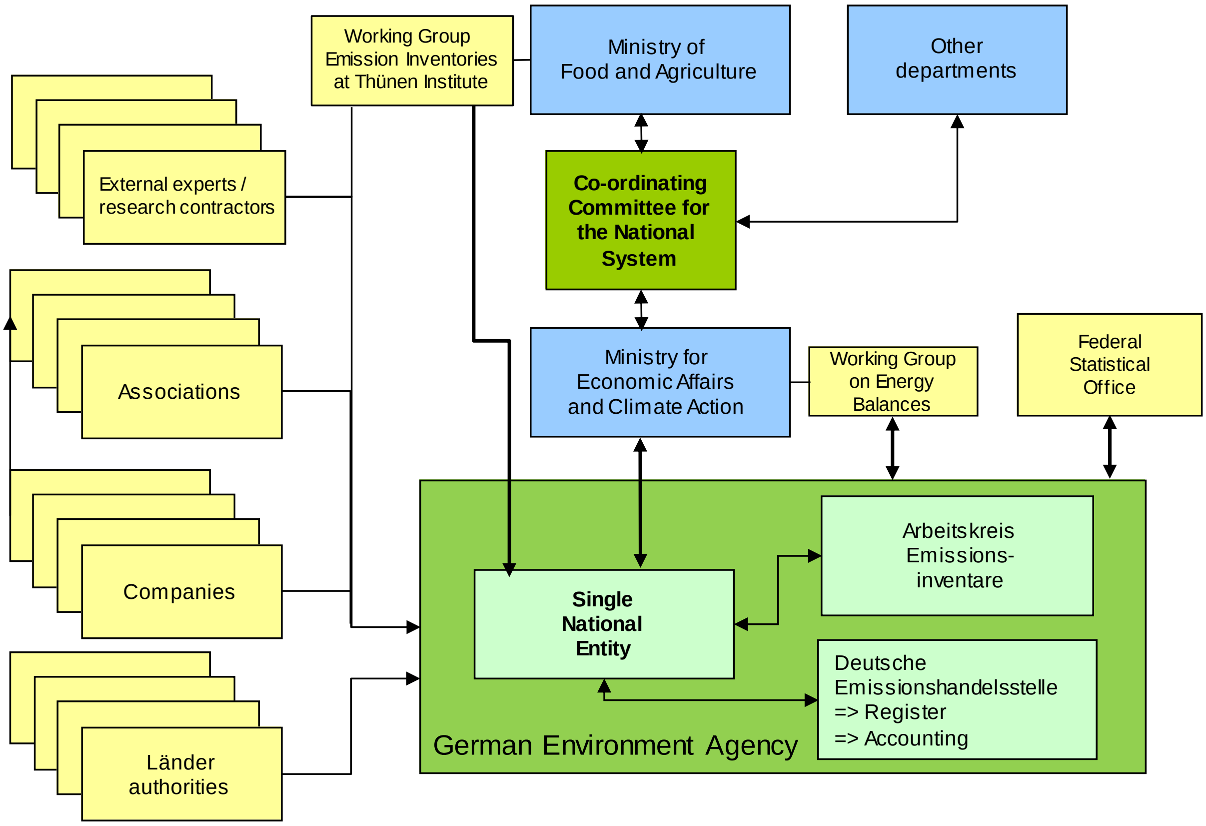
With the restructuring of responsibilities within the Federal Government following the 2021 parliamentary elections (to the Bundestag), the responsibility for the area of national climate action – and, therefore, for management of reporting on greenhouse emissions – passed to the Federal Ministry for Economic Affairs and Climate Action (BMWK).

The "National Emissions Reporting System" policy paper also assigns the German Environment Agency the task of serving as the Single National Entity for Germany. Within the German Environment Agency, the Emissions Situation section has been entrusted with this task (cf. Chapter 1.2.1.2). At the level of the German Environment Agency, the Single National Entity integrates other specialised agencies within the system of national institutional arrangements, and it coordinates the contributions of the other institutions and organisations involved in emissions reporting. For co-ordination of pertinent work within the German Environment Agency, a working group on emissions inventories was established (cf. Chapter 1.2.1.3). For implementation, within the German 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 19.1.1.

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 (BMUV) and to include representatives of all federal ministries that participate in emissions reporting. Following the restructuring of responsibilities within the Federal Government, the responsibility for managing the National Co-ordinating Committee lies with the Federal Ministry for Economic Affairs and Climate Action (BMWK).

The National Co-ordinating Committee has the tasks of supporting the emissions-reporting process and clarifying open issues pertaining to the institutionalisation. 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 releases of inventories and of the National Inventory Report.

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

Now, after the second commitment period of the Kyoto Protocol, the National Co-ordinating Committee continues to be an important, established component of the institutionalised arrangements for emissions reporting in Germany.

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 German Environment Agency (UBA) to carry out tasks of the **Single National Entity** for emissions reporting (**national co-**

ordination agency). The German 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 emissions reporting process. 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 data streams**. Furthermore, institutions and organisations that need to be integrated within the reporting process 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 period of the Kyoto Protocol, and on implementation of the Revised UNFCCC Reporting Guidelines, within the reporting system. Since 2021, its work has been concentrated on implementation of the modalities, procedures and guidelines (MPG) of the enhanced transparency framework under the Paris Agreement, and on making preparations for reporting under the Paris Agreement. 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 German 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 German 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 German 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 German 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 German 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 German 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 reporting system, for purposes of data provision, primarily via the German 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 German 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 a newsletter produced by the Single National Entity on the Central System on Emissions (CSE) 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 reporting

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 remain valid after 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 German 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 German 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 German 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 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 German 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 German 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 German 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 German 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 2021, cooperation agreements were concluded with both soda ash producers (for all three production facilities in Germany). At the German Environment Agency (UBA), the reported data on production quantities are combined, and used in time-series formats (for the period as of 2013).

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 German 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 for productionof emissions inventories

The binding schedule for preparation of emissions inventories and of the NIR is announced to all relevant internal and external stakeholders via the German 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 German 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 German 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 German Environment Agency
6 November	In-house consultations at the German 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 Federal Ministry for Economic Affairs and Climate Action (BMWK), 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 BMWK)
as of 2 January	Final editing by the German 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 German 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.

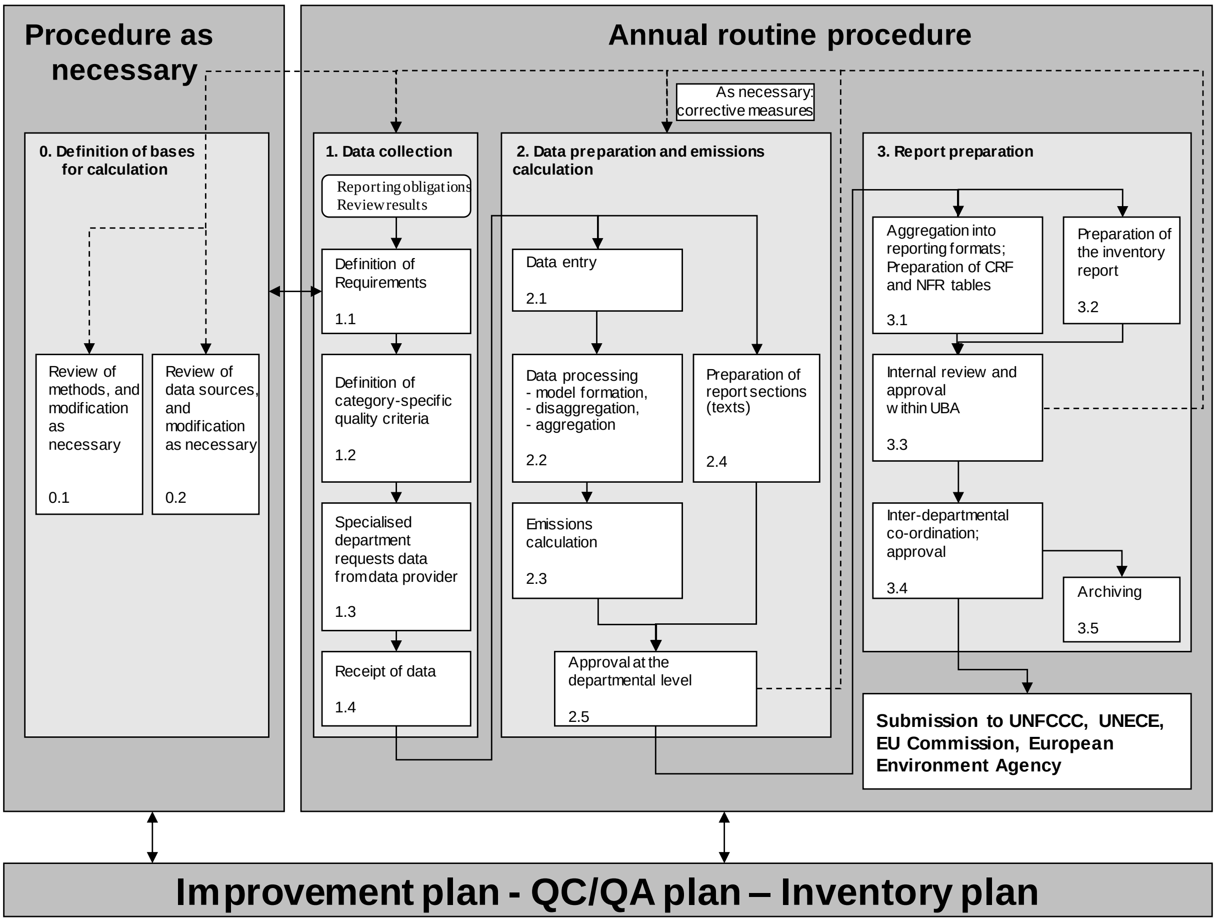
1.2.3 Overview of inventory preparation and management

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, preparation of National Inventory Reports and 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 inventory

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 German 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 institutional arrangements

As a result of the manner in which reporting has been institutionalised, reporting 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 cooperation 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.

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 German 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

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 German 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 *German Environment Agency's Working Group on Emissions Inventories*, via the German 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 German 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) 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.

As of this year, calculation of greenhouse-gas emissions, in terms of CO_2 equivalents, is being carried out using the global warming potentials (GWP) published in the *Fifth Assessment Report.*[17] The GWP, which are presented in the following table, are oriented to the impacts of greenhouse gases throughout a time horizon of 100 years.

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 German 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 German 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 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 German 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 German Environment Agency, the QSE has been made binding via the agency's in-house directive (UBA-Hausanordnung) 11/2005.

[17] cf. Appendix 8.A, Table 8.A.1 in IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. URL: https://www.ipcc.ch/report/ar5/wg1/

Details regarding assurance of the QSE's binding nature for other NaSE participants are provided in Annex 19.1.1.

1.3.3.1.1 Directive 11/2005 of the German Environment Agency

In 2005, via its *in-house directive (Hausanordnung) 11/2005*, the German 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 German 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 German 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 19.1.2.1). 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 19.1.1).

Further information regarding the German Environment Agency's necessary organisational measures for implementing these requirements is provided in the following chapters and in a complementary section in the Annex, 19.1.2.1.11.

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 German 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 3).

Table 3: 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)

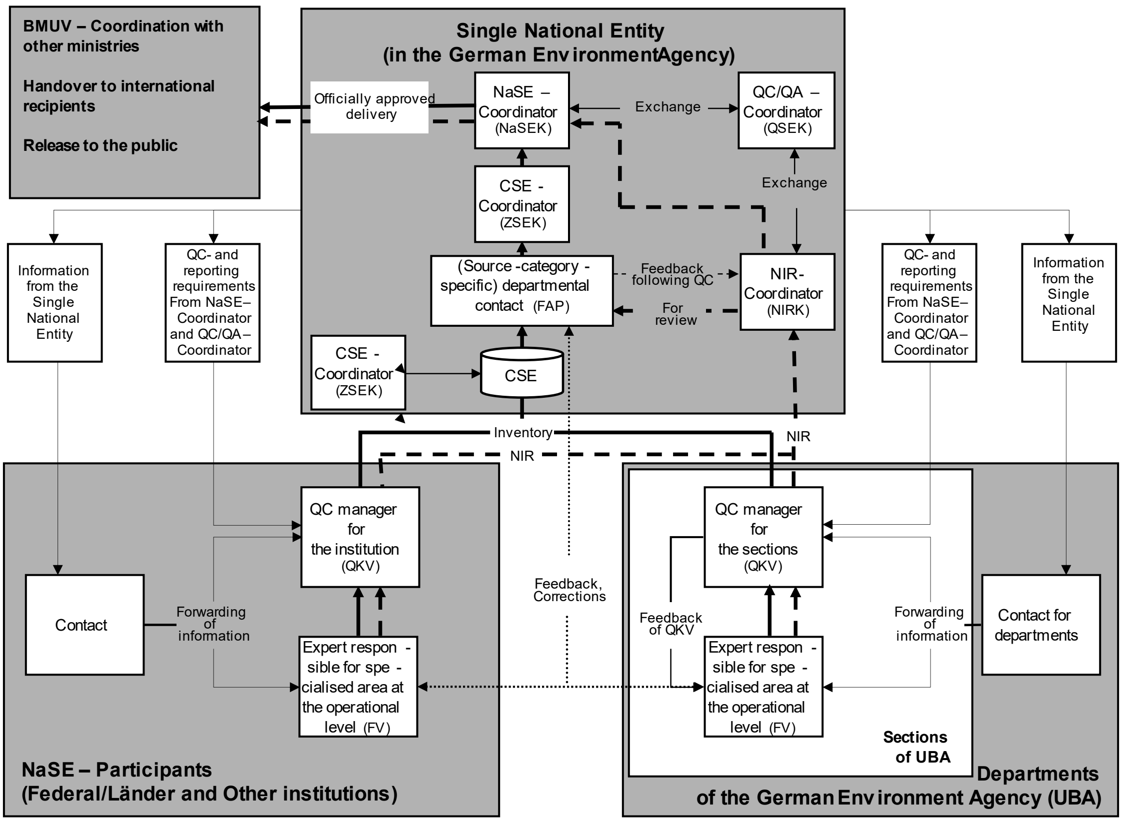
In very rare exceptional cases, the German Environment Agency (UBA) is unable to fill the position of the responsible expert at the operational level (FV) for a particular category. In such cases, the Single National Entity assumes complete responsibility for the QSE role system, by itself filling the 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

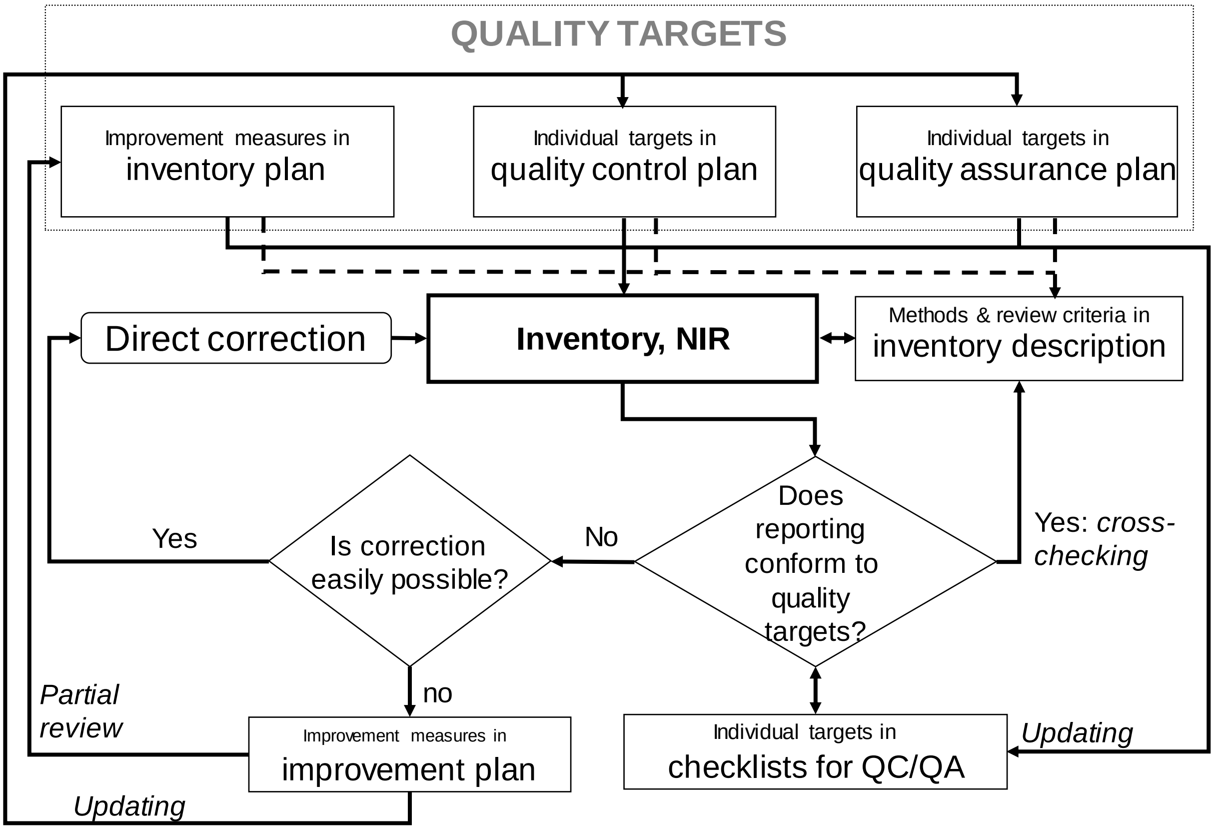


The required quality reviews pursuant to Paragraph 25 (f) of the *Reporting* Guidelines (24/CP.19) are provided, in the form of quality checklists and along with data requirements, to the FV, QKV, FAP and NIRK (cf. Table 3). They are completed in the course of the relevant supporting work.

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 19.1.2.1), 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[18] 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 German 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 German Environment Agency via an in-house directive (cf.

[18] 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 German Environment Agency, describes the Quality System for Emissions Inventories (QSE).

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

1.3.3.1.7 Support for the UNFCCC review

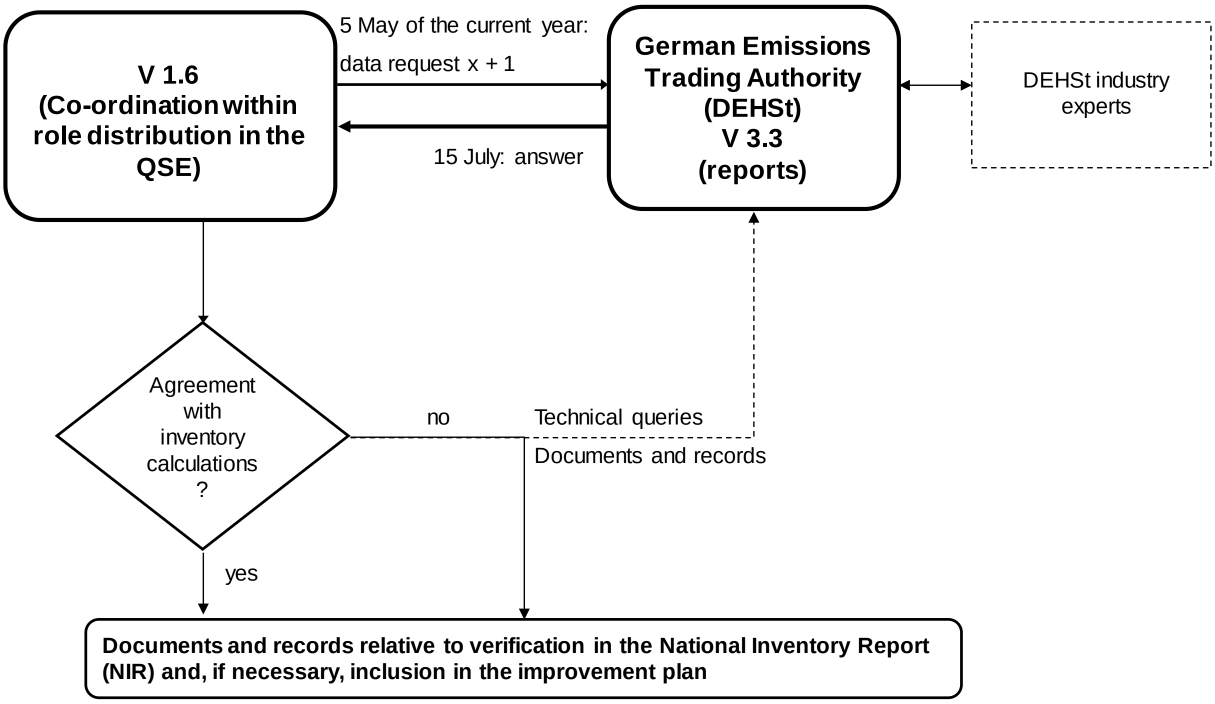
In addition to the German Environment Agency's own quality control and assurance measures, the UNFCCC review provides important impetus for inventory improvement. Consequently, it is in the Single National Entity’s own interest to fulfill the requirements for provision of archived inventory information 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



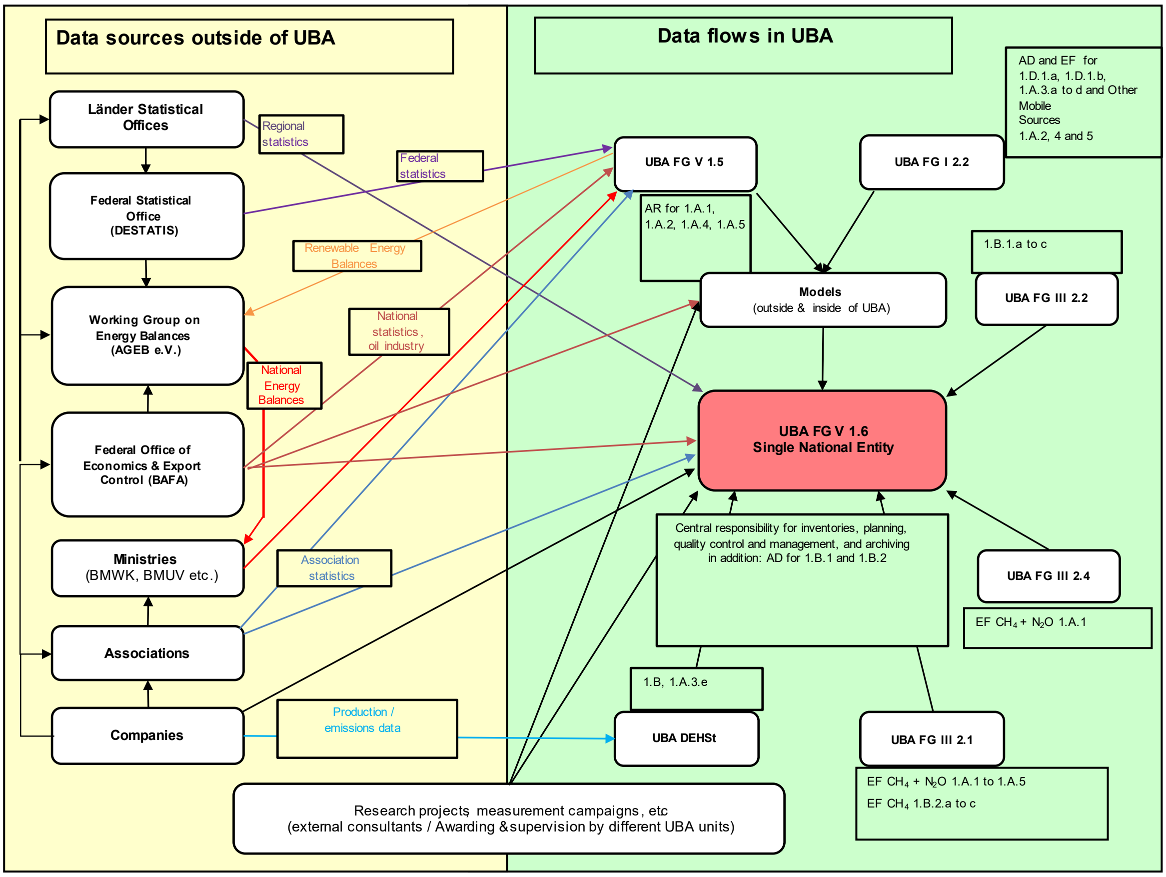
Regarding the details of data use in QC/QA, cf. also Chapter 1.6.2.1 Verification in selected categories.

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

1.4.1 Data sources

1.4.1.1 Energy

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



The central data source for determination of activity data for category 1.A is the "*Energy Balance of the Federal Republic of Germany*" ("Energiebilanzen der Bundesrepublik Deutschland"; hereinafter referred to as: the "Energy Balance"), which is published by the Working Group on Energy Balances (Arbeitsgemeinschaft Energiebilanzen – AGEB) and is based, for the most part, on official statistics of the *Federal Statistical Office*. For the area of renewable energies, the AGEB receives Energy Balance data from the Working Group on Renewable Energy Statistics (Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat). The Energy Balance provides an overview of the interconnections within Germany's energy sector, and it supports breakdowns by energy sources / fuels, and by their production, transformation and use. .

Since 2007, the AGEB has been commissioned, for preparation of Energy Balances, by the Federal Ministry for Economic Affairs and Energy (BMWi; now the BMWK). In the framework of multi-year contracts, the AGEB has been contractually required to apply the National System of Emissions' minimum requirements for quality assurance. Since 2012, the AGEB has submitted quality reports for the Energy Balance (cf. Chapter 15.4.1) and prepared an "Energy-Data Action Plan for inventory improvement" ("Energiedaten Inventarverbesserung"; cf. Chapter 15.6).

The *Federal Statistical Office* (Statistisches Bundesamt) is the most important data source for determination of activity data and for the preparation of Energy Balances. For purposes of inventory preparation, the Federal Statistical Office's *Fachserie 4 (Reihe 4.1.1 and Reihe 6.4)* is used. 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 preparation of waste-data balances, the *Federal Statistical Office* makes use of energy statistics, and of the *Statistical Report on Waste Management* (*Statistische Bericht Abfallentsorgung*), which is published every two years (Statistisches Bundesamt, 2022i). Since 2022, the Federal Statistical Office makes almost-final data for the previous year – extrapolated on the basis of existing survey data, using an imputation procedure – available in August of the current year. With these data, the AGEB is able to produce considerably improved provisional Energy Balances for inventory preparation.

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 Energy Balance, 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) and the German lime-industry association (BV Kalk)

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.

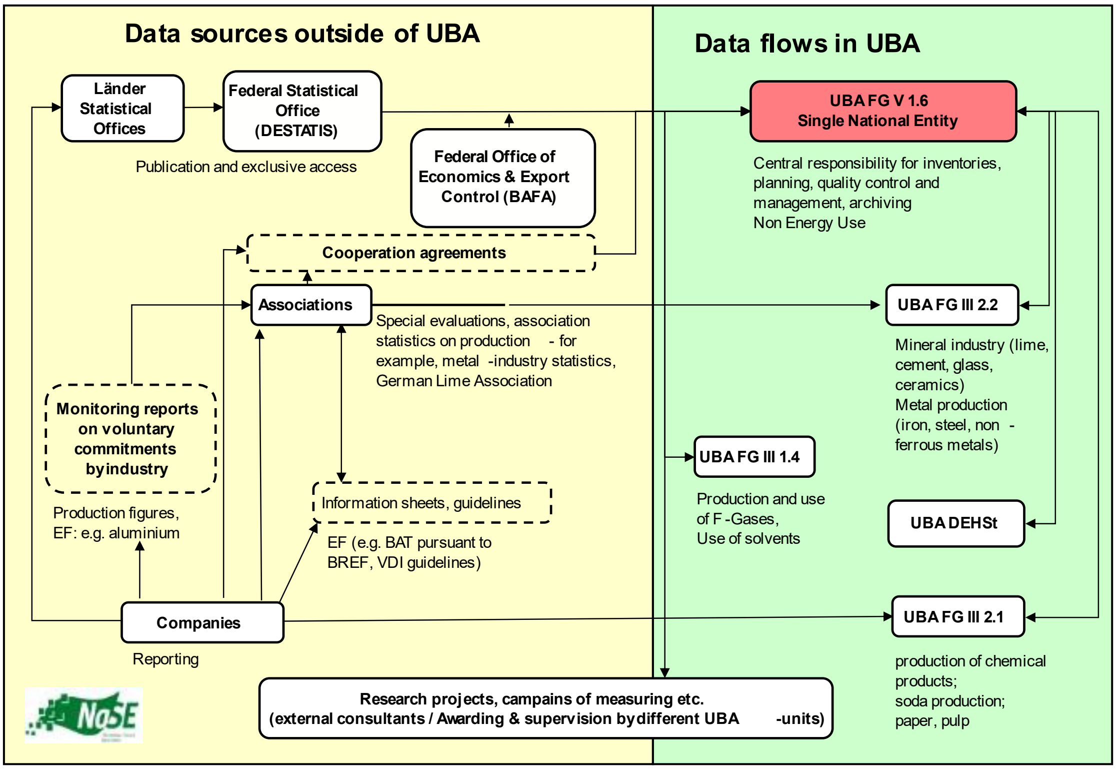
Data for categories of category 1.B.1 are taken from publications of Statistik der Kohlenwirtschaft e.V. (coal-industry statistics), the Federal Ministry for Economic Affairs and Climate Action (BMWK), the DEBRIV Federal German association of lignite-producing companies and their affiliated organisations, 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; and, now, from its successor, the industry association Wirtschaftsverband Fuels und Energie e. V. (en2x)), 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).

1.4.1.2 Industrial processes

Activity data for the mineral industry are obtained primarily from association statistics. Data for the cement industry (2.A.1) are obtained from the German Cement Works Association (VDZ), in cooperation with the German Emissions Trading Authority (DEHSt). 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 German 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 German 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 (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 German 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 German 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 German 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 German 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 total amounts of soda ash produced in Germany (2.B.7) are determined by the Federal Statistical Office, with the most-recent data coming directly from the two producers (via a cooperation agreement). The emission factors for soda ash production 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 German 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 German Environment Agency; in some cases, they are also based on information provided by experts in the context of dialogues with industry.

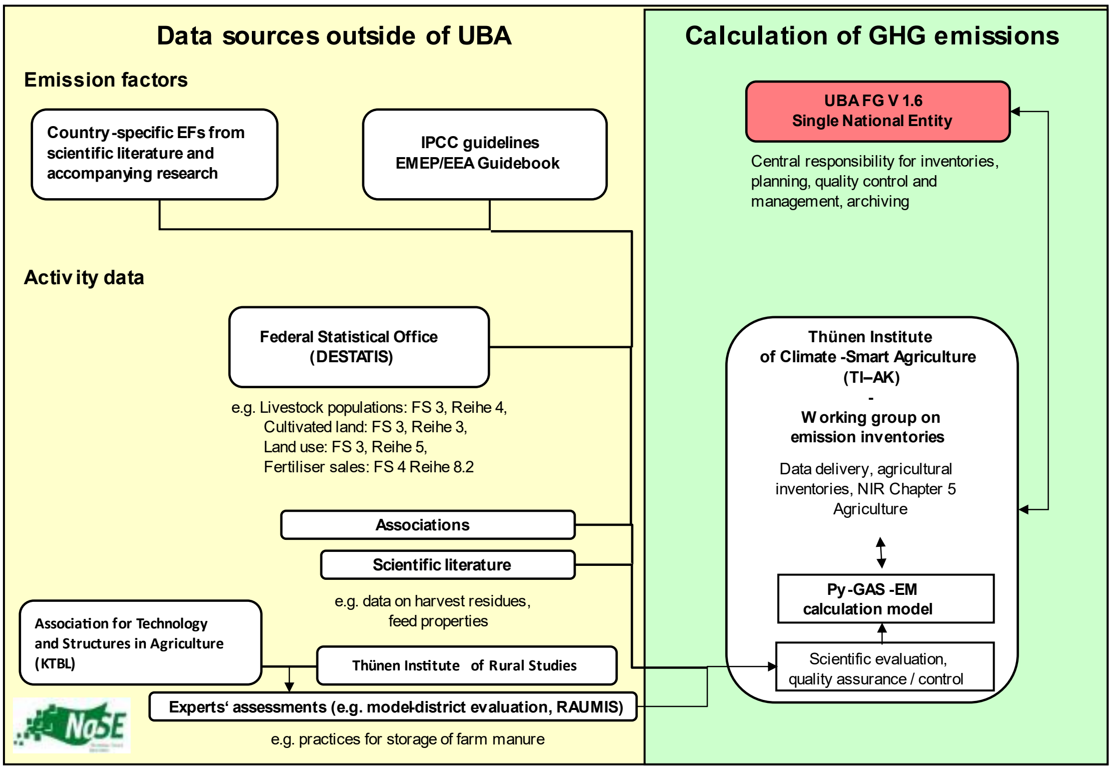
More-detailed pertinent information regarding emission factors is presented in the descriptions of methods for the various categories. The activity data for the electronics industry (2.E), for product use as substitutes for ODS (2.F) and for other product production and use (2.G), have been determined 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.

1.4.1.3 Agriculture

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



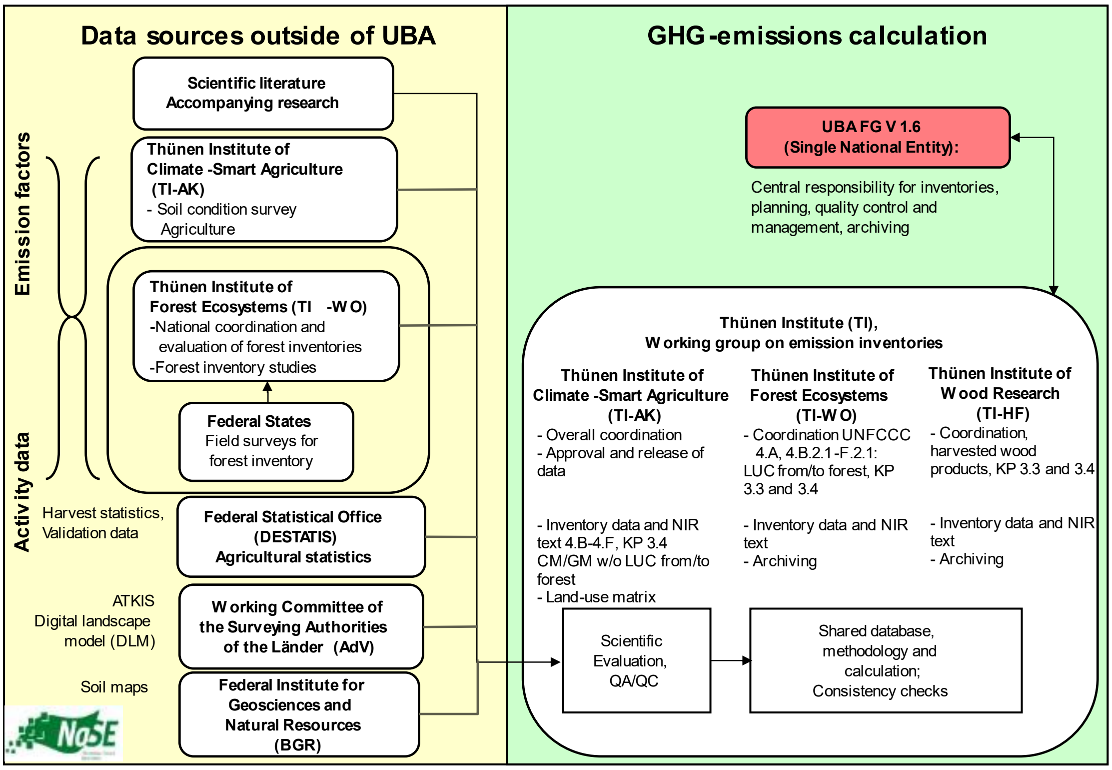
Emissions calculations for category 3 (Agriculture) are carried out by the Thünen Institute (TI). The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and the Federal Ministry of Food and Agriculture (BMEL) initiated a project for calculation of agricultural 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; Rösemann et al., 2023)). For purposes of the 2022 submission, that model was 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 feed 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).

1.4.1.4 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



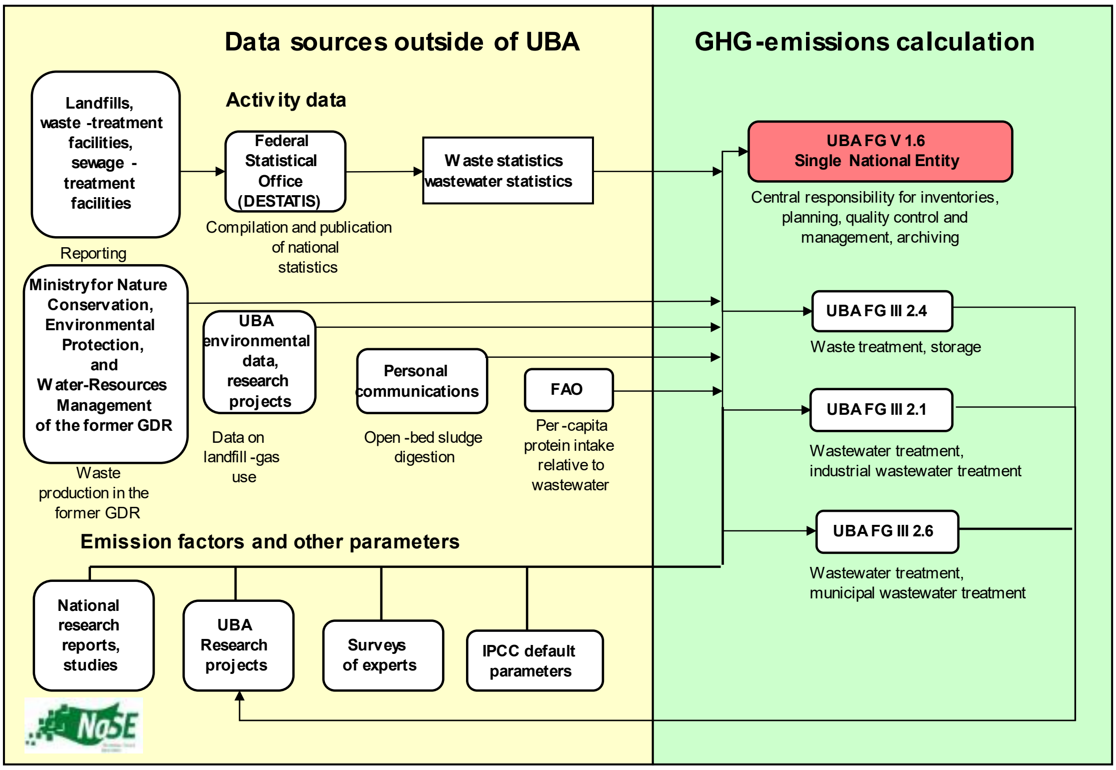
In the 2012 Submission, a consistent, unified method was introduced for taking account of land-use changes in the LULUC sector and the forestry sector. The method expands the existing sample-based system for determining forest-land areas, and land-use changes to and from forest land, for all land-use 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.

1.4.1.5 Waste and wastewater

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



German 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 German 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 German 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 German 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 German 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).

1.4.2 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")[19]. 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.

1.5 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 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 14.1.2).

[19] 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.

For the current report, the Approach 1 procedure identified 51 categories, out of a total of 172 source and sink categories studied, as key categories. 32 of these were identified, by both trend and level analysis, as key categories. In addition, 14 categories were identified as key categories solely by trend analysis, and 5 categories were so identified solely by level analysis. Via the Approach 2 procedure, 17 additional key categories were identified (cf. Table 6).

Ultimately, 68 key categories were defined as a result. These are summarised in Table 4.

Table 4: Number of categories and key categories

Category		**171**	
			Key categories
by Level	Level & Trend	Trend	
5	32	14	**51 (Approach 1)** **+17 (Approach 2)** **68 (total)**

Table 5 provides an overview of the results of the key-category analysis based on Approach 1. Table 6 shows the additional key categories identified via Approach 2 analysis. Annex 1 (Chapter 14) 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 has increased to 51.

Three key categories have been added.

- CH_4 Emissions from Road Transport (1.A.3.b)
- CH_4 Emissions from Wetlands (4.D)
- 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.

Table 5: Key categories for Germany pursuant to the Approach 1 method, with GWP from IPCC AR5

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2021	Level 2020 + LULUCF	Trend 2021	Trend 2021 + 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 b, Residential		CH_4	-	-	-	-	-	-	•	-	-/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/T
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/-
2 B 2, Nitric Acid Production		N_2O	-	-	-	-	-	-	•	•	-/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	-	-	-	-	-	-	•	•	-/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

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2021	Level 2020 + LULUCF	Trend 2021	Trend 2021 + LULUCF	KCA decision
2 G, Other Product Manufacture and Use		SF_6	•	•	•	•	•	•	•	•	L/T
3 A, Enteric Fermentation	Dairy cows	CH_4	•	•	•	•	•	•	•	•	L/T
3 A, Enteric Fermentation	non-dairy cattle	CH_4	•	•	•	•	•	•	-	-	L/-
3 B, Manure Management	Dairy cows	CH_4	-	-	-	-	•	•	•	•	L/T
3 B, Manure Management	swine	CH_4	•	•	•	•	•	•	-	-	L/-
1 A 3 d, Domestic Navigation		N_2O	-	-	-	-	-	-	-	-	-/-
1 A 3 e, Other Transportation	fossil fuels	CO_2	-	-	-	-	-	-	-	-	-/-
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 D, Wetlands		CH_4	-	•	-	•	-	•	-	•	L/T
4 E, Settlements		CO_2	-	-	-	-	-	-	-	•	-/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 6: Key categories for Germany identified solely via the Approach 2 method

IPCC Source Categories	Activity	Emissions of
1 A 1 a, Public Electricity and Heat Production		N_2O
1 A 4 b, Residential		N_2O
1 B 1, Solid Fuels	fossil fuels	CO_2
1 B 2 c, Venting and Flaring		CO_2
2 C 2, Ferroalloys Production		CO_2
2 C 3, Aluminium Production		CO_2
2 D 2, Paraffin Wax Use		CO_2
3 B, Manure Management	dairy cows	N_2O
3 B, Manure Management	non dairy cattle	N_2O
3 B, Manure Management	deposition	N_2O
3 J, Other		N_2O

IPCC Source Categories	Activity	Emissions of
4 A , Forest Land		N_2O
4 B, Cropland		N_2O
4 C, Grassland		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" (German 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 19.1.2.1.11). These lists currently comprise some 85 role-specific individual targets and some 50 optional targets.

Currently, some 50 German 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 19.1.2.1.10.3) 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 are 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 7. 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 7: Inventory plan 2015 – 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, 1.B.2.b	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, ARR	2017, 2022
Industrial Processes	2.A.4.b.		Sonstige	2020
LULUCF	4		NIR	2023
Energy	1.A.3.d.(a), 1.A.4.	Check whether there are any gaps in time series.	CHKL	2020, 2023
Energy	1. fossil fractions of biofuels, 1.B.2, 1.B.2.a	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, ARR	2020, 2022, 2023
Industrial Processes	2.B.2, 2.C.2, 2.C.3.a		Audit, NIR	2016, 2023
Energy	1.A.4.c.iii, 1.A.5.b.(iii)	Check whether uncertainties have been determined, are complete and up to date.	CHKL	2012, 2020, 2023
Industrial Processes	2.B.7, 2.B.10.(i), 2.C.3.a., 2.D.3.(b)		Audit, CHKL	2012, 2016, 2018, 2021-23
Waste	5.D.1		CHKL, Sonstige	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, ARR, CHKL	2015+16, 2018. 2022
Energy	1.A, 1.A.3.a+c+d.(a+b)+e., 1.A.4.c.iii,, 1.A.5.b (i+ii+iii), 1.B.2		ARR, CHKL	2018-20, 2022+23
Industrial Processes	2.A.1+3+4a, 2.B.3+8+10(i), 2.C.3.a., 2.D, 2.D.1.(b), 2.D.3.(a,d,e,f,g,h,i)+j		Audit, CHKL	2016, 2018-20, 2023
Agriculture	3.D.a.2.c + 3.D.b		ARR	2020
LULUCF	4.A		ARR	2020
Waste	5.A.1, 5.B.1+2, 5.D.1+2, 5.E.1.(a)		Audit, CHKL	2016, 2019, 2022+23
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+23
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, 2018
Energy	1.A.1, 1.A.2+f, 1.A.3.d., 1.A.4.a.i.+b.i+c.i+iii., 1.A.5.a+b.(iii), 1.D.1.a.		ARR, Audit, CHKL, Sonstige	2015+16, 2022+23
Industrial Processes	2.B.1, 2.B.7, 2.B.10.(i), 2.C.2+3a+5+6, 2.G.3.a.		Audit, CHKL	2015+16, 2019-23
LULUCF	4.B.1. + 4.C.1.		ARR	2020
Waste	5.A.1, 5.B.1+2, 5.D.1+2, 5.E.1.(a)		CHKL, Sonstige	2018-20, 2022+23
General	0.	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+e., 1.A.4.a.ii.+b.ii+c.ii, 1.A.5.b, 1.AD, 1.B.2.a+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, 2.C.2., 2.C.3.a., 2.E.3		ARR, Audit, CHKL	2016, 2020, 2023
Waste	5.B.2		ARR	2020
Industrial Processes	2.H.2.	Check whether the EF are plausible and complete (have no gaps and are completely documented) and up to date.	NIR	2021
Waste	5.D.1		ARR	2022
Industrial Processes	2.A.3, 2.C.2	Check whether the AR are plausible and complete (have no gaps and are completely documented) and up to date.	ARR, Audit	2016, 2018, 2022
Agriculture	3.D.a.2.b		ARR	2022

LULUCF	4., 4.D		NIR	2023
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
General	0.	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	2022
Energy	1., 1.A.1.a , 1.A.3.b.i, 1.AD, 1.B.2,		ARR	2015+16, 2022
Industrial Processes	2.B.3+9+10.(i), 2.C.2+5+6, 2.F.1+2, 2.G.3.b.(ii)		ARR, CHKL	2015+16, 2019+20, 2022+23
Agriculture	3.B.1, 3.D.a		ARR	2022
Waste	5.A.1, 5.B.1, 5.D.1, 5.E.1.(a)		ARR, CHKL	2018, 2022+23
Energy	1.A	Check whether any recalculations are required. If they are they must be documented in a logical manner.	ARR	2018
Industrial Processes	2.A.4.b.		ARR	2020
General	0.	Various types of required action.	Sonstige	2014, 2016
Energy	1., 1.A.1, 1.A.2, 1.A.2.g.vii, 1.A.3.b+c+d(a+b), 1.A.4.a.i+ii+b.i+ii+c, 1.A.5.b., 1.B.2.c. - Flaring		ARR, CHKL	2015, 2017-23
Industrial Processes	2.B.7+8+10.(i), 2.C.3.a.		Audit, CHKL, NIR	2015+16, 2021+22
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+d, 2.D.2, 2.D.3.a,b,d,e,f,g,h,i, 2.G.3.a.+b(ii), 2.G.4.(c)		CHKL, Sonstige, NIR	2012, 2019, 2023
Waste	5.D.1	Initiated research projects for inventory improvement.	NIR	2016, 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 90 categories.

In the course of the current round of reporting, about 80 additional required improvements have been identified. These include about 40 recommendations in ARR 2022 (new, as well as reactivated old recommendations). About 90 required actions have been successfully completed.

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 8 presents more-detailed information on the improvement items that have been successfully addressed. Both tables (Table 7 & Table 8) include review results from the years as of 2010, statements made in the NIR relative to planned improvements for the period as of 2012, other improvement items for the period as of 2014 and CHKL results from the years as of 2012

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 470 (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 471 (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 8: 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
LULUCF	4, 4.B-E. 4.(V), KP	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, NIR	2020, 2022
LULUCF	4	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.	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
Waste	5.A.1, 5.B, 5.D.2		Audit, Sonstige	2016, 2020
Energy	1.A.2.e+g.vii., 1.A.3.a-c+d.(b), 1.A.4.a.ii.+b.ii.+c.ii., 1.A.5.b.(iii)	Check whether obligations pertaining to keeping of records and documentation are fulfilled and whether the relevant documents are complete, meaningful and up to date.	CHKL	2013, 2019-2022
Industrial Processes	2.D.1.(b)		CHKL	2021
LULUCF	KP		ARR	2020
Waste	5.A.1, 5.B.1.+2		Audit, CHKL	2016, 2020+21
General	0.	Check whether requirements for cross-checking and verification of data and their underlying assumptions have been fulfilled.	ARR	2015+16
Energy	1.A.3.d.(a), 1.A.4.c.iii., 1.A.5.b.(iii)		CHKL	2023
LULUCF	KP		ARR	2020
Waste	5.B.1.+2		CHKL, Sonstige	2019, 2022
Energy	1.A.2.g.vii., 1.A.3.b+c+d.(a+b), 1.A.4.a.ii.+c.ii+c.iii, 1.A.5.b.(iii)	Check whether data-consistency requirements are fulfilled and whether the relevant documents are complete and meaningful.	CHKL	2022
Industrial Processes	2.D.1.(b), 2.D.3.(j)		CHKL	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.		ARR	2018
Waste	5.A.1		ARR, NIR	2018-20
Energy	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.).	CHKL	2021
Waste	5.D.2		CHKL	2018
Agriculture	3.D	Various types of required action.	CHKL	2022
LULUCF	KP		ARR	2020
Industrial Processes	2.A.4.c.	Check whether pertinent responsibilities need to be updated.	Sonstige	2019
Waste	5.A.1	Initiated research projects for inventory improvement.	ARR	2015+16

1.6.1.4 Audit

In April 2016, the German 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 German 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 German 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 German 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 19. 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 19. 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 19.

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 15.7, 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 (Volker 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.

1.6.3 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 German 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 German 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 German 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 German 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

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 (V. 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 German 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 2021, pursuant to Approach 1, is 3.2 %; pursuant to Approach 2, it is -2.9 / +3.3%. The following table provides a concise overview of the uncertainties of the inventory as a whole:

Table 9: Overview of the uncertainties for the inventory as a whole

	Base Year	2021	Trend	Method	Base year uncertainty		2021 uncertainty		Trend uncertainty	
	kt	kt	%		%		%		%	
National total incl. LULUCF	1,290,897	764,356	-40.79	Approach 1	3.83		3.22		3.63	
				Approach 2	-2.94	+3.07	-2.93	+3.26	-10.20	+10.89
National total w/o LULUCF	1,254,922	760,358	-39.41	Approach 1	3.95		3.11		2.98	
				Approach 2	-2.28	+2.47	-1.96	+2.39	-6.96	+7.44

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 2021 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 19.2). 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.

1.8 General checking of completeness

Completeness information for the various individual categories is presented in CRF Table 9(a), which is summarised in NIR Chapter 18 (Table 516 and

Emissio ns 2020

kt CO2 equiv	**national total (without LULUCF)**	**749.254**	
kt CO2 equiv	thereof 0.1 %	749	
kt CO2 equiv	thereof 0.05 %	375	
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	< 15.9	see NIR Chapter 4.3.4.2
2.B.6	Titan dioxid 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	148	see NIR Chapter 16.3.1
3.A.4	Rabbits	4.44	see NIR Chapter 16.3.1
3.A.4	Fur-bearing animals	0.18	see NIR Chapter 16.3.1
3.B(a).4	Deer	1.63	see NIR Chapter 16.3.1
3.B(a).4	Fur-bearing animals	1.21	see NIR Chapter 16.3.1
3.B(a).4	Rabbits	0.99	see NIR Chapter 16.3.1
3.B(a).4	Ostrich	1.21	see NIR Chapter 16.3.1
3.B(b).4	Fur-bearing animals	0.60	see NIR Chapter 16.3.1
3.B(b).4	Rabbits	0.73	see NIR Chapter 16.3.1
3.B(b).4	Ostrich	0.05	see NIR Chapter 16.3.1
3.B(b).5	Indirect emissions	0.90	see NIR Chapter 16.3.1
3.D	Other animals	35.88	The entries for other animals are not shown in CRF Reporter under 3 D., see NIR Chapter 16.3.1
5.A	Flaring	0.67	see NIR Chapter 7.2.1.2.9
5.E.	accidental fires (buildings, cars ...)	< 100	see NIR Chapter 7.6
Sum		**716**	

Table 517). The following are differentiated in Germany:

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

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 German Environment Agency are confidential, due to data-protection requirements, and thus are reported only in aggregated form – although they are reported completely.

2 Trends in Greenhouse Gas Emissions

Table 10 below shows the total emissions, as determined for this inventory, of direct and indirect greenhouse gases and of the acid precursor SO_2. Table 11 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 39.2 %, with respect to 1990[20].

All detailed tables relative to discussion of trends are presented in Annex Chapter 19.3.

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

With regard to the previous year, 2020, total emissions rose slightly, by 4.0 %. This re-increase is due primarily to the re-increase of energy-industry emissions that occurred after their marked decrease of 2020. Emissions from public hard-coal-fired and lignite-fired power stations increased particularly markedly, as a result of higher coal use for power generation. On the other hand, use of natural gas, which has lower emissions than coal does, decreased in the second half of the year, as a result of gas-price increases. The primary reason for the increased use of hard coal and lignite for electricity generation is that renewables-based electricity generation decreased considerably with respect to the previous year. The decrease in electricity generation from wind energy was especially marked.

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

Table 10: 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	2021
								(kt)								
CO_2 emissions (without LULUCF)	**1,054,741**	**939,897**	**898,938**	**865,471**	**831,130**	**807,614**	**812,816**	**833,804**	**794,739**	**798,085**	**801,745**	**785,986**	**754,811**	**707,491**	**647,252**	**678,799**
Net CO_2 emissions/removals	1,083,501	909,585	891,603	865,778	820,839	791,170	787,704	809,946	778,062	779,213	780,350	767,606	739,346	692,963	643,742	675,066
CH_4 (without LULUCF)	**4,736**	**4,130**	**3,430**	**2,592**	**2,146**	**2,091**	**2,103**	**2,068**	**2,013**	**1,996**	**1,935**	**1,905**	**1,825**	**1,724**	**1,680**	**1,632**
CH_4 (including LULUCF)	4,962	4,356	3,656	2,821	2,379	2,324	2,336	2,301	2,246	2,230	2,169	2,139	2,063	1,958	1,915	1,866
N_2O (without LULUCF)	**195**	**185**	**123**	**126**	**104**	**104**	**104**	**105**	**106**	**106**	**106**	**104**	**100**	**97**	**94**	**93**
N_2O (including LULUCF)	198	189	126	130	108	108	108	109	111	111	110	108	104	101	98	98
F gases, sum (CO_2 equivalent, 1995 base year)	**12,324**	**16,021**	**12,735**	**13,576**	**13,701**	**13,880**	**14,056**	**14,085**	**14,085**	**14,523**	**14,619**	**14,710**	**13,879**	**13,212**	**11,697**	**11,104**
Total emissions (without LULUCF)(CO_2 equi.)	**1,251,225**	**1,120,661**	**1,040,192**	**984,987**	**932,379**	**907,502**	**913,348**	**933,505**	**893,394**	**896,658**	**898,560**	**881,583**	**846,171**	**794,634**	**730,923**	**760,358**
Total emissions / removals with LULUCF (CO_2 equi.)	1,287,200	1,097,542	1,040,041	992,819	929,723	898,693	895,881	917,293	884,395	885,486	884,832	870,878	838,514	787,811	735,120	764,356
NO_x	**2,847**	**2,172**	**1,868**	**1,617**	**1,458**	**1,437**	**1,432**	**1,435**	**1,391**	**1,366**	**1,332**	**1,276**	**1,188**	**1,104**	**974**	**966**
SO_2	**5,464**	**1,743**	**643**	**473**	**403**	**388**	**369**	**357**	**336**	**334**	**310**	**301**	**290**	**260**	**241**	**254**
NMVOC	**3,949**	**2,363**	**1,814**	**1,490**	**1,363**	**1,274**	**1,258**	**1,213**	**1,173**	**1,147**	**1,139**	**1,143**	**1,096**	**1,066**	**1,029**	**1,044**
CO	**13,354**	**7,234**	**5,146**	**3,863**	**3,536**	**3,457**	**3,206**	**3,168**	**3,000**	**3,102**	**2,973**	**2,981**	**2,863**	**2,756**	**2,454**	**2,587**

Table 11: 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 2020	Base Year to 2021	compared to prev. year (2020 – 2021)
CO_2 emissions (without LULUCF)	*1990*	**-38.6**	**-35.6**	**+4.9**
Net CO_2 emissions/removals	1990	-40.6	-37.7	+4.9
CH_4 (without LULUCF)	*1990*	**-64.5**	**-65.5**	**-2.9**
N_2O (without LULUCF)	*1990*	**-51.7**	**-52.0**	**-0.6**
F gases, sum	*1995*	**-28.6**	**-32.0**	**-4.7**
Total emissons (without LULUCF)	1990	**-41.4**	**-39.2**	**+4.0**
NO_x	*1990*	**-65.8**	**-66.1**	**-0.9**
SO_2	*1990*	**-95.6**	**-95.3**	**+5.4**
NMVOC	*1990*	**-74.0**	**-73.6**	**+1.5**
CO	*1990*	**-81.6**	**-80.6**	**+5.4**

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

From 1990 through 2021, greenhouse-gas emissions were reduced considerably, by 39.2 %[21]. 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;

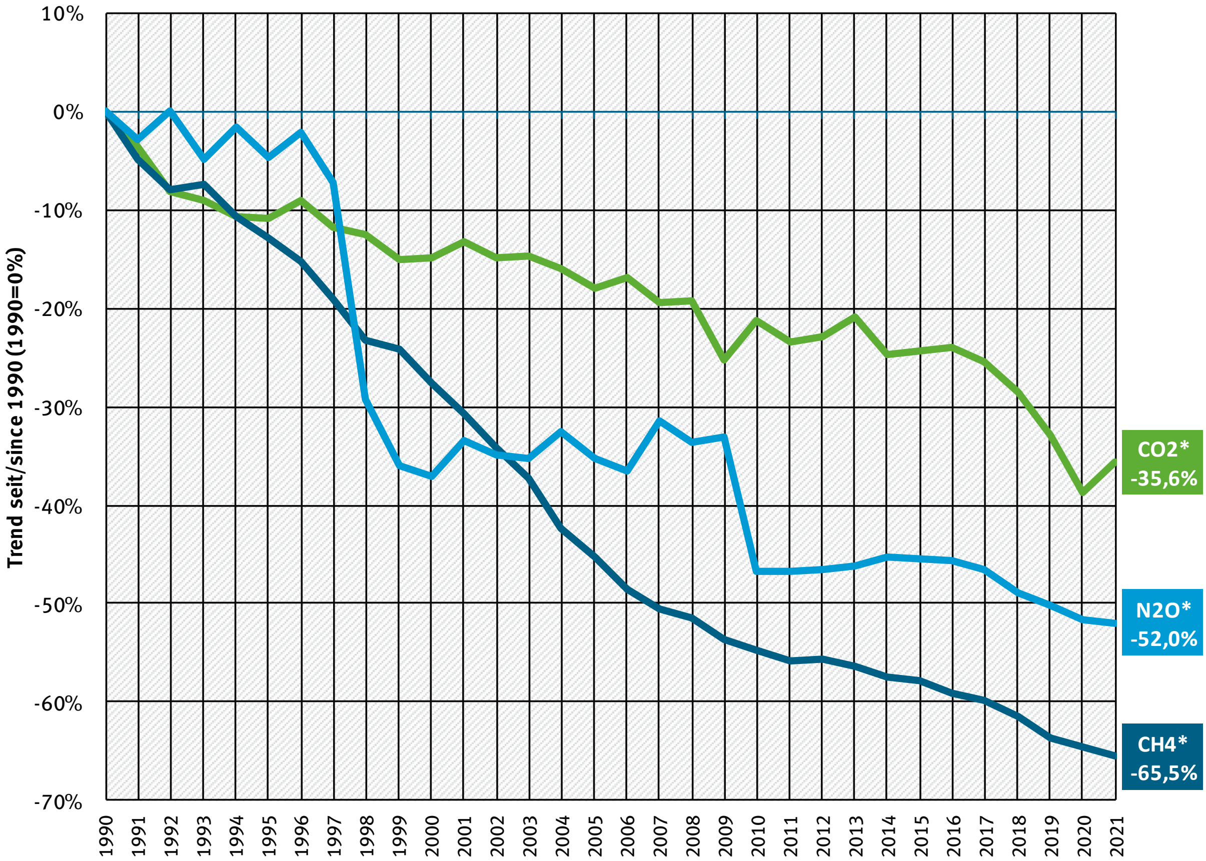
Such areas are considered in greater detail in the discussion below of trends for the various individual greenhouse gases.

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.

[21] 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



* not including 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 (cf. Figure 15).

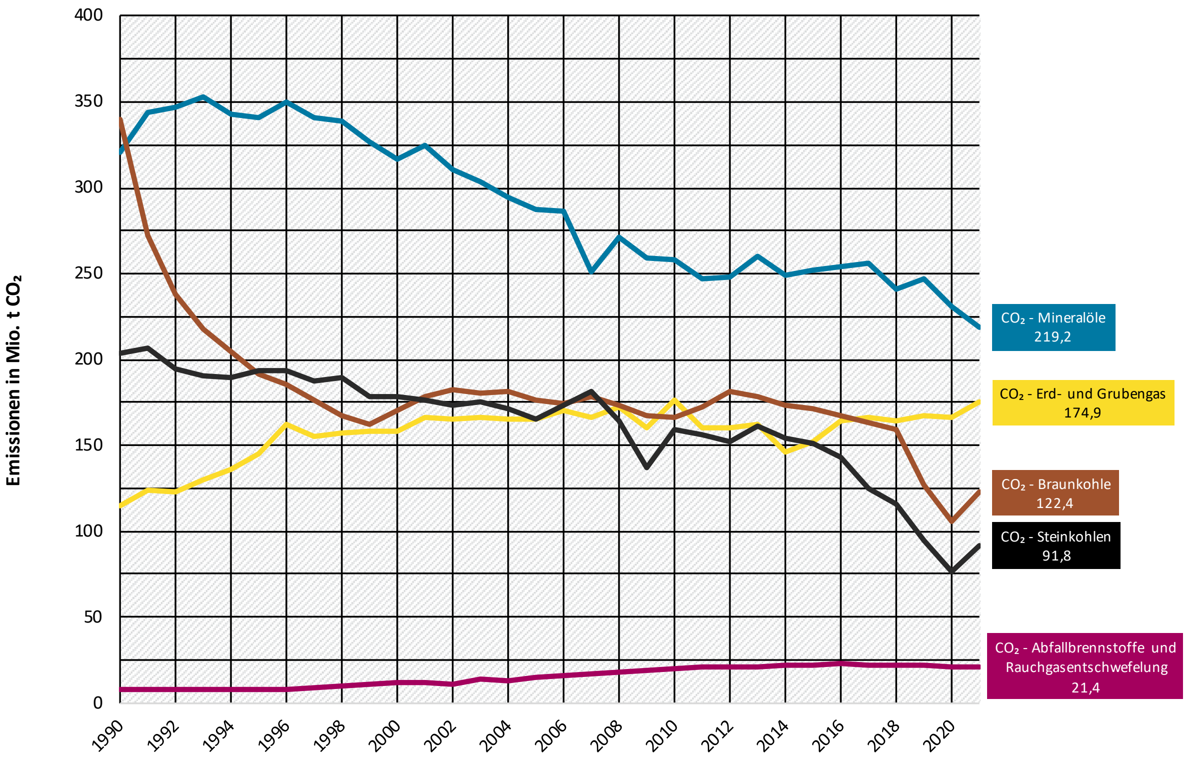


Figure 15: Carbon dioxide emissions, by fuels

The situation is somewhat different only in the transport sector, which is dominated by road transports: CO_2 emissions in this area increased slightly through 1999, to nearly 184 million t, and then decreased slightly as a result of reductions in consumption, shifting of refueling to other countries[22], substitution of diesel fuel for gasoline[23] 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 levels seen in 2020 and 2021 – 145 and 146 million t, respectively – lie considerably below the long-term trend, and they are due to various special effects.

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

CO_2 emissions – especially those of the energy industry, which predominate in terms of quantity – increased again sharply, with respect to the previous year (+13.0 %, or nearly +27 million t). Emissions of the manufacturing sector also increased again markedly after 2020 (+4.6 %, or +5.5 million t), as did emissions from industrial processes (+6.4 %, or +2.7 million t). Transport-

[22] 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.

[23] 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.

sector emissions are slightly above the level seen in the previous year, while residential-sector emissions actually decreased considerably (-7.1 %, or -6.3 million t).

2.2.2 Nitrous oxide N_2O

Since 1990, N_2O emissions have decreased by about 52 %. 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 98 %, 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 slightly with respect to the previous year (-0.6 %), as a result of further decreases in the agricultural sector, the predominating area in terms of emissions quantities (decreases in that area: -1.4 %) The considerable emissions increases that occurred in the energy industry (+10.1 %) have dampened this effect, however.

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 65.5 % 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 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 95 % 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 2.9 %. The largest emissions decreases, in quantitative terms, occurred in the areas of agriculture, landfills, and fugitive emissions from fuels. Emissions from combustion of fossil fuels increased with respect to the previous year, however.

2.2.4 F gases

In 2021, emissions of F gases accounted for only about 1.5 % of total emissions. Since 1995 (the base year for F gases), they have decreased by 32 %. 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 38.5 % since 1990. In that period, the transport emissions included in those emissions decreased – primarily as a result of special effects – by about 10.2 %. 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 525 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 38.7 % GHG equivalents results, along with emissions increases with respect to the previous year, 2020.

Agriculture

The decrease in agricultural emissions since 1990, amounting to over 22.4 %, 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 LULUCF sector's net emissions are shaped mainly by forest biomass, and by related storage in harvested wood products. As a result of natural disruptions (including negative factors such as drought, storms and insect infestations) of forest-biomass carbon stocks, the constant, and high, total emissions from organic soils and water bodies are no longer being sufficiently offset. As a result, the entire LULUCF sector became a source of greenhouse-gas emissions in the years 1990, 2002-2007, 2020 and 2021.

With respect to the base year, only the land-use category Grassland exhibits a marked, clearly directional emissions decrease. The following section discusses the trends in the various land-use categories.

<u>Forest Land:</u> 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.

<u>Cropland:</u> The total emissions in 2021 increased by 7 % in comparison to the base year. The primary factor driving the overall trend is an increase in emissions from mineral soils, resulting mainly from grassland tillage.

<u>Grassland:</u> The total emissions in 2021 decreased by 13 % in comparison to the base year. These emissions consist of the sum of the emissions from the sub-categories grassland (in the strict sense), woody grassland, and hedges. GHG emissions in each of these three sub-categories differ considerably from those in the other sub-categories, both quantitatively and qualitatively. In the time series for total emissions, emissions in the sub-category grassland (in the strict sense) – in particular, emissions from organic soils – predominate in terms of absolute emissions quantity. The course of the time series is also shaped by emissions and removals from biomass and from

mineral soils. While carbon removals in biomass, and CO_2 emissions, fluctuate between the various years concerned, mineral soils function as a constant sink. Over time, that sink function has exhibited a highly significant negative trend, the sink performance of mineral soils has increased.

Wetlands: 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 trend in this category results mainly from CO_2 releases from organic soils, as well as from methane emissions from flowing and standing man-made water bodies. The CO_2 emissions are caused by two, nearly equal, contributing factors: Peat extraction and drainage of terrestrial organic soils.

Settlements: The trend in the land-use category Settlements is also 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.

Waste and wastewater

The most significant emissions reduction, at 89.1 %, 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 93.1 %. Emissions from wastewater treatment, which also belong to the category waste & wastewater, are produced in considerably lower quantities than landfill emissions are. Nonetheless, they also decreased very sharply.

The relevant detailed data are presented in Table 526 in Annex Chapter 19.3.

Table 12: 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	2021
1. Energy	0.0%	-11.6%	-16.4%	-20.2%	-23.4%	-25.7%	-25.0%	-23.0%	-26.9%	-26.5%	-26.4%	-28.3%	-31.2%	-35.7%	-41.3%	-38.5%
2. Industrial processes	0.0%	1.6%	-17.8%	-20.5%	-33.7%	-33.7%	-34.6%	-34.8%	-34.9%	-36.0%	-34.0%	-29.8%	-32.9%	-36.1%	-40.9%	-38.7%
3. Agriculture	0.0%	-13.0%	-13.6%	-17.9%	-18.3%	-18.2%	-17.3%	-16.2%	-14.5%	-14.7%	-15.3%	-16.2%	-18.4%	-19.4%	-20.8%	-22.4%
5. Waste	0.0%	-2.6%	-31.4%	-55.2%	-73.7%	-75.8%	-77.8%	-79.7%	-81.1%	-82.6%	-83.9%	-84.8%	-85.7%	-87.0%	-88.1%	-89.1%
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**	**2021**
1. Energy	0.0%	-0.5%	-0.4%	-2.4%	5.0%	-3.0%	0.9%	2.6%	-5.1%	0.7%	0.1%	-2.6%	-4.1%	-6.6%	-8.6%	4.7%
2. Industrial processes	0.0%	-1.6%	4.4%	-4.0%	-3.4%	-0.1%	-1.4%	-0.3%	-0.1%	-1.6%	3.0%	6.4%	-4.4%	-4.8%	-7.4%	3.7%
3. Agriculture	0.0%	0.0%	-1.0%	-0.3%	-0.7%	0.1%	1.1%	1.3%	2.1%	-0.2%	-0.7%	-1.1%	-2.6%	-1.2%	-1.7%	-2.1%
5. Waste	0.0%	-3.3%	-6.4%	-8.3%	-10.3%	-8.0%	-8.2%	-8.6%	-7.2%	-7.8%	-7.2%	-5.6%	-6.1%	-8.8%	-8.8%	-8.3%

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 16 and in Table 11. In the period 1990 through 2021, considerable reductions of emissions of these gases were achieved: For example, emissions of SO_2 decreased by 95.3 %, while those of CO decreased by 80.6 %, those of NMVOC decreased by 73.6 % and those of NO_X decreased by about 66.1 %.

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.

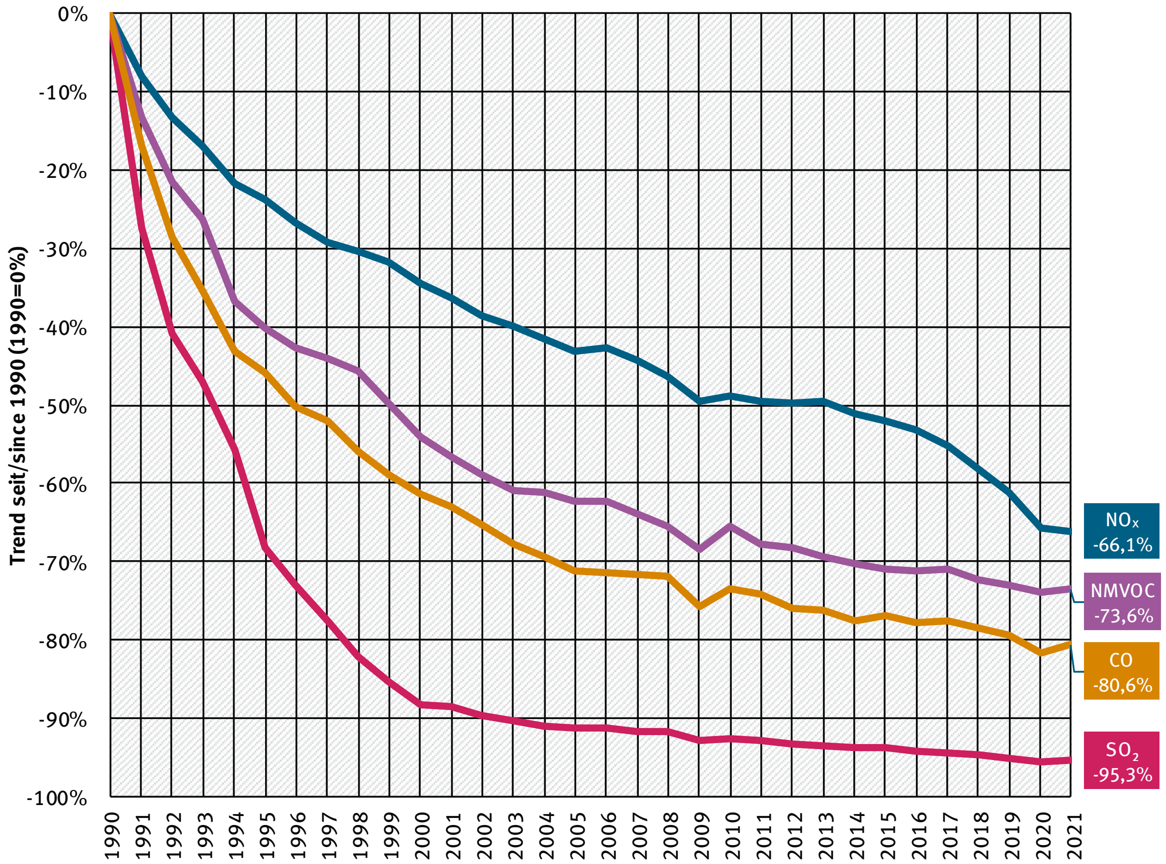
A range of different factors are responsible for this trend. These factors, which differ in the significance and extent of their relevance, include:

- 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 German Environment Agency[24].

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

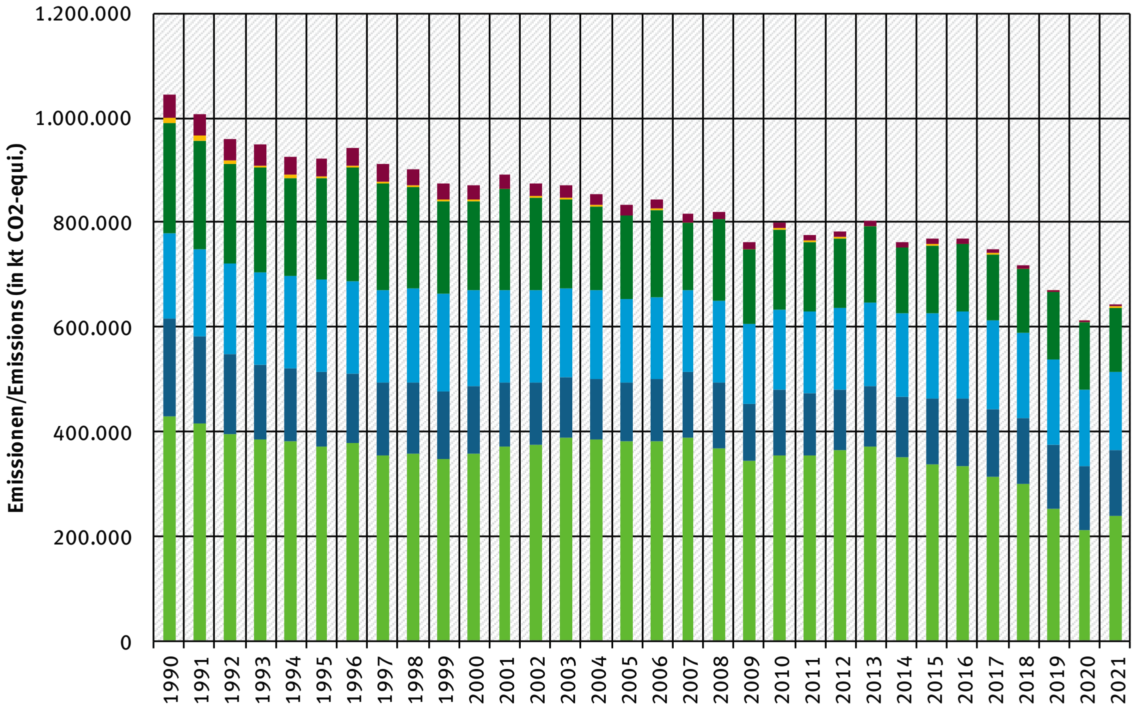
Figure 16: Emissions trends for indirect greenhouse gases and SO_2



3 Energy (CRF Sector 1)

3.1 Overview (CRF Sector 1)

Figure 17: Overview of greenhouse-gas emissions in CRF Sector 1



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 15.7). 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 German 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 15.1 through 15.4.

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 & Merten, 2006). For a detailed description of the procedure used for revision of the activity data for stationary combustion systems, see the 2010 NIR.

With the help of additional statistics, and of various assumptions, the Energy Balance data for 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 following Energy Balance lines are used for determination of emissions-relevant fuel inputs from stationary sources:

A: Transformation inputs (comprises Energy Balance lines 9 through 19); of these

1. **Thermal power stations of the public supply** (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 (only for electricity generation)** (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 systems** (line 14): “other systems” comprises all systems/plants that generate electricity from biogas, landfill gas, sewage 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 in statistical collection of data on such systems, this category includes very small systems in the residential and commercial/institutional sectors.
4. **Thermal (CHP) power stations for the public supply** (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.

B: Energy consumption in the transformation sector (Energy Balance lines 33 through 40)

6. Lines 33 to 39 and the total line 40 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.
   The balance sheet for lignite pits and briquette plants is one of the special aspects of the transformation sector to consider. The own consumption of ignite pits and briquette plants is listed together with production-related transformation inputs of briquette plants, in line 10. As a result, the emissions-causing inputs within own consumption cannot be read out of the Energy Balance; they must be calculated from the transformation input.
   The total fuel inputs consist of a) the fuel inputs for CHP-based heat generation and b) the fuel inputs for electricity generation by power stations in the hard-coal-mining, lignite-mining and refinery sectors. 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. In **Final energy consumption by industry** (mining, non-metallic minerals, manufacturing, and line 60 of the Energy Balance), the fuel inputs refer to the fuel used for heat generation for production and for space heating. No distinction is made with regard to the type of heat generation concerned. The total fuel input in industry facilities consists of a) part of the final energy consumption in these categories and b) industrial power stations' fuel input for electricity generation.
8. The data on **Final energy consumption in the residential sector** (Energy Balance line 66) 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** (Energy Balance line 67) comprise fuel inputs for hot water production, space heating and process-heat generation in this sector.

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 German Environment Agency's own calculations. The following Figure 18 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 analysed within the energy-data database (Enerdat))
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 18: Characteristics of the German Environment Agency's structure of the Balance of Emission Causes, with regard to disaggregation of the Energy Balance

The BEU model provides a data structure that can be used for a range of different reporting obligations. In particular, this disaggregation, into consistent time series, is needed for determination of emissions of “classical” air pollutants, and for calculation of nitrous-oxide and methane emissions.

For the subdivision as described, the fuels pursuant to the Energy Balance are also listed individually in the database. 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. In keeping with reporting requirements, the various grades of fuel, with different carbon-content levels, are assigned to the five categories of 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 German 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. In keeping with the need to calculate conservatively, 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 data on the biogenic fraction of the industrial waste in the aforementioned sectors were obtained from the research project "Inputs of secondary fuels" ("Einsatz von Sekundärbrennstoffen") ((Lechtenböhmer, Nanning, Hillebrand, et al., 2006), 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 apply a sectoral approach that 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 also determined with the Reference Approach (1.AB) pursuant to the 2006 IPCC Guidelines (IPCC (2006a): Vol. 2, Chapter 6: Reference Approach), which 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.

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 the following figures and tables, as well as in Chapter 17 in Annex 4 of this report. In Figure 19 and Figure 20, they are compared with other available data sets.

3.2.1.2 Verification with other data sets available for Germany

In keeping with the provisions of the IPCC Guidelines, the results of detailed sectoral energy-related CO_2 emissions calculations are to be compared with other data sets available for the reporting country.

In the framework of such verification, a comparison with the data set *CO_2 emissions from fuel combustion: World CO_2 Emissions from Fuel Combustion (detailed estimates)* of the International Energy Agency (IEA) is presented here.

Table 13 and Figure 19 compare the results of the 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 20, the relative discrepancies in the data records are depicted in order to illustrate these level differences.

Table 13: Comparison of CO_2 inventories with IEA data; absolute values in millions of t

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
	[millions of t] / *[%]*											
UBA (1.AA)	**988.1**	**879.0**	**835.8**	**807.9**	**780.1**	**749.2**	**751.1**	**731.7**	**702.8**	**657.8**	**600.8**	**629.6**
IEA	**940.0**	**856.6**	**812.3**	**786.9**	**758.8**	**729.7**	**734.5**	**718.8**	**694.5**	**645.4**	**590.0**	**622.0**
Difference	48.1	22.4	23.5	21.0	21.3	19.5	16.7	12.9	8.24	12.4	10.8	7.65
	5.11%	*2.61%*	*2.90%*	*2.67%*	*2.80%*	*2.67%*	*2.27%*	*1.79%*	*1.19%*	*1.92%*	*1.83%*	*1.23%*
UBA (1.AB)	**986.7**	**861.5**	**820.4**	**802.2**	**757.0**	**731.5**	**742.9**	**728.7**	**710.4**	**661.4**	**600.8**	**632.9**
Difference	**1.39**	**17.42**	**15.46**	**5.71**	**23.08**	**17.67**	**8.28**	**3.00**	**-7.61**	**-3.59**	**-0.03**	**-3.24**
	0.14%	2.02%	1.88%	0.71%	3.05%	2.42%	1.11%	0.41%	-1.07%	-0.54%	-0.01%	-0.51%

Source: UBA(1.AA) & UBA (1.AB): own calculations; IEA: CO2 emissions from fuel combustion: World CO_2 Emissions from Fuel Combustion (detailed estimates), IEA, Paris, 2022[25]

The data used for the comparison are compiled and published by the IEA. Since various institutions in Germany collect, process and provide data for the IEA questionnaires, and since the IEA carries out its own calculations for preparation of IEA Energy Balances, these results do not conform exactly with the data in the national Energy Balances.

In spite of these methodological restrictions, the comparison with the IEA data shows an average discrepancy of only 2.85%, and therefore confirms the CO_2 emissions determined for Germany.

[25] https://www.iea.org/data-and-statistics/data-product/greenhouse-gas-emissions-from-energy#co2-emissions-from-fuel-combustion-detailed-estimates

In all of the years concerned, the comparable national emissions are higher than the pertinent results published by the IEA. (Minimum: +1.19 % (2018); Maximum: +5.11 % (1990)).

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

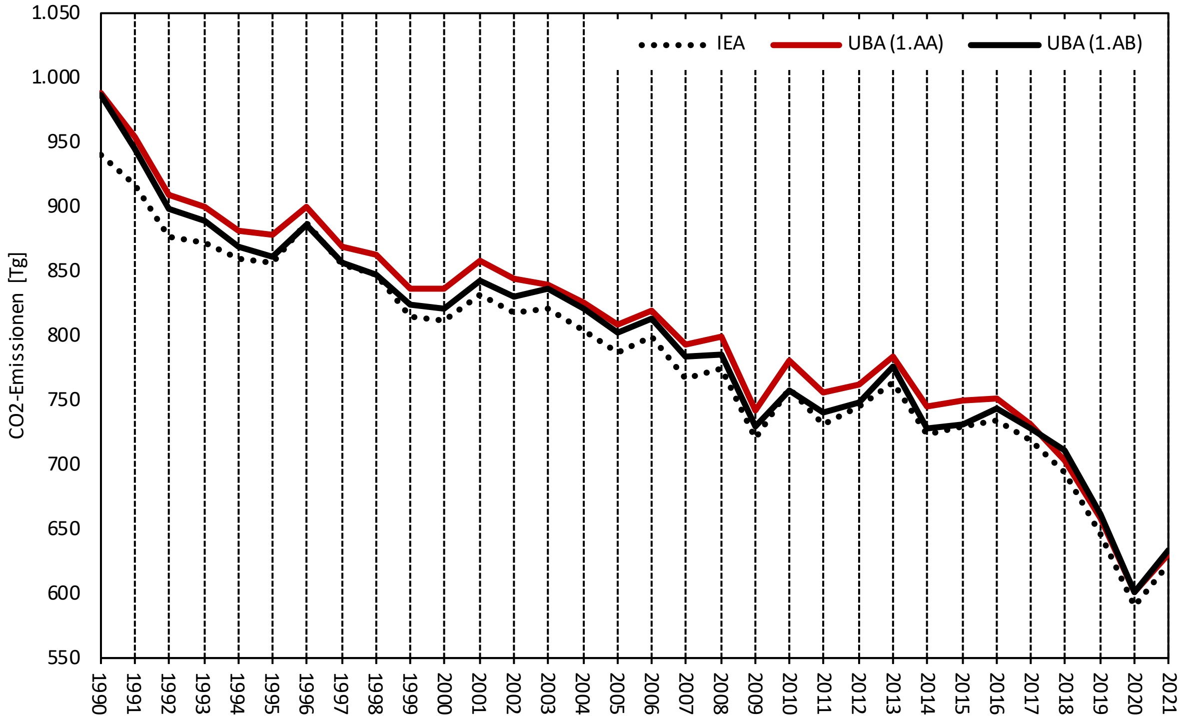
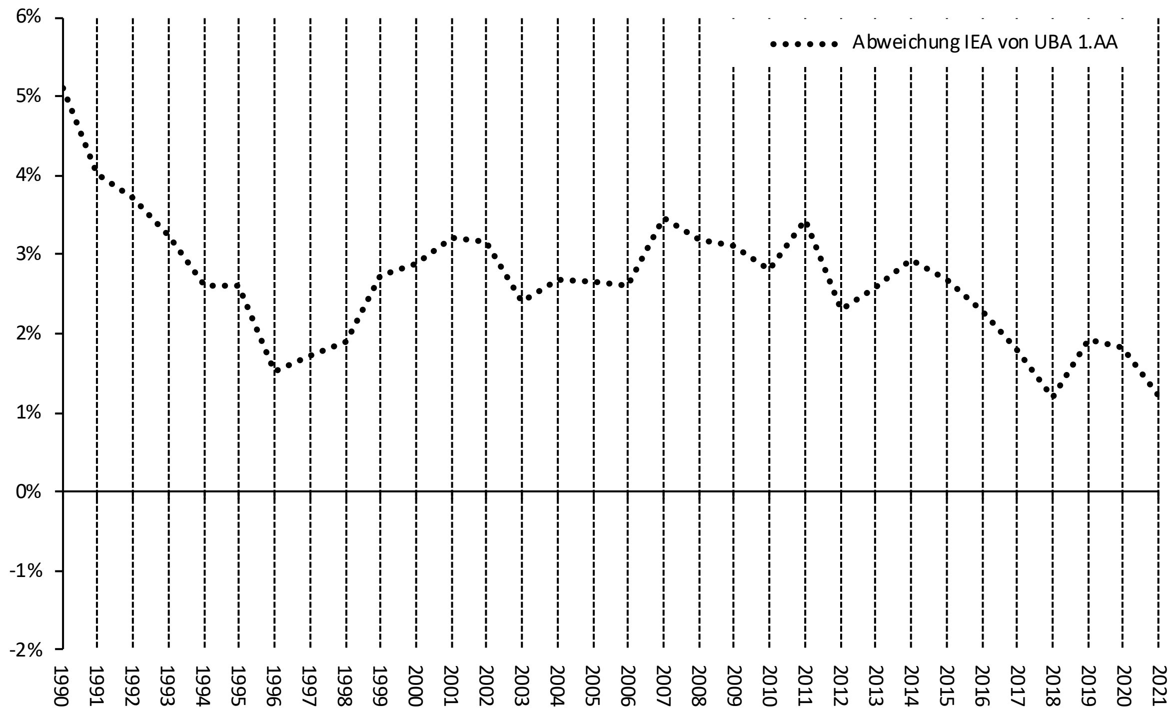


Figure 20: CO_2 emissions in Germany – discrepancies with respect to the IEA data



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 civil aviation (1.D.1.a)

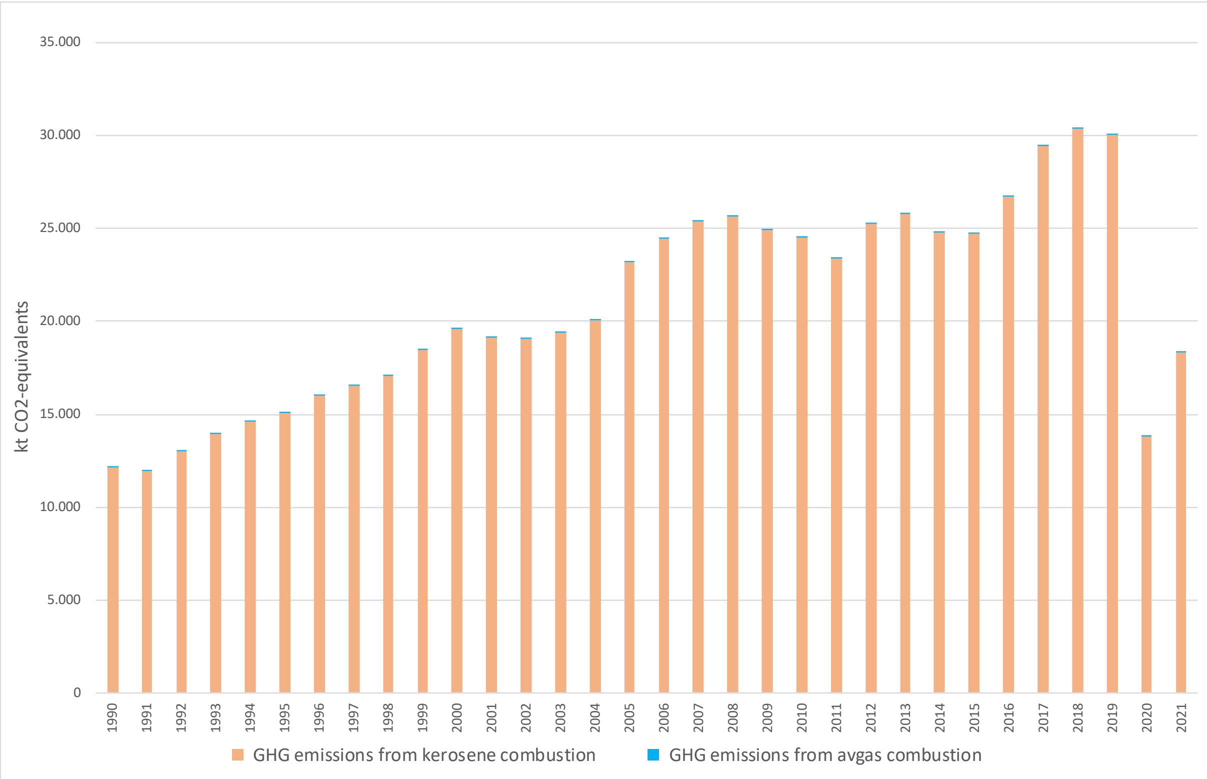
3.2.2.2.1 Category description (1.D.1.a)

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 21: 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, Allekotte, et al., 2021).

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, 2022c), are as follows:

Table 14: International flights' annual shares of domestic deliveries of kerosene and avgas, in [%]

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Kerosene	85.0	87.3	89.2	91.3	91.7	92.4	92.9	93.7	93.8	93.5	93.5	96.2
Avgas	21.0	19.1	20.3	22.0	22.6	18.4	9.42	9.60	8.87	7.87	6.26	8.19

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

Additional information relative to the activity data and emission factors used is presented in Chapter 3.2.8.1 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 16.1.4).

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

Cf. Domestic aviation, Chapter 3.2.8.1.3.

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

Cf. Domestic aviation, Chapter 3.2.8.1.4.

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

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

With respect to the 2022 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 15: Revised percentage shares of domestic deliveries of kerosene

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Jet fuel / kerosene											
2023 Submission	85.0	87.3	89.2	91.3	91.7	92.4	92.9	93.7	93.8	93.5	93.5
2022 Submission	83.9	87.9	88.2	90.3	91.4	92.7	92.8	93.2	93.3	93.1	93.0
Absolute change	1.06	-0.60	1.05	0.97	0.31	-0.24	0.08	0.54	0.56	0.39	0.47
Relative change	1.26%	-0.68%	1.19%	1.08%	0.34%	-0.26%	0.09%	0.57%	0.61%	0.42%	0.50%
Avgas											
2023 Submission	21.0	19.1	20.3	22.0	22.6	18.4	9.42	9.60	8.87	7.87	6.26
2022 Submission	21.0	19.1	20.3	22.0	22.7	18.5	9.44	9.61	8.88	7.88	6.28
Absolute change	0.00	0.00	0.00	0.00	-0.02	-0.04	-0.02	-0.02	-0.01	-0.01	-0.02
Relative change	0.00%	0.00%	0.00%	0.00%	-0.09%	-0.22%	-0.18%	-0.19%	-0.12%	-0.11%	-0.29%

Source: Own calculations, based on TREMOD AV

The resulting change in fuel consumption is as follows:

Table 16: Revised fuel quantities, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Jet fuel / kerosene											
2023 Submission	164,304	203,795	265,259	313,919	331,794	334,227	361,443	398,413	410,244	406,043	186,883
2022 Submission	162,259	205,197	262,146	310,569	330,659	335,097	361,113	396,137	407,774	404,342	185,951
Absolute change	2,045	-1,402	3,113	3,350	1,135	-870	330	2,276	2,470	1,701	932
Relative change	1.26%	-0.68%	1.19%	1.08%	0.34%	-0.26%	0.09%	0.57%	0.61%	0.42%	0.50%
Avgas											
2023 Submission	511	218	228	154	129	102	38.4	38.7	34.5	25.1	13.0
2022 Submission	511	218	228	154	129	102	38.4	38.7	34.6	25.1	13.0
Absolute change	0.00	0.00	0.00	0.00	-0.11	-0.23	-0.07	-0.08	-0.04	-0.03	-0.04
Relative change	0.00%	0.00%	0.00%	0.00%	-0.09%	-0.22%	-0.18%	-0.19%	-0.12%	-0.11%	-0.29%
TOTAL FUEL INPUTS											
2023 Submission	164,815	204,013	265,487	314,073	331,923	334,329	361,482	398,452	410,279	406,068	186,896
2022 Submission	162,770	205,415	262,373	310,723	330,788	335,200	361,152	396,176	407,809	404,367	185,964
Absolute change	2,045	-1,402	3,113	3,350	1,135	-871	330	2,276	2,470	1,701	932
Relative change	1.26%	-0.68%	1.19%	1.08%	0.34%	-0.26%	0.09%	0.57%	0.61%	0.42%	0.50%

Source: Own calculations, based on TREMOD AV

In addition, and on the basis of the results of a broad-based measurement campaign, the default emission factor used to date for CO_2 from use of avgas, 70,000 kg/TJ, was replaced with a country-specific value of 71,199 kg/TJ (Juhrich, 2022).

Also, the breakdown of kerosene consumption by the L/TO and cruise flight phases, which have widely differing methane emission factors, has been revised.

All in all, these adjustments have led to the following different greenhouse-gas emissions:

Table 17: Revised GHG emissions, in kt CO_2 equivalents

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Carbon dioxide – CO_2 [a]											
Subm. 2023	12,073	14,945	19,448	23,007	24,315	24,491	26,481	29,189	30,055	29,747	13,691
Subm. 2022	11,922	15,047	19,220	22,762	24,232	24,555	26,456	29,022	29,874	29,622	13,623
Abs. change	150	-102	228	246	83.3	-63.6	24.2	167	181	125	68.3
Rel. change	1.26%	-0.68%	1.19%	1.08%	0.34%	-0.26%	0.09%	0.57%	0.61%	0.42%	0.50%
Methane – CH_4											
Subm. 2023	0.19	0.15	0.13	0.13	0.13	0.14	0.15	0.15	0.16	0.15	0.07
Subm. 2022	0.20	0.15	0.14	0.14	0.14	0.14	0.15	0.17	0.18	0.16	0.07
Abs. change	-0.01	0.01	-0.01	-0.01	-0.01	0.00	0.00	-0.01	-0.01	-0.01	0.00
Rel. change	-6.52%	4.94%	-8.81%	-10.0%	-3.64%	3.28%	-1.16%	-7.82%	-8.36%	-5.62%	-6.62%
Nitrous oxide – N_2O											
Subm. 2023	0.383	0.471	0.613	0.729	0.770	0.775	0.838	0.924	0.951	0.941	0.433
Subm. 2022	0.378	0.474	0.605	0.720	0.767	0.777	0.837	0.918	0.945	0.937	0.431
Abs. change	0.005	-0.003	0.008	0.008	0.003	-0.002	0.001	0.006	0.006	0.004	0.002
Rel. change	1.32%	-0.73%	1.27%	1.17%	0.37%	-0.29%	0.10%	0.64%	0.68%	0.47%	0.56%
TOTAL GREENHOUSE GASES [a]											
Subm. 2023	12,191	15,089	19,634	23,228	24,548	24,726	26,734	29,468	30,343	30,031	13,822
Subm. 2022	12,040	15,192	19,403	22,980	24,464	24,790	26,710	29,300	30,160	29,906	13,753
Abs. change	152	-103	230	248	84.0	-64.2	24.4	168	183	126	68.9
Rel. change	1.26%	-0.68%	1.19%	1.08%	0.34%	-0.26%	0.09%	0.57%	0.61%	0.42%	0.50%

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 3.2.8.1.6.

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)

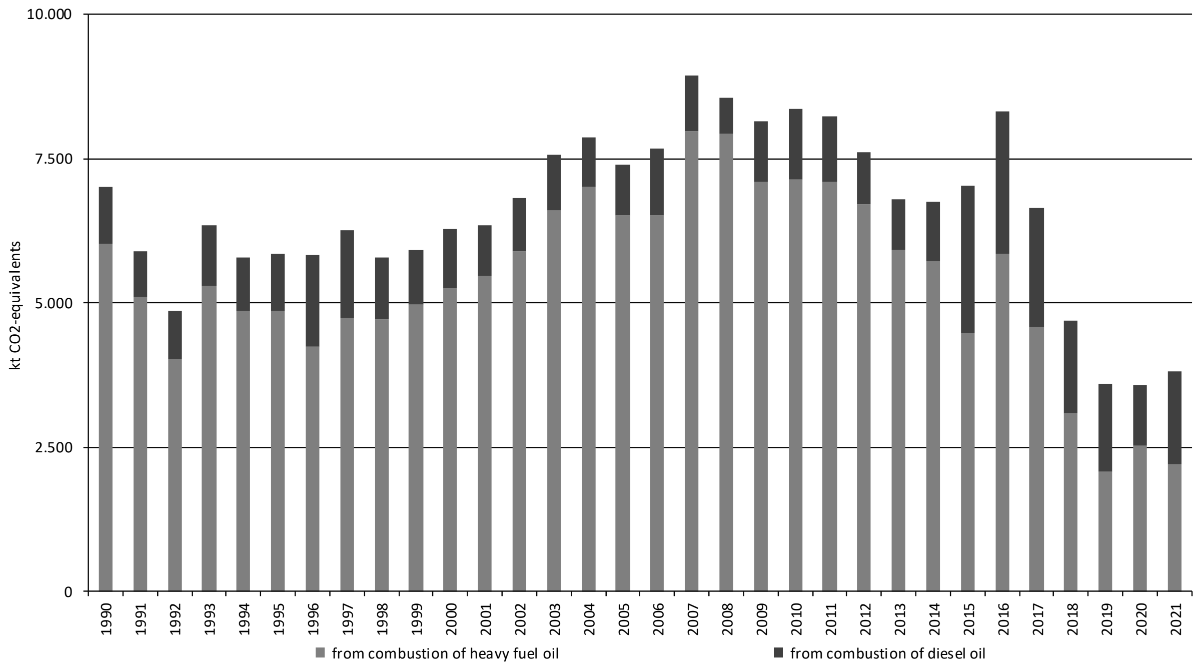
Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS (Tier 2)	NS/IS/M	D [a] / CS
CH_4	CS (Tier 2)	NS/IS/M	CS (M)
N_2O	CS (Tier 2)	NS/IS/M	CS (M)
NO_X, CO, NMVOC, SO_2	CS (Tier 2)	NS/IS/M	CS (M)

[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.

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 22: Development of GHG emissions from international water-borne navigation since 1990



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 (2022c); 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 (2022), 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.[26]

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 16.1.3).

With regard to the pertinent **emission factors** for carbon dioxide, we refer to Chapter 15.7.

The pertinent methane and nitrous oxide emissions are calculated with the emission factors from Deichnik (2022) 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 3.2.8.4.3.

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

Cf. Chapter 3.2.8.4.4.

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

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

With respect to the 2022 Submission, recalculations were carried out solely to take account of revised emission factors for carbon dioxide from use of heavy fuel oil (cf. 3.2.8.4.5).

Table 18: Revised emission factors for CO_2 from heavy fuel oil, in [kg/TJ]

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
2023 Submission	77,241	77,241	77,241	77,241	77,241	76,445	77,188	77,188	77,188	77,188	77,188
2022 Submission	79,751	79,751	79,751	79,567	79,704	80,877	81,626	80,834	79,892	79,400	79,671
Absolute change	-2,510	-2,510	-2,510	-2,326	-2,463	-4,431	-4,438	-3,646	-2,704	-2,212	-2,483
Relative change	-3.15%	-3.15%	-3.15%	-2.92%	-3.09%	-5.48%	-5.44%	-4.51%	-3.38%	-2.79%	-3.12%

Source: Deichnik (2022)

From this revision, the following recalculated emissions quantities result:

[26] 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)

Table 19: Revised GHG emissions, in kt and kt CO_2-eq

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Carbon dioxide[a]											
2023 Submission	6,917	5,764	6,196	7,303	8,257	6,932	8,205	6,564	4,624	3,548	3,518
2022 Submission	7,111	5,919	6,365	7,497	8,482	7,188	8,537	6,778	4,730	3,607	3,598
Absolute change	-193	-156	-168	-194	-225	-256	-332	-214	-106	-58.8	-79.7
Relative change	-2.72%	-2.63%	-2.65%	-2.58%	-2.65%	-3.56%	-3.89%	-3.16%	-2.25%	-1.63%	-2.22%
TOTAL GREENHOUSE GASES [a]											
2023 Submission	7,011	5,842	6,280	7,403	8,370	7,028	8,317	6,655	4,687	3,597	3,567
2022 Submission	7,205	5,998	6,449	7,596	8,594	7,284	8,649	6,869	4,794	3,656	3,647
Absolute change	-193	-156	-168	-194	-225	-256	-332	-214	-106	-58.8	-79.7
Relative change	-2.68%	-2.60%	-2.61%	-2.55%	-2.61%	-3.52%	-3.84%	-3.12%	-2.22%	-1.61%	-2.19%

[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 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. Part of these fuels are also used in non-energy-related applications, as feedstock for production processes. In the German Energy Balance (EB), this non-energy-related consumption is listed separately in line 43 (EB line 43).

The predominant consumer in this area is the chemical industry: It uses fossil fuels in steam crackers, in reforming processes, in synthetic-gas production and in the produciton of graphite electrodes. The most important derived products obtained via cracking and reforming include ethylene, propylene, 1,3-butadiene, benzene, toluene and xylene; the most important from production of synthesis gas include ammonia and methanol.

Bitumen, lubricants and paraffin waxes are produced in refineries: Applications for bitumen include road surfacing and production of roof sheeting, while lubricants are used, inter alia, in road vehicles and in various types of machines.

Without suitable adjustments, it is not possible to compare the consumption data listed in EB line 43 with the data on CO_2 and NMVOC emissions from non-energy-related applications that are reported in the inventory under *CRF 2 – Industrial processes*. One reason for this is that "industrial processes" takes account only of emissions from product manufacture and use, while EB line 43 comprises all feedstock emissions, including both process-specific emissions and the carbon quantities stored in the relevant products. The latter account for far and away the largest share of the feedstock emissions.

Another important difference is that calculation of emissions from product use takes account of imported and exported quantities. In the interest of complete accounting, Table 21 (see below) takes account of the carbon stored in the relevant fossil fuel products. 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 is made on the basis of a) the specific carbon content pursuant to Table 3.10 in Volume 3 of the 2006 IPCC-

GL (IPCC, 2006b) and b) the molar mass of CO_2. The pertinent CO_2 equivalent emissions are then split among the three feedstocks used in Germany (naphta, LP gas and other petroleum products), in keeping with (internal) data provided by associations.

For simplification purposes, carbon black is assumed to consist of pure carbon; that carbon is 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 20: 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 2021, the sum total of the emitted carbon and the carbon stored in products is equivalent to 107 % of the carbon from non-energy-related consumption pursuant to EB line 43. Consequently, the relevant material-related use can clearly be shown to include the quantities listed in the Energy Balance. No gaps in determination of non-energy-related CO_2 emissions are apparent in the inventory.

Table 21: Verification of the completeness of reported data on CO_2 from non-energy-related use of fossil fuels, for 2021

			COAL				PETROLEUM					GASES	
			Hard coal + hard-coal coke	Lignite	Other lignite products	Total Solid fuels	Naphtha (Naphtha)	Petrol coke	LPG	Other Petroleum products	Total Liquid fuels	Natural gas	Total, gas
A: Listed NEU quantity (Energy Balance line 43)		TJ	3,112.5	256.0	13,239.1	**16,607.6**	355,278.8	6,319.1	92,092.0	383,023.9	**836,713.8**	129,621.4	**129,621.4**
B: Carbon content		kg C/GJ	26.8	30.2	26.9		20.0	27.8	18.1	19.0		15.2	
C: Total input as feedstock / non-energy use		kt C	83.4	7.7	356.6	**447.8**	7,102.3	175.4	1,666.0	7,276.9	**16,220.7**	1,973.1	**1,973.1**
D: Total input as feedstock / non-energy use		**kt CO_2**	**305.9**	**28.4**	**1,307.5**	**1,641.8**	**26,041.9**	**643.3**	**6,108.8**	**26,682.1**	**59,476.1**	**7,234.8**	**7,234.8**
E: Implied oxidised carbon fraction		**%**	**147%**				**112%**	**109%**	**123%**	**105%**	**110%**	**98%**	**98%**
	AD in [kt]	**EM in [kt CO_2]**	**Activity data + emissions (C in Gg CO_2)**										
F: Total reported fossil IPPU CO_2		**7,003**	**449**				**29,270**	**702**	**7,527**	**28,037**	**65,536**	**7,115**	**7,115**
2 Industrial processes		**7,003**	**449**				**29,270**	**702**	**7,527**	**6,724**	**44,223**	**7,115**	**7,115**
2.B: Chemical industry		**5,859**					**29,270**	**6**	**7,527**	**6,724**	**43,527**	**7,115**	**7,115**
2.B.1: Ammonia production	2,892	5,246										5,246	**5,246**
2.B.5: Carbide production	C	6						6			**6**		
2.B.6: Titanium dioxide production		NE											
2.B.8: Petrochemical industry (1)													
Methanol	*1,359*											*1,869*	**1,869**
Ethylene	*5,196*						*11,416*		*2,935*	*1,957*	**16,308**		
Propylene	*3,553*						*7,809*		*2,008*	*1,339*	**11,155**		
Butene and 1,3-Butadiene	*2,186*						*4,982*		*1,281*	*854*	**7,117**		
Benzene	*1,578*						*3,736*		*961*	*641*	**5,338**		
Toluene	*567*						*1,328*		*341*	*228*	**1,897**		
Xylene													
Carbon black	*309*	*607*								*1,706*	**1,706**		
2.C: Metal industry		1,145						**696**			**696**		
2.C.1: Iron and steel production (2)		IE	**469**										
2.C.2: Production of ferroalloys	54	6											
2.C.3: Primary aluminium production	509	696	6					696			**696**		
2.C.5: Lead production (2)	C	IE											
2.C.6: Zinc production (2)	C	IE											
2.D: Non-energy-related products from fuels and solvents (1)													
Lubricants	*2,522*									***21,313***	**21,313**		
Waxes, paraffins, vaseline, etc.	*338*									*7,434*	**7,434**		
Bitumen	*3,972*									*998*	**998**		
Solvents and other product use (3)	IE	IE								*12,881*	**12,881**		

(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.

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

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

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	1 A 1 a, Public Electricity and Heat Production	fossil fuels	CO_2	338,451.2	26.2 %	207,344.8	27.1 %	-38.7 %
L/T	1 A 1 a, Public Electricity and Heat Production		CH_4	192.8	0.0 %	2,579.2	0.3 %	1237.5 %
-/-/2	1 A 1 a, Public Electricity and Heat Production		N_2O	2,140.9	0.2 %	1,590.8	0.2 %	-25.7 %

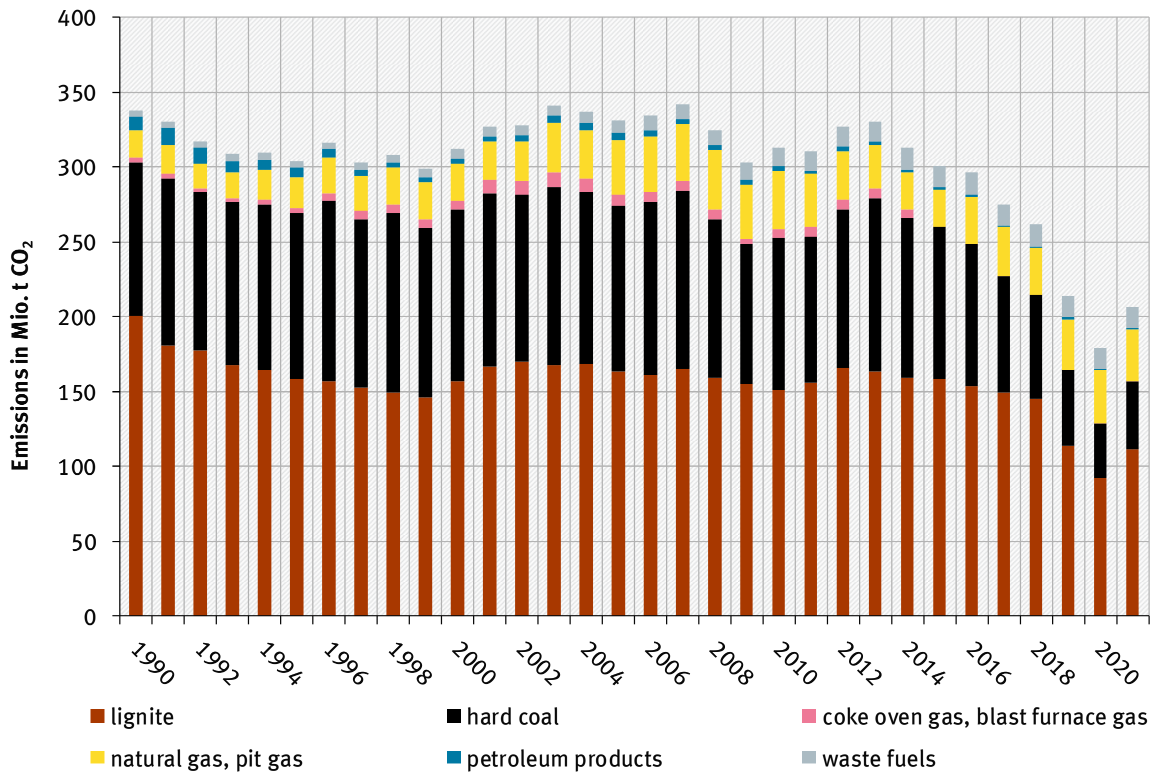
Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS	NS	CS
CH_4	Tier 2	NS	CS
N_2O	Tier 2	NS	CS
NO_x, CO, NMVOC, SO_2	CS	NS	CS

The category *Public electricity and heat production* is a key category for CO_2 and CH_4 emissions in terms of level and trend. Pursuant to method 2 analysis, it is also a key category for N_2O.

Category 1.A.1.a, "Public electricity and heat production," 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.

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

Figure 23: Development of CO_2 emissions in category 1.A.1.a (in millions of t of CO_2)



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. In general, the trend is driven mainly by economic trends (such as the collapse of industry in the new German Länder in the 1990s, the economic and financial crisis of 2009 (in particular) and the coronavirus pandemic in 2020); by (relative) fuel prices; by carbon-allowance prices in emissions trading; by regulatory decisions (such as the 2020 Act on termination of coal-fired power generation (Kohleverstromungsbeendigungsgesetz 2020) and the 2011 amendment of the Atomic Energy Act); by the foreign-trade balance for electricity (affected, for example by the increase in exports that occurred as of 2012); by weather conditions (such as the cold winters of 2010, 2012 and 2013); and by statistical artefacts tied to re-registration of power stations in other sectors. The key fuel-specific driving factors include:

Lignite:

- Through 1999, many lignite-fired installations in the new German Länder were decommissioned.
- In 2012, three new power plant blocks went into operation. These were the last new power plant blocks to come on line.
- Thereafter, as of the time of reporting, additional power plants have been decommissioned, and placed in a security-readiness status, available for temporary use in the case of bottlenecks (this status is scheduled to last four years; in particular, such status changes occurred in 2018 and 2019, with significant effects on electricity generation in 2019 and 2020).

Hard coal:

- 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.
- In the mid-1990s and in 2012: Re-registration of companies, from “industry” to the “public supply”
- 2016, 2017, 2020: Price-related shifts in the fuel mix, leading away from hard coal and to natural gas

Coke oven gas; blast furnace gas and basic oxygen furnace gas; fuel gas:

- In 2015, re-registration of blast-furnace-gas-powered power plants in the steel industry

Natural gases (natural gas, mine gas):

- Since 1990, a considerable increase in use of natural gas for electricity generation
- As of 2005, commissioning of an entire group of large gas-and-steam power plants and medium-sized gas-turbine power plants
- Increasing use as control energy for electricity generated from fluctuating renewable energies

Petroleum:

- 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.

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, presumably, 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.

A more-detailed discussion of the trends in the years 1990 through 2020 is provided in the descriptive chapter for category (1.A.1.a) in the 2022 NIR.

3.2.4.2 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 German 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. The data are updated at regular intervals, for purposes of current reporting.

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 sub-project A, "Revision and Documentation of Fuel Inputs for Stationary Combustion Systems in the new German Länder for the year 1990" (Zander & Merten, 2006).

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 stations, the 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).

Prior to the year 2003, 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). Since then, the quality of energy statistics data has improved considerably, and the various energy-input quantities have come into agreement, relatively steadily. 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. Table 25 in the 2022 NIR provides an overview of relevant emissions from use of blast-furnace gas, for the entire time series since 1990.

Emission factors

Since CO_2 emissions depend on fuel quality, CO_2 emission factors are calculated and used inter-sectorally. A detailed description of the relevant procedures, and a list of the factors used, is presented in the Annex, in Chapter 15.7.

The underlying data for the emission factors 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 have been 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 3.2.5, 3.2.6 and 3.2.7, in instances where the factors include power stations, gas turbines and boilers for generation of steam and hot/warm water. The aim of the research project 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 of the 2022 NIR discusses the procedure used in the research project.

In 2011, the emission factors (except for that for CO_2) were updated, as part of a major research project (Fichtner et al. (2011)). 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). In 2008, VGB carried out additional relevant measurements. The project Fichtner et al. (2011) has reviewed and updated the values used to date. Table 22 shows the results for large installations of public power stations (with thermal outputs from combustion of 50 megawatts or more), while Table

23 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 22: 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 23: 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 24: 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), "Processing of data in emissions declarations pursuant to the 11th Ordinance on the

Execution of the Federal Immission Control Act" ("Aufbereitung von Daten der Emissionserklärungen gemäß 11. BImSchV" (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 inventorisation 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 et al., 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-incinerated 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

In the framework of the research project "limestone balance" ("Kalksteinbilanz"; (Lechtenböhmer, Nanning, Hillebrand, et al., 2006), 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. 3.2.4.2). 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):

$$CaCO_3 + SO_2 + 1/2O_2 + 2H_2O \implies CaSO_4.2H_2O + CO_2$$

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 years 2020 and 2021. For those two years, therefore, gypsum production was we estimated, 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, 2020 and 2021, such an assumption is justified. This procedure was selected in light of the fact that electricity generation varied sharply over those two years.

Table 25: CO_2 emissions from flue-gas desulphurisation in public power stations

Year CRF 1.A.1	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
					Figures in kt					
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	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
					Figures in kt					
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**	**2015**	**2016**	**2017**	**2018**	**2019**
					Figures in kt					
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**	**2021**								
					Figures in kt					
CO_2 from flue-gas desulphurisation in public power stations	590	745								

Source: Calculation on the basis of of the "limestone balance" project ((Lechtenböhmer, Nanning, Hillebrand, et al., 2006), 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 %.

3.2.4.3 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. Those uncertainties have retained their validity (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 15.4.

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 German 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 projects Rentz et al. (2002) and Fichtner et al. (2011), which are mentioned in Chapter 3.2.4.2.

3.2.4.3.1 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.

3.2.4.3.2 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.

3.2.4.3.3 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 3.2.4.2). The CH_4 emission factors that were determined, for various fuels, in the research project Fichtner et al. (2011), and that are used in the present report for combustion and gas-turbine systems (including gas-and-steam systems), were last presented in Chapter 19.1.2.2 of the 2022 NIR. 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.

3.2.4.3.4 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 every time series, therefore, we have assumed that the values have remained constant in the period since 1995.

In this light, the time series for N_2O must be assessed as consistent overall.

The time series of CH_4 emission factors were also reviewed and assessed as internally consistent. 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-few measurements are 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.

3.2.4.4 Category-specific quality assurance / control and verification (1.A.1.a)

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 relevant involved experts and the Single National Entity.

To document its quality-assurance measures in preparation of Energy Balances, the Working Group on Energy Balances (AGEB) submits pertinent quality reports to the German Environment Agency (UBA) (cf. Chapter 15.4.1). 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 15.4.1).

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* (Statistisches Bundesamt, 2022e).

In addition to these measures, the AGEB plays a role in the annual review process as necessary, and regular exchanges take place with the AGEB in the framework of an annual meeting, or of a written circulation procedure, to which the German 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 16.1.1.1. Their results were reported in the NIR 2005.

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

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC

AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

Table 26: Recalculations, CRF 1.A.1.a

Units [kt]	CO_2 discrepancy, absolute					CO_2 discrepancy, relative
Year	gas	liquid	other	solid	Total	Total
2020	-203.6	-38.9	-912.4	-86.3	-1,241.2	-0.7%

For the year 2020, 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.

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

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

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

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

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**1 A 1 b, Petroleum Refining**	**fossil fuels**	**CO_2**	**24,102.6**	**1.9 %**	**19,983.9**	**2.6 %**	**-17.1 %**
-/-	1 A 1 b, Petroleum Refining		CH_4	18.0	0.0 %	14.6	0.0 %	-18.8 %
-/-	1 A 1 b, Petroleum Refining		N_2O	89.3	0.0 %	48.0	0.0 %	-46.2 %

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

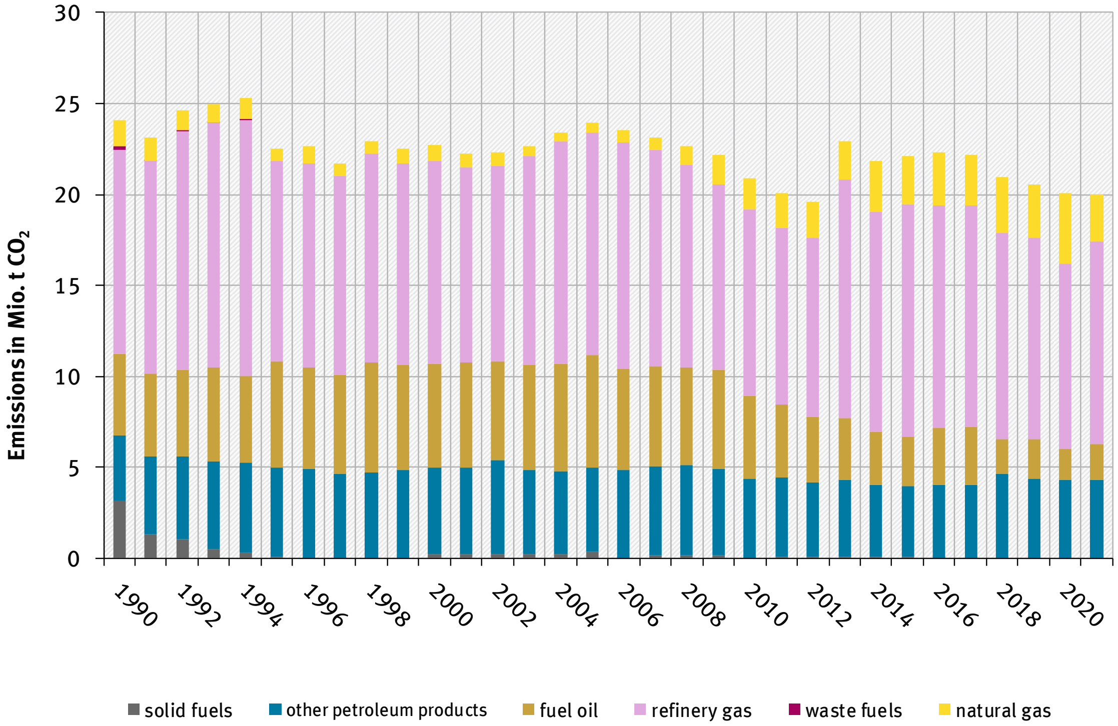
The category *Petroleum refining* is a key category for CO_2 emissions in terms of emissions level and trend.

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

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 24: Development of CO_2 emissions in category 1.A.1.b (in millions of t of CO_2)



The general factors driving the emissions trends include the total-production quantities (in 2005, for example, they reached their maximum to date, 123.6 million t of petroleum products); the manner in which production quantities are distributed among various sectors (for example, increased production of lighter petroleum products, and intensified deep desulphurisation, lead to increases in specific fuel-consumption figures), and plant efficiency. Also, the total production quantities involved were increased, temporarily, in spite of plant closures.

3.2.5.2 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 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. In category 1.A.1.b, therefore, only processing of crude oil is reported.

For purposes of reporting on emissions from crude oil refineries, the relevant plants are subdivided into refinery power stations and refinery bottom-heating systems. The activity data for refinery-process bottom heating are obtained by deducting fuel inputs in refinery power stations from the relevant energy-statistics data and 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 description of the relevant procedures, and a list of the CO_2 emission factors used, is presented in the Annex, Chapter 15.7.

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 provided in Chapter 3.2.4.2. 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.

3.2.5.3 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).

3.2.5.3.1 Result for N_2O

The results of Chapter 3.2.4.3.2 apply mutatis mutandis.

3.2.5.3.2 Result for CH_4

The results of Chapter 3.2.4.3 apply mutatis mutandis.

3.2.5.3.3 Time-series consistency of emission factors

The results of Chapter 3.2.4.3.4 apply mutatis mutandis.

3.2.5.4 Category-specific quality assurance / control and verification (1.A.1.b)

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 relevant involved experts and the Single National Entity.

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 3.2.4.4).

With regard to emission factors, the results of Chapter 3.2.4.3 apply mutatis mutandis.

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

Table 27: Recalculations for CRF 1.A.1.b, by fuels

Units [kt]	CO_2 discrepancy, absolute					CO_2 discrepancy, relative
Year	gas	liquid	other	solid	Total	Total
2018	-2,041.5	1,730.7	0.0	0.0	-310.8	-1.5%
2019	-2,502.9	1,211.8	0.0	0.0	-1,291.1	-5.9%
2020	249.4	1,287.4	0.0	12.4	1,549.1	8.3%

Table 28: Recalculations for CRF 1.A.1.b, total

Units [kt]	Discrepancy for the sum of all fuels, CO_2 absolute									
Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	3937.04	4260.34	5086.07	4824.93	5113.89	2749.28	2575.02	2380.96	2624.07	2127.87
Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	1825.74	1158.18	1303.46	1156.64	1524.6	1548.66	2045.16	1490.76	810.28	212.43
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	149.48	41.93	292.12	3759.4	3065.13	3339.64	2506.63	1893.91	-310.81	-1291.13
Year	2020									
	1549.11									

As a result of a detailed comparison between the statistical data and the emissions trading data, major recalculations were carried out throughout the entire time series. The main reason why this was necessary is that shifting between refineries and industry combustion systems has been carried out, in order to ensure that the inventory and the emissions trading sector agree in their allocations. In the course of this work, gaps in the data were filled in. Overall as a result of the recalculations, emissions in source category 1.A.1.b have increased, and those in source category 1.A.2.gviii have decreased.

Provisional values for the year 2020 were replaced when the figures from the final Energy Balance for 2013 became available. That also led to recalculations for all fuels.

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

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

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

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

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**1 A 1 c, Manufacture of Solid Fuels and Other Energy**	**fossil fuels**	**CO_2**	**65,289.1**	**5.1 %**	**8,645.5**	**1.1 %**	**-86.8 %**
-/-	1 A 1 c, Manufacture of Solid Fuels and Other Energy		CH_4	103.0	0.0 %	139.8	0.0 %	35.7 %
-/-	1 A 1 c, Manufacture of Solid Fuels and Other Energy		N_2O	586.2	0.1 %	114.0	0.0 %	-80.6 %

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.

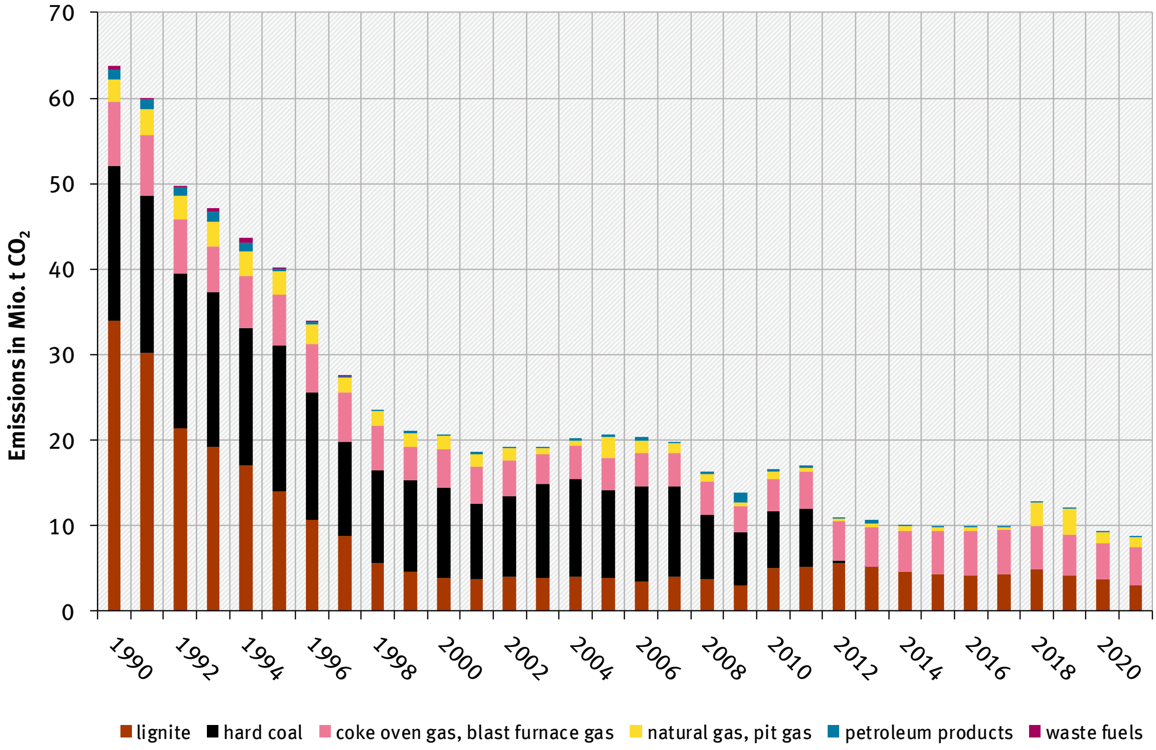
The above figures refer to power stations, and to other boiler furnaces for production of steam and hot/warm water, in category 1.A.1.c.

Category 1.A.1.c includes hard-coal and lignite mining, coking and briquetting plants and extraction of crude oil and natural gas. The fuel inputs required for installations' own operations are reported in category 1.A.1.c.

In category 1.A.1.c *Manufacture of solid fuels and other energy industries*, the CSE differentiates the following: 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 plants" 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, broken down by aggregated fuels. The figure clearly shows how sharply emissions in this category have decreased since 1990:

Figure 25: Development of CO_2 emissions in category 1.A.1.c (in millions of t of CO_2)



Lignite

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 economy of the former GDR was based centrally on lignite. Toward the end of the 1990s, it had to make extensive conversions to other fuels. In the process, significant lignite-based capacities were eliminated, without being replaced. In the region's households, coal stoves were replaced with newer heating systems using heating oil and natural gas, and this changed the overall shape of demand.

Hard coal

Emissions from use of hard coal in sector 1.A.1.c have been decreasing markedly since 1990. The main reason for this is that hard-coal production decreased sharply (in 1990, it was at over 70 million t) and then, in 2018, was terminated altogether. Registration of installations in the hard-coal-mining and lignite-mining sectors has shifted between the public supply and the relevant industrial sectors. In the time series, this has led to statistical effects (cf. 2011/2012) for which plausibility checks have to be carried out, via consideration of intersectoral trends, and taking account of Sector 1.A.1.a, with regard to actual emissions changes.

Beginning in 2010, fuel inputs in 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. As of 2012, re-registration of hard-coal-fired power stations occurred.

Coke oven gas; blast furnace gas and basic oxygen furnace gas (industrial gases)

The figures show considerable emissions reductions – especially through the end of the 1990s. They were due especially to termination of town-gas production by 1996 and to a considerable reduction of coke production (1990: 19 million t; 2009: 6.7 million t; 2018: 9.2 million t hard-coal coke). 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. Hard-coal-coke production is affected by steel production, which is tied to economic trends. Overall, plant closures and efficiency increases have decreased emissions markedly in this sector. For years now, as a result of the Federal Government's ambitious climate action goals, which call for phasing out coal-fired electricity generation, and, increasingly, as a result of the coronavirus pandemic occurring since 2020, companies that produce solid fuels have been having to make operational adjustments. Such adjustments entail emissions reductions.

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

A country-specific calculation method (Tier 3) has been used for key categories identified via current 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, 2022d). 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[27] 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. On an annual basis, the data are obtained from the DEBRIV Federal German association of lignite-producing companies and their affiliated organisations, and updated.

The quantities of fuel used for production of hard-coal coke are taken directly from 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.

CO_2 emissions from blast-furnace-gas combustion in coking plants are also 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.

[27] Statistik der Kohlewirtschaft, siehe https://kohlenstatistik.de/daten-fakten/ (Braunkohlen im Überblick)

Table 29: CO_2 emissions from blast-furnace-gas combustion in coking plants

[Millions of t of CO_2)									
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	**2021**								
3.945	4.111								

Revision of the data for 1990, and for the subsequent years 1991-1994, for the new German Länder, was last described in Annex 19.1.1 of the 2022 NIR.

Emission factors

A list of the CO_2 emission factors used, and a description of the relevant methods, are provided in the Annex, Chapter 15.7.

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 provided in Chapter 3.2.4.2. Within the sector, the research projects differentiate between 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.

3.2.6.3 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 3.2.4.3.1.

3.2.6.3.1 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. The 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 3.2.4.3.2 apply mutatis mutandis.

3.2.6.3.2 Result for CH_4

The results of Chapter 3.2.4.3.3 apply mutatis mutandis.

3.2.6.3.3 Time-series consistency of emission factors

The results of Chapter 3.2.4.3.4 apply mutatis mutandis.

3.2.6.4 Category-specific quality assurance / control and verification (1.A.1.c)

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

The results of Chapter 3.2.4.2 apply mutatis mutandis.

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

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

Units [kt]	CO_2 discrepancy, absolute					CO_2 discrepancy, relative
Year	gas	liquid	other	solid	Total	Total
2018	2,041.5	0.0	0.0	0.0	2,041.5	19.1%
2019	2,502.9	0.0	0.0	0.0	2,502.9	26.3%
2020	897.3	1.6	0.0	-694.7	204.2	2.3%

Provisional figures for the year 2020 were replaced with figures from the now-available final Energy Balance for that year. This led to recalculations for all fuels. In addition, following detailed review of the ETS data on natural gas, changes were made in the correlations between the refinery sector (1.A.1.b) and the other transformation sector (1.A.1.c), for the years 2018 through 2020.

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

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

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

The calculation algorithms for BEU structural elements in category 1.A.2 were revised, via 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. The calculation algorithms were substantiated in detail in the aforementioned research project.

For the most part, process-combustion data are reported on a sector-specific basis. The available data do not permit fully UNFCCC-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, 2022d).

Until 2001, Statistik 067 showed only the fuel inputs for electricity production in electricity production systems. As of 2002, it also includes the fuel inputs for both heat and electricity production. (No data are available for inputs for heat production for years prior to 2002.).

The applicable relationship between the fossil and biogenic fractions of industrial waste is obtained from waste statistics (Statistisches Bundesamt, 2021a), from the relevant industrial associations' figures on substitute fuels, and from the research project "Use of secondary fuels" ("Einsatz von Sekundärbrennstoffen" Lechtenböhmer, Nanning, Hillebrand, et al. (2006), 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 and disaggregated in the Balance of Emission Causes (BEU). In addition to the figures provided from the Energy Balance, substitute fuels have now been listed for the most-important industrial sectors. The relevant fuels were identified in the research project Lechtenböhmer, Nanning, Hillebrand, et al. (2006) and are now updated annually with the help of association data

Detailed sector-specific data on use of substitute fuels in process combustion, and in industrial power stations, are used for the industrial sectors paper and pulp production and lime production.

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

The uncertainties for the new structural elements referred to in the research project "Documentation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten") (Juhrich & Wachsmann, 2007) were determined in keeping with the method described in the research project Lechtenböhmer, Nanning, Hillebrand, et al. (2006). 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 in this category.

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 German reunification in 1990.

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

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

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**1 A 2 a, Iron and steel**	**fossil fuels**	**CO_2**	**35,269.3**	**2.7 %**	**37,835.2**	**5.0 %**	**7.3 %**
-/-	1 A 2 a, Iron and steel		CH_4	69.9	0.0 %	78.3	0.0 %	12.0 %
-/-	1 A 2 a, Iron and steel		N_2O	137.9	0.0 %	101.5	0.0 %	-26.4 %

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	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.

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

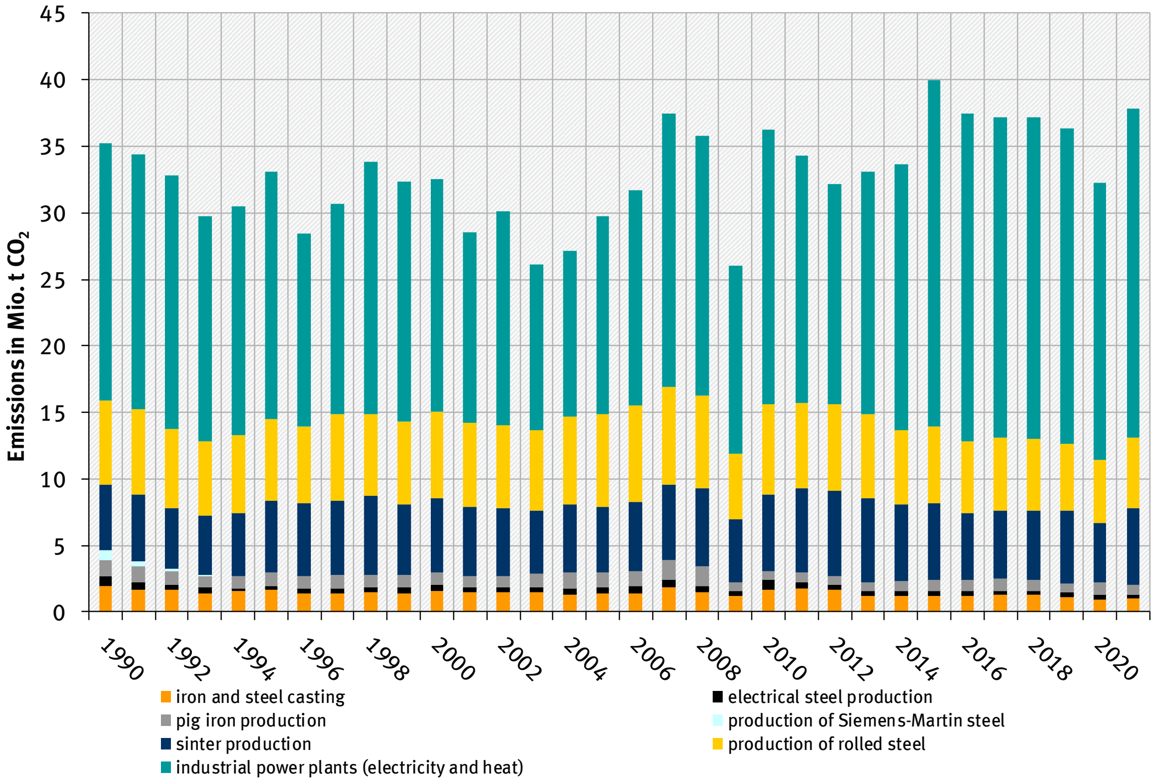
This sub-category comprises process combustion in the various production areas of the iron and steel industry. The category includes the production areas of pig iron (blast furnaces), sponge iron (direct reduction), sinter, rolled steel, iron and steel casting, Siemens-Martin steel, electric steel and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

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 relevant 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. For reasons of confidentiality, it is not possible to list the CO_2 emissions 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 26: Development of CO_2 emissions in category 1.A.2.a, by products (in millions of t of CO_2)



The overview shows that fluctuations, some of them major, have occurred over the years. In most cases, those swings were tied to fluctuations in production – and, thus, to economic trends in the steel industry. 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 after 1990. The development in the years 2009 and 2010 was a reflection of the economic and financial crisis of the time and of the economic recovery that followed it.

The noticeable emissions increase in 2015 is due to re-registration, entailing shifting from the public electricity supply (CRF 1.A.1.a) to industry (1.A.2.a), of several power stations fired with blast furnace gas. This shifted the relevant emissions. On the whole, CO_2 emissions increased only slightly in this year, as a result of the production increase. This relationship is clearly apparent in *Figure 44: 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 and lignite dust are increasingly being tested as substitutes for injected pulverised hard 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. In 2021, emissions followed the development of pig-iron production and returned to their level of 2019.

3.2.7.1.2 Methodological issues (1.A.2.a)

As of report year 2011, reporting on the “BGS” group (the “BGS form”; including the 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) has been used a source of activity data for conventional fuels in this category. That source has improved disaggregation of energy data in the Balance of Emissions Sources (BEU). As of reporting year 2012, data are being provided on the basis of an agreement with the Wirtschaftsvereinigung Stahl German steel industry association, and in the same format.

In addition to providing activity data for sintering plants, blast furnaces, basic oxygen furnaces (converters) and rolling mills, these 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 is based on the results of the research project “Inputs of secondary fuels” (“Einsatz von Sekundärbrennstoffen”); Lechtenböhmer, Nanning, Hillebrand, et al. (2006), FKZ 204 42 203/02).

the area of 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.

3.2.7.1.3 Uncertainties and time-series consistency (1.A.2.a)

In 2004, uncertainties were determined for all fuels (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, Nanning, Hillebrand, et al. (2006). The uncertainties for the activity data were updated in the research project "Documentation of the data quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten" (FKZ 204 41 132) and included in the relevant final report.

3.2.7.1.4 Category-specific quality assurance / control and verification (1.A.2.a)

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 relevant involved experts and the Single National Entity.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.4.4).

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.

3.2.7.1.5 Category-specific recalculations (1.A.2.a)

Provisional figures for the year 2020 were replaced with figures from the now-available final Energy Balance for that year.

Table 31: Recalculations in CRF 1.A.2.a

Units [kt]	CO_2 discrepancy, absolute					CO_2 discrepancy, relative
Year	gas	liquid	other	solid	**Total**	**Total**
2020	-42.0	-1.2	0.0	-287.8	-331.0	-1.0%

3.2.7.1.6 Category-specific planned improvements (1.A.2.a)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.7.2 Manufacturing industries and construction – non-ferrous metals (1.A.2.b)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	1 A 2 b, Non-ferrous metals	fossil fuels	CO_2	1,629.2	0.1 %	1,444.7	0.2 %	-11.3 %
-/-	1 A 2 b, Non-ferrous metals		CH_4	1.6	0.0 %	1.8	0.0 %	15.6 %
-/-	1 A 2 b, Non-ferrous metals		N_2O	15.2	0.0 %	6.7	0.0 %	-56.2 %

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.

3.2.7.2.1 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.

3.2.7.2.2 Methodological issues (1.A.2.b)

The pertinent fuel inputs are contained in the Balance of Emission Causes (BEU). The source for the fuel inputs consists of manufacturing-industry statistics (Statistik 060) – *Energieverwendung des produzierenden Gewerbes* (*"Energy use in the manufacturing sector"*) (Statistisches Bundesamt, 2022b) Melde-Nr. (reporting number) 27.43 alt (old) (WZ 2003) → 24.43 neu (new) (WZ 2008) ("WZ" refers to the German Classification of Economic Activities): *"Production and initial processing of lead, zinc and tin" ("Erzeugung und erste Bearbeitung von Blei, Zink und Zinn")* and 27.44 old (WZ 2003) → 24.44 new (WZ 2008): *"Production and initial processing of copper" ("Erzeugung und erste Bearbeitung von Kupfer"*); for differentiation from heat and electricity production, Statistik 067 is used (Statistisches Bundesamt, 2022d).

The relevant calculation algorithms are described in detail in the final report for the research project "Documentation 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 documented, with the help of new data, in the project "Base year and updating" ("Basisjahr und Aktualisierung") (Zander & Merten, 2006); cf. Annext Chapter 19.1.1 of the 2022 NIR.

3.2.7.2.3 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.

3.2.7.2.4 Category-specific quality assurance / control and verification (1.A.2.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 relevant involved experts and the Single National Entity.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.4.4).

3.2.7.2.5 Category-specific recalculations (1.A.2.b)

Table 32: Recalculations in CRF 1.A.2.b

Units [kt]		CO_2 discrepancy, absolute				CO_2 discrepancy, relative
Year	gas	liquid	other	solid	Total	Total
2020	-66.4	28.7	-	0.3	-37.4	-2.5%

Provisional values for the year 2020 were replaced when the figures from the final Energy Balance for 2013 became available. This has led to recalculations for all fuels.

3.2.7.2.6 Category-specific planned improvements (1.A.2.b)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.7.3 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,” for 1990 in the new German Länder (Zander & Merten, 2006): the relevant coke was used as a feedstock 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 existing data can be cross-checked against the 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. Only as of the year 2012 do energy statistics report significant quantities of gas. The first analytical step, therefore, was to identify the chemical industry areas in which other produced gases occur and are used for energy generation. Over 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 prior to 2012, the main products produced in each sector were determined. The pertinent data are available, for the period back through 1990, in the annual “Chemical Industry in Figures” (“Chemiewirtschaft in Zahlen”) reports of the VCI chemical industry association. 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 by the AGEB in the Energy Balance. 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.

3.2.7.4 Manufacturing industries and construction – Pulp, paper and print (1.A.2.d)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	1 A 2 d, Pulp, Paper and Print	fossil fuels	CO_2	3.6	0.0 %	10.8	0.0 %	195.6 %
-/-	1 A 2 d, Pulp, Paper and Print		CH_4	0.7	0.0 %	2.7	0.0 %	267.8 %
-/-	1 A 2 d, Pulp, Paper and Print		N_2O	2.5	0.0 %	9.2	0.0 %	267.8 %

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.

3.2.7.4.1 Category description (1.A.2.d)

The energy consumption for production of pulp and paper can be modelled only for substitute fuels. That said, those fuels account for a large fraction of the fuels used overall.

Emissions from use of regular fuels in process combustion, and emissions generated by plants in own-power production, are not listed separately in this category. They are summarised under 1.A.2.g *Other*.

3.2.7.4.2 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") Lechtenböhmer, Nanning, Hillebrand, et al. (2006). 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. According to the currently used system for classification of economic activities (Wirtschaftszweigsystematik – WZ 2008), fuel inputs in this category are to be assigned in keeping with classification number (Wirtschaftszweignummer) 17, “Production of paper, cardboard and products” (“Herstellung von Papier, Pappe und Waren”).

This source cannot be unambiguously assigned to a time series, in keeping with the old system for classification of economic activities (WZ 2003). Industrial activity (WZ) area 17 within the new system for classification of economic activities (WZ 2008) corresponds to parts of WZ areas 17, 21, 22 and 36 under the old system, WZ 2003, which is no longer used.

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, 2022d), which is used for differentiation from electricity and heat generation.

3.2.7.4.3 Uncertainties and time-series consistency (1.A.2.d)

In the framework of the research project Lechtenböhmer, Nanning, Hillebrand, et al. (2006), the uncertainties of the CO_2 emission factors derived for substitute fuels were determined using the Monte Carlo method. 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 have a large uncertainty range. 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.

3.2.7.4.4 Category-specific quality assurance / control and verification (1.A.2.d)

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 relevant involved experts and the Single National Entity.

The paper industry has long kept records of inputs of secondary fuels. The data are published annually, in a performance report. In spite of minor structural discontinuities, the data provided in that source clearly show the paper industry's increasing use of substitute fuels in place of regular fuels.

3.2.7.4.5 Category-specific recalculations (1.A.2.d)

No recalculations were required.

3.2.7.4.6 Category-specific planned improvements (1.A.2.d)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.7.5 Manufacturing industries and construction – Sugar production (1.A.2.e)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/T	**1 A 2 e, Food Processing, Beverages and Tobacco**	**fossil fuels**	**CO_2**	**2,015.9**	**0.2 %**	**231.0**	**0.0 %**	**-88.5 %**
-/-	1 A 2 e, Food Processing, Beverages and Tobacco		CH_4	5.0	0.0 %	0.2	0.0 %	-96.3 %
-/-	1 A 2 e, Food Processing, Beverages and Tobacco		N_2O	21.9	0.0 %	1.8	0.0 %	-92.0 %

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 5). Because relevant emissions have fallen 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.

3.2.7.5.1 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.

3.2.7.5.2 Methodological issues (1.A.2.e)

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)).

3.2.7.5.3 Uncertainties and time-series consistency (1.A.2.e)

The existing uncertainties, which were determined for all activity data, for the first time, in 2004, continue to apply. The relevant method is described in Annex Chapter 13.6 of the NIR 2007.

3.2.7.5.4 Category-specific quality assurance / control and verification (1.A.2.e)

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 relevant involved experts and the Single National Entity.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.4.4).

3.2.7.5.5 Category-specific recalculations (1.A.2.e)

Table 33: Recalculations in CRF 1.A.2.e

Units [kt]	CO_2 discrepancy, absolute					CO_2 discrepancy, relative
Year	gas	liquid	other	solid	Total	Total
2020	25.7	-20.7	-	-6.6	-1.6	-0.7%

Provisional figures for the year 2020 were replaced with figures from the now-available final Energy Balance for that year. That necessitated recalculations for nearly all fuels.

3.2.7.5.6 Category-specific planned improvements (1.A.2.e)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.7.6 Manufacturing industries and construction – Non-metallic minerals industry (1.A.2.f)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**1 A 2 f, Non-Metallic Minerals**	**fossil fuels**	**CO_2**	**18,507.4**	**1.4 %**	**12,149.8**	**1.6 %**	**-34.4 %**
-/-	1 A 2 f, Non-Metallic Minerals		CH_4	56.3	0.0 %	16.3	0.0 %	-71.0 %
-/-	1 A 2 f, Non-Metallic Minerals		N_2O	182.5	0.0 %	98.7	0.0 %	-45.9 %

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/IE	NS/IE	CS/IE

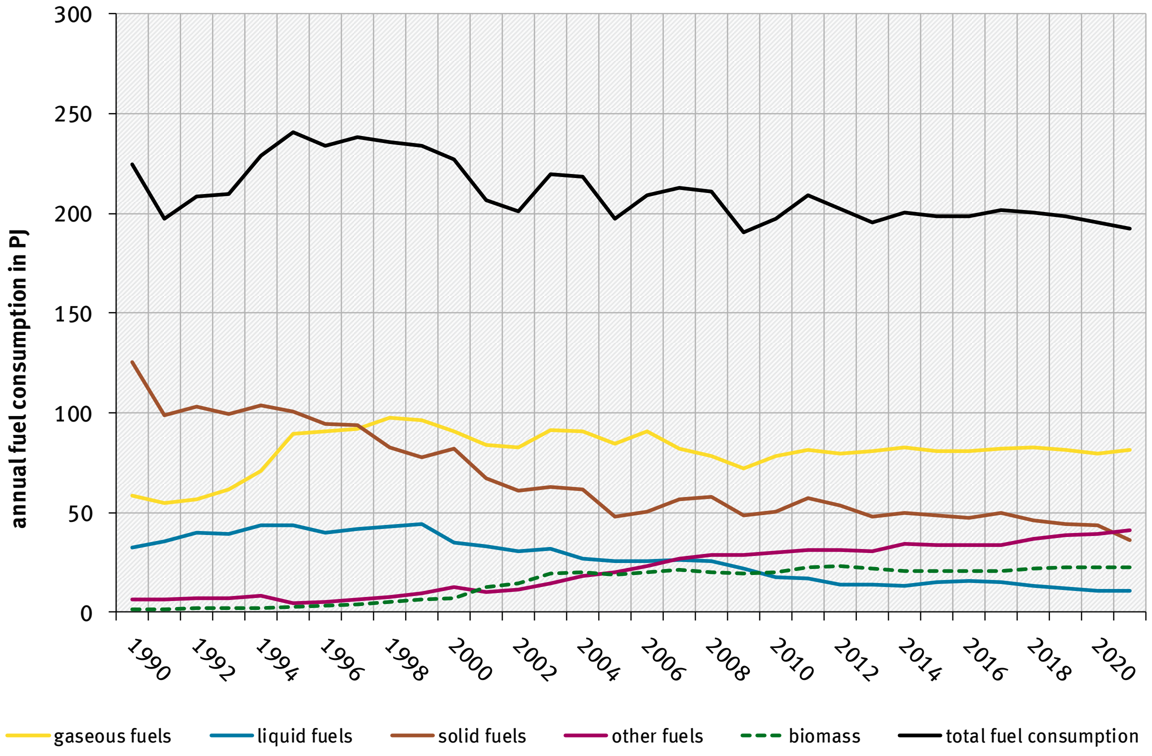
The category *Manufacturing industries and construction – Non-metallic minerals industry* (all sub-categories) is a key category, in terms of emissions level and trend, for CO_2 emissions.

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.

3.2.7.6.1 Category description (1.A.2.f, Non-metallic minerals industry)

The areas listed in this category include process combustion from burning of cement clinkers. 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 also taken into account. 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 burnt lime production is also taken into account. Any electricity generation by the sector's own installations is also included in 1.A.2.gviii *Other*.

Figure 27: Development of fuel inputs in category 1.A.2.f Non-metallic minerals



Several changes of fuels have occurred in the area of the non-metallic minerals industry. In the mid-1990s, for example, gaseous fuels (natural gases) began supplanting solid fuels to a greater and greater degree. 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 also by biomass.

In recent years, solid fuels have been supplanted to an ever-greater extent by secondary fuels.

3.2.7.6.2 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: Melde-Nr. (reporting number) 26.51alt (old) (WZ 2003) → 23.51neu (new) (WZ 2008): Production of cement, Melde-Nr. 26.40 alt (WZ 2003) → 23.32 neu (WZ 2008): Brickyards, production of other structural ceramics, Melde-Nr. 26.1 alt (WZ 2003) → 23.1 neu (WZ 2008): Production of glass and glass products, and Melde-Nr. 26.52 alt (WZ 2003) → 23.52 neu (WZ 2008): 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, Statistik 067 (Statistisches Bundesamt, 2022d) is used.

Since 2002, the data of Statistik 067 have been available only in the three-digit reporting-number (Meldenummer) range. This means that only (aggregated) data for reporting number 26.5 old (WZ 2003) → 23.5 new (WZ 2008) (production of cement, lime and burnt plaster) can be used.

The relevant calculation algorithms are described in detail in the final report for the research project “Documentation of the quality of activity data” ("Dokumentation der Datenqualität von Aktivitätsraten" (Juhrich & Wachsmann, 2007)) and in the 2013 NIR, Chapters 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 data of the relevant industry associations (in addition to the cement industry, this also applies to the lime industry). 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, Nanning, Hillebrand, et al. (2006), 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 a second step, biogenic fractions were derived for mixed fuels and then, with the help of split factors, entered into the calculations. In addition, CO_2 emission factors were derived on the basis of data on carbon content, water content and net calorific values.

3.2.7.6.3 Uncertainties and time-series consistency (1.A.2.f, Non-metallic minerals industry)

In 2004, uncertainties were determined for all fuels and for the aforementioned substitute fuels. The relevant methods are described in Annex 13.6 of the 2007 NIR and in the final report of the research projuect (Lechtenböhmer, Nanning, Hillebrand, et al., 2006). The uncertainties for all the activity data were updated in the research project “Documentation of the quality of activity data” (“Dokumentation der Datenqualität von Aktivitätsraten”) (Juhrich & Wachsmann, 2007) and included in the pertinent final report.

3.2.7.6.4 Category-specific quality assurance / control and verification (1.A.2.f, Non-metallic minerals industry)

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 relevant involved experts and the Single National Entity.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.4.4).

3.2.7.6.1 Category-specific recalculations (1.A.2.f, Non-metallic minerals industry)

Table 34: Recalculations in CRF 1.A.2.f

Units [kt]	CO_2 discrepancy, absolute					CO_2 discrepancy, relative
Year	gas	liquid	other	solid	Total	Total
2020	141.0	-134.9	26.9	-59.5	-26.5	-0.2%

For the year 2020, 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.

3.2.7.6.2 Planned improvements (category-specific) (1.A.2.f, Non-metallic minerals industry)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.7.7 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**1 A 2 g, Other**	**fossil fuels**	**CO_2**	**126,762.0**	**9.8 %**	**73,315.6**	**9.6 %**	**-42.2 %**
-/-	1 A 2 g, Other		CH_4	148.8	0.0 %	237.5	0.0 %	59.6 %
-/-	1 A 2 g, Other		N_2O	842.6	0.1 %	530.0	0.1 %	-37.1 %

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.

3.2.7.7.1 Category description (1.A.2.g Other, stationary)

In this sub-category 1.A.2.g, 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 65% of all CO_2 emissions of category 1.A.2.

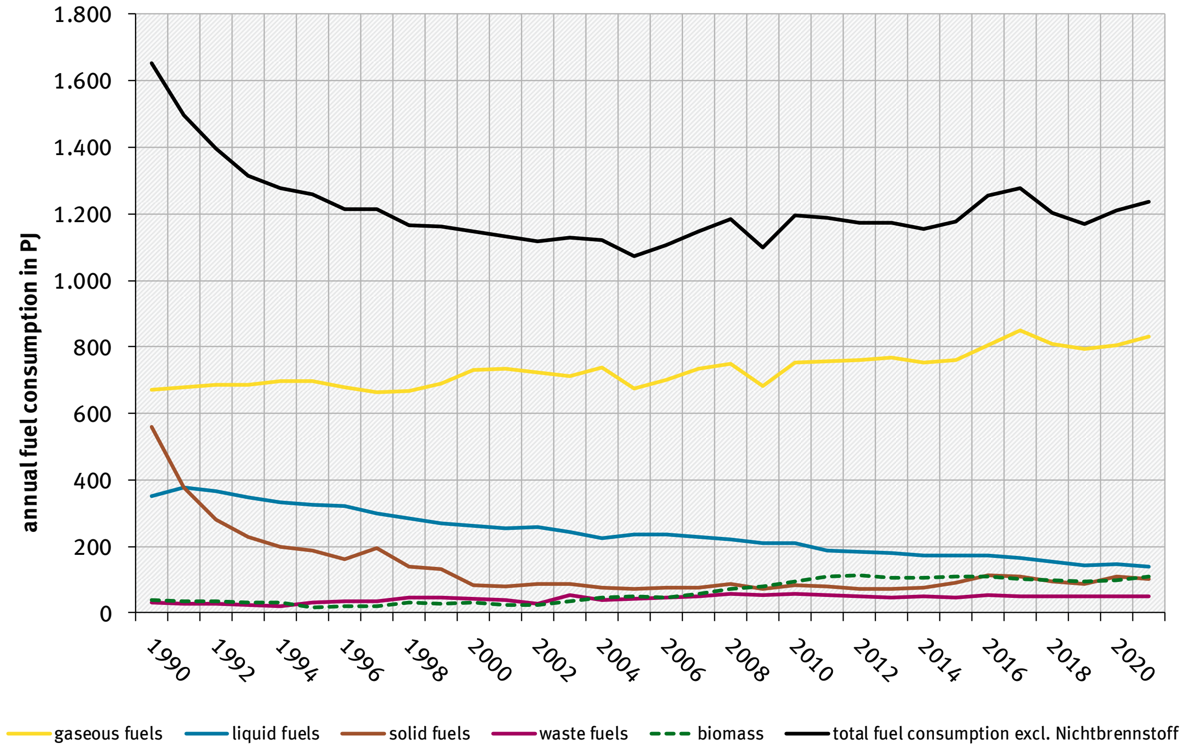
All electricity and heat generation in industrial power stations and boilers is listed in this sub-category, because such systems can justifiably be grouped together in this sub-category, in light of their emissions behaviour. Since the chemical industry, and systems in category 1.A.2.c, primarily use CHP systems and boilers, these emissions are reported not in that category but in sub-category 1.A.2.gviii “Other.” Any further subdivision of industrial power stations and boilers, among the planned sub-categories, would not lead to higher data quality, since such systems' emissions behaviour does not depend on the industrial sector involved. In addition, preparation of time series in an additional sub-category would entail considerable difficulty, since in 1990 Germany still consisted of two countries, with two different statistical systems. Those statistical systems were merged in transition phase lasting through 1994. Furthermore, great efforts have been made to provide the required documentation and data quality for the base year, 1990. Also, the 2003 amendment of the Act on Energy Statistics (Energiestatistikgesetz) considerably improved data collection, especially for CHP systems. Such data cannot be retroactively collected for the period 2002 – 1990. By and large, while time-series consistency has been achieved at the aggregated level, further disaggregation would lead to breaks in the time series. 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 2017 amendment of the Act on Energy Statistics (Energiestatistikgesetz) brought no improvements with regard to the possibilities for disaggregating data on industrial power stations and boilers.

Furthermore, the boundary between the various individual industrial sectors and the public supply sector cannot, ultimately, 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. In addition, frequent structural changes occurred in the course of energy-market liberalisation. For example, energy generation installations were unbundled from legal groupings of companies, which led to changes in patterns of reporting for purposes of energy statistics. 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 28: Development of fuel inputs in category 1.A.2.g viii Other



This category exhibits marked shifting in fuel inputs.

The decrease in the use of solid fuels through 2013 – including, especially, a considerable reduction in the use of lignite – is especially striking. The decrease was especially pronounced in the 1990s. Since the 2000s, utilisation of natural gases has shaped the overall energy-input trend. From the end of the 1990s until the early 2010s, the trend included a growing reliance on biomass. In the area of biomass, the applicable quantities have been completely recorded only since the introduction of the Act on Energy Statistics in 2003. In earlier years, statistical surveys covered biomass utilisation for energy generation either only partly or not at all. Use of waste fuels has grown, in comparison to the releval levels in the 1990s. Since about 2010, it has remained at an approximately constant level.

3.2.7.7.2 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.

Allocation of fuel inputs to heat production in industrial power stations and boiler systems is possible only with additional data from the *Federal Statistical Office*. 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 is provided in the final report for the research project “Documentation of the 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 15.7.

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 provided in Chapter 3.2.4.2. The research projects break down the relevant sector into industrial power stations and other boiler combustion systems for production of steam and hot/warm water.

3.2.7.7.3 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 activity data were updated in the research project “Documentation of the quality of activity data” (“Dokumentation der Datenqualität von Aktivitätsraten” and included in the relevant final report (Juhrich & Wachsmann, 2007).

Emission factors

The procedure for determining uncertainties is described in Chapter 3.2.4.3.1.

Result for N_2O: The results of Chapter 3.2.4.3.2 apply mutatis mutandis.

Result for CH_4: The results of Chapter 3.2.4.3.3 apply mutatis mutandis.

The results obtained in Chapter 3.2.4.3.4 in determination of time-series consistency apply mutatis mutandis.

3.2.7.7.4 Category-specific quality assurance / control and verification (1.A.2.g, Other, stationary)

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 relevant involved experts and the Single National Entity.

For further information on quality assurance, cf. CRF 1.A.1.a (Chapter 3.2.4.4).

Activity data

The quality of the data was reviewed in the research project "Documentation of the quality of activity data" ("Dokumentation der Datenqualität von Aktivitätsraten" (Juhrich & Wachsmann, 2007)) and improved via use of statistics of the *Federal Statistical Office*. No other data sources with long-term availability have been identified.

Emission factors

The results obtained in Chapter 3.2.4.2, in the general procedure for source-specific quality assurance / control and verification, apply mutatis mutandis.

3.2.7.7.5 Category-specific recalculations (1.A.2.g, Other, stationary)

Table 35: Recalculations in CRF 1.A.2.gviii, by fuels

Units [kt]	CO_2 discrepancy, absolute					CO_2 discrepancy, relative
Year	gas	liquid	other	solid	Total	Total
2018	0.0	-1,301.1	0.0	0.0	-1,301.1	-1.9%
2019	0.0	-1,000.8	0.0	0.0	-1,000.8	-1.5%
2020	2,598.3	-630.8	112.7	2,391.0	4,471.2	6.9%

Table 36: Recalculations in CRF 1.A.2.gviii – Discrepancies in the sum of all fuels

Discrepancy for the sum of all fuels, CO_2 absolute										
Units [kt]	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	-983.77	-1109.75	-1186.47	-1301.15	-1433.36	-1531.31	-1578.76	-1656.78	-1801.68	-1834.85
Units [kt]	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	-1975.39	-1846.51	-1641.3	-1665.84	-2313.9	-2096.9	-2192.96	-2211.06	-2231.54	-1574.37
Units [kt]	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	-1439.83	-1434.34	-1102.07	-1106.61	-678.94	-987.03	-1156.38	-1487.76	-1301.1	-1000.78
Units [kt]	2020									
	4471.18									

Provisional values for the year 2020 were replaced when the figures from the final Energy Balance for 2013 became available. This has led to recalculations for all fuels. The need for additional recalculations, throughout the entire time series, arose through recalculation of the CO_2 emissions for “other produced gases” (as refinery products, allocated to the liquid fuels). The recalculation was carried out on the basis of current evaluations of emissions trading data. The original calculations, which were based on older ETS evaluations, led to an overestimation of emissions, and to a different allocation (cf. Chapter 3.2.5.2).

3.2.7.7.6 Planned improvements (category-specific) (1.A.2.g, Other, stationary)

Activity data:

No improvements are planned at present.

Emission factors:

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.7.8 Construction-sector transports (1.A.2.g vii)

3.2.7.8.1 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)

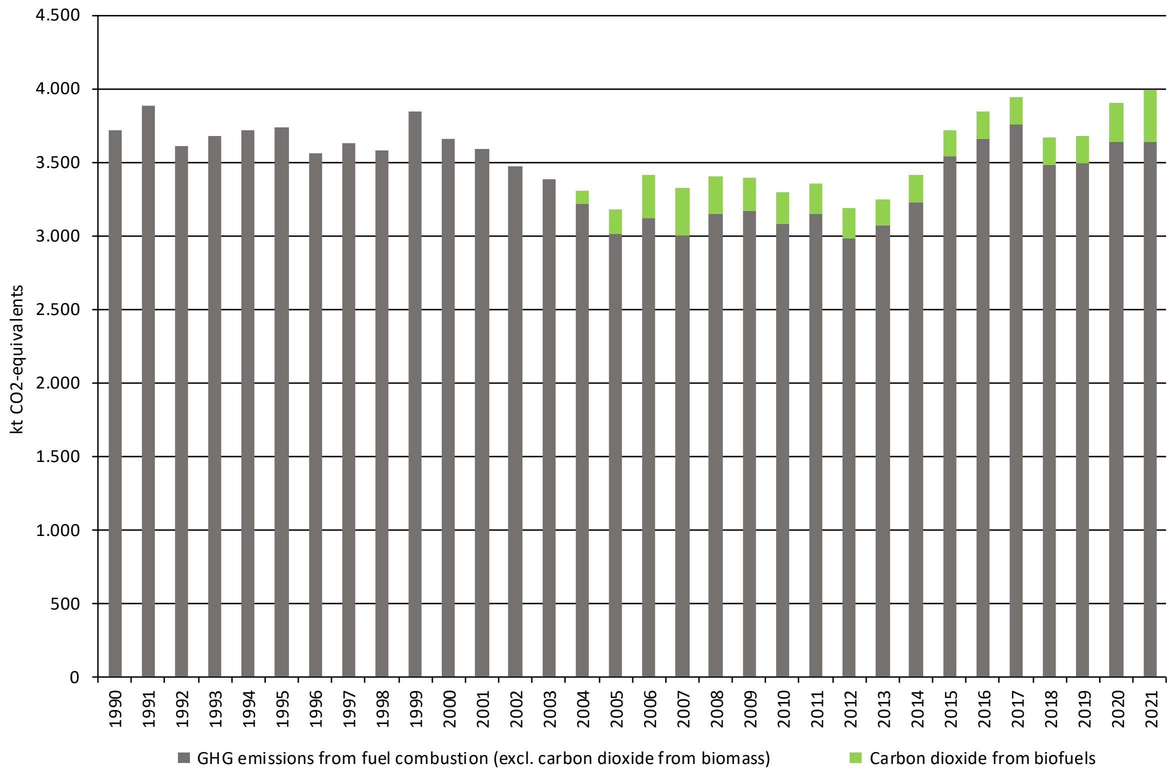
The stationary and mobile sources in 1.A.2.g are grouped together for purposes of assignment to key categories. (For an overview, cf. Chapter 3.2.7.7.). Accordingly, the category 1.*A.2.g vii – Other: Offroad vehicles and other machines*, in which emissions from construction-sector transports are taken into account, is a key category for CO_2 in terms of emissions level and trend.

3.2.7.8.2 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 16.1.4).

Figure 29: 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, Heidt, & Bergk, 2021)).

The relevant **emission factors** are based on the results of various German Environment Agency research projects and expert opinions.

With regard to carbon dioxide, we refer in general to Chapter 15.7. Both country-specific and default values (biodiesel) are used. Further information regarding co-combustion of lubricants in particular is provided in Chapter 16.1.3.

For methane and nitrous oxide, country-specific values from Knörr, Heidt, and Bergk (2021) 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 37: Emission factors used for reporting year 2021, in kg/TJ

	CH_4	N_2O	Origin
Diesel & biodiesel	0.66 (4.15)	2.95 (28.60)	Pursuant to Knörr, Heidt, and Bergk (2021)
Gasoline & bioethanol	18.9 (50)	1.41 (2.00)	Pursuant to Knörr, Heidt, and Bergk (2021)

In parentheses: Defaults pursuant to IPCC (2006a): Volume 2 – Energy, Chapter 3 – Mobile , Tab. 3.3.1: Industry

3.2.7.8.3 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.

For the specific energy inputs calculated as described above for diesel fuel and gasoline, uncertainties of ±10% are assumed.

The uncertainties assumed for the emission factors used are shown in the following table.

Table 38: Percentage uncertainties for emission factors*

	CO_2	CH_4	N_2O
Gasoline	±0.4%	±34%	-40% / +140%
Diesel	±3%	±34%	-40% / +140%

* Upper and lower bounds of the 95% percentile

3.2.7.8.4 Category-specific quality assurance / control and verification (1.A.2.g vii)

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 relevant involved experts and the Single National Entity.

Quality reports of the Working Group on Energy Balances (AG Energiebilanzen – AGEB) have been submitted to the German 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	74,950	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 2021; [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 [a]	74,370	2.25	3.02
Belgium	74,001	6.98	5.15
Denmark	73,631	1.99	3.46
France			
Italy			
Netherlands	72,276	1.33	0.70
Spain	73,318	0.60	3.17
EU-27			
UK	74,137	13.0	2.92

Germany: IEF for report year 2021; all other countries: IEF for 2020, pursuant to 2022 CRF submission

3.2.7.8.5 Category-specific recalculations (1.A.2.g vii)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

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 2020, in the 2022 Submission, have been replaced with the corresponding figures from the final 2020 NEB. 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 2020, in terajoules

	Diesel fuel	Gasoline	Biodiesel	Bioethanol
2023 Submission	105,634	12,465	8,775	567
2022 Submission	104,580	11,106	8,687	505
Absolute change	1,054	1,360	87	62
Relative change	1.01%	12.2%	1.01%	12.3%

Source: Energy Balance 2020 (AGEB, 2021c), and own calculations on the basis of Knörr, Heidt, and Bergk (2021)

At the same time, the split factors generated in TREMOD-MM, for breakdowns of the primary activity data with regard to the small consumers (residential, institutional and commercial) subsumed in Energy Balance lines, were corrected, for all years. In the process, construction-related transports' percentage shares of EB line 67 changed as follows:

Table 43: Revised percentage shares of Energy Balance line 67:

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Diesel fuels											
Subm. 2023	0.430	0.464	0.471	0.438	0.432	0.432	0.431	0.430	0.426	0.425	0.422
Subm. 2022	0.430	0.464	0.470	0.437	0.431	0.431	0.430	0.429	0.426	0.424	0.421
Change, absolute	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Change, relative	0.17%	0.17%	0.17%	0.16%	0.16%	0.15%	0.15%	0.16%	0.16%	0.16%	0.16%
Gasoline											
Subm. 2023	0.315	0.597	0.551	0.586	0.645	0.667	0.684	0.681	0.642	0.632	0.597
Subm. 2022	0.315	0.597	0.551	0.586	0.645	0.667	0.684	0.681	0.642	0.632	0.596
Change, absolute	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Change, relative	0.01%	0.00%	0.02%	0.02%	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%	0.02%

Source: Own calculations, based on Knörr, Heidt, and Bergk (2021)

In sum, the above-described adjustments result in the following changes in the activity data most recently assigned to construction-related transports:

Table 44: Resulting revision of activity data, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Diesel fuel											
Subm. 2023	48,161	45,414	44,743	35,942	38,221	43,753	45,351	46,567	43,154	43,577	44,476
Subm. 2022	48,078	45,337	44,668	35,884	38,160	43,686	45,281	46,495	43,087	43,509	43,962
Change, absolute	83.9	76.9	74.5	58.5	61.1	67.2	70.0	72.1	67.4	68.3	514
Change, relative	0.17%	0.17%	0.17%	0.16%	0.16%	0.15%	0.15%	0.16%	0.16%	0.16%	1.17%
Gasoline											
Subm. 2023	1,420	4,453	4,079	4,284	2,845	3,364	3,441	3,421	3,220	2,937	3,961
Subm. 2022	1,420	4,453	4,079	4,283	2,844	3,363	3,440	3,421	3,220	2,937	3,150
Change, absolute	0.15	-0.09	0.63	0.72	0.41	0.46	0.44	0.45	0.47	0.44	812
Change, relative	0.01%	0.00%	0.02%	0.02%	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%	25.8%
Biodiesel											
Subm. 2023	0	0	0	2,297	2,930	2,393	2,404	2,486	2,509	2,482	3,694
Subm. 2022	0	0	0	2,293	2,926	2,390	2,401	2,482	2,505	2,478	3,652
Change, absolute	0.00	0.00	0.00	3.74	4.68	3.68	3.71	3.85	3.92	3.89	42.6
Change, relative				0.16%	0.16%	0.15%	0.15%	0.16%	0.16%	0.16%	1.17%
Bioethanol											
Subm. 2023	0	0	0	29	110	146	149	144	145	127	181
Subm. 2022	0	0	0	29	110	146	149	144	145	127	144
Change, absolute	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	37.1
Change, relative				0.02%	0.01%	0.01%	0.01%	0.01%	0.01%	0.02%	25.8%

Source: Own calculations, based on Knörr, Heidt, and Bergk (2021)

In addition, the emission factors for methane from use of diesel fuel were revised:

Table 45: Revised emission factors, in kg/TJ

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Subm. 2023	4.54	3.82	3.22	2.15	1.41	0.98	0.91	0.84	0.78	0.72	0.67
Subm. 2022	4.54	3.82	3.22	2.15	1.41	0.98	0.90	0.83	0.77	0.71	0.66
Change, absolute	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Change, relative	-0.03%	-0.02%	0.00%	0.03%	0.05%	0.27%	0.47%	0.69%	0.94%	1.22%	1.52%

Source: Knörr, Heidt, and Bergk (2021)

The described corrections necessitated recalculations of the reported emissions.

Table 46: Revised emissions quantities, in kt and kt CO_2 equivalents

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Carbon dioxide[a]											
Subm. 2023	3,669	3,687	3,610	2,983	3,049	3,502	3,626	3,715	3,447	3,457	3,605
Subm. 2022	3,663	3,682	3,605	2,979	3,045	3,497	3,621	3,710	3,442	3,452	3,506
Change, absolute	6.22	5.69	5.56	4.39	4.57	5.02	5.23	5.39	5.04	5.11	98.2
Change, relative	0.17%	0.15%	0.15%	0.15%	0.15%	0.14%	0.14%	0.15%	0.15%	0.15%	2.80%
Methane											
Subm. 2023	0.253	0.271	0.226	0.168	0.117	0.115	0.114	0.112	0.102	0.094	0.113
Subm. 2022	0.252	0.271	0.226	0.167	0.116	0.114	0.114	0.111	0.102	0.093	0.094
Change, absolute	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.019
Change, relative	0.15%	0.15%	0.16%	0.16%	0.17%	0.25%	0.32%	0.39%	0.47%	0.91%	20.2%
Nitrous oxide											
Subm. 2023	0.138	0.137	0.137	0.119	0.126	0.141	0.146	0.150	0.140	0.140	0.148
Subm. 2022	0.138	0.137	0.137	0.119	0.126	0.141	0.146	0.150	0.139	0.140	0.145
Change, absolute	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Change, relative	0.14%	0.14%	0.15%	0.15%	0.15%	0.14%	0.15%	0.15%	0.15%	0.15%	1.95%
TOTAL GREENHOUSE GASES [a]											
Subm. 2023	3,716	3,735	3,657	3,023	3,090	3,547	3,673	3,763	3,492	3,501	3,651
Subm. 2022	3,710	3,729	3,651	3,018	3,085	3,542	3,667	3,757	3,486	3,496	3,552
Change, absolute	6.29	5.75	5.63	4.45	4.63	5.09	5.30	5.46	5.11	5.19	99.5
Change, relative	0.17%	0.15%	0.15%	0.15%	0.15%	0.14%	0.14%	0.15%	0.15%	0.15%	2.80%

Source: Own calculations;[a] including fossil CO_2 from use of biofuels

3.2.7.8.6 Planned improvements (category-specific) (1.A.2.g vii)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.8 Transport (1.A.3)

3.2.8.1 Transport – Domestic aviation (1.A.3.a)

3.2.8.1.1 Category description (1.A.3.a)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	1 A 3 a, Domestic Aviation	fossil fuels	CO_2	2,263.4	0.2 %	732.3	0.1 %	-67.6 %
-/-	1 A 3 a, Domestic Aviation		CH_4	2.8	0.0 %	1.7	0.0 %	-40.6 %
-/-	1 A 3 a, Domestic Aviation		N_2O	20.3	0.0 %	6.6	0.0 %	-67.4 %

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 Houghton et al. (1997) and from the specific net calorific value pursuant to AGEB (2021c)

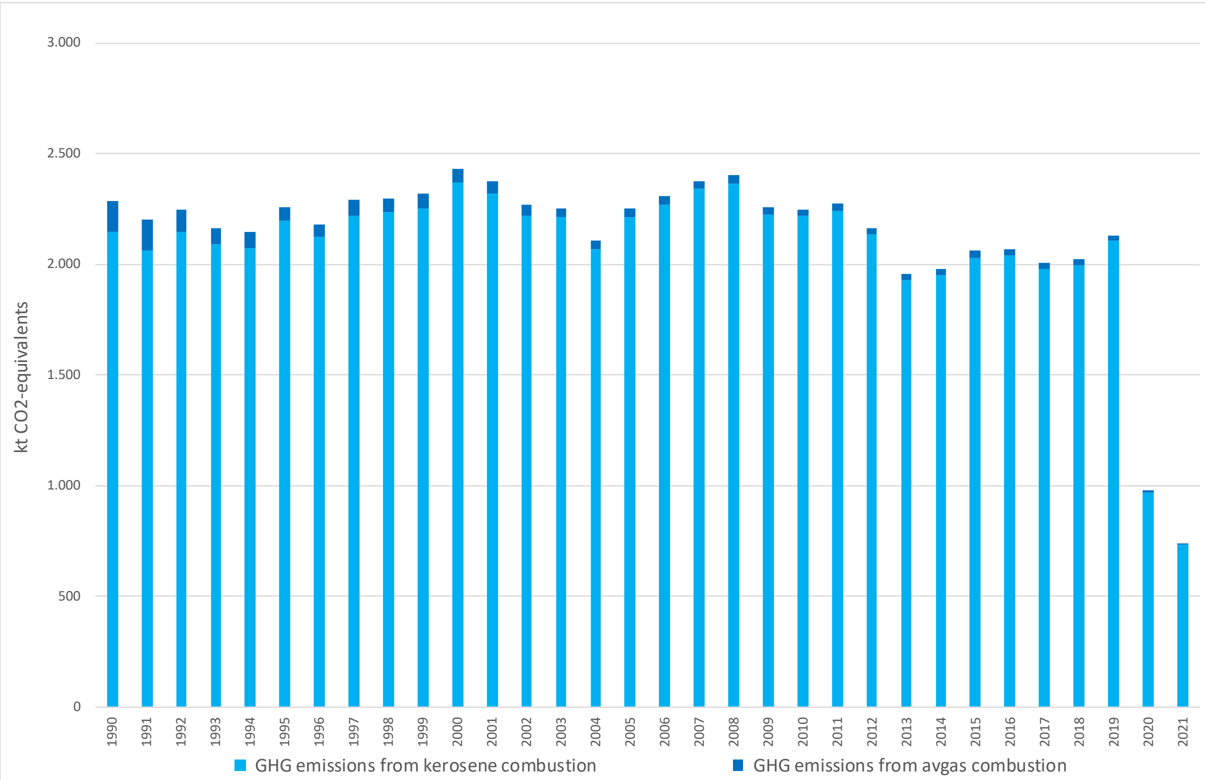
[c] Derived from Tier 3 default values pursuant to EMEP/EEA (2019a)

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 30: Development of GHG emissions in national civil air transports since 1990



3.2.8.1.2 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, 2022c) 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, 2022c)*.

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 47: Domestic flights' annual shares of domestic fuel deliveries, in [%]

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Kerosene	15.0	12.7	10.8	8.70	8.28	8.74	7.78	6.95	7.28	7.58	7.09	6.29	6.17	6.55	6.53	3.83
Avgas	79.0	80.9	79.7	78.0	77.4	82.3	81.9	82.0	83.4	81.6	90.6	90.4	91.1	92.1	93.7	91.8

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

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 16.1.3 in the Annex).

With regard to the **emission factors** used for carbon dioxide, we refer, in general, to Chapter 15.7.

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 484). 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 16.1.2.1 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 48: Emission factors used for report year 2020, in kg/TJ

	CH_4	N_2O	Origin
Kerosene: LTO	16.4	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, Allekotte, et al. (2021) and Gores (2021); in parentheses: Defaults pursuant to IPCC (2006a): Volume 2, Chapter 3.6, Tab. 3.6.5

3.2.8.1.3 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.

The uncertainties were determined for primary activity data (PAD); their distribution parameters (split factors, SF); the resulting specific activity data; and the emission factors used. The uncertainties for the primary activity data taken from the national Energy Balances, and for the carbon-dioxide emission factors, were estimated by experts. All other uncertainties were derived in the framework of a study (Allekotte et al., 2022). All uncertainties figures apply for the entire time series in each case.

The following table provides an overview of the pertinent specific uncertainties.

Table 49: Specific uncertainties used

Parameter		Distribution	Lower bound	Upper bound
PAD	Kerosene	Normal	-5.00%	5.00%
	Avgas	Regular	-5.00%	5.00%
SF	Kerosene, national	Log-normal	-7.06%	7.44%
	Avgas, national	Normal	-16.2%	16.2%
	Kerosene, national: L/TO	Log-normal	-7.42%	7.85%
	Avgas, national: L/TO	Log-normal	-85.1%	250%
AD	Kerosene – L/TO	Normal	-4.10%	4.10%
	Kerosene – cruise	Normal	-9.91%	9.91%
	Avgas – L/TO	Log-normal	-81.8%	221%
	Avgas - cruise	Normal	-39.9%	39.9%
EF	CO_2, kerosene	Normal	-5.00%	5.00%
	CO_2, avgas	Normal	-5.00%	5.00%
	CH_4, kerosene: L/TO	Log-normal	-59.6%	81.4%
	CH_4, kerosene: Cruise		NA	
	N_2O, kerosene: L/TO	Normal	-38.0%	38.0%
	N_2O, kerosene: Cruise	Normal	-24.0%	24.0%
	CH_4, avgas: L/TO	Log-normal	-71.4%	156%
	CH_4, avgas: Cruise		NA	
	N_2O, avgas: L/TO	Normal	-44.8%	44.8%
	N_2O, avgas: Cruise	Normal	-43.5%	43.5%

Source: Expert judgement, or Allekotte et al. (2022)

3.2.8.1.4 Category-specific quality assurance / control and verification (1.A.3.a)

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 relevant involved experts and the Single National Entity.

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/EEA (2019a). Country-specific consumption and emissions data provided by Eurocontrol are currently being used only for verification purposes.

Table 50: 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 51
CH_4, N_2O	Specific Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter 3.6, Tab. 3.6.5	cf. Table 48
CO_2, CH_4, N_2O	specific IEF of other countries	cf. Table 52

Table 51: 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	71,199		*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 52: 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	5.53	2.49	71,199	35.9	2.30
Belgium	72,148	4.44	5.81	71,991	31.5	2.58
Denmark	71,868	0.40	3.22	72,769	8.11	2.00
France	73,488	0.50	2.00	70,500	13.5	2.00
Italy	71,500	1.15	2.00	70,000	4.87	1.98
Netherlands	71,500	0.50	2.00	72,000	0.50	2.00
Spain	72,917	1.06	1.98	70,602	0.50	1.98
EU-27	72,713	1.26	2.83	70,447	9.77	4.50
UK	71,713	1.30	2.28	69,766	56.2	2.23

Germany: current IEF for report year 2021; all other countries: IEF for 2020, pursuant to 2022 CRF submission

3.2.8.1.5 Category-specific recalculations (1.A.3.a)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

Recalculations with respect to the 2022 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 53: Revised annual shares, for domestic flights, of domestic fuel deliveries, in %

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Jet fuel / kerosene											
2023 Submission	15.0	12.7	10.8	8.70	8.28	7.58	7.09	6.29	6.17	6.55	6.53
2022 Submission	16.1	12.1	11.8	9.67	8.59	7.34	7.17	6.82	6.73	6.94	6.99
Absolute change	-1.06	0.60	-1.05	-0.97	-0.31	0.24	-0.08	-0.54	-0.56	-0.39	-0.47
Change, rel.	-6.58%	4.97%	-8.87%	-10.1%	-3.65%	3.28%	-1.18%	-7.85%	-8.39%	-5.64%	-6.67%
Avgas											
2023 Submission	79.0	80.9	79.7	78.0	77.4	81.6	90.6	90.4	91.1	92.1	93.7
2022 Submission	79.0	80.9	79.7	78.0	77.3	81.5	90.6	90.4	91.1	92.1	93.7
Absolute change	0.00	0.00	0.00	0.00	0.02	0.04	0.02	0.02	0.01	0.01	0.02
Change, rel.	0.00%	0.00%	0.00%	0.00%	0.03%	0.05%	0.02%	0.02%	0.01%	0.01%	0.02%

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

The quantities of fuel consumed for domestic flights were upwardly corrected by the same amount.

Table 54: Resulting revision of domestic consumption, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Jet fuel / kerosene											
2023 Submission	29,025	29,642	31,999	29,908	29,957	27,424	27,581	26,727	26,959	28,447	13,048
2022 Submission	31,070	28,240	35,112	33,258	31,092	26,554	27,911	29,003	29,429	30,148	13,980
Absolute change	-2,045	1,402	-3,113	-3,350	-1,135	870	-330	-2,276	-2,470	-1,701	-932
Change, rel.	-6.58%	4.97%	-8.87%	-10.1%	-3.65%	3.28%	-1.18%	-7.85%	-8.39%	-5.64%	-6.67%
Avgas											
2023 Submission	1,927	924	892	544	439	451	369	364	354	294	195
2022 Submission	1,927	924	892	544	439	451	369	364	354	294	195
Absolute change	0.00	0.00	0.00	0.00	0.11	0.23	0.07	0.08	0.04	0.03	0.04
Change, rel.	0.00%	0.00%	0.00%	0.00%	0.03%	0.05%	0.02%	0.02%	0.01%	0.01%	0.02%
TOTAL FUEL INPUTS											
2023 Submission	30,952	30,566	32,891	30,452	30,396	27,875	27,949	27,091	27,313	28,741	13,243
2022 Submission	32,997	29,164	36,005	33,802	31,531	27,004	28,279	29,367	29,783	30,442	14,175
Absolute change	-2,045	1,402	-3,113	-3,350	-1,135	871	-330	-2,276	-2,470	-1,701	-932
Change, rel.	-6.2%	4.8%	-8.6%	-9.9%	-3.6%	3.2%	-1.2%	-7.7%	-8.3%	-5.6%	-6.6%

Source: Own calculations

In addition, and on the basis of the results of a broad-based measurement campaign, the default emission factor used to date for CO_2 from use of avgas, 70,000 kg/TJ, was replaced with a country-specific value of 71,199 kg/TJ (Juhrich, 2022)..

In sum, the aforementioned adjustments lead to the emissions recalculations shown in the following table.

Table 55: Revised GHG emissions, in kt and kt CO_2-eq

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Carbon dioxide – CO2											
Subm. 2023	2,263	2,237	2,408	2,230	2,226	2,041	2,047	1,984	2,000	2,105	970
Subm. 2022	2,411	2,133	2,635	2,474	2,308	1,977	2,070	2,150	2,181	2,229	1,038
Absolute change	-147	104	-227	-245	-82.6	64.3	-23.7	-166	-181	-124	-68.1
Change, rel.	-6.12%	4.87%	-8.62%	-9.89%	-3.58%	3.25%	-1.15%	-7.73%	-8.28%	-5.57%	-6.56%
Subm. 2023	0.101	0.082	0.086	0.079	0.076	0.079	0.078	0.079	0.082	0.087	0.056
Subm. 2022	0.105	0.079	0.093	0.086	0.078	0.077	0.079	0.086	0.089	0.092	0.060
Absolute change	-0.004	0.003	-0.007	-0.008	-0.003	0.002	-0.001	-0.006	-0.007	-0.005	-0.004
Change, rel.	-4.17%	3.78%	-7.17%	-8.73%	-3.24%	2.88%	-1.09%	-7.23%	-7.73%	-5.28%	-6.27%
Subm. 2023	0.076	0.075	0.081	0.075	0.075	0.069	0.069	0.067	0.067	0.071	0.033
Subm. 2022	0.082	0.072	0.088	0.083	0.078	0.067	0.070	0.072	0.073	0.075	0.035
Absolute change	-0.005	0.003	-0.008	-0.008	-0.003	0.002	-0.001	-0.006	-0.006	-0.004	-0.002
Change, rel.	-6.22%	4.82%	-8.66%	-9.92%	-3.60%	3.23%	-1.17%	-7.76%	-8.30%	-5.59%	-6.59%
Subm. 2023	2,289	2,262	2,434	2,254	2,250	2,064	2,069	2,006	2,022	2,128	981
Subm. 2022	2,438	2,157	2,663	2,501	2,334	1,999	2,093	2,174	2,205	2,254	1,050
Absolute change	-149	105	-229	-247	-83.5	65.0	-24.0	-168	-183	-126	-68.9
Change, rel.	-6.12%	4.87%	-8.62%	-9.89%	-3.58%	3.25%	-1.15%	-7.73%	-8.28%	-5.57%	-6.56%

Source: Own calculations

3.2.8.1.6 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)[28].

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.8.2 Transport – Road transportation (1.A.3.b)

3.2.8.2.1 Category description (1.A.3.b)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	1 A 3 b, Road Transport	fossil fuels	CO_2	151,889.8	11.8 %	142,140.8	18.6 %	-6.4 %
-/T	1 A 3 b, Road Transport		CH_4	1,812.7	0.2 %	231.4	0.0 %	-87.2 %
-/T	1 A 3 b, Road Transport		N_2O	1,123.4	0.1 %	1,351.5	0.2 %	20.3 %

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).

3.2.8.2.2 Methodological issues (1.A.3.b)

- Cf. also Chapter 16.1.2.2 -

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

[28] 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; 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).

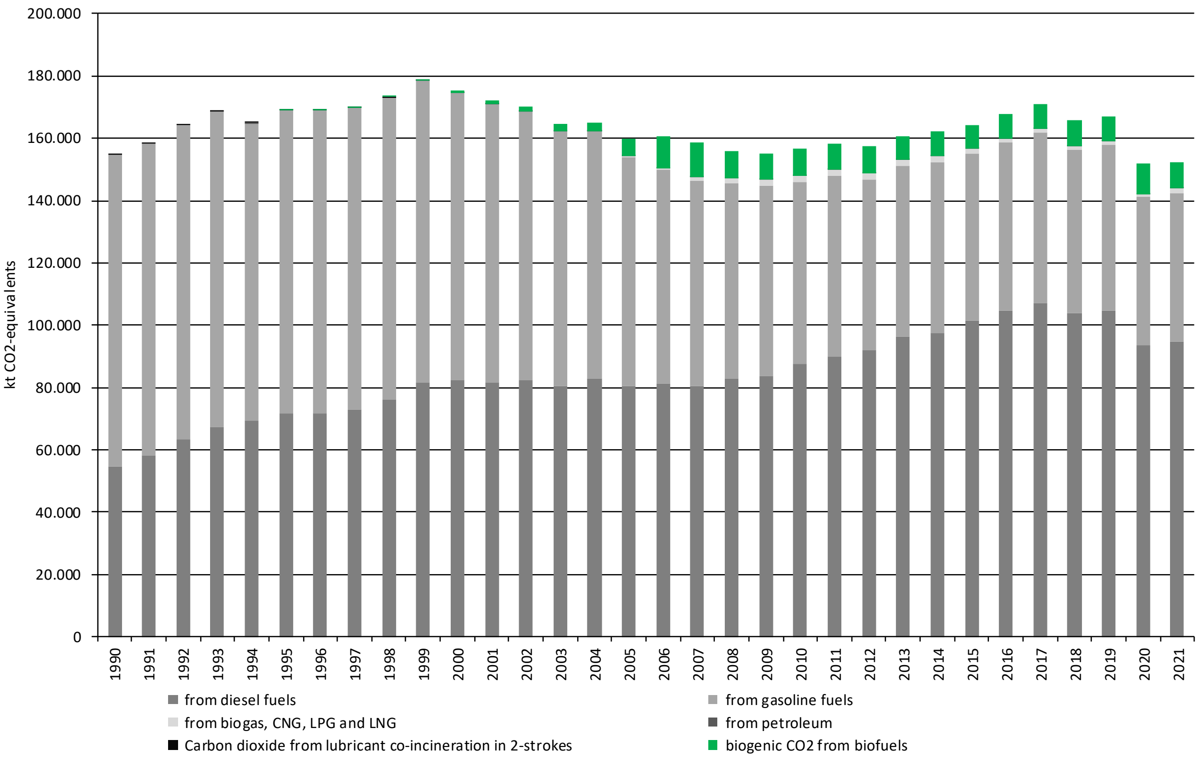
The CO_2 emissions from the fossil fractions of the biofuels used are allocated to the total national emissions (cf. the explanatory remarks in Chapter 16.1.4).

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.

In 2021, the pandemic still played a central role, even if that year lacked the drastic social restrictions of the previous year. In particular, automobile traffic levels remained considerably below the levels of 2019. Traffic emissions remained low by comparison with those of the year 2019, as a result of reductions in driving, tied to lockdowns and travel restrictions, and the concomitant reduced fuel consumption. To a smaller degree, the emissions reductions also resulted from engine-efficiency improvements and to further-increased sales, with respect to 2019, of electric vehicles. On the other hand, two effects led to emissions increases: mileage in road transports of goods was up slightly over the previous year, and sales of biofuels were down. In sum, the re-increase of greenhouse-gas emissions that occurred in 2021, with respect to 2020, was quite moderate, at nearly 1%.

Figure 31: 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 16.1.2.2) (Knörr, Heidt, Gores, et al., 2021)[29]. 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.

[29] 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 56: 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	151,890	0	64.7	4.24	1,313	7,598	1,536	76.3
1995	166,452	106	31.9	5.87	1,140	4,332	703	69.3
2000	172,541	869	19.8	5.30	973	2,550	355	19.7
2005	153,040	5,591	13.1	2.84	782	1,620	206	0.80
2010	146,752	8,530	9.53	3.36	661	1,219	127	0.72
2015	155,315	7,538	8.65	4.54	600	1,091	100	0.75
2016	158,430	7,561	8.88	4.85	572	1,061	97.5	0.83
2017	161,492	7,706	9.21	5.14	538	1,036	95.6	0.77
2018	155,930	8,024	8.96	5.15	479	967	89.8	0.75
2019	157,444	7,985	8.99	5.33	433	934	87.8	0.83
2020	140,593	9,636	8.37	5.04	341	772	81.6	0.75
2021	142,141	8,617	8.27	5.10	319	759	80.3	0.75

Source: Own calculations, based on Knörr, Heidt, Gores, et al. (2021)

[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, Heidt, Gores, et al. (2021).

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)). 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 15.7.

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 16.1.3.

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.

3.2.8.2.3 Uncertainties and time-series consistency (1.A.3.b)

The uncertainties for the activity data entering into TREMOD, and for the emission factors generated therein for methane and nitrous oxide, have been determined in the framework of a still-unpublished study. The uncertainties for the carbon-dioxide emission factors, on the other hand, are based on experts' estimates and on fuel analyses.

Table 57: Relative uncertainties for carbon-dioxide emission factors*, in %

	EF CO_2
Diesel fuels	±3.00
Gasoline	±0.40
Natural gas	±1.00
LPG	±2.00
LNG	±1.00
Biodiesel	±5.00
Bioethanol	±1.00

* Upper and lower bounds of the 95% percentile; based on experts' estimates and fuel analyses

Table 57: Relative uncertainties of the activity data and IEF for methane and nitrous oxide*, in %

	AD		IEF CH_4		IEF N_2O	
	U_{min}	U_{max}	U_{min}	U_{max}	U_{min}	U_{max}
1.A.3.b i – Passenger cars						
Diesel fuels	-18.5	27.0	-47.4	95.1	-36.5	74.7
Gasoline	-17.3	27.5	-36.2	53.0	-33.5	81.6
Natural gas	-30.2	52.2	-24.3	40.8	-31.8	50.7
LPG	-34.0	53.7	-36.7	77.7	-84.8	354
Biodiesel	-18.6	26.9	-47.5	95.6	-36.9	75.8
Bioethanol	-17.5	27.3	-36.1	52.4	-33.3	80.2
1.A.3.b ii – Light duty vehicles						
Diesel fuel	-14.0	18.2	-46.2	101	-35.8	67.5
Gasoline	-20.6	28.6	-30.1	37.8	-21.9	30.4
Natural gas	-21.7	36.4	-35.5	59.9	-23.3	31.5
Biodiesel	-14.3	18.8	-46.1	103	-35.8	68.2
Bioethanol	-20.8	28.8	-30.4	37.5	-21.9	30.7
1.A.3.b iii – Heavy duty vehicles (including buses)						
Diesel fuel	-25.8	34.1	-36.1	51.7	-28.8	51.4
Natural gas	-27.0	40.8	-18.8	34.7	NA	NA
LNG	-35.9	48.0	-14.2	11.4	NA	NA
Biodiesel	-25.8	33.9	-36.5	52.0	-28.9	52.8
1.A.3.b iv – Motorised two-wheelers (motorcycles and mopeds)						
Gasoline	-27.4	45.1	-22.5	29.4	-25.7	46.4
Bioethanol	-27.1	44.9	-22.5	29.9	-25.6	45.5

* Upper and lower bounds of the 95% percentile; modelled

3.2.8.2.4 Category-specific quality assurance / control and verification (1.A.3.b)

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 relevant involved experts and the Single National Entity.

Quality reports of the Working Group on Energy Balances (AGEB) have been submitted to the German 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[30].

[30] 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 57: 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 58
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 59

Table 58: 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	74,950	69,300	67,500	73,000
Natural gas	55,786	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 2021; [b] pursuant to IPCC (2006a): Chapter 2, Table 2.4

Table 59: International comparison of reported EF (CO_2), in kg/TJ

	Gasoline	Diesel	LPG	CNG	LNG	Biomass	Biodiesel	Bioethanol	Biogas
Germany	74,950	74,027	66,334	55,786	55,944	71,720	70,800	71,607	90,584
Belgium	72,229	74,235	64,896	57,861		71,950			
Denmark	72,986	74,094	63,100	56,800		74,449			
France	74,421	74,835	65,254	56,349		70,120			
Italy	72,502	73,512	65,986	57,763		74,091			
Netherlands	73,023	72,454	66,700	56,400		72,097			
Spain	74,816	73,648	67,133	56,089		76,786			
EU-27	72,831	74,163	65,374	57,161		72,184			
UK	70,209	73,792	IE	IE		IE			

[a] used for reported year 2021; b pursuant to UNFCCC GHG Locator 2022

For a detailed comparison of the implied emission factors for methane and nitrous oxide, with the relevant figures of other countries, and with the values resulting for the EU (27), we refer to Chapter 16.1.2.3.3 in the Annex of this report.

3.2.8.2.5 Category-specific recalculations (1.A.3.b)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

With respect to the 2022 submission, recalculations have been carried out to take account of revised activity data and emission factors.

In addition, provisional energy-consumption figures in the 2020 Energy Balance have been replaced with final values.

Table 60: Revised energy inputs for 2020, in terajoules

	Diesel	Biodiesel	Gasoline	Biogasoline	Natural gas	LPG	LNG	Biogas	Lubricants*
2023 Submission	1,239,658	102,973	629,435	28,737	5,912	9,551	2,511	3,181	80.4
2022 Submission	1,241,557	103,133	629,926	28,759	6,933	13,667	2,108	3,181	78.0
Absolute change	-1,898	-159	-491	-22.6	-1,021	-4,115	402	0.00	2.45
Relative change	-0.15%	-0.15%	-0.08%	-0.08%	-14.7%	-30.1%	19.1%	0.00%	3.14%

Source: Knörr, Heidt, Gores, et al. (2021) based on AGEB (2021b) and (en2x, 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 2022 Submission.

Table 61: Revised greenhouse gas emissions, in kt CO_2 equivalents

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
1.A.3.b i – automobiles											
Subm. 2023	115,320	118,085	114,904	105,795	95,631	100,083	102,089	104,306	100,005	100,282	86,228
Subm. 2022	114,752	117,271	113,960	104,796	95,178	99,526	101,541	103,759	99,513	99,861	86,585
Change,	569	814	944	998	453	557	549	547	492	421	-357
Change,	0.50%	0.69%	0.83%	0.95%	0.48%	0.56%	0.54%	0.53%	0.49%	0.42%	-0.41%
1.A.3.b ii – light duty vehicles											
Subm. 2023	5,044	8,192	10,500	9,859	9,106	10,669	11,283	11,895	11,803	12,086	11,478
Subm. 2022	4,024	6,410	8,313	8,532	8,407	10,080	10,712	11,380	11,384	11,722	11,251
Change,	1,020	1,783	2,187	1,326	700	589	571	515	419	364	227
Change,	25.34%	27.81%	26.31%	15.54%	8.32%	5.84%	5.33%	4.52%	3.68%	3.11%	2.01%
1.A.3.b iii – Heavy duty vehicles (including buses)											
Subm. 2023	32,476	41,189	47,354	36,781	41,761	44,670	45,221	45,510	44,380	45,373	43,026
Subm. 2022	34,137	43,928	50,620	39,274	43,050	46,006	46,551	46,801	45,530	46,404	43,855
Change,	-1,661	-2,739	-3,266	-2,493	-1,289	-1,336	-1,331	-1,291	-1,150	-1,031	-829
Change,	-4.86%	-6.24%	-6.45%	-6.35%	-2.99%	-2.90%	-2.86%	-2.76%	-2.53%	-2.22%	-1.89%
1.A.3.b iv – Motorised two-wheelers											
Subm. 2023	1,745	1,499	1,850	1,774	1,487	1,423	1,444	1,467	1,407	1,417	1,448
Subm. 2022	1,695	1,459	1,806	1,742	1,468	1,406	1,428	1,456	1,399	1,412	1,437
Change,	49.7	40.2	43.6	31.1	19.1	17.5	15.2	10.8	8.09	5.48	11.1
Change,	2.93%	2.76%	2.42%	1.79%	1.30%	1.24%	1.06%	0.74%	0.58%	0.39%	0.77%
CO_2 from co-combustion of lubricants in											
Subm. 2023	186	33	6.06	5.75	6.05	5.72	5.72	5.67	5.57	5.61	5.90
Subm. 2022	183	33	5.90	5.64	5.97	5.65	5.67	5.65	5.54	5.59	5.72
Change,	3.49	0.56	0.15	0.11	0.09	0.07	0.06	0.02	0.03	0.02	0.18
Change,	1.91%	1.70%	2.62%	2.02%	1.44%	1.17%	1.00%	0.39%	0.53%	0.37%	3.14%
1.A.3.b - TOTAL GREENHOUSE GAS											
Subm. 2023	154,772	168,999	174,614	154,213	147,991	156,850	160,042	163,184	157,601	159,164	142,185
Subm. 2022	154,791	169,100	174,706	154,351	148,108	157,023	160,238	163,402	157,831	159,404	143,133
Change,	-19.2	-101	-91.4	-137	-117	-173	-196	-219	-230	-240	-948
Change,	-0.01%	-0.06%	-0.05%	-0.09%	-0.08%	-0.11%	-0.12%	-0.13%	-0.15%	-0.15%	-0.66%

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.

3.2.8.2.6 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.8.3 Transport – Railways (1.A.3.c)

3.2.8.3.1 Category description (1.A.3.c)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**1 A 3 c, Railways**	**fossil fuels**	**CO_2**	**3,122.1**	**0.3 %**	**853.3**	**0.1 %**	**-72.7 %**
-/-	1 A 3 c, Railways		CH_4	19.7	0.0 %	0.3	0.0 %	-98.3 %
-/-	1 A 3 c, Railways		N_2O	6.8	0.0 %	1.9	0.0 %	-72.3 %

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/EEA (2019a): 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.

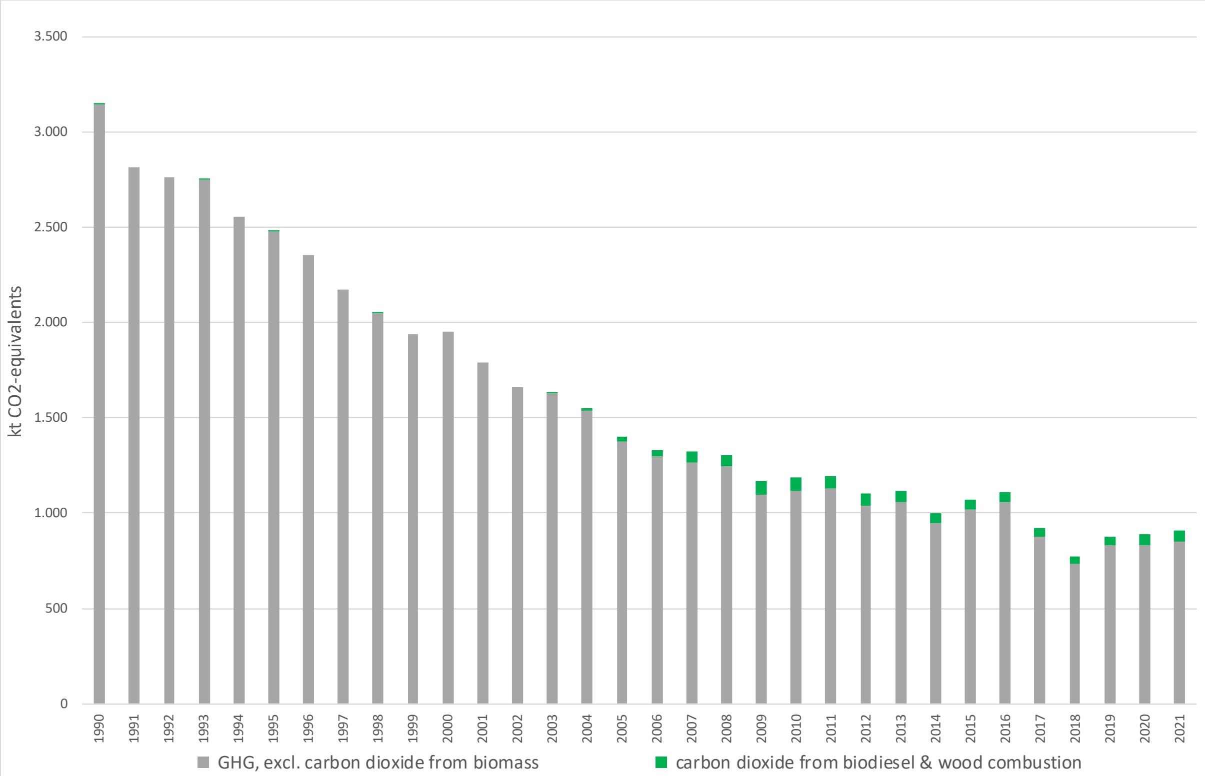
Germany's railway sector is undergoing a long-term modernisation process, aimed at making electricity the main energy source for rail transports. Its share of the energy used for traction is currently about 78 % (AGEB, 2021b). Railways' power stations for generation of required traction current are allocated 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 32: 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

3.2.8.3.2 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 16.1.4).

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")) (en2x, 2021b).[31]

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.

[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 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 62: 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
Firewood	as of 2015: Survey; previously: Extrapolation

With regard to the **emission factors** used for carbon dioxide, we refer, in general, to Chapter 15.7.

For methane and nitrous oxide, country-specific values pursuant to (Knörr, Heidt, Gores, et al. (2021): 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 63: Emission factors used for reporting year 2020, in kg/TJ

	CH_4	N_2O	Origin
Diesel & biodiesel	0.90 (4.15)	0.56 (28.60)	CH_4: pursuant to Knörr, Heidt, Gores, et al. (2021); N_2O: Tier 2 default pursuant to EMEP/EEA (2019a)
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*

3.2.8.3.3 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 implied emission factors modelled in TREMOD and for the emissions calculated in the Central System of Emissions (CSE).

Table 64: Percentage uncertainties for activity data and emission factors*

	AD	EF CO_2	EF CH_4	EF N_2O
Diesel fuels	±10%	±3%	±34%	-42% / 75%
Lignite briquettes	±20%	±5%	-28% / 40%	-42% / 75%
Crude lignite	±20%	±3%	-28% / 40%	-42% / 75%
Hard coal	±20%	±2%	-28% / 40%	-42% / 75%
Hard-coal coke	±20%	±2%	-28% / 40%	-42% / 75%
Firewood	±10%	±5%	-28% / 40%	-42% / 75%

* Upper and lower bounds of the 95% percentile

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.

3.2.8.3.4 Category-specific quality assurance / control and verification (1.A.3.c)

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 relevant involved experts and the Single National Entity.

Quality reports of the Working Group on Energy Balances (AGEB) have been submitted to the German 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 65: 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 58
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 67

Table 66: 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	99,169	97,500	*87,300*	*109,000*
Crude lignite	105,774	101,000	*90,900*	*115,000*
Hard coal	93,932	94,600	*89,500*	*99,700*
Hard-coal coke	107,846	107,000	*95,700*	*119,000*
Biodiesel	70,800		*59,800*	*84,300*
Firewood	102,000	112,000	95,000	132,000

[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 67: 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	74,027	0.90	0.56	93,965	3.05	1.50
Belgium	74,100	4.94	6.86	NO	NO	NO
Denmark	74,100	1.06	2.24	NO	NO	NO
France	74,837	10.6	2.95	IE	IE	IE
Italy	73,510	4.21	29.0	NO	NO	NO
Netherlands	72,454	4.26	0.56	NO	NO	NO
Spain	74,100	4.15	0.56	NO	NO	NO
EU-27	74,651	2.95	10.8	94,991	49.8	1.10
UK	74,938	0.93	0.56	96,100	87.6	0.70

Sources: [a] IEF for reported year 2021; otherwise: IEF for 2020, pursuant to 2022 CRF submission

3.2.8.3.5 Category-specific recalculations (1.A.3.c)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

Almost all recalculations carried out with respect to the 2022 submission have been carried out to take account of revised activity data.

In the process, the energy inputs for diesel fuels, which had still been provisional, were replaced with final values for 2020. This led to a corresponding correction of the figure for biodiesel used as an admixture.

	Diesel	Biodiesel
2023 Submission	10,782	896
2022 Submission	10,145	843
Absolute change	637	52.9
Relative change	6.28%	6.27%

Sources: AGEB (2021b); Knörr, Heidt, Gores, et al. (2021)

The emission factors for methane from diesel and biodiesel were corrected for the years as of 2013. Otherwise, the emission factors have not been changed with respect to the 2022 report.

Table 68: Corrected emission factors for methane from diesel fuels, in kg/TJ

	2013	2014	2015	2016	2017	2018	2019	2020
2023 Submission	1.04	1.02	0.96	0.96	0.93	0.90	0.89	0.93
2022 Submission	1.03	1.01	0.95	0.94	0.91	0.87	0.84	0.87
Absolute change	0.01	0.01	0.02	0.02	0.01	0.04	0.05	0.05
Relative change	0.82%	1.18%	1.76%	2.03%	1.56%	4.42%	6.19%	6.04%

Source: Knörr, Heidt, Gores, et al. (2021)

The above-described adjustments lead to the following recalculated emissions quantities:

Table 69: Revised emissions quantities, in kt and kt CO_2 equivalents

	2013	2014	2015	2016	2017	2018	2019	2020
Carbon dioxide – CO_2 [a]								
2023 Submission	1,057	946	1,022	1,057	877	734	832	830
2022 Submission	1,057	946	1,022	1,057	877	734	832	783
Absolute change	0	0	0	0	0	0	0	47.1
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.05%
Methane – CH_4								
2023 Submission	0.017	0.015	0.014	0.015	0.012	0.010	0.011	0.012
2022 Submission	0.017	0.014	0.014	0.015	0.012	0.010	0.011	0.011
Absolute change	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001
Relative change	0.74%	1.08%	1.67%	1.88%	1.41%	3.92%	5.56%	11.6%
Nitrous oxide – N_2O								
2023 Submission	0.009	0.008	0.008	0.009	0.007	0.006	0.007	0.007
2022 Submission	0.009	0.008	0.008	0.009	0.007	0.006	0.007	0.007
Absolute change	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	5.84%
Total GHG [a]								
2023 Submission	1,060	949	1,025	1,059	879	736	834	833
2022 Submission	1,060	949	1,025	1,059	879	736	834	785
Absolute change	0	0	0	0	0	0	0	47.3
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.05%

Source: Own calculations; [a] including fossil CO_2 from use of biodiesel

3.2.8.3.6 Category-specific planned improvements (1.A.3.c)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.8.4 Transport – Water-borne navigation (1.A.3.d)

3.2.8.4.1 Category description (1.A.3.d)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/-	**1 A 3 d, Domestic Navigation**	**fossil fuels**	**CO_2**	**2,993.4**	**0.2 %**	**1,449.9**	**0.2 %**	**-51.6 %**
-/-	1 A 3 d, Domestic Navigation		CH_4	2.2	0.0 %	5.6	0.0 %	158.1 %
-/-	1 A 3 d, Domestic Navigation		N_2O	18.6	0.0 %	10.8	0.0 %	-41.6 %

Gas	Method used	Source for the activity data	Emission factors used
CO_2	CS (Tier 2)	NS/IS/M	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)

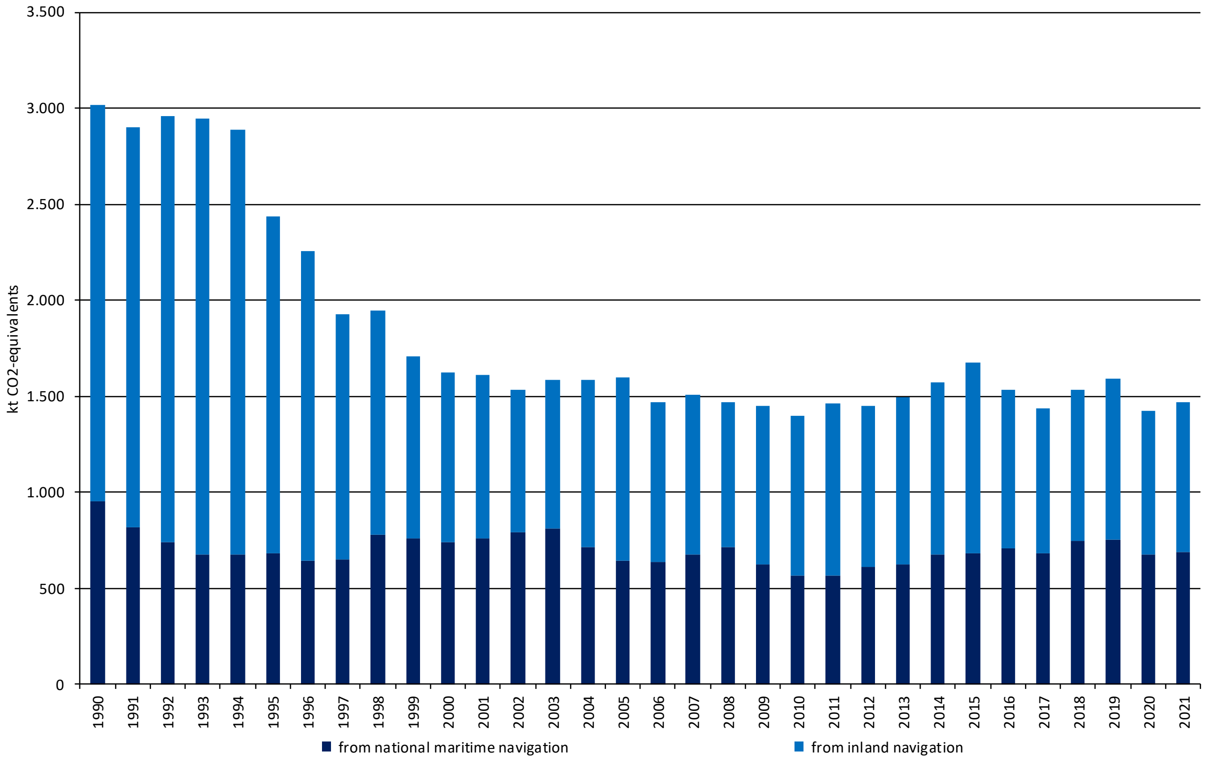
The category *Domestic navigation* is a key category for carbon dioxide in terms of emissions level.

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 33: Development of GHG emissions from domestic water-borne navigation, since 1990



3.2.8.4.2 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/EEA (2019a): Sectoral guidance chapters, 1.A.3.d Navigation (shipping)) (Deichnik, 2022). 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, Heidt, Gores, et al., 2021). 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 en2x). 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 70: 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"
Heavy fuel oil	NEB	6	"International marine bunkers"
LNG	To date, not available in the NEB; instead it has been modelled in (Deichnik, 2022)		

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).

In the present report, inputs of LNG in domestic water-borne navigation is being taken into account for the first time. Since this aspect has not yet been included in the national Energy Balances, modelled activity data pursuant to (Deichnik, 2022) have been used.

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[32], 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 15.7. Further information – in particular, with regard to carbon dioxide from lubricant co-combustion – is also provided in Chapter 16.1.3.

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 (2022).

For the area of *inland navigation*, CH_4 emission factors from Knörr, Heidt, Gores, et al. (2021) 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 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 71: Emission factors used for reporting year 2021, in kg/TJ

	CH_4	N_2O	Origin
Inland navigation			
Diesel	1.41 (-)	1.00 (-)	Country-specific value pursuant to Knörr, Heidt, Gores, et al. (2021)
Domestic water-borne navigation			
Diesel	0.84 (-)	3.34 (2.00)	Pursuant to Deichnik (2022)
Heavy fuel oil	0.75 (7.00)	3.55 (2.00)	
LNG	610	2.51	
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

[32] 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.

3.2.8.4.3 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.

For the specific energy inputs calculated as described above, uncertainties of ±5% are assumed.

The uncertainties assumed for the emission factors used are shown in the following table.

Table 72: Percentage uncertainties for emission factors*

	CO_2	CH_4	N_2O
Diesel: Inland vessels	±3%	±34%	-40% / +75%
Diesel: Seagoing vessels	±3%	±50%	-40% / +140%
Heavy fuel oil	±5%	±40%	-40% / +140%
LNG	±2%	-75% / +150%	±50%

* Upper and lower bounds of the 95% percentile

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.

3.2.8.4.4 Category-specific quality assurance / control and verification (1.A.3.d)

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 relevant involved experts and the Single National Entity.

Quality reports of the Working Group on Energy Balances (AGEB) have been submitted to the German 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[33].

Table 73: 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 74
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 75

[33] AG Energiebilanzen (Working Group on Energy Balances): explanations relative to revision of the Energy Balances 2003 – 2009; URL: https://ag-energiebilanzen.de/wp-content/uploads/2021/01/revision_der_energiebilanzen_2003_bis_2009_05.pdf (last checked on 20 Oct. 2022)

Table 74: Comparison of the EF(CO_2) used for reporting year 2021 with IPCC default values

	Inventory value	Default [a]	*Lower bound*	*Upper bound*
Diesel fuel	74,027	74,100	*72,600*	*74,800*
Heavy fuel oil	77,188	77,400	*75,500*	*78,800*
LNG	55,944	56,100	*54,300*	*58,300*

[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 (27).

Table 75: International comparison of reported IEF, in kg/TJ

	Diesel fuel			Heavy fuel oil			LNG		
	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
Germany	74,027	1.17	2.05	77,188	0.75	3.55	55,944	610	2.51
Belgium	73,342	2.00	1.96	IE	IE	IE			
Denmark	74,050	1.95	1.81	78,000	2.02	1.95			
France	74,704	7.05	1.91	78,000	7.50	2.00			
Italy	74,048	6.95	1.86	77,400	7.31	1.95			
Netherlands	72,454	7.00	2.00	NO	NO	NO			
Spain	74,100	7.00	2.00	77,400	7.00	2.00			
EU-27	74,471	3.80	4.01	76,462	6.17	2.21			
UK	75,151	0.81	3.41	77,531	1.25	3.64			

Germany: current IEF for report year 2021; all other countries: IEF for 2020, pursuant to 2021 CRF submission

3.2.8.4.5 Category-specific recalculations (1.A.3.d)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

With regard to the 2022 submission, recalculations have been carried out to take account of a) updating, and first-time entry, of activity data, and b) adjustments in emission factors. As described above, in the 2023 report inputs of LNG in domestic water-borne navigation are being taken into account for the first time. Quantity data for the period as of 2014 are available for this area that are modelled in (Deichnik, 2022).

In the process, provisional Energy Balance data for the year 2020 have been replaced with the corresponding final data.

Table 76: Revised energy inputs, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Diesel fuel											
2023 Submission	37,199	30,389	19,231	19,250	16,872	22,301	20,466	19,110	20,064	20,756	18,416
2022 Submission	37,199	30,389	19,231	19,250	16,872	22,301	20,466	19,110	20,064	20,756	18,417
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.29
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.01%
Heavy fuel oil											
2023 Submission	3,103	2,186	2,382	2,054	1,810	108	37.0	81.1	262	394	368
2022 Submission	3,103	2,186	2,382	2,054	1,810	108	37.0	81.1	262	394	368
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
LNG											
2023 Submission						22.0	64.4	58.8	197	153	276
2022 Submission						NR	NR	NR	NR	NR	NR
Absolute change						22.0	64.4	58.8	197	153	276
TOTAL FUEL INPUTS											
2023 Submission	40,303	32,575	21,613	21,304	18,682	22,431	20,567	19,250	20,524	21,303	19,060
2022 Submission	40,303	32,575	21,613	21,304	18,682	22,409	20,503	19,191	20,326	21,150	18,785
Absolute change	0.00	0.00	0.00	0.00	0.00	22.0	64.4	58.8	197	153	274
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%	0.31%	0.31%	0.97%	0.72%	1.46%

Source: Own calculations, based on Deichnik (2022), and Knörr, Heidt, Gores, et al. (2021)

At the same time, the implied emission factors derived from the models used were updated, especially for recent years. In addition, the emission factors for use of heavy fuel oil were revised, with effects on the entire time series: To this end, the factors previously used, which had been adopted from the area of stationary use of heavy fuel oil, were replaced with specific, modelled values from (Deichnik, 2022).

Table 77: Revised CO_2 emission factors for use of heavy fuel oil, in kg/TJ

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
2023 Submission	77,241	77,241	77,241	77,241	77,241	76,445	77,188	77,188	77,188	77,188	77,188
2022 Submission	79,751	79,751	79,751	79,567	79,704	80,877	81,626	80,834	79,892	79,400	79,671
Absolute change	-2,510	-2,510	-2,510	-2,326	-2,463	-4,431	-4,438	-3,646	-2,704	-2,212	-2,483
Relative change	-3.15%	-3.15%	-3.15%	-2.92%	-3.09%	-5.48%	-5.44%	-4.51%	-3.38%	-2.79%	-3.12%

Source: Deichnik (2022)

The above-described corrections lead to the following recalculated emissions quantities:

Table 78: Revised GHG emissions, in kt and kt CO_2-eq

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Carbon dioxide[a]											
2023 Submission	2,993	2,418	1,608	1,584	1,389	1,660	1,521	1,424	1,517	1,575	1,407
2022 Submission	3,001	2,424	1,614	1,588	1,393	1,660	1,518	1,421	1,506	1,568	1,393
Absolute change	-7.79	-5.49	-5.98	-4.78	-4.46	0.75	3.44	2.99	10.3	7.66	14.4
Relative change	-0.26%	-0.23%	-0.37%	-0.30%	-0.32%	0.05%	0.23%	0.21%	0.69%	0.49%	1.03%
Methane											
2023 Submission	0.078	0.059	0.032	0.031	0.026	0.043	0.067	0.062	0.154	0.126	0.203
2022 Submission	0.078	0.059	0.032	0.031	0.026	0.028	0.025	0.023	0.024	0.025	0.022
Absolute change	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.04	0.13	0.10	0.18
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	51.6%	172%	170%	550%	410%	835%
Nitrous oxide											
2023 Submission	0.07	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2022 Submission	0.07	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.12%	0.37%	0.35%	1.10%	0.83%	1.70%
TOTAL GREENHOUSE GASES [a]											
2023 Submission	3,016	2,436	1,622	1,597	1,400	1,674	1,536	1,438	1,533	1,592	1,424
2022 Submission	3,024	2,441	1,628	1,601	1,405	1,673	1,531	1,434	1,520	1,582	1,405
Absolute change	-7.79	-5.49	-5.98	-4.78	-4.46	1.13	4.55	4.01	13.7	10.3	19.1
Relative change	-0.26%	-0.22%	-0.37%	-0.30%	-0.32%	0.07%	0.30%	0.28%	0.90%	0.65%	1.36%

Source: Own calculations;[a] including fossil CO_2 from use of biofuels

The specific emission factors for methane from the LNG use that is being taken into account for the first time are very high. As a result, the adjustments for this greenhouse gas, for the period beginning in 2014, have turned out to be relatively considerable. On the other hand, this has had only a slight effect on the relevant total category-specific GHG emissions; they have increased by no more than 1.36% (2020).

3.2.8.4.6 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.8.5 Transport – Other transportation (1.A.3.e)

3.2.8.5.1 Category description (1.A.3.e)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	1 A 3 e, Other Transportation	fossil fuels	CO_2	1,083.3	0.1 %	836.2	0.1 %	-22.8 %
-/-	1 A 3 e, Other Transportation		CH_4	6.0	0.0 %	4.6	0.0 %	-23.0 %
-/-	1 A 3 e, Other Transportation		N_2O	12.9	0.0 %	6.4	0.0 %	-50.0 %

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

Currently, only emissions from *Gas turbines in natural-gas-compressor stations of the transport network* are reported here. Emissions from gas turbines of pumping stations are reported under 1.A.1.c, while fugitive emissions from compressors are reported under 1.B.2.b.iii & iv.

Gas compressors used in the chemical industry are reported, in keeping with the relevant statistical structure, under 1.A.2.g – Other.

3.2.8.5.2 Methodological issues (1.A.3.e)

As of the year 2005, the **activity data** are reported on the basis of the natural gas quantities reported in emissions trading and aggregated by the German Emissions Trading Office (DEHSt). The approach used in calculating the fuel inputs for the years 1990 through 2005 is described in the 2022 NIR (in the same section).

Energy statistics' surveys take account of natural gas compressors of pumping stations, and those compressors are already included in category 1.A.1.c. To prevent double-counting, only those natural gas compressors are considered here that have to be grouped with the transport network.

The **emission factors** used are based, for each specific gas, on the results of various German Environment Agency (UBA) 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 factors for CH4 and N_2O have been obtained from the report Fichtner et al. (2011).

The procedure used in the studies is described in Chapter 3.2.4.2.

3.2.8.5.3 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 relevant approach is described in Annex 2, in the Chapter "Uncertainties for the activity data of stationary combustion systems," of the NIR 2007.

The procedure for determining uncertainties for the emission factors is described in Chapter 3.2.4.2. Results for N_2O are presented in Chapter 3.2.4.3.2, while those for CH_4 are presented in Chapter 3.2.4.3.3.

3.2.8.5.4 Category-specific quality assurance / control and verification (1.A.3.e)

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 relevant involved experts and the Single National Entity.

The results of Chapter 3.2.4.2 apply mutatis mutandis.

3.2.8.5.5 Category-specific recalculations (1.A.3.e)

No recalculations were carried out.

3.2.8.5.6 Category-specific planned improvements (1.A.3.e)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.9 Other: Residential, commercial/institutional, agriculture, forestry and fisheries (1.A.4 Stationary)

3.2.9.1 Category description (1.A.4 stationary)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**1 A 4 a, Commercial/Institutional**	**fossil fuels**	**CO_2**	**64,110.8**	**5.0 %**	**33,306.7**	**4.4 %**	**-48.0 %**
-/T	**1 A 4 a, Commercial/Institutional**		**CH_4**	**1,637.1**	**0.1 %**	**97.2**	**0.0 %**	**-94.1 %**
-/-	1 A 4 a, Commercial/Institutional		N_2O	131.1	0.0 %	92.0	0.0 %	-29.9 %
L/T	**1 A 4 b, Residential**	**fossil fuels**	**CO_2**	**128,635.8**	**10.0 %**	**82,296.5**	**10.8 %**	**-36.0 %**
-/T	**1 A 4 b, Residential**		**CH_4**	**2,782.9**	**0.2 %**	**991.0**	**0.1 %**	**-64.4 %**
-/-/2	**1 A 4 b, Residential**		**N_2O**	**683.7**	**0.1 %**	**256.4**	**0.0 %**	**-62.5 %**
L/-	**1 A 4 c, Agriculture/Forestry/Fishing**	**fossil fuels**	**CO_2**	**10,172.1**	**0.8 %**	**6,082.9**	**0.8 %**	**-40.2 %**
-/-	1 A 4 c, Agriculture/Forestry/Fishing		CH_4	270.2	0.0 %	190.2	0.0 %	-29.6 %
-/-	1 A 4 c, Agriculture/Forestry/Fishing		N_2O	54.2	0.0 %	60.3	0.0 %	11.4 %

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

For the category 1.A.4 *Other*, stationary and mobile sources are grouped together for purposes of determination of key-category status (for an overview, cf. Chapter 3.2.9.1). 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, categories 1.A.4.a and 1.A.4.b are key categorys in terms of trend. Also, sub-category 1.A.4.b has been identified, via Approach 2 analysis, as a key category for N_2O.

Category 1.A.4 Stationary comprises combustion systems in the areas *Commercial and Institutional, Residential* and *Agriculture*.

In sub-category 1.A.4.ai *Commercial and institutional (stationary)*, heat-generation systems in small combustion systems of small commercial and institutional users are reported.

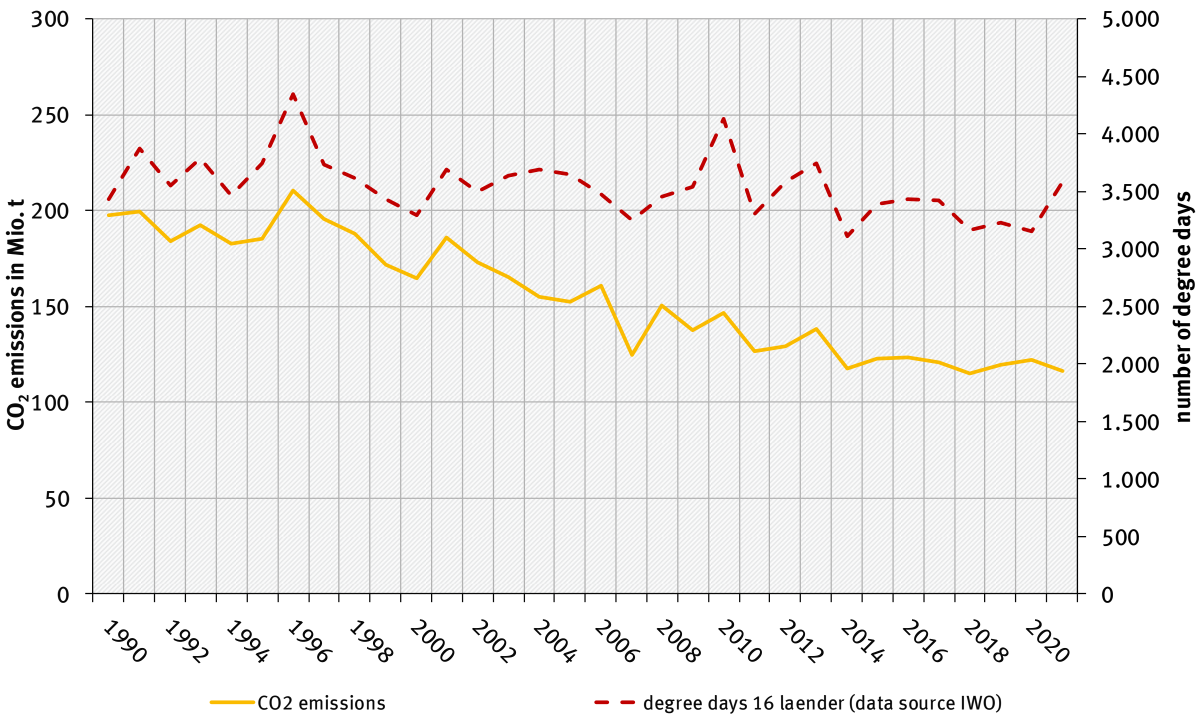
In sub-category 1.A.4.bi, emissions from stationary combustion systems in residential sector are reported. Sub-category 1.A.4.ci comprises the stationary portion of the areas agriculture, forestry and fisheries. In this category, emissions from heat generation in small and medium-sized combustion systems (1st Ordinance Implementing the Federal Immission Control Act (BImSchV)) are reported.

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 combustion systems with a rated thermal output of 1 MW, to name but a few examples. In total in 2018, more than 33 million combustion systems were were in place in Germany in the residential and commercial/institutional sectors (ZIV, 2019[34]). Gas-fired combustion systems

[34] Zentralinnungsverband des Schornsteinfegerhandwerks (ZIV) https://www.schornsteinfeger.de/erhebungen.aspx

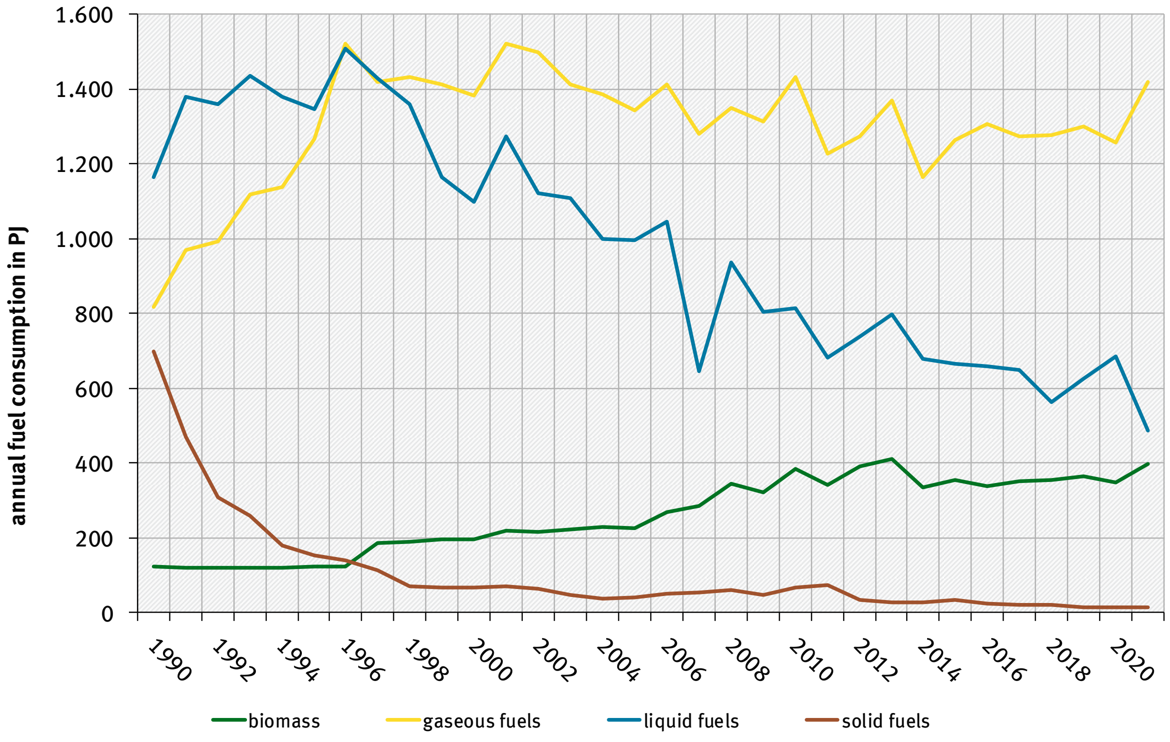
accounted for a majority of these systems, or some 15.4 million, while combustion systems using solid fuels accounted for some 12.2 million systems and oil-fired furnaces accounted for some 5.5 million systems.

Figure 34: Change in total emissions of 1.A.4 (stationary), as a function of temperature (in millions of t of CO_2)



The main driver of CO_2 emissions in 1.A.4 is energy consumption for purposes of space heating. For this reason, fluctuations in consumption depend, relatively strongly, on the weather. Over the years, these factors have caused energy use – especially, use of light heating oil and natural gas – to fluctuate sharply. The trend toward lower CO_2 emissions is a result of higher standards for new buildings, of energy-efficiency-oriented modernisations of existing buildings and of conversions to fuels with lower CO_2 emissions. CO_2 emissions tied to the power consumption of electrical heat pumps are not reported here; they are reported under 1.A.1.a.

Figure 35: Trends in energy consumption in 1.A.4 (stationary), for 4 fuel categories



Shifting from heating oil and coal to 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. Fluctuations have been induced, for example, via changes in prices for fuels for which – as is the case for light heating oil – quantity data are determined on the basis of sales, and not consumption per se.

3.2.9.2 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, which are 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 3.2.11.2 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 Forsten* (BLE, 2022a) (Statistical yearbook on food, agriculture and forests). The structure of the relevant energy sources is described in the 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 amtlichen Statistik erfassten Bereichen") (AGEB, 2016). In the AGEB Evaluation Tables on the Energy Balance[35], the pertinent data are listed as a subset of the Energy Balance.

Data on wood consumption in the residential and commercial / institutional sectors – like data on consumption of other biofuels – 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[36].

The results relative to firewood in the residential sector are based on surveys of consumption carried out in the framework of the "Rohstoffmonitoring Holz" ("Monitoring of raw materials – wood") project.[37] That project collected data both on firewood purchased via commercial sellers and wood gathered in forests. In addition, a regression model is applied that takes account of numbers of degree days; of the price indexes for conventional fuels; and of 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.

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 15.7.

The underlying data for the emission factors used for N_2O and CH_4 emissions of stationary combustion systems are provided by 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

[35] https://ag-energiebilanzen.de/10-0-Auswertungstabellen.html
[36] cf. also https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Arbeitsgruppe/arbeitsgruppe_ee.html
[37] https://www.kiwuh.de/projekte-und-foerderung/projekte/holzbereitstellung/rohstoffmonitoring-holz/

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 along the lines of the fuels that account for significant shares of Germany's final energy consumption:

- 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 various system types, to make it possible to determine sectoral emission factors weighted by energy inputs. Table 79 shows the sectoral emission factors used.

Table 79: Sectoral emission factors for combustion systems in the residential and commercial/institutional sectors for reference year 2010

	CH_4	N_2O
1.A.4.bi – Residential	**[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 (Small Consumers) & Agriculture, Forestry, Fisheries		
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.

3.2.9.3 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 use of 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.

3.2.9.4 Category-specific QA/QC and verification (1.A.4, stationary)

Emission factors: 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 relevant involved experts and the Single National Entity.

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

Information on quality assurance for **activity data** is provided in Chapter 3.2.4.4. For further information on quality assurance, cf. Chapter 15.4.1.

For the purposes of quality assurance for data relative to the **emission factors** of *stationary combustion systems*, in the context of the aforementioned research and development project, all the input data taken from literature and from the research contractor's own surveys 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 German 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 *2006 IPCC Guidelines for National Greenhouse Gas 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 80.

Table 80: 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 agriculture, forestry and fisheries sectors are also included in the commercial and institutional (small consumers) sector.

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 exhibits 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 emissions sources of households, agricultural transports and fisheries. 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.

3.2.9.5 Category-specific recalculations (1.A.4, stationary)

Table 81: Recalculations in CRF 1.A.4 (stationary)

Units [kt]	CO_2 discrepancy, absolute				CO_2 discrepancy, relative
Year	gas	liquid	solid	Total	Total
2020	-156.6	3,864.2	-	-0.4	3,707.2

For the year 2020, recalculations were carried out, since the provisional figures in the 2022 submission have been replaced with final figures from the Energy Balance.

With regard to wood use, recalculations were carried out to take account of adjustments in the regression models used for calculation. Non-empirical data for interim years were replaced with new empirical data points (supporting years).

3.2.9.6 Planned improvements, category-specific (1.A.4, stationary)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

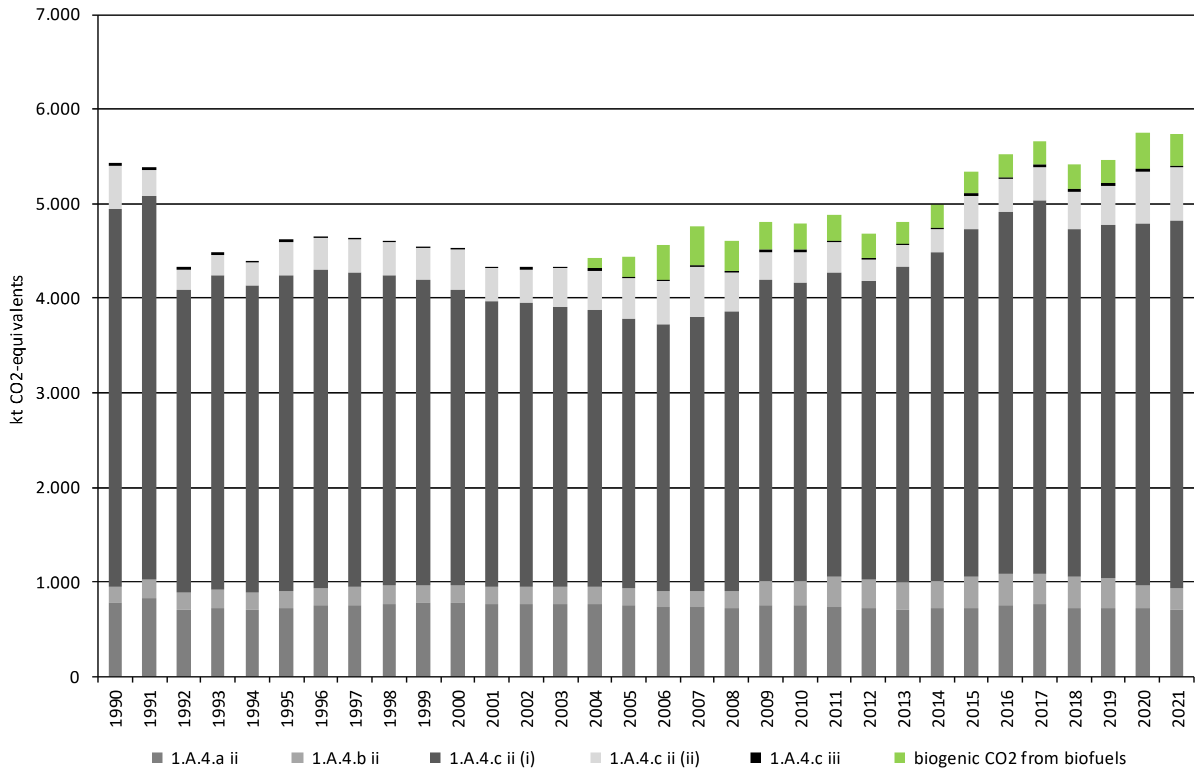
3.2.10 Other: Residential, commercial/institutional, agriculture, forestry and fisheries (1.A.4 mobile)

3.2.10.1 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 3.2.9.1). 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 36: Development of GHG emissions in the various considered sub-sectors since 1990



3.2.10.2 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*).

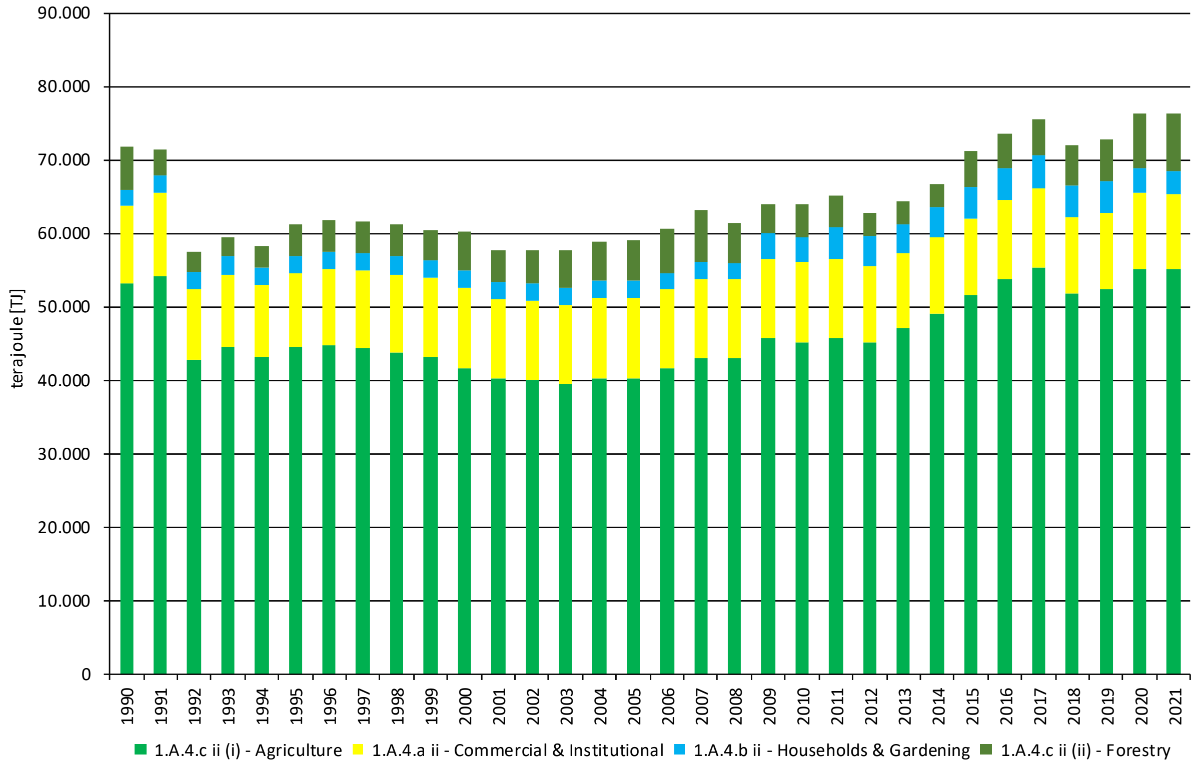
NEB line 67 – Commercial and Institutional also includes fuel consumption areas of the military sector that are that are separately recorded in statistics of BAFA (2022c); those areas can thus be deducted here (cf. Chapter 3.2.12 regarding mobile sources in the military sector). The additional breakdown 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, Heidt, and Bergk (2021).

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 (AIS)). The renewed increase in energy inputs seen in this area as of 2015 reflects the development in the number of vehicles that were classified, via their AIS signals, as fishing vessels, and for which consumption data were modelled.

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 16.1.3).

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 16.1.4).

Figure 37: 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 15.7. Further information – in particular, with regard to carbon dioxide from lubricant co-combustion – is also provided in Chapter 16.1.3.

For methane and nitrous oxide, country-specific values pursuant to Knörr, Heidt, and Bergk (2021) and Deichnik (2022) 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 82: Emission factors used for report year 2021, 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	0.96 (4.15)	2.89 (28.60)	Pursuant to Knörr, Heidt, and Bergk (2021)
LPG	7.10 (-)	3.45 (-)	
1.A.4.b ii – Mobile sources of the residential sector			
Gasoline: Machinery/equipment, two-stroke	200 (180)	0.46 (0.40)	Pursuant to Knörr, Heidt, and Bergk (2021)
Gasoline: Machinery/equipment, four-stroke	25.7 (120)	1.32 (2)	
Gasoline: Recreational boats, two-stroke	62.5 (-)	0.29 (-)	
Gasoline: Recreational boats, four-stroke	24.5 (-)	1.26 (-)	
1.A.4.c ii (i) – Mobile sources of the agricultural sector			
Diesel & biodiesel	1.63 (4.15)	2.89 (28.6)	Pursuant to Knörr, Heidt, and Bergk (2021)
1.A.4.c ii (ii) – Mobile sources of the forestry sector			
Diesel & biodiesel	0.40 (4.15)	3.11 (28.6)	Pursuant to Knörr, Heidt, and Bergk (2021)
Gasoline: Two-stroke engines	219 (170)	0.46 (0.40)	
1.A.4.c (iii) – Fisheries (here: *high-seas fisheries)*			
Diesel	0.91 (-)	3.35 (-)	Pursuant to Deichnik (2022)
Heavy fuel oil	NA	NA	Use 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.

3.2.10.3 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.

For the specific energy inputs, calculated as described above, for diesel fuel and gasolines, uncertainties of ±10% are assumed, while for modelled quantities of the LP gas used in 1.A.4.a ii, uncertainties of ±5% are assumed.

The uncertainties assumed for the emission factors used are shown in the following table.

Table 83: Percentage uncertainties for emission factors*

	CO_2	CH_4	N_2O
Gasoline	±0.4%	-28% / +40%	±50%
Diesel	±3%	±50%	-40% / +140%
LPG	±2%	±50%	±75%

* Upper and lower bounds of the 95% percentile

3.2.10.4 Category-specific QA/QC and verification (1.A.4 mobile)

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 relevant involved experts and the Single National Entity.

Table 84: 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 85
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 82
CO_2, CH_4, N_2O	specific IEF of other countries	cf. Table 86

Table 85: Comparison of the EF(CO_2), in kg/TJ, 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]	*74,917*			
Four-stroke engines	*74,950*			
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 2021; [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(27). It should be noted that the comparison is hampered by the fact that the factors involved represent an extremely heterogeneous group of categories.

Table 86: 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	70,964	3.53	3.12	75,139	60.0	1.16	74,027	1.63	2.89
Belgium	NO	NO	NO	72,406	37.7	1.42	74,165	2.51	16.5
Denmark	73,163	10.5	2.86	73,000	51.7	1.16	74,099	0.94	3.54
France							74,835	0.81	28.7
Italy				73,081	190	0.47	73,510	3.98	27.9
Netherlands	71,703	2.87	1.00	73,023	46.8	0.60	72,454	1.11	0.60
Spain	75,920	406	0.40	IE	IE	IE	73,318	0.69	3.22
EU-27				IE	IE	IE	73,927	2.35	16.3
UK				70,517	9.49	0.89	74,938	3.56	3.10
	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	74,917	219	0.46	NO	NO	NO	74,027	0.93	3.34
Belgium	72,405	316	0.44	NO	NO	NO	74,100	10.0	0.60
Denmark	72,993	143	1.29	77,945	2.29	1.83	73,940	2.13	1.65
France	74,421	164	0.55	NO	NO	NO	74,523	7.04	1.88
Italy	73,081	143	0.85	NO	NO	NO	73,510	4.21	1.45
Netherlands	73,023	282	0.60	NO	NO	NO	72,454	7.00	2.00
Spain	75,920	202	0.47	NO	NO	NO	74,100	7.00	2.00
EU-27	73,170	164	1.58	77,623	6.45	2.18	74,202	5.60	2.05
UK	70,209	48.7	0.34	*534,999*	10.1	26.7	75,313	1.03	3.41

Germany: Current IEF for report year 2021; all other countries: IEF for 2020, pursuant to 2022 CRF submission

3.2.10.5 Category-specific recalculations (1.A.4 mobile)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

As described above, the activity data for the emissions sources considered here are part of the primary activity data listed in Energy Balance line 67. The provisional data provided for the year 2020, in the 2022 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.

In addition, considerable corrections had to be made in the primary activity data for the energy inputs in mobile consumers in the residential sector in 2020, which are also listed in EB line 66.

Table 87: Revised primary activity data for 2020, in terajoules

	Diesel	Gasoline	Biodiesel	Bioethanol	LPG
2023 Submission	105,634	11,596	8,775	529	16,960
2022 Submission	104,580	11,106	8,687	505	20,622
Absolute change	1,054	490	87.4	24.9	-3,662
Relative change	1.01%	4.42%	1.01%	4.94%	-17.8%

Source: Revised NEB 2020 (AGEB, 2021b) and own calculations

At the same time, a slight adjustment, affecting all years, was made in the distribution factors used to distribute the primary activity data in EB line 67, pursuant to TREMOD MM.

The activity data modelled in (Deichnik, 2022) for fishing remained unchanged (they were the only data to remain unchanged), which is why sub-sector 1.A.4.c iii is not included in the following table.

The described corrections result in the following changed specific energy inputs:

Table 88: Revised energy inputs for sub-sectors, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
1.A.4.a ii											
2023 Submission	10,627	9,951	10,899	10,796	10,836	10,376	10,799	10,884	10,339	10,269	10,361
2022 Submission	10,634	9,958	10,907	10,803	10,844	10,383	10,807	10,892	10,346	10,276	10,306
Absolute change	-7.31	-7.08	-8.40	-7.59	-7.71	-7.32	-7.72	-7.84	-7.16	-7.10	55.0
Relative change	-0.07%	-0.07%	-0.08%	-0.07%	-0.07%	-0.07%	-0.07%	-0.07%	-0.07%	-0.07%	0.53%
1.A.4.b ii											
2023 Submission	2,177	2,395	2,395	2,411	3,510	4,411	4,412	4,406	4,418	4,410	3,332
2022 Submission	2,177	2,395	2,395	2,411	3,510	4,411	4,412	4,406	4,418	4,410	4,238
Absolute change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-906
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-21.4%
1.A.4.c ii (i)											
2023 Submission	53,188	44,553	41,633	40,315	45,191	51,520	53,670	55,302	51,795	52,448	55,129
2022 Submission	53,263	44,622	41,696	40,366	45,246	51,580	53,732	55,367	51,855	52,509	54,641
Absolute change	-75.7	-68.7	-63.4	-51.4	-54.6	-59.9	-62.4	-64.3	-59.9	-60.6	488
Relative change	-0.14%	-0.15%	-0.15%	-0.13%	-0.12%	-0.12%	-0.12%	-0.12%	-0.12%	-0.12%	0.89%
1.A.4.c ii (ii)											
2023 Submission	5,787	4,335	5,372	5,565	4,405	4,839	4,673	4,849	5,460	5,614	7,545
2022 Submission	5,788	4,336	5,375	5,569	4,409	4,843	4,677	4,853	5,465	5,619	6,930
Absolute change	-1.05	-1.05	-3.34	-3.95	-3.93	-4.18	-4.07	-4.25	-4.72	-4.95	615
Relative change	-0.02%	-0.02%	-0.06%	-0.07%	-0.09%	-0.09%	-0.09%	-0.09%	-0.09%	-0.09%	8.88%

Source: Own calculations, based on AGEB (2021b), Knörr, Heidt, and Bergk (2021)

At the same time, the implied emission factors modelled for the various individual mobile emitters were updated. These updates have affected the emissions of all sub-sectors (cf. also Chapter 3.2.8.4.5).

In sum, the described adjustments lead to the following recalculated emissions quantities:

Table 89: Revised emissions quantities, in kilotonnes of CO_2-eq

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
1.A.4.a ii											
2023 Submission	774	717	777	745	742	724	754	760	720	715	712
2022 Submission	775	718	778	745	743	724	755	761	720	716	708
Absolute change	-0.55	-0.53	-0.63	-0.53	-0.54	-0.52	-0.55	-0.55	-0.50	-0.50	3.83
Relative change	-0.07%	-0.07%	-0.08%	-0.07%	-0.07%	-0.07%	-0.07%	-0.07%	-0.07%	-0.07%	0.54%
1.A.4.b ii											
2023 Submission	178	191	187	186	260	329	329	328	328	328	246
2022 Submission	178	191	187	186	260	329	329	328	328	328	314
Absolute change	0.02	0.01	0.00	0.01	0.07	0.06	0.05	0.04	0.03	0.00	-68.3
Relative change	0.01%	0.01%	0.00%	0.01%	0.03%	0.02%	0.02%	0.01%	0.01%	0.00%	-21.8%
1.A.4.c ii (i)											
2023 Submission	3,988	3,341	3,122	2,853	3,162	3,674	3,832	3,948	3,682	3,732	3,834
2022 Submission	3,994	3,346	3,126	2,856	3,165	3,678	3,837	3,952	3,686	3,736	3,800
Absolute change	-5.69	-5.16	-4.76	-3.64	-3.82	-4.27	-4.45	-4.58	-4.25	-4.30	34.0
Relative change	-0.14%	-0.15%	-0.15%	-0.13%	-0.12%	-0.12%	-0.12%	-0.12%	-0.12%	-0.12%	0.89%
1.A.4.c ii (ii)											
2023 Submission	462	349	429	431	326	357	345	357	401	412	547
2022 Submission	462	349	429	431	326	357	345	358	401	412	500
Absolute change	-0.14	-0.08	-0.26	-0.29	-0.28	-0.31	-0.30	-0.31	-0.34	-0.36	46.6
Relative change	-0.03%	-0.02%	-0.06%	-0.07%	-0.09%	-0.09%	-0.09%	-0.09%	-0.09%	-0.09%	9.32%
1.A.4.c iii											
2023 Submission	25.5	20.0	19.9	18.9	18.9	21.3	22.4	22.0	26.7	24.2	26.9
2022 Submission	25.6	20.1	20.0	18.9	19.0	21.3	22.4	22.0	26.7	24.2	26.9
Absolute change	-0.08	-0.07	-0.07	-0.06	-0.06	0.00	0.00	0.00	0.00	0.00	0.00
Relative change	-0.33%	-0.32%	-0.33%	-0.30%	-0.32%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
1.A.4 - MOBILE EMITTERS, TOTAL											
2023 Submission	5,428	4,617	4,535	4,232	4,509	5,104	5,282	5,415	5,157	5,211	5,366
2022 Submission	5,434	4,623	4,541	4,237	4,514	5,109	5,287	5,421	5,162	5,216	5,350
Absolute change	-6.44	-5.82	-5.71	-4.51	-4.63	-5.03	-5.24	-5.41	-5.06	-5.16	16.1
Relative change	-0.12%	-0.13%	-0.13%	-0.11%	-0.10%	-0.10%	-0.10%	-0.10%	-0.10%	-0.10%	0.30%

Source: Own calculations; including fossil CO_2 from use of biofuels

3.2.10.6 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.11 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"*.

3.2.11.1 Category description (1.A.5.a stationary)

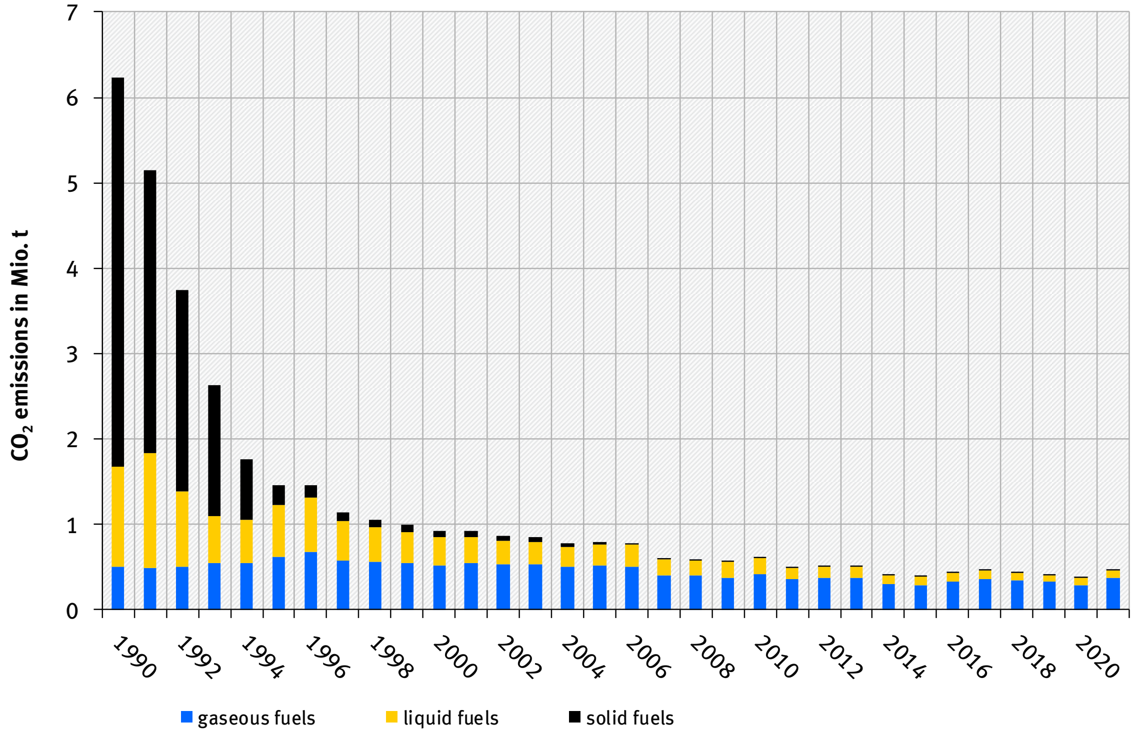
KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**1 A 5, Other: Military**	**fossil fuels**	**CO_2**	**11,764.6**	**0.9 %**	**980.3**	**0.1 %**	**-91.7 %**
-/-	1 A 5, Other: Military		CH_4	313.0	0.0 %	2.0	0.0 %	-99.4 %
-/-	1 A 5, Other: Military		N_2O	54.1	0.0 %	4.0	0.0 %	-92.6 %

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. Consequently, category 1.A.5 *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 38: Development of CO_2 emissions in category 1.A.5.a (in millions of t of CO_2)



The particularly large emissions reduction results from the closure of numerous military offices, as well as from a clear trend toward less use of solid fuels.

3.2.11.2 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 German Environment Agency. 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. For the time series as of 2003, the data are 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 15.7.

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 German 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 method described for category 1.A.4. Table 90 shows the sectoral emission factors used.

Table 90: Sectoral emission factors for military agencies, with reference year 2005; updated

	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	0.03	0.56
Natural gas	0.042	0.29

3.2.11.3 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.

3.2.11.4 Category-specific QA/QC and verification (1.A.5.a, stationary)

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 relevant involved experts and the Single National Entity.

Since no other sources of data for Germany are known, it is currently not possible to verify the emissions reported here via comparison.

3.2.11.5 Category-specific recalculations (1.A.5.a, stationary)

No recalculations were required for report year 2020.

3.2.11.6 Planned improvements, category-specific (1.A.5.a, stationary)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.12 Other (1.A.5.b Mobile)

3.2.12.1 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)

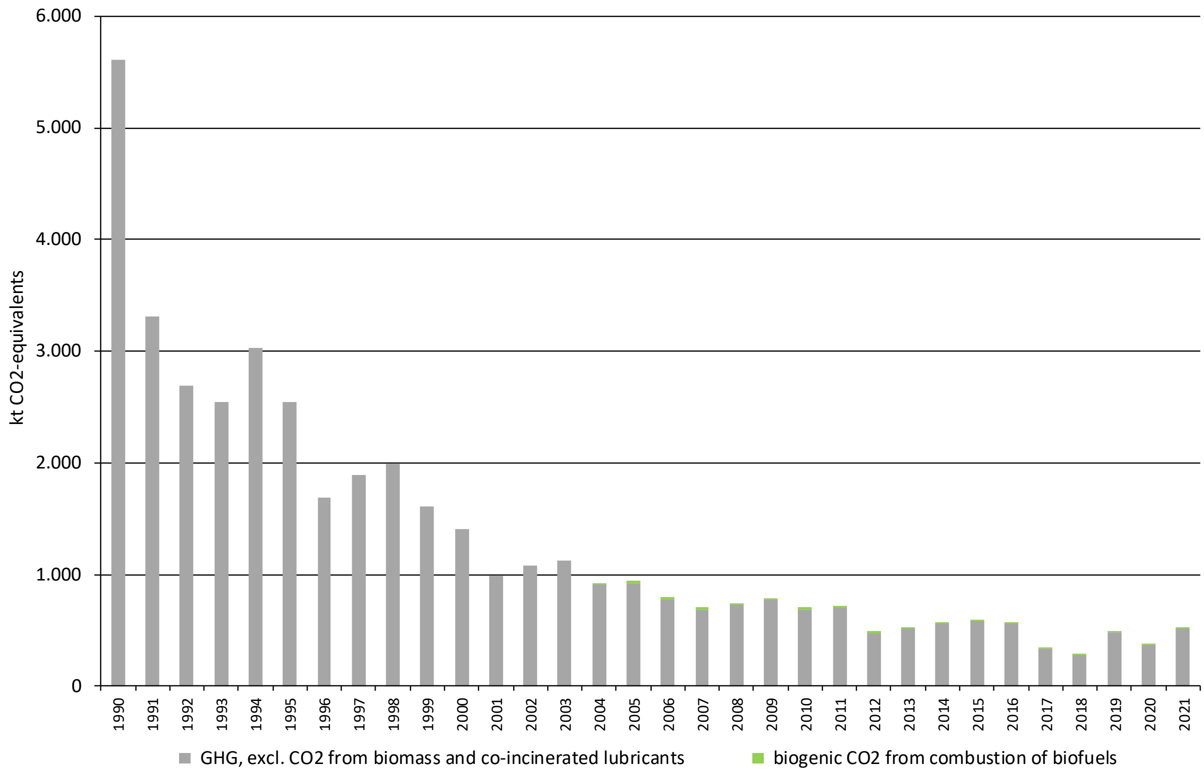
[a] for biodiesel and avgas: Default EF pursuant to IPCC (2006a): Volume 2, Chapter 2, Table 2.4

[b] Military Ship transports: calculated in Deichnik (2022)

The key category analysis for *1.A.5 – Other* is carried out on an overarching basis, for both stationary and mobile sources (cf. Chapter 3.2.11.1). 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 39: Development of GHG emissions of mobile sources in the military sector since 1990



3.2.12.2 Methodological issues (1.A.5.b mobile)

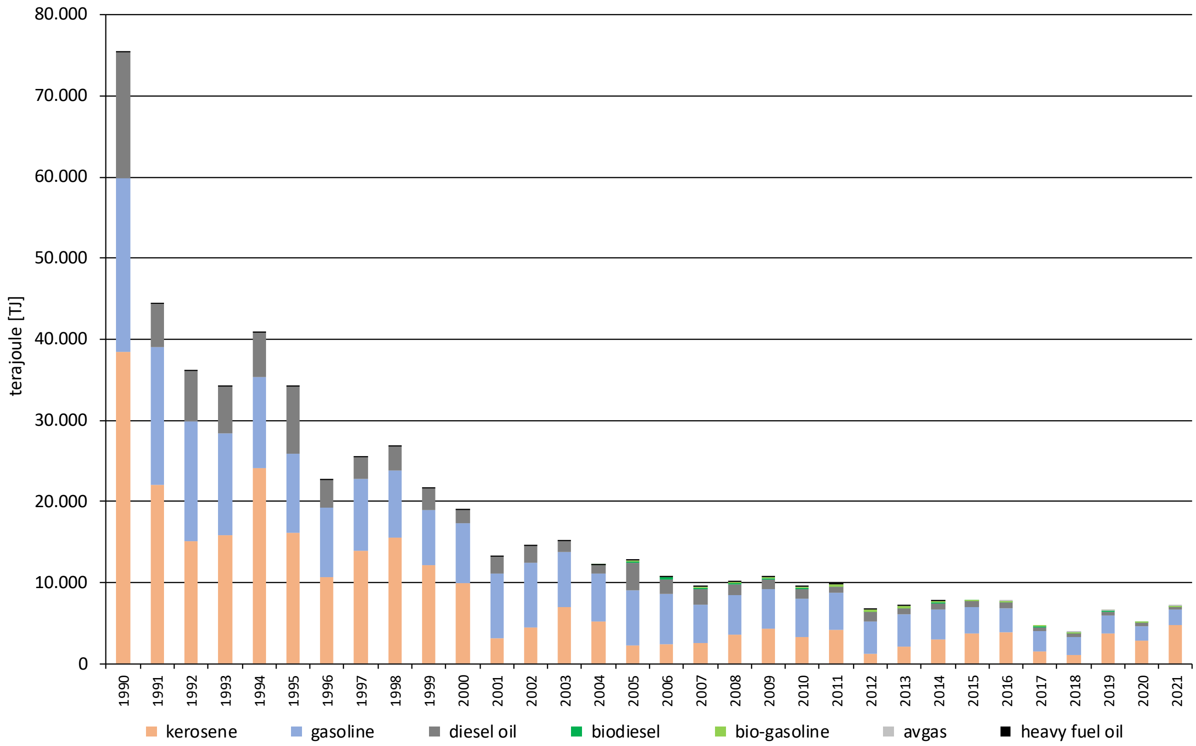
Activity data

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 (2022c) 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 3.2.8.4.4.

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 16.1.3).

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 16.1.4).

Figure 40: Development of fuel inputs since 1990



Emission factors

With regard to the **emission factors** used for carbon dioxide, we refer, in general, to Chapter 15.7. Both country-specific and default values (biodiesel, avgas) are used. Further information regarding co-combustion of lubricants in particular is provided in Chapter 16.1.3.

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 (2022). 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 91: Emission factors used for report year 2021, 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	0.5 (7.00)	5.24 (2.00)	Pursuant to Deichnik (2022)
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.

3.2.12.3 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 (Deichnik).

For the specific energy inputs calculated as described above, uncertainties of ±5% are assumed.

The uncertainties assumed for the emission factors used are shown in the following table.

Table 92: Percentage uncertainties for emission factors*

	CO_2	CH_4	N_2O
Gasoline	±0.4%	-28% / +40%	-40% / +140%
Diesel	±3%	±50%	-40% / +140%
Kerosene	±1%	-57% / +100%	-70% / +150%
Avgas	±1%	-57% / +100%	-70% / +150%
Heavy fuel oil	±5%	±50%	-40% / +140%

* Upper and lower bounds of the 95% percentile

3.2.12.4 Category-specific QA/QC and verification (1.A.5.b mobile)

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 relevant involved experts and the Single National Entity.

Table 93: 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 94
CO_2	Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter 2, Table	for 1.A.5.b i: cf. Table 94
CH_4, N_2O	Specific Tier 1 default EF pursuant to IPCC (2006a)	for 1.A.5.b ii & iii: cf. Table 90
CH_4, N_2O	Tier 1 default EF pursuant to IPCC (2006a): Volume 2, Chapter 2, Table	1.A.5.b i: cf. Table 90
CO_2	specific IEF of other countries	cf. Table 86

Table 94: 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	74,950	69,300	*67,500*	*73,000*
Kerosene	73,256	71,500	*69,800*	*74,400*
Avgas	71,199		*67,500*	*73,000*
Biodiesel	70,800		*59,800*	*84,300*
Bioethanol	71,607	70,800	*59,800*	*84,300*

[a] for reported year 2021; [b] pursuant to IPCC (2006a): Volume 2, Chapter 2, Table 2.4

With regard to the country-specific CO_2 emission factor for fossil gasolines, which lies outside the range of the default values, we refer to Chapter 3.2.8.2.

3.2.12.5 Category-specific recalculations (1.A.5.b Mobile)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

Recalculations were made with respect to the 2020 submission because CO_2 emissions from use of heavy fuel oil in military maritime transports, which ended in 2014, were not calculated in the framework of the 2021 submission. In addition, the emission factor used in 2020 for carbon dioxide from combustion of fossil gasolines in land vehicles was revised (cf. Chapter 3.2.8.2). The simultaneous introduction of a country-specific emission factor for carbon dioxide from combustion of avgas (cf. Chapter 3.2.8.1), on the other hand, has no noticeable impact on the reported emissions, due to the extremely small consumption quantities involved.

These adjustments lead to changes in the reported greenhouse-gas emissions, for all years considered.

Table 95: Revised emissions data, in kt CO_2 equivalents

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
Military land transports & mobile machinery											
Subm. 2023	2,733	1,327	658	745	427	293	268	218	195	193	144
Subm. 2022	2,733	1,327	658	745	427	293	268	218	195	193	144
Change, absolute	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.57
Change, relative	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.40%
Military Air transports											
Subm. 2023	2,836	1,193	729	162	243	275	284	111	76	277	215
Subm. 2022	2,836	1,193	729	162	243	275	284	111	76	277	215
Change, absolute	0.02	0.01	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. 2023	40.4	27.8	24.2	18.1	15.9	11.6	10.6	11.7	9.95	12.32	14.72
Subm. 2022	28.7	19.8	17.2	12.9	11.3	11.6	10.6	11.7	9.95	12.32	14.64
Change, absolute	11.7	8.01	6.99	5.21	4.55	0.00	0.00	0.00	0.00	0.00	0.09
Change, relative	40.8%	40.4%	40.6%	40.3%	40.2%	0.00%	0.00%	0.00%	0.00%	0.00%	0.60%
MILITARY MOBILE EMITTERS, TOTAL											
Subm. 2023	5,610	2,548	1,410	925	685	580	562	341	281	482	373
Subm. 2022	5,598	2,540	1,403	920	681	580	562	341	281	482	373
Change, absolute	11.7	8.02	6.99	5.21	4.55	0.00	0.00	0.00	0.00	0.00	-0.49
Change, relative	0.21%	0.32%	0.50%	0.57%	0.67%	0.00%	0.00%	0.00%	0.00%	0.00%	-0.13%

Source: Own calculations; including fossil CO_2 from use of biofuels

3.2.12.6 Category-specific planned improvements (1.A.5.b Mobile)

No specific improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

3.2.13 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* (cf. Chapters 3.2.11 and 3.2.12).

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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-/2	1 B 1, Solid Fuels	fossil fuels	CO_2	1,832.8	0.2 %	634.2	0.1 %	-65.4 %
L/T	1 B 1, Solid Fuels		CH_4	28,619.8	2.2 %	159.5	0.0 %	-99.4 %

The category Coal mining and handling is a key category for CH_4 emissions in terms of emissions level and trend and a key category for CO_2 emissions pursuant to Approach 2 analysis.

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 96: Usable output of lignite, in millions of t.

1990	1995	2000	2005	2010	2015	2020	2021
356.5	192.7	167.7	177.9	169.4	178.1	107.4	126.3

(Statistik der Kohlenwirtschaft, 2022)

Emission factors

In keeping with figures of the DEBRIV German lignite-industry association (DEBRIV, 2004), an average emission factor of 0.015 m^3 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 97: 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 98: Emissions in category 1.B.1.a.ii – open-pit mining

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
Methane	3.9 kt	1.2 kt	1.4 kt	-64 %	17 %	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 in conformance with the requirements of the QSE manual and its associated applicable documents, have been carried out 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 99). 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 99: 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 (H. O. Meiners, Michael; Kerber, Vitali, 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 100: activity data for processed products [figures in tonnes]

	1990	1995	2000	2005	2010	2015	2020	2021
Lignite briquettes	40,045,000	5,010,829	1,819,263	1,489,922	2,024,103	1,709,000	1,285,809	1,335,743
Lignite coke	3,355,937	191,883	179,453	173,443	175,932	170,000	145,525	157,610
Lignite dust	3,791,431	2,700,110	2,678,926	2,923,620	3,632,333	4,398,000	3,799,643	3,980,807
Hard-coal coke	17,580,000	11,102,000	9,115,000	8,397,000	8,171,000	8,800,000	7,942,860	8,247,424

(Statistik der Kohlenwirtschaft, 2022); 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 (H. 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 101: 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.

Emissions and trend

Table 102: Emissions in category 1.B.1.b – solid fuel transformation

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
Methane	2.4 kt	1.8 kt	1.9 kt	-21 %	-5 %	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	632 kt	634 kt	0 %	0 %	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:

$$\text{Emissions [kt } CH_4\text{]} = \text{EF [m}^3\text{ } CH_4 \text{ /t]} * AR_{\text{transformation product}} * \text{conversion factor [kt/}10^6\text{m}^3\text{]}$$

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%.

[38] The emission factor covers the area of production of hard-coal and lignite coke

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 in conformance with the requirements of the QSE manual and its associated applicable documents, have been carried out by the Single National Entity.

In consideration of emission factors, the IPCC conversion factor of 0.67 Gg/$10^6 m^3$ 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 Nm^3/kg (1.01325 bar, 0°C) **= 0.67 Gg/$10^6 m^3$** (20°C, 1 atmosphere) *** 1.07 Nm^3/m^3**

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 change in hard-coal-coke production has led to minor recalculations 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 (until 1997)
	iv)	**Transport**		Emissions from long-distance high-pressure pipelines and from underground gas storage (caverns and porous-rock reservoirs)
	v)	**Distribution**		Emissions from pipelines for natural gas distribution; above-ground storage facilities
	vi)	**Other**		Fugitive emissions from installations in the residential and commercial (small consumers) sector Fugitive leakage from tanks of natural-gas-powered vehicles
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	Flare emissions in natural-gas production
			Combined	No emissions in this category
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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	1 B 2 a, Oil		CO_2	477.6	0.0 %	406.3	0.1 %	-14.9 %
-/-	1 B 2 a, Oil		CH_4	270.9	0.0 %	22.0	0.0 %	-91.9 %
-/-	1 B 2 a, Oil		N_2O	0.3	0.0 %	0.2	0.0 %	-21.4 %

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 103: Number of exploratory wells (sum total for oil and natural gas)

1990	1995	2000	2005	2010	2015	2020	2021
12	17	15	23	16	18	12	8

(BVEG, 2022a)

Emission factors

Table 104: 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 105: Emissions in category 1.B.2.a.i

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
Methane	768 kg	768 kg	512 kg	0 %	-33 %	The emissions have decreased with respect to their level in 1990, as a result of reduced drilling.
Carbon dioxide	5.76 kg	5.76 kg	3.84 kg	0 %	-33 %	
NMVOC	6,912 kg	6,912 kg	4,608 kg	0 %	-33 %	

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 quality assurance, 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.

Due to a lack of country-specific data, an external assessment (Bender & Langer, 2009) 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 106: Extracted quantity of petroleum, in kt

1990	1995	2000	2005	2010	2015	2020	2021
3,606	2,959	3,113	3,573	2,516	2,414	1,907	1,804

(BVEG, 2022a)

Emission factors

Table 107: Emission factors used for production and processing

Gas	Emission factor	Method	Source
CO_2	93 g/m³	Tier 2	Expert estimate
CH_4	97 g/m³	Tier 2	Expert estimate
NMVOC	79 g/m³	Tier 2	Expert estimate

Emissions and trend

Table 108: Emissions in category 1.B.2.a.ii

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
Methane	1,081 t	84 t	165 t	-85 %	96 %	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	194 t	194 t	-58 %	0 %	
NMVOC	108 t	33 t	203 t	88 %	610 %	

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, 2022b). The emission factors are determined from the reported emissions and the activity data shown in Table 106.

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 quality assurance, 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.

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 109: 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]
CO_2	93 g/m³	$1.1*10^{-07}$ to $2.6*10^{-04}$	0.11 – 260.00
CH_4	97 g/m³	$1.5*10^{-06}$ to $6.0*10^{-02}$	1.50 – 60,000
NMVOC	79 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 110: Transports of domestically produced crude oil, in kt

1990	1995	2000	2005	2010	2015	2020	2021
3,606	2,959	3,113	3,573	2,516	2,414	1,907	1,804

(BVEG, 2022a)

Table 111: Transports of imported crude oil, in kt

1990	1995	2000	2005	2010	2015	2020	2021
84,043	86,063	89,280	97,474	93,270	91,275	83,049	81,403

(BAFA, 2022b)

Table 112: Crude-oil transports via inland-waterway tankers, in kt

1990	1995	2000	2005	2010	2015	2020	2021
88.9	66.6	111.8	176.4	5.6	43.1	46.4	64.2

(Statistisches Bundesamt, 2022j)

Emission factors

Table 113: 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	

Emissions and trend

Table 114: Emissions in category 1.B.2.a.iii

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
NMVOC	5,885 t	5,579 t	5,466 t	-7 %	-2 %	The increasing trend is driven primarily by increases in the quantities of transported oil.
CH_4	588 t	558 t	457 t	-22 %	-18%	

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" (Jochen 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 quality assurance, 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.

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 German 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 115: 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 (2009), the emission factors for storage of crude oil and of petroleum products may be assumed to take cleaning processes into account.

Activity data

Table 116: Quantity of crude oil refined, in kt

1990	1995	2000	2005	2010	2015	2020	2021
107,058	96,475	107,632	114,589	95,378	93,391	83,990	84,139

(en2x, 2022)

Table 117: Capacity utilisation in refineries, in percent

1990	1995	2000	2005	2010	2015	2020	2021
106.2	92.1	95.3	99.5	81.1	91	81.8	79.6

(en2x, 2022)

Table 118: Crude-oil-refining capacity in refineries, in kt

1990	1995	2000	2005	2010	2015	2020	2021
100,765	104,750	112,940	115,630	117,630	103,080	105,655	105,655

(en2x, 2022)

Table 119: Tank-storage capacity in refineries and pipeline terminals, in millions of m^3

1990	1995	2000	2005	2010	2015	2020	2021
27.2	28.4	24.9	24.0	22.5	22.1	20.7	20.9

(Koj, 2021)

Table 120: Storage capacity of tank-storage facilities outside of refineries, including caverns, in millions of m^3

1990	1995	2000	2005	2010	2015	2020	2021
15.4	15.9	18.1	17.0	15.95	15.3	15.3	14.98

(Koj, 2021)

Table 121: Storage capacity of caverns, in millions of m^3

1990	1995	2000	2005	2010	2015	2020	2021
26.6	25.3	27.9	27.2	27.3	25.5	25.5	25.5

(Koj, 2021)

Emission factors

Table 122: 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 123: 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 124: 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 125: 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/m³	Tier 2	Expert estimate
NMVOC	100 g/m³	Tier 2	Expert estimate

Emissions and trend

Table 126: Emissions in category 1.B.2.a.iv

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
Carbon dioxide	477,166 t	393,070t	406,152 t	-15 %	3 %	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	37.1 t	37.1 t	- 99 %	0 %	
NMVOC	73,151 t	3,897 t	3,827 t	- 95 %	0 %	

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, 2009), 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, 2009), 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 (cf. Chapter 4.3.10), 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, 2009) and (Jochen 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 quality assurance, 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.

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 127: Filling stations in Germany (number)

1990	1995	2000	2005	2010	2015	2020	2021
19,317	17,957	16,324	15,187	14,744	14,531	14,459	14,429

(bft, 2022)

Table 128: Distributed quantities of petroleum products, in kt

	1990	1995	2000	2005	2010	2015	2020	2021
Diesel fuel	21,817	26,208	28,922	28,531	32,128	36,756	35,163	34,980
Jet fuel	4,584	5,455	6,939	8,049	8,465	8,550	4,725	6,129
Light heating oil	31,803	34,785	27,875	25,380	21,005	16,127	15,558	11,206
Gasoline	31,257	30,333	28,833	23,431	19,634	18,226	16,218	16,428

(BAFA, 2022a)

Emission factors

The emission factors listed below have been verified by the study (Jochen 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 129: 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

[39] The factor does not include reduction measures – cf. Table 135

Table 130: 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 131: 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 132: 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 133: 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

Emissions and trend

Table 134: Emissions in category 1.B.2.a.v

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
NMVOC	87.8 kt	15.8 kt	15.6 kt	- 82 %	-1 %	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 (von Winkler, 2004).

[40] The reference figure is the total quantity of gasoline transported in Germany with the relevant type of vehicle.

As transport media, **pipelines** produce no significant emissions (von 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 (Jochen Theloke et al., 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 (BMJ & BfJ, 2017a, 2017b) 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 (BMJ & BfJ, 2017a) and the area of fuelling of vehicles, with gasoline, at filling stations (BMJ & BfJ, 2017b).

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 135).

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 135: 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 129) * (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% (Jochen 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 quality assurance, 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.

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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	1 B 2 b, Natural Gas		CO_2	986.7	0.1 %	492.3	0.1 %	-50.1 %
L/T	**1 B 2 b, Natural Gas**		**CH_4**	**9,788.6**	**0.8 %**	**1,811.3**	**0.2 %**	**-81.5 %**

The category 1.B.2.b "Natural gas" is a key category of CH_4 emissions in terms of emissions level and trend.

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 quality assurance 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.

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 136: Extracted quantity of natural gas, in billions of m^3

1990	1995	2000	2005	2010	2015	2020	2021
15.3	19.1	20.1	18.8	12.7	8.6	5.2	5.2

(BVEG, 2022a)

Emission factors

Table 137: Emission factors used for production

Gas	Emission factor	Method	Source
CO_2	0.1 g/m³	Tier 2	Expert estimate
CH_4	0.02 g/m³	Tier 2	Expert estimate
NMVOC	0.002 g/m³	Tier 2	Expert estimate

Emissions and trend

Table 138: Emissions in category 1.B.2.b.ii

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
Methane	5,799 t	258 t	103 t	-98%	-60%	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	507 t	522 t	-64%	3%	
NMVOC	580 t	10 t	10 t	-98%	0%	

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, 2021). 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 3 method.

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 quality assurance 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.

The emission factors that have been used are of the same order of magnitude as those given in the 2006 IPCC Guidelines.

[41] WEG: "Leitfaden zu Erfassung der Umweltdaten der WEG Mitgliedsfirmen", published in-house, and last revised in Dec. 2016

Table 139: 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	0.2 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 3	AS	CS
CO	Tier 2	AS	CS
SO_2, NMVOC	Tier 2, Tier 3	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).

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 140: Sulphur production from natural gas production in Germany, in kt

1990	1995	2000	2005	2010	2015	2020	2021
915	1,053	1,100	1,050	832	628	**353**	**382**

(BVEG, 2022a)

[42] WEG 2008a: Erdgas-Erdöl, Entstehung-Suche-Förderung, Hannover, 34 p.

Figures for natural gas production are presented in Chapter 3.3.2.2.2.1, in Table 136.

Emission factors

Table 141: Emission factors used for category 1.B.2.b.iii, "Processing"

Gas	Emission factor	Method	Source
NMVOC	0.004 kg / 1,000 m³		Association data
CH_4	0.06 kg / 1,000 m³	Tier 3	(only one production
CO_2	340 kg / 1,000 m³		site)

Emissions and trend

Table 142: Emissions in category 1.B.2.b.iii

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
Methane	5,340 t	103 t	124 t	-98%	20%	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	469 kt	491 kt	-50%	-1%	
NMVOC	12 t	8 t	8 t	-33%	0%	

3.3.2.2.3.2 Methodological issues (1.B.2.b.iii)

The emissions were calculated in keeping with the Tier 3 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 m^3, is used, since, according to the BVEG, the German desulphurisation plant is comparable to the Austrian plant.

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 Category-specific quality assurance / control and verification (1.B.2.b.iii)

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 relevant involved experts and the Single National Entity.

[43] WEG: "Leitfaden zu Erfassung der Umweltdaten der WEG Mitgliedsfirmen", published in-house, and last revised in Dec. 2016

Table 143: Comparison of IEF with the relevant IPCC default values

Source	CS emission factor used	2006 IPCC GL (Table 4.2.4)[44]	
	Units in [g/m³]	Units in [Gg/10⁶m³]	Units in [g/m³]
CO_2	340	$7.9*10^{-06}+3.6*10^{-3}+6.3*10^{-2}$	66.608
CH_4	0.06	$9.7*10^{-05}+2.4*10^{-6}$	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 (Table 144). 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.

Table 144: Comparison of emission factors for carbon dioxide (2022)

Source	CS emission factor used Units in [g/m³]
Austria	269
Germany	340

It was not possible to cross-check the figures against the corresponding figures of additional countries, since the CRF tables do not indicate what shares of processed natural gas must be assigned to the “sour gas” category.

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.

Only steel pipelines are used to transmit natural gas (Zöllner, 2014).

Activity data

Table 145: Length of long-distance high-pressure pipelines, in km

1990	1995	2000	2005	2010	2015	2020	2021
22,696	29,866	32,214	34,086	35,503	34,270	33,809	34,035

(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).

[44] Addition of fugitive emissions, flare emissions and raw-CO_2 venting

Table 146: Underground gas-storage volume, in billions of m³

	1990	1995	2000	2005	2010	2015	2020	2021
Cavern reservoirs	2.8	4.8	6.1	6.8	9.2	14.3	15.1	14.8
Porous-rock reservoirs	5.2	8.5	12.5	12.4	12.1	9.8	8.6	8.5

(BVEG, 2022a)

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). The pipelines are also fitted with shut-off devices (sliding sleeves), which are safety mechanisms located 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.

The operators of long-distance pipelines report annually to the International Methane Emissions Observatory (IMEO), using the OGMP 2.0 reporting framework. The pertinent data are also used for emissions reporting. A detailed analysis of these data, and a derivation of the emission trend of the preceding years, was carried out in the background paper "Updating of emission factors for methane for the natural gas supply" ("Aktualisierung der Emissionsfaktoren für Methan für die Erdgasbereitstellung") (Böttcher, 2022).

The NMVOC and CO_2 emission factors were determined using split factors from the gas composition described by Lubenau and Schuetz (2014) Böttcher (2022) (Chapter 6).

Emissions and trend

The long-distance pipeline operators have repeatedly, in keeping with the Scope 2 approach, transmitted the following data set to IMEO:

Table 147: Long-distance-network emissions pursuant to OGMP (not including storage facilities)

Asset	Emissions
Transmission grid	2,891 t
TSO - Reduction & regulating stations / Measurement stations / Valve stations / Consumer supply stations for metering and regulating	5,978 t
Compressor stations	5,376 t

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 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 data for the period from 1990 through 2020 were extensively analysed in the background paper Böttcher (2022) (Chapter 3).

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 Category-specific quality assurance / control and verification (1.B.2.b.iv)

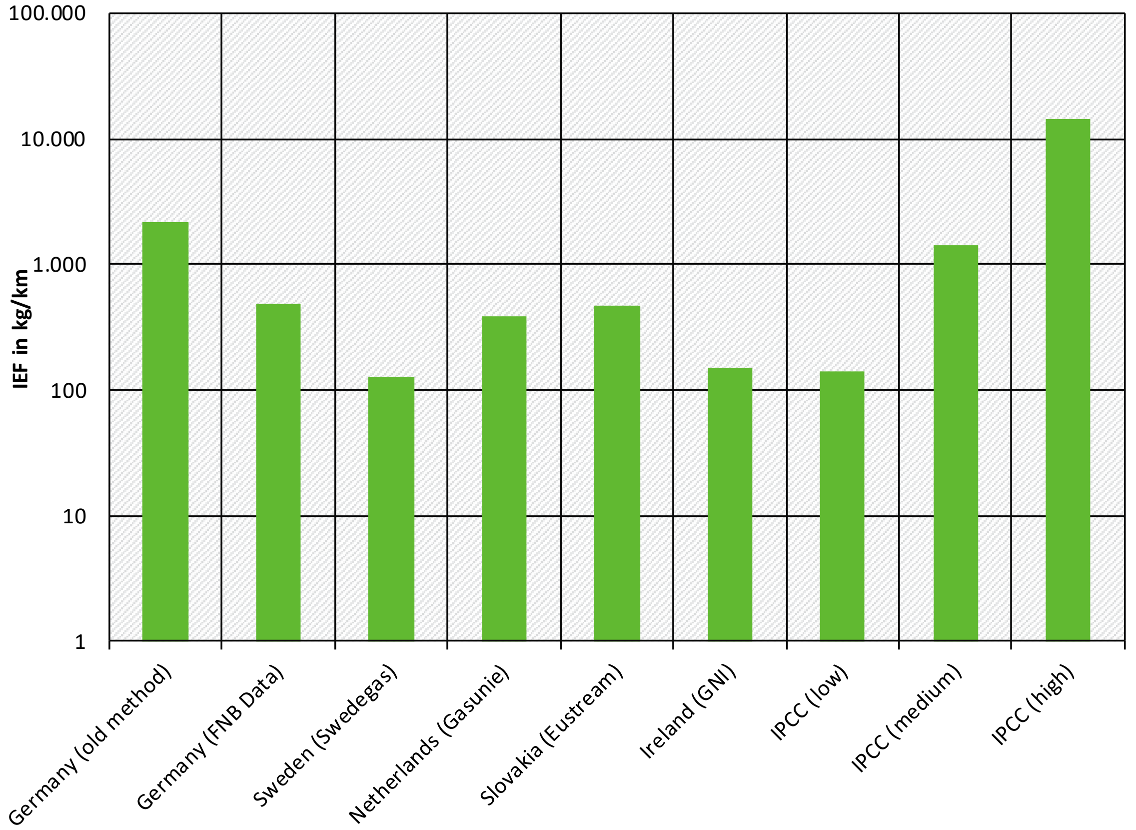
General and category-specific quality control and quality assurance have been carried out, in conformance with the requirements of the QSE manual and its associated applicable documents, by the Single National Entity. The additional quality control and quality assurance were carried out by an external contractor (Grosse, 2022). In addition, an extensive analysis was carried out in connection with the change of methods, and presented in a background paper (Böttcher, 2022). The long-distance-network data have also been reviewed by the IMEO[45].

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. In comparison with neighbouring countries that have carried out similar measurement programmes, Germany occupies a solid mid-range position (cf. Figure 41).

[45] https://www.unep.org/resources/report/eye-methane-international-methane-emissions-observatory-2021-report

Figure 41: Comparison of IEF

Logarithmic presentation; reference to the year 2020



Data of the IPCC (Volume 2 , Chapter 4 – Table 4.2.8) converted from m³/a into kg/a, with a density of 0.717 kg/m³

Source: Background paper (Böttcher, 2022), German Environment Agency

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 considerably, even though gas throughput has increased markedly 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. 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 148: Gas distribution network; figures in km

Parameter	1990	1995	2000	2005	2010	2015	2019	2020	2021
Total length of pipeline network[46]	282,612	366,987	362,388	402,391	471,886	474,570	489,100	503,543	554,400

(Kiesel, 2019); (BNetzA & BKartA, 2022)

Table 149: Emissions and trend in category 1.B.2.b.v

Gas	Total emissions			Trend		Gas
	1990	2020	2021	Since 1990	With respect to the previous year	
Methane	212 kt	12 kt	8 kt	-96%	-33%	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	5.15 kt	0.4 kt	0.3 kt	-96%	-33%	
Carbon dioxide	1.59 kt	0.09 kt	0.07 kt	-96%	-33%	

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 pipeline-length data available in the monitoring report (BNetzA & BKartA, 2022) and the breakdown by supply and grid-connection lines given in the GaWaS online application. 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.

The emission factors were obtained from the study of the German Technical and Scientific Association for Gas and Water (DVGW) Große et al. (2022).

Storage reservoirs

Man-made above-ground storage facilities are suitable for storage of medium-sized quantities of natural gas, and for meeting and balancing 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.

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). Two are currently being built (Böttcher (2022), Chapter 8.2). 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).

[46] The data given include building-connection lines

3.3.2.2.5.3 Uncertainties and time-series consistency (1.B.2.b.v)

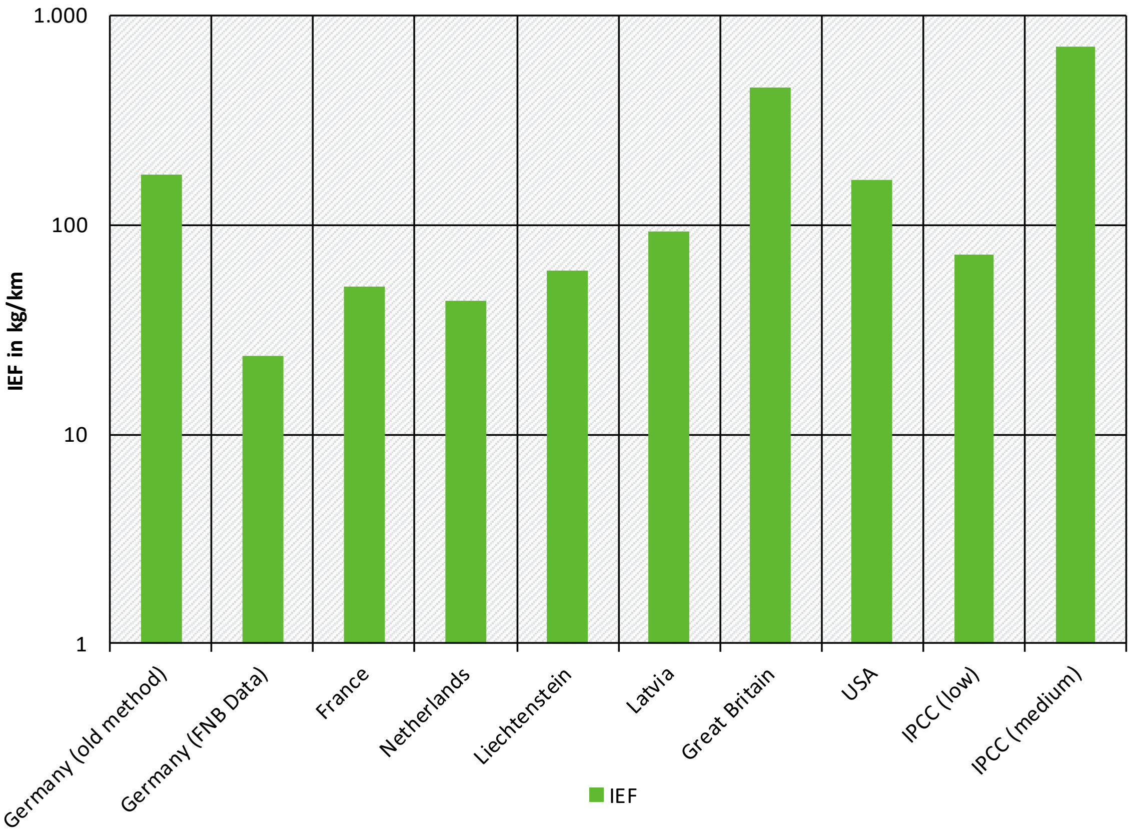
The uncertainties range for the category is given as 44 through 112 % (Große et al., 2022) (Chapter 5.2.4).

3.3.2.2.5.4 Category-specific quality assurance / control and verification (1.B.2.b.v)

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. The additional quality control and quality assurance were carried out by an external contractor (Grosse, 2022).

Böttcher (2022) (Chapter 4.3) compared the results for this category with other countries' corresponding results. The comparison found that the implied emission factor is quite low overall (Figure 42). That said, it must be noted that Germany lists “post-meter” emissions separately, under 1.B.2.b.vi. When those emissions are taken into account, Germany’s IEF lies within the range for neighbouring countries.

Figure 42: Comparison of IEF



Logarithmic presentation; reference to the year 2020; Data of the IPCC (Volume 2 , Chapter 4 – Table 4.2.8) converted from m^3/a into kg/a, with a density of 0.717 kg/m^3

Source: Own description, German Environment Agency

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 the emissions from leakage in the residential sector and the institutional and commercial (small consumers) sector; from start-stop processes in natural-gas appliances, and from natural-gas-powered vehicles.

Activity data

Table 150: Number of natural-gas-powered vehicles in Germany

	1990	1995	2000	2005	2010	2015	2020	2021
Number	0	0	7,500	28,500	90,000	97,804	100,807	101,688

Source: gas.info

Activity data

Table 151: Activity data used for category 1.B.2.b.vi, "Fugitive emissions at sites of natural gas use"

	1990	1995	2000	2005	2010	2015	2020	2021
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

Own survey

Emissions and trend

Table 152: Emissions in category 1.B.2.b.vi

Gas	Total emissions			Trend	
	1990	2020	2021	Since 1990	With respect to the previous year
Methane	60.4 kt	42.4 kt	41.5 kt	-31%	-2%
NMVOC	1.5 kt	1.5 kt	1.5 kt	-4%	-1%
Carbon dioxide	0.3 kt	0.3 kt	0.3 kt	-4%	-1%

3.3.2.2.6.2 Methodological issues (1.B.2.b.vi)

Residential, institutional and commercial (small consumers)

Emissions from natural-gas appliances were studied in a still-unpublished study of the GWI (a research and service institute for the German gas sector), under commission to the German Technical and Scientific Association for Gas and Water (DVGW) (Brandes, 2022). The study found that the pertinent fugitive emissions amount to 2,019 t methane per year, while start-stop emissions amount to 39,064 t methane per year. In sum, while fugitive emissions were overestimated in the previous reportion rounds, the start-stop emissions were underestimated. To prevent underestimations, all start-stop emissions are reported under 1.B.2.b.v.

Pursuant to Arbeitsblatt [Worksheet] G 600 (Schuhmann, 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 building installations. When a leak test shows that an installation is leaking at a rate higher than that figure, the installation has to be promptly repaired. The maximum emissions thus convert to between 0 und 8.76 m^3 natural gas / year, or 6.3 kg natural gas / year. In a conservative approach, that value is applied for the year 1990. To that end, the 8.76 m^3 natural gas / year are multiplied by 0.9, to take account of the methane fraction. The so-determined value of 7.9 m^3 CH_4/year is considerably higher than the previously used value,1.8 m^3 CH_4/year, however.

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.

3.3.2.2.6.3 Uncertainties and time-series consistency (1.B.2.b.vi)

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 Category-specific quality assurance / control and verification (1.B.2.b.vi)

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. The additional quality control and quality assurance were carried out by an external contractor (Grosse, 2022).

Böttcher (2022) (Chapter 5.6) compared the results for this category with other countries' corresponding results. It was found that while the UK has carried out similar studies, their emissions are an order of magnitude smaller than the German emissions. Betzenbichler et al. (2016b) reached a similar conclusion. 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 153: Comparison 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	4.4 m³/No.	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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	1 B 2 c, Venting and Flaring		CO_2	543.5	0.1 %	298.2	0.0 %	-45.1 %
-/-	1 B 2 c, Venting and Flaring		CH_4	1.8	0.0 %	0.6	0.0 %	-67.8 %
-/-/2	**1 B 2 c, Venting and Flaring**		**N_2O**	**1.7**	**0.0 %**	**0.6**	**0.0 %**	**-65.4 %**

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 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.

Category 1.B.2.c, "Venting and flaring," is a key category for CO_2 pursuant to Approach 2 analysis.

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 154: Refined crude-oil quantity, in millions of t.

1990	1995	2000	2005	2010	2015	2018	2020	2021
107	96	108	115	95	93	87.7	84.0	84.1

(en2x, 2021a), (en2x, 2022)

Table 155: Flared natural gas, in millions of m³

1990	1995	2000	2005	2010	2015	2018	2020	2021
36	33	36	19	12	10	11	14	11

(BVEG, 2021), (BVEG, 2022a)

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 156: 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 157: 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 (Jochen Theloke et al., 2013). In the interest of maintaining a conservative approach, the IPCC default value has been used in the relevant calculation.

Table 158: 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 159: 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 (Jochen 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 160: Emissions in category 1.B.2.c "Venting and flaring"

Gas	Total emissions			Trend		Remark
	1990	2020	2021	Since 1990	With respect to the previous year	
Methane	66 t	22 t	21 t	- 68 %	- 4 %	Emissions from flaring systems have decreased continuously as a result of improvements in gas-recovery methods.
Carbon dioxide	544 kt	311 kt	298 kt	-45 %	-4 %	
NMVOC	522 t	334 t	256 t	-51 %	- 23 %	
Nitrous oxide	6.5 t	2.3 t	2.3 t	- 64 %	- 2 %	The air-pollution emissions of the exploration and production industry are determined in keeping with a procedure accepted throughout the industry[47]. For this reason, the annual emissions figures vary somewhat from year to year and do not yield a straight line.

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 155) 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 J. Theloke et al. (2013).

The emissions are calculated in keeping with the Tier 2 method.

[47] WEG: "Leitfaden zu Erfassung der Umweltdaten der WEG Mitgliedsfirmen", published in-house, and last revised in Dec. 2016

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) (Jochen 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 quality assurance, 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.

In the Centralised Review 2022, Number E14, it was noted that in the CRF Tables “IE” was entered in the “combined” field, although pertinent activity data are given in the NIR. Since the determined emissions refer to different activity data, no activity data should be given in the report, since otherwise the IEF would lead to misinterpretations. The emission factors are listed in Table 161.

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 participating experts agreed that the default values are considerably higher than the emission factors currently used in Europe.

Table 161: Comparison of IEF with the relevant IPCC default values

Gas and system	CS emission factor used[48]	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	7759	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 (usually, 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 normally use the heat in their thermal-water flows

[48] For refineries, determined as a mean value between normal operation and operation during disruptions

directly, and provide heating and cooling to end consumers via district heating / district 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 2021, a total of 42 deep geothermal power stations were in operation. In sum, they have an electrical output of 53 MW and a thermal output of 380 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" (Houghton 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 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. Jochen 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 18).

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. In addition, inventory improvements were made in 1.B.2.b.iii-vi that entailed recalculations, some of them considerable.

Table 162: Recalculations in category 1.B.2 – NMVOC emissions, in kt

	1990	1995	2000	2005	2010	2015	2020
2023 Submission	176.40	118.10	77.42	47.16	37.46	32.04	28.12
2022 Submission	175.43	116.25	75.27	44.99	35.69	32.25	30.39
Difference	0.97	1.85	2.15	2.17	1.76	-0.21	-2.27

Table 163: Recalculations in category 1.B.2 – methane emissions, in kt

	1990	1995	2000	2005	2010	2015	2019
2023 Submission	359.33	377.55	283.49	238.48	193.67	131.39	72.18
2022 Submission	329.64	342.72	248.60	216.50	193.55	191.21	191.30
Difference	29.69	34.83	34.89	21.98	0.12	-59.82	-119.12

Table 164: Recalculations in category 1.B.2 – carbon dioxide emissions, in kt

	1990	1995	2000	2005	2010	2015	2020
2023 Submission	2,007.85	2,127.01	2,213.85	2,212.85	1,898.13	1,672.12	1,174.51
2022 Submission	2,007.65	2,126.56	2,213.20	2,212.29	1,897.71	1,672.21	1,185.39
Difference	0.19	0.44	0.65	0.56	0.42	-0.09	-10.88

3.3.2.6 Planned improvements, category-specific (1.B.2 all)

Additional measurement campaigns for determination of emissions from natural gas networks are currently underway in Germany. 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). Tentative plans call for integration of the relevant finding within future reports.

In the area of end-user emissions (1.B.2.b.vi), some overlapping with emissions from 1.A.1., 1.A.2 and 1.A.4 occurs. Review is thus needed to determine whether any double-counting is occurring in this area. Chapter 10.4 presents an overview, Inventory Improvements (Table 471), of any improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

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

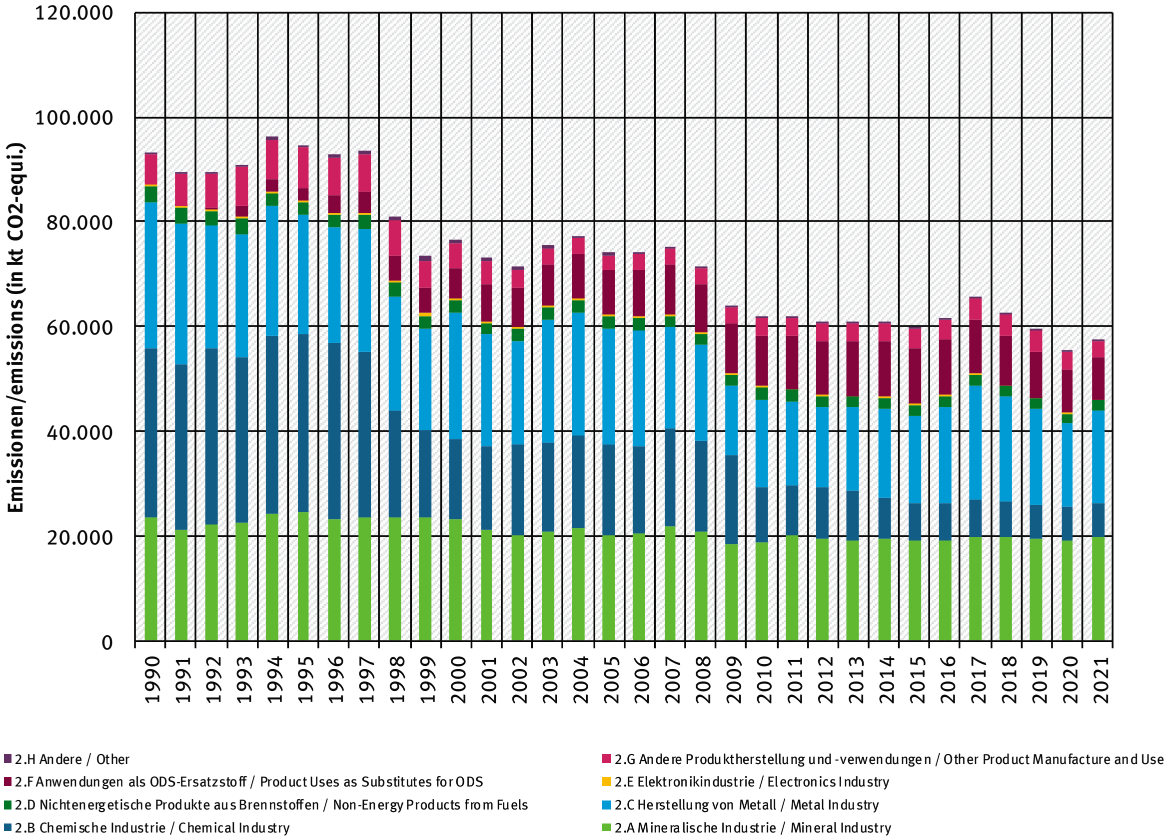
According to the operator of the only pilot installation in Germany, about 67 kt CO_2 have been sequestered to date for experimental purposes (GFZ, 2018). The installation's monitoring and measurement system has not registered any leakage since the sequestration was carried out. In the interest of conservative 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.

4 Industrial processes (CRF Sector 2)

4.1 Overview (CRF Sector 2)

Figure 43: 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	2 A 1, Cement Production		CO_2	15,297.3	1.2 %	13,640.2	1.8 %	-10.8 %

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 165, 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, 2022), clinker production in 2021 in Germany amounted to 25,232 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 13,640 kt CO_2 in 2021.

Table 165: Production and raw-material-related CO_2 emissions in the German cement industry

Year	Clinker production + discharged bypass dust[49] [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

[49] 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[49] [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
2021	25,736	0.53	13,640	35,622

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), (DEhSt, 2021) and (DEhSt, 2022)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 165 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 two research projects, (Ruppert, 2009) and (Schäfer et al., 2022), and it was confirmed by the VDZ for the other 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 emissions = emission factor ($EF_{clinkers}$) x clinker production + emission factor ($EF_{clinkers}$) x bypass dust (%) x clinker production

Table 165 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 +/- 1 %. This was confirmed via surveys in the framework of a research project (Schäfer et al., 2022).

4.2.1.4 Source-specific quality assurance / control and verification (2.A.1)

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 relevant involved experts and the Single National Entity.

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.

The comparison with the emissions-trading figures for process-related emissions showed very good agreement.

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 improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	2 A 2, Lime Production		CO_2	5,986.6	0.5 %	4,524.9	0.6 %	-24.4 %

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).

Table 166: 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
2021	5.809	4.333	0.221	0.192

Source: Production: Basic data from (BVKalk, 2021) and (BVKalk, 2022); supplemented by UBA

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 quality assurance 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.

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 very 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 improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 A 3, Glass Production		CO_2	780.5	0.1 %	916.9	0.1 %	17.5 %

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) (Bundesverband Glasindustrie e.V., 2022). 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 167: 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 Glas]
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	7,394,700	856,430	0.116
2021	7,803,000	916,911	0.118

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 intermittently, and 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 2021:

Table 168: Glass: Activity data for the various industry sectors (types of glass)

Industry sector	Activity data, 2021 [t]
Container glass	3,973,800
Flat glass	2,125,700
Glass fibre and wool	373,100
Special glass	337,000
Stone wool	605,100
Domestic glass	44,200

Source: (Bundesverband Glasindustrie e.V., 2022)

The following sector-specific cullet percentages are assumed:

Table 169: 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 (Bundesverband Glasindustrie e.V., 2022)

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(Bundesverband Glasindustrie e.V., 2022). 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 170: 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, 73 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 quality assurance, 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.

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 0.4% higher 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)

Recalculations were carried out in 2020 to account for slight corrections of individual production figures.

4.2.3.6 Planned improvements, category-specific (2.A.3 Glass production)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 A 4, Other Process Uses of Carbonates	CO_2	1,458.0	0.1 %	816.4	0.1 %	-44.0 %	1,458.0

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 171) comprise the activity data and process-related CO_2 emissions of the entire ceramics industry in Germany, for the period since 1990[50]. The non-CO_2 emissions (NO_X, NMVOC, SO_2, etc.) for the entire ceramics industry are calculated via these activity data.

Table 171: 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][51]
	Total ceramics production	CO_2-relevant ceramics production[51]	
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

50 Expanded clay is not included here, since no pertinent data (production quantities / activity data) are available

51 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][51]
	Total ceramics production	CO_2-relevant ceramics production[51]	
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
2021	12,245	10,828	581

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 (Statistisches Bundesamt, 2021b). 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. In the process, the previously used conversion factors have lost their suitability. 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[52]. 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 product groups (raw-material composition)[53]. 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 172 shows the CO_2 emission factors determined for the various product groups.

Table 172: 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 171). With this approach, an IEF of 0.053 $t_{CO2}/t_{product}$ has been calculated for 2018[54]. 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 172 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 172 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.

4.2.4.1.4 Category-specific quality assurance / control and verification (2.A.4.a Ceramics)

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 relevant involved experts and the Single National Entity.

[54] 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.

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)

No recalculations were required for the present report.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 173: 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
2010	528,885	219.5
2011	587,144	243.7
2012	516,444	214.3
2013	703,049	291.8
2014	694,907	288.4
2015	665,206	276.1
2016	644,664	267.5
2017	712,518	295.7
2018	706,461	293.2
2019	718,245	298.1
2020	613,470	254.6
2021	568,343	235.9

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.). 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. Consultations have now taken place with soda-ash producers, and this has brought improvements of the production figures for the period since 2013. Work continues on improving the calculatory export figures.

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.

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 in conformance with the requirements of the QSE manual and its associated applicable documents, have been carried out 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)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

Recalculations were required, and they led to the following higher figures for the period since 2013:

Emissions in kt CO_2	2022 Submission	2023 Submission	Change
2013	245.3	291.8	46.4
2014	214.5	288.4	73.9
2015	195.2	276.1	80.9
2016	205.7	267.5	61.8
2017	205.4	295.7	90.3
2018	190.6	293.2	102.6
2019	141.5	298.1	156.6
2020	95.5	254.6	159.1

4.2.4.2.6 Category-specific planned improvements (2.A.4.b)

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 18 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 non-quantifiable 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 improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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" (Simone 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 improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/-	2 B 1, Ammonia Production		CO_2	6,025.0	0.5 %	4,012.0	0.5 %	-33.4 %

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.

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. With use of the Tier 2 and Tier 3 methods, the collected data meet for the requirements for key categories, throughout the entire time series.

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 quality assurance 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/T	2 B 2, Nitric Acid Production		N_2O	2,896.8	0.2 %	344.3	0.1 %	-88.1 %

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 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 German Environment Agency (UBA). After carrying out quality assurance, the German 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 German 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.

For the year 2021, one producer, who is responsible for minor emissions quantities, was unable to carry out emissions measurements completely. For this reason, the emissions of 2020 were carried forward for that producer’s plant. Plans call for correction of these data in the next submission.

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 quality assurance 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.

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)

The emissions data for the one small producer who was unable to carry out measurements completely in 2021 are to be corrected in the next submission.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	2 B 3, Adipic Acid Production		N_2O	16,074.9	1.3 %	66.3	0.0 %	-99.6 %

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 quality assurance 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.

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[55] 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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.

[55] Cf.: https://www.jicdm.dehst.de/promechg/pages/project1.aspx

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 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[56], 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 9.5 kt CO_2-eq. (AR5) 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 15.9 kt CO_2-eq. (AR5) 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 18 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.

[56] 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)

4.3.4.3 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 (jährlich - 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 B 5, Carbide Production		CO_2	443.2	0.0 %	5.9	0.0 %	-98.7 %

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 quality assurance, 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 18 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 B 7, Soda Ash Production		CO_2	615.5	0.1 %	457.8	0.1 %	-25.6 %

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1/2	NS/PS	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[57] the Solvay process[58]. 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 total amounts of soda ash produced in Germany are determined with the help of two data suppliers.

The *Federal Statistical Office* has long time series for this area: The time period 1990 through 1994 results from combination of data of formerly "old" German Länder and from transfer of data for the new German Länder into the joint records for Germany as a whole. From 1995 through 2008, the categories *light soda* and *heavy soda* were listed separately. As of 2009, only one position for these categories is now listed (reporting number (Meldenummer) 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.

Due to the presence of a nearly inexplicable trend in the data of the Federal Statistical Office for the period since 2015, the relevant producers were contacted, and in 2021 cooperation agreements were signed with both producers (for all three production sites; cf. also 1.2.1.4). The German Environment Agency (UBA), which consolidates the relevant data, has decided that as of 2013 the pertinent time series is to be filled with the producers' data (this overlaps with a comparison carried out for the period 2013 through 2021).

[57] 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.

[58] Ammonia-soda process pursuant to Ernst Solvay

Since Germany has only two producers, the production-quantity data from the two sources 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 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

Uncertainties exist with regard to the production quantities given by the Federal Statistical Office, especially for the period since the quantities were listed separately and for the period as of 2015.

The uncertainty for the producers's figures agrees with that for reporting in the framework of the EU-ETS; for this reason, it is set at -1/+1 percent.

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 quality assurance, 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.

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)

Recalculations were required for the entire time series. They are needed in order to take account of changes in the activity data since 2013. In addition, the emission factor had to be derived anew, because the originally derived factor, which had been derived for the year 2013, needed to be updated to take account of the changes in production figures that had occurred (the new factor had to be applied to the entire time series).

All in all, the emissions for 1990 decreased by about 52 kt of carbon dioxide, while those for 2020 increased by about 89 kt of carbon dioxide.

4.3.7.6 Category-specific planned improvements (2.B.7)

No improvements are planned.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 B 8, Petrochemical and Carbon Black Production		CO_2	974.0	0.1 %	861.6	0.1 %	-11.5 %
-/-	2 B 8, Petrochemical and Carbon Black Production		CH_4	373.7	0.0 %	570.0	0.1 %	52.5 %

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[59].

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)

[59] Chemiewirtschaft in Zahlen 2016, Verband der Chemischen Industrie e.V. (2017): https://www.vci.de/services/publikationen/broschueren-faltblaetter/chemiewirtschaft-in-zahlen.jsp

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.

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 quality assurance, 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.

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[60]). 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

[60] Website: http://www.petrochemistry.eu

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. For the period 2005 through 2021, therefore, the DEHSt emissions figures have been 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), the activity data have been back-calculated. The emissions of one installation that is not subject to emissions-trading requirements have been reported by the operator directly to the German 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. Since 2022, UBA has obtained the emissions data directly from the two operators.

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 174: Emission factors used in Germany for other pollutants

	Carbon black [kg CO / t]	Carbon black [kg SO_2/t][61]
1990	4.8 / 5	19.5 / ([62])
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).

Activity data

The production statistics of the Federal Statistical Office include the following products (cf. the following table).

Table 175: 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.

[61] Where two EF are listed, the second figure refers to the new German Länder.

[62] No EF is listed for the new German Länder, since these SO_2 emissions can be taken account of only as a lump sum.

4.3.8.2.4 Category-specific quality assurance / control and verification (2.B.8 Carbon black)

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 relevant involved experts and the Single National Entity.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1995-2021
L/T	**2 B 9 a, By-product Emissions**		**HFC-23**	**C**	**C**	**C**	**C**	**C**
-/-	2 B 9 b, Fugitive Emissions		SF_6	164.5	0.0 %	1.0	0.0 %	-99.4 %
-/-	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

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 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 relevant involved experts and the Single National Entity.

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 improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 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 relevant involved experts and the Single National Entity.

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 improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1995-2021
-/-	2 B 10, Other Chemical Industry		CH_4	66.6	0.0 %	65.0	0.0 %	-2.4 %
-/-	2 B 10, Other Chemical Industry		N_2O	C	C	C	C	C

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 176: 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 177: 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, 2009), 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 (cf. Table 178), 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. All CH_4 emissions are recorded under 2.B.10.

Table 178: Derivation of split factors for liquid petroleum products

		1990	1995	2000	2005	2010	2015	2020	2021
Gasoline	kt	31,257	30,333	28,833	23,431	19,634	18,226	16,218	16,428
	Share in %	73.03	69.41	64.18	56.52	54.17	52.74	57.87	54.55
Naphtha	kt	11,546	13,370	16,091	18,024	16,611	16,331	11,804	13,686
	Share in %	26.97	30.59	35.82	43.48	45.83	47.26	42.13	45.45

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 quality assurance 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**2 C 1, Iron and Steel Production**		**CO_2**	**22,810.3**	**1.8 %**	**16,418.9**	**2.2 %**	**-28.0 %**
-/-	2 C 1, Iron and Steel Production		CH_4	5.2	0.0 %	5.5	0.0 %	5.6 %
-/-	2 C 1, Iron and Steel Production		N_2O	23.6	0.0 %	11.9	0.0 %	-49.5 %

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 2021, a total of 28.2 t million t of raw steel, from ore, was produced in Germany in six integrated steel works. Electric steel production amounted to 12.1 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.

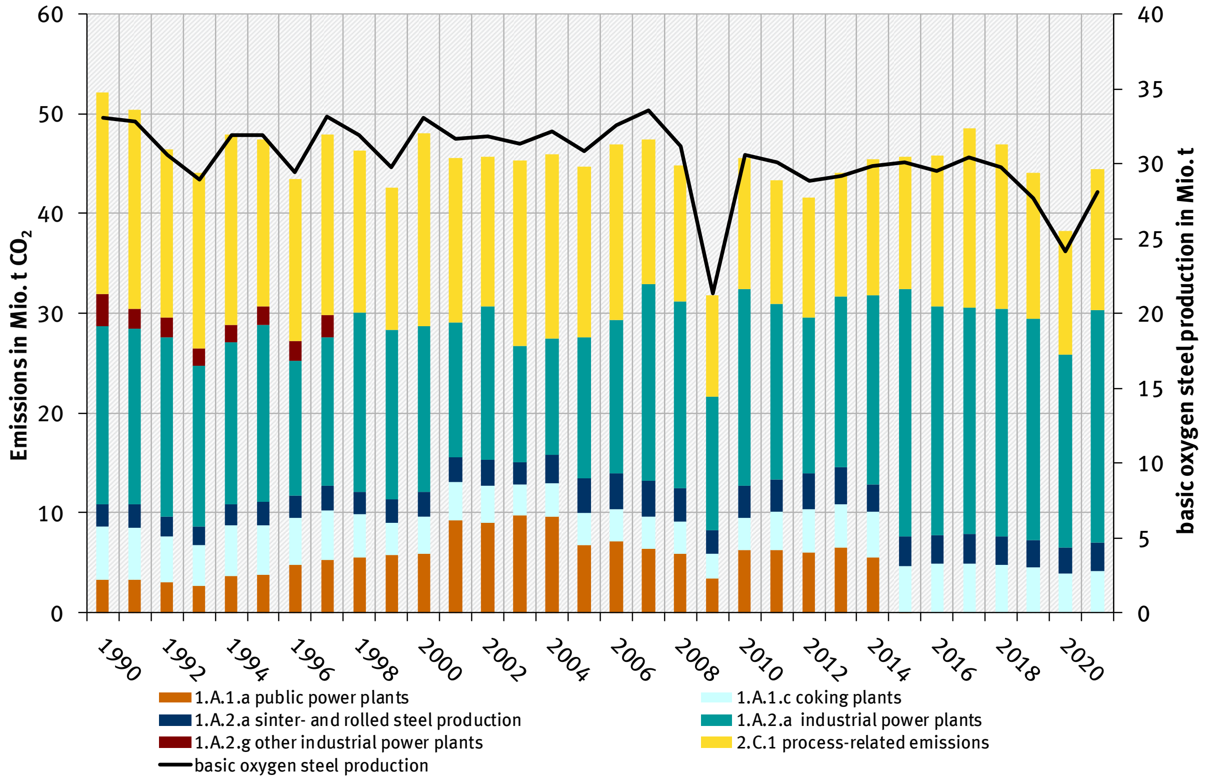
Method for calculating the CO_2 emissions resulting from use of reducing agents in blast furnaces

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)[63].

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 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).

[63] 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 %),

Figure 44: CO_2 emissions from use of reducing agents for primary steel production and from use of blast furnace gas – chronological sequence, and category allocation (in millions of t of CO_2)



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 179: 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	2021
1.A.1.a Public power stations	0.000	0.000
1.A.1.c Coking plants	3.954	4.111
1.A.2.a Sinter and rolled-steel production	2.524	2.958
1.A.2.a Industry power stations	19.346	23.241
1.A.2.f Other industry power stations	0.000	0.000
2.C.1 Process emissions	12.476	14.195

In the iron and steel industry, secondary fuels were basically used only in the period 1996 through 2019 for production of pig iron in blast furnace processes. Recently, they have been used – in very small quantities – by only one plant. 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, Nanning, 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 180). 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 180.

Table 180: 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] Blast furnaces AD	Limestone input [t/a] Sinter plant AD	Own production Burnt lime [t/a] AD	CO_2 emissions [t/a] Limestone inputs EF 440 kg/t	CO_2 emissions [t/a] Lime production EF 746 kg/t	CO_2 emissions [t/a] 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
2021	733,223	3,865,442	149,500*)	2,023,412	111,527*)	2,134,939

Source: Until 2004: Calculation of limestone inputs by the "limestone balance" project ((Lechtenböhmer, Nanning, 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 181.

Table 181: 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**
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	93,070	**15,652,946**
2016	15,100,844	2,105,041	92,863	**17,298,748**
2017	18,075,302	2,275,491	95,909	**20,446,702**
2018	16,450,331	2,182,283	93,669	**18,726,283**
2019	14,667,114	2,193,175	87,787	**16,948,076**
2020	12,476,463	1,880,095	85,057	**14,441,615**
2021	14,194,851	2,134,939	89,157	**16,418,947**

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.

In addition, the activity data used since 2017 to calculate the industry's own production of burnt lime are no longer publicly available. For this reason, the activity data are assumed to have remained constant since then. In keeping with the assumptions made, the uncertainty for the activity data here is ± 7%.

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 quality assurance 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.

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 2020, to take account of replacement of data from the provisional Energy Balance with data from the final Energy Balance. As a result, the total CO_2 emissions have decreased by 96.46 kt (0.66 %). The data on CO_2 emissions from electrode consumption have been updated for 2015 through 2020. This has not led to changes in the total CO_2 emissions, however, while the data changes only consist of corrections of transfer errors.

4.4.1.6 Category-specific planned improvements (2.C.1)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-/2	**2 C 2, Ferroalloys Production**		**CO_2**	**429.0**	**0.0 %**	**6.0**	**0.0 %**	**-98.6 %**
-/-	2 C 2, Ferroalloys Production		CH_4	9.6	0.0 %	1.8	0.0 %	-81.0 %

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 *Production of ferroalloys* is a key category for CO_2 pursuant to Approach 2 analysis.

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 emission factor used is considerably lower than the standard emission factor pursuant to the 2006 IPCC Guidelines. The reason for this is that only process-related CO_2 emissions from electrode consumption are included in 2.C.2. In keeping with the structure of the national Energy Balance, the remaining CO_2 emissions from consumption of reducing agents are listed in 1.A.2. Use of the standard emission factor, therefore, would lead to impermissible double-counting.

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 2022 (Idoine et al., 2022) have been used, because the official production statistics no longer contain usable data for this context. The currently available data are from 2020. The activity data have been carried forward into 2021.

4.4.2.3 Uncertainties and time-series consistency (2.C.2)

The activity data provided by the British Geological Survey Idoine et al. (2022) are based partly on estimates and thus are subject to relatively large uncertainties. The uncertainty for the activity rate is estimated to be +/- 50%.

The relevant data of the British Geological Survey Idoine et al. (2022) 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. The uncertainty is +/- 50% for all years.

4.4.2.4 Source-specific quality assurance / control and verification (2.C.2)

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 relevant involved experts and the Single National Entity.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990/1995-2021
-/-/2	**2 C 3, Aluminium Production**		**CO_2**	**1,011.9**	**0.1 %**	**696.1**	**0.1 %**	**-31.2 %**
-/-	2 C 3, Aluminium Production		SF_6	C	C	C	C	C
-/T	**2 C 3, Aluminium Production**		**CF_4**	1,385.7	0.1 %	49.0	0.0 %	-96.5 %
-/-	2 C 3, Aluminium Production		C_2F_6	233.1	0.0 %	9.9	0.0 %	-95.7 %

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 3	AS	CS
CH_4	-	-	NE
PFC	Tier 2	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 addition, it is a key category for CO_2 emissions in terms of Approach 2 analysis.

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 182 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 15.7). 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 182 were checked against the emission data in Best Available Techniques Reference Documents (BREF)[64] and other sources (such as VDI Guideline 2286 VDI (1998): Sheet 1) and the relevant data from the EU Emissions Trading System (ETS).

Table 182: 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[65] 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 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.

64 cf. http://www.bvt.umweltbundesamt.de/kurzue.htm

65 "...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...." (Schwarz & Leisewitz, 1996).

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.

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 quality assurance 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1995-2021
-/-	2 C 4, Magnesium Production		SF_6	C	C	C	C	C
-/-	2 C 4, Magnesium Production		HFC-134a	0.0	0.0 %	7.5	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 quality assurance, 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 C 5, Lead Production		CO_2	157.9	0.0 %	64.4	0.0 %	-59.2 %

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 quality assurance, 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 C 6, Zinc Production		CO_2	670.8	0.1 %	289.2	0.0 %	-56.9 %

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 quality assurance, 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 D 1, Lubricant Use		CO_2	188.6	0.0 %	198.3	0.0 %	5.1 %

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.

Consumption of lubricants in Germany has remained relatively constant, apart from two downturns that occurred in the years 2009 and 2020. In 2022, consumption amounted to 653,165 t, not including mobile applications.

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 16.1.3. 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)[66] 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.

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

66 http://www.bafa.de/SharedDocs/Downloads/DE/Energie/Mineraloel/moel_erhebungskreisliste.xls;jsessionid=8F5CC4170FEBCC89A69DE21218062873.2_cid378?__blob=publicationFile&v=4

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 183: 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.

In the interest of conformity with the 2006 IPCC Guidelines and EU emissions reporting, 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 184: 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 185: Overview of the specific co-combustion fractions used

Sector	Fuel	Fraction	Source / remark
1.A.2.g vii	OK	0.00 %	Assumption, based on Wallfarth (2014)
	DK	0.10 %	
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	0.10 %	Like 1.A.3.b
	LPG	0.10 %	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	0.00 %	Assumption, based on Wallfarth (2014)
	DK	0.10 %	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	0.00 %	Assumption, based on Wallfarth (2014)
	DK	0.15 %	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 186: 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	2021
1.A.2.g vii	3.53	3.33	3.28	2.80	3.02	3.38	3.50	3.60	3.35	3.38	3.53	3.49
1.A.3.a	0.23	0.22	0.24	0.22	0.22	0.20	0.20	0.20	0.20	0.21	0.10	0.07
1.A.3.b	86.1	104	114	118	121	129	131	133	134	135	118	119
1.A.3.c	1.41	1.14	0.93	0.68	0.57	0.51	0.53	0.44	0.37	0.42	0.43	0.43
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	2.13
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	0.74
1.A.4.b ii	Here, only use of two-stroke gasoline engines											
1.A.4.c ii	3.90	3.27	3.05	2.96	3.31	3.78	3.93	4.05	3.80	3.84	4.04	4.05
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	0.35	0.35
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	0.03
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	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	0.04
Total	**103**	**117**	**126**	**128**	**131**	**140**	**143**	**144**	**145**	**146**	**129**	**130**
1.D.1.a	1.20	1.49	1.94	2.30	2.43	2.45	2.65	2.92	3.01	2.98	1.37	1.82
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	5.44

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 *Stationary* lubricant uses, result from the emission-factor ranges shown in Table 183.

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 %.

Since the co-combusted lubricant quantities tied to *mobile* lubricant use are calculated using a conservative approach, a considerably higher uncertainty – ± 25% – is assumed here. The same holds for the default emission factor for CO_2 that has been used. Because the lubricants product group is relatively heterogeneous, the uncertainty for that factor is assumed to be ±10%.

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 use, no recalculations were made with respect to the 2022 submission.

For *mobile* lubricant use, the unintentionally co-combusted quantities of lubricants were very slightly adjusted with respect to the 2021 submission.

Table 187: Revised unintentionally co-combusted quantities, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
2023 Submission	1,400	1,601	1,713	1,746	1,792	1,916	1,946	1,971	1,977	1,990	1,765
2022 Submission	1,400	1,602	1,714	1,747	1,796	1,914	1,941	1,963	1,965	1,983	1,771
Absolute change	-0.20	-0.68	-0.89	-0.52	-3.94	1.39	4.74	8.63	11.7	6.98	-5.52
Relative change	-0.01%	-0.04%	-0.05%	-0.03%	-0.22%	0.07%	0.24%	0.44%	0.60%	0.35%	-0.31%

Source: TREMOD and TREMOD MM

The emissions from this unintentional co-combustion have been recalculated accordingly.

Table 188: Revised CO_2 emissions from unintentional co-combustion, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
2023 Submission	103	117	126	128	131	140	143	144	145	146	129
2022 Submission	103	117	126	128	132	140	142	144	144	145	130
Absolute change	-0.01	-0.05	-0.07	-0.04	-0.29	0.10	0.35	0.63	0.86	0.51	-0.40
Relative change	-0.01%	-0.04%	-0.05%	-0.03%	-0.22%	0.07%	0.24%	0.44%	0.60%	0.35%	-0.31%

Source: Own calculations

The revision of the total calculated carbon dioxide emissions is based, consequently, only on the adjustments made in the area of mobile uses.

Table 189: Revised CO_2 emissions from stationary and mobile uses, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
2023 Submission	188.6	180.4	191.2	186.8	193.4	218.5	224.7	233.9	227.2	226.5	182.0
2023 Submission	188.6	180.4	191.3	186.8	193.6	218.4	224.3	233.3	226.3	226.0	182.4
Absolute change	-0.01	-0.05	-0.07	-0.04	-0.29	0.10	0.35	0.63	0.86	0.51	-0.40
Relative change	-0.01%	-0.03%	-0.03%	-0.02%	-0.15%	0.05%	0.15%	0.27%	0.38%	0.23%	-0.22%

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 uses: General quality control, and quality assurance in conformance with the requirements of the QSE manual and its associated applicable documents, have been carried out 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 a) uses in which primarily CO_2 emissions occur, via co-combustion of lubricants, and b) 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.

For mobile uses: 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 relevant involved experts and the Single National Entity.

4.5.1.6 Category-specific planned improvements (2.D.1)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-/2	**2 D 2, Paraffin Wax Use**		**CO_2**	**242.7**	**0.0 %**	**502.3**	**0.1 %**	**107.0 %**
-/-	2 D 2, Paraffin Wax Use		N_2O	0.6	0.0 %	1.3	0.0 %	107.0 %

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 a key category for CO_2 emissions pursuant to Approach 2 analysis.

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 % (Michael Matthäi & Petereit, 2004) and 22 % (M. 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.

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 (jährlich - 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 2021 amounted to 200538.7 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 2020, 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 0.12 % for that year, however. 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 quality assurance in conformance with the requirements of the QSE manual and its associated applicable documents, have been carried out by the Single National Entity.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 D 3, Other		CO_2	2,551.1	0.2 %	1,328.8	0.2 %	-47.9 %

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[67].

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**

[67] 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)

<u>2.D.3.e Degreasing</u>

- **Metal degreasing**
- **Production of electronic components**
- **Other industrial cleaning** (precision mechanics, optics, watch-making)

<u>2.D.3.f Chemical cleaning (dry cleaning)</u>

- **Dry cleaning**

<u>2.D.3.g Production and processing of chemical products</u>

- **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 the 2006 IPCC Guidelines, NMVOC emissions from use of metal-processing oils (cooling lubricants) and of other lubricants (industrial lubricants) are reported not in category 2.D.3.i. – “Other uses,” but together with the emissions from all other lubricant uses – with the exception of transport-related emissions – in 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)[68]. For purposes of the definition of solvents, the term "solvent use" is also defined in keeping with the EC solvents directive[69].

[68] 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.

[69] 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:

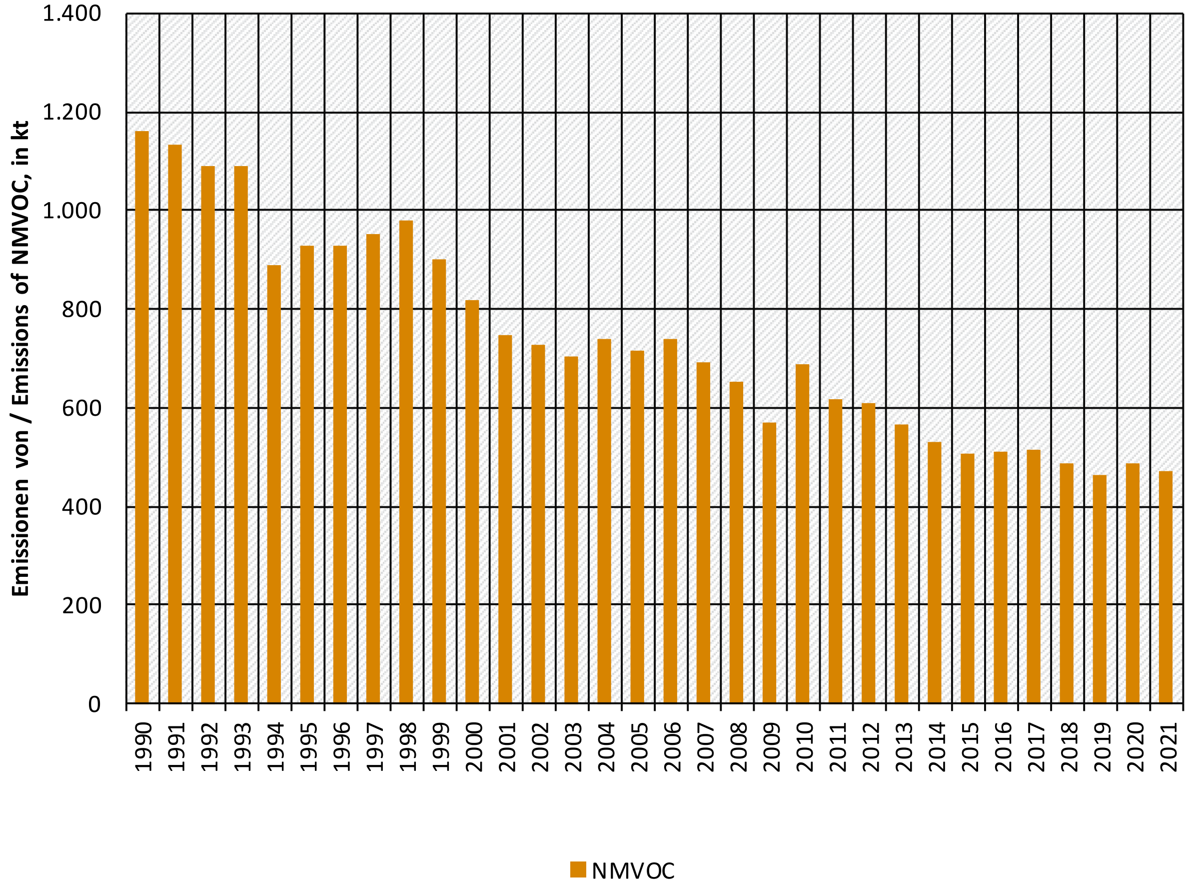
- the quantities of VOC-containing (pre-) products and agents used in the reporting year,
- the VOC concentrations in these products (substances and preparations),
- the relevant application and emission conditions (or the resulting specific emission factor).

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 45: 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, 2022c). 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)[70].

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.

[70] Informative Inventory Report – Germany http://iir.umweltbundesamt.de

The uncertainties for the sub-category “Asphalt blowing” have been quantified via expert assessment. As a result of the poor data situation, a large uncertainty, of up to 100%, must be assumed for the percentage share applying to blown asphalt, with respect to the total production of bitumen, and for the emission factor for NMVOC.

4.5.3.4 Category-specific quality assurance / control and verification (2.D.3 Solvents)

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

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. For the year 2020, such recalculation has been postponed to the 2024 report, because the calculation bases for some uses have to be reviewed for additional years, and it was not possible to complete such review in time for the 2023 report.

4.5.3.6 Planned improvements, category-specific (2.D.3 Solvents)

No further improvements are planned at present; cf. the first paragraph under “category-specific recalculations.”

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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[71].

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 190. 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 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

[71] Cf. the discussion relating to indirect CO_2 emissions, under "Methodological aspects".

sheeting can increase slightly, even when the quantities of sheeting used decrease, because use of bitumen roofting 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 [71]).

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, 2022), 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 190: Production and laying of roof and sealing sheeting with bitumen, and relevant activity data and emission factors

	Produced or used area in 2021 [millions of m^2]	EF/ IEF [kg/ m^2]
Production of roof and sealing sheeting with bitumen	169	NMVOC 0.000358
Laying of roof and sealing sheeting containing bitumen	144	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 improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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[72].

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 [72]).

In 2021, a total of about 38 million t of asphalt (DAV, 2022) 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).

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

[72] Cf. the discussion relating to indirect CO_2 emissions, under "Methodological aspects".

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 191: 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 improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)

Since 2004, increasing numbers of vehicles in Germany have been equipped with Selective Catalytic Reduction (SCR) catalytic converters. Such catalytic converters control NO_x emissions with the help of a liquid-reductant agent, an aqueous urea solution.[73] 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).

[73] Average urea concentration pursuant to DIN 70070: 32.5 %

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, Heidt, Gores, et al., 2021) on the basis of fuel-consumption data for vehicles equipped with SCR catalytic converters.

Table 192: Modelled quantities of AdBlue® used, in tonnes

	2004	2005	2010	2015	2016	2017	2018	2019	2020	2021
Automobiles			3,031	53,918	97,538	141,597	177,957	202,643	181,881	199,353
Light-duty vehicles				606	4,632	18,012	37,363	55,848	65,773	80,769
Trucks	203	7,640	344,837	574,584	630,691	682,151	724,394	736,761	730,089	749,876
Buses	51	201	17,382	38,476	44,676	48,600	53,110	57,703	40,510	41,954
Σ road	**254**	**7,841**	**365,250**	**667,582**	**777,538**	**890,359**	**992,823**	**1,052,956**	**1,018,252**	**1,071,953**
Construction sector				5,915	16,062	29,023	41,793	54,236	66,729	79,331
Commercial and institutional				876	2,405	4,347	6,256	8,132	10,018	11,944
Agriculture				2,363	6,749	13,098	20,145	27,241	35,105	44,826
Forestry sector				334	1,064	2,129	3,786	5,235	7,552	9,089
Σ Offroad				**9,488**	**26,279**	**48,597**	**71,981**	**94,844**	**119,404**	**145,189**
Total	**254**	**7,841**	**365,250**	**677,070**	**803,817**	**938,955**	**1,064,804**	**1,147,800**	**1,137,657**	**1,217,142**

Source: Knörr, Heidt, and Bergk (2021); Knörr, Heidt, Gores, et al. (2021)

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 193: CO_2 emissions resulting from use of AdBlue®, in kilotonnes

	2004	2005	2010	2015	2016	2017	2018	2019	2020	2021
Automobiles			0.72	12.85	23.25	33.75	42.41	48.30	43.35	47.51
Light-duty vehicles				0.14	1.10	4.29	8.90	13.31	15.68	19.25
Trucks	0.05	1.82	82.19	136.94	150.31	162.58	172.65	175.59	174.00	178.72
Buses	0.01	0.05	4.14	9.17	10.65	11.58	12.66	13.75	9.65	10.00
Σ road	**0.06**	**1.87**	**87.1**	**159**	**185**	**212**	**237**	**251**	**243**	**255**
Construction sector				1.41	3.83	6.92	9.96	12.93	15.90	18.91
Commercial and institutional				0.21	0.57	1.04	1.49	1.94	2.39	2.85
Agriculture				0.56	1.61	3.12	4.80	6.49	8.37	10.68
Forestry sector				0.08	0.25	0.51	0.90	1.25	1.80	2.17
Σ Offroad				**2.26**	**6.26**	**11.6**	**17.2**	**22.6**	**28.5**	**34.6**
Total	**0.06**	**1.87**	**87.1**	**161**	**192**	**224**	**254**	**274**	**271**	**290**

Source: Knörr, Heidt, and Bergk (2021); Knörr, Heidt, Gores, et al. (2021)

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*.

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.

In a conservative approach, an uncertainty of ±20% is assumed for the activity data. For the emission factor, an uncertainty of ±10% is assumed.

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 relevant involved experts and 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 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 194: Revised annual fuel consumption of vehicles with SCR systems, in terajoules

	2004	2005	2010	2015	2016	2017	2018	2019	2020
2023 Submission	204	6,413	362,363	983,205	1,095,009	1,169,391	1,242,910	1,291,487	1,207,384
2022 Submission	204	6,402	366,267	972,677	1,099,810	1,210,755	1,300,247	1,375,806	1,299,775
Absolute change	0.28	11.3	-3,905	10,528	-4,801	-41,364	-57,338	-84,319	-92,392
Relative change	0.14%	0.18%	-1.07%	1.08%	-0.44%	-3.42%	-4.41%	-6.13%	-7.11%

Source: Own calculations, based on Knörr, Heidt, and Bergk (2021); Knörr, Heidt, Gores, et al. (2021)

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 195: Revised quantities of AdBlue® used, in tonnes

	2004	2005	2010	2015	2016	2017	2018	2019	2020
2023 Submission	254	7,841	365,250	677,070	803,817	938,955	1,064,80	1,147,80	1,137,65
2022 Submission	254	7,827	370,680	670,930	787,423	911,309	1,027,54	1,126,85	1,136,33
Absolute change	0.35	13.9	-5,431	6,140	16,394	27,646	37,262	20,946	1,323
Relative change	0.14%	0.18%	-1.47%	0.92%	2.08%	3.03%	3.63%	1.86%	0.12%

Source: Own calculations, based on Knörr, Heidt, and Bergk (2021); Knörr, Heidt, Gores, et al. (2021)

The corrections of the AdBlue® quantities lead to the CO_2-emissions adjustments shown below.

Table 196: Revised CO_2 emissions, in kilotonnes

	2004	2005	2010	2015	2016	2017	2018	2019	2020
2022 Submission	0.06	1.87	87.1	161	192	224	254	274	271
2021 Submission	0.06	1.87	88.3	160	188	217	245	269	271
Absolute change	0.00	0.00	-1.29	1.46	3.91	6.59	8.88	4.99	0.32
Relative change	0.14%	0.18%	-1.47%	0.92%	2.08%	3.03%	3.63%	1.86%	0.12%

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

4.6 Electronics industry (2.E)

KC	Category	Activity	EM of	1995 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1995-2021
-/-	2 E, Electronics Industry		SF_6	48.7	0.0 %	33.3	0.0 %	-31.7 %
-/-	2 E, Electronics Industry		NF_3	5.0	0.0 %	13.7	0.0 %	177.0 %
-/-	2 E, Electronics Industry		HFC-23	14.3	0.0 %	12.3	0.0 %	-13.9 %
-/-	2 E, Electronics Industry		HFC-32	0.0	0.0 %	0.0	0.0 %	
-/-	2 E, Electronics Industry		CF_4	92.1	0.0 %	64.8	0.0 %	-29.6 %
-/-	2 E, Electronics Industry		C_2F_6	147.8	0.0 %	43.9	0.0 %	-70.3 %
-/-	2 E, Electronics Industry		C_3F_8	0.0	0.0 %	14.1	0.0 %	
-/-	2 E, Electronics Industry		c-C_4F_8	0.0	0.0 %	5.8	0.0 %	
-/-	2 E, Electronics Industry		C_6F_{14}	21.6	0.0 %	0.0	0.0 %	-100.0 %

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 of fluorinated greenhouse gases cannot be determined solely on the basis of input quantities (sales by gas vendors), 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 quality assurance, 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 quality assurance, 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 quality assurance, 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1995-2021
-/-	2 F, Product Uses as Substitutes for ODS		HFC-23	13.6	0.0 %	63.3	0.0 %	364.5 %
-/-	2 F, Product Uses as Substitutes for ODS		HFC-32	0.8	0.0 %	244.4	0.0 %	32133.2 %
-/-	2 F, Product Uses as Substitutes for ODS		HFC-43-10mee	C	C	C	C	C
-/T	**2 F, Product Uses as Substitutes for ODS**		**HFC-125**	**135.7**	**0.0 %**	**1,874.6**	**0.3 %**	**1281.0 %**
L/T	**2 F, Product Uses as Substitutes for ODS**		**HFC-134a**	**2,062.0**	**0.2 %**	**4,216.9**	**0.6 %**	**104.5 %**
-/T	**2 F, Product Uses as Substitutes for ODS**		**HFC-143a**	**76.6**	**0.0 %**	**1,233.3**	**0.2 %**	**1510.1 %**
-/-	2 F, Product Uses as Substitutes for ODS		HFC-152a	100.2	0.0 %	23.5	0.0 %	-76.5 %
-/-	2 F, Product Uses as Substitutes for ODS		HFC-227ea	0.7	0.0 %	81.4	0.0 %	12001.5 %
-/-	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_2F_6	0.0	0.0 %	2.4	0.0 %	
-/-	2 F, Product Uses as Substitutes for ODS		C_3F_8	20.1	0.0 %	0.9	0.0 %	-95.5 %
-/-	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 197/Table 198	cf. Table 197/Table 198	cf. Table 197/Table 198

The category *Product Uses as Substitutes for ODS* is a key category for HFC-134a emissions in terms of level and trend, and a key category for HFC-143a and HFC-125 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 197: 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 198: 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		Tier 2a	HFC		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		Tier 2a	HFC		50 (D)	C	0.0066 (CS)	NO
open-cell	2.F.2b							
- XPS foam with 152a		Tier 2a	HFC		-	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	HFC		-	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	HFC		-	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 197).

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. It is reported voluntarily as an "additional greenhouse gas" (Chapter 4.9.3).

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 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 Global Warming Potential (GWP) of 2,500 or greater. As of 2022, the GWP limit in this regard drops 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[74] (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).

[74] EPEE: The European Partnership for Energy and the Environment.

- 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.
- 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 (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 197), 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 individual units, the recovery factor was 32.6 % in 2003, and 60 % as of 2020. For condensing units, the recovery factor was 47.5 % in 2005 and 80 % as of 2013, 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[75]. 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 (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

[75] EHI – EHI Retail Institute, Cologne; The Nielsen Company GmbH, Frankfurt am Main.

refrigeration systems that use refrigerants. Since 1997, the refrigerants used have been HFC-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 197). 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 % (as of 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 cooling capacity installed, 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 (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 197.

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 % as of 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 % as of 2020. For refrigeration systems of sectoral application areas, the recovery factor was 45 % in 2002 and 80 % as of 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 2021, at 4 % and 8 %, 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 197.

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. After that year, it decreased continuously through the year 2020, to a level of 5 %(cf. Table 197), in keeping with the increasing care being taken in managing and handling HFC refrigerants. 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 commonly used as a 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, jährlich - 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 (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 197.

The emission factors used have been obtained via: studies of the literature (for example, Schwarz and Harnisch (2003); Siegl et al. (2002); Clodic and Barrault (2011); Clodic et al. (2012); (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 % as of 2020. The estimated recovery factors are as follows: 38 % for buses, 11.7 % for agricultural machinery and 75.6 % (2017) to 80 % (as of 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 197.

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 197). 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 % (as of 2020); and for VRF multi-split units, they range from 8.1 % (2003) to 4.9 % (as of 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 % as of 2020; for single-split units, it was 37.9 % in 2008 and 60 % as of 2020; while for multi-split units, it was 62 % in 2011 and 80 % as of 2020. For VRF multi-split units, it was 72 % in 2016 and 80 % as of 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.
- 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 197.

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 % (as of 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, is 65.8 % in 2003 and 80 % as of 2020, while the factor for turbo-compressor systems is 69.5 % in 2003 and 80 % as of 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 197.

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 is 50 % in 2010 and 65 % as of 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 197.

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 (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 197.

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 as of 2020, it is 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 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) (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)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

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. In addition, the number of service-station shops for 2020 has been upwardly corrected. It now also includes autobahn service stations. This has led to changes in emissions from production and use of HFC-125, HFC-134a, HFC-143a and HFC-32 in the year 2020.

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 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 meat and wine production were updated for the year 2020, on the basis of new statistics. In addition, the fractions of R404A and R407C, in the years 2016 through 2020, in refrigeration units for wine production, and, for the year 2019, in systems for fruit-juice production, had to be recalculated to take account of a model update. This has led to changes in emissions from production and use of HFC-125, HFC-134a, HFC-143a and HFC-32 in the years 2016 through 2020.

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 railway vehicles (sub-category 2.F.1.e), the quantities consumed for production had to be changed for the year 2020. This led to changes in emissions from production and use of HFC-134a.

As a result of new findings, for single-split room air-conditioners (sub-category 2.F.1.f), the fraction of HFC-32 in new units had to be increased from 60 to 90 %, and the fraction of R410A decreased from 40 to 10 %, for the year 2020. This has led to changes in emissions from production and use of HFC-125 and HFC-32.

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 2016 through 2020, are shown in Table 199.

Table 199: 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 2016 through 2020

	Units	2016	2017	2018	2019	2020
EM HFC-125						
2023 Submission	t CO_2eq	2,258,185	2,272,571	2,252,195	2,146,960	2,069,043
2022 Submission	t CO_2eq	2,258,185	2,272,571	2,252,195	2,146,963	2,079,388
Difference	t CO_2eq	± 0.010	± 0.010	± 0.013	- 2.041	- 10,344
EM HFC-134a						
2023 Submission	t CO_2eq	5,188,984	4,999,080	4,822,681	4,564,614	4,464,259
2022 Submission	t CO_2eq	5,188,984	4,999,080	4,822,681	4,564,614	4,371,671
Difference	t CO_2eq	± 0.003	± 0.003	± 0.004	- 0.600	- 7,412
EM HFC-143a						
2023 Submission	t CO_2eq	1,937,129	1,827,008	1,637,116	1,450,989	1,257,200
2022 Submission	t CO_2eq	1,937,130	1,927,008	1,637,116	1,450,985	1,257,474
Difference	t CO_2eq	- 0.032	- 0.021	- 0.027	± 4.356	- 274
EM HFC-32						
2023 Submission	t CO_2eq	148,062	164,621	179,929	193,290	217,709
2022 Submission	t CO_2eq	148,062	164,621	179,929	193,290	215,778
Difference	t CO_2eq	- 0.001	- 0.0004	- 0.0005	± 0.073	± 1,931
EM HFC-227ea						
2023 Submission	t CO_2eq					2,341
2022 Submission	t CO_2eq					2,324
Difference	t CO_2eq					± 17
EM HFC-23						
2023 Submission	t CO_2eq					57,469
2022 Submission	t CO_2eq					58,593
Difference	t CO_2eq					- 1,124
EM PFC-116						
2023 Submission	t CO_2eq					2,627
2022 Submission	t CO_2eq					2,691
Difference	t CO_2eq					- 63
EM PFC-218						
2023 Submission	t CO_2eq					1,214
2022 Submission	t CO_2eq					1,259
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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 198.

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[76]); 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.

[76] 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 198.

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[77] association or by its EXIBA[78] 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.

[77] CEFIC – The European Chemical Industry Council
[78] 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 198.

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 198.

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)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

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.

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 2020, to take account of determination of the relevant propellants' applicable fractions via surveys pursuant to the Environmental Statistics Act (UStatG, 2005).

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). 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.

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), for the year 2020, are shown in Table 200.

Table 200: 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 year 2020

	Units	2020
EM HFC-134a		
2023 Submission	t CO_2eq	63,926
2022 Submission	t CO_2eq	64,588
Difference	t CO_2eq	- 662
EM HFC-152a		
2023 Submission	t CO_2eq	19,679
2022 Submission	t CO_2eq	31,087
Difference	t CO_2eq	- 11,408
EM HFC-227ea		
2023 Submission	t CO_2eq	9,625
2022 Submission	t CO_2eq	10,804
Difference	t CO_2eq	- 1,179
EM HFC-245fa		
2023 Submission	t CO_2eq	207,443
2022 Submission	t CO_2eq	130,493
Difference	t CO_2eq	± 76,950
EM HFC-365mfc		
2023 Submission	t CO_2eq	89,258
2022 Submission	t CO_2eq	87,129
Difference	t CO_2eq	± 2,129

4.7.2.7 Planned improvements, category-specific (2.F.2 all)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 198.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 198.

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 198.

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)

The applicable quantity of HFC-1234ze for domestic filling, and the quantity of HFC-1234ze sold in general-purpose aerosols, for the years 2018 through 2020, had to be recalculated to take account of new data from producers. This led to changes in emissions from production and use. Since HFC-1234ze is among the substances that are reported on a voluntary basis, no further quantification is carried out.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 QA/QC and verification (2.F all)

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 relevant involved experts and the Single National Entity.

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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	2 G, Other Product Manufacture and Use		CH_4	5.1	0.0 %	23.7	0.0 %	367.4 %
-/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		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 %	-
-/-	2 G, Other Product Manufacture and Use		$C_{10}F_{18}$	C	C	C	C	C

Gas	Method used	Source for the activity data	Emission factors used
CO_2, CH_4, N_2O, SF_6, PFC, HFC	cf. Table 201	cf. Table 201	cf. Table 201

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 201.

Table 201: 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 decreased, primarily as a result of reductions of emissions from the high-voltage sector through 2020. Emissions from medium-voltage systems and other equipment have been increasing, partly as a result of the continually growing numbers of systems in service. The total emissions remained constant in 2021. . 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 201.

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 202 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 202: 2021 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:	**562**	**3203**	**11**	**3.7**	**6.0**
MV switchgear and controlgear *	185	1481	1.2	0.3	1.5
HV switchgear and controlgear **	304	1351	9	1.2	3.5
Other electrical equipments ***	72	371	0	2.2	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 quality assurance 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 (Schwarz et al., 2012). Only very 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 203: SF_6 stocks in particle accelerators, in 5 application sectors, as of 1995, in t

User category	1995	2001	2003	2010	2015	2021
(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	0.137
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 204: 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	2021
(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	0.522
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 205).

Table 205: 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	2021
(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 the 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 (Schwarz & Leisewitz, 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 201.

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 quality assurance 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.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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[79], 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.

[79] 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[80]. 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[81], 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.

[80] Personal communication: Federal Office for Material Research and Testing (BAM).
[81] 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 quality assurance in conformance with the requirements of the QSE manual and its associated applicable documents, have been carried out by the Single National Entity.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 201.

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 quality assurance, 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.

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)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report (IPCC AR4), in order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

The HFC-245fa-charge quantity for the year 2020 was updated on the basis of information provided by producers. This led to a reduction of emissions from production and use of HFC-245fa from 13,333 to 13,245 t CO_2 equivalents.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 201.

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 QA/QC 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 quality assurance in conformance with the requirements of the QSE manual and its associated applicable documents, have been carried out by the Single National Entity.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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.

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 206: 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), and review of the emission factors on the basis of actual installation measurements from 2021)

in kg/t	NO_X	NMVOC	SO_2	CO
Sulphate pulp	1.071	C	0.017	0.474
Sulphite pulp	1.66		1.54	0.1

According to the most recent figures, the following quantities were produced, in a total of 153 plants:

Table 207: Pulp and paper production, produced quantities

Product	Quantities produced in 2021	
Production of paper, cardboard and carton (PCC):	23.12	million t
Raw-material production:		
Paper pulp	1,571	kt
Wood pulp	756	kt
Recycled paper	14,470	kt
Quantity of recycled paper used for this purpose	(18,294 kt)	

Source: (DIE PAPIERINDUSTRIE e. V. - Erzeugerpreisindex StaBu, 2022)

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 (Statistisches Bundesamt, 2022f), have to be converted from volume-based units into mass-based units.

Table 208: Converted activity data for the particle-board industry

Year	2016	2017	2018	2019	2020	2021
Particle-board production [in t]	4,560,000	4,703,000	4,322,168	4,489,681	4,430,611	4,775,500

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 2022, since the activity data for sulphite pulp for the year 2020, as summed, failed to include one plant's production. 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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, Nanning, et al. (2006b); Lechtenböhmer, Nanning, 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 (2019a), 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 15.4 kt of NMVOC emissions result for 2021. Of those, 4.1 kt NMVOC are from bread production, 3.8 kt NMVOC are from sugar production and 3.7 kt NMVOC are from production of spirits. The changes with respect to the previous year lie within the customary fluctuation range. Considerable decreases occurred only in the area of bread production, while harvest-related increases occurred in the area of sugar 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)

Recalculations for NMVOC in the area of animal-feed production were required, to take account of minimal corrections in the previous year's statistics. They led to an increase of less than one tonne of NMVOC. Corrections in the statistics for production of dried green fodder led to a 7-tonne increase of particulate matter emissions, which corresponds to an increase of 3.8%.

4.9.2.6 Category-specific planned improvements (2.H.2)

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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, SF_6	Cf. Chapter 4.6.4: Table 198/ Table 201	Cf. Chapter 4.6.4 / 4.7.5 / 4.8.2	cf. Table 198/Table 201

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 209, 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 210 shows the emissions of these greenhouse gases, which are not subject to reporting obligations, in aggregated form.

Table 209: Overview of voluntarily reported fluorinated greenhouse gases, their global warming potentials (AR5 GWP) and their areas of application

GHG	Formula	GWP	Area of application	QG
HFCKW-1233zd	$CHCl=CH-CF_3$ (E)	1	Stationary air conditioning systems	2.F.1.f
HFC-1234yf	$CF_3-CF=CH_2$	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)	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)	$CHF_2OCHClCF_3$	491	Inhaled anaesthetic	2.G.2.e
HFE-236ea2 (desflurane)	$CHF_2OCHFCF_3$	1,790	Inhaled anaesthetic	2.G.2.e
HFE-347mmz1 (sevoflurane)	$CH_2FOCH(CF_3)_2$	216	Inhaled anaesthetic	2.G.2.e
PFPE/PFPMIE	$CF_3(OCF(CF_3)CF_2)_n(OCF_2)_mOCF_3$	9,710	ORC systems	2.G.4
Sulphuryl difluoride	SO_2F_2	4,090	Container fumigation	2.G.4

Source: 5 IPCC Assessment Report, Chapter 8, p. 731, Appendix 8.A (Stocker et al., 2014).

Table 210: 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	4,262
1991	5,323
1992	6,480
1993	7,733
1994	9,082
1995	10,527
1996	21,650
1997	32,320
1998	43,855
1999	56,254
2000	69,519
2001	80,526
2002	92,161
2003	104,423
2004	118,336
2005	130,831
2006	379,351
2007	416,911
2008	368,045
2009	417,697

Year	Emissions, in t CO_2 equivalents
2010	394,191
2011	310,949
2012	348,969
2013	424,495
2014	387,923
2015	401,615
2016	375,204
2017	337,966
2018	430,866
2019	848,613
2020	1,036,812
2021	633,557

5 Agriculture (CRF Sector 3)

5.1 Overview (CRF Sector 3)

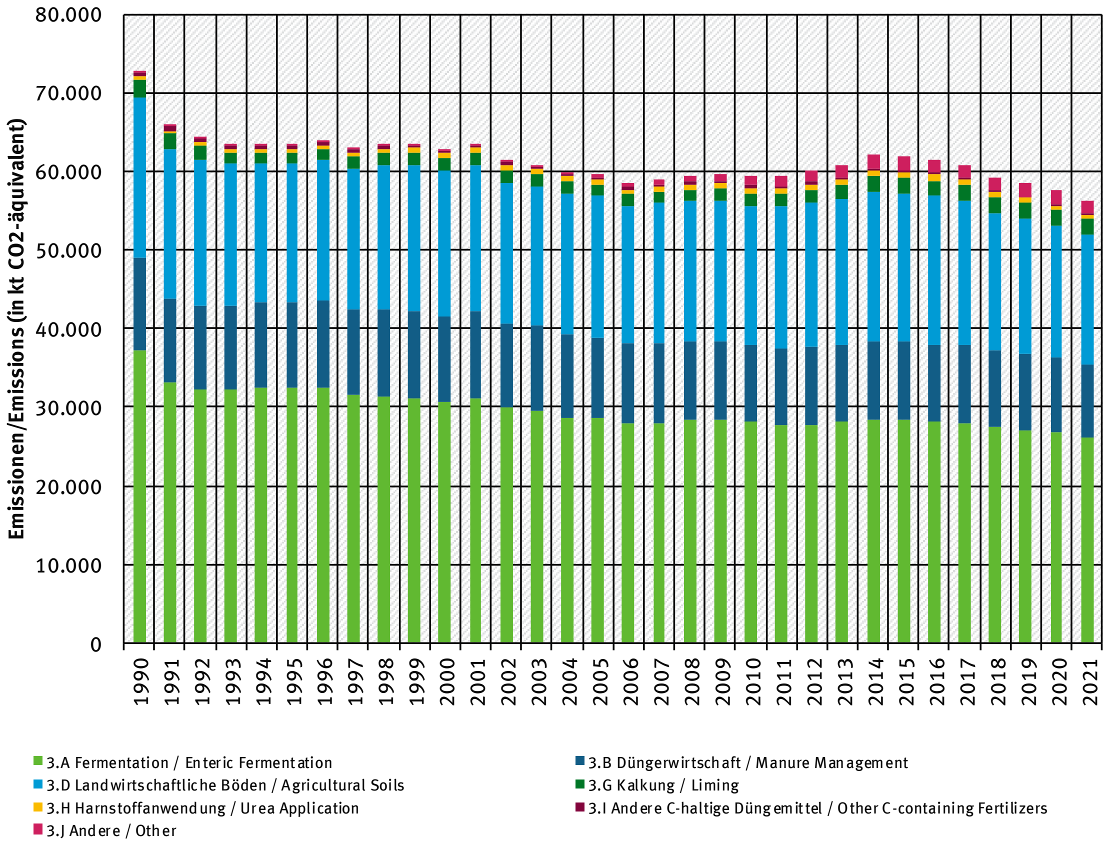
5.1.1 Categories and total emissions, 1990 - 2021

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 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). However, in the present 2023 submission, emissions from spreading of digestates of waste, and from spreading of compost of biowaste and garden waste, are being reported, for the first time, in 3.D.

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. Rösemann et al. (2023), Chapter 2.8.9) (NO).

For the present 2023 NIR, Figure 46 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 46: 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 Py-GAS-EM emissions-inventory model is based primarily on the relevant sets of guidelines (greenhouse gases: IPCC (2006c, Vol. 1 & 4); (IPCC, 2019a)air pollutants, especially NH_3: EMEP/EEA (2019a). 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 (Rösemann et al., 2023). 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 47 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 47: 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.)

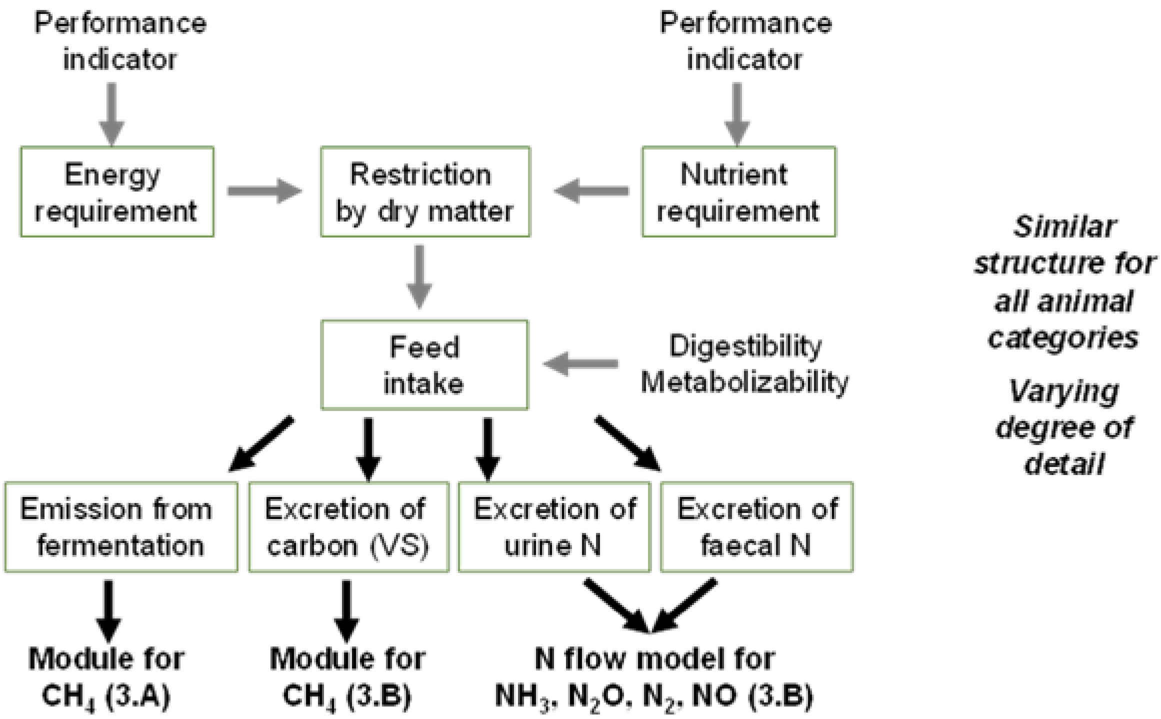
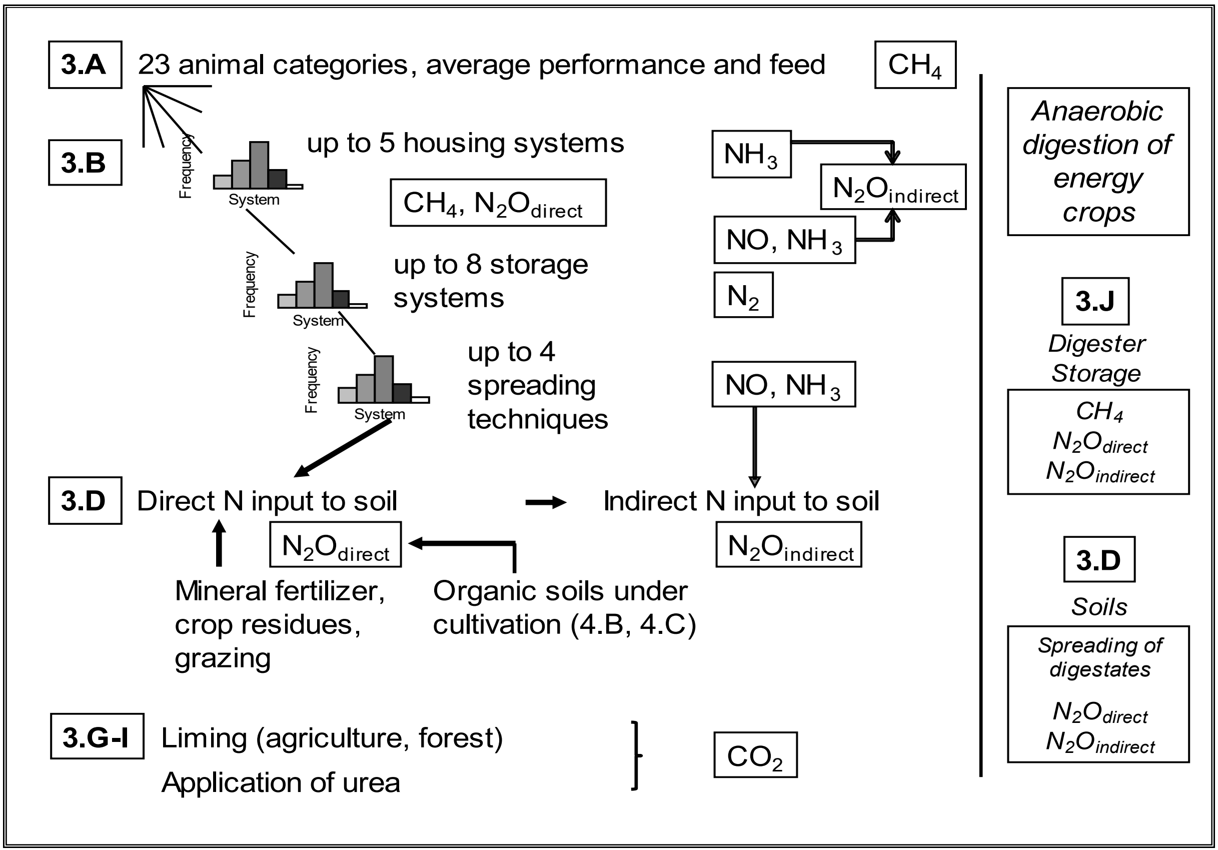


Figure 48 shows how the Py-GAS-EM model, for purposes of calculations in categories 3.A and 3.B, first differentiates between animal categories and sub-categories and then further subdivides those categories into housing systems, storage systems (with digestion as a separate storage system) and procedures 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 48: Concept and thematic content behind the 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 4.2 in Rösemann et al. (2023) .

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. Chapter 4.2.2 in Rösemann et al. (2023). 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 direct and indirect N_2O emissions from agricultural soils, resulting from application of mineral fertiliser, sewage sludge, digestates of waste, and biowaste/garden waste compost, 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 211 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 UNFCCC (2014a para 37)) and German statistical surveys do not record the respective animal numbers. The emissions contributions from those categories are estimated in Chapter 16.3.1. All those sources for which no emissions are reported ("NE" is entered) are listed in Chapter 18.

Table 211: 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
1	Dairy cows	"Dairy cows" [a]
	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 2.3.1 in Rösemann et al. (2023).

[b] For definitions of dairy heifers and female beef cattle, cf. Rösemann et al. (2023), Chapter 2.2.

[c] These animals do not occur in Germany.

[d] These animals are not reported on, since their emissions contribution is insignificant; cf. Chapter 16.3.1.

[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 1.1.2.2 in Rösemann et al. (2023).

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 (2006c Vol 4, Section 10.2.2): Vol. 4, Section 10.2.2., a definition that has also been adopted by EMEP (cf. EMEP/EEA (2019a 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 that, in addition to collecting other data, carry out censuses of 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 (Statistische Ämter des Bundes und der Länder, 2010), a more extensive census.

Thereafter, they were carried out again in 2013, 2016 and 2020. 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 (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 adjusted in this regard. 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 2.2 in Rösemann et al. (2023)). The total number of other cattle in the inventory always corresponds to the total number of other cattle surveyed, however. For details, cf. Chapter 2.3.1 in Rösemann et al. (2023).

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 (Deutscher Büffelverband); cf. Chapter 2.3.1 in Rösemann et al. (2023). 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 2.3.1 of Rösemann et al. (2023). 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 2.3.1 of Rösemann et al. (2023)).

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 2.3.4 in Rösemann et al. (2023). 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. The relevant animal number for 2021 has been estimated via extrapolation of the trend prevailing between 2016 and 2020.

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. In keeping with data of the Interessengemeinschaft für Esel und Maultiere (IGEM) (Schmutz, 2009), the applicable number for mules and asses has been estimated at 8,500 mules and asses per year. Gaps within the time series for horses have been filled in via linear interpolation. The relevant animal number for 2021 has been estimated via extrapolation of the trend prevailing between 2016 and 2020.

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. Chapter 2.3.3 in Rösemann et al. (2023). 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. Except with regard to laying hens, the values for 2020 have been retained for 2021. For laying hens, the figures for 2021 were estimated on the basis of the figures for 2020 and the trends in the data published by the Federal Statistical Office on numbers of housing places (Rösemann et al., 2023).

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 212 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 2.3 of Rösemann et al. (2023). 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. In the swine category as well, a noticeable decrease has occurred since 2017. It follows a period of years with no consistent trend. For dairy cows, other cattle and swine, the animal counts for the year 2021 are the lowest seen throughout the entire relevant period since 1990. The reason for the decrease cannot be unambiguously determined. Examples of possible reasons for this include an unfavourable economic framework; a lack of feed, resulting from the widespread drought that prevailed in Germany in 2018 and 2020; 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. That trend did not continue in the last time-series year, however. 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 254 in Chapter 5.1.6.

Table 212: 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
2021	3,833	7,207	19,729	1,795	159	457	173,995

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, 2022a). 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 15 August 2022: time series through 2020) are compared with the data used in the 2023 submission: From 1990 through 2020, only about 13 % 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: The FAOSTAT animal-population data agree with the official German data only for the years 2014 – 2020. 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)

As a result of quality-assurance measures and the availability of updated input data, numerous changes have been carried out, with respect to the 2022 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 1.3.6 in Rösemann et al. (2023)).

- 2020 agricultural census: The results of the 2020 agricultural census that have been used, with regard to proportions of housing, storage and application procedures, and to grazing, were assumed to hold for the year 2019 – and not, as was assumed in the 2022 submission, for the year 2020. As a result, the data obtained via interpolation, for the various proportions, have changed slightly. In some cases, the changes reach back into the year 2000. For the first time in such surveys, the survey has yielded data on field-stored cattle and swine manure, as a share of total manure production. With the help of this share, which is assumed to be constant for the entire time series, indirect emissions from leaching from manure storage are being reported for the first time.
- Dairy cows: The 2020 milk-yield and slaughter-weight data have been slightly corrected in the official statistics. An averaging error in connection with VS excretions has been corrected, with slight impacts on the methane emissions in 3.B.
- Heifers: The 2020 slaughter-weight data have been slightly corrected in the official statistics.
- 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 Lower Saxony, and for the years 2015-2020, the number of piglets per sow and year has been corrected (reduced).
- Fattening pigs: With regard to the crude-protein feed parameter for fattening-pig feed, the results of the Federal Statistical Office's additional survey "Protein inputs in pig fattening" ("Proteineinsatz in der Schweinemast") for the year 2020 were available (Statistisches Bundesamt, 2022g). Via interpolation, the crude-protein levels have decreased, with the result that the N excretions of fattening pigs have also decreased, back to the year 2011. For Lower Saxony, the weight-gain rates were corrected for the years 2018 and 2019, and the final weights were corrected for the year 2019.
- Broilers: The extrapolated values for the input variable "total gross meat quantity obtained at slaughter," for 2020, were replaced with data of the Federal Statistical Office.
- Laying hens: On-pasture emissions for laying hens have been introduced, since an expert judgement of the Association for Technology and Structures in Agriculture (KTBL) (Grebe & Eurich-Menden, 2022) has made it possible to estimate the proportion of excretions of free-range laying hens that occur on pasture. On the basis of the results of the LZ2020 agricultural census, a new NH_3 emission factor for barn (floor) housing has been derived for 2020 (for the years 2011-2019, new emission factors then result, via linear interpolation). For periods in which laying hens are not on pasture, the NH_3 emission factor for free-range management is equivalent to the NH_3-EF for barn housing.

Table 213 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 2.4.1 in Rösemann et al. (2023). With regard to calculation of the mean animal weights for other cattle, swine and poultry, also see Chapter 2.4.1 in Rösemann et al. (2023).

Table 213: 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	2021
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	600.8
Other cattle	316.3	328.6	338.1	334.9	337.1	334.4	333.4	334.4	333.9	335.3	335.6	336.1	337.7	340.5	342.2	342.4
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	64.3
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	1.69	1.69

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. Chapter 2.4.1 in Rösemann et al. (2023).

Table 214 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 2020, with respect to the 2022 NIR, is a result of the above-described updating of milk-yield data.

Table 214: 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	2021
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	23.16	23.25

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 Chapter 2.4.5 in Rösemann et al. (2023). Such calculations are based on the IPCC concept (IPCC (2006c 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. 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 Chapter 2.4.5 in Rösemann et al. (2023). No GE intake figures are determined for the remaining animal categories (sheep, goats, horses, poultry).

Table 215 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 215: 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	2021
Dairy cows	241.3	264.0	283.0	298.8	307.5	310.5	312.5	312.1	316.0	318.9	322.3	322.5	329.4	336.7	342.5	343.4
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	111.4
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	36.0	36.3	36.8

Table 216 through Table 218 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 Chapter 2.4.6 in Rösemann et al. (2023). 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 216: Daily DM intake

[kg $^{-1}$ place^{-1} d^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Dairy cows	13.20	14.44	15.47	16.32	16.75	16.91	17.00	16.97	17.18	17.33	17.51	17.52	17.89	18.28	18.59	18.64
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	6.08
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	2.24

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 217 and Table 218 and b) the corresponding table values in the 2022 NIR result from the aforementioned changes in performance and feed data.

Table 217: Digestibility of organic matter in feed (3.A)

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Dairy cows	75.5	75.4	75.5	75.8	75.7	75.7	75.7	75.6	75.6	75.7	75.7	75.7	75.8	75.9	75.9	76.0
Other cattle	74.5	74.3	74.1	74.2	74.1	74.1	74.1	74.1	74.1	74.1	74.1	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	84.3

Table 218: Ash content of feed

[kg kg^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Dairy cows	0.084	0.084	0.083	0.082	0.078	0.078	0.077	0.076	0.076	0.076	0.075	0.075	0.075	0.075	0.074	0.074
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	0.087	0.087	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	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 Chapter 4.1.2 in (Rösemann et al., 2023) .

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 16.3.2, Table 510).

Table 219 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}). As a result of the changes mentioned in Chapter 5.1.3.3, slightly different N excretions, in comparison to the relevant figures in the 2022 NIR, resulted for cattle. The N excretions of swine have decreased since 2011, as a result of updating of crude-protein feed parameters for fattening pigs, as described in Chapter 5.1.3.3. Updating of the total gross meat quantity obtained at slaughter, for broilers, has led to slightly higher N excretions for poultry in 2020 than were reported in the 2022 NIR.

Table 219: 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	2021
Dairy cows	92.0	97.9	103.8	108.9	110.2	110.9	111.2	110.7	111.6	112.8	114.1	113.8	116.1	119.1	121.4	121.9
Other cattle	37.9	39.9	41.3	41.2	42.1	42.0	42.0	42.2	42.2	42.5	42.5	42.7	42.9	43.4	43.7	43.8
Swine	13.0	13.4	13.2	13.0	12.8	12.7	12.7	12.6	12.6	12.7	12.7	12.6	12.6	12.5	12.4	12.6
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	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	48.9
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	0.66

Table 220 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 with regard to the 2022 submission are due mainly to reinterpolation of the data from the 2020 agricultural census (Landwirtschaftszählung 2020), the new crude-protein parameters for fattening-pig feed, and the introduction of on-pasture time for laying hens; cf. Chapter 5.1.3.3.

Table 220: 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	2021
Total	1555.1	1336.2	1301.0	1254.0	1246.6	1248.6	1265.4	1277.5	1289.6	1286.3	1275.4	1267.2	1244.9	1232.0	1218.8	1184.5
Slurry-based [a]	870.5	820.1	803.0	739.9	634.3	615.7	618.7	606.7	611.0	609.6	609.8	607.2	600.1	600.5	593.1	566.4
Straw-based [b]	423.1	292.6	283.7	281.2	279.1	272.2	268.9	263.8	257.3	248.3	237.9	229.0	219.5	210.3	206.4	204.3
Deep bedding [a]	48.4	49.9	53.6	61.6	68.1	70.3	74.8	80.5	85.5	88.9	92.7	95.7	98.1	101.1	98.8	96.4
Digestion	0.04	0.56	4.8	32.4	132.6	161.7	175.4	198.4	207.3	211.1	208.6	210.8	205.2	199.8	202.0	201.0
Grazing	213.1	173.0	155.9	138.9	132.5	128.7	127.4	128.1	128.6	128.4	126.4	124.5	122.0	120.3	118.5	116.4

[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 4.1.1 in Rösemann et al. (2023).

Equation 5: Calculation of VS excretions

$$VS_i = m_{\text{feed, DM, i}} \cdot (1 - X_{\text{DOM,i}}) \cdot (1 - x_{\text{ash, feed}})$$

VS_i	VS excretions for animal category i (in kg place⁻¹ d⁻¹)
$m_{\text{feed, DM, i}}$	Dry-matter intake, animal category i (in kg place⁻¹ d⁻¹)
$X_{\text{DOM, i}}$	Digestibility of organic matter, animal category i (in kg kg⁻¹)
$X_{\text{ash, i}}$	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 4.1.1 in Rösemann et al. (2023): 0.029 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 221. For dairy cattle, the VS excretions differ slightly from the figures given in the 2022 NIR, as a result of the model correction mentioned in Chapter 5.1.3.3.

Table 221: 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	2021
Dairy cows	2.96	3.26	3.47	3.63	3.75	3.79	3.81	3.82	3.87	3.90	3.93	3.94	4.01	4.08	4.14	4.15
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	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	0.34
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	0.025

Table 222 shows the daily VS excretions for sheep, goats and horses. Cf. in this regard , Chapter 4.1.1 in Rösemann et al. (2023). 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 222: Daily VS excretions for sheep, goats and horses (3.B(a))

[kg place^{-1} d^{-1}]	*VS*	Mean value, 2021
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 2.5 in Rösemann et al. (2023). With regard to description of the frequency distributions at the level of Germany as a whole, we refer to Chapter 16.3.2 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. The changes with regard to the 2022 submission are due mainly to changed interpolation of the data from the 2020 agricultural census (Landwirtschaftszählung 2020), and to the introduction of on-pasture emissions for laying hens; cf. Chapter 5.1.3.3.

Other changes with respect to the 2022 NIR are the result of updating of input data for manure digestion; cf. Chapter 5.1.3.6.5.

Table 223: 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	2021
Dairy cows	53.1	69.5	72.1	70.0	59.6	57.0	56.4	54.8	54.7	55.2	56.2	56.3	57.2	58.5	58.1	57.9
Other cattle	58.0	55.1	51.3	44.4	35.3	34.0	33.7	33.1	32.8	32.8	33.0	32.8	33.2	33.4	33.2	33.2
Swine	81.5	87.7	89.6	88.9	83.2	81.8	81.5	79.9	79.7	79.2	79.5	79.7	79.9	80.4	80.4	79.1

Table 224: 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	2021
Dairy cows	26.8	15.1	14.7	15.4	14.8	13.9	13.1	12.4	11.6	10.8	10.0	9.2	8.5	7.7	7.7	7.7
Other cattle	19.8	18.4	19.0	21.1	22.7	21.5	20.2	18.9	17.9	16.9	15.8	14.7	13.6	12.5	12.5	12.4
Swine	16.3	10.3	8.4	7.3	6.1	5.6	5.1	4.8	4.5	4.2	3.9	3.6	3.3	3.1	3.0	3.0
Poultry	99.9	99.9	99.3	96.3	89.3	88.0	87.5	85.8	85.4	84.7	84.8	85.1	85.4	85.3	84.6	84.6

Table 225: 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	2021
Dairy cows	0.1	0.2	0.2	0.2	0.5	0.9	1.2	1.6	1.9	2.3	2.7	3.0	3.4	3.8	3.8	3.8
Other cattle	7.3	9.6	10.9	14.1	15.8	16.5	17.3	18.1	18.9	19.5	20.4	21.1	21.9	22.7	22.6	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	1.3

Table 226: Digestion systems, in % of excreted VS (3.B(a))

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Dairy cows	0.003	0.053	0.52	3.4	15.3	18.7	20.0	22.2	23.0	23.1	22.9	23.5	23.3	22.7	23.1	23.3
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	10.5	10.7	10.9
Swine	0.002	0.040	0.32	2.4	9.5	11.3	12.2	14.0	14.5	15.3	15.3	15.5	15.5	15.2	15.4	16.6
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	14.3	14.3

Table 227: Grazing, in % of excreted VS (3.B(a))

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Dairy cows	20.0	15.2	12.5	11.2	9.8	9.6	9.3	9.1	8.8	8.5	8.2	7.9	7.6	7.3	7.3	7.3
Other cattle	14.9	16.9	18.5	18.5	19.1	19.3	19.3	19.5	19.8	20.1	20.3	20.5	20.7	21.0	21.0	20.9
Poultry	0.0	0.1	0.2	0.4	0.5	0.6	0.7	0.7	0.8	0.8	0.9	0.8	1.0	1.0	1.1	1.1

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 510 in Chapter 16.3.2 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 4.2.1 in Rösemann et al. (2023)), the bedding-material N quantities listed in Table 228, for the various animal categories, result.

Slight discrepancies with respect to the 2022 NIR occur in all animal categories, except for sheep, goats and horses. This is due mainly to changes in interpolation of data from the 2020 agricultural census; cf. Chapter 5.1.3.3.

Table 228: 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	2021
Total	**52.6**	**40.5**	**38.6**	**38.3**	**39.4**	**39.0**	**39.2**	**39.9**	**40.3**	**40.1**	**39.7**	**39.5**	**38.9**	**38.4**	**37.5**	**36.8**
Dairy cows	17.2	7.6	7.1	6.7	6.7	6.6	6.6	6.6	6.6	6.5	6.3	6.2	5.9	5.7	5.6	5.5
Other cattle	24.0	21.1	21.5	21.4	23.3	22.9	23.2	23.8	24.3	24.4	24.4	24.3	24.0	23.7	22.9	22.4
Swine	3.18	1.78	1.56	1.38	1.15	1.12	1.10	1.05	1.03	0.95	0.92	0.89	0.83	0.78	0.78	0.71
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	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	0.08
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	6.06
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	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 229 *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 (2006c): 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 4.4.1.1 in Rösemann et al. (2023). Owing to variations in the population fractions for the various poultry categories, *the mean* B_o for poultry is not a constant, as Table 230 illustrates.

Table 229: Maximum methane-producing capacity B_o (3.B(b))

[m^3 kg^{-1}]	B_o	Source
Cattle	0.23	(Dämmgen, Amon, et al., 2012)
Swine	0.30	(Dämmgen, Amon, et al., 2012)
Sheep	0.19	(IPCC, 2006c Vol 4, 10.82)
Goats	0.18	(IPCC, 2006c Vol 4, 10.82)
Horses	0.30	(IPCC, 2006c Vol 4, 10.82)
Laying hens	0.39	(IPCC, 2006c Vol 4, 10.82)
Broilers	0.36	(IPCC, 2006c Vol 4, 10.82)
Ducks	0.36	(IPCC, 2006c Vol 4, 10.82)
Turkeys	0.36	(IPCC, 2006c Vol 4, 10.82)
Pullets	0.39	Assumption (see text)
Geese	0.36	Chapter 4.4.1.1 in Rösemann et al. (2023)

Table 230: 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	2021
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	0.372	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 231 shows the MCF values for cattle, broken down by the storage systems commonly used in Germany. The national values proposed by Dämmgen, Amon, et al. (2012) 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 (2006c Vol 4, 10.44).

Table 231: 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 232 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, Amon, et al., 2012), default values from IPCC (2006c Vol 4, 10.44) IPCC (2006c) 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 232: *Methane-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 233 shows.

Table 233: 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	2021
Dairy cows	14.3	14.0	14.0	14.3	14.8	14.9	14.8	14.8	14.8	14.8	14.7	14.7	14.6	14.6	14.6	14.6
Other cattle	14.6	14.4	14.6	14.8	15.0	15.0	15.0	15.0	14.9	14.9	14.9	14.8	14.8	14.7	14.7	14.7
Swine	24.7	23.7	23.6	22.8	22.2	22.4	22.5	22.6	22.6	22.7	22.8	22.9	23.0	23.0	23.1	23.1

For storage of manure from other animals (goats, sheep, horses and poultry), default values from IPCC (2006c Vol 4, 10.44) are used (cf. Table 234).

Table 234: 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 (2006c, 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 2.6 and 4.4 in Rösemann et al. (2023)). The time series for the activity data have been provided on the basis of data of the Deutsches Biomasseforschungszentrum (DBFZ; German biomass research centre), 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. (2022) 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. (2022) 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 2022 submission.

Table 235 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 244 in the 2022 NIR result from the changes in the N excretions calculated for the inventory.

Table 235: 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	2021
Total	**0.003**	**0.048**	**0.42**	**2.9**	**11.9**	**14.4**	**15.4**	**17.3**	**17.9**	**18.2**	**18.2**	**18.4**	**18.3**	**18.0**	**18.4**	**18.8**
Cattle slurry	0.005	0.066	0.60	4.2	18.3	22.4	23.9	26.3	27.1	27.4	27.1	27.6	26.8	25.9	26.5	**27.0**
Cattle solid manure	0.001	0.015	0.13	0.9	3.2	4.0	4.4	4.8	5.0	5.2	5.3	5.5	5.4	5.5	5.7	**5.8**
Swine slurry	0.003	0.045	0.36	2.6	10.3	12.2	13.1	15.1	15.5	16.3	16.3	16.4	16.4	16.1	16.3	**17.6**
Poultry manure	0.004	0.057	0.44	3.3	10.2	11.5	11.9	13.6	13.9	14.6	14.5	14.3	13.9	13.9	14.6	**14.6**

The data in Table 235 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 4.4.1.2 in Rösemann et al. (2023).

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 236 shows the methane conversion factors $MCF\%_{ps}$ for pre-storage systems. For derivation of this equation, cf. Chapter 2.6 in Rösemann et al. (2023).

Table 236: 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., 2022), 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 2.6 in Rösemann et al. (2023).

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., 2022). In a 2016 study, the German Environment Agency (UBA) also assumed a leakage rate of 1 % 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

$$MCF\%_{residues} = x_{gts} \cdot (100 \cdot L_{sto,gt}) \; + \; (1-x_{gts}) \cdot MCF\%_{ngts}$$

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 237 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. (2022) 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 2020 have been updated with respect to the 2022 submission. This has led to an increase of about 0.5 percentage points in the distribution share for gas-tight covers. For 2021, the values for 2020 have been carried forward, due to a lack of new data.

Table 237: 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	2021
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	63.3	63.3
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	36.7	36.7

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 238: 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	2021
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	2.79
Other cattle	2.98	2.89	2.84	2.78	2.66	2.64	2.59	2.58	2.57	2.56	2.56	2.56	2.55	2.55	2.54	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	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	1.30	1.30

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 239 lists the N_2O emissions that the inventory takes account of for the various relevant sub-systems and manure types. For details, cf. Chapters 4.3.2.2 and 4.4.2.2 in Rösemann et al. (2023).

N_2O and NO emissions from agricultural soils, resulting from application of digestates, are described in Chapter 5.5.

Table 239: 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

$$E_{\text{N2O-N, dig,ps}} = (N_{\text{excr, dig}} + N_{\text{straw,dig}}) \cdot EF_{\text{N2O-N, dig,ps}}$$

Where

$E_{N2O\text{-}N, dig, ps}$	N losses via N_2O emissions from pre-storage of solid manure or poultry manure (in kg N_2O-N a^{-1})
$N_{excr, dig}$	Fraction of annual in-stable N excretions that goes to digestion (in kg a^{-1})
$N_{straw, dig}$	Fraction of annual N inputs from bedding material that goes to digestion (in kg a^{-1})
$EF_{N2O\text{-}N, dig, ps}$	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

$E_{N2O\text{-}N, dig, ngts}$	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})
$N_{tot, dig, ferm}$	Total N quantity from digestates that leaves the digester (in kg a^{-1})
$EF_{N2O\text{-}N, dig, ngts}$	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 240. For the derivation of these factors, we refer to Chapter 2.6 in Rösemann et al. (2023).

Table 240: N_2O-N emission factors for manure pre-storage and for storage of digestates

	[kg kg^{-1}]	Solid manure	Poultry manure
Pre-storage systems	$EF_{N2O\text{-}N, dig, ps}$	0.001	0.0001
Systems for storage of digestates, non-gas-tight	$EF_{N2O\text{-}N, dig, ngts}$	0.005	0.005

The N quantity in digestates at the beginning of storage ($N_{tot, dig, ferm}$) 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 4.3.2.2 in Rösemann et al. (2023), 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 4.3.1.2 and 2.6 in Rösemann et al. (2023).

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., 2022). 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 5.1 and 2.6 in Rösemann et al. (2023).

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 241. 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 2020 have been updated, with respect to the 2022 NIR, by (Grebe et al., 2022). The results show a very slight increase in 2020. The values from 2020 have been carried forward, due to a lack of data for 2021.

Table 241: 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	2021
	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	20,551	20,551

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 242.

Table 242: 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	2021
	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	19,462	19,462

The N quantities required for calculation of the N emissions are obtained with the help of the relevant N content; cf. Table 243.

Table 243: 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	2021
	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	304.2	304.2

In keeping with Grebe et al. (2022), 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 244 shows the fractions of gas-tight storage of residues of energy-crop digestion, as percentages of the pertinent input fresh matter (Grebe et al., 2022). The data for 2020 have been updated with respect to the 2022 submission. Since no data on frequencies of use of gas-tight storage were available for 2021, the relevant figures for 2020 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 237). 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 244: 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	2021
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	65.8	65.8
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	34.2	34.2

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 (for the year 2019); cf. Chapter 16.3.2, Table 512.

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 2023 submission, emissions from application of waste digestates, and of composts of biowaste and garden waste, in the agricultural sector, are being reported for the first time. In CRF 3.D.2.c, they are listed as "other organic fertilisers," and combined with the emissions from application of energy-crop digestates. Tier 2 emission factors are used for a) direct N_2O emissions from application of mineral fertiliser, manure, sewage sludge and other organic fertilisers 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 the distribution of N quantities at the NUTS-3 level are provided in Chapter 5.5.2.1.1. Tier 1 emission factors from IPCC (2006c) 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. (2020b) are used.

5.1.5.1.2 The N quantities behind direct N_2O emissions (3.D)

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 2020, a moving, centered three-year average; for 2021, a weighted average of 2020 (with weighting of 1/3) and 2021 (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, 2022b).

The N quantity in the total quantity of applied manure is calculated with the help of the N-flow concept (cf. Chapter 4.2 in Rösemann et al. (2023)); cf. Table 245. The leached N quantities refer to leaching in connection with field-edge storage of solid manure. In the present submission, such storage is being reported for the first time; cf. Chapter 5.1.5.1.5 (IPCC, 2019a; LAWA, 2019).

Table 245: 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	2021
N excretions [a]	1342.0	1163.2	1145.1	1115.1	1114.2	1119.9	1137.9	1149.5	1161.0	1157.9	1149.0	1142.8	1122.9	1111.7	1100.3	1068.0
+ bedding material N [b]	52.6	40.5	38.6	38.3	39.4	39.0	39.2	39.9	40.3	40.1	39.7	39.5	38.9	38.4	37.5	36.8
- (NH_3-N + NO-N) [c]	-244.4	-201.5	-200.4	-200.6	-197.1	-196.6	-198.9	-198.8	-198.9	-196.4	-193.3	-191.5	-185.8	-182.1	-178.8	-172.0
- 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	-4.1	-4.0
- N_2 [e]	-15.8	-14.2	-13.8	-13.8	-13.6	-13.3	-13.1	-13.1	-13.2	-13.1	-13.0	-12.9	-12.6	-12.5	-12.3	-11.9
- N leached	-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	0.0	0.0	0.0
Result	**1129.1**	**983.2**	**964.8**	**934.4**	**938.3**	**944.4**	**960.7**	**973.0**	**984.8**	**984.1**	**978.1**	**973.6**	**959.1**	**951.3**	**942.6**	**916.9**

[a] Total N excretions after deduction of excretions during grazing; cf. Table 220 in the present NIR (corresponds to the sum of line 38 in CRF Table 3.B(b))

[b] cf. Table 228 in the present NIR

[c] cf. cell O37 in CRF Table 3.B(b)

[d] cf. Table 286 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. Rösemann et al. (2023), Chapter 4.2.4)

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.

The N quantities in digestates of waste, in compost of biowaste, and in compost of garden waste have been derived from the waste statistics of the Federal Statistical Office.

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 2021, the relevant figure for 2020 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. The data on cultivated areas and fresh-matter yields are reported by the Federal Statistical Office (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. With regard to the input data and calculation methods, cf. Chapters 2.8.6 and 5.3.1 in Rösemann et al. (2023).

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, 6.4.2.7.3 and 6.5.2.3.2).

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 N quantities in digestates of waste, in compost of biowaste, and in compost of garden waste are available only at the national (Germany) level. In a first step, they are distributed among the German federal states, in keeping with the relevant populations. Then, within the German federal states, they are distributed among the NUTS-3 regions, in keeping with the pertinent agricultural areas.

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 a 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 49 (Mathivanan et al., 2021).

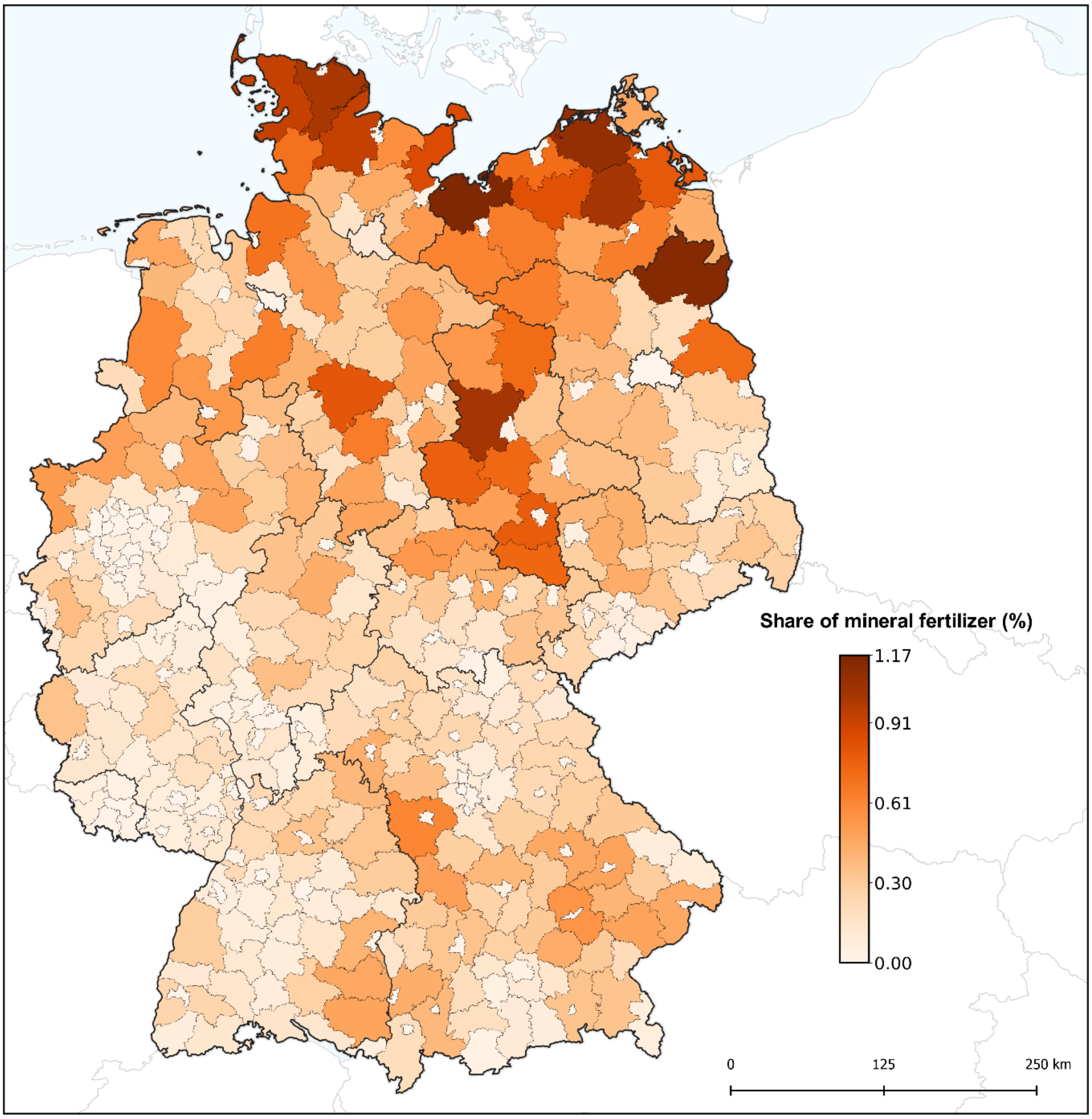


Figure 49: **NUTS-3 regions' shares of national mineral-fertiliser quantities, as averages for the years 2014-2016.**

Changes with respect to the 2022 submission result for the following input data and N quantities on which calculation of direct N_2O emissions is based:

- **2020 agricultural census:** In contrast to the procedure used with the 2022 submission, the results for the year 2019 – instead of those for the year 2020 – were assumed to be true. This leads to slight changes – to some extent, back to the year 2000 – in interpolated data for shares for housing systems, for manure-storage and manure-application procedures, and for grazing. For the first time, data on shares (i.e. of storage overall) for field storage of cattle and swine manure are available. For this reason, leaching of N from manure storage is being reported for the first time.
- **Digestates of energy crops:** The total mass of digested energy crops has been updated, with respect to the 2022 NIR, for the years 2019 and 2020; cf. Chapter 5.1.4.2. This has led to a slight increase.

- **Digestates of waste, compost of biowaste, compost of garden waste:** Emissions from application of these substances are being reported in the agriculture sector for the first time.
- **Sewage sludge:** The sewage sludge quantity extrapolated for the year 2020, in the 2022 NIR, has been replaced with the corresponding values from official statistics.
- **Grazing:** The N quantities are slightly lower, for all years, than the corresponding quantities reported in the 2022 NIR. This results mainly from inclusion of on-pasture emissions for laying hens, although it is also due to reinterpolation of grazing data from the 2020 agricultural census.
- **Crop residues:** The N quantity has changed slightly in all years as of 2000. This results mainly from reinterpolation of data from the 2020 agricultural census.
- **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 about twice as large as the corresponding values in the 2022 submission.
- **Cultivated organic soils:** Updating of areas and emissions, for the period as of 1990.

Table 246 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 246: 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	2021
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	1326.6	1301.0
Manure, including digestates from manure digestion	1129.1	983.2	964.8	934.4	938.3	944.4	960.7	973.0	984.8	984.1	978.1	973.6	959.1	951.3	942.6	916.9
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	299.4	299.4
Digestates of waste	0.0	0.0	1.6	5.0	10.5	10.9	11.0	11.8	13.9	15.1	14.0	13.8	14.0	13.8	13.4	13.0
Compost of biowaste	4.5	19.5	31.9	28.8	22.6	23.9	23.9	21.8	23.6	22.6	23.3	21.9	25.1	24.3	25.4	25.5
Compost of garden waste	1.1	4.9	7.7	9.5	11.3	11.3	12.4	10.8	13.2	13.7	14.3	14.9	14.9	15.9	16.7	16.8
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	12.5	12.5
Grazing	213.1	173.0	155.9	138.9	132.5	128.7	127.4	128.1	128.6	128.4	126.4	124.5	122.0	120.3	118.5	116.4
Crop residues	485.3	498.3	560.4	586.8	572.4	560.0	604.6	604.6	688.8	605.7	588.5	620.5	499.0	558.7	574.5	587.8
Mineralisation	5.6	5.4	5.3	4.7	4.1	4.0	4.0	3.9	3.8	3.8	3.7	3.6	3.5	3.4	3.3	3.2

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 247 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 2022 NIR.

Table 247: 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	2021
Total	**1297.4**	**1299.1**	**1300.9**	**1300.8**	**1291.8**	**1290.1**	**1288.4**	**1286.7**	**1285.1**	**1283.4**	**1281.1**	**1278.9**	**1276.7**	**1274.5**	**1272.3**	**1268.1**
$Cropland_{annual}$	333.1	326.8	320.4	332.4	334.8	338.1	341.4	344.6	347.9	351.2	347.1	343.0	338.9	334.8	330.7	329.0
Grassland	964.3	972.4	980.4	968.4	957.0	952.0	947.1	942.1	937.1	932.2	934.1	935.9	937.8	939.7	941.5	939.2

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). "Application" comprises application of mineral fertiliser, manure, manure digestates, sewage sludge and other organic fertilisers (digestates of energy crops, digestates of waste, compost of biowaste, compost of garden waste).

Table 248 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. With respect to the 2022 submission, the quantities in sector 3 B are lower. This is mainly the result of a correction in the area of manure storage: To date, for housing with deep straw bedding, NH_3 emissions were reported both for in-stable emissions and for emissions from subsequent manure-heap storage. It must be assumed, however, that solid manure from housing with deep bedding is applied immediately following mucking of stables, and that no further storage in manure heaps takes place. For this reason, as of the 2023 submission no NH_3 emissions from storage are being calculated for this form of housing. Similar data for the sector 3.D are provided in Table 249. The differences in the two tables, with respect to the 2022 Submission, result from the updating of input data described above, in connection with Table 246. 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. In this area, the quantity of manure is larger, in all years, than as reported in the 2022 submission. This is due mainly to the aforementioned correction in the area of housing systems with deep straw bedding.

Table 248: 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	2021
3.B, Manure, including digestates from manure digestion	244.4	201.5	200.4	200.6	197.1	196.6	198.9	198.8	198.9	196.4	193.3	191.5	185.8	182.1	178.8	172.0
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	2.7	2.7

Table 249: 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	2021
3.D, Total	**364.5**	**303.2**	**307.6**	**295.2**	**314.1**	**320.3**	**324.9**	**330.7**	**338.5**	**340.0**	**337.1**	**322.0**	**304.1**	**289.7**	**259.8**	**255.4**
3.D, Manure, digestates from manure digestion, mineral fertiliser, grazing	364.2	302.0	304.5	283.6	277.9	275.7	278.3	277.3	284.3	285.8	284.4	271.0	254.6	241.0	210.8	206.4
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	48.9	47.2	45.6	44.7	45.1	45.1
3.D Digestates of waste, compost	0.3	1.1	2.1	2.6	3.5	3.6	3.7	3.7	4.1	4.1	3.9	3.8	3.9	3.9	3.9	3.9

5.1.5.1.5 Leaching and surface runoff (3.D)

For sector 3.B, N_2O emissions from leaching and surface runoff are being calculated for the first time, since data on field storage of manure are now available for the first time, in the 2020 agricultural census. Leaching is assumed only for this share of manure storage, since with all other types of storage the legal provisions applying to construction of storage facilities prevent leaching. Pursuant to the Federal/Länder Working Group on Water Issues (LAWA) (LAWA, 2019), field-edge storage sites have to be covered with waterproof coverings no later than four weeks after their usage has commenced. Leaching out of N, therefore, occurs only in the first four weeks of storage. The leached-out fraction of the stored N quantity ($Frac_{LEACHMS}$) is calculated with the help of (IPCC, 2019a) – cf. Chapter 4.4.3 in Rösemann et al. (2023) – and amounts to 0.00333 kg kg^{-1}.

For calculation of N_2O emissions from leaching and surface runoff in sector 3.D and in accordance with IPCC (2006c): Vol. 4, the sum of the nitrogen in the applied quantities of mineral fertiliser, manure and manure digestates, sewage sludge and other organic fertilisers (digestates of energy crops, digestates of waste, compost of biowaste, compost of garden waste), and the N quantities available via grazing and mineralisation, is used as the figure for the total activity data. For details, cf. Chapter 5.3.2.1 in Rösemann et al. (2023). Only part of this available N quantity is leached out. The ratio of that quantity to the available N quantity is given by $Frac_{LEACH}$ (cf. IPCC (2006c Vol 4, 11.21)). For $Frac_{LEACH}$, Germany uses the IPCC default value 0.30 kg kg^{-1} (IPCC (2006c Vol 4, 11.21)).

The criterion for the application of these values for $Frac_{LEACHMS}$ and $Frac_{LEACH}$ is that the soil's water-retention capacity is exceeded; cf. (IPCC (2006c 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 250. The differences in 3.D, with respect to the 2022 submission, result from the updating of input data described in Chapter 5.1.5.1.2, in connection with Table 246.

Table 250: Sectors 3.B and 3.D: 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	2021
3.B	0.12	0.07	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.03
3.D	1217.6	1032.0	1105.4	1072.7	1055.5	1074.3	1106.8	1112.2	1165.3	1149.1	1139.4	1111.3	1032.2	1019.1	999.4	986.8

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 (2006c 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 (2006c).

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 251 shows the lime-fertiliser quantities, for the agriculture and forestry sectors taken together, on which the emissions calculations are based; cf. Chapter 2.8.1 in Rösemann et al. (2023). The discrepancies in the data for 2020, with respect to the 2022 submission, result from inclusion of the data for 2021 within the overarching average.

Table 251: 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	2021
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	4455.0	4438.5
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	104.0	112.1
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	421.5	414.0

The CO_2 emissions from urea application are calculated in proportion to the quantities of applied urea listed in Table 252 (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 252: 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	2021
	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	590.8	544.7

5.1.5.3 NMVOC emissions from agricultural crops

Table 253 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 (2019b -3D-16) and EMEP/EEA (2019b -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 (2019b -3D-16)) and applied, analogously, to the other crops involved.

Table 253: 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	2021	1990	2021		
Wheat	2419.9	2901.5	6.3	7.3	0.86	0.3
Rye	1067.1	631.1	3.8	5.3	0.86	0.3
Barley	2612.5	1539.6	5.4	6.8	0.86	0.3
Oats	533.5	184.871	4.4	4.3	0.86	0.3
Triticale	77.3	313.097	5.1	5.9	0.86	0.3
Grain for whole-plant harvest	0.0	107.7	0.0	30.4	0.35	0.3
Grain maize	228.4	430.634	6.8	10.4	0.86	0.3
Silage maize	1365.4	2219.615	40.4	47.2	0.28	0.3
Rape	557.5	996.764	3.0	3.5	0.91	0.3
Root crops	1249.6	648.7	40.6	66.6	0.22	0.3
Grass clover ley, alfalfa, forage grass	856.6	660.3	34.0	39.4	0.20	0.5
Legumes	121.2	244.7	3.4	3.4	0.86	0.3
Pastures and meadows	5417.2	4482.196	31.6	33.7	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 (2006c 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 (2006c 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 (2006c 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 6 in Rösemann et al. (2023).

Table 254 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 254 also shows the uncertainty for the overall trend since 1990. All emissions values are given in CO_2 equivalents, obtained using the greenhouse warming potential (GWP) conversion factors of IPCC AR5, 28 kg kg^{-1} for CH_4 and 265 kg kg^{-1} for N_2O.

In the interest of clarity, the presentation in Table 254 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 254, but with all individual animal sub-categories included, is provided in Chapter 6.10 in Rösemann et al. (2023).

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 254 were aggregated using error propagation calculations, and taking account of the uncertainties for the application contributions of the various individual animal categories.

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 23.0 % (valid for the year 2021). The uncertainty for the trend for the period 1990 – 2021 is 10.2 %.

Table 254: Total-uncertainties calculation for emissions from Sector 3 (animal husbandry, use of agricultural soils), including digestion of energy crops (GWP pursuant to IPCC AR5)

Source category EntFer = Enteric Fermentation MM = Manure Management DEC = Digestion of Energy Crops	Gas	Base year emissions, in CO_2 equivalents (GWP$_{CH4}$ = 28, GWP$_{N2O}$ = 265)	Year 2021 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	19,844.4	15,114.3	4	20	20.4	29.9	0.00	0.21	0.08	1.18	1.39
EntFer, other cattle	CH_4	15,699.0	9,814.7	2.2	10.8	11.0	3.7	0.03	0.14	0.35	0.42	0.30
EntFer, swine	CH_4	775.5	658.1	2.9	15.0	15.3	0.0	0.00	0.01	0.01	0.04	0.00
EntFer, sheep	CH_4	580.4	319.8	10	30	31.6	0.0	0.00	0.00	0.05	0.06	0.01
EntFer, goats	CH_4	12.6	22.3	10	30	31.6	0.0	0.00	0.00	0.01	0.00	0.00
EntFer, horses	CH_4	229.1	212.1	10	30	31.6	0.0	0.00	0.00	0.01	0.04	0.00
MM, dairy cows	CH_4	2,468.8	2,494.3	4	20	20.4	0.8	0.01	0.03	0.16	0.19	0.06
MM, other cattle	CH_4	2,683.8	1,548.3	2.2	11.2	11.4	0.1	0.01	0.02	0.08	0.07	0.01
MM, swine	CH_4	3,426.6	2,621.9	2.9	16.4	16.6	0.6	0.00	0.04	0.01	0.15	0.02
MM, sheep	CH_4	25.2	13.9	10	30	31.6	0.0	0.00	0.00	0.00	0.00	0.00
MM, goats	CH_4	0.6	1.0	10	30	31.6	0.0	0.00	0.00	0.00	0.00	0.00
MM, horses	CH_4	43.4	40.2	10	30	31.6	0.0	0.00	0.00	0.00	0.01	0.00
MM, poultry	CH_4	99.8	164.1	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	849.9	623.6	4	100	100.1	1.2	0.00	0.01	0.05	0.05	0.00
MM, direct N_2O, other cattle	N_2O	874.0	625.8	2.2	51.8	51.9	0.3	0.00	0.01	0.04	0.03	0.00
MM, direct N_2O, pigs	N_2O	356.4	286.0	2.9	77.4	77.5	0.2	0.00	0.00	0.01	0.02	0.00
MM, direct N_2O, sheep	N_2O	25.4	13.9	10	100	100.5	0.0	0.00	0.00	0.01	0.00	0.00
MM, direct N_2O, goats	N_2O	1.4	2.6	10	100	100.5	0.0	0.00	0.00	0.00	0.00	0.00
MM, direct N_2O, horses	N_2O	53.4	49.5	10	100	100.5	0.0	0.00	0.00	0.01	0.01	0.00
MM, direct N_2O, poultry	N_2O	32.6	54.8	6.2	52.7	53.0	0.0	0.00	0.00	0.02	0.01	0.00
MM, indirect N_2O, all animals (deposition)	N_2O	1017.6	716.3	40	400	402.0	26.1	0.00	0.01	0.40	0.56	0.47
MM, indirect N_2O, all animals (leaching)	N_2O	0.4	0.1	170	230	286.0	0.0	0.00	0.00	0.00	0.00	0.00
Soils, mineral fertilisers	N_2O	5,549.4	3,288.4	0.5	20.5	20.5	1.4	0.01	0.05	0.29	0.03	0.08
Soils, spreading of manure	N_2O	3,086.6	2,520.4	9.5	19.0	21.3	0.9	0.00	0.03	0.03	0.47	0.22
Soils, other organic fertilisers (spreading)	N_2O	15.1	954.1	8.5	34.0	35.0	0.4	0.01	0.01	0.44	0.16	0.22
Soils, sewage sludge	N_2O	71.9	29.7	20	40	44.7	0.0	0.00	0.00	0.01	0.01	0.00
Soils, crop residues	N_2O	1,221.7	1,468.3	50	40	64.0	2.8	0.01	0.02	0.29	1.43	2.13
Soils, organic soils	N_2O	3,352.6	3,281.3	0.13	245	245.0	203.7	0.01	0.05	2.30	0.01	5.27
Soils, mineralisation	N_2O	23.5	13.2	11.88	200	200.4	0.0	0.00	0.00	0.01	0.00	0.00
Soils, grazing	N_2O	1,695.0	915.9	20	200	201.0	10.7	0.01	0.01	1.10	0.36	1.33
Soils, indirect N_2O (deposition)	N_2O	1,517.8	875.8	50	400	403.1	39.3	0.00	0.01	1.66	0.85	3.48
Soils, indirect N_2O (leaching, runoff)	N_2O	3,805.7	2,804.5	170	230	286.0	202.7	0.00	0.04	0.47	9.28	86.39

Source category EntFer = Enteric Fermentation MM = Manure Management DEC = Digestion of Energy Crops	Gas	Base year emissions, in CO_2 equivalents (GWP$_{CH4}$ = 28, GWP$_{N2O}$ = 265)	Year 2021 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	1,500.2	10	20	22.4	0.4	0.02	0.02	0.41	0.29	0.26
DEC, storage, direct N_2O	N_2O	0.1	216.3	10	100	100.5	0.1	0.00	0.00	0.30	0.04	0.09
DEC, storage, indirect N_2O (deposition)	N_2O	0.0	11.1	10	400	400.1	0.0	0.00	0.00	0.06	0.00	0.00
DEC, soils, indirect N_2O (deposition)	N_2O	0.0	187.8	10	400	400.1	1.8	0.00	0.00	1.03	0.04	1.07
DEC, soils, indirect N_2O (leaching, runoff)	N_2O	0.0	280.5	10	230	230.2	1.3	0.00	0.00	0.89	0.05	0.79
Liming, without dolomite	CO_2	1,849.8	1,952.9	3	3	4.2	0.0	0.01	0.03	0.02	0.11	0.01
Liming, dolomite	CO_2	350.7	53.4	100	3	100.0	0.0	0.00	0.00	0.01	0.10	0.01
Liming, calcium ammonium nitrate	CO_2	510.4	182.2	3	3	4.2	0.0	0.00	0.00	0.01	0.01	0.00
Application of urea	CO_2	481.0	399.5	1	1	1.4	0.0	0.00	0.01	0.00	0.01	0.00
Total		72,632.0	56,332.9									
					Percentage uncertainty in total inventory:		23.0			Trend uncertainty (percentage):		10.2

[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 (2006b Vol 1, 3.31, Table 3.2, column H). Note, however, that the column heading as prescribed by IPCC (2006b 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 (2006b 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 (2006b 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 (Thünen-Institut, 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 2023, the following changes were made (cf. Chapter 1.3.6 in Rösemann et al. (2023)):

- Explicit inclusion of the on-pasture excretions of laying hens
- Inclusion of field storage of manure, in calculation of indirect emissions from leaching from manure management
- NH_3 emissions from deep straw bedding are completely included in stable emissions (no additional storage in manure heap). This has an effect especially on indirect emissions in 3.B (reduced) and on the N quantity applied with manure, in 3.D (increased)
- First-time inclusion of emissions from application of digestates of waste, compost of biowaste and compost of garden waste, in the agriculture sector

The other calculation procedures agree formally with those used for the 2022 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 2023 Submission was checked for consistency with the corresponding time series in the 2022 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 (2006c) 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 2023 and the CRF tables, in an EXCEL file that is available as a supplement to Rösemann et al. (2023) (cf. Chapter 1.3.8 in Rösemann et al. (2023)).

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 (2006c) 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[82] 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 key data from industry-association publications. The suckler-cow model was similarly adjusted for the 2022 submission.

No review was carried out for the 2019 submission.

[82] Cf. the Review Report, https://unfccc.int/sites/default/files/resource/arr2018_DEU.pdf

The ERT for the 2020 submission review recommended[83] that transparency be improved in the NIR, or in supporting documentation, regarding the effects of German reunification on the development of livestock populations; inclusion of grazing for swine; and direct and indirect emissions from application of biowaste.

The first two of the above points were addressed in the 2022 submission. In the present 2023 submission, direct and indirect emissions from application of waste digestates, and of composts of biowaste and garden waste, are being explicitly reported in sector 3.D for the first time.

In the various EU reviews of the submissions since 2019, pursuant to Article 19(2) of EU Regulation 525/2013, no requirements whatsoever for changes in the inventory methods or input data have emerged (EEA, 2019, 2020, 2021, 2022).

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 (2006c) 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**3 A, Enteric Fermentation**	**Dairy cows**	**CH_4**	**19,844.4**	**1.5 %**	**15,114.3**	**2.0 %**	**-23.8 %**
L/-	**3 A, Enteric Fermentation**	**non-dairy cattle**	**CH_4**	**15,699.0**	**1.2 %**	**9,814.7**	**1.3 %**	**-37.5 %**
-/-	3 A, Enteric Fermentation	other animals	CH_4	1,597.6	0.1 %	1,212.2	0.2 %	-24.1 %

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 255 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

[83] cf. the Review Report, https://unfccc.int/sites/default/files/resource/2020 ARR of DEU complete.pdf

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 255: 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	2021
CH_4	-29.6	80.9	75.7
GHG (CO_{2eq})		46.9	42.4

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 suckler cows, a Tier 2 method based on that used for dairy cows has been used. For other cattle and swine, the calculation is carried out using a Tier 2 procedure (IPCC, 2006c 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, Rösemann, et al., 2012), 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)

$$EF_{\mathrm{CH4,ent}} = a \cdot M_{\mathrm{XFi}} + b \cdot M_{\mathrm{NFE}} + c \cdot M_{\mathrm{XP}} + d \cdot M_{\mathrm{XF}} + e$$

Where

$EF_{\mathrm{CH4,\,ent}}$	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:

$$x_{\mathrm{CH4,GE}} = \frac{\eta_{\mathrm{CH4}} \cdot EF_{\mathrm{CH4,ent}}}{GE}$$

Where

$x_{\mathrm{CH4,\,GE}}$	Methane-conversion factor for dairy cows (in MJ MJ^{-1})
η_{CH4}	Energy content of methane (η_{CH4} = 55.65 MJ (kg CH_4)$^{-1}$)
$EF_{\mathrm{CH4,\,ent}}$	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)

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 2.4. 5 in Rösemann et al. (2023). 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 256 and Chapter 5.2.2.3.

Table 256: Dairy cows: Milk yield, GE intake, enteric-fermentation related CH_4 emissions and methane conversion factor (3.A)

	1990	2021
Average daily milk yield [kg animal place^{-1} d^{-1}]	12.9	23.3
Annual GE intake [GJ animal place^{-1} a^{-1}]	88.1	125.3
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, which is based on that used for dairy cows (cf. (Rösemann et al., 2023), Chapter 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 (2006c Vol 4, 10.31))

$$EF_{\text{CH4,ent}} = GE \cdot \frac{x_{\text{CH4,GE}}}{\eta_{\text{CH4}}}$$

Where

$EF_{\text{CH4, ent}}$	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)
$x_{\text{CH4, GE}}$	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 257. Due to changes in the composition of the overall population, the weighted average value for all other cattle varies slightly over the years. Table 257 shows the average value for all other cattle for the first and last year of the time series.

Table 257: 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 (2006c Vol 4, Table 10.12)
Suckler cows	0.086 - 0.084	Rösemann et al. (2023), Chapter 3.2
Calves	0.043	Rösemann et al. (2023), Chapter 3.2
Average value for all other cattle, 1990	0.0650	Calculation
Average value for all other cattle, 2020	0.0666	Calculation

Table 258 shows the national category-specific methane conversion factors for the various swine categories (Dämmgen, Schulz, et al., 2012), 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 258: Methane conversion factors for swine (Dämmgen, Schulz, et al., 2012) (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, 2021	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 in Rösemann et al. (2023). Animal-specific details are also provided in Chapter 3 in Rösemann et al. (2023).

5.2.2.2 Emission factors (3.A)

Table 259 shows the CH_4 emission factors calculated per animal place for enteric fermentation of dairy cows, other cattle and swine.

Table 259: 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	2021
Dairy cows	111.5	120.2	126.5	131.3	131.7	132.3	132.5	132.0	132.9	133.8	134.8	134.9	136.9	139.0	140.6	140.8
Other cattle	42.7	45.2	46.9	46.8	47.3	47.1	47.0	47.1	47.0	47.3	47.2	47.4	47.6	48.0	48.4	48.6
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	1.19

Table 260 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 (2006c Vol 4, Table 10.10). The emission factors given in IPCC (2006c Vol 4, Table 10.10) for sheep and horses have been used for adult sheep and heavy horses; cf. Chapter 3.3 in Rösemann et al. (2023). 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. Chapter 3.3 in Rösemann et al. (2023). 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 260 shows the average value for the last time-series year.

Table 260: 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 2021
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 261.

Table 261: 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	2021
Total	**1326.5**	**1162.4**	**1096.4**	**1019.6**	**1007.3**	**993.7**	**993.9**	**1006.5**	**1015.0**	**1014.4**	**1004.1**	**996.1**	**980.5**	**969.0**	**953.9**	**933.6**
in % of 1990	**100.0**	**87.6**	**82.7**	**76.9**	**75.9**	**74.9**	**74.9**	**75.9**	**76.5**	**76.5**	**75.7**	**75.1**	**73.9**	**73.1**	**71.9**	**70.4**
Dairy cows	708.7	628.4	578.1	556.1	551.1	554.2	555.3	563.4	570.9	573.3	568.6	566.4	561.2	557.5	551.3	539.8
Other cattle	560.7	481.8	467.5	411.9	408.5	392.8	391.1	396.2	396.8	394.7	389.5	383.1	373.6	366.4	357.5	350.5
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	23.5
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	11.4
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	8.4

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 2021 was about 40 % lower than it was in 1990; the corresponding figure for other cattle is about 45 % 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 254 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 (2006c Vol 4, 10.33). With regard to the uncertainty for the activity data (numbers of animals), cf. Chapter 6.3 in Rösemann et al. (2023).

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 262 and Table 263). At the time the German 2023 emissions report was being prepared, the results of the other countries' 2023 emission reporting were not yet known. For this reason, data from 2022 reports are being used for those countries, while the German data have been taken from the current 2023 report. The international comparison is being carried out for 2020 (the last time-series year in the 2022 report).

Table 262 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, the Czech Republic 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, only the 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 remaining countries' methane conversion factors are lower than the IPCC default value, with the UK's value coming closest to the IPCC default value.

Table 262: Methane emissions from enteric fermentation of dairy cows, in various countries – a comparison of Implied Emission Factors (IEF) for the time-series year 2020

	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	130.27	0.0630	315.3	19.96
Belgium	127.61	0.0610	319.0	24.13
Czech Republic	159.45	0.0650	374.0	24.98
Denmark	157.41	0.0576	415.5	28.56
France	126.61	0.0612	315.4	20.26
Germany	**140.59**	**0.0627**	**342.5**	**23.16**
Netherlands	136.84	0.0582	282.7	NA
Poland	120.53	0.0650	282.7	16.78
Switzerland	139.82	0.0690	309.0	23.26
UK	123.81	0.0643	293.4	22.49
IPCC (2006c Vol 4, 10.15 bis 10.31, 10.72)[a]	117	0,065	Equation 10.3-10.16	16.44

Source: Germany: 2023 Submission; other countries: UNFCCC (2022b)

NE, NA, n/a: no data available

[a] calculated from the annual milk yield assumed in IPCC (2006c Vol 4), 6,000 kg place^{-1} a^{-1}

Table 263 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 34.75 kg place^{-1} a^{-1} (Netherlands) to 58.95 kg place^{-1} a^{-1} (Czech Republic). 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.

With regard to swine, half of the countries considered use the IPCC default value for the IEF. The five 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 Austria, Denmark, Germany and Switzerland. Germany's value is close to Denmark's value.

Table 263: 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 2020

	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	54.10	144.19	0.97	30.08
Belgium	46.26	121.47	1.50	NE
Czech Republic	58.95	148.15	1.50	NA
Denmark	40.87	129.71	1.05	37.65
France	52.94	124.88	0.74	NE
Germany	**48.44**	**110.93**	**1.18**	**36.35**
Netherlands [a]	34.75	89.63	1.50	NA
Poland	50.57	118.62	1.50	n/a
Switzerland [a]	46.76	118.72	1.01	25.57
UK [b]	54.89	104.22	1.50	NE
IPCC (2006c)	57	Equation 10.3-10.16	1.5	Equation 10.3-10.16

Source: Germany: 2023 submission; other countries: UNFCCC (2022b)

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 264 shows, for dairy cows, other cattle and swine, GE intake in comparison to the corresponding data in the 2022 submission. The differences are small and, in the presentation format chosen, are apparent only for dairy cows and swine, at the end of the time series. The differences are due to the changes, as mentioned in Chapter 5.1.3.3, in the input data used for modelling sows and fattening pigs, and to the changes made in interpolation of grazing data from the LZ2020 agricultural census. 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 264.

Table 264: Comparison of mean daily GE intakes, for dairy cows, other cattle and swine (3.A), as reported in the 2022 and 2023 submissions

[MJ/animal]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows, 2023	241.3	264.0	283.0	298.8	307.5	310.5	312.5	312.1	316.0	318.9	322.3	322.5	329.4	336.7	342.5
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	342.6
Other cattle, 2023	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
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	110.9
Swine, 2023	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	36.0	36.3
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	36.4

Table 265: 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 2022 and 2023 submissions

[MJ/animal]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows, 2023	111.5	120.2	126.5	131.3	131.7	132.3	132.5	132.0	132.9	133.8	134.8	134.9	136.9	139.0	140.6
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	140.8
Other cattle, 2023	42.7	45.2	46.9	46.8	47.3	47.1	47.0	47.1	47.0	47.3	47.2	47.4	47.6	48.0	48.4
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	48.4
Swine, 2023	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	1.2
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	1.2

The discrepancies with respect to the 2022 submission that are seen in Table 265 (emission factors) and Table 266 (emissions) are also due to the reasons mentioned in connection with Table 264.

Table 266: 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 2022 and 2023 submissions

[Tg a^{-1} CH_4]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Mammals, 2023	1.326	1.162	1.096	1.020	1.007	0.994	0.994	1.006	1.015	1.014	1.004	0.996	0.980	0.969	0.954
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	0.955
Dairy cows, 2023	0.709	0.628	0.578	0.556	0.551	0.554	0.555	0.563	0.571	0.573	0.569	0.566	0.561	0.558	0.551
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	0.552
Other cattle, 2023	0.561	0.482	0.468	0.412	0.409	0.393	0.391	0.396	0.397	0.395	0.389	0.383	0.374	0.366	0.358
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	0.358
Swine, 2023	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	0.025
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	0.025

5.2.6 Planned improvements (3.A)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**3 B, Manure Management**	**Dairy cows**	**CH_4**	**2,468.8**	**0.2 %**	**2,494.3**	**0.3 %**	**1.0 %**
-/-	3 B, Manure Management	non-dairy cattle	CH_4	2,683.8	0.2 %	1,548.3	0.2 %	-42.3 %
L/-	**3 B, Manure Management**	**swine**	**CH_4**	**3,426.6**	**0.3 %**	**2,621.9**	**0.4 %**	**-23.5 %**
-/-	3 B, Manure Management	other animals	CH_4	169.0	0.0 %	219.1	0.0 %	29.6 %
-/-/2	**3 B, Manure Management**	**Dairy cows**	**N_2O**	**849.9**	**0.1 %**	**623.6**	**0.1 %**	**-26.6 %**
-/-/2	**3 B, Manure Management**	**non-dairy cattle**	**N_2O**	**874.0**	**0.1 %**	**625.8**	**0.1 %**	**-28.4 %**
-/-	3 B, Manure Management	swine	N_2O	356.4	0.0 %	286.0	0.0 %	-19.8 %
-/-	3 B, Manure Management	other animals	N_2O	112.8	0.0 %	120.8	0.0 %	7.0 %
-/-/2	**3 B, Manure Management**	**deposition and leaching**	**N_2O**	**1,017.9**	**0.1 %**	**716.4**	**0.1 %**	**-29.6 %**

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	CS/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. 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 Approach 2 analysis. N_2O emissions of other cattle, and indirect N_2O from deposition, have also been identified as key categories, 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, field storage of manure leads to only very slight quantitites of indirect N_2O emissions from leachage / surface runoff.

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 267 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.

Table 267: 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	2021
CH_4, MM	-21.3	19.1	19.9
N_2O_{MM}, direct	-24.5	9.3	8.6
N_2O_{MM}, indirect	-29.6	4.3	3.7
$CH_{4,\ MM}$ + N_2O_{MM} (as GHG in CO_{2eq})	-22.8	16.2	16.0
$NMVOC_{MM}$	-28.1	98.1	98.7

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})[84]

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 16.3.2. 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 268 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 268: 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	2021
Dairy cows	13.9	18.7	20.6	21.6	20.6	20.3	20.3	20.1	20.4	20.8	21.3	21.5	22.2	23.0	23.3	23.2
Other cattle	7.3	7.5	7.7	7.4	6.9	6.8	6.9	6.9	7.0	7.1	7.2	7.3	7.4	7.6	7.6	7.7
Swine	4.6	5.0	5.2	4.8	4.4	4.4	4.4	4.4	4.4	4.5	4.5	4.6	4.7	4.7	4.7	4.7
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	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	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	3.1
Poultry	0.031	0.030	0.032	0.035	0.036	0.035	0.034	0.032	0.033	0.033	0.034	0.034	0.034	0.034	0.034	0.034

5.3.2.2.3 Emissions (CRF 3.B, CH_4)

Table 269 shows the calculated total CH_4 emissions from manure management, in both absolute values and relative percentage values referenced to 1990.

Table 269: CH_4 emissions from manure management (3.B(a))

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
[kt a^{-1}]	312.43	285.58	289.69	272.90	249.74	248.60	254.01	254.32	259.11	259.22	260.69	262.38	259.92	259.85	257.94	245.84
[% of 1990]	100.0	91.4	92.7	87.3	79.9	79.6	81.3	81.4	82.9	83.0	83.4	84.0	83.2	83.2	82.6	78.7

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).

Table 270 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

[84] 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.

emissions for all animals. The ratios between the emissions of cattle and those of swine have been added as supplementary information.

Table 270: 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	2021
Dairy cows	88.2	97.7	94.2	91.4	86.1	85.0	85.2	85.8	87.8	89.2	90.0	90.3	91.1	92.4	91.2	89.1
Other cattle	95.8	80.4	76.5	65.2	59.7	57.0	57.3	58.4	59.0	59.3	59.4	58.9	58.4	58.0	56.4	55.3
Swine	122.4	101.3	112.8	109.7	97.2	99.4	104.0	102.4	104.5	102.9	103.5	105.4	102.6	101.6	102.5	93.6
Total	306.4	279.4	283.5	266.3	242.9	241.5	246.5	246.6	251.3	251.4	252.9	254.6	252.1	252.0	250.1	238.0
% share	98.1	97.8	97.8	97.6	97.3	97.1	97.1	97.0	97.0	97.0	97.0	97.0	97.0	97.0	97.0	96.8
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	1.5	1.5	1.4	1.5

The CH_4-emissions reductions achieved via manure digestion are shown in Table 271. Without digestion, the so-saved emissions would have been emitted in addition to the quantities shown in Table 269. The percentage reductions refer to the emissions that would have occurred without digestion.

Table 271: 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	2021
[kt a^{-1}]	-0.01	-0.08	-0.7	-6.6	-27.0	-33.4	-37.0	-42.2	-44.6	-45.5	-45.3	-46.6	-45.7	-44.6	-45.0	-44.7
[%]	-0.003	-0.03	-0.2	-2.4	-9.8	-11.9	-12.7	-14.2	-14.7	-14.9	-14.8	-15.1	-15.0	-14.6	-14.9	-15.4

5.3.2.3 Uncertainties and time-series consistency (3.B, CH_4)

Table 254 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 (2006c Vol 4, Table 10.48). With regard to the uncertainty for the activity data (numbers of animals), cf. Chapter 6.3 in Rösemann et al. (2023).

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 2020 were compared with those (for 2020) of neighbouring countries and of the UK (2022 Submission for 2020, UNFCCC (2022b)).

Table 272 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 (21.4 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 the values of France and Switzerland). 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 110 % of the median.

Table 272: 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 2020

	IEF_{CH4} [kg place^{-1} a^{-1}]	VS excretions [kg place^{-1} d^{-1}]	Slurry systems (without digestion)	
			Frequency [%]	Mean MCF [%]
Austria	17.12	5.04	53.97	8.76
Belgium	26.15	4.57	47.67	19.00
Czech Republic	13.28	6.90	10.70	17.00
Denmark	48.77	12.21	62.38	12.28
France	11.06	4.28	15.07	17.86
Germany	**23.25**	**4.14**	**58.04**	**14.58**
Netherlands	37.57	4.73	83.36	17.00
Poland	7.84	4.88	10.53	17.00
Switzerland	19.45	4.27	51.93	13.37
UK	38.43	5.32	60.98	17.00
IPCC (2006c), Western Europe, cool region 10°C/11°C	21 to 23	5.1	35.7	17 to 19

Source: Germany: 2023 Submission; other countries: UNFCCC (2022b)

Table 273 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 274 indicates, with regard to swine, Germany's IEF for CH_4 from manure management lies in the upper portion of the range, slightly above the median.

Table 273: 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 2020

	IEF_{CH4} [kg place^{-1} a^{-1} CH_4]	VS excretions [kg place^{-1} d^{-1}]	Slurry systems (without digestion)	
			Frequency [%]	Mean MCF [%]
Austria	6.81	2.38	33.61	8.34
Belgium	2.82	1.48	15.97	19.00
Czech Republic	3.55	2.95	6.50	17.00
Denmark	14.41	2.55	31.38	12.28
France	3.37	1.91	2.48	19.52
Germany	**7.65**	**1.44**	**31.76**	**14.73**
Netherlands [a]	7.81	1.17	68.44	17.00
Poland	1.73	1.80	5.06	17.00
Switzerland [a]	5.47	2.26	30.26	13.37
UK [b]	6.97	1.97	17.89	17.00
IPCC (2006c): 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 (2022b)

[a] Calculated from CRF data

[b] UK: Cattle, not including dairy cows, and not including dairy replacements (with calves)

Table 274: 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 2020

	IEF_{CH4}	VS excretions	Slurry systems (without digestion)	
			Frequency	Mean MCF
	[kg place^{-1} a^{-1} CH_4]	[kg place^{-1} d^{-1}]	[%]	[%]
Austria	1.26	0.32	88.23	3.39
Belgium	4.45	0.22	96.86	19.00
Czech Republic	2.00	0.31	22.80	17.00
Denmark	3.39	0.07	89.52	13.31
France	4.14	0.19	79.05	22.23
Germany	**4.74**	**0.33**	**78.98**	**22.74**
Netherlands	5.66	0.42	47.18	36.00
Poland	1.38	0.31	24.90	17.00
Switzerland	3.90	0.31	79.88	13.37
UK	4.06	0.25	36.17	17.00
IPCC (2006c 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 (2022b)

Table 275 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 275: 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 2020

	IEF_{CH4} [kg place^{-1} a^{-1}]	VS excretions [kg place^{-1} d^{-1}]	Mean animal weight [kg animal^{-1}]
Austria	0.023	0.02	NA
Belgium	0.023	NE	1.55
Czech Republic	0.104	NA	1.32
Denmark	0.027	0.003	2.00
France	0.025	0.019	NE
Germany	**0.034**	**0.025**	**1.69**
Netherlands	0.029	0.023	NA
Poland	0.028	NA	NA
Switzerland	0.017	0.013	NA
UK	0.018	0.020	NE
IPCC (2006c 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 (2022b)

[a] low value: laying hens; high value: turkeys

5.3.2.5 Source-specific recalculations (3.B, CH_4)

Table 276 through Table 278 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.

In the numerical presentation chosen, slight differences between the two submissions are apparent only in the area of VS excretions of dairy cows. They result from a correction in feed-ration calculation within the model; cf. Chapter 5.1.3.3. In the area of emission factors and emissions, differences are also apparent with regard to the other animal categories – mainly as of the year 2000. They are due mainly to the reinterpolation, mentioned in Chapter 5.1.3.3, of data from the 2020 agricultural census. With regard to poultry, the changes are due primarily to introduction of on-pasture excretions for laying hens; cf. Chapter 5.1.3.3.

Table 276: Comparison of VS excretions as reported in the 2023 and 2022 submissions (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, 2023	2.96	3.26	3.47	3.63	3.75	3.79	3.81	3.82	3.87	3.90	3.93	3.94	4.01	4.08	4.14
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	4.12
Other cattle, 2023	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
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	1.44
Swine, 2023	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	0.332
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	0.332
Poultry, 2023	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	0.0253
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	0.0252

Table 277: Comparison of the animal-place-based CH_4 emission factors, as reported in the 2022 and 2023 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	2020
Dairy cows, 2023	13.9	18.7	20.6	21.6	20.6	20.3	20.3	20.1	20.4	20.8	21.3	21.5	22.2	23.0	23.3
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	23.2
Other cattle, 2023	7.30	7.54	7.68	7.41	6.91	6.84	6.89	6.94	6.99	7.10	7.20	7.29	7.44	7.61	7.65
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	7.66
Swine, 2023	4.62	4.97	5.18	4.82	4.37	4.36	4.40	4.38	4.42	4.48	4.55	4.60	4.66	4.70	4.74
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	4.78
Poultry, 2023	0.0313	0.0304	0.0321	0.0349	0.0365	0.0352	0.0339	0.0323	0.0329	0.0333	0.0337	0.0339	0.0341	0.0341	0.0338
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	0.0338

Table 278: Comparison of CH_4 emissions from manure management as reported in the 2022 and 2023 Submissions (3.B(a))

[kt a-1]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
All animals, 2023	**312.4**	**285.6**	**289.7**	**272.9**	**249.7**	**248.6**	**254.0**	**254.3**	**259.1**	**259.2**	**260.7**	**262.4**	**259.9**	**259.9**	**257.9**
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**	**258.8**
Dairy cows, 2023	88.2	97.7	94.2	91.4	86.1	85.0	85.2	85.8	87.8	89.2	90.0	90.3	91.1	92.4	91.2
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	91.1
Other cattle, 2023	95.8	80.4	76.5	65.2	59.7	57.0	57.3	58.4	59.0	59.3	59.4	58.9	58.4	58.0	56.4
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	56.6
Swine, 2023	122.4	101.3	112.8	109.7	97.2	99.4	104.0	102.4	104.5	102.9	103.5	105.4	102.6	101.6	102.5
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	103.3
Poultry, 2023	3.57	3.38	3.86	4.20	4.70	5.11	5.46	5.73	5.79	5.83	5.84	5.88	5.91	5.90	5.85
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	5.86

5.3.2.6 Planned improvements (3.B, CH_4)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 (2006c) does not provide any method for calculating NMVOC emissions from manure management. EMEP/EEA (2019b) 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, 2019b-3B-28), and the Tier 1 method for other animals (EMEP/EEA, 2019b -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 on the NMVOC-emissions calculations, cf. Rösemann et al. (2023), Chapter 4.3.3. With regard to the equation set used in the Tier 2 method, we refer to EMEP/EEA (2019b-3B-29).

5.3.3.2.2 Emission factors (NMVOC)

For the Tier 1 method, EMEP/EEA (2019b -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 279 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 4.3.3.1 in Rösemann et al. (2023)):

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 (2019b) 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 (2019b) has been interpreted as applying to heavy horses. For light horses and ponies, the emission factor given in EMEP/EEA (2019b) 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 279: NMVOC: Tier 1 emission factors pursuant to EMEP/EEA (2019b) 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 280 shows, for selected years, the calculated Tier 2 implied emission factors (IEF) for dairy cows and other cattle.

Table 280: NMVOC: Tier 2 emission factors (IEF) calculated in the inventory

[kg place^{-1} a^{-1}]	1990	2005	2021
Dairy cows	30.94	36.56	40.64
Other cattle	11.71	11.64	11.38

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 (2019b -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 281 lists the NMVOC emissions from manure management that are to be reported under CRF 3s1.

Table 281: NMVOC emissions from manure management

[kt a⁻¹]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total	**390.9**	**332.3**	**318.0**	**296.9**	**296.2**	**296.4**	**298.2**	**303.3**	**305.5**	**304.1**	**300.9**	**297.8**	**293.8**	**290.8**	**286.9**	**281.2**
in % of 1990	**100.0**	**85.0**	**81.4**	**76.0**	**75.8**	**75.8**	**76.3**	**77.6**	**78.1**	**77.8**	**77.0**	**76.2**	**75.1**	**74.4**	**73.4**	**71.9**
Dairy cows	196.6	171.0	161.9	154.9	155.8	157.6	157.7	159.9	162.7	163.4	162.4	161.4	160.7	160.3	158.9	155.7
Other cattle	153.8	124.4	117.5	102.4	100.5	96.5	95.6	96.5	96.0	94.8	93.0	90.9	88.2	85.9	83.6	82.0
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	12.7
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	0.24
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	0.09
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	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	27.3

As Table 282 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 = 95.7 %). 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 282: Percentage contributions to NMVOC emissions, from manure management

[%]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Cattle	89.6	88.9	87.9	86.7	86.5	85.7	84.9	84.5	84.7	84.9	84.9	84.7	84.7	84.7	84.5	84.6
Poultry	4.7	5.5	6.2	6.8	7.3	8.0	8.7	9.3	9.1	9.1	9.1	9.2	9.3	9.4	9.5	9.7
Other animals	5.7	5.7	5.9	6.5	6.2	6.2	6.3	6.2	6.1	6.0	6.0	6.1	6.0	6.0	6.0	5.7

5.3.3.3 Uncertainties and time-series consistency (NMVOC)

EMEP/EEA (2019b-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 6.7 in Rösemann et al. (2023). With regard to the uncertainty for the activity data (numbers of animals), cf. Chapter 6.3 in Rösemann et al. (2023).

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 2022 NIR, while for the other animal categories the NMVOC emissions agree with the corresponding figures in the 2022 NIR. Table 283 shows the different emissions data reported in the 2023 and 2022 submissions. The different emission factors are not included, since the emissions are directly proportional to the emission factors. The differences between the two submissions, which are shown in Table 283, result mainly from the changes in the NH_3 emissions conditions applied in connection with the NMVOC Tier 2 method – in particular, from the changes in NH_3 emissions in systems with deep bedding; cf. Chapter 5.3.3.2.1 and Chapter 5.1.7.2.

Table 283: Comparison of NMVOC emissions, as reported in the 2023 NIR and the 2022 NIR, for dairy cows and other cattle

[kt a⁻¹]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dairy cows, 2023	196.6	171.0	161.9	154.9	155.8	157.6	157.7	159.9	162.7	163.4	162.4	161.4	160.7	160.3	155.8
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	155.8
Other cattle, 2023	153.8	124.4	117.5	102.4	100.5	96.5	95.6	96.5	96.0	94.8	93.0	90.9	88.2	85.9	100.5
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	101.6

5.3.3.6 Planned improvements (NMVOC)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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

$$E_{N2O\text{-}N} = \sum_{i,j} [(N_{excr,\,i} + N_{straw,i,\,j}) \cdot MS_{i,\,j}] \cdot EF_{N2O\text{-}N,\,j}$$

Where:

$E_{N2O\text{-}N}$	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 $place^{-1}$)
$EF_{N2O\text{-}N,\,j}$	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 16.3.2.

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 (2006c) are used: Outdoor storage facilities without natural crust cover (equivalent to "open tank, without natural crust" in Table 284); 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 (2006c 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 the above source,

IPCC (2006c 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 (without storage in heaps). 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. Chapter 4.4.2 in

Rösemann et al. (2023)). For deep bedding, therefore, the IPCC (2006c) default value of 0.010 kg N_2ON (kg N)$^{-1}$ is used IPCC (2006c 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 (2006c) default values of 0.005 and 0.001 kg N_2ON (kg N)$^{-1}$ are used IPCC (2006c Vol 4, 10.63).

IPCC (2006c 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 calculates N_2O emissions from manure digestion, broken down by different types of manure and digestates storage; cf. Chapter 5.1.3.6.5.

Table 284 shows the N_2O-N emission factors used in the present 2023 submission.

Table 284: 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 (2006c 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 (2006c Vol 4) does not give any emission factors for NO. The Tier 1 emission factors given in EMEP/EEA (2019b-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 285 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 284). 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 285 is higher than the factor given in Table 284. 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 285 also include the considerably lower emission factor for poultry (cf. Table 284). 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).

Table 285: 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	2021
Slurry-based [a]	3.05	3.42	3.38	3.35	3.36	3.32	3.28	3.25	3.22	3.19	3.16	3.12	3.10	3.07	3.07	3.08
Straw-based [b]	4.89	4.61	4.47	4.50	4.25	4.07	3.94	3.82	3.77	3.71	3.66	3.58	3.50	3.43	3.43	3.38
Deep bedding [a]	11.28	11.41	11.40	11.35	11.38	11.41	11.44	11.48	11.50	11.52	11.55	11.58	11.60	11.61	11.60	11.61
Digestion	5.44	5.10	4.86	4.57	3.32	3.06	2.47	2.36	2.26	2.22	2.19	2.19	2.17	2.13	2.10	2.11

[a] Without digestion

[b] Without deep bedding and without digestion

5.3.4.2.3 Emissions (3.B, N_2O_{direct} & NO)

Table 286 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 16.3.2), and gradually (over the years) increasing emissions reductions achieved via manure digestion (cf. Chapter 5.1.3.6.5).

Table 286: 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	2021
MM total	8.28	7.43	7.25	7.21	7.12	6.99	6.88	6.87	6.89	6.85	6.79	6.73	6.61	6.54	6.44	6.25
in % of 1990	100.0	89.8	87.6	87.2	86.0	84.4	83.1	83.0	83.3	82.7	82.1	81.4	79.9	79.0	77.8	75.5
Slurry-based [a]	4.17	4.41	4.27	3.89	3.35	3.21	3.19	3.10	3.09	3.05	3.03	2.98	2.92	2.90	2.86	2.74
Straw-based [b]	3.25	2.12	1.99	1.99	1.86	1.74	1.67	1.58	1.52	1.45	1.37	1.29	1.21	1.13	1.11	1.09
Deep bedding [a]	0.86	0.90	0.96	1.10	1.22	1.26	1.35	1.45	1.55	1.61	1.68	1.74	1.79	1.85	1.80	1.76
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	0.67	0.67

[a] Without digestion

[b] Without deep bedding and without digestion

Table 287 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 287: 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	2021
[kt a^{-1}]	0.0001	0.0008	0.006	0.04	-0.12	-0.20	-0.36	-0.42	-0.47	-0.47	-0.46	-0.46	-0.45	-0.44	-0.45	-0.45
[%]	0.001	0.011	0.08	0.6	-1.6	-2.8	-5.0	-5.8	-6.3	-6.5	-6.4	-6.4	-6.4	-6.3	-6.5	-6.7

Table 288 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 288: NO emissions from manure management

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
	1.129	1.013	0.989	0.984	0.971	0.953	0.938	0.937	0.940	0.934	0.926	0.918	0.902	0.892	0.878	0.852

5.3.4.3 Uncertainties and time-series consistency (3.B, N_2O_{direct} & NO)

Table 254 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 (2006c Vol 4, Table 10.21). See also in this regard Chapters 4.2.2.4 and 14.4.1 in Rösemann et al. (2023). With regard to the uncertainty for the activity data (numbers of animals), cf. Chapter 6.3 in Rösemann et al. (2023).

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 2020 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 289 and Table 290.

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 9 % below 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 1.1.2.2 in Rösemann et al. (2023). The lower N-excretions values given by the other countries may be due in part to non-AAP-consistent inclusion of vacancy periods.

Germany also has the second-highest average N-excretions figure in the case of poultry. 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 (2019b-3B-31)).

Table 289: N excretions per animal place, for dairy cows, other cattle, swine and poultry of various countries, for the time-series year 2020

	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	106.90	51.53	10.93	0.53
Belgium	121.81	53.49	8.89	0.57
Czech Republic	109.20	58.73	10.99	0.50
Denmark	156.36	42.45	7.31	0.48
France	116.72	59.66	9.51	0.47
Germany	**121.35**	**43.68**	**12.39**	**0.66**
Netherlands [a]	83.00	39.15	14.24	0.57
Poland	114.55	51.12	10.91	0.73
Switzerland [a]	111.38	39.69	9.11	0.47
UK [b]	114.33	44.49	9.32	0.48
IPCC (2006c 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 (2019b-3B-31)	105	41	12.1 / 34.5 [d]	0.36 to 1.64

Source: Germany: 2023 Submission; other countries: UNFCCC (2022b)

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 (2006c 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 (2006c Vol 4) Sows and boars: 30.4, other: 9.3; EMEP/EEA (2019b): Sows: 34.5, fattening pigs: 12.1

e Poultry: Assumptions for lacking values: Weight of geese = 1/2 standard weight of turkeys IPCC (2006c Vol 4); N excretions of geese = standard N excretions of turkeys IPCC (2006c Vol 4); weight of pullets = 1/2 standard weight of laying hens IPCC (2006c Vol 4); N excretions of pullets = standard N excretions of laying hens IPCC (2006c Vol 4)

Table 290 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 6 % above the median and, as a result, approximately at the level of the values reported by the Czech Republic and Denmark. In the case of poultry, Germany has the fourth-largest value (33 % higher than the median); its IEF, and that of Poland, are higher than the IEF of the majority of neighbouring countries. Only the Czech Republic and the UK have higher IEFs – and they are higher by a factor of 3.

Table 290: IEFs of various countries for direct N_2O emissions from manure management for dairy cows, other cattle, swine and poultry, in 2020

	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	0.798	0.475	0.086	0.00080
Belgium	0.720	0.547	0.030	0.00089
Czech Republic	0.579	0.317	0.048	0.00373
Denmark	0.948	0.366	0.058	0.00074
France	0.402	0.185	0.004	0.00069
Germany	**0.612**	**0.327**	**0.054**	**0.00119**
Netherlands [a]	0.413	0.235	0.028	0.00090
Poland	0.807	0.353	0.086	0.00120
Switzerland [a]	0.315	0.127	0.023	0.00072
UK [b]	0.535	0.579	0.163	0.00408

Source: Germany: 2023 Submission; other countries: UNFCCC (2022b)

[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 291 shows the direct N_2O emissions from manure management in comparison to the corresponding results in the 2022 submission. The underlying N-excretions data are shown in Table 292.

With regard to the N excretions, growing differences between the two submissions have emerged over the years. They are due mainly to use of new survey data on the raw-protein content in feed for fattening pigs, and to reinterpolation of 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 reinterpolation of additional housing-system data from the 2020 agricultural census has some retroactive effects back to the year 2000.

Table 291: Comparison of direct total N_2O emissions from manure management, as calculated in the 2022 and 2023 submissions

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2023	8.276	7.430	7.254	7.215	7.122	6.987	6.880	6.868	6.893	6.849	6.794	6.734	6.614	6.542	6.439
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	6.529

Table 292: Comparison of total N excretions as calculated in the 2023 and 2022 submissions (cf. Chapter 5.1.3.4)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2023	1555.1	1336.2	1301.0	1254.0	1246.6	1248.6	1265.4	1277.5	1289.6	1286.3	1275.4	1267.2	1244.9	1232.0	1218.8
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	1234.2

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 293

Table 293: 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	2020
2022	1.129	1.013	0.989	0.984	0.971	0.953	0.938	0.937	0.940	0.934	0.926	0.918	0.902	0.892	0.878
2021	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

5.3.4.6 Planned improvements (3.B, N_2O_{direct} & NO)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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, $N_2O_{indirect}$)

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 (2006c Vol 4, 11.21), in proportion to the deposited N quantity:

Equation 16: Indirect N_2O emissions from manure management (deposition)

$$E_{\text{N2O indirect, MM, Dep}} = \frac{44}{28} \cdot (E_{\text{NH3-N, MM}} + E_{\text{NO-N, MM}}) \cdot EF_4$$

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, along with relevant animal-specific details, in Chapters 4.3.1 and 4.3.2 in Rösemann et al. (2023).

The indirect N_2O emissions from leaching from manure management are reported in proportion to the quantity of N in manure in field-based storage.

Leaching of nitrogen is reported only in connection with field-edge storage of solid manure, since with all other types of storage the legal provisions applying to construction of storage facilities prevent leaching. Pursuant to the Federal/Länder Working Group on Water Issues (LAWA) (LAWA, 2019), field-edge storage sites have to be covered with waterproof coverings no later than four weeks after their usage has commenced. In a conservative approach, therefore, it is assumed that leaching of N occurs in the first four weeks of storage. The leached-out fraction of the stored N quantity ($Frac_{LEACHMS}$) is calculated with the help of (IPCC, 2019a) – cf. Chapter 4.4.3 in Rösemann et al. (2023) – and amounts to 0.00333 kg kg^{-1}.

The indirect N_2O emissions from leaching are calculated, with the Tier 1 method pursuant to IPCC (2006c Vol 4, 11.21), as the product of the N_2O-N-conversion factor 44/28, the leached-out N quantity and the emission factor (0.0075 kg N_2O-N (kg N)$^{-1}$; cf. IPCC (2006c Vol 4, 11.24, Table 11.3):

Equation 17: Indirect N_2O emissions as a result of manure management (leaching)

$$E_{\text{N2O indirect, MM, Leach}} = \frac{44}{28} \cdot N_{\text{leaching, MM}} \cdot EF_5$$

Where:

$E_{\text{N2O, indirect,-MM, Leach}}$	Indirect N_2O emissions from leaching of N from manure management (kg a^{-1})
$N_{\text{leaching, MM}}$	N quantity that is leached out during field-edge storage (kg a^{-1})
EF_5	N_2O-N emission factor for leaching; cf. Chapter 5.3.5.2.2

A detailed description of the calculation of indirect N_2O emissions resulting from leaching and surface runoff is provided in Chapter 5.3.2.1 in Rösemann et al. (2023).

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, 2006c Vol 4, 11.24, Table 11.3).

The emission factor EF_5 for indirect N_2O emissions from leaching from manure management (only for field storage of manure) is 0.0075 kg N_2O-N (kg N)$^{-1}$ (IPCC, 2006c Vol 4, 11.24, Table 11.3).

5.3.5.2.3 Emissions (3.B, $N_2O_{indirect}$)

Table 294 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. Table 295 shows the resulting indirect N_2O emissions from leaching from manure management. In last year's submission, these emissions were not yet being reported.

In general, the trend for 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 2022 submission and the 2023 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 294: Indirect N_2O emissions as a result of deposition of NH_3 and NO from manure management (2023 and 2022 submissions)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
2023	3.840	3.167	3.149	3.153	3.098	3.089	3.126	3.125	3.125	3.086	3.037	3.009	2.920	2.862	2.810	2.703
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	

Table 295: Indirect N_2O emissions as a result of leaching from manure management (2023 and 2022 submissions)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
2023	0.0014	0.0008	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007	0.0007	0.0006	0.0006	0.0005	0.0005	0.0004	0.0004	0.0004
2022	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	

5.3.5.3 Uncertainties and time-series consistency (3.B, $N_2O_{indirect}$)

Table 254 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 indirect N_2O emissions from agricultural soils (cf. Chapter 6.5 in Rösemann et al. (2023)) has been used here as well. With regard to estimation of the uncertainty of the activity data (available quantity of reactive nitrogen), cf. Chapter 6.3 in Rösemann et al. (2023).

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	3 D, Agricultural Soils		N_2O	20,339.2	1.6 %	16,619.9	2.2 %	-18.3 %

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 sewage sludge
- application of other organic fertilisers (digestates of energy crops and waste; composts of biowaste and garden waste)
- grazing
- crop residues
- mineralisation
- cultivation of organic soils

In the present 2023 submission, emissions from application of compost, and of digestates of waste, are being reported in the agriculture sector for the first time.

The indirect N_2O emissions in Sector 3.D result from deposition of reactive nitrogen and from leaching and surface runoff.

Table 296 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 296: Percentage change in emissions from use of agricultural soils since 1990, and percentage shares of total agricultural sector emissions of N_2O and GHG

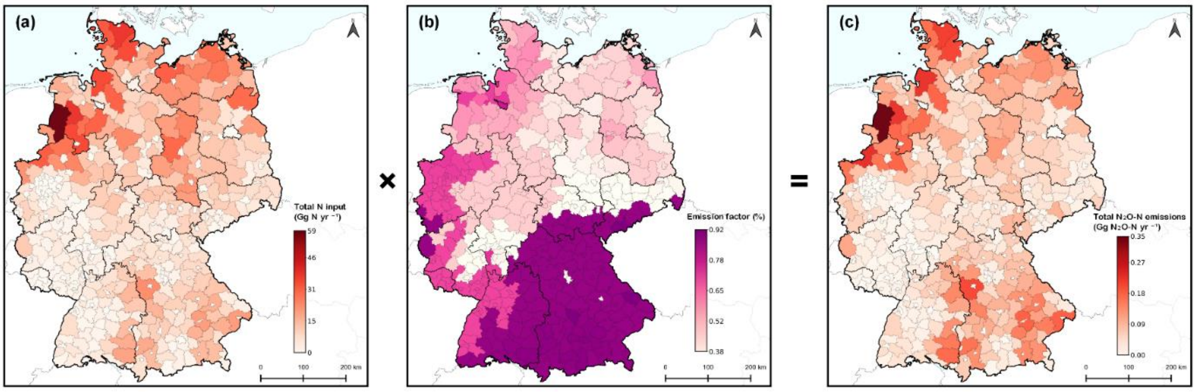
[%]	Change Since 1990	Share of total agricultural emissions (N_2O, GHG) 1990	2021
N_2O_{soils}, direct	-16.9	63.8	64.9
N_2O_{soils}, indirect	-22.1	226	21.6
Total of N_2O_{soils}	-18.3	86.4	86.5
ditto, as GHG (in CO_2 eq.)	-18.3	32.4	34.0

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) shows 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 %; and c) district-level annual direct N_2O emissions from application of N-containing substrates and from crop residues

Figure 50: 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 50). 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 297. (Mathivanan et al., 2021; Metzger et al., 2005).

Table 297: N_2O 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 (2006c 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 IPCC default emission factors are used: For cattle, swine and poultry, 0.02 kg N_2O-N per kg of excreted nitrogen; for sheep, goats and horses, 0.01 kg N_2O-N per kg of excreted nitrogen; cf. IPCC (2006c) Vol. 4, Table 11.1. 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 (2006c Vol 4, 11.7), in proportion to the relevant released N quantities (cf. Chapter 5.1.5.1). Pursuant to IPCC (2006c), the relevant emission factor is 0.01 kg N_2O-N per kg of released 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., 2020b), 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. (2020b) 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 298 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 298: Average N_2O-N emission factors for agricultural soils

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
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	0.0061
Application of manure [kg kg^{-1}]	0.0066	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	0.0066	0.0066
Application of digestates of energy crops [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	0.0065	0.0065
Application of digestates of waste [kg kg^{-1}]	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0065	0.0065	0.0065
Application of compost of biowaste [kg kg^{-1}]	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0065	0.0065	0.0065
Application of compost of garden waste [kg kg^{-1}]	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0064	0.0065	0.0065	0.0065
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	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	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	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	0.01
Cultivated organic soils [kg ha^{-1}]	6.21	6.17	6.14	6.19	6.21	6.23	6.25	6.27	6.29	6.30	6.29	6.27	6.25	6.24	6.21	6.21

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 (2006c 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 sewage sludge,
- application of other organic fertilisers (digestates of energy crops and waste; composts of biowaste and garden waste),
- 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 5.3.2.2 in Rösemann et al. (2023). 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. chapters 5.2.1.2 and 5.2.2.2 in Rösemann et al. (2023). Calculation of NH_3 and NO emissions from manure application (including application of manure digestates) and from grazing is described in chapters 4.3.1.1 and 4.3.2.1 in Rösemann et al. (2023). With regard to application of digestates of energy crops, digestates of waste, compost of biowaste, compost of garden waste, and sewage sludge, we refer to Chapters 5.1, 5.2.1.2 and 5.2.2.2 in Rösemann et al. (2023). As of 2020, application of urea fertiliser is subject to legal restrictions: "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 (2006c 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 (2006c 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 5.3.2.1 in Rösemann et al. (2023).

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 (2019b-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 (2019b-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 (2019b-3D, Table 3.1, p.13, Supplement A2.3), also uses it for N excretions on pasture and from application of sewage sludge and of other organic fertilisers.

5.5.2.1.5 NMVOC emissions

IPCC (2006c) 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 (2019b)-3D-30 ff:

Equation 18: Calculation of annual NMVOC emissions from agricultural crops pursuant to EMEP/EEA (2019b)

$$E_{\mathrm{NMVOC,\,cult,i}} = A_{\mathrm{i}} \cdot m_{\mathrm{FM,i}} \cdot x_{\mathrm{DM,i}} \cdot t_{\mathrm{i}} \cdot EF_{\mathrm{NMVOC,\,cult,i}}$$

Where

$E_{NMVOC, cult, i}$	NMVOC emissions from agricultural crop i (in kg a^{-1})
A_i	Area under cultivation with crop i (in ha)
$m_{FM, i}$	Average fresh matter yield from crop i (in kg ha^{-1} a^{-1})
$x_{DM, i}$	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})
$EF_{NMVOC, cult, i}$	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 (2019b 3D Table 3.3); cf. Table 299. 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 299: 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, 2006c 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 (2006c 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 300. 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, 2019b), until 2019 $Frac_{GASF}$ correlates very well with the ratio of urea-N to total-mineral-fertiliser-N; cf. (Rösemann et al., 2023). 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 300: $Frac_{GASF}$ 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	2021	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	0.034	0.050

Pursuant to IPCC (2006c Vol 4, 11.21, eq.11.9), $Frac_{GASM}$ denotes the fraction of the N quantity that is applied via manure (including manure digestates), sewage sludge, other organic fertilisers and grazing and that is emitted as NH_3-N and NO-N; cf. Table 301. (The $Frac_{GASM}$ definition in CRF Table 3.D does not conform to this definition.)

Table 301: $Frac_{GASM}$ 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	2021	Mean
$Frac_{GASM}$	0.199	0.185	0.178	0.170	0.169	0.171	0.167	0.166	0.163	0.160	0.159	0.157	0.155	0.153	0.150	0.151	0.172

5.5.2.3 Emissions (3.D)

Table 302 presents an overview of the contributions of the various individual sub-sources to overall N_2O emissions from agricultural soils.

Table 302: 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	2021
Total emissions	**76.8**	**66.8**	**69.7**	**67.7**	**67.2**	**68.1**	**69.5**	**69.8**	**72.3**	**71.6**	**71.1**	**69.6**	**65.8**	**64.9**	**63.4**	**62.7**
Total direct emissions	**56.7**	**49.9**	**51.8**	**50.4**	**49.8**	**50.4**	**51.4**	**51.5**	**53.3**	**52.7**	**52.4**	**51.4**	**48.9**	**48.3**	**47.6**	**47.1**
Total indirect emissions	**20.1**	**16.9**	**17.9**	**17.3**	**17.4**	**17.7**	**18.2**	**18.3**	**19.1**	**18.9**	**18.7**	**18.2**	**16.9**	**16.6**	**15.9**	**15.7**
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	12.7	12.4
Manure	11.6	10.4	10.1	9.8	9.8	9.8	10.0	10.1	10.2	10.2	10.1	10.1	10.0	9.9	9.8	9.5
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	3.0
Waste digestates and compost	0.1	0.2	0.4	0.4	0.4	0.5	0.5	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6
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	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	3.5
Crop residues	4.6	4.7	5.3	5.5	5.3	5.3	5.7	5.6	6.5	5.6	5.5	5.9	4.8	5.3	5.4	5.5
Mineralisation	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Organic soils	12.7	12.6	12.5	12.7	12.6	12.6	12.7	12.7	12.7	12.7	12.7	12.6	12.5	12.5	12.4	12.4
Indirect, deposition	5.7	4.8	4.8	4.6	4.9	5.0	5.1	5.2	5.3	5.3	5.3	5.1	4.8	4.6	4.1	4.0
Indirect, leaching	14.4	12.2	13.0	12.7	12.4	12.7	13.1	13.1	13.7	13.5	13.4	13.1	12.2	12.0	11.8	11.6

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 2021, they are 13.3 % 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 246in 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, due to drought, with the result that harvest residues in 2018 were smaller than they were in 2017 (cf. Chapter 5.1.5.1.2). The emissions-reducing effect of the livestock-population reductions occurring in recent years has been been partly offset by the emissions-increasing effects of increases in yield and performance. Also, since 2005, application of increasing quantities of digestates of manure and of energy crops has been having an impact in this regard.

Table 303 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 303: N_2O from agricultural soils: Percentage shares of sub-sources

[%]	1990	2021
Mineral fertiliser	27.3	19.8
Manure (including digestates from manure digestion)	15.2	15.2
Digestates of energy crops	0.0	4.8
Waste digestates and compost	0.1	0.9
Sewage sludge	0.4	0.2
Grazing	8.3	5.5
Crop residues	6.0	8.8
Mineralisation	0.12	0.08
Organic soils	16.5	19.74
Total indirect N_2O	26.2	25.0

The results of the NO-emissions calculations are shown in Table 304. With regard to the sources, cf. Chapter 5.5.2.1.2. Table 304 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 304: NO emissions from agricultural soils

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total	**91.8**	**75.6**	**80.3**	**76.8**	**75.7**	**77.6**	**79.3**	**79.7**	**82.1**	**82.9**	**82.5**	**79.3**	**75.6**	**72.9**	**70.8**	**69.5**
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	7.7	7.7
Other sources	91.8	75.6	80.1	75.6	71.4	72.2	73.3	72.6	74.6	75.1	74.7	71.6	68.1	65.4	63.1	61.8

Table 305 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 305: NMVOC emissions from agricultural crops

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
[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	9.43
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	122.6

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 306 and Table 307, 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 2020.

Table 306: Comparison of the N_2O-N emission factors used in the German inventory with those of neighboring countries, for the time-series year 2020

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	0.0169	0.010	0.0075
Belgium	0.0100	0.0100	0.0100	0.0100	8.0000	0.0194	0.010	0.0075
Czech Republic	0.0100	0.0100	0.0100	NO	NO	0.0189	0.010	0.0023
Denmark	0.0100	0.0100	0.0100	0.0100	7.4349	0.0176	0.010	0.0048
France	0.0100	0.0100	0.0100	NO	3.4190	0.0191	0.010	0.0075
Germany	**0.0061**	**0.0066**	**0.0060**	**0.0100**	**6.2143**	**0.0189**	**0.010**	**0.0075**
Netherlands	0.0105	0.0080	0.0138	NO	4.4463	0.0313	0.012	0.0075
Poland	0.0100	0.0100	0.0100	0.0100	8.0000	0.0197	0.010	0.0075
Switzerland	0.0097	0.0100	0.0100	0.0100	8.0000	0.0187	0.026	0.0075
UK	0.0073	0.0061	0.0100	0.0100	9.5391	0.0033	0.014	0.0075
IPCC (2006c 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: 2023 Submission; other countries: UNFCCC (2022b)

[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 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 (2006c) default emission factor of 8 kg ha^{-1}. Two countries have factors that are higher than this default value, while three countries have lower factors. Of the latter group, two countries (the Netherlands and France) have factors that are considerably lower. The German value, which is based on national emission factors for cropland and grassland (cf. Chapter 5.5.2.1.1), 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 (2006c). 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 (2006c) default values.

Table 307: Comparison of Germany's Frac values with those of neighboring countries, for the time-series year 2020

[kg kg^{-1}]	$Frac_{GASF}$	$Frac_{GASM}$	$Frac_{LEACH}$
Austria	0.051	0.16	0.15
Belgium	0.067	0.17	0.30
Czech Republic	0.100	0.20	0.30
Denmark	0.052	0.09	0.21
France	0.061	0.11	0.25
Germany	**0.034**	**0.15**	**0.30**
Netherlands	0.049	NA	0.13
Poland	0.100	0.20	0.30
Switzerland	0.065	0.22	0.18
UK	0.034	0.04	0.19
IPCC (2006c Vol 4, 11.24)	0.100	0.20	0.30

Source: Germany: 2023 Submission; other countries: UNFCCC (2022b)

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 for the year 2020 is the smallest of the values compared. The reason for this is that as of that year the country's calculations employ an NH_3emission factor for urea that has been reduced by 70 % (cf. Chapter 5.5.2.1.2). The German value for $Frac_{GASM}$ lies somewhat below the median. For $Frac_{LEACH}$, Germany, like a number of other countries, uses the default value given in IPCC (2006c).

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 254 in Chapter 5.1.6.

The emission-factor uncertainties for direct N_2O from mineral fertiliser, organic fertiliser (manure, digestates, compost, 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 (2006c Vol 4, 11.11, Table 11.1). With regard to the uncertainty for the activity data (N quantities), cf. Chapter 6.3 in Rösemann et al. (2023).

The activity-data and emission-factor uncertainties for direct N_2O emissions from drained organic soils have been derived from national data; cf. Chapters 6.3 and 6.5 in Rösemann et al. (2023). The same applies to mineralisation of organic soil substance; cf. Chapters 6.3 and 6.5 in Rösemann et al. (2023).

For NO from application of mineral fertiliser, manure, sewage sludge and other organic fertilisers, and from N excretions on pasture, the German inventory uses a 95 % confidence interval of -95 % to +400 %; cf. Rösemann et al. (2023), Chapter 6.5. With regard to the uncertainties for the activity data (N quantities), we refer to the discussion on N_2O emissions above.

With regard to the uncertainties in connection with the indirect N_2O emissions, cf. Chapter 6.5 in Rösemann et al. (2023).

EMEP/EEA (2019b) 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 (2019b-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; cf. Chapter 6.7 in Rösemann et al. (2023). With regard to the uncertainty of the activity data, the uncertainty of the activity data for crop residues is taken from the uncertainty figures for N_2O. 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 consistent and complete.

5.5.5 Category-specific recalculations (3.D)

Table 308 compares the N_2O emissions from agricultural soils as reported in the present submission and in last year's submission.

Table 308: Total N_2O from agricultural soils, in the 2022 and 2023 submissions (3.D)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2023	76.8	66.8	69.7	67.7	67.2	68.1	69.5	69.8	72.3	71.6	71.1	69.6	65.8	64.9	63.4
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	62.7

Table 309 shows the changes in N_2O emissions with respect to the figures given in last year's submission.

Table 309: Change, between the 2022 submission and the 2023 submission, in total N_2O emissions (direct + indirect) from use of agricultural soils (negative values: reduction from the 2022 submission to the 2023 submission)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**0.347**	**0.636**	**0.882**	**0.925**	**0.933**	**0.981**	**1.028**	**1.021**	**1.132**	**1.152**	**1.151**	**1.123**	**1.169**	**1.162**	**0.528**
Mineral fertiliser	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	0.000	-0.339
Manure	0.100	0.113	0.112	0.110	0.105	0.111	0.117	0.126	0.129	0.132	0.132	0.128	0.126	0.124	0.111
Other organic fertilisers	0.056	0.245	0.414	0.436	0.449	0.466	0.479	0.449	0.514	0.520	0.523	0.512	0.548	0.547	0.634
Sewage sludge	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	0.000	-0.015
Grazing	0.001	0.002	0.007	0.020	-0.006	-0.003	0.002	0.008	0.009	0.007	0.010	0.007	0.011	0.011	0.038
Crop residues	0.000	0.000	0.000	-0.002	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	-0.003	0.000
Mineralisation	0.050	0.047	0.045	0.038	0.032	0.032	0.031	0.031	0.030	0.030	0.029	0.027	0.026	0.025	0.024
Organic soils	-0.065	-0.064	-0.062	-0.044	-0.028	-0.026	-0.024	-0.022	-0.020	-0.018	-0.016	-0.014	-0.011	-0.009	-0.006
Indirect, deposition	0.140	0.157	0.172	0.167	0.184	0.197	0.210	0.225	0.243	0.251	0.244	0.237	0.233	0.228	0.143
Indirect, leaching	0.065	0.136	0.195	0.200	0.200	0.207	0.214	0.207	0.230	0.232	0.233	0.228	0.239	0.238	-0.064

The emissions reported in the 2023 submission are higher, in all years, than the corresponding emissions in the 2022 submission. The most noticeable change with respect to the 2022 submission, and the largest in terms of its absolute value, is seen in the area of organic fertilisers. It results in that emissions from application of digestates of waste, and application of compost, are being reported in the agricultural sector for the first time. The additional changes seen in Table 309, with respect to the 2022 submission, have resulted from updating of input data.

Table 310 compares the total NO emissions with the corresponding data from last year's submission. In Table 311, the differences between the two submissions are broken down by sub-sources. 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. As in the case of N_2O, the largest change has occurred in the area of other organic fertilisers. The changes that result for 2020, for mineral fertiliser, result from multiple-year averaging, using a moving average.

Table 310: 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	2020
2023	2023	91.8	75.6	80.3	76.8	75.7	77.6	79.3	79.7	82.1	82.9	82.5	79.3	75.6	72.9
2022	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

Table 311: Changes, between the 2022 submission and the 2023 submission, in NO emissions from use of agricultural soils (negative values: reduction from the 2022 submission to the 2023 submission)

[kt a^{-1}]	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**0.391**	**0.911**	**1.345**	**1.402**	**1.406**	**1.464**	**1.513**	**1.461**	**1.631**	**1.649**	**1.655**	**1.616**	**1.701**	**1.693**	**0.926**
Mineral fertiliser	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	0.000	-0.914
Manure	0.245	0.281	0.283	0.273	0.270	0.280	0.293	0.313	0.319	0.323	0.320	0.310	0.302	0.296	0.262
Other organic fertilisers	0.145	0.629	1.057	1.112	1.141	1.186	1.219	1.142	1.305	1.319	1.327	1.300	1.390	1.387	1.592
Sewage sludge	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	0.000	-0.045
Grazing	0.001	0.001	0.006	0.016	-0.005	-0.002	0.002	0.006	0.007	0.006	0.008	0.006	0.009	0.009	0.031

In the area of NMVOC emissions, no changes have occurred with respect to the previous year's submission.

Table 312: 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	2020
2023	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	9.156
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	9.156

5.5.6 Planned improvements (3.D)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 2.8.9 in Rösemann et al. (2023).

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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**3 G, Liming**		**CO_2**	**2,200.5**	**0.2 %**	**2,006.4**	**0.3 %**	**-8.8 %**
-/-	3 H, Urea Application		CO_2	481.0	0.0 %	399.5	0.1 %	-17.0 %
-/-	3 I, Other carbon-containing fertilisers		CO_2	510.4	0.0 %	182.2	0.0 %	-64.3 %

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 1	NS	D

The category *CO_2 from liming* is a key category for CO_2 emissions in terms of emissions level and 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 the 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 (2006c 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 313, 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 313: 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	2021
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 (2006c Vol 4, 11.27) is based on use of the Tier 1 equation (equation 11.12 in IPCC (2006c 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 (2006c 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 5.3.3 in Rösemann et al. (2023).

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 (2006c 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 314 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 314: 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	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**	**2233.1**	**2195.2**	**2188.5**
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**	**81.0**	**80.7**
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	1960.2	1952.9
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	49.6	53.4
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	185.5	182.2

The Tier 1 method for CO_2-C emissions from urea application (IPCC, 2006c 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, 2006c 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 315 presents the resulting time series.

Table 315: CO_2 emissions from urea application (3.H)

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
[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	433.3	399.5
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	90.1	83.0

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 2020 CO_2 emissions from liming and urea application in Germany (current 2023 Submission) were compared with those of neighboring countries and the UK (2022 Submission, UNFCCC (2022b)); cf. Table 316.

Table 316: Comparison of the CO_2 IEF values used in the German inventory with those of neighboring countries, for the time-series year 2020

[kg CO_2-C per kg of fertiliser]	Limestone	Dolomite	Other carbon-containing fertilisers	Urea application
	[kg kg⁻¹]	[kg kg⁻¹]	[kg kg⁻¹]	[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	0.02600	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 (2006c): Vol. 4, 11.27	0.12	0.13		0.20

Source: Germany: 2023 Submission; other countries: UNFCCC (2022b)

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 (2006c): Vol. 4. With the exception of Denmark, this also applies in the case of dolomite use. Use of other lime-containing fertilisers is reported by only a few countries. The German IEF is close to the Danish value. All compared countries report CO_2 emissions from urea application, and all use the default emission factor given in IPCC (2006c).

5.8.4 Uncertainties and time-series consistency (3.G-I)

Table 254 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 6.3 and 6.9 in Rösemann et al. (2023).

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 254 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 2020 do the emissions differ from those reported in the 2022 submission. This is a direct result of multiple-year averaging of activity data; cf. Chapter 5.1.5.2.

Table 317: 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	2021
2023, 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	2195.2	2188.5
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	
2023 - 2022	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	42.3	
2023 - 2022, 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	0.0	2.0	

5.8.6 Planned improvements (3.G-I)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-e.)	(fraction)	Trend 1990-2021
-/T	3 J, Other		CH_4	0.3	0.0 %	1,500.2	0.2 %	485,379.3 %
-/-/2	3 J, Other		N_2O	0.1	0.0 %	227.4	0.0 %	205,276.5 %

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 for CH_4 emissions in terms of trend and a key category for N_2O emissions in terms of Approach 2 analysis.

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, no indirect N_2O emissions result from leaching / surface runoff from storage systems.

Table 318, 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 318 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 318: 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	2021
$CH_{4,EC}$	0.0	4.3
N_2O_{EC}	0.0	1.2
$CH_{4,EC}$ + N_2O_{EC} as GHG (in CO_{2eq})	0.0	2.9

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 5.1 in Rösemann et al. (2023).

5.9.3 CH_4 emission factor and emissions (3.J, CH_4)

Table 319 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 319: 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	2021
	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	2.61

The CH_4 emissions from digestion of energy crops (digesters and systems for storage of digestates) are shown in Table 320. 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 320: 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	2021
	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	53.58	53.58

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 321. 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 321 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 321: 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	2021
	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	1.71	1.71

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 (2006c 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 322. 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 322: 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	2021
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**	**0.858**	**0.858**
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	0.816	0.816
$N_2O_{indirect}$	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	0.042	0.042

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 323 shows the trend in NO emissions from digestion of energy crops (systems for storage of digestates).

Table 323: 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	2021
	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	0.111	0.111

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 254 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. Chapter 6.3 in Rösemann et al. (2023).

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 emissions time series of CH_4 and N_2O (cf. Chapter 5.1.4.2) were recalculated, using the same calculation method used for the 2022 submission. Table 324 compares the results of the present submission with those of last year's submission. Discrepancies are seen only for the years 2019 and 2020. They result from updating of activity data for those years; cf. Chapter 5.1.4.2.

Table 324: Comparison of GHG emissions from digestion of energy crops (digesters and systems for storage of digestates), as reported in the 2022 and 2023 Submissions (3.J), GWP pursuant to IPCC AR5

CO_2eq	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2023, kt	0.42	5.3	44.7	365.1	1138.7	1375.4	1394.7	1657.4	1711.5	1769.1	1756.1	1731.0	1702.4	1695.2	1727.6
2022 kt	0.42	5.3	44.7	365.1	1138.7	1375.4	1394.7	1657.4	1711.5	1769.1	1756.1	1731.0	1702.4	1695.2	1695.3
2023 - 2022, kt	0	0	0	0	0	0	0	0	0	0	0	0	0	-0,001	32.33
2023 - 2022, %	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.00004	1.9

5.9.9 Planned improvements (3.J)

No further improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 - 2021

In the LULUCF sector (Common Reporting Framework Sector 4), Germany reports on positive (source) and negative (sink) CO_2 emissions from the carbon pools[85]

- above-ground and below-ground biomass
- dead wood, litter (dead organic matter),
- 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 and hedges), 4.D, 4.E (emissions from the categories 4.B Cropland and 4.C Grassland in the narrow sense) (i.t.n.s.) 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,

[85] 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 conversion categories (4.A.2 - 4.F.2) for a total of 20 years. After 20 years in a conversion category, the areas are reported under the relevant remaining categories. In cases in which land-use changes resume, prior to the end of the conversion period, the relevant areas are assigned – with immediate effect as of the time of the land-use change – to the pertinent new conversion category. A new 20-year period (the effective conversion period) then begins for those areas.

Table 325 presents an overview of the German LULUCF reporting system, with all of the relevant land-use categories, sub-categories, pools, possible conversion categories and GHG emissions summarized in tabular form.

Table 325: Overview of the German LULUCF reporting system: Land-use categories, sub-categories and pools; and possible transitions and their related greenhouse-gas emissions

Category[1)]	Land use / land-use change (areas)[2)]			Pools (emissions)[2)]					
	Remaining in	from	to	Biomass	Soil mineral	Soil organic	Waters	Wildfire	DOM
forl	x			CO_2 [$EF_{biomass\_forest\_management}$]	CO_2, N_2O_{dir}, N_2O_{indir} [$EF_{BZE\ soil\ inventory}$ + Yasso Model]	CO_2+DOC, N_2O, $CH_{4\_org\_soil}$+$CH_{4\_ditch\_org\_soil}$ [EF_{org_soil}IPCC default values_forest]	/	CH_4, N_2O [$AD_{official\ statistics}$, $EF_{wildfires}$]	CO_2 [$EF_{DOM\_forest\_management}$]
forl		to all LUC, except cro1, crow, croh, croo, crob, gra1, gra2, wet2, wet4, wet5, set2, othl		CO_2 [$EF_{biomass\_deforestation}$]	CO_2, N_2O_{dir}, N_2O_{indir} [EF+Yasso]	CO_2+DOC, N_2O, $CH_{4\_org\_soil}$+$CH_{4\_ditch\_org\_soil}$, [3)]	/	/	CO_2 [$EF_{DOM\_deforestation}$]
forl			from all LUC, except cro1, crow, croh, croo, cros, crox, gra1, set1[9)], wet2, wet4, wet5, set2	CO_2 [$EF_{biomass\_afforestation}$]	CO_2, N_2O_{dir}, N_2O_{indir} [EF+Yasso]	CO_2+DOC, N_2O, $CH_{4\_org\_soil}$+$CH_{4\_ditch\_org\_soil}$ [EF_{org_soil}IPCC default values_forest]	/	/	CO_2 [$EF_{DOM\_afforestation}$]
cro1	x			/	/	CO_2+DOC, $CH_{4\_org\_soil}$+$CH_{4\_ditch\_org\_soil}$[5)]	/	/	/
cro1		to all LUC, except forl, wet2, wet4, wet5, set2, othl		CO_2 [EF $cropland_{annual}$]	CO_2, N_2O [8)]	CO_2+DOC, $CH_{4\_org\_soil}$+$CH_{4\_ditch\_org\_soil}$ N_2O [3)]	/	/	CO_2, only to forl
cro1			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [EF $cropland_{annual}$]	CO_2, N_2O [4)]	CO_2+DOC, $CH_{4\_org\_soil}$+$CH_{4\_ditch\_org\_soil}$[5)]	/	/	CO_2, only from forl
croh	x			/	/	CO_2+DOC, $CH_{4\_org\_soil}$+$CH_{4\_ditch\_org\_soil}$[5)]	/	/	/
croh		to all LUC, except forl, wet2, wet4, wet5, set2, othl		CO_2 [EF croh]	CO_2, N_2O [8)]	CO_2+DOC, $CH_{4\_org\_soil}$+$CH_{4\_ditch\_org\_soil}$, N_2O[3)]	/	/	CO_2, only to forl
croh			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [EF croh]	CO_2, N_2O [4)]	CO_2+DOC, $CH_{4\_org\_soil}$+$CH_{4\_ditch\_org\_soil}$[5)]	/	/	CO_2, only from forl

Category[1)]	Remaining in	Land use / land-use change (areas)[2)] from	to	Pools (emissions)[2)] Biomass	Soil mineral	Soil organic	Waters	Wildfire	DOM
croo	x			CO_2 [fruit model]	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	/
croo		to all LUC, except wet2, wet4, wet5, set2, othl		CO_2 [fruit model]	CO_2, N_2O [8)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O[3)]	/	/	CO_2, only to forl
croo			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [fruit model]	CO_2, N_2O [4)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	CO_2, only from forl
cros	x			CO_2 [KUP model]	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	/
cros		to all LUC, except wet2, wet4, wet5, set2, othl		CO_2 [KUP model]	CO_2, N_2O [8)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O[3)]	/	/	CO_2, only to forl
cros			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [KUP model]	CO_2, N_2O [4)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	CO_2, only from forl
crot	x			CO_2 [tree nursery model]	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	/
crot		to all LUC, except forl, wet2, wet4, wet5, set2, othl		CO_2 [tree nursery model]	CO_2, N_2O [8)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O[3)]	/	/	CO_2, only to forl
crot			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [tree nursery model]	CO_2, N_2O [4)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	CO_2, only from forl
crow	x			CO_2 [vineyards model]	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	/
crow		to all LUC, except forl, wet2, wet4, wet5, set2, othl		CO_2 [vineyards model]	CO_2, N_2O [8)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O[3)]	/	/	to forl, CO2
crow			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [vineyards model]	CO_2, N_2O [4)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	from forl, CO2
crox	x			CO_2 [Christmas trees model]	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	/
crox		to all LUC, except forl, wet2, wet4, wet5, set2, othl		CO_2 [Christmas trees model]	CO_2, N_2O [8)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O[3)]	/	/	CO_2, only to forl
crox			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [Christmas trees model]	CO_2, N_2O [4)]	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$ [5)]	/	/	CO_2, only from forl

Category[1)]	Remaining in	Land use / land-use change (areas)[2)]		Pools (emissions)[2)]					
					Soil				
		from	to	Biomass	mineral	organic	Waters	Wildfire	DOM
gra1	x			/	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	/
gra1		to all LUC, except forl, wet2, wet4, wet5, set2, othl		CO_2 [EF Grassland $_{annual}$]	CO_2, N_2O_{dir}, $N2O_{indir}$	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O [3)]	/	/	CO_2, only to forl
gra1			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [EF Grassland $_{annual}$]	CO_2, N_2O_{dir}, $N2O_{indir}$	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$[5)]	/	/	CO_2, only from forl
gra2	x			CO_2 [Hedges / woody grassland model]	/	CO_2+DOC, $CH_{4\_org\_soil}$+$CH_{4\_ditch\ org\_soil}$, N_2O [EF_{org_soil}IPCC default values]	/	/	/
gra2		to all LUC, except wet2, wet4, wet5, set2, othl		CO_2 [Hedges / woody grassland model] [6)]	CO_2, N_2O_{dir}, N_2O_{indir}	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O [3)]	/	/	CO_2, only to forl
gra2			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [Hedges / woody grassland model]	CO_2, N_2O_{dir}, N_2O_{indir}	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O [EF_{org_soil}IPCC default values_forest]	/	/	CO_2, only from forl
gra3	x			CO_2 [Hedges / woody grassland model]	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O	/	/	/
gra3		to all LUC, except wet2, wet4, wet5, set2, othl		CO_2 [Hedges / woody grassland model] [6)]	CO_2, N_2O_{dir}, N_2O_{indir}	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O 3)	/	/	CO_2, only to forl
gra3			from all LUC, except forl, wet2, wet4, wet5, set2	CO_2 [Hedges / woody grassland model]	CO_2, N_2O_{dir}, N_2O_{indir}	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O	/	/	CO_2, only from forl
wet1	x			CO_2 [Terrestrial wetlands model]	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O	/	/	/
wet1		to all LUC, except wet2, wet4, wet5, set2, othl		CO_2 [Terrestrial wetlands model]	CO_2, N_2O_{dir}, N_2O_{indir}	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O [3)]	/	/	CO_2, only to forl
wet1			from all LUC, except wet2, wet4, wet5, set2	CO_2 [Terrestrial wetlands model]	CO_2, N_2O_{dir}, N_2O_{indir}	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O	/	/	CO_2, only from forl
wet2	x	/	/	/	/	/	/	/	/

Category[1)]	Remaining in	Land use / land-use change (areas)[2)] from	to	Pools (emissions)[2)] Biomass	Soil mineral	Soil organic	Waters	Wildfire	DOM
wet3	x			/	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O [on-site emissions]	/	/	/
wet3		to all LUC, except wet2, wet5, set2, othl		CO_2 [$EF_{peat\_extraction}$]	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O [3)]	CH_4 [EF $wet4_{org\_soil}$] [7)]	/	CO_2, only to forl
wet3			from all LUC, except wet2, wet4, wet5, set2	CO_2 [$EF_{peat\_extraction}$]	/	CO_2, CH_4, N_2O [on-site emissions]	/	/	CO_2, only from forl
wet3				/	/	CO_2 [off-site emissions]	/	/	/
wet4	x			/	/	/	CH_4 [EF $wet4_{org\_soil}$] + CH_4 [EF $wet4_{min\_soil}$]	/	/
wet4		/		/	/	/	/	/	/
wet4			only from wet3	/	/	/	CH_4 [EF $wet4_{org\_soil}$]	/	/
wet5	x	/	/	/	/	/	CH_4 [EF wet5]	/	/
set1	x			CO_2 [Settlements model]	/	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O	/	CH_4, N_2O [peat fire]	/
set1		to all LUC, except wet2, wet4, wet5, set2, othl		CO_2 [Settlements model]	CO_2, N_2O_{dir}, N_2O_{indir}	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O [3)]	/	/	to forl, CO_2
set1			from all LUC, except wet2, wet4, wet5, set2	CO_2 [Settlements model]	CO_2, N_2O_{dir}, N_2O_{indir}	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O	/	/	from forl, CO_2
set2	x	/	/	/	/	/	/	/	/
othl	x			/	/	/	/	/	/
othl		from all LUC, except wet2, wet4, wet5, set2		/	CO_2, N_2O_{dir}, N_2O_{indir}	CO_2+DOC, $CH_{4\_org\_soil}$+ $CH_{4\_ditch\ org\_soil}$, N_2O [3)]	/	/	CO_2, only to forl
othl			/	/	/	/	/	/	/

1) For definitions, cf. Table 335, Chapter 6.1.2
2) For all pools and land-use categories, identification of areas, and emissions calculation, are carried out at the state (Land) level
3) N_2O, CRF 3.D.a.6, in the case of LUC leading to gra1 and other cropland categories (cro*)
4) N_2O, CRF 3.D.a.5, in the case of LUC from other cropland categories (cro*)
5) N_2O, CRF 3.D.a.6
6) In the case of LUC to forl, only 50 % biomass loss
7) Only in the case of LUC to wet4
8) N_2O, CRF 3.D.a.5, in the case of LUC leading to cro1, croo, cros, crot, crow, crox
9) Exceptions: Heap / open-pit mine / landfill to forest land are all possible

Figure 51, Figure 52 and Figure 53 provide an overview, for the present 2023 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, 2020 and 2021 (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 351).

The course of net emissions shows that the LULUCF sector functioned as a sink in most of the years in the period 1990 through 2021. 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, 2002 through 2007, 2020 and 2021, the LULUCF sector was a source for greenhouse gases. This resulted primarily from a reduction of forests' sink function – which, in turn, resulted from increased logging. Logging was increased primarily for the purpose of addressing forest damage resulting from various calamities (such as storms, droughts, pest infestations).

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 51: Time series for GHG emissions and removals (sum of CO_2, CH_4 and N_2O) [kt CO_2 e pursuant to IPCC AR5] in the LULUCF sector since 1990, by sub-categories

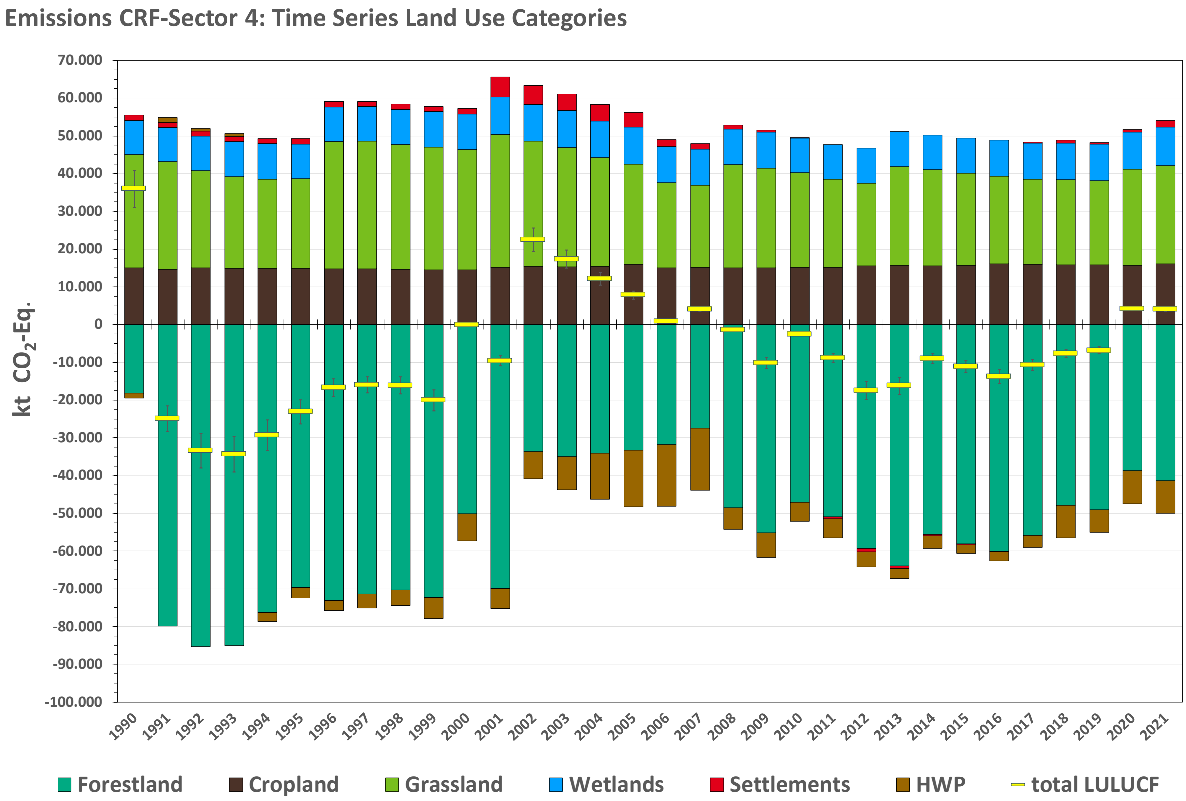


Figure 52: Time series for GHG emissions and removals (sum of CO_2, CH_4 and N_2O) [kt CO_2 e pursuant to IPCC AR5] in the LULUCF sector since 1990, by pools

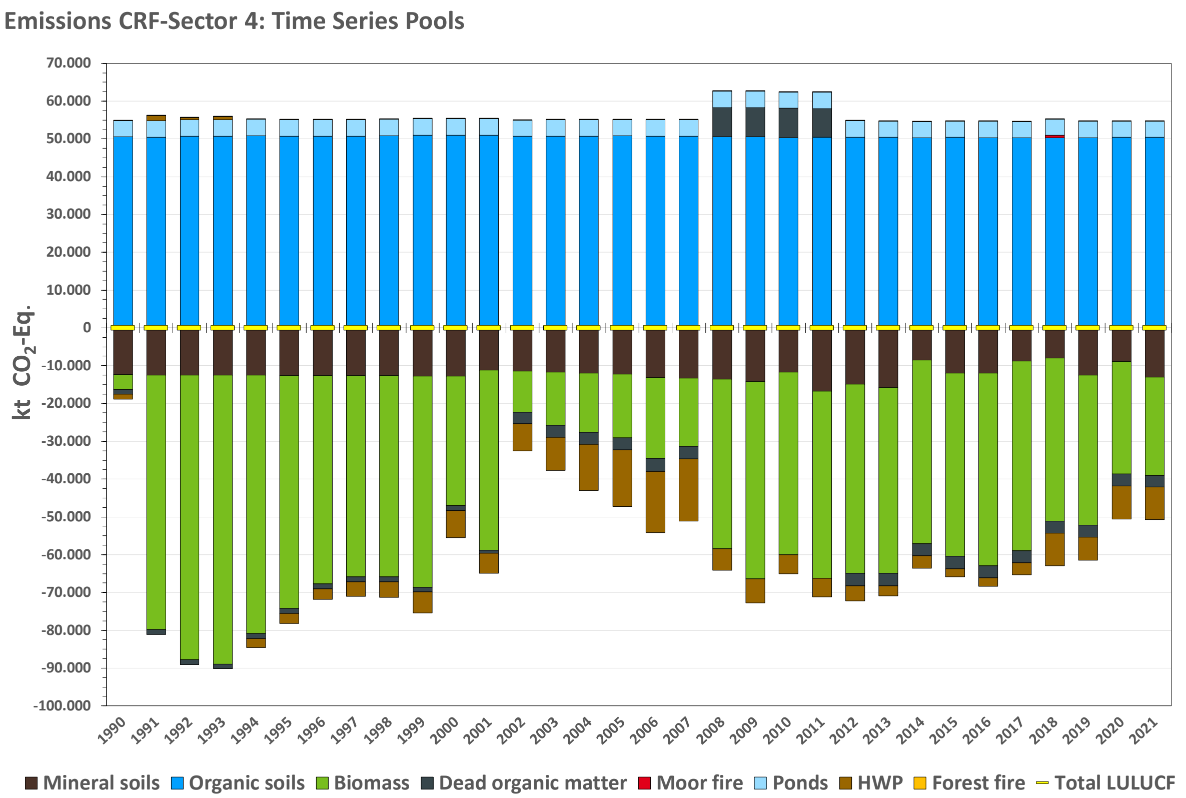
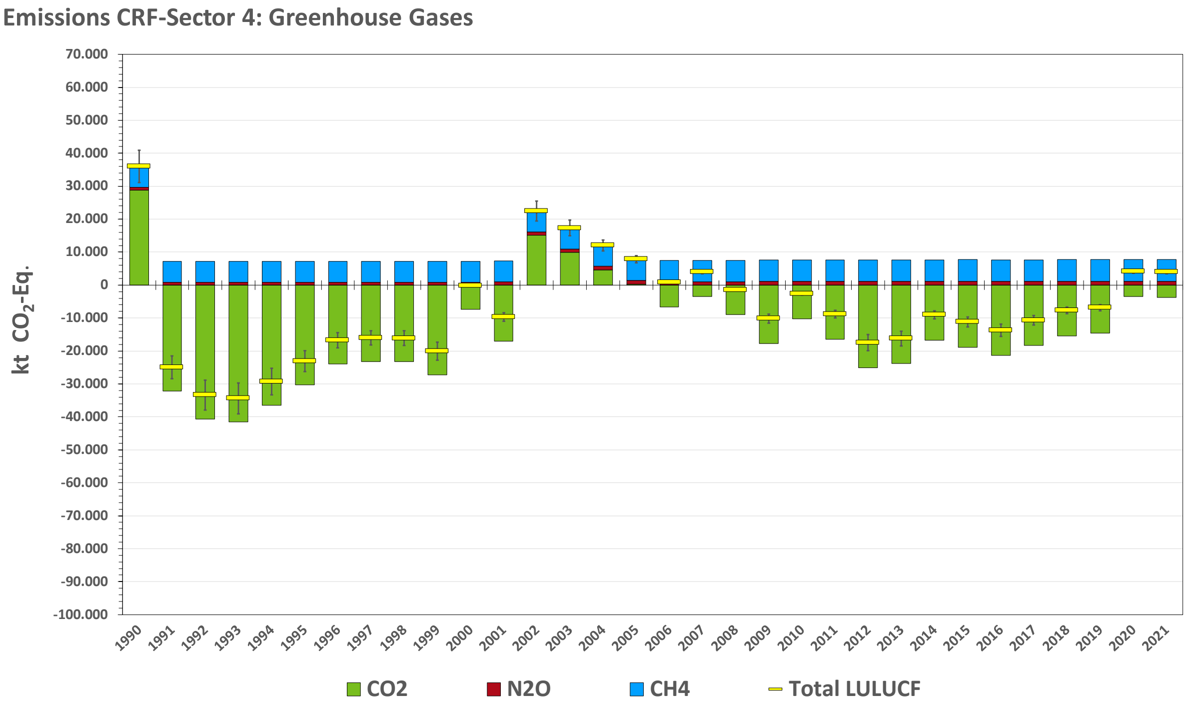


Figure 53: Time series for GHG emissions and removals (sum of CO_2, CH_4 and N_2O) [kt CO_2 e pursuant to IPCC AR5] in the LULUCF sector since 1990, by greenhouse gases (GHG)



The pertinent calculation shows that the total uncertainty of the German LULUCF inventory (not including harvested wood products) is 13.6 %. The pertinent details are presented in the relevant chapters for the individual land-use categories and in Chapter 6.1.2.10.

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 326, and additional explanatory remarks are provided in Chapter 6.2 (cf. also Chapter 6.3).

Table 326: Correlation of the German reporting categories with the IPCC land-use categories

IPCC category	German land-use category or sub-category		
	Abbreviation	**Full designation**	**Description**
4.A Forest Land	forl	***Forest Land***	Deciduous-forest, coniferous-forest and mixed-forest land
4.B Cropland	**Cropland**		Total consisting of $cropland_{annual}$, hops-cultivation areas, vineyards, orchards, tree nurseries, Christmas tree plantations, short-rotation plantations
	cro1	***$Cropland_{annual}$***	Areas for cultivation of crops and vegetables
	croh	***Hops***	Refers to agricultural areas that are equipped with special fixtures for hops cultivation
	crow	***Vineyards***	Vineyards are agricultural areas that are equipped with special fixtures for planting of grapevines
	croo	***Orchards***	Orchards are areas that are used primarily for intensive fruit cultivation, and that contain fruit trees and shrubs. Orchards differ from meadow orchards in that they are monocultures, and are uniformly and densely planted.
	crot	***Tree nurseries***	Tree nurseries are areas on which woody plants are grown from seeds, shoots and cuttings, and are transplanted multiple times in the process.
	crox	***Christmas tree plantations***	Christmas tree plantations are agricultural areas that are planted primarily with Christmas trees.
	cros	***Short-rotation plantations***	Short-rotation plantations are areas on which trees 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.
4.C Grazing Land	**Grassland**		Total of grassland (in the strict sense), woody grassland and hedges
	gra1	***Grassland (in the strict sense)***	Grassland (in the strict sense) (meadows, pastures, mowed pastures, wet grassland, rough pastures....)

IPCC category	German land-use category or sub-category		
	Abbreviation	**Full designation**	**Description**
	gra2	***Woody Grassland***	Areas that contain scattered trees, groups of trees, bushes and shrubs, and that do not fall within the definition of Forest Land or Grassland (in the strict sense).
	gra3	***Hedges***	Hedges consist of shrubs (and trees, in some cases) growing in dense linear formations (with either one or multiple rows)
4.D Wetlands	**Wetlands**		Total of terrestrial wetlands, natural water bodies, peat extraction, and standing and flowing man-made water bodies
	wet1	***Terrestrial Wetlands***	Terrestrial wetlands that do not fall within one of the other land-use categories (such as semi-natural peatlands)
	wet2	***Natural water bodies***	Natural water areas and watercourses
	wet3	***Peat extraction***	Areas that are located on organic soils and that are used for peat extraction
	wet4	***Standing man-made water bodies***	Man-made standing waters (water areas), such as reservoirs, quarry ponds and other types of ponds, lakes formed from open-pit mines, and artificial freshwater pools of all kinds (exception: wastewater-treatment facilities)
	wet5	***Flowing man-made water bodies***	Man-made, flowing water bodies (watercourses), such as drainage ditches for water-resources management (exception: drainage ditches on organic soils), basins along inland waters, and canals
4.E Settlements	**Settlements**		Total comprising settlements and roads
	set1	***Buildings and open areas***	Areas used for residential, production and traffic purposes, and urban green areas and other areas used for rest and recreation
	set2	***Roads***	Traffic routes for road vehicles and pedestrians
4.F Other Land	othl	***Other Land***	Vegetation-free, un-managed areas

Basic elements of the LULUCF inventory, and the steps required to prepare it

1. **Land-use matrix$_{\text{annual}}$** *[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, Hedges, Terrestrial wetlands, Natural waters, Man-made flowing water bodies, Man-made standing water bodies, 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, 2020 and 2021. 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 (2006a), 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 conversion 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 conversion categories larger, than the corresponding areas in an annual land-use matrix.

The relevant areas are shown in the CRF tables Table 349 and Table 350. When areas undergoing a 20-year conversion 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 conversion category, and they enter a new 20-year conversion period.

5. **Emission factors** *[EF]* **and implied emission factors** *[IEF]* **for the twenty-year conversion 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 conversion 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 conversion categories, as a result of new land-use changes within the 20-year conversion 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 conversion 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 conversion 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 conversion 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 conversion 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 conversion 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 conversion 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 265 (GWP 100 pursuant to IPCC AR5).**
9. **The CH_4 emissions are** converted into CO_2 equivalents using the factor 28 (GWP 100 pursuant to **IPCC AR5**.

The 2023 Submission was compiled in accordance with the following provisions:

- 2006 IPCC Guidelines (IPCC, 2006a)
- 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)
- 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC)

. The key inventory-improvement measures that were carried out for the present submission and that led to recalculations:

- Complete reimplementation of the LULUCF calculation model in the programming languages R and C++ (see below)
- Introduction of additional land-use sub-categories (cf. Table 326):
    - Hedges (under land-use category Grassland; cf. Chapter 6.2.3)
    - Natural water bodies (under land-use category Wetlands; cf. Chapter 6.2.4)
    - Standing man-made water bodies (under land-use category Wetlands; cf. Chapter 6.2. 4)
    - Flowing man-made water bodies (under land-use category Wetlands; cf. Chapter 6.2. 4)
    - Roads (under land-use category Settlements; cf. Chapter 6.2.5)
- Thematic, spatial and chronological 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 models for determination of emissions in the new land-use categories, including determination of activity data and emission factors (cf. Chapters 6.6.2 and 6.8.2)
    - Introduction of new, regionalised emission factors for mineral soils in the sub-category buildings and open areas of the land-use category Settlements (cf. Chapter 6.1.2.1.6) and the land-use category Other Land (cf. Chapter 6.1.2.1.7)

- Implementation of complete-coverage, high-resolution maps of regionalised mineral-soil carbon and nitrogen stocks, for the land-use categories $Cropland_{annual}$, Grassland and Forest Land, within the method for determining GHG emissions from mineral soils (cf. Chapter 6.1.2.1ff)
- Mineral soils of Forest Land: Expansion of the “stock-difference method,” with computer-aide modelling with YASSO15, and combination of both methods with the “overlap method” (cf. Chapter 6.1.2.1ff and Chapter 6.4.2.5ff)
- Wildfires: Inclusion of the biomass of the pools dead wood and litter in connection with wildfires, beginning with this submission (cf. Chapter 6.4.2.7.5)

Apart from these changes, the methods, data sources and emission factors used in the previous submission were again used.

Implementation of the inventory model

The calculations for determination of all emissions and inventory-relevant values for Germany's LULUCF sector are carried out completely automatically, via a digital program system coupled with a combined geoinformation/database system. For the 2023 submission, the program system has been completely revamped, to enable fulfillment of growing performance requirements pertaining to implementation of review requirements. The inventory model is implemented as a package in R (The R Core Team, 2022), and it provides the necessary performance by relying strongly on the R packages data.table (Dowle et al., 2022) and Rcpp (Eddelbuettel & François, 2011). The interface for the LULUCF database consists of the R packages DBI[86] (Wickham & Müller, 2022) and RPostgres (Wickham et al., 2022). The software is administrated in an internal version-control environment[87].

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, 2006a), as the difference between the stocks prior to relevant land-use changes and the stocks after the changes. The emission factors are country-specific. For the land-use categories Forest Land, $Cropland_{annual}$ and Grassland, they have been taken, for the first time, from maps of the carbon and nitrogen stocks of Germany's mineral soils. The maps are based on results of soil inventories for forest land and agricultural land that, with the help of various computer-based methods, have been regionalised and georeferenced via a complete-coverage approach that takes account of numerous location factors (such as climate, topography, geology, pedology, utilisation) (cf. Chapter 6.4.2.5.3).

For the land-use category Other Land, representative carbon stocks, weighted by area, were determined for mineral soils with depths to 30 cm, from data of the Agricultural Soil inventory. 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 (cf. Chapter 6.1.2.1.6). As a result, the reporting on mineral soils applies a Tier 2 or Tier 3 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

[86] DBI https://dbi.r-dbi.org/
[87] GitLab https://about.gitlab.com/

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 Forest Land remaining Forest Land, the changes in carbon and nitrogen stocks as of the year 2009 were calculated, for the first time, and on an annual basis, with the Yasso model. The pertinent soil-characteristics maps were updated on an annual, complete-coverage basis (Chapter 6.4.2.5ff.).

In the category Wetlands (4.D), mineral soils occur only in the sub-categories *Terrestrial Wetlands* and *Waters*. In the case of land-use changes to *Waters*, no carbon-stock changes are assumed. For land-use changes from Waters to other 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 conversion 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. For *Forest Land, Cropland*$_{annual}$ and *Grassland*, the final values are taken from the relevant maps, which are updated annually. Pursuant to the IPCC default (IPCC, 2006a), 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 conversion 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).

To take account of the 20-year conversion period, the total stock change for each conversion category in question (EF_ann) is divided by 20. This yields the implied emission factors for the conversion categories for land-use changes leading out of a remaining category (IEF_20y).

$$\Delta C_i = \begin{cases} \dfrac{(C_{final,i} - C_{initial,i})}{20}, i = 0 \\ \dfrac{(C_{final,i} + 0{,}41t - C_{initial,i})}{(20 - i)}, i > 0 \end{cases}$$

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 (ΔC_i + $C_{initial,\,i}$).

Areas affected by land uses remain for at least 20 years within a conversion 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 conversion time" concept, an area affected by a land-use change is assigned to its relevant new conversion category right at the time of the pertinent use change. This is done regardless of how long the area has already been in a conversion 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 known for all grid points and for all relevant times. While final stocks (C_{final}) are given by the relevant soil map, initial stocks are variable. In each case, they represent the value achieved, until the time of the next land-use change, in the previous conversion category. Carbon-stock changes for areas undergoing early removal from conversion categories are also calculated using the above algorithms, although $C_{initial}$ then represents the current mineral-soil carbon stocks attained in the previous conversion 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 conversion category in a given reported year.

6.1.2.1.2 Database and procedure for determination of carbon stocks

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:

- Results of the Forest Soil Inventories I and II (BZE-Wald I and BZE-Wald 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))
- Soil map (Bodenübersichtskarte; BÜK), scaled to 1:1,000,000 (BÜK 1000; BGR 1995 & 1997, Düwel et al. (2007))
- Map of soil regions and major soil landscapes (Karte der Bodenregionen und Bodengroßlandschaften), scaled to 1:5,000,000 (BGL 5000; BGR 2008)
- Map of soil climate regions (Karte der Bodenklimaräume) (ROSSBERG et al., 2007)
- Map of organic soils (Karte organischer Böden) (ROSSKOPF et al., 2015)
- Maps from the LUCAS programm
- Nitrogen, pH (Stickstoff, pH) (BALLABIO et al., 2016)
- Clay content, available water capacity (Tongehalt, verfügbare Wasserkapazität) (BALLABIO et al., 2016)
- Geomorphographic map of Germany (Geomorphografische Karte Deutschlands) (BGR 2007)
- Hydrogeological map of Germany (Hydrogeologische Karte Deutschlands) (BGR & SDG 2019)
- Map of net soil erosion and deposition rates in Europe (Karte der Netto-Bodenerosion und der Ablagerungsraten in Europa) (BORELLI et al., 2018)
- Digital elevation model of Europe (Digitales Höhenmodell Europas) (EU-DEM; European Union Copernicus Land Monitoring Service and EEA, 2016)
- Data of the German Weather Service (Deutscher Wetterdienst) (DWD, various years)
- 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)
- Corine Land Cover from the years 1990 and 2000, for determination of land-use changes from 1990 to 2000

- The INSPIRE standard grid, newly scanned, with a resolution of 100 m (Eurostat Grid Generation Tool for ArcGIS, https://www.efgs.info/information-base/best-practices/tools/eurostat -grid-generation-tool-arcgis/; last accessed: 10 December 2020)
- IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Other Land Use (IPCC, 2006a)

Because the various land-use categories differ in terms of their data situations, location-specific mineral-soil carbon and nitrogen stocks were determined separately for the various categories. The values for *Forest Land*, *Cropland$_{annual}$* and the Grassland categories are obtained from maps of the carbon and nitrogen stocks of Germany's mineral soils. In the present submission, the maps, which were developed on the basis of the results of the Forest Soil Inventories (BZE-Wald I and BZE-Wald II; WELLBROCK et al. 2016) and of the Agricultural Soil Inventory (JACOBS et al. 2018), are being used for the first time. These land-use categories current comprise about 85 % of Germany's area, and thus represent the main land uses to consider. The various models used for preparation of the maps are described in Chapter 6.1.2.1.3, for Forest Land, and in Chapter 6.1.2.1.4 and Chapter 6.1.2.1.5 for *Cropland$_{annual}$* and *Grassland*.

For the perennial Cropland sub-categories *Hops, Orchards, Vineyards, Christmas tree plantations, Tree nurseries* and *Short-rotation plantations* (Chapter 6.1.2.1.4), and for *Terrestrial Wetlands* and *Other Land* (Chapter 6.1.2.1.7), area-weighted, use-specific and soil-specific, average carbon and nitrogen stocks were determined for mineral soils, using data from the Agricultural Soil Inventory. The mineral-soil carbon stocks for Settlement soils have been derived from the results of these soil inventories (cf. Chapter 6.1.2.1.6).

6.1.2.1.3 Forest Land

Beginning with the present submission, reporting on GHG emissions from mineral soils on Forest Land exhibits several new features:

1. The reporting uses different methods for two different time periods.
    - For the period 1990 - 2008, changes in carbon and nitrogen stocks in mineral soils are determined with the "stock-difference" method, as was the case in the past (Chapter 6.4.2.5.4).
    - For the period as of 2008, the results are based on the mathematical model Yasso15 (Järvenpää et al., 2018; Tuomi et al., 2009). This division into two time periods was necessary for the reason that only as of 2008 are enough input data sets available to enable correct calculation of organic carbon stocks in mineral soils using Yasso15.
    - The two approaches were combined using the overlap method (2006 IPCC Guidelines). The relevant methods are described in detail in Chapters 6.4.2.5.3 and 6.4.2.5.4.
2. The results of the soil inventories (Grueneberg et al. (2014)), with regard to the carbon and nitrogen stocks of mineral soils on Forest Land, have been regionalised.
    - Using Yasso15, on the basis of the results of the Forest Soil Inventory, and of the legend units of the BÜK 1000 Soil map for the Federal Republic of Germany (1:1,000,000), Forest Land regions with the same carbon and nitrogen stocks were identified, taking account of their pedological, geological and climatic circumstances. The results are presented annually, in the form of chronologically dynamic, georeferenced maps (cf. Chapter 6.4.2.5.3). The carbon and nitrogen stocks shown in

the maps serve as the basis for all calculations in connection with mineral forest soils.

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 – BZE-LW) 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.

Cropland with annual crops

For the land-use category $Cropland_{annual}$, complete-coverage grid maps (100 x 100 m grids) of soil carbon stocks and C/N ratios for Germany's mineral-soils areas were prepared, via regionalisation of the results of the Agricultural Soil Inventory. Ensemble-learning procedures were used for this process. This entailed application of machine-learning algorithms to decision-tree ensembles generated with independent partial data sets. The basis for this work consisted of data of the Agricultural Soil Inventory and numerous covariates from the following areas:

- Soil, geology, geomorphology, hydrology
- Climate
- Organic factors, vegetation indices
- Topography, relief

In order to reduce the model's multi-collinearity, strongly correlating covariates (R > 0.9) were removed from the ensemble; ultimately, 34 parameters entered into the model calculations. Detailed explanations of the procedure, and the covariates involved, are provided in (Sakhaee et al.) and (Gebauer et al.).

In the C/N model, the algorithms *Random Forest* and *Support Vector Machine for Regression* were used as base learners. The predictions of the base learners were then averaged, in order to obtain the final prediction. In most instances of ensemble learning, the tuning of each base learner is carried out independently. In the ensemble approach used, the hyperparameter tuning was integrated within the training / learning program, however (Shahhosseini et al., 2022).

The SOC model was preapred with a new method, *Regressor Chaining* (Spyromitros-Xioufis et al., 2016). By using intercorrelated parameters, this method is able to improve predictions of soil characteristics (Santana et al., 2021). First, a *Regressor Chaining* model was developed that, with the help of *Random Forest*, can predict C/N ratios. The predicted C/N ratios were then used, in an ensemble approach (*Random Forest* and *Support Vector Machine for Regression*), for SOC prediction. Like the ensemble approach, which was used for creation of the C/N model, the hyperparameter tuning of the *Regressor Chaining* approach was part of the training/learning process. Further details and explanations relative to the *Regressor Chaining* method are provided in Spyromitros-Xioufis et al. (2016). For all models, the hyperparameter tuning was carried out with the *Differential Evolution (DE)* algorithm (Sakhaee et al.).

The robustness of the models, in connection with the combination of hyperparameter tuning and model evaluation, was checked via stratified, hierarchical/nested cross-validation (Sakhaee et al.).

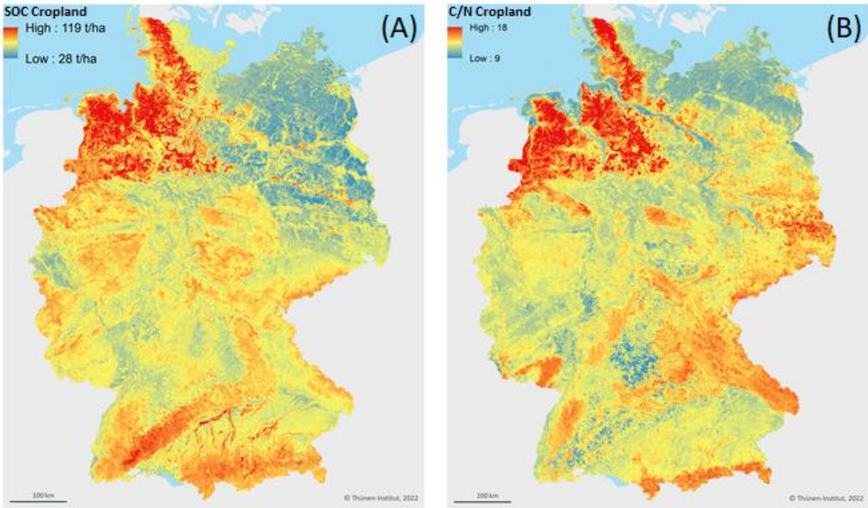


Figure 54: Map of (A) SOC stocks [t C ha^{-1} 30 cm^{-1}] and (B) C/N ratios in Germany's mineral soils that are managed as cropland with annual crops (*Cropland$_{annual}$*)

Figure 54 shows the so-determined grid maps. The measured (results of the BZE-LW Agricultural Soil Inventory, Jacobs et al. (2018)) and predicted average values and medians of the C/N ratios and soil organic carbon stocks (cf. Figure 54), and the statistical indicators needed for assessing the model, are shown in Table 327.

Table 327: Average values and medians of the measured and predicted C/N ratios and soil organic carbon stocks [t C ha^{-1} 30 cm^{-1}] in mineral soils under annual cropland (*Cropland$_{annual}$*)

Cropland$_{annual}$		Central tendency		Statistical indicators, model quality				
		Average	Median	RMSE	MAE	MAPE [%]	Bias [%]	Number
C/N	measured	11.10	10.43	1.5	0.98	8.39	-0.02	2204
	predicted	11.12	10.57					
SOC [t C ha^{-1} 30 cm^{-1}]	measured	61.18	55.58	20.92	13.84	23.24	-0.05	2204
	predicted	59.04	57.11					

Cropland with perennial crops

In the BZE-LW Agricultural Soil Inventory, only a small number of soil profiles on sites with special crops and/or perennial biomass (orchards, vineyards, hops, tree nurseries, Christmas tree plantations and short-rotation plantations) were studied. For this reason, it was not possible to regionalise the results for mapping purposes.

For the sub-categories hops, tree nurseries, Christmas tree plantations and short-rotation plantations, the number of sites studied was even too small for derivation of specific average mineral-soil carbon stocks for the relevant crops, since, consequently, it was not possible to prove or calculate statistically significant differences between 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 higher prevalence of such areas, with respect to the other special crops. Germany's vineyards all lie basically within the same climate zone. For this reason, their soils do not need to be stratified in terms of climatic influences. On the other hand, Germany's two main fruit-growing regions, in the north (“Altes Land” region) and the extreme south (the Lake Constance region), do lie in different climate zones (Sakhaee et al., 2022) . While a comparison of a) the mineral-soil carbon stocks of fruit-growing areas in the northern part of the country and b) the mineral-soil carbon stocks of relevant areas in the southern part of the country does turn up considerable differences with regard to average soil organic carbon stocks (80 t C/ha as opposed to 66 t C/ha), those differences are not statistically significant, in light of the absolute number of samples involved and the very large range that results (93 t C/ha in the north, and 60 t C/ha in the sourth). For this reason, a single value is used, nationwide, for orchards.

The mean carbon-stocks values for mineral soils in the various individual cropland sub-categories are shown in Table 328.

Table 328: Mean area-based mineral-soil carbon stocks to a soil depth of 30 cm [t C ha^{-1} $30cm^{-1}$], and pertinent uncertainties [%] for croplands with annual and perennial crops

Mineral soils	Carbon stocks [t C ha^{-1}]	Uncertainty [%]
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

6.1.2.1.5 Grassland

The land-use category *Grassland* comprises the sub-categories *Grassland in the strict sense, Woody Grassland* and *Hedges* (cf. Chapter 6.2.3). With regard to the characteristics of the mineral soils within these sub-categories, and to their carbon and nitrogen stocks, it is assumed that they do not differ significantly as a result of use and location. For this reason, for all three sub-categories, the mineral soils' carbon and nitrogen stocks were derived in a consistent manner from the Agricultural Soil Inventory's results for grassland (Jacobs et al., 2018).

As was done for $Cropland_{annual}$, a complete-coverage map of the C stocks and the C/N ratios of Germany's grassland soils was prepared, on the basis of the results of the Bodenzustandserhebung Landwirtschaft Agricultural Soil Inventory and numerous covariates. A short description of the approach used is provided in Chapter 6.1.2.1.4. A detailed description of the underlying method is provided by (Sakhaee et al.). The grid maps are shown in Figure 55, while the measured and estimated central tendencies, and several statistical indicators for assessment of the quality of the predictive model, are presented in Table 329.

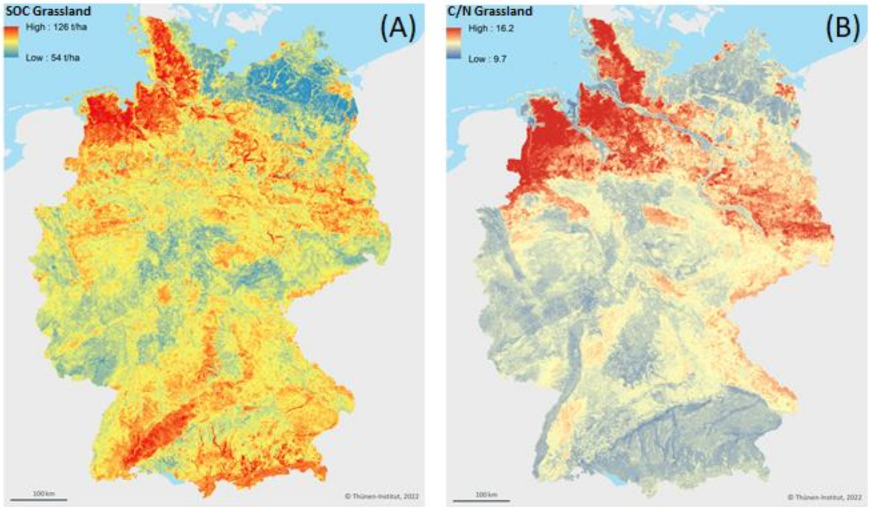


Figure 55: Map of (A) SOC stocks [t C ha^{-1} 30 cm^{-1}] and (B) C/N ratios in Germany's mineral soils under *Grassland*

Table 329: Average values and medians of the measured and predicted C/N ratios and soil organic carbon stocks [t C ha^{-1} 30 cm^{-1}] in mineral soils under *Grassland*

Cropland$_{annual}$		Central tendency		Statistical indicators, model quality				
		Average	Median	RMSE	MAE	MAPE [%]	Bias [%]	Number
C/N	measured	11.13	10.52	1.75	1.08	8.97	-0.01	740
	predicted	11.09	10.68					
SOC [t C ha^{-1} 30 cm^{-1}]	measured	88.09	83.21	30.48	21.42	27.57	-0.1	740
	predicted	59.04	57.11					

6.1.2.1.6 Settlements

The remarks in the following section refer only to the land-use sub-category *Buildings and open areas*, since the sub-category *Roads* was introduced with this submission only on an initial, static basis (cf. Chapter 6.1.1). For this reason, the terms *Settlements* and *Buildings and open areas* are used synonymously in this chapter, except where further differentiation is explicitly mentioned.

Emissions resulting from active construction measures

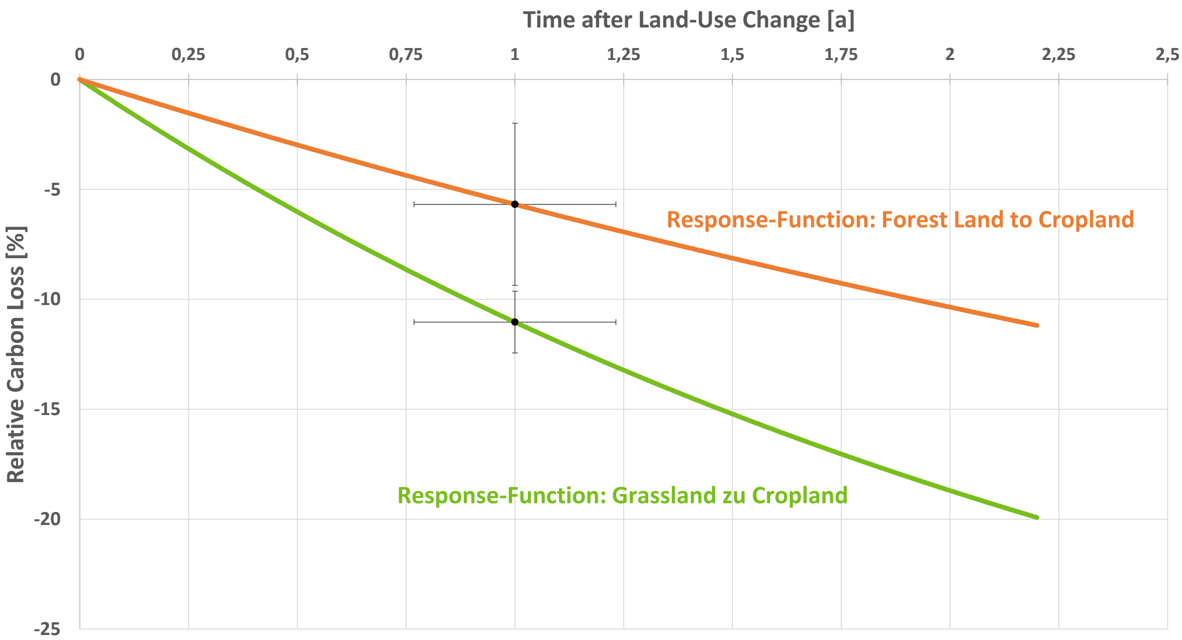
In the case of land-use changes leading to Settlements, the humus-rich topsoil layer (30 cm soil depth), which is relevant for reporting purposes, is completely removed on the affected area. German law mandates special protection for topsoil (Section 202 German Building Code (Bundesanzeiger Verlag (2015))), 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 (BMJ & BfJ, 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 2006 IPCC Guidelines 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 (2006a), 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) (cf. Figure 56). Such land-use changes result in enormous, lasting disruptions of the topsoil, including intensified aeration of the topsoil.
- 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)]
- Δ CSOC_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:

- Function Grassland converted to Cropland: -11.0 %
- Function Forest Land converted to Cropland: -5.7 %

Figure 56: 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 56) 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)). 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 (in the present NIR, they fall into the land-use category *Roads*) – 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 19, which takes account of the above-described assumptions.

Equation 19:

$$SOC_{min\_set} = SOC_{Ini\_prev} * (AF_{unsealed} * CF_{unsealed} + AF_{buildings} * CF_{buildings})$$

SOC_{min_set}: Organic mineral-soil carbon stocks of the sub-category *Buildings and open areas*, 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 = 0.6; 60 % unsealed area share of the area of sub-category *Buildings and open areas*, pursuant to the assumptions made in Chapter 6.2.5
$CF_{unsealed}$: Carbon factor for the unsealed area = 1; 100 % SOC_{Ini_prev}
$AF_{buildings}$: Area factor = 0.4; 40 % sealed area share of the area of sub-category *Buildings and open areas*, pursuant to the assumptions made in Chapter 6.2.5
$CF_{buildings}$: Carbon factor for Building $area_{sealed}$ = 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 conversion 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, regionalised at the federal-state (Länder) level, weighted by area and the previous use in each case, are assumed for mineral soils. To this end, for each conversion 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 the SOC_{Ini_prev} for mineral soils on settlement areas in the relevant German Länder.. The actual area-related stocks are estimated using Equation 19. The uncertainty for the area-allocation estimations is assumed to be 10 %. Consequently, for *"Buildings and open areas"* areas whose previous use is not known, the carbon and nitrogen stocks listed in Table 330 are obtained for mineral soils in the various German federal states. The so-determined stocks are used as a basis for all other calculations with urban soils at the relevant points.

Table 330: Average carbon [t C ha^{-1} 30 cm^{-1}] and nitrogen stocks [t N ha^{-1} 30 cm^{-1}] of mineral soils on settlement areas (sub-category *Buildings and open areas*) with correction for sealing ($SOC_{min\_set\_1990}$ or $N_{min\_set\_1990}$) and the relevant uncertainties [%]

Mineral soils	Soil organic carbon stocks [t C ha^{-1} 30 cm^{-1}]	Uncertainty C [%]	Nitrogen stocks [t N ha^{-1} 30 cm^{-1}]	Uncertainty N [%]
Brandenburg	38.9	28.2	3.1	27.2
Berlin	39.2	37.2	3.2	44.9
Baden-Württemberg	43.6	18.6	4.2	18.8
Bavaria	43.0	18.5	4.1	17.9
Bremen	55.7	42.1	5.0	31.4
Hesse	36.1	27.8	3.5	31.4
Hamburg	50.1	92.0	3.5	77.6
Mecklenburg – West Pomerania	35.3	32.1	3.1	30.1
Lower Saxony	48.9	22.0	3.8	20.3
North Rhine – Westphalia	42.6	19.2	3.7	18.3
Rhineland-Palatinate	37.7	21.0	3.8	21.6
Schleswig-Holstein	51.6	30.4	4.0	23.9
Saarland	42.4	34.5	4.0	46.0
Saxony	37.7	28.7	3.2	29.0
Saxony-Anhalt	44.0	30.7	3.8	32.5
Thuringia	40.2	22.6	3.8	23.0

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 conversion period of no more than 20 years is assumed.

6.1.2.1.7 Terrestrial Wetlands and Other Land

Terrestrial Wetlands

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 & 1997);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 shares 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 331).

Table 331: 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

Other Land

The database on which the BÜK 1000 (BGR) soil map is based shows nearly no dominant soil profiles for soils on *Other Land*. It shows such profiles only for Forest Land, Cropland and Grassland sites. To date, carbon stocks of mineral soils have been derived from the soil characteristics listed, for these land-use categories, in the map legend. The values given for the stocks, 56 t C/ha, were very high, and were based solely on estimates. To improve the inventory in this area, therefore, a method for deriving the carbon stocks of mineral soils under *Other Land* needed to be developed that would use actual measurements, and take regional site factors into account. For estimation purposes, therefore, the data set of the Bodenzustandserhebung Landwirtschaft Agricultural Soil Inventory (Jacobs et al., 2018) was used as a basis. As a rule, *Other Land* consists of vegetation-free areas that predominantly have very low concentrations of soil organic matter, although they may include areas with higher concentrations of soil organic matter (such as in the catchment areas of watercourses). For this reason, the average carbon and nitrogen stocks of mineral soils were estimated by using the relevant state's smallest value, in each case, in the BZE-LW Agricultural Soil Inventory. Furthermore, it was assumed that such values, in each case, represented the upper bounds for soil carbon/nitrogen stocks in the land-use category *Other Land*, for the relevant state. The average value was then obtained, in each case, on the basis of the standard deviation for the C and N stocks of all of the mineral-soil sites on which the relevant determination was based. As of the present submission, the so-determined values for the carbon and nitrogen stocks of mineral soils, at the regional level of the Länder (states), are being used for all emissions calculations in connection with the land-use category *Other Land*. The average carbon and nitrogen stocks are listed in Table 332.

Table 332: Average carbon and nitrogen stocks [t C ha^{-1}], and their uncertainties (standard deviation[%]), in mineral soils on *Other Land*, to a depth of 30 cm

Mineral soils	Soil organic carbon stocks [t C ha^{-1} 30 cm^{-1}]	Uncertainty C [%]	Nitrogen stocks [t N ha^{-1} 30 cm^{-1}]	Uncertainty N [%]
Brandenburg	10.3	44.0	0.9	40.5
Berlin	29.1	30.1	2.5	14.4
Baden-Württemberg	10.0	21.1	1.0	22.1
Bavaria	10.0	24.6	0.9	24.8
Bremen	23.1	37.1	2.0	37.1
Hesse	21.5	19.2	2.0	19.8
Hamburg	21.1	50.2	2.2	40.2
Mecklenburg – West Pomerania	13.4	35.2	1.7	29.0
Lower Saxony	19.3	35.6	1.1	26.3
North Rhine – Westphalia	16.8	26.1	2.2	20.8
Rhineland-Palatinate	7.6	18.3	1.1	19.1
Schleswig-Holstein	17.9	36.2	1.7	26.8
Saarland	32.8	19.9	1.8	25.3
Saxony	22.1	25.9	1.9	23.3
Saxony-Anhalt	17.8	28.2	1.6	28.7
Thuringia	15.1	29.2	1.6	29.0

6.1.2.1.8 Uncertainties

Except where a different value is explicitly listed, half of the 95% confidence interval is always used as the uncertainty. In the case of samples that do not exhibit a normal distribution, the pertinent upper and lower bounds are given as well. 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, Short-rotation plantations, Terrestrial Wetlands, Settlements* and *Other Land* were calculated from the measurements of the Agricultural Soil Inventory (Jacobs et al.). The uncertainties for *Cropland$_{annuell}$* and *Grassland* were derived from the interquartile intervals calculated by the map-creation model.

6.1.2.1.9 Planned improvements

With the present submission, Germany has implemented an ERT recommendation from the 2020 review process (ARR 2020: L.8, Table 5), by regionalising the carbon and nitrogen stocks of mineral soils. The results have been recorded in complete-coverage, high-resolution, georeferenced and dynamically updated thematic maps. In addition, reporting with regard to mineral soils of the Forest Land remaining category has been supplemented with the results of work with the YASSO15 mathematical model.

The planned improvements for the coming years include the following:

- Implementation of regionalised carbon and nitrogen stocks for mineral soils in the land-use category *Terrestrial wetlands*
- Introduction of models for calculation of carbon and nitrogen stocks in mineral soils in the land-use category *Cropland*. This will have to be preceded by the development of a model for derivation of complete-coverage, regionalised cultivation data from the database of the EU's Integrated Administration and Control System (IACS) (in progress).
- Introduction of model-based calculation of carbon and nitrogen stocks in mineral soils in the land-use category *Grassland*. No truly reliable data sets are available for validation of models in the area of Grassland. Development of such calculation, therefore, will depend on the availability of results of repeat soil-inventory sampling (this commenced in 2022).

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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:	Conversion 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[88] (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., 2020a).

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

[88] 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 (2006a) 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 & 1997), 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 333 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 long-term series 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.

Table 333: Areas of organic soils and drainage ditches, by land-use categories, for the year 2021

	Area of organic soils [ha]	Area of drainage ditches [ha]
Forest Land	278,080	3,164
Cropland	328,971	3,152
Grassland (in the strict sense)	939,166	14,887
Woody Grassland	28,326	437
Terrestrial Wetlands	113,088	713
Waters	29,802	76
Peat extraction	17,425	66
Settlements	87,219	1,257
Other Land	32	0
∑	**1,822,109**	**23,755**

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 333).

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. (2020a) 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 2021. 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. (2020a) 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-categorie *Woody Grassland* and *Hedges*.

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.

(2020a) 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., 2020a).

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, the following also have to be taken into account: non-drained, wet areas; 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 334 for CO_2, CH_4 and N_2O emissions from Germany's organic soils, for the year 2019.

Table 334: 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 2021

Land use	CO_2-onsite + DOC		CH_{4_land} + CH_{4_ditch}		N_2O-onsite	
	IEF	95% percentile	IEF	95% percentile	IEF	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	2.90	(2.34 - 3.55)	3.29	(1.04 - 6.62)	2.78	(-0.32 - 5.81)
$Cropland_{annual}$	9.63	(6.56 - 11.03)	10.30	(6.19 - 16.87)	11.04	(4.22 - 17.87)
Hops	9.09	(0.14 - 17.72)	12.54	(-0.2 - 26.64)	11.05	(-1.17 - 23.26)
Vineyards	8.58	(2.98 - 13.65)	8.53	(2.46 - 15.98)	11.10	(1.83 - 20.37)
Orchards	9.51	(5.8 - 12.65)	10.22	(5.54 - 16.41)	11.05	(5.02 - 17.09)
Tree nurseries	9.72	(6.67 - 11.46)	7.81	(4.65 - 12.51)	11.07	(8.08 - 14.05)
Christmas tree plantations	9.64	(6.49 - 11.31)	12.46	(7.38 - 19.66)	11.03	(4.32 - 17.73)
Short-rotation plantations	9.37	(1.46 - 16.65)	9.15	(-0.2 - 20.47)	2.95	(-0.12 - 6.03)
Grassland (in the strict sense)	7.82	(1.92 - 10.58)	34.83	(17.01 - 166.39)	4.52	(0.89 - 8.15)
Woody Grassland	2.89	(2.5 - 3.34)	4.20	(2.4 - 6.96)	2.76	(0.69 - 4.79)
Hedges	2.89	(2.29 - 3.58)	4.01	(1.42 - 8)	2.77	(-0.46 - 5.92)
Terrestrial Wetlands	5.23	(1.99 - 8.81)	165.78	(62.23 - 300.11)	0.69	(0.17 - 2.07)
Peat extraction	1.60	(1 - 2.21)	5.90	(2.49 - 10.78)	0.90	(0.45 - 1.35)
Settlements	7.86	(5.22 - 11.57)	15.06	(10.05 - 15.06)	3.88	(1.58 - 6.71)

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, Hedges, Terrestrial Wetlands, Settlements
- all conversion 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 (2006a)), 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 (2006a)). "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.

Emissions from biomass are listed in the year in which they occur. To this end, a method is used 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).

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 (2006a)):

$$\Delta C_{Bio} = \sum_{i=1}^{n} \left(A_i * EF_{final} - A_i * EF_{initial} \right)$$

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 conversion categories
i:	Conversion 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 335, while those for Grassland (in the strict sense) are shown in Table 336.

As Table 335 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 335: 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
2021	6.58 ± 0.77	4.90 ± 0.67	1.68 ± 0.38

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 336). 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 336. 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 336: 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, 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 337.

Table 337: 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 conversion category or a remaining category.
- Regardless of the rotation cycles involved, the conversion period lasts no longer than 20 years (the "effective conversion time" concept (Chapter 6.1.2)); at the end of the conversion period, the crop is transferred into the remaining category that corresponds to the relevant conversion 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, all points for "Other perennial crops" are assigned to one of the categories *Tree nurseries, Christmas tree plantations,* or *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 20

$$Emission\left[t\,CO_2\,ha^{-1}a^{-1}\right] = \left(C_{curr\,year} - C_{prev\,year}\right) * {}^{-44}/_{12}$$

$C_{curr\,year}$: 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 21

$$C_{cultspec} = C_{cultspec\_abo} + C_{cultspec\_bel}$$

$C_{cultspec}$: 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 22

$$C_{abo} = C_{stem,branch} * GF + C_{cut} * GF + C_{gra1_{abo}} * GF$$

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 23

$$C_{bel} = C_{roots} * GF + C_{gra1_{bel}} * GF$$

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 Statistisches Bundesamt (FS 3, R 3.1.4)[89]), 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)[90].

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:

[89] 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.

[90] $Phytomass_{below\text{-}ground} = 0.489 * (Phytomass_{above\text{-}ground}\ Trees)^{0.890}$ – 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 24

$$C_{croo_{stem,branch}} = -1.9798 + \frac{16.9435}{(1 + e^{-\frac{a-13.0365}{6.1938}})}$$

$C_{croo\ stem,branch}$: 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 25

$$C_{croo_{abo}} = C_{croo_{stem,branch}} + C_{croo_{cut}} + C_{gra1_{abo}} * 0.75$$

$C_{croo\ stem,branch}$: 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 26

$$C_{croo_{roots}} = 0.489 * C_{croo_{abo}}^{0.89}$$

$C_{croo\ roots}$: 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 27

$$C_{croo_{bel}} = C_{croo_{roots}} + C_{gra1_{bel}} * 0.75$$

$C_{croo\ bel}$: 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 57.

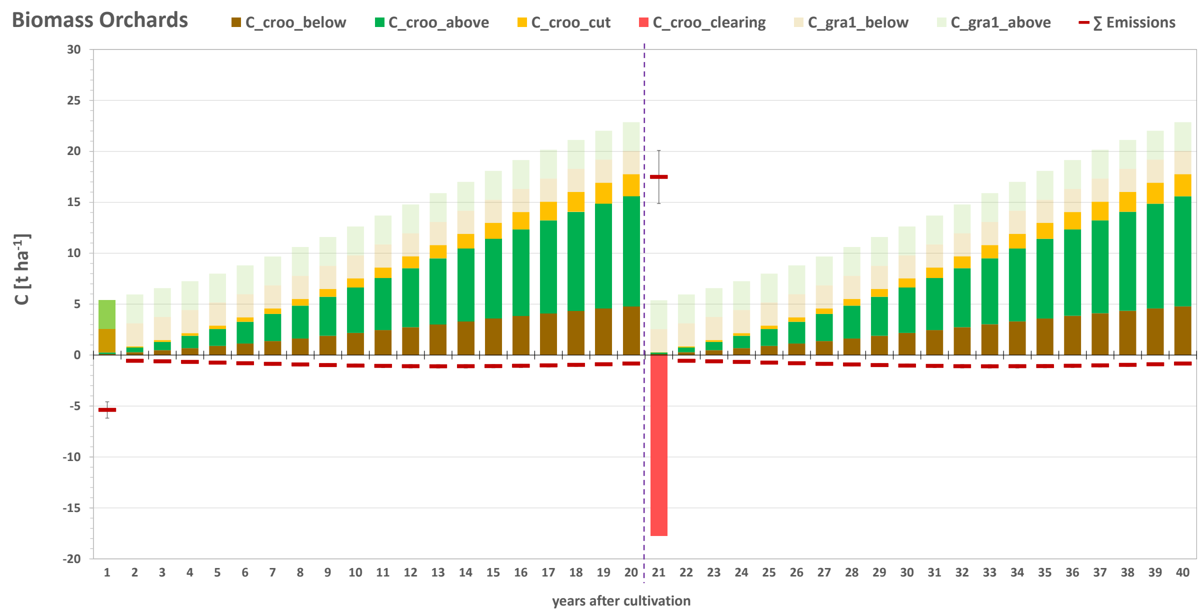


Figure 57: Development of carbon stocks [t C ha^{-1}] in compartments of plant biomass of orchards, and the resulting emissions [t C ha^{-1}], in successive rotation cycles (|). Transparent bars are emissions-relevant only in the case of land-use changes

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 28: 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 29: 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 30: 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 31: Sum of below-ground biomass of vineyards [t C ha^{-1}]

$$C_{crow_{bel}} = C_{crow_{roots}} + C_{gra1_{bel}} * 0.75$$

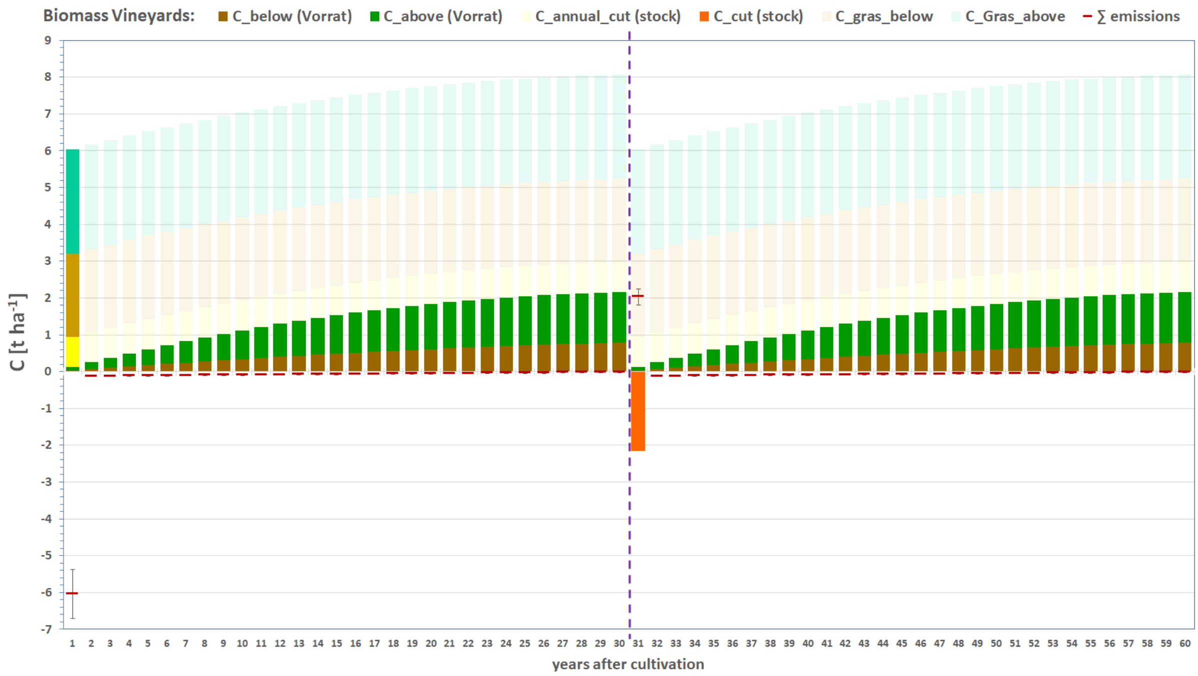
$C_{crow\ bel}$: Carbon stocks of below-ground biomass of vineyards [t C ha^{-1}]

$C_{crow\ roots}$: 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 58.

Figure 58: 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 (Bösch & Kändler) 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 32: 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 33: Below-ground biomass of tree nurseries [t C ha^{-1}]

$$C_{crot_{bel}} = 0.0599 * a^2 + 0.1562 * a + \frac{C_{gra1_{bel}}}{3}$$

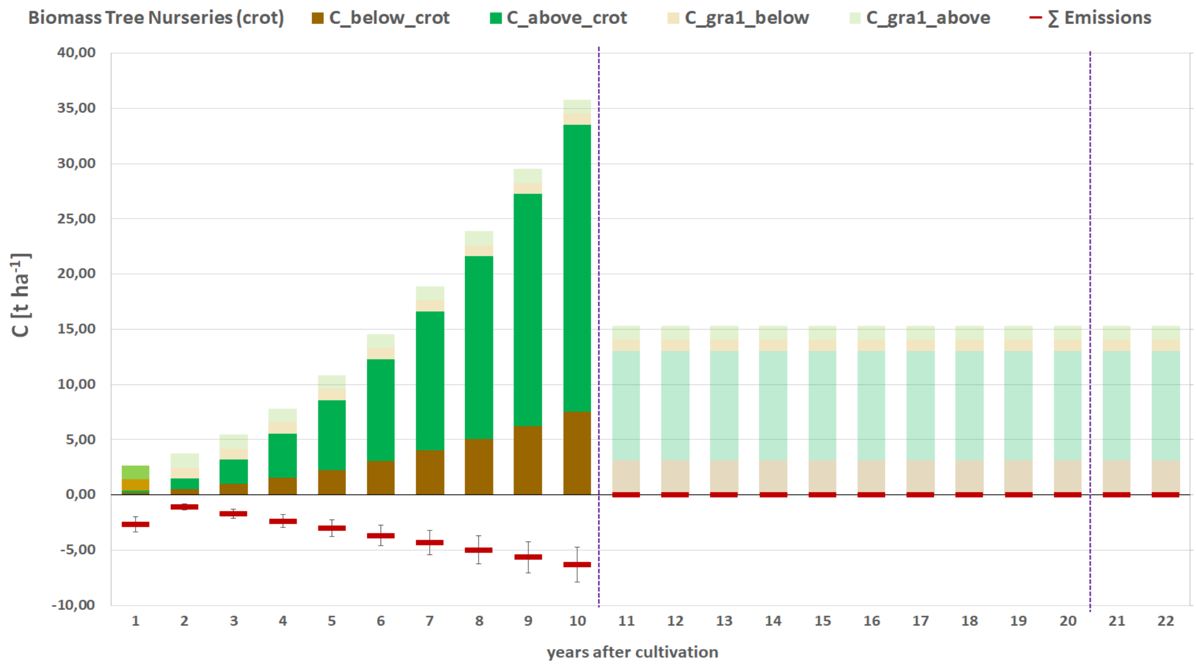
$C_{crot\ bel}$: Carbon stocks of above-ground biomass of tree nurseries [t C ha^{-1}]

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 59 shows the development of carbon stocks in tree nurseries during successive rotation cycles, along with the resulting emissions.

Figure 59: 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 34: 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 35: Below-ground biomass of Christmas tree plantations

$$C_{croz_{bel}} = 0.489 * x^{0.89} + C_{gra1_{bel}} * 0.75$$

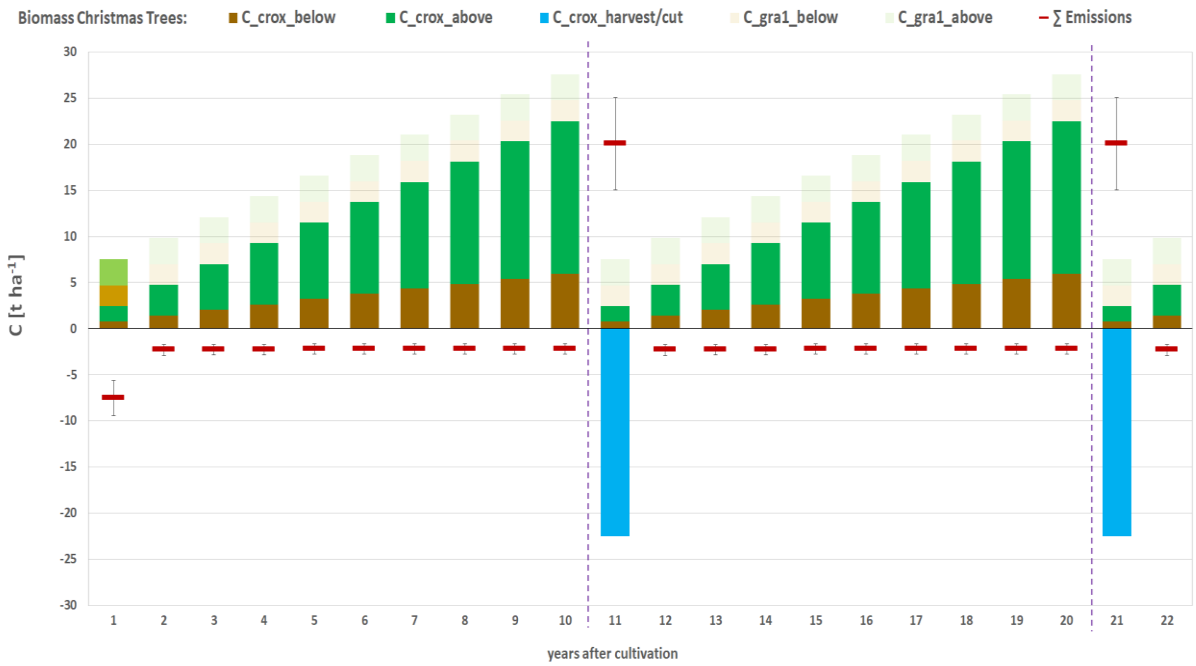
$C_{crox\ bel}$: Carbon stocks in the below-ground biomass of Christmas tree plantations [t C ha^{-1}]

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 60.

Figure 60: 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. The biomass occurring following the harvest that is used solely for energy generation is listed in 4.B as a carbon-stock change. This prevents double-counting in the energy sector and within the area of 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[91], 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 36: 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 37: Below-ground biomass of short-rotation plantations

$$C_{cros_{bel}} = 0.489 * x^{0.89}$$

Ccros bel: below-ground biomass of short-rotation plantations [t ha-1]

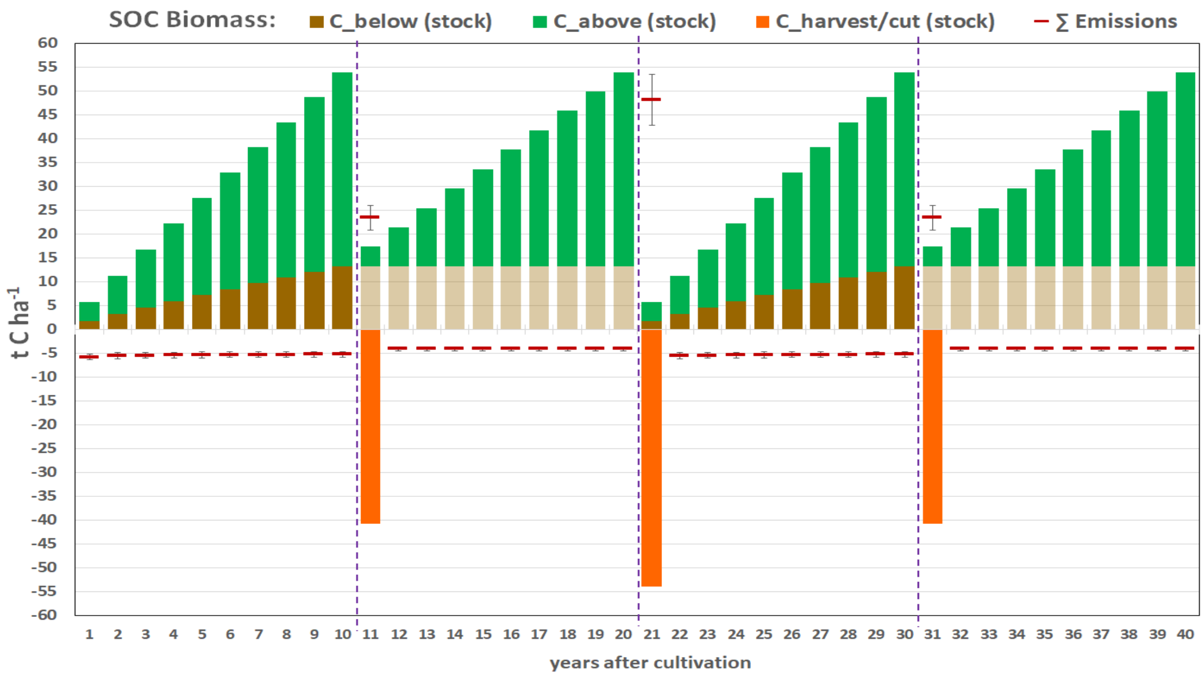
x: Carbon stocks in the above-ground biomass $C_{cros\ abo}$

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 61 shows the development of carbon stocks in short-rotation plantations during successive rotation cycles, along with the resulting emissions.

---

[91] 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); 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); p. 20).

Figure 61: 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. T. Graf et al. (2014); T. M. 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 338 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 338: 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 38: 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

$$C_{gra2_{bel}} = 0.489 * C_{gra2_{abo}}{}^{0.89}$$

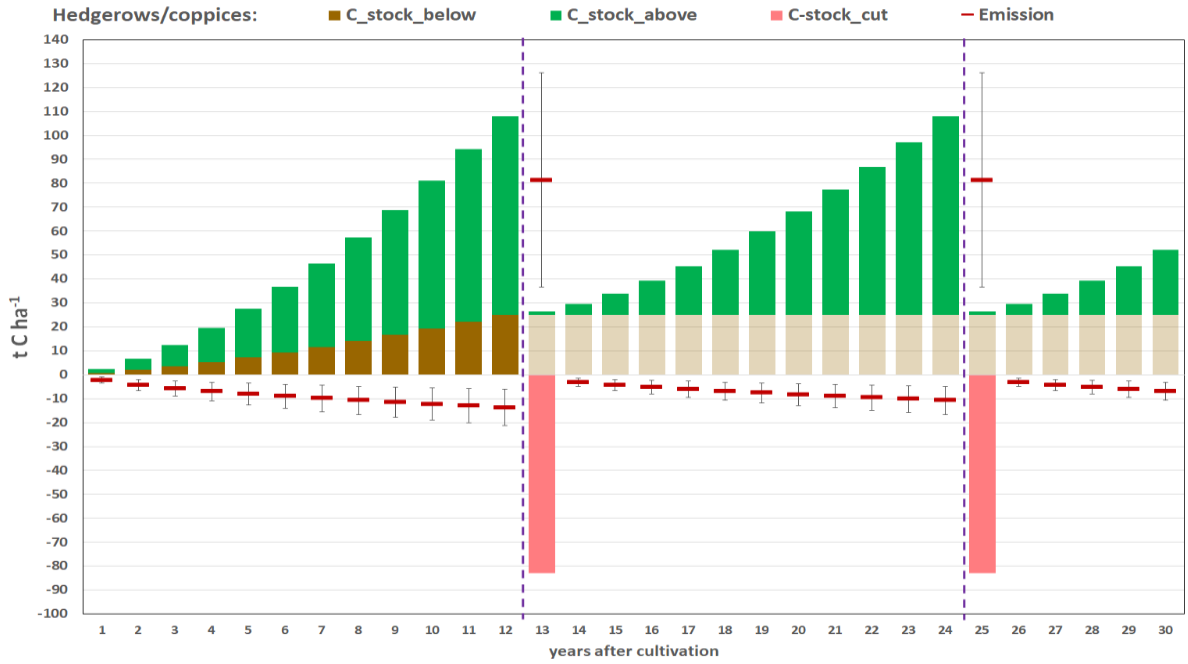
$C_{gra2\ bel}$: Average carbon stocks of above-ground biomass in hedges / field copses [t C ha^{-1}]

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 62.

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 62: 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 39: Biomass of Terrestrial Wetlands

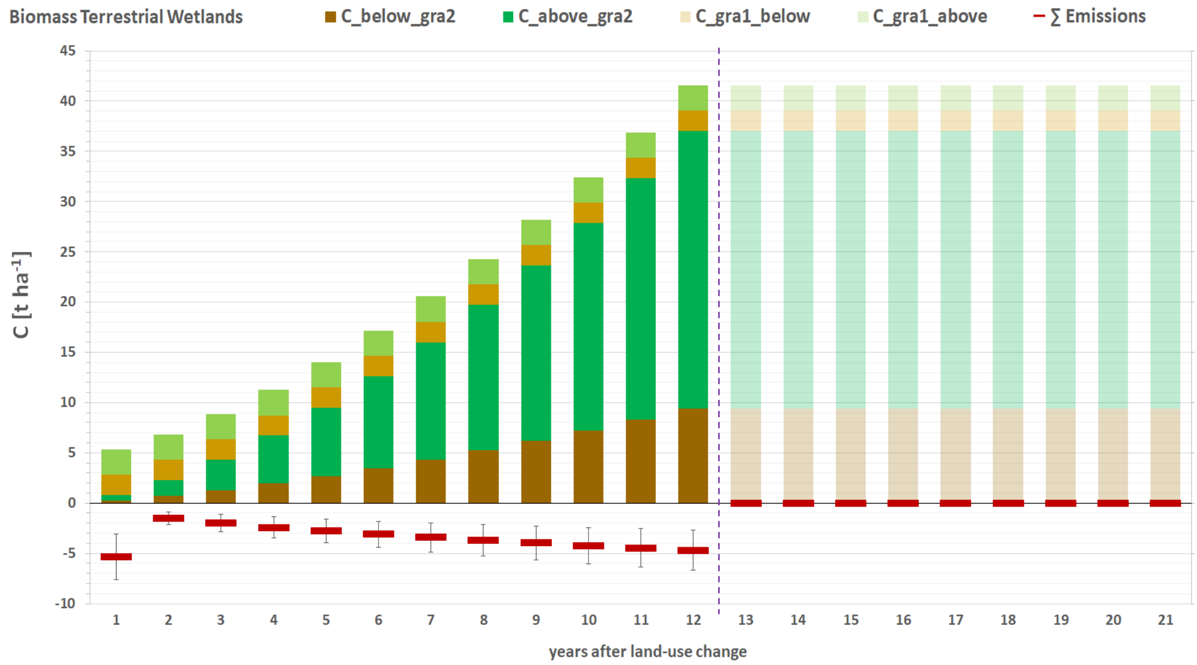
$$C_{wet1} = \frac{1}{3} C_{gra2} + \frac{2}{3} C_{gra1}$$

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 63: 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 40: Biomass of Settlement areas

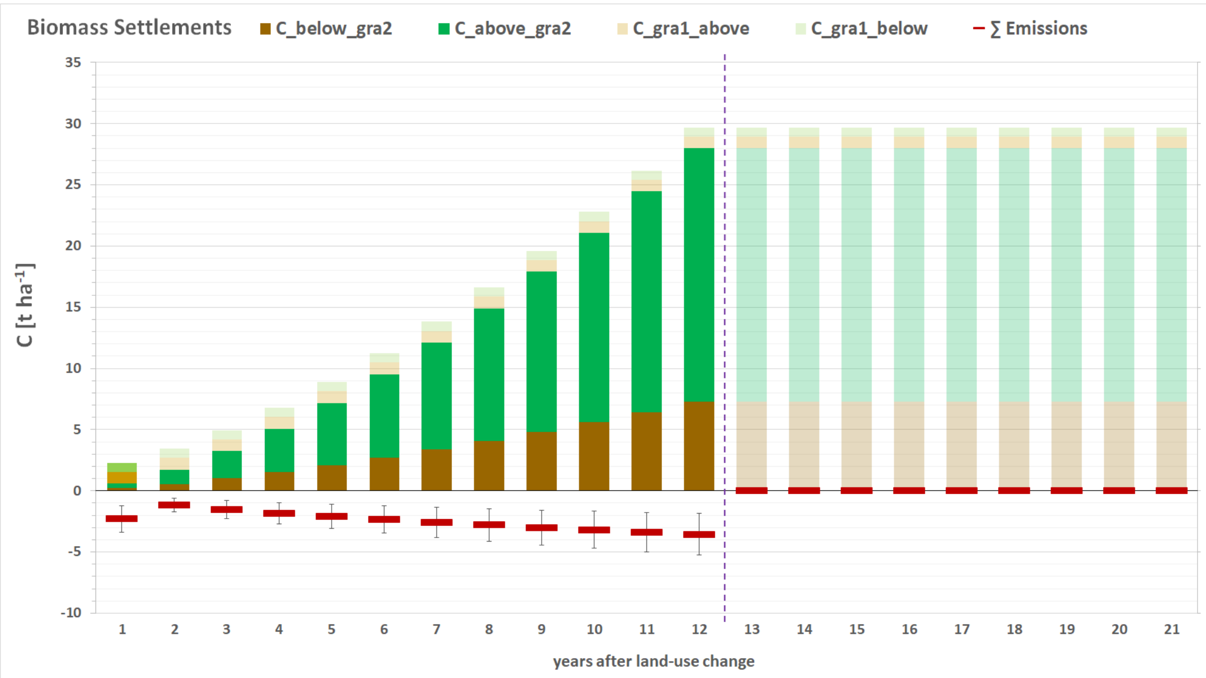
$$C_{set1} = \frac{\frac{1}{2}C_{gra2} + \frac{1}{2}C_{gra1}}{2}$$

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 64: 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, (Frank 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 356. The annual carbon-stocks changes in forest biomass, following afforestation, are shown in Table 355 in Chapter 6.4.2.2.2).

Table 339: 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
2021	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 conversion 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 flowing and standing man-made water bodies, and from drainage or organic and mineral soils (4(II))

In keeping with the 2006 IPCC Guidelines (IPCC, 2006a) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019a), methane emissions from man-made flowing and standing water bodies that are subject to fluctuations in their water levels are now being reported (for the first time), under *Flooded Land remaining Flooded Land*. To this end, the land-use sub-category *Flooded Land* has been further subdivided into the following categories:

1. *Natural water bodies* (wet2): All flowing and standing water bodies that do not fall under wet4 and wet5
2. *Standing man-made water bodies* (wet4):

- Reservoirs, quarry ponds and mining lakes
- Ponds, water storage facilities, artificial freshwater basins of all types (exception: wastewater treatment facilities)

3. *Flowing man-made water bodies* (wet5): Channels and drainage ditches for water-resources management (exception: drainage ditches on organic soils), basins along inland waters

Emissions from drainage of soils in Germany are reported for organic soils – and, with the present submission, they are being reported for mineral soils as well, for the first time. They are determined via determination of the emissions from the relevant drainage ditches. Emissions from rewetting of organic soils are taken into account only in the case of methane related to flooding of former peat-extraction areas. Otherwise, they are listed in the CRF Table as NO (not occurring). The method is in keeping with the pertinent remarks in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019a).

In keeping with the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019a), only the Managed Land Proxy (MLP) is to be applied. With the MLP, it is assumed that all emissions originating from managed land are anthropogenic.

Carbon emissions from drainage of 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 have been entered. IE (included elsewhere) has been entered for CO_2. The methane emissions of the remaining sub-categories are reported in CRF-Table 4.(II). 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.

Methods

Standing man-made water bodies- wet4

In “Standing man-made water bodies,” the emissions from

- Reservoirs, quarry ponds and mining lakes,
- Ponds, water storage facilities and artificial freshwater basins of all types

are subsumed. The methane emissions of both sub-categories are calculated in keeping with the default method of the 2019 Refinement to the 2006 IPCC Guidelines (IPCC, 2019a), for

Reservoirs, quarry ponds and mining lakes, pursuant to Formula 7.10 (IPCC (2019a); p. 7.12):

$$F_{CH4\_tot} = F_{CH4\_reservoir} + F_{CH4\_downstream}$$

$$F_{CH4\_reservoir} = \alpha_r * EF_{r\_CH4>20a} * A_{reservoir}$$

$$F_{CH4\_downstream} = \alpha_r * EF_{r\_CH4>20a} * A_{reservoir} * R$$

F_{CH4_tot}: All annual methane emissions from artificial reservoirs, quarry ponds and mining lakes that are more than 20 years old [kg CH_4 a^{-1}]
$F_{CH4\_reservoir}$: Annual methane emissions from the surfaces of artificial reservoirs, quarry ponds and mining lakes (that are more than 20 years old) [kg CH_4 a^{-1}]
$F_{CH4\_downstream}$: Annual methane emissions from artificial reservoirs, quarry ponds and mining lakes (that are more than 20 years old) that occur downstream of the relevant dam [kg CH_4 a^{-1}]
α_r: Adjustment factor for the emission factor that depends on the trophic state of the reservoir, quarry pond or mining lake (dimensionless)
$EF_{r\_CH4>20a}$: Methane emission factor for artificial reservoirs, quarry ponds and mining lakes that are more than 20 years old [kg CH_4 ha^{-1} a^{-1}]
$A_{reservoir}$: Surface area of artificial reservoirs, quarry ponds and mining lakes (more than 20 years old) [ha]
R: Ratio of the methane emissions of artificial reservoirs, quarry ponds and mining lakes (more than 20 years old) that occur downstream from the dam [kg CH_4 a^{-1}] to the methane emissions emitted from the water bodies’ surfaces [kg CH_4 a^{-1}]

For ponds, water storage facilities and artificial freshwater basins of all types, Formula 7.12 (IPCC (2019a); p. 7.17) is used:

$$F_{CH4\_ponds} = \alpha_p * EF_{p\_CH4>20a} * A_{ponds}$$

F_{CH4_ponds}: The total annual methane flows of ponds, water storage facilities and artificial freshwater basins of all types [kg CH_4 a^{-1}]
α_p: Adjustment factor for the emission factor that depends on the trophic state of the pond, water storage facility or artificial freshwater basin (of any type) (dimensionless)
$EF_{p\_CH4>20a}$: Methane emission factor for ponds, water storage facilities and artificial freshwater basins that are more than 20 years old [kg CH_4 ha^{-1} a^{-1}] Surface area of ponds, water storage facilities and artificial freshwater basins of all types (older than 20 years) [ha]

Flowing man-made water bodies- wet5

Flowing man-made water bodies mainly includes channels and drainage ditches for water-resources management and basins along inland waters. The methane emissions for this sub-category are calculated in keeping with the default method of the 2019 Refinement to the 2006 IPCC Guidelines, and also with Formula 7.12 (IPCC (2019a); p. 7.17):

$$F_{CH4\_channels} = \alpha_c * EF_{c\_CH4>20a} * A_{channels}$$

$F_{CH4\_channels}$: The total annual methane flows of channels and drainage ditches for water-resources management and basins along inland waters [kg CH_4 a^{-1}]
α_c: Adjustment factor for the emission factor that depends on the trophic state of the channel, drainage ditch for water-resources management or basin along inland waters (dimensionless)
$EF_{c\_CH4>20a}$: Methane emission factor for channels and drainage ditches for water-resources management, and basins along inland waters, that are more than 20 years old [kg CH_4 ha^{-1} a^{-1}]
$A_{channels}$: The surface area of channels and drainage ditches for water-resources management and basins along inland waters (older than 20 years) [ha]

Activity data

The basis for determination of the activity data for the sub-categories of the sub-category *Waters* consists of the following data sources:

- 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, 2020 and 2021 (AdV 2000; 2005; 2010; 2015; 2020; 2021)
- A data set of the BfG (Bundesanstalt für Gewässerkunde), with georeferenced data on man-made standing water bodies > 50 ha
- A study on surveys of ponds in Bavaria (Seitel & Oberle, 2022).
- Data sets of official statistics on aquaculture operations, and on the sizes of their facilities, at the level of the German federal states (Statistisches Bundesamt, 2022a)

By combining statistical data with data sets obtained in georeferenced formats, with geoinformational methods, it was possible to determine the areas of Germany's standing and flowing man-made water bodies, differentiated by types. The areas of natural water bodies are obtained by deducting the so-determined areas from Germany's total water-body area.

The areas for the various water-body categories have been kept at constant sizes in the inventory, since

- only in recent years have such areas been included within the B-DLM, and since, in light of the area changes detected in previous years, such areas do not represent true land-use changes – instead, they are cartographic artefacts
- the area data are a combination of georeferenced data and of statistical data that ultimately has lost its georeferencing

The basis for defining the relevant areas consists of the areas within the LUM 2021 (the best B-DLM). With regard to land changes relative to the wetlands category, the following rules apply:

- No land-use changes to/from *Natural waters* and *Flowing man-made water bodies* to/from other land-use categories, until a reliabille, georeferenced AD basis becomes available. In general, this also applies to *Standing man-made water bodies*, with one exception: Land-use changes from *Peat extraction* to *Standing man-made water bodies* are permitted, unilaterally
- No land-use changes between *Natural waters*, *Standing man-made water bodies* and *Flowing man-made water bodies*
- *Terrestrial wetlands* and *Peat extraction* are handled in the same manner used to date, apart from the fact that land-use changes between (to/from) those categories and *Natural waters*, *Standing man-made water bodies* and *Flowing man-made water bodies* are excluded (exception: *Peat extraction* to *Standing man-made water bodies*)

Emission and adjustment factors

Natural water bodies

Pursuant to the 2019 Refinement (IPCC), GHG emissions do not have to be reported for "Natural waters"; consequently, no emission factors (EF) are required for that category.

Standing man-made water bodies- wet4

Emission factors

Methane emissions from Germany's standing man-made water bodies (artificial reservoirs, quarry ponds and mining lakes; and ponds, water storage facilities and artificial freshwater basins of all types) are calculated using the default emission factors in the 2019 Refinement (IPCC). For cool, temperate latitudes, that factor is as follows:

For reservoirs, quarry ponds and mining lakes (> 20 a):

$EF_{r\_CH4>20a}$ = 54.0 [kg CH_4 ha^{-1} a^{-1}] (95 % confidence interval: -10.6 % / 10.2 %) (IPCC (2019a); p. 7.15; Table 7.9)

Ponds, water storage facilities, artificial freshwater basins of all types:

$EF_{p\_CH4>20a}$ = 183 [kg CH_4 ha^{-1} a^{-1}] (95 % confidence interval: -35.5 % / 24.6 %) (IPCC (2019a); p. 7.18; Table 7.12)

Adjustment factors

The adjustment factor α, for the trophic state of the water bodies, was determined country-specifically for reservoirs, quarry ponds and mining lakes (α_r) and for ponds, water storage facilities and artificial freshwater basins of all types (α_p). The basis for this consisted of the research project "Ecological assessment of man-made and significantly modified lakes, and highland lakes, on the basis of the phytoplankton biological component, and in keeping with the requirements of the EU Water Framework Directive" ("Ökologische Bewertung von künstlichen und erheblich veränderten Seen sowie Mittelgebirgsseen anhand der biologischen Komponente Phytoplankton nach den Anforderungen der EU-Wasserrahmenrichtlinie") (Hoehn et al., 2009), which determined trophic classes, inter alia, for 280 artificial and 16 natural standing water bodies in Germany (including lakes in low mountains, mining lakes, flooded open-pit mines, reservoirs and special types of lowland water bodies). On the basis of that study, each trophic class was assigned an average adjustment factor α in keeping with Table 7.11 (p. 7.15) of the 2019 Refinement (IPCC). To this end, the range of the adjustment factors listed in the Refinement (IPCC) for the various trophic classes was adapted to the higher resolution of the research project. This was done by dividing the range by the number of sub-categories, and by distributing the range linearly among the trophic classes. From within the so-resulting new upper and lower bounds, the average values were assigned, as trophic adjustment factors α_i, to the German trophic classes (Table 340).

Table 340: Determination of average trophic adjustment factors αi (pursuant to the 2019 IPCC Refinement) for Germany's man-made standing water bodies, by trophic classes (Hoehn et al., 2009)

LAWA 2009; Hoehn et al.		IPCC (2019 refinement)		Allocation of trophic adjustment factors αi			Uncertainty (assumption: Range = 95 %KI)	
Trophic class	**Abbreviation**	**Trophic class**	**α_i**	**α_i US**	**α_i _OS**	**α_i _Trophic-class-average**	**[%]**	**Distribution**
oligotrophic	ol	oligotrophic	0.7	0.7	0.7	0.7	50	Normal
mesotrophic 1	meso 1	mesotrophic	0.7 - 5.3	0.7	3	1.85	62.2	normal
mesotrophic 2	meso 2			3	5.3	4.15	27.7	normal
eutrophic 1	eu 1	eutrophic	5.3 - 14.5	5.3	9.9	7.6	30.3	normal
eutrophic 2	eu 2			9.9	14.5	12.2	18.9	normal
polytrophic 1	poly 1		14.5 - 39.4	14.5	22.8	18.65	22.3	normal
polytrophic 2	poly 2			22.8	31.1	26.95	26.7	normal
hypereutrophic	hyper	hypereutrophic		31.1	39.4	35.25	26.7	normal

The so-determined adjustment factors were allocated, via the trophic classes, to the water bodies covered by the German study and weighted on the basis of the number of different water-body types in the various trophic classes (Table 341).

Table 341: Determination of average trophic adjustment factors in keeping with the trophic states of Germany's man-made standing water bodies, on the basis of (HOEHN et al. 2009)

Water-body type	oligotrophic	mesotrophic 1	mesotrophic 2	eutrophic 1	eutrophic 2	polytrophic 1	polytrophic 2 / hypereutrophic	∑ Water bodies
				Number				
Quarry pond	11	24	21	21	11	3	2	93
Pond						1	8	9
Natural lake	4	4	5		1		2	16
Storage reservoir	1				1		4	6
Mining lake	20	8	5	1				34
Dammed reservoir	35	27	33	11	12	11	9	138
∑ total	71	63	64	33	25	15	25	296
∑ without natural lakes	67	59	59	33	24	15	23	280
α_i_trophic-class average	0.7	1.85	4.15	7.6	12.2	18.65	31.1	
	ol	**meso 1**	**meso 2**	**eu 1**	**eu 2**	**poly 1**	**poly 2 / hyper**	**Adjustment factor**
				α_i trophic-class average * number				**α_i_average**
Quarry pond	7.7	44.4	87.15	159.6	134.2	55.95	62.2	5.9
Pond						18.65	248.8	29.7
Natural lake	2.8	7.4	20.75		12.2		62.2	6.6
Storage reservoirs	0.7				12.2		124.4	22.9

Mining lake	14	14.8	20.75	7.6				1.7
Dammed reservoir	24.5	49.95	136.95	83.6	146.4	205.15	279.9	6.7
α_r Dammed reservoir / mining lake / quarry pond	46.2	109.15	244.85	250.8	280.6	261.1	342.1	5.8
α_p_Pond / storage facility	0.7				12.2	18.65	373.2	27.0

It proves to be the case that the so-determined trophic adjustment factors for ponds and storage facilities are considerably larger than those for the other man-made water bodies, since ponds and storage facilities are mostly eutrophic to hypereutrophic. The other man-made water bodies have intermediate, and comparable, trophic states. Their states are very similar to those of natural lakes. Mining lakes are one exception; they are predominantly oligotrophic to mesotrophic (Hoehn et al., 2009).

For man-made lakes over organic soils, or over catchment areas characterised by organic soils, an equal distribution between mesotrophic and eutrophic is assumed, since such lakes can all exhibit these trophic states, depending on their surrounding areas, inflows, water-quality characteristics and management (Riedmüller et al., 2013) and (Mauersberger & Kopp, 2006).

In light of these results, the following weighted, average trophic adjustment factors have been determined:

1. Ponds, water storage facilities, artificial freshwater basins of all types α_p = 27.0 (Table 341)
2. Reservoirs, quarry ponds and mining lakes,
    - mineral subsoil / catchment area α_r_mineral = 5.8 (Table 341)
    - Organic subsoil / catchment area α_r_organic = 7.6

.

For the factor R as well, which describes the ratio between a) the methane emissions of dammed reservoirs (more than 20 years old) at or below the dam's spillway and b) the methane emissions from their surfaces, the default factor of the 2019 Refinement (IPCC 2019) is used. The median value for this ratio, which is dimensionless, is as follows (95% confidence interval of the median):

R = 0.09 (-44.4 % / 144.4 %) (Table 7.1; p. 7.15; IPCC 2019)

<u>Flowing man-made water bodies – wet5</u>

The default value for the emission factor, for channels, drainage ditches for water-resources management and basins along inland waters

$EF_{c\_CH4>20a}$ = 183 kg CH_4 ha^{-1} a^{-1} (95 % confidence interval: -35.5 % / 24.6 %) (IPCC 2019; p. 7.18; Table 7.12),

the default value for the dimensionless adjustment factor for the emission factor, as a function of the trophic state of the flowing waters

α_c = 1 (IPCC 2019; p. 7.17; Equation 7.12)

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 (2006a)). The N stocks for forest soils have been taken from soil maps based on the results of the BZE-Wald Forest Soil Inventory (Wellbrock et al., 2016) (cf. Chapter 6.1.2.1.3, Chapter 6.4.2.5.3 and Chapter 6.4.2.5.4). The emission factors for the remaining land-use categories have been derived from the regionalised results of the BZE-Landwirtschaft Agricultural Soil Inventory with regard to the C/N ratios of mineral soils (Jacobs et al., 2018) (cf. Chapter 6.1.2.1.4, Chapter 6.1.2.1.5; Chapter 6.1.2.1.6 and Chapter 6.1.2.1.7). The C/N ratios for mineral soils, in the category *Terrestrial Wetlands*, have not yet been regionalised.

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, 2006a). The so-determined N_2O emissions are listed in CRF Table 4(III), while the implied emission factors are shown in Table 342. The uncertainties are summarised in the relevant 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 Uncertainties and time-series consistency).

The nitrous oxide emissions are also subject to conversion times; like the carbon-stock changes, they are distributed over 20 years. The methods used for carbon also apply with regard to the effective conversion time. For Forest Land, the remarks made with regard to derivation of the implied emission factors for carbon also apply with regard to derivation of the implied emission factors for nitrogen (cf. Chapter 6.1.2.1.1).

Pursuant to the 2006 IPCC Guidelines, direct nitrous oxide emissions from decomposition of organic matter in the remaining category Cropland[92] are reported in the agriculture sector, under 3.D.a.5.

[92] 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*

Table 342: 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 2021

Implied emission factors$_{mineral\ soils}$ [kg N_2O ha^{-1} a^{-1}] for the year 2021															
Initial\Final	Forest Land	Cropland$_{annual}$	Hops	Vineyards	Orchards	Tree nurseries	Christmas tree plantations	Short-rotation plantations	Grassland (in the strict sense)	Woody Grassland	Hedges	Terrestrial Wetlands	Peat	Settlements	Other Land
Forest Land		5.00	0	0	0	0	0	0	2.20	1.75	2.33	0.19	NO	0.57	NO
Cropland$_{annual}$	0.65		*0.05*	*0.15*	*0.03*	*0.09*	*0.07*	*0.07*	0	0	0.01	0.02	NO	0.27	NO
Hops	0.71	0.70		*0.85*	*0.01*	*0*	*0*	*0*	0	0	0	0	NO	0.69	NO
Vineyards	0.07	0.16	0		0	*0*	*0*	*0*	0	0	0	0	NO	0.30	NO
Orchards	1.46	1.29	*0.60*	*1.37*		*0.51*	*0.56*	*0.61*	0.03	0.11	0.07	0	NO	0.33	NO
Tree nurseries	0.73	0.67	0	*0, 83*	*0.00*		0	0	0	0.01	0	0	NO	0.76	NO
Christmas-tree plantations	0.72	0.72	0	*0.80*	*0.01*	0		0	0.01	0.01	0	0	NO	0.50	NO
Short-rotation plantations	0.00	0.58	0	0	0.01	0	0		0	0	0	0	NO	0.32	NO
Grassland (in the strict sense)	1.30	1.09	0.75	1.10	0.59	0.84	0.83	0.82		0	0.01	0.07	NO	0.64	NO
Woody Grassland	1.50	1.20	0.93	0.95	0.21	0	0.84	0.81	0		0.04	0.03	NO	1.18	NO
Hedges	1.15	1.12	0	0	0.15	1.04	0	0	0.959	0		0	NO	10.87	NO
Terrestrial Wetlands	2.11	1.81	0	0.88	1.36	1.92	0	0	0.68	0.86	0		NO	1.02	NO
Peat	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO		NO	NO
Settlements	0.75	0.49	0.32	0.33	0.03	0.15	0.09	0.09	0.02	0.05	0.08	0.02	NO		NO
Other Land	0	0	0	0	0	0	0	0	0	0	0	0	NO	0.01	

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 (2006a) 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). The N stocks for forest soils have been taken from soil maps (cf. Chapter 6.1.2.1.3, Chapter 6.4.2.5.3 and Chapter 6.4.2.5.4) based on the results of the BZE-Wald Forest Soil Inventory (WELLBROCK et al. 2016). The emission factors for the remaining land-use categories have been derived from the regionalised results of the BZE-Landwirtschaft Agricultural Soil Inventory with regard to the C/N ratios of mineral soils (JACOBS et al. (2018) (cf. Chapter 6.1.2.1.4, Chapter 6.1.2.1.5, Chapter 6.1.2.1.6 and Chapter 6.1.2.1.7). The C/N ratios for mineral soils, in the category *Terrestrial Wetlands*, have not yet been regionalised.

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, 2006a). The emission factors for the indirect nitrous oxide emissions, for the year 2019, are listed in Table 343. 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 conversion times; like the carbon-stock changes, they are distributed over 20 years. The methods used for carbon also apply with regard to the effective conversion time. For Forest Land, the remarks made with regard to derivation of the implied emission factors for carbon also apply with regard to derivation of the implied emission factors for nitrogen (cf. Chapter 6.1.2.1.1).

Pursuant to the 2006 IPCC Guidelines, direct nitrous oxide emissions from decomposition of organic matter in the remaining category Cropland[93] are reported in the agriculture sector, under 3.D.a.5.

Table 343: 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 2021

Implied emission factors$_{mineral\ soils}$ [kg N_2O ha^{-1} a^{-1}] for the year 2021														
Initial\Final	**Forest Land**	**Cropland$_{annual}$**	**Hops**	**Vineyards**	**Orchards**	**Tree nurseries**	**Christmas tree plantations**	**Short-rotation plantations**	**Grassland (in the strict sense)**	**Woody Grassland**	**Hedges**	**Terrestrial Wetlands**	**Peat**	**Settlements**	**Other Land**
Forest Land		1.09	0	0	0	0	0	0	0.49	0.39	0.54	0.04	NO	0.13	NO
Cropland$_{annual}$	0.15		*0.01*	*0.03*	*0.01*	*0.02*	*0.02*	*0.01*	0	0	0	0.01	NO	0.06	NO
Hops	0.16	0.16		*0.19*	*0*	*0*	*0*	*0*	0	0	0	0	NO	0.16	NO
Vineyards	0.02	0.04	*0*		*0*	*0*	*0*	*0*	0	0	0	0	NO	0.07	NO
Orchards	0.33	0.29	*0.13*	*0.31*		*0.11*	*0.13*	*0.14*	0.01	0.03	0.01	0	NO	0.07	NO
Tree nurseries	0.00	0.15	*0*	*0.19*	*0*		*0*	*0*	0	0	0	0	NO	0.07	NO
Christmas-tree plantations	0.16	0.16	*0*	*0.18*	*0*	*0*		*0*	0	0	0	0	NO	0.17	NO
Short-rotation plantations	0.16	0.13	*0*	*0*	*0*	*0*	*0*		0	0	0	0	NO	0.11	NO
Grassland (in the strict sense)	0.29	0.24	0.17	0.25	0.13	0.19	0.19	0, 18		0	0	0.02	NO	0.14	NO
Woody Grassland	0.34	0.27	0.21	0.21	0.05	0	0.19	0	0		0.01	0.01	NO	0.27	NO
Hedges	0.26	0.25	0	0	0.03	0.23	0	0	0.15	0		0	NO	2.45	NO
Terrestrial Wetlands	0.47	0.41	0	0.20	0.31	0.43	0	0	0	0.19	0		NO	0.23	NO
Peat	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO		NO	NO
Settlements	0.17	0.11	0.07	0.07	0.01	0.03	0.02	0.02	0.01	0.01	0.02	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

6.1.2.9 Burning of Biomass (CRF Table 4(V))

In Germany, combustion of biomass in the land-use sector takes place solely via wildfires. 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.

[93] 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

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 2021.

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 asymmetric 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.

The total uncertainty of the LULUCF section of the German GHG inventory thus amounts to 13.6 % with respect to the level of emissions. The largest contribution to the total uncertainty comes from the CO_2 emissions (88.1 %). The total-uncertainty contributions from emissions of methane (3.8 %) and nitrous oxide emissions (8.1 %) are marginal.

With respect to pools, organic soils make far and away the largest contribution (94.2 %) to the total uncertainty of the LULUCF inventory. The contribution of biomass amounts to 2.4 %, while those of dead organic matter and methane emissions from water bodies are each 1.4 % and that of all other categories is < 1 %.

All in all, the land-use categories *Grassland (in the strict sense)* (91.2 %), *Forest Land* (4.3 %) and *Cropland$_{annual}$* (4.3 %) account for 98.8 % 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 the land areas, 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 conversion 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.

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 conversion time 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. In those cases, the new emission factors are plausible, and the differences between such factors and 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.

Calculations:

- The basic calculations and the calculations for the annual land-use changes and the conversion time 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.

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

Important recommendations emerging from review processes of recent years have been addressed and acted on. The following section lists only the most important of the relevant improvements:

1. Regionalisation of the carbon and nitrogen stocks of mineral soils (Chapter 6.1.2.1ff)

- This point has been completely resolved. In the process, complete-coverage, high-resolution grid maps of soil carbon stocks and C/N ratios on Germany's mineral-soil areas have been prepared. The regionalisation in the maps has been carried out on the basis of pedological, geological, hydrological, topographic and climatic location factors.
- For Forest Land, the requirement was met by using the Yasso model (Chapter 6.4.2.5)

2. Inclusion of DOM in the case of wildfires: In the present submission, combustion of dead wood and litter in connection with wildfires has been taken into account along with combustion of biomass (cf. Chapter 6.4.2.7.5)
3. Mineral-soil emissions from the remaining categories of Cropland and Grassland have been calculated, using the Tier 1 method of the 2006 IPCC Guidelines, in order to show that the assumption of an equilibrium is a conservative one (Chapter 6.5.2.3.2 and Chapter 6.6.2.3)

6.1.4 Planned improvements

Apart from the medium- to long-term measures, listed in Chapter 6.1.2.1.9, for improving reporting in the area of mineral soils, only minor measures are planned. These measures, which are short-term measures, will be aimed at consolidating the activity data with regard to the new water-body categories.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 (2006b): Vol. 4, Ch. 2.2). The manner in which national land-use systems are allocated to this category is shown in Table 345 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 conversion 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 to the 2006 IPCC Guidelines (IPCC (2006b): Vol. 4, Ch. 3.2). The manner in which national land-use systems are allocated to this category is shown in Table 345 in Chapter 6.3.2.1. 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 conversion 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 2.1 % of the total Cropland area in 2021.
- Calculation of emissions from soils: Chronologically constant stratification in accordance with the pools organic soils and mineral soils, and broken down by uses (cf. Chapters 6.1.2.1 and 6.1.2.2). A complete-coverage 100 x 100 m grid map of the soil characteristics of mineral soils under annual Cropland, tied to numerous site-specific parameters, has been prepared (cf. Chapter 6.1.2.1.4)
- 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 345 in Chapter 6.3.2.1.

Grassland is divided into three sub-categories: a) areas covered with grasses and herbs (*Grünland im engeren Sinn / Grassland in the strict sense*); b) areas that are covered with trees and shrubs (*Gehölze / Woody Grassland*) but that do not fall under the definition of Forest Land; and woody grassland areas with linear structures (*Hecken / Hedges*). 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 2021, *Grassland (in the strict sense)* accounted for 92.9 % of the total grassland area, while *Woody Grassland* accounted for 6.8 % of that total area and *Hedges* accounted for 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)*."
- Extensive areas with field copses and shrubbery make up the sub-category "*Woody Grassland*."
- *Hedges* are defined as consisting of shrubs (and trees, in some cases) growing in dense linear formations (with either one or multiple rows).

Conversions and changes between these sub-categories are treated like land-use changes.

For purposes of emissions calculation, the grassland sub-categories are stratified by pools.

- Calculation of biomass stocks: Stratification within the sub-categories, by crop types. For Grassland (in the strict sense), the stratifications include above-ground and below-ground biomass of grasses and herbaceous plants (Chapter 6.6.2.2). For Woody Grassland and Hedges, a model for calculation of the biomass of hedge plants and field copses as a function of age, rotation cycles, growth density and growth height has been developed (Chapter 6.1.2.3.6).
- Calculation of emissions from soils: Constant stratification over time, by organic soils and mineral soils; further differentiation by use; for mineral soils, regionalisation as a function of numerous covariates (cf. Chapter 6.1.2.1.5).
    - 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 remaining categories of *Grassland (in the strict sense)*, *Woody Grassland* and *Hedges*; and by Land converted to *Grassland (in the strict sense), Woody Grassland* or *Hedges*. 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 (2006b)). 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 2021 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 other wetlands on mineral soils. In the sub-category Waters, a distinction is also made in terms of the degree of anthropogenic influence – between a) flooded land[94] and b) natural water bodies, including non-regulated and regulated water bodies (the latter of which are not covered by reporting obligations). In the present submission, to facilitate determination of the emissions in the sub-category *Water bodies*, the relevant water bodies have been differentiated by types, for the first time. The sub-category *Water bodies* now consists of the following sub-categories:

- Natural water bodies,
- Standing man-made water bodies,
- Flowing man-made water bodies,

. Table 344 shows how Germany's wetlands areas have been classified, for the year 2021, in accordance with these provisions. It also includes the relevant definitions and areas.

Table 344: Subdivision of the land-use category *Wetlands* into sub-categories, pursuant to the 2006 IPCC Guidelines and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019); also included are the sub-categories of the sub-category *Water bodies*, and the relevant areas, for 2021 [ha]. Data on drainage ditches on organic soils (*italics*), which are to be reported under 4.A, B, C and E, are also included.

Wetlands			Area
Sub-category	**Abbreviation**	**Area composition**	**[ha]**
Terrestrial Wetlands	wet1	Terrestrial wetlands that do not fall within one of the other land-use categories (such as semi-natural peatlands)	133,475
Natural water bodies	wet2	Areas of flowing and standing water bodies have been taken from the B-DLM; the wet4 areas have been deducted	572,083
Peat-extraction areas	wet3	Areas that are located on organic soils and that are used for peat extraction	17,425
Man-made standing water bodies	wet4	Reservoirs, quarry ponds and mining lakes	34,175
	wet4	Ponds, water storage facilities, artificial freshwater basins of all types (exception: wastewater treatment facilities)	31,254
Man-made flowing water bodies	wet5	Channels and drainage ditches for water-resources management, basins along inland waters	23,571
		Drainage ditches on organic soils (to be reported under 4.A - 4.E)	*13,407*

The sub-categories Peat Extraction, Terrestrial Wetlands and Water Bodies 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). In the land-use category Wetlands, land areas are calculated by means of annually updated stratification by *Terrestrial Wetlands*, *Water bodies* and *Peat-extraction areas*. In addition, the total areas of the sub-categories *Terrestrial Wetlands* and *Peat-extraction areas* are further subdivided into the categories a) land "remaining as ..." and b) land converted into *Terrestrial Wetlands* or *Peat-extraction areas*.

The relevant area 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, in keeping with the guidelines outlined in Chapter 6.1.2.6.

For purposes of emissions calculation, the sub-categories *Peat Extraction, Terrestrial Wetlands* and *Water Bodies* are stratified by pools.

Remaining category:

[94] 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)

- 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.
- For the water-body sub-categories *Standing man-made water bodies* and *Flowing man-made water bodies*, methane emissions are reported as a function of the type and trophic state of the water body in each case (Chapter 6.1.2.6)

Conversion 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 *Water Bodies*. 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 (2006b): Vol. 4, Ch. 2.2). The entire Settlement area has been subdivided into the sub-categories *Buildings and Open areas* and *Roads*.

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, 2021; 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, 2021; 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). For the year 2021, the land-use matrix shows that *Roads* (only roads per se – not all traffic routes) have a share of 21 %. In light of the above findings, for *Buildings and open areas*, therefore, the German inventory assumes the following basic land-cover breakdown:

- 60 % unsealed areas (such as parks, residential gardens/yards, allotment gardens (Kleingärten), recreational areas, roadside vegetation, etc.)
- 40 % 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:

- Calculation of biomass stocks: The biomass of the category *Buildings and Open areas* has been derived from the relevant figures for *Grassland (in the strict sense), Woody Grassland* and *Hedges* (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, from the data of the Forest Soil and Agricultural Soil Inventories (BZE Wald und Landwirtschaft), taking account of the different degrees of soil sealing involved (cf. Chapter 6.1.2.1) and of the relevant previous use. 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: Stratification by the remaining use, and by Land converted to Buildings and Open areas, is carried out and annually updated. 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 345 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 (2006b): 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).

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. This procedure makes it possible to identify, on a detailed level, 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, 2020 and 2021,
- Map of Germany's organic soils
- The OpenStreetMap dating from 2020 (©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 (a 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 345).

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 345).

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 345). 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 345).

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 345).

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 345: 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

Object number, AAA levels	Attribute, AAA levels	Object number, levels	ATKIS Object-type catalog Object type		Description / attributes pursuant to ATKIS object-type catalog	CORINE LAND COVER Nomenclature code
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
54001	BWS 1100		Hedge		A hedge consists of a dense row of mostly wild shrubs.	No allocation
61003	BEZ ART2000 Knick		Wall hedge		Wall hedges consists of a stone wall with a hedge on top. They occur only in Schleswig-Holstein and in Lower Saxony.	No allocation
IPCC category: Wetlands						
43005		4105	Peatland		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		5101	Natural flowing waters		Rivers at least 12 m wide	511
44004	FKT not 8300		Natural flowing waters		Rivers 3 m to 12 m wide, consisting of line elements	511
44003			Man-made flowing waters		Channels at least 12 m wide	511
		5103	Man-made flowing waters		Ditches 3 m to 12 m wide, consisting of line elements	511
44006			Natural, standing inland water bodies		Lakes	512
44006	BWF 2030 and BWF 2040		Man-made inland water bodies		Dammed lakes (lakes with a dam, or with a dam wall no more than 10 m away)	512
44005		3402	Man-made inland water bodies		Harbour basin	512
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

Object number, AAA levels	Attribute, AAA levels	Object number, levels	ATKIS Object-type catalog Object type	Description / attributes pursuant to ATKIS object-type catalog	CORINE LAND COVER Nomenclature code
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 (2006b): 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 2006 IPCC Guidelines, land-use changes since 1970 are taken into account. As a result, the conversion 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 in preparing 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 conversion-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 "conversion-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, 2015.2020 and 2021). The basic table (cf. Table 346) is structured as follows (the table is shown here with three sampling points provided by way of the example):

Table 346: Basic table for derivation of land uses

Point ID	LBM 2012	OSM	Org. Soil	DLM 2000	DLM 2005	DLM 2010	DLM 2015	DLM 2020	DLM 2021	CORINE 1990	CORINE 2000	CORINE 2006	LBM 2012
1	set1	0	0	crop	crop	crop	set1	set1	set1	gra1	gra1	gra1	set1
1000	gra1	1	0	gra1	gra1	gra1	gra1	gra1	gra1	gra1	gra1	gra1	gra1
2000	crop	0	0	crop	gra1	crop	crop	crop	crop	gra1	crop	crop	crop

The following land-use-class codes are used in the data sets:

Table 347: Codes in the basic table

Code	Category	Sub-category
crop	$Cropland_{annual}$	$Cropland_{annual}$
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
gra3	Grassland	Hedges
forl	Forest Land	Forest Land
wet1	Wetlands	Terrestrial Wetlands
wet2	Wetlands	Natural water bodies
wet3	Wetlands	Peat extraction
wet4	Wetlands	Man-made standing water bodies
wet5	Wetlands	Man-made flowing water bodies
set1	Settlements	Buildings and open areas
set2	Settlements	Roads
othl	Other Land	Other Land
dlm0	No information[95]	

The decision trees were applied to this basic table for the respective years, 1990, 2000, 2005, 2010, 2015, 2020 and 2021. 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 348) with, in each case, the most likely land uses per sample point and year (1990, 2000, 2005, 2010, 2015 and 2021) and the best data source.

Table 348: Most probable land use (LU) and pertinent data sources (DB)

Point ID	LU 1990	LU 2000	LU 2005	LU 2010	LU 2015	LU 2020	LU 2021	DB 1990	DB 2000	DB 2005	DB 2010	DB 2015	DB 2020	DB 2021
1	crop	crop	crop	crop	sett	set1	set1	dlm(OA)	dlm	dlm	dlm	dlm	dlm	dlm
1000	set1	set1	set1	set1	set1	set1	set1	osm	osm	osm	osm	osm	osm	osm
2000	gra1	crop	gra1	crop	crop	crop	crop	clc	dlm	dlm	dlm	dlm	dlm	dlm

(For abbreviations, see Table 347)

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.

[95] No land-use information at this point in the Basis-DLM data

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 2021) 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 conversion period following a land-use change takes place in several sub-steps:

- All land-use changes that occur within a conversion period covered by the included observations (1990-2021) 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 conversion periods of different lengths (1990-2000, 2001-2005, 2006-2010, 2011-2015, 2016-2020, 2021), and the annual changes in those conversion 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 conversion 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 UNFCCC

The method described here for determining land-use changes, and the resulting land-use matrix (cf. Table 349), including a 20-year “conversion time” beginning in 1970, are compliant with reporting requirements pursuant to the UNFCCC, as set forth in the 2006 IPCC Guidelines. Table 350 shows the complete detailed land-use matrix for 2021, by way of example.

Table 349: Areas of the various land-use categories, and their transitions, including a 20-year conversion 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	10,572,845	232,820	13,032,733	485,396	6,406,718	350,018	776,173	1,668	3,654,179	210,776	66,796	0
1991	10,583,473	232,905	13,037,471	484,128	6,393,404	347,375	776,166	1,682	3,657,578	210,235	65,705	0
1992	10,594,107	232,974	13,042,083	482,999	6,379,870	344,954	776,169	1,684	3,660,883	209,768	64,631	0
1993	10,604,741	233,040	13,046,482	482,083	6,365,965	342,904	776,168	1,685	3,664,166	209,323	63,565	0
1994	10,615,379	233,094	13,050,863	481,181	6,351,749	341,164	776,167	1,684	3,667,360	208,975	62,506	0
1995	10,626,018	233,135	13,055,067	480,458	6,337,388	339,574	776,161	1,687	3,670,489	208,690	61,455	0
1996	10,636,659	233,161	13,059,208	479,797	6,322,724	338,291	776,163	1,685	3,673,620	208,403	60,411	0
1997	10,647,303	233,176	13,063,201	479,284	6,307,701	337,374	776,165	1,682	3,676,646	208,211	59,379	0
1998	10,657,949	233,182	13,067,005	478,958	6,292,461	336,677	776,167	1,679	3,679,667	208,026	58,351	0
1999	10,668,593	233,182	13,070,692	478,741	6,276,924	336,287	776,167	1,676	3,682,565	207,966	57,329	0
2000	10,679,238	233,175	13,074,267	478,636	6,261,172	336,119	776,171	1,670	3,685,474	207,888	56,312	0
2001	10,683,466	230,194	12,951,541	530,695	6,166,205	454,141	774,054	6,565	3,669,526	269,397	54,338	0
2002	10,687,706	227,174	12,828,420	583,154	6,070,804	572,610	771,949	11,429	3,653,236	331,248	52,392	0
2003	10,691,956	224,135	12,704,689	636,234	5,974,576	691,904	769,865	16,261	3,636,778	393,263	50,461	0
2004	10,696,219	221,061	12,580,390	689,890	5,877,707	811,850	767,795	21,086	3,620,135	455,443	48,546	0
2005	10,700,493	217,966	12,455,612	744,036	5,780,186	932,443	765,729	25,906	3,603,230	517,877	46,644	0
2006	10,707,280	215,552	12,386,049	762,232	5,738,326	988,078	765,015	28,050	3,600,043	553,827	45,670	0
2007	10,714,082	213,064	12,316,132	780,828	5,696,143	1,044,029	764,343	30,154	3,596,628	590,002	44,717	0
2008	10,720,902	210,533	12,245,840	799,846	5,653,533	1,100,394	763,661	32,253	3,593,161	626,218	43,781	0
2009	10,727,728	207,968	12,175,363	819,090	5,610,644	1,157,026	762,971	34,354	3,589,752	662,364	42,862	0
2010	10,734,562	205,367	12,104,624	838,638	5,567,262	1,214,134	762,296	36,440	3,586,189	698,654	41,956	0
2011	10,742,689	199,806	12,001,530	900,220	5,499,202	1,278,811	761,903	37,323	3,589,996	737,169	41,473	0
2012	10,750,808	194,218	11,897,674	962,601	5,430,963	1,343,673	761,506	38,198	3,593,723	775,754	41,004	0
2013	10,758,928	188,612	11,793,333	1,025,466	5,362,238	1,409,030	761,137	39,057	3,597,234	814,535	40,552	0
2014	10,767,051	182,998	11,688,542	1,088,795	5,292,864	1,475,042	760,765	39,907	3,600,756	853,288	40,114	0
2015	10,775,166	177,383	11,583,445	1,152,433	5,223,626	1,540,920	760,386	40,767	3,604,156	892,154	39,686	0
2016	10,781,768	179,137	11,529,068	1,177,026	5,180,488	1,580,854	759,649	42,690	3,605,518	914,706	39,218	0
2017	10,788,370	180,864	11,473,979	1,202,373	5,137,053	1,621,058	758,944	44,581	3,606,768	937,357	38,775	0
2018	10,794,974	182,575	11,418,627	1,228,001	5,093,202	1,661,687	758,253	46,456	3,608,067	959,941	38,339	0
2019	10,801,580	184,272	11,362,597	1,254,314	5,049,142	1,702,531	757,558	48,339	3,609,208	982,669	37,912	0
2020	10,808,190	185,955	11,306,297	1,280,901	5,004,842	1,743,622	756,902	50,181	3,610,221	1,005,514	37,497	0
2021	10,808,790	194,381	11,281,093	1,263,877	5,026,804	1,717,458	760,962	51,021	3,668,402	979,939	37,395	0

Table 350: Land-use matrix for 2021. 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 conversion times)

Land-use matrix for 2021: 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*	*Hedges*	*Terrestrial Wetlands*	*Natural water bodies*	*Peat extraction*	*Man-made standing water bodies*	*Man-made flowing water bodies*	*Settlements*	*Roads*	*Other Land*	**Σ reductions**	**Σ additions - Σ reductions**
Forest Land	**10,808,790**	3	0	0	0	0	0	0	800	233	10	9,808	0	92	0	0	89,411	0	0	100,357	94,024
Cropland$_{annual}$	1,033	**10,996,022**	5,081	3,351	14,168	8,703	4,252	1,047	1,450,712	51,620	436	995	0	432	0	0	462,960	0	0	2,004,790	-717,044
Hops	95	2,974	**15,041**	7	118	0	0	3	244	1	0	0	0	0	0	0	105	0	0	3,547	2,211
Vineyards	184	3,135	2	**107,434**	219	28	4	3	4,605	3,077	12	0	0	0	0	0	2,050	0	0	13,319	-6,894
Orchards	1,150	30,146	162	523	**52,843**	444	203	92	16,279	1,720	25	2	0	0	0	0	4,239	0	0	54,985	-33,292
Tree nurseries	1,790	8,419	8	13	690	**13,207**	0	453	1,458	328	84	0	0	0	0	0	811	0	0	14,054	-3,523
Christmas tree plantations	1,579	3,616	7	18	1,029	0	**6,772**	0	1,729	419	38	9	0	36	0	0	871	0	0	9,351	4,544
Short-rotation plantations	0	784	0	0	72	0	0	**0**	258	81	0	0	0	0	0	0	131	0	0	1,326	6,277
Grassland (in the strict sense)	50,511	1,132,396	445	1,672	4,530	907	3,552	249	**4,472,282**	166,558	191	22,475	0	2,025	0	0	370,972	0	0	1,756,483	36,306
Woody Grassland	117,984	49,344	37	625	504	0	5,796	5,731	170,475	**195,578**	18	6,377	0	31	0	0	45,027	0	0	401,949	-140,614
Hedges	65	459	0	0	2	1	0	0	214	51	**21,437**	6	0	1	0	0	57	0	0	856	-15
Terrestrial Wetlands	6,348	1,108	0	1	7	6	1	0	8,134	1,437	0	**81,332**	0	1,109	0	0	1,100	0	0	19,251	32,892
Natural water bodies	0	0	0	0	0	0	0	0	0	0	0	0	**572,083**	0	0	0	0	0	0	0	0
Peat extraction	56	1,880	0	0	2	0	0	0	925	57	0	3,926	0	**13,512**	71	0	166	0	0	7,083	-3,170
Man-made standing water bodies	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**65,358**	0	0	0	0	0	71
Man-made flowing water bodies	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**23,571**	0	0	0	0	0
Settlements	10,998	52,765	16	215	352	442	87	25	130,774	33,643	27	8,545	0	187	0	0	**2,688,655**	0	0	238,076	741,863
Roads	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**979,747**	0	0	0
Other Land	2,588	717	0	0	0	0	0	0	6,182	2,110	0	0	0	0	0	0	2,039	0	**37,395**	13,636	-13,636
Σ additions	194,381	1,287,746	5,758	6,425	21,693	10,531	13,895	7,603	1,792,789	261,335	841	52,143	0	3,913	71	0	979,939	0	0		
Σ Land-use category	11,003,171	12,283,768	20,799	113,859	74,536	23,738	20,667	7,603	6,265,071	456,913	22,278	133,475	572,083	17,425	65,429	23,571	3,668,594	979,747	37,395		
Area of Germany										35,790,122											

Table 351: Annual areas of land-use changes used as a basis for inventory calculations in reporting for the UNFCCC (20-year conversion period)

Land-use change [hectares per year]	1990-2000	2001-2005	2006-2010	2011-2015	2016-2020	2021
… to Forest Land						
$Cropland_{annual}$ to Forest Land	0	208	23	13	5	6
Hops to Forest Land	0	0	19	0	0	0
Vineyards to Forest Land	0	0	37	0	0	0
Orchards to Forest Land	0	0	230	0	0	0
Tree nurseries to Forest Land	0	0	0	0	0	0
Christmas tree plantations to Forest Land	0	0	358	0	0	0
Short-rotation plantations to Forest Land	0	0	316	0	0	0
Grassland (in the strict sense) to Forest Land	6,236	1,783	2,541	1,188	4,105	4,222
Woody Grassland to Forest Land	3,022	4,726	4,563	4,327	8,494	12,175
Hedges to Forest Land	0	0	0	0	0	63
Terrestrial Wetlands to Forest Land	42	697	346	95	219	275
Wetlands to Forest Land	0	0	0	0	0	0
Peat extraction to Forest Land	0	0	2	3	5	3
Settlements to Forest Land	2,019	859	571	443	439	309
Other Land to Forest Land	360	321	109	49	98	30
… to $Cropland_{annual}$						
Forest Land to $Cropland_{annual}$	0	0	0	0	0	3
Hops to $Cropland_{annual}$	0	0	89	341	221	95
Vineyards to $Cropland_{annual}$	12	274	310	127	158	164
Orchards to $Cropland_{annual}$	2,693	3,158	2,307	838	1,193	1,325
Tree nurseries to $Cropland_{annual}$	0	0	0	98	77	77
Christmas tree plantations to $Cropland_{annual}$	0	0	428	918	543	516
Short-rotation plantations to $Cropland_{annual}$	0	0	126	329	404	275
Grassland (in the strict sense) to $Cropland_{annual}$	16,176	79,083	50,019	91,869	54,183	63,783
Woody Grassland to $Cropland_{annual}$	4,296	5,035	2,410	2,261	2,966	3,497
Hedges to $Cropland_{annual}$	0	0	0	0	0	459
Terrestrial Wetlands to $Cropland_{annual}$	17	56	35	53	101	116
Waters to $Cropland_{annual}$	0	0	0	0	0	0
Peat extraction to $Cropland_{annual}$	0	0	79	157	165	4
Settlements to $Cropland_{annual}$	3,405	9,123	4,608	2,370	3,365	3,177
Other Land to $Cropland_{annual}$	126	160	26	1	22	1

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**	**2021**
... to Hops						
Forest Land to Hops	0	0	0	0	0	0
Cropland$_{annual}$ to Hops	0	0	65	347	551	395
Vineyards to Hops	0	0	0	0	0	0
Orchards to Hops	0	0	19	6	4	38
Tree nurseries to Hops	0	0	0	0	0	0
Christmas tree plantations to Hops	0	0	0	1	0	0
Short-rotation plantations to Hops	0	0	0	0	1	0
Grassland (in the strict sense) to Hops	0	0	6	38	35	87
Woody Grassland to Hops	0	0	0	2	5	3
Hedges to Hops	0	0	0	0	0	0
Terrestrial Wetlands to Hops	0	0	0	0	0	0
Waters to Hops	0	0	0	0	0	0
Peat extraction to Hops	0	0	0	0	0	0
Settlements to Hops	0	0	0	1	1	4
Other Land to Hops	0	0	0	0	0	0
... to Vineyards						
Forest Land to Vineyards	0	0	0	0	0	0
Cropland$_{annual}$ to Vineyards	7	103	85	242	316	307
Hops to Vineyards	0	0	0	0	0	7
Orchards to Vineyards	0	0	16	43	53	45
Tree nurseries to Vineyards	0	0	0	0	0	0
Christmas tree plantations to Vineyards	0	0	3	0	0	0
Short-rotation plantations to Vineyards	0	0	0	2	1	0
Grassland (in the strict sense) to Vineyards	3	32	41	125	175	178
Woody Grassland to Vineyards	1	5	9	43	72	69
Hedges to Vineyards	0	0	0	0	0	0
Terrestrial Wetlands to Vineyards	0	0	0	0	0	0
Waters to Vineyards	0	0	0	0	0	0
Peat extraction to Vineyards	0	0	0	0	0	0
Settlements to Vineyards	0	4	4	20	20	24
Other Land to Vineyards	0	0	0	0	0	0

Land-use change [hectares per year]	1990-2000	2001-2005	2006-2010	2011-2015	2016-2020	2021
... to Orchards						
Forest Land to Orchards	0	0	0	0	0	0
Cropland$_{annual}$ to Orchards	329	937	547	1,002	1,343	2,262
Hops to Orchards	0	0	2	4	19	8
Vineyards to Orchards	0	0	9	19	22	24
Tree nurseries to Orchards	0	0	0	14	7	16
Christmas tree plantations to Orchards	0	0	37	56	47	127
Short-rotation plantations to Orchards	0	0	82	67	50	117
Grassland (in the strict sense) to Orchards	144	125	77	291	505	837
Woody Grassland to Orchards	58	45	7	36	59	86
Hedges to Orchards	0	0	0	0	0	2
Terrestrial Wetlands to Orchards	0	0	0	0	1	2
Waters to Orchards	0	0	0	0	0	0
Peat extraction to Orchards	0	0	0	0	0	2
Settlements to Orchards	81	47	13	27	40	49
Other Land to Orchards	0	0	0	0	0	0
... to Tree nurseries						
Forest Land to Tree nurseries	0	0	0	0	0	0
Cropland$_{annual}$ to Tree nurseries	0	1	0	0	1,455	1,674
Hops to Tree nurseries	0	0	0	0	0	0
Vineyards to Tree nurseries	0	0	0	0	5	3
Orchards to Tree nurseries	0	0	0	0	48	209
to Tree nurseries	0	0	0	0	0	0
to Tree nurseries	0	0	0	0	0	0
Grassland (in the strict sense) to Tree nurseries	0	0	0	216	0	1
Woody Grassland to Tree nurseries	0	0	0	0	0	0
Hedges to Tree nurseries	0	0	0	0	0	1
Terrestrial Wetlands to Tree nurseries	0	0	0	0	1	0
Waters to Tree nurseries	0	0	0	0	0	0
Peat extraction to Tree nurseries	0	0	0	0	0	0
Settlements to Tree nurseries	0	0	0	0	81	55
Other Land to Tree nurseries	0	0	0	0	0	0
... to Christmas tree plantations						
Forest Land to Christmas tree plantations	0	0	0	0	0	0
Cropland$_{annual}$ to Christmas tree plantations	0	0	0	1,151	0	0
Hops to Christmas tree plantations	0	0	0	0	0	0
Vineyards to Christmas tree plantations	0	0	0	2	0	0

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**	**2021**
Orchards to Christmas tree plantations	0	0	0	52	0	0
Tree nurseries to Christmas tree plantations	0	0	0	0	0	0
Short-rotation plantations to Christmas tree plantations	0	0	0	0	0	0
Grassland (in the strict sense) to Christmas tree plantations	0	0	0	193	488	365
Woody Grassland to Christmas tree plantations	0	0	0	670	486	344
Hedges to Christmas tree plantations	0	0	0	0	0	0
Terrestrial Wetlands to Christmas tree plantations	0	0	0	1	0	0
Waters to Christmas tree plantations	0	0	0	0	0	0
Peat extraction to Christmas tree plantations	0	0	0	0	0	0
Settlements to Christmas tree plantations	0	0	0	27	0	0
Other Land to Christmas tree plantations	0	0	0	0	0	0
… to Short-rotation plantations						
Forest Land to Short-rotation plantations	0	0	0	0	0	0
$Cropland_{annual}$ to Short-rotation plantations	0	0	335	0	0	0
Hops to Short-rotation plantations	0	0	1	0	0	0
Vineyards to Short-rotation plantations	0	0	5	0	0	0
Orchards to Short-rotation plantations	0	0	32	0	0	0
Tree nurseries to Short-rotation plantations	0	0	0	0	0	0
Christmas tree plantations to Short-rotation plantations	0	0	180	0	0	0
Grassland (in the strict sense) to Short-rotation plantations	0	0	79	0	0	0
Woody Grassland to Short-rotation plantations	0	0	51	627	415	534
Hedges to Short-rotation plantations	0	0	0	0	0	0
Terrestrial Wetlands to Short-rotation plantations	0	0	0	0	0	0
Waters to Short-rotation plantations	0	0	0	0	0	0
Peat extraction to Short-rotation plantations	0	0	0	0	0	0
Settlements to Short-rotation plantations	0	0	12	0	0	0
Other Land to Short-rotation plantations	0	0	0	0	0	0

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**	**2021**
… to Grassland (in the strict sense)						
Forest Land to Grassland (in the strict sense)	0	0	0	0	0	800
$Cropland_{annual}$ to Grassland (in the strict sense)	13,459	116,901	76,657	106,594	73,094	94,216
Hops to Grassland (in the strict sense)	0	0	9	19	29	24
Vineyards to Grassland (in the strict sense)	6	331	655	196	299	352
Orchards to Grassland (in the strict sense)	719	747	661	1,637	889	687
Tree nurseries to Grassland (in the strict sense)	0	0	0	19	29	47
Christmas tree plantations to Grassland (in the strict sense)	0	0	46	123	155	148
Short-rotation plantations to Grassland (in the strict sense)	0	0	50	131	189	120
Woody Grassland to Grassland (in the strict sense)	3,449	16,534	7,892	7,365	11,137	18,627
Hedges to Grassland (in the strict sense)	0	0	0	0	0	214
Terrestrial Wetlands to Grassland (in the strict sense)	20	1,017	411	244	429	383
Waters to Grassland (in the strict sense)	0	0	0	0	0	0
Peat extraction to Grassland (in the strict sense)	0	0	43	76	132	6
Settlements to Grassland (in the strict sense)	1,970	14,531	10,568	6,616	9,790	10,642
Other Land to Grassland (in the strict sense)	430	817	649	129	191	62
… to Woody Grassland						
Forest Land to Woody Grassland	0	0	0	0	0	233
$Cropland_{annual}$ to Woody Grassland	595	4,736	3,684	2,923	3,260	3,382
Hops to Woody Grassland	0	0	0	0	0	1
Vineyards to Woody Grassland	0	160	329	118	175	110
Orchards to Woody Grassland	41	177	206	112	103	78
Tree nurseries to Woody Grassland	0	0	0	5	10	19
Christmas tree plantations to Woody Grassland	0	0	116	37	37	22
Short-rotation plantations to Woody Grassland	0	0	54	27	55	30
Grassland (in the strict sense) to Woody Grassland	663	11,423	12,111	9,674	12,167	12,743
Hedges to Woody Grassland	0	0	0	0	0	51
Terrestrial Wetlands to Woody Grassland	0	316	46	71	130	66
Waters to Woody Grassland	0	0	0	0	0	0
Peat extraction to Woody Grassland	0	0	0	7	7	4
Settlements to Woody Grassland	260	3,353	2,231	1,700	2,554	2,881
Other Land to Woody Grassland	47	210	74	215	93	5

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**	**2021**
… to Hedges						
Forest Land to Hedges	0	0	0	0	0	10
$Cropland_{annual}$ to Hedges	0	0	0	0	0	436
Hops to Hedges	0	0	0	0	0	0
Vineyards to Hedges	0	0	3	0	0	0
Orchards to Hedges	0	0	5	0	0	2
Tree nurseries to Hedges	0	0	0	0	0	0
Christmas tree plantations to Hedges	0	0	17	0	0	0
Short-rotation plantations to Hedges	0	0	8	0	0	1
Grassland (in the strict sense) to Hedges	0	0	0	0	0	191
Woody Grassland to Hedges	2	0	0	0	0	18
Terrestrial Wetlands to Hedges	0	0	0	0	0	0
Waters to Hedges	0	0	0	0	0	0
Peat extraction to Hedges	0	0	0	0	0	0
Settlements to Hedges	0	0	0	0	0	27
Other Land to Hedges	0	0	0	0	0	0
… to Terrestrial Wetlands						
Forest Land to Terrestrial Wetlands	9	1,269	361	134	353	810
$Cropland_{annual}$ to Terrestrial Wetlands	16	228	46	26	24	12
Hops to Terrestrial Wetlands	0	0	0	0	0	0
Vineyards to Terrestrial Wetlands	0	0	0	0	0	0
Orchards to Terrestrial Wetlands	0	0	0	0	0	0
Tree nurseries to Terrestrial Wetlands	0	0	0	0	0	0
Christmas tree plantations to Terrestrial Wetlands	0	0	0	0	0	0
Short-rotation plantations to Terrestrial Wetlands	0	0	0	0	0	6
Grassland (in the strict sense) to Terrestrial Wetlands	42	1,624	953	634	1,448	3,639
Woody Grassland to Terrestrial Wetlands	9	452	199	164	383	1,254
Hedges to Terrestrial Wetlands	0	0	0	0	0	6
Waters to Terrestrial Wetlands	0	0	0	0	0	0
Peat extraction to Terrestrial Wetlands	0	0	90	165	442	522
Settlements to Terrestrial Wetlands	6	1,378	808	11	23	15
Other Land to Terrestrial Wetlands	5	1	0	0	0	0

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**	**2021**
... to Waters						
Forest Land to Waters	0	0	0	0	0	0
Cropland$_{annual}$ to Waters	0	0	0	0	0	0
Hops to Waters	0	0	0	0	0	0
Vineyards to Waters	0	0	0	0	0	0
Orchards to Waters	0	0	0	0	0	0
Tree nurseries to Waters	0	0	0	0	0	0
Christmas tree plantations to Waters	0	0	0	0	0	0
Short-rotation plantations to Waters	0	0	0	0	0	0
Grassland (in the strict sense) to Waters	0	0	0	0	0	0
Woody Grassland to Waters	0	0	0	0	0	0
Hedges to Waters	0	0	0	0	0	0
Terrestrial Wetlands to Waters	0	0	0	0	0	0
Peat extraction to Waters	0	0	0	0	0	0
Settlements to Waters	0	0	0	0	0	0
Other Land to Waters	0	0	0	0	0	0
... to Peat extraction						
Forest Land to Peat extraction	0	0	1	7	6	29
Cropland$_{annual}$ to Peat extraction	0	0	10	47	47	4
Hops to Peat extraction	0	0	0	0	0	0
Vineyards to Peat extraction	0	0	0	0	0	0
Orchards to Peat extraction	0	0	0	0	0	0
Tree nurseries to Waters	0	0	0	0	0	0
Christmas tree plantations to Waters	0	0	0	0	0	0
Short-rotation plantations to Waters	0	0	0	1	6	0
Grassland (in the strict sense) to Peat extraction	0	0	22	185	215	35
Woody Grassland to Peat extraction	3	0	3	1	2	2
Hedges to Peat extraction	0	0	0	0	0	1
Terrestrial Wetlands to Peat extraction	0	0	3	75	122	237
Waters to Peat extraction	0	0	0	0	0	0
Settlements to Peat extraction	0	2	1	7	31	1
Other Land to Peat extraction	0	0	0	0	0	0

Land-use change [hectares per year]	**1990-2000**	**2001-2005**	**2006-2010**	**2011-2015**	**2016-2020**	**2021**
… to Settlements						
Forest Land to Settlements	997	6,116	4,458	3,452	4,688	6,172
$Cropland_{annual}$ to Settlements	5,745	40,277	24,721	28,065	14,155	15,889
Hops to Settlements	0	0	3	14	6	7
Vineyards to Settlements	4	161	134	87	77	74
Orchards to Settlements	246	437	309	150	117	126
Tree nurseries to Settlements	0	0	0	18	13	4
Christmas tree plantations to Settlements	0	0	23	73	64	66
Short-rotation plantations to Settlements	0	0	24	68	84	42
Grassland (in the strict sense) to Settlements	3,113	25,484	19,947	18,891	17,993	22,560
Woody Grassland to Settlements	388	1,835	1,842	2,607	2,837	4,736
Hedges to Settlements	0	0	0	0	0	57
Terrestrial Wetlands to Settlements	10	110	19	24	135	45
Waters to Settlements	0	0	0	0	0	0
Peat extraction to Settlements	0	0	2	5	28	8
Other Land to Settlements	77	425	79	60	34	4

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 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 Agricultural Soil Inventory (BZE-LW) and the B-DLM arise solely through the survey methods used. Whereas the Agricultural Soil Inventory 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 Agricultural Soil Survey, 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 352). With regard to the small difference between the total area represented in the Agricultural Soil Survey and that represented in the B-DLM, it should be noted that statistical survey systems with relatively coarse resolution often overestimate the sizes of small areas (cf. Jacobs et al. (2018)).

Table 352: Percentage distribution of agriculturally used land areas, pursuant to the Agricultural Soil Inventory (BZE-LW), the Basic Digital Landscape Model of ATKIS® (B-DLM) and the Agricultural Structural Survey (ASE) The reference area is the total area covered by the BZE-LW.

	BZE-LW	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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**4 A , Forest Land**		**CO_2**	**-18,696.5**	**-1.5 %**	**-41,870.9**	**-5.5 %**	**124.0 %**
-/-	4 A , Forest Land		CH_4	34.4	0.0 %	26.6	0.0 %	-22.5 %
-/-/2	**4 A , Forest Land**		**N_2O**	**461.8**	**0.0 %**	**435.5**	**0.1 %**	**-5.7 %**

* 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, with GWP pursuant to IPCC AR5

Gas	Method used	Source for the activity data	Emission factors used
CO_2	Tier 2 / Tier 3	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 categories for CO_2 emissions and removals in terms of emissions level and trend, and key categories for N_2O pursuant to Method 2 analysis.

In the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006b), 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 conversion 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 conversion 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 conversion period, are removed from the relevant conversion 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 2021, the total emissions from forests amounted to -41,409 kt CO_2 equivalents pursuant to IPCC AR5. Table 353 lists the emissions for the category Forest Land, by pools and GHG, and with the pertinent uncertainties included.

Table 353: Emissions in the category Forest Land for the year 2021

Source category	Gas	Emission	2.5 % percentile	97.5 % percentile	2.5 % percentile	97.5 % percentile
			[kt CO_2-eq.]		%	
Forest Land$_{total}$ [96]		-41,408.8	-37,964.2	-44,764.3	8.20	8.24
Mineral soils	CO_2 [97]	-13,812.1	-12,366.4	-15,257.9	10.47	10.47
	$N_2O_{indirect}$ [98]	20.9	-10.8	83.9	151.65	302.08
	N_2O_{direct} [99]	92.7	-20.2	299.1	121.81	222.55
Organic soils	CO_2 [100]	2,955.6	2,387.3	3,618.5	19.23	22.43
	CH_4 [101]	25.6	8.1	51.6	68.34	101.11
	N_2O [102]	321.4	-37.0	672.3	111.52	109.20
Biomass	CO_2 [103]	-27,414.9	-24,982.0	-29,848.6	8.87	8.88
Litter	CO_2 [104]	163.0	107.5	218.6	34.07	34.07
Dead wood	CO_2 [105]	-3,762.5	13,868.8	-21,393.9	468.60	468.60
Wildfires	CO_2 [106]	IE	IE	IE	IE	IE
	CH_4 [107]	1.0	0.2	1.8	82.26	82.26
	N_2O [108]	0.5	0.2	0.8	57.21	57.21

In the category Forest Land (2021), the most important factors for removals are the pools biomass (63.93 %), mineral soils (27.29 %) and dead wood (8.77 %). Sources occur via litter,

[96] Sum of the emissions from CRF tables 4.A, 4(II).A, 4(III).A, 4(IV).2, 4(V).A
[97] CRF table 4.A
[98] 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
[99] CRF table 4(III).A
[100] CRF table 4.A
[101] CRF table 4(II).A
[102] CRF table 4(II).A
[103] CRF table 4.A
[104] CRF table 4.A
[105] CRF table 4.A
[106] CRF table 4(V).A
[107] CRF table 4(V).A
[108] CRF table 4(V).A

drainage, mineralisation and wildfires. Such sources account for only a very small share – 7.62 % – of the greenhouse-gas balance for forests, however.

Figure 65: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq. pursuant to IPCC AR5] as a result of land use and land-use changes in Forest Land, 1990 – 2021, by sub-categories

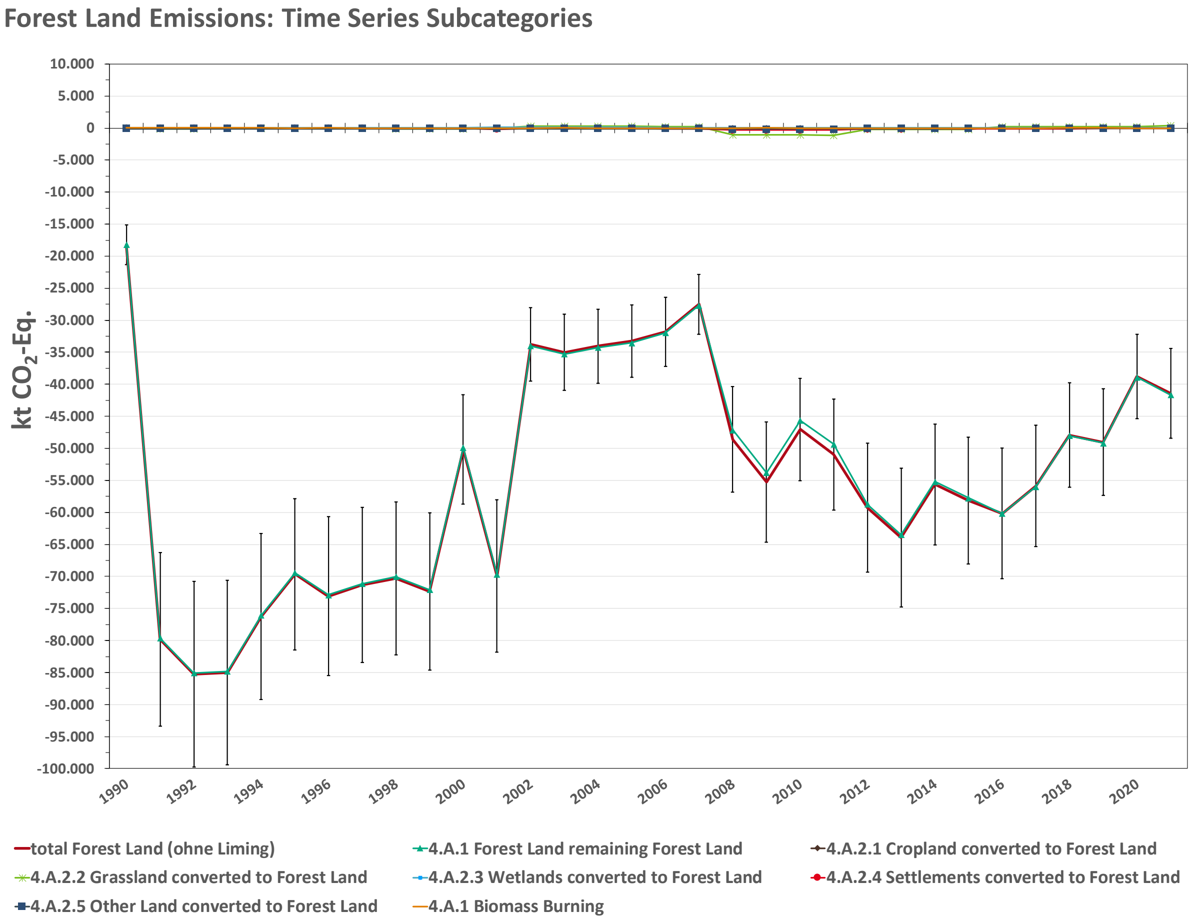
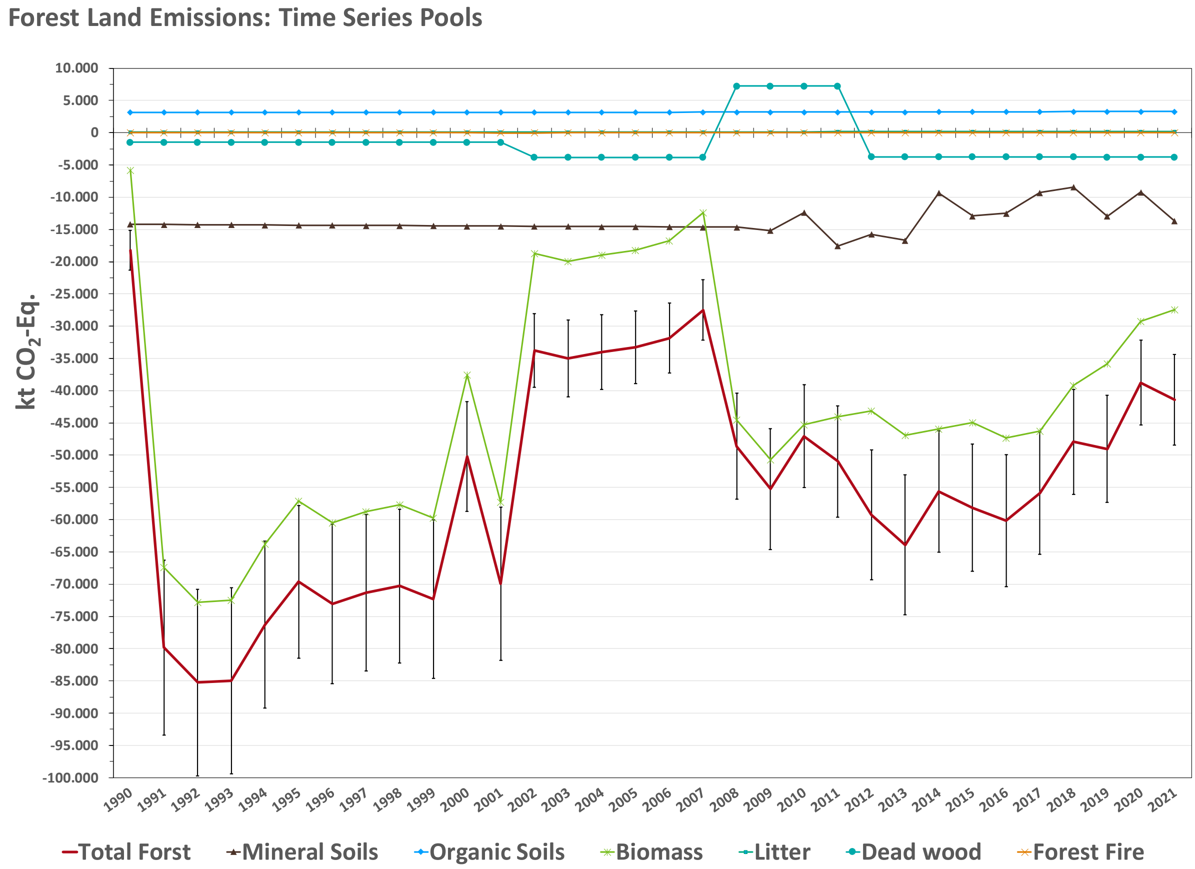


Figure 66: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq. pursuant to IPCC AR5] as a result of land use and land-use changes in forests, 1990 – 2021, by pools



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-Wald)
- Forest Soil Inventory II (Bodenzustandserhebung im Wald II; BZE II-Wald)
- 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[109]. 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 (BMELV, 2005; Polley, 2001). 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; F 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 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 (BMELF, 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 (BZE-Wald)

Carbon emissions from forest soils have been determined via the YASSO soil-carbon model. Yasso calculates the quantity of organic carbon in the soil, the changes in that quantity, and the heterotrophic soil respiration (cf. also Chapter 6.4.2.5). The input data consisted of data from the BZE I-Wald and BZE II-Wald soil surveys. The Forest Soil Inventory I (BZE I-Wald) was carried out from 1987 to 1992, while the Forest Soil Inventory II (BZE II-Wald) 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-Wald (Wolff & Riek, 1997) and BZE II-Wald (Wellbrock et al., 2006), forest soils throughout Germany were sampled using 8 km x 8 km grids. 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-Wald, there were 1,800 grid points; for the BZE II-

[109] For further information: http://www.bundeswaldinventur.de

Wald, there were 2,000. 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-Wald occurred.

For the BZE I-Wald, 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-Wald, 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 grid points available from the BZE II-Wald[110].

Currently, the BZE III-Wald Forest Soil Inventory is being carried out. When its results have been published, they will be used as input data for modelling with YASSO. They are expected to improve the modelling results.

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 Steffi Röhling et al. (2016).

Figure 67 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 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.

[110] cf.: https://www.thuenen.de/de/wo/arbeitsbereiche/waldmonitoring/bodenzustandserhebung/

Figure 67: 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

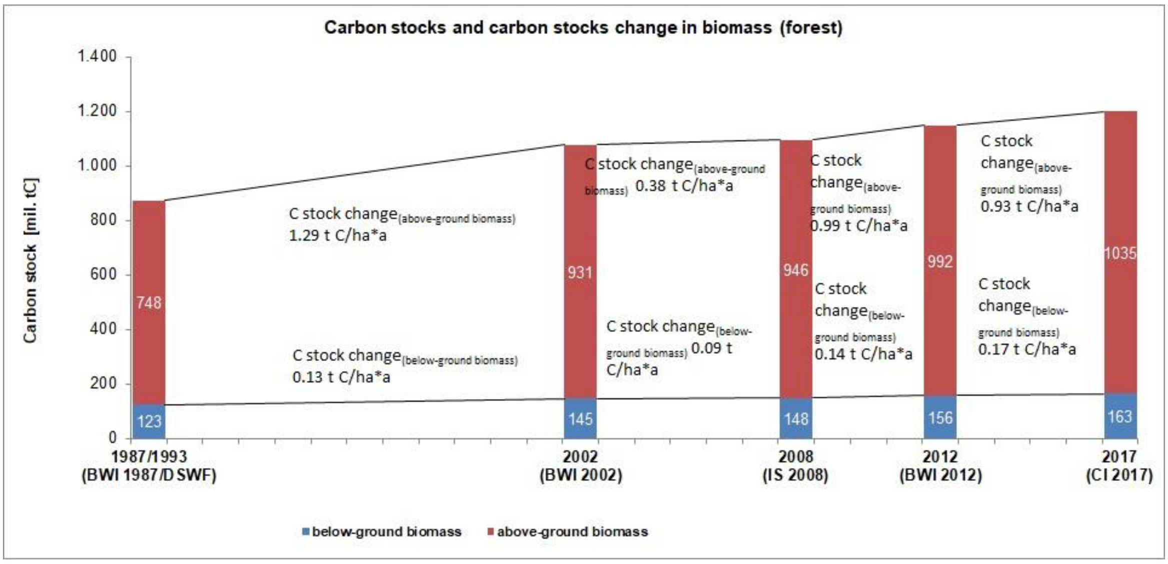


Figure 68 shows the relevant logging statistics for Germany. The method used to derive these statistics is described in Chapter 6.10.2.1 and in (Rüter). The annual EF, which are shown in Table 354, have been derived from the logging recalculation.

Figure 68: Quantities of wood logged in Germany (in millions of m³ per year)

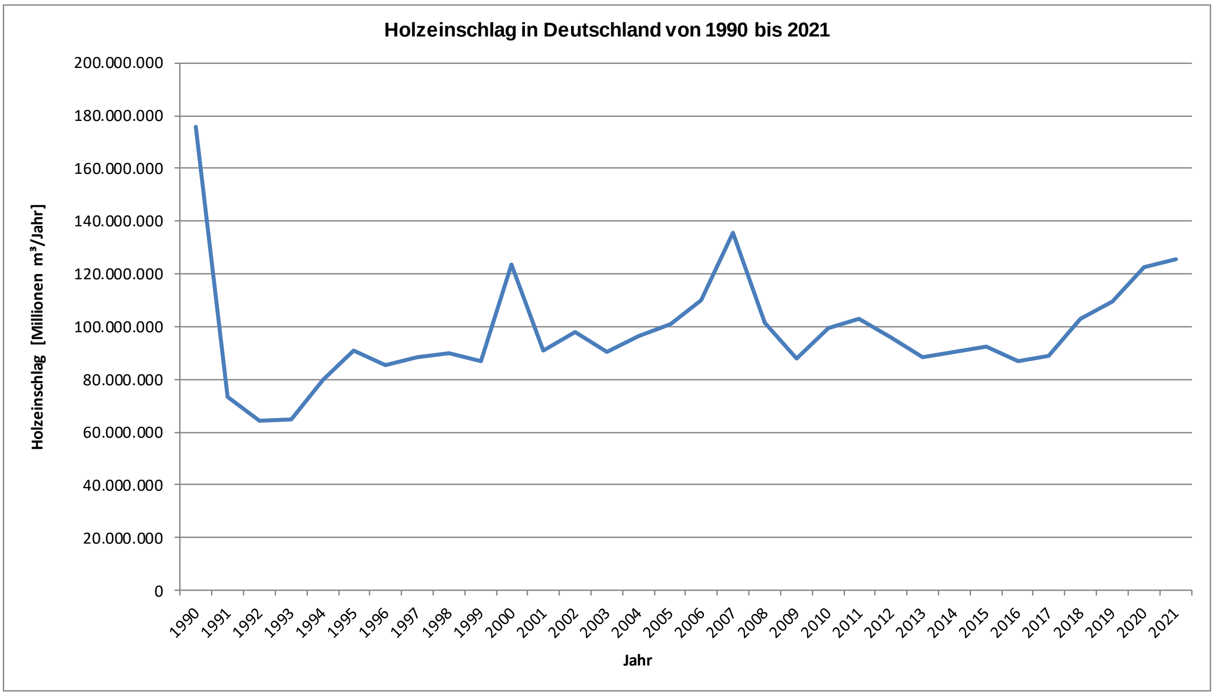


Table 354: Emission factors for above-ground and below-ground biomass on Forest Land remaining Forest Land

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
2021	0.60	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 m³ of timber. In 2007, hurricane "Kyrill" struck, leaving behind about 37 million m³ 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 m³ (BMEL, 2020). The figures reported for the years 2018 through 2020 do not yet reflect the full extent 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 355 shows the EF for the annual increase in the above-ground and below-ground biomass on afforestation areas, without reference to previous uses.

Table 355: EF for above-ground and below-ground biomass on Land converted to Forest Land

Period	1990-2001	2002-2007	2008-2011	2012-2021
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 Bösch and Kändler (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 (2006b)) instead of the gain-loss method (IPCC (2006b)).

6.4.2.2.4 Conversion into above-ground individual-tree biomass

The some 1,600 trees covered by the study of Bösch and Kändler (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 41:

$$Y_{BIOM_0} = b_0 e^{b_1 \frac{BHD}{BHD+k_1}} e^{b_2 \frac{D03}{D03+k_2}} H^{b_3}$$

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 356: 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[111]

Trees > 1.3 m height and < 10 cm DBH

Equation 42:

$$Y_{BIOM_0} = b_0 + \left(\frac{b_s - b_0}{d_s^2} + b_3(BHD - d_s)\right) BHD^2$$

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 357: 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 43:

$$Y_{BIOM_0} = b_0\, H_1^b$$

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 358: 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

[111] 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 359: 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 360: 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 44.

Equation 44:

$$Y_{BIOM_u} = b_0\ BHD^{(b_1)}$$

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 361: 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[112]	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)[113]	0.000116	DBH [mm]	2.290300	15.9	South Sweden	(Johansson & Hjelm, 2012)

The log functions available in the literature (cf. Figure 69) 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 69).

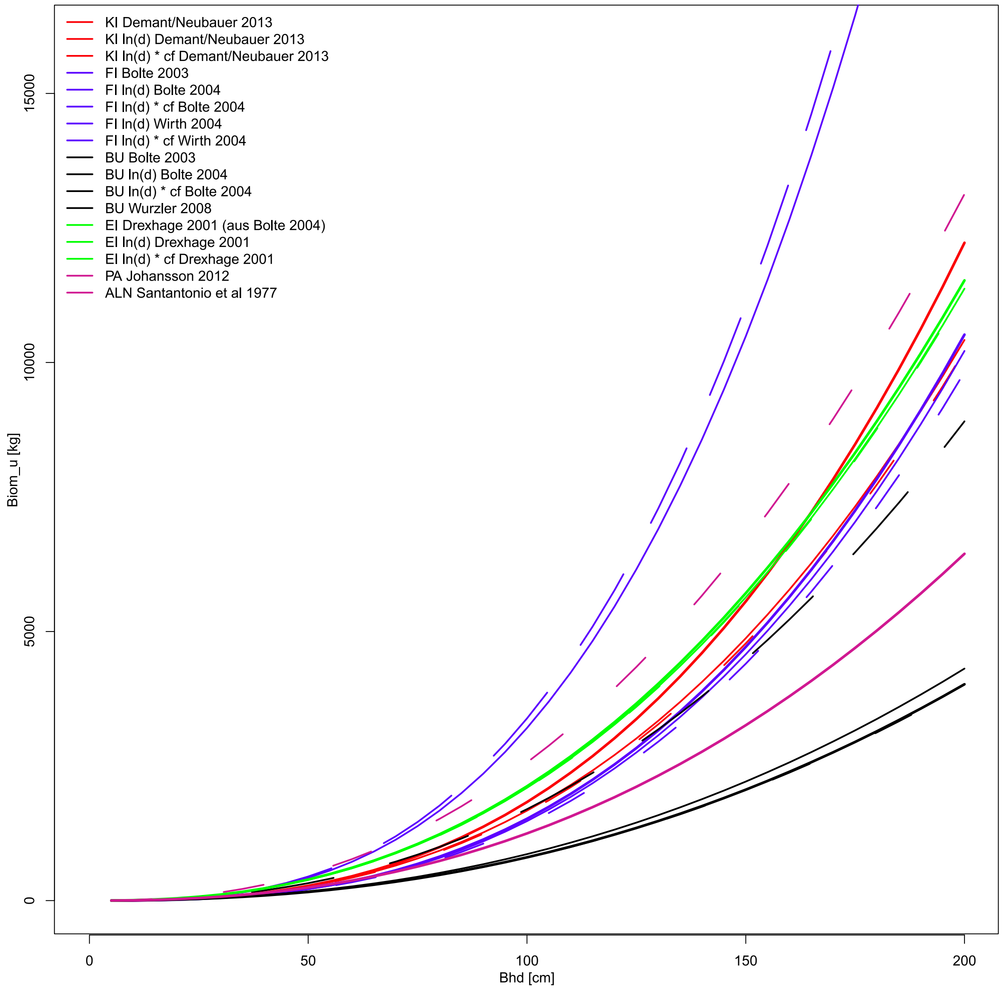
At the same time, the chosen functions for spruce and beech were derived from data of a small region, the "Solling" region. On the other hand, the functions of Wutzler et al. (2008) and Wirth et al. (2004) make use of data from various, and geographically different, studies.

This comparison of the chosen functions for spruce, beech and soft hardwoods (in each case, the unbroken line in Figure 69) 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.

112 For this function, no figure for RMSE% is available. Therefore, the IPCC default value of 50% has been used.

113 The mean RMSE% for both functions (root-stump biomass + root biomass) is 24.2%.

Figure 69: 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 45:

$$Y_{lc} = \frac{\sum_{m=1}^{M} I_{l,c,m} Y_{l,c,m}}{M_{l,c}}$$

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 46:

$$\hat{\hat{Y}}_l = \frac{\sum_{c_l=1}^{C_l} M_{l,c} Y_{lc}}{\sum_{c_l=1}^{C_l} M_l}$$

$\hat{\hat{Y}}$ = 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 47:

$$\hat{\hat{Y}}_{st} = \sum_{l=1}^{L} \hat{\hat{Y}}_l \frac{\lambda(U_{l)}}{\lambda(U)}$$

$\hat{\hat{Y}}_{st}$ = 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 $\lambda(U)$.

Equation 48:

$$\hat{Y}_{st} = \hat{\bar{Y}}_{st}\lambda(U)$$

$\hat{Y}_{st}$= 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 49:

$$\hat{R}_{st} = \frac{\hat{Y}_{st}}{\lambda(U_{Wald})}$$

$\hat{R}_{st}$ = 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 50:

$$\hat{G}_l = \hat{Y}_l^{(t_2)} - \hat{Y}_l^{(t_1)}$$

$\hat{G}_l$= 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 50. The estimated total change is calculated by means of Equation 51. The change in the area-related mean estimator is determined via:

Equation 51:

$$\hat{G}_{R\,st} = \hat{R}_{st}^{(t_2)} - \hat{R}_{st}^{(t_1)}$$

$\hat{G}_{R_{st}}$= 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 (Steffi 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 52:

$$EF_{LFM} = EF * (1 + F_1)$$

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 53:

$$F_1 = \frac{(L_{fp} - L_{fa})}{L_{fp}}$$

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 2.19, IPCC (2006b)).

The carbon stocks in dead wood were calculated with data of the NFI 2002 (BMELV, 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 362.

Table 362: 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 54 (Equation 2.19, IPCC (2006b)). The EF for dead wood on Forest Land remaining Forest Land are shown in Table 363.

Equation 54:

$$\Delta C_{FF_{DW}} = \frac{A * \left(B_{t_2} - B_{t_1}\right)}{T} CF$$

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 363: Dead-wood EF for Forest Land remaining Forest Land

Period	1990-2001	2002-2007	2008-2011	2012-2021
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, 2006b). That equation is identical with the equation for calculating changes in dead-wood carbon stocks on Forest Land remaining Forest Land (cf. Equation 54). 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 364.

Table 364: Dead-wood EF for Land converted to Forest Land

Period	1990-2007	2008-2011	2012-2021
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-Wald and BZE II-Wald; cf. Chapter 6.4.2.1.2 and Grüneberg et al. (2014)). A slight decrease in carbon stocks in litter, amounting to -0.02 t C ha^{-1} a^{-1}, occurred in the period from 1990 (BZE I-Wald) to 2006 (BZE II-Wald) (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-Wald) is currently being prepared. Relevant field measurements will be carried out beginning in 2022. When the results of BZE III-Wald 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 (2006b)). 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 conversion 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-Wald and BZE II-Wald Forest Soil Inventories. According to those calculations, the mean carbon stocks in litter, referenced to 1990 (BZE I-Wald), were 19.0 t C ha^{-1}, and, referenced to 2006 (BZE II-Wald), were 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 365). A description of the method used to derive carbon stocks in litter is presented in Chapter 6.4.2.4.

Table 365: 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	2021
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	0.4663

Regarding the conversion 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 equilibrium to form pursuant to (Paul et al.) 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. 2022 National Inventory Report 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, 2006b). 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 N. 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 ± 2 σ) 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 366). 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, and carbon sequestration in litter in connection with afforestation (cf. Chapter 6.4.2.4.2).

Table 366: 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-Wald) to 2006 (BZE II-Wald)

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-Wald / BZE II-Wald and the average difference (cf. Chapter 6.4.2.4.2 and Table 365).

Calculations relative to deforestation were carried out with the status data of the BZE I-Wald and BZE II-Wald 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-Wald) and to 18.83 t C ha^{-1} in 2006 (BZE II-Wald). 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.

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 using the overlap method, with a Tier 2 and Tier 3 approach (2006 IPCC Guidelines – Equ. 2.25, IPCC (2006b)).

For the period 1990 until 2008, the carbon stocks and carbon-stock changes in mineral soils were calculated with the “stock-difference” method; for the period as of 2008, they were calculated with results from modelling with Yasso15. The introduction of the new method was accompanied by a regionalisation of the relevant soils (cf. also Chapter 6.1.2.1.3). The data needed for this are based on the nationwide Forest Soil Inventories (BZE I-Wald and BZE II-Wald; cf. Chapter 6.4.2.1.2 and Grüneberg et al. (2014)). The relevant methods are described in detail in the following Chapter 6.4.2.5.3 and Chapter 6.4.2.5.4.

The third Forest Soil Inventory (BZE III-Wald) is currently being carried out. The results of the BZE III-Wald inventory will improve the method used.

6.4.2.5.2 Land converted to Forest Land

For Land converted to Forest Land, the carbon-stock change on mineral soils is calculated, as is done for Forest Land remaining Forest Land, with an overlap method combining a Tier 2 approach and a Tier 3 approach (Equ. 2.25, IPCC (2006b)).

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.

6.4.2.5.3 Database, and methods, for calculating the rates of change of organic soil carbon stocks

The database for calculating the annual rates of change of organic soil carbon stocks consists of data from the nationwide Forest Soil Inventory (cf. Chapter 6.4.2.1.2 and Grüneberg et al. (2014)). With a nationwide, representative and systematic 8x8 km sampling grid, the Forest Soil Inventory (BZE Wald) covers Germany's entire forested area. The first such inventory (BZE I-Wald) took place in the years 1987 through 1993, and included 1,936 sampling points. The second inventory (BZE II-Wald) was carried out between 2006 and 2008. It included some of the same points that were used in the first inventory, and added additional points.

In the inventories, mineral soil was sampled at depths of relevance for the national inventory report; at most BZE plots, this involved depths of up to 30 cm, and 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 (N. 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.

With the Yasso15 soil-carbon model (Järvenpää et al. 2018, Tuomi et al. 2009), all BZE points were modelled separately in monthly steps, throughout a time frame ranging from the BZE I measurements to 2050. In cases in which no data from the BZE I-Wald Forest Soil Inventory were available, the modelling began with the time of the BZE II-Wald inventory. The model results show the changes in organic soil carbon stocks down to a mineral-soil depth of 30 cm. The climate data required for the modelling (mean monthly air temperatures and monthly precipitation) were calculated from data of the German Weather Service (DWD), which are currently available with a resolution of 1 km^2, and adjusted using spatial interpolation between the four nearest data points around each BZE point . In the process, the spatial intervals, and the squares of the geodetic elevation differences, were entered as inverse proportions into the calculation, as weighting factors. The modelling into the future was carried out on the basis of randomly selected climate data from the period 2010 through 2020. The data on carbon inputs into the soil, at the relevant BZE points, were derived in keeping with Ziche et al. (2019).

Yasso15 was executed with the Sorcering modelling framework (Scherstjanoi & Dechow 2021), in the R software environment (v.4.0.2, R Core Team 2020). In the process, Sorcering had to be adapted, however (Scherstjanoi & Dechow in prep.), so that it would be able to support modelling of wood inputs, as described in Ziche et al. (2019). The simulations with Yasso were initiated with a 3,000-year model spin-up that was carried out for all BZE points. Before the simulations were commenced, the quantity ratios between the Yasso model pools that were obtained at the end of the spin-up were transferred to the measured BZE starting values for organic soil carbon stocks. This generated starting values for the simulations. For determination of the model uncertainties, the simulations were repeated hundreds of times, with stochastically varying model sizes:

i. The Yasso15 developers prepared a list of 10,000 model-parameter sets, using Bayesian methods and Markov chain Monte Carlo sampling. From that list, a random selection was made in each stochastic repetition.
ii. In earlier work, Ziche et al. (2019) generated distributions for each carbon input, in order to take account of uncertainties. 100 sets of input data were then created via random selection from those distributions.

The model results for each output year were stratified, to provide a basis for a nationwide cartographic depiction. The basis for the stratification 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 (Finnern et al., 1994) and FAO (FAO, 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 367). 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 367: Combined legend units on the basis of the BÜK 1000 soil map

Abb.	New dominant soil units, by substrate type, soil type and lime content
1	Soils from nutrient-poor sands
2	Soils from sandy-to-loamy terrace or riverine deposits
3	Soils from calcareous, loamy-clayey terrace or riverine deposits
4	Soils from sandy-loamy sediment deposits (without damming or groundwater impacts)
5	Soils from sandy-loamy sediment deposits (with damming or groundwater impacts)
6	Soils of loess areas (without damming or groundwater impacts)
7	Soils of loess areas (with damming or groundwater impacts)
8	Soils from redistribution products of limestone, dolomite, marl and clay weathering
9	Soils from alkiline and intermediary magmatic rock
10	Soils from acidic magmatic and metamorphic rock
11	Soils from acidic sedimentary rock
12	Soils from loess-containing covering layers over acidic sedimentary rock or magmatic and metamorphic rock
13	High-mountain soils
14	Peatland
15	Tide-influenced soils
16	Initial soils

For purposes of analysis, carbon-stocks data were available from a total of 1,865 points from the BZE I inventory, and from 1,813 points 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 point with exactly one BZE II point. To exclude implausible values, every data point for which doubling or halving of the carbon stocks had occurred, between the BZE time points, was excluded from the modelling. After this had been done, 1,710 points remained, of which 1,205 points had BZE I-Wald measurements.

6.4.2.5.4 Rates of change of organic soil carbon stocks

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 inventory. Those figures translate 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. 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.

The average soil carbon stocks modelled with YASSO are shown in Figure 70. The upper line, colored green, shows the initial survey of one of the 1,710 sites, while the red lines in the lower portion of the figure show BZE-Wald state, the blue line shows the BZE-Wald change and the black line shows the Yasso15 results. The figure makes the following clear:

- that the results of the calculation of the change from BZE I-Wald to BZE II-Wald (blue line) are extended in the model results, and that the overlap range, from 2009 through 2014, contains results that are identical in both the change calculation and Yasso15,

- that the trend in the Yasso15 results tends to flatten out toward the year 2050,
- and, as long as the modelling does not include all sites (until 2008), that the average model results are subject to fluctuations.

For this reason, only the model results as of 2009 are used for the report.

The average modelled rates of change of the soil carbon stocks of the BZE points within the relevant new dominant soil units were determined for each simulation year. From this, rates of change of about 0.23 t C ha^{-1} a^{-1} were obtained for the period 1985 to 2050.

Due to the fluctuations of model results prior to 2009 (mentioned under point 3 in the previous section), the rates of change for the period 1990 to 2008 were determined as described in section 1. In the process, the rate of change was applied to the Yasso15 model results of 2008. This was done by back-extrapolating the rate of change at each point. In the process, the rate of change at each point was scaled with the following equation:

delta_i = delta_mw * SOC_i / SOC_mw

delta_mw = rate of change (0.41 t C/ha)

SOC_mw = average soil carbon stocks for all points (year 2008)

SOC_i = soil organic carbon stocks at point i

This procedure brings the Yasso15 model results into line with the change calculation from the BZE-Wald I and II inventories, and it produces an overlap range with nearly identical values.

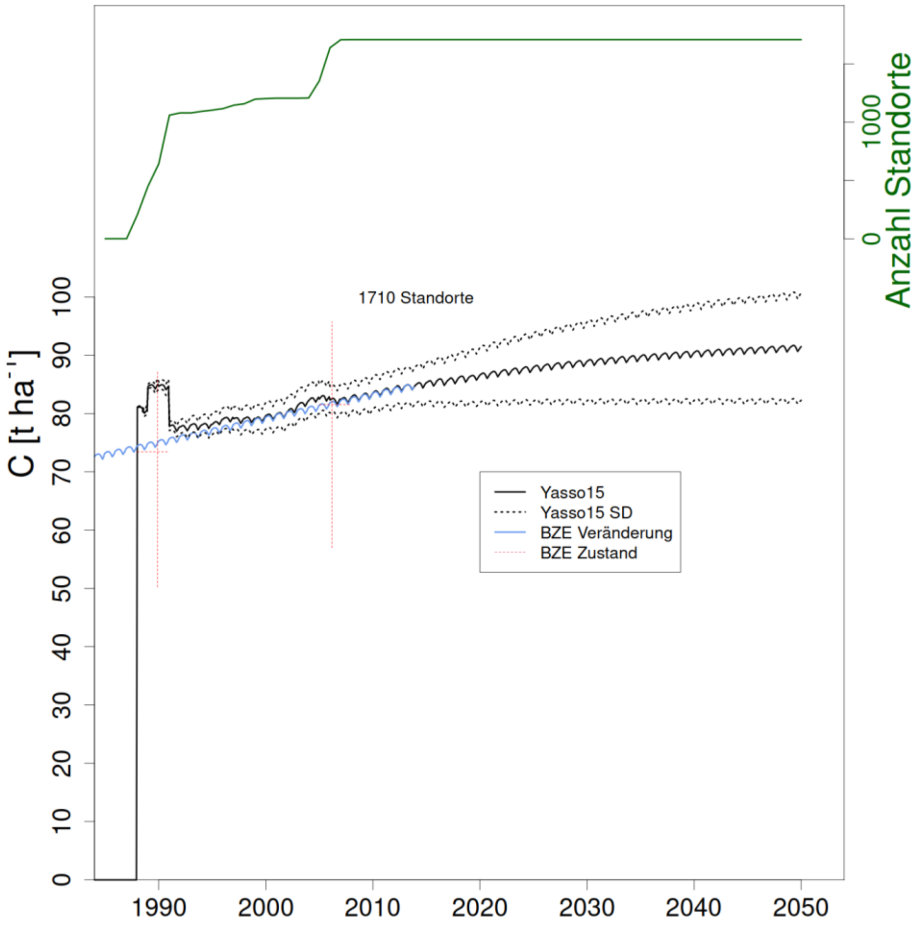


Figure 70: Average soil organic carbon stocks as modelled/calculated with Yasso15 and the BZE-Wald results, in t ha^{-1} , and showing numbers of sites (Anzahl Standorte)

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 2021 is 257,308 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 368 summarizes the implied emission factors for organic forest soils.

Table 368: Implied emission factors (IEF) (carbon) for organic soils

Year	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
IEF [t CO_2 ha^{-1}]	10.629	10.629	10.628	10.629	10.629	10.629	10.630	10.630	10.630	10.630	10.630	10.618

6.4.2.6.2 Land converted to Forest Land

For Land converted to Forest Land, the organic soils area for the year 2021 is 20,772 ha (cf. Chapter 6.1.2.2.1). The emission factors presented in Table 368 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 369 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 369: Implied emission factors (IEF) (methane and nitrogen) for organic soils

Year	Methane [kg CH_4 ha-1]	Nitrogen [kg N_2O ha-1]
1990	3.2944	2.7750
1995	3.2952	2.7750
2000	3.2978	2.7749
2005	3.2904	2.7760
2010	3.2877	2.7767
2011	3.2864	2.7771
2012	3.2859	2.7774
2013	3.2829	2.7773
2014	3.2824	2.7768
2015	3.2795	2.7752
2016	3.2765	2.7760
2017	3.2744	2.7765
2018	3.2713	2.7768
2019	3.2675	2.7768
2020	3.2645	2.7765
2021	3.2661	2.7760

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).

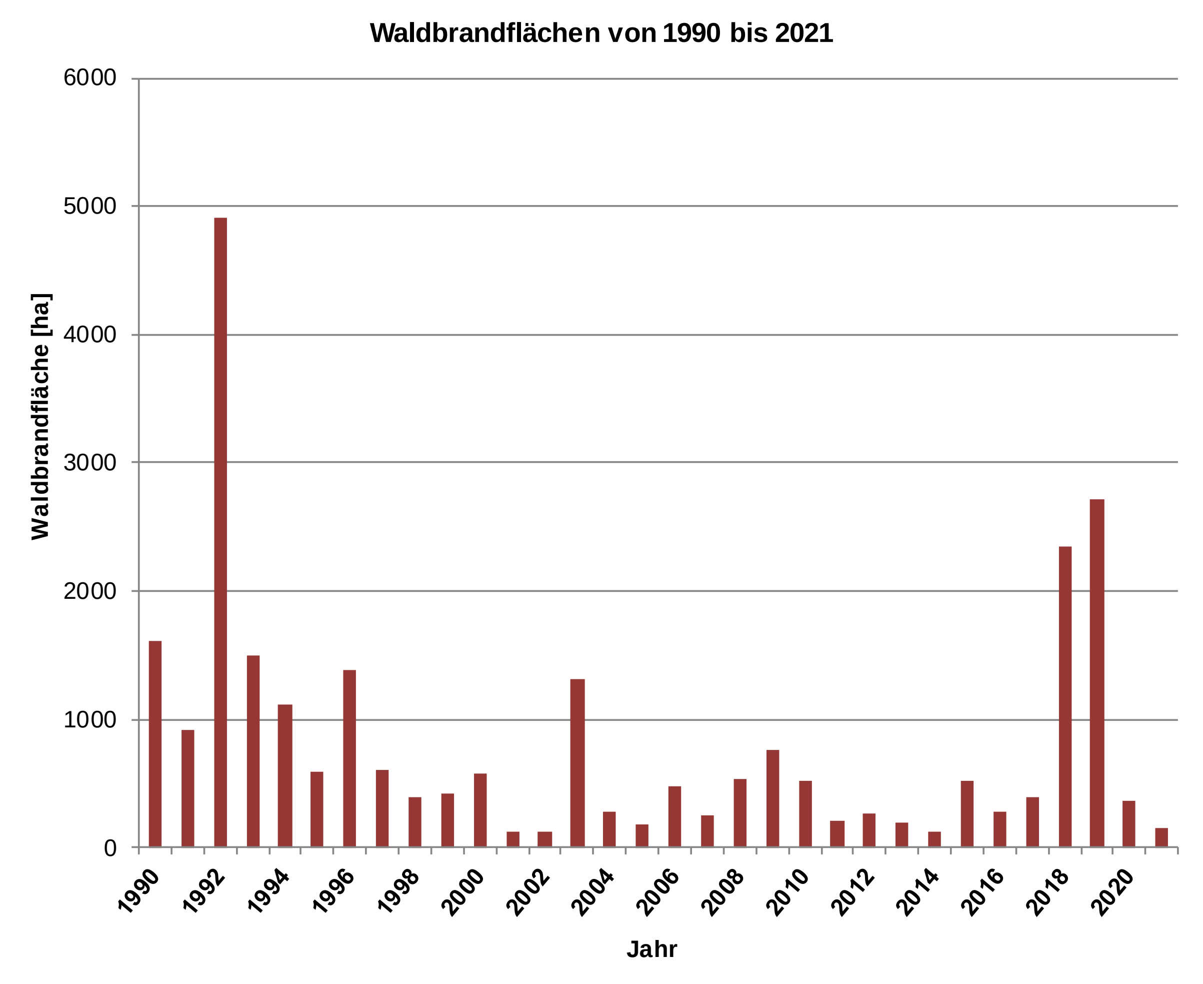
6.4.2.7.4 Indirect nitrous oxide emissions from cultivated soils (CRF Table 4(IV))

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 (2022b)) and their data on areas affected by wildfires (cf. Figure 71). The mean forest area affected annually by wildfires, in the period 1990 – 2021, was 817 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 71: Areas affected by wildfires between 1990 and 2021 (pursuant to BLE, 2022; areas in ha)



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 55 (Equation 2.27, IPCC (2006b)).

Equation 55:

$$L_{fire} = A * B * C * D * 10^{-6}$$

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 56:

$$M(C) = 0.45 * A * B * \alpha * \beta$$

0.45 = Average fraction of carbon in fuel wood

A *= Area burnt [m^2];*

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 2021 have been taken from the wildfire statistics maintained by the Federal Agency for Agriculture and Food (BLE; Waldbrandstatistik – BLE 2022). 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 the biomass and dead wood pools include the data for 1990 from the BWI 1987 and DSWF; the data for 2002 from the BWI 2002; the data for 2008 from the IS08; the data for 2012 from the BWI 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. The biomass of the litter pool was calculated from the data of the BZE I-Wald (1990) and BZE II-Wald (2006) inventories. In the procedure used, the annual biomass is obtained via linear interpolation between 1990 and 2006, and via extrapolation as of 2016.

Pursuant to the expert judgement carried out by H. C. 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, 2006b), 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, 2006b). 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 370.

Table 370: Greenhouse gases emitted via wildfires

Year	Above-ground biomass	Dead wood	Litter	Wildfire burned area	Emitted GHG [t]				
	[t ha^{-1}]			[ha]	CH_4	N_2O	CO	NO_X	NMVOC
1990	170.9	14.0	38.0	1,606	353.31	19.54	8,043.39	225.52	710.4
1991	171.0	13.7	38.0	920	202.18	11.18	4,602.83	129.05	406.5
1992	171.2	13.3	38.0	4,908	1,077.45	59.60	24,529.28	687.74	2,166.4
1993	171.4	12.9	37.9	1,493	327.41	18.11	7,453.88	208.99	658.3
1994	171.5	12.5	37.9	1,114	244.04	13.50	5,555.84	155.77	490.7
1995	171.7	12.1	37.9	592	129.55	7.17	2,949.36	82.69	260.5
1996	171.9	11.8	37.9	1,381	301.89	16.70	6,872.92	192.70	607.0
1997	172.0	11.4	37.8	599	130.81	7.24	2,977.93	83.49	263.0
1998	172.2	11.0	37.8	397	86.60	4.79	1,971.60	55.28	174.1
1999	172.4	10.6	37.8	415	90.43	5.00	2,058.81	57.72	181.8
2000	172.6	10.2	37.8	581	126.47	7.00	2,879.27	80.73	254.3
2001	172.7	9.9	37.7	122	26.53	1.47	603.96	16.93	53.3
2002	172.9	9.5	37.7	122	26.52	1.47	603.81	16.93	53.3
2003	173.6	9.1	37.7	1,315	286.09	15.83	6,513.03	182.61	575.2
2004	174.4	8.7	37.7	274	59.76	3.31	1,360.47	38.14	120.2
2005	175.1	8.3	37.6	183	40.01	2.21	910.97	25.54	80.5
2006	175.8	8.0	37.6	482	105.34	5.83	2,398.16	67.24	211.8
2007	176.6	7.6	37.6	256	55.93	3.09	1,273.33	35.70	112.5
2008	177.3	7.2	37.6	539	118.01	6.53	2,686.58	75.32	237.3
2009	179.3	6.8	37.5	757	167.04	9.24	3,802.89	106.62	335.9
2010	181.2	6.4	37.5	522	115.99	6.42	2,640.59	74.04	233.2
2011	183.2	6.1	37.5	214	47.89	2.65	1,090.30	30.57	96.3
2012	185.2	5.7	37.5	269	60.53	3.35	1,377.95	38.63	121.7
2013	187.2	5.9	37.4	199	45.19	2.50	1,028.88	28.85	90.9
2014	189.1	6.0	37.4	120	27.55	1.52	627.12	17.58	55.4
2015	191.1	6.2	37.4	526	121.74	6.73	2,771.48	77.70	244.8
2016	193.1	6.4	37.4	283	66.16	3.66	1,506.11	42.23	133.0
2017	194.4	6.6	37.3	395	92.86	5.14	2,114.11	59.27	186.7
2018	196.2	6.8	37.3	2,349	557.15	30.82	12,683.97	355.63	1,120.2
2019	198.1	7.0	37.3	2,711	648.42	35.87	14,761.88	413.88	1,303.7
2020	199.9	7.2	37.3	368	88.66	4.90	2,018.52	56.59	178.3
2021	201.8	7.3	37.2	148	35.94	1.99	818.16	22.94	72.3

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 57).

Equation 57:

$$U = \frac{\sqrt{\sum_i (U_i x_i)^2}}{\sum_i x_i}$$

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 58).

Equation 58:

$$U = \sqrt{\sum_i (U_i)^2}$$

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 371: 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	Softwoo d$_{Foliage}$	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	Softwoo d$_{Foliage}$	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 372: 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	Softwoo d$_{Foliage}$	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
Afforestation (AR), 2002 – 2008	Error % (biomass conversion)						Error % (C)	SE %	RMSE%
Germany	Spruce	Pine	Beech	Oak	Softwoo d$_{Foliage}$	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 (AR), 2008 – 2012	Error % (biomass conversion)						Error % (C)	SE %	RMSE%
Germany	Spruce	Pine	Beech	Oak	Softwoo d$_{Foliage}$	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 (AR), 2012 – 2017	Error % (biomass conversion)						Error % (C)	SE %	RMSE%
Germany	Spruce	Pine	Beech	Oak	Softwoo d$_{Foliage}$	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 373: 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	Softwoo d$_{Foliage}$	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	Softwoo d$_{Foliage}$	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
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
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 374: 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
Afforestation (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
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 conversion category 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 Forest Soil Inventory I and Forest Soil Inventory II (BZE I-Wald and BZE II-Wald) 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 the 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 BZE II-Wald, the repeatability standard deviation was determined as the mean within-laboratory standard deviation (DIN ISO 5725 2) of several carbon measurements, 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 Forest Soil Inventory I (BZE I-Wald), the values provided by Wolff and Riek (1997) were used, including coefficients of variation ranging from 5 to 20 % for carbon measurements in mineral soils and from 5 to 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-Wald, 0.058 t C ha^{-1} a^{-1}; for such analysis at the time of the BZE II-Wald, 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, the emissions were calculated a) either with the same method or with methods that yield the same results within an overlap range (overlap method); and b) either with the same data sources or with mutually consistent data sources;
- 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 QA / QC 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 every case, a distinction is made between Forest Land remaining Forest Land, afforestation, and deforestation, and calculations are carried out separately for each area. 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 (BMELV, 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 (N. 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).

[114] Cf. also: https://bundeswaldinventur.de/ and https://bwi.info/

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 particular, the methods and procedures used to deal with conversion time (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 375: Carbon-stock changes in living biomass, in forests of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	0.68	2.08	2.15	2.10	1.88	1.64	NO
Denmark	0.15	2.67	2.64	2.96	3.29	NA	NO,NA
France	0.31	1.04	1.18	1.03	1.02	1.01	0.88
UK	0.79	0.85	0.89	0.85	NO	0.85	NO
Netherlands	1.26	3.51	3.77	3.32	3.79	3.88	3.78
Austria	0.23	1.19	1.19	1.19	1.22	1.22	1.17
Poland	0.40	0.87	0.57	1.89	NO	NO	NO
Switzerland	0.55	0.60	0.51	0.59	0.44	0.87	0.67
Czech Republic	2.17	2.42	2.42	2.42	2.42	2.42	NO
Germany, 2020	**0.75**	**-0.51**	**1.03**	**-0.71**	**0.43**	**-0.04**	**1.04**
Germany, 2021	**0.75**	**-0.58**	**1.03**	**-0.72**	**-0.17**	**-0.32**	**0.17**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

Table 376: Carbon-stock changes in dead wood, in forests of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	0.06	0.05	0.06	0.03	0.05	NO
Denmark	0.07	0.01	0.01	0.01	0.01	NA	NO,NA
France	-0.02	0.05	0.09	0.04	0.16	0.06	0.23
UK	0.30	0.03	0.03	0.03	NO	0.03	NO
Netherlands	0.13	NE	NE	NE	NE	NE	NE
Austria	0.01	0.02	0.02	0.02	0.02	0.02	0.02
Poland	0.14	NO,NA	NA	NA	NO	NO	NO
Switzerland	0.01	0.15	0.14	0.14	0.34	0.26	0.19
Czech Republic	0.15	0.04	0.04	0.04	0.04	0.04	NO
Germany, 2020	**0.09**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**
Germany, 2021	**0.95**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

Table 377: Carbon-stock changes in litter, in forests of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	0.23	0.21	0.23	0.13	0.20	NO
Denmark	0.36	0.31	0.31	0.34	0.37	NA	NO,NA
France	NA	0.27	0.43	0.25	0.35	0.27	0.29
UK	0.04	0.03	0.03	0.03	NO	0.03	NO
Netherlands	0.14	NE	NE	NE	NE	NE	NE
Austria	NE,IE	1.21	1.40	1.24	0.78	1.20	1.21
Poland	NO	NO,NA	NA	NA	NO	NO	NO
Switzerland	-0.07	0.68	0.46	0.69	0.66	0.44	0.67
Czech Republic	0.41	0.33	0.33	0.33	0.33	0.33	NO
Germany, 2020	**-0.01**	**0.47**	**0.47**	**0.47**	**0.47**	**0.47**	**0.47**
Germany, 2021	**-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, 2021)

Table 378: Carbon-stock changes in mineral soils of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	1.19	2.44	0.98	-0.18	1.94	NO
Denmark	NO,NA	0.16	0.17	NA	NA	NA	NO,NA
France	NA	0.07	1.06	-0.06	NO	0.44	NA
UK	0.39	-0.83	-0.84	-0.83	NO	-0.80	NO
Netherlands	NA	0.01	0.49	-0.29	0.06	0.33	2.13
Austria	-0.18	0.71	1.21	-0.90	NO	2.64	2.89
Poland	0.09	0.25	0.36	-0.21	NO	NO	NO
Switzerland	0.00	1.19	0.42	1.08	1.58	2.14	4.29
Czech Republic	0.03	0.27	0.29	0.16	NO	0.32	NO
Germany, 2020	**0.41**	**0.21**	**0.31**	**0.12**	**-0.36**	**1.59**	**0.73**
Germany, 2021	**0.34**	**0.48**	**1.14**	**0.35**	**-0.18**	**1.20**	**3.63**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

Table 379: Carbon-stock changes in organic soils of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	NA	NO,NA
France	NO	NO	NO	NO	NO	NO	NO
UK	0.00	-2.07	-2.05	-2.08	NO	-2.07	NO
Netherlands	-0.92	-0.94	-0.82	-0.95	-1.05	-0.89	-0.71
Austria	NO	NO	NO	NO	NO	NO	NO
Poland	-0.68	-0.74	-0.82	-0.74	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, 2020	**-2.65**	**-2.66**	**-2.68**	**-2.65**	**-2.66**	**-2.68**	**-2.49**
Germany, 2021	**-2.90**	**-2.89**	**-2.88**	**-2.89**	**-2.90**	**-2.70**	**-2.49**

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

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).
- As of the present submission, the biomass of the dead wood and litter pools are taken into account in combustion related to forest fires (cf. Chapter 6.4.2.7.5).
- For the mineral soils pool on Forest Land, the “stock-difference” method was used. In addition, modelling with YASSO was carried out, and the “overlap method” was used (cf. Chapter 6.4.2.5ff).

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 380.

Table 381 shows the emissions as given in the present submission and the last submission, broken down by greenhouse gases, and including the resulting differences.

The reason why the method for the mineral soils pool had to be changed is that with the “stock-difference” method, which has been used until now, the data are from the years 1990 and 2006, and results have to be extrapolated as of 2006. Extrapolation over such a long period of time is not in keeping with the IPCC Guidelines. For this reason, a change of method – to modelling with Yasso – has been made for the period as of 2009. The two methods overlap in the period from 2009 through 2014; in this period, the values yielded by the two methods are nearly identical. This approach is in conformance with the IPCC Guidelines; it is in keeping with the “overlap method” they describe. A comparison of the pertinent emissions is provided in Table 382.

The emissions changes for forest fires (wildfires) are shown in Table 383.

Table 380: Comparison of the land-use matrix as reported in the 2022 submission and as reported in the 2023 submission

CRF No.	Area [kha]	Submission	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
4.A	Forest land	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	11,018.31
		2023	10,805.67	10,859.15	10,912.41	10,918.46	10,939.93	10,952.55	10,960.91	10,969.23	10,977.55	10,985.85	10,994.15
		Difference	-32.74	-30.96	-29.38	-26.57	-24.99	-24.00	-23.99	-24.02	-24.06	-24.10	-24.16
		in %	-0.3%	-0.3%	-0.3%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%	-0.2%

Table 381: Comparison of emissions, as reported in the 2022 and 2023 submissions, for the gases CO_2, methane and nitrous oxide (in [kt CO2-eq. with GWP pursuant to IPCC AR5])

CRF No. 4.A Forest Land				
CO_2	**2022 Submission**	**2023 Submission**	**Difference**	**in %**
1990	-19,707.07	-18,696.50	1,010.57	-5%
1995	-71,100.39	-70,131.15	969.24	-1%
2000	-51,620.53	-50,666.09	954.44	-2%
2005	-34,757.61	-33,742.36	1,015.25	-3%
2010	-51,058.87	-47,601.17	3,457.70	-7%
2015	-61,754.28	-58,639.37	3,114.90	-5%
2016	-64,173.78	-60,638.79	3,534.99	-6%
2017	-63,163.65	-56,355.49	6,808.16	-11%
2018	-56,103.53	-48,420.84	7,682.69	-14%
2019	-52,777.52	-49,514.44	3,263.08	-6%
2020	-46,252.00	-39,243.83	7,008.17	-15%
CH_4	**2022 Submission**	**2023 Submission**	**Difference**	**in %**
1990	44.21	34.39	-9.8	-22%
1995	39.62	28.22	-11.4	-29%
2000	39.82	28.23	-11.6	-29%
2005	37.71	25.66	-12.0	-32%
2010	39.84	28.16	-11.7	-29%
2015	39.84	28.55	-11.3	-28%
2016	38.33	27.12	-11.2	-29%
2017	38.67	27.94	-10.7	-28%
2018	38.37	41.02	2.7	7%
2019	38.02	43.69	5.7	15%
2020	40.24	28.09	-12.2	-30%
N_2O	**2022 Submission**	**2023 Submission**	**Difference**	**in %**
1990	413.55	461.78	48.2	12%
1995	396.04	455.62	59.6	15%
2000	379.91	452.78	72.9	19%
2005	353.41	432.55	79.1	22%
2010	352.20	518.50	166.3	47%
2015	339.50	457.41	117.9	35%
2016	337.83	452.94	115.1	34%
2017	337.10	449.90	112.8	33%
2018	341.59	453.96	112.4	33%
2019	341.61	438.65	97.0	28%
2020	333.83	439.75	105.9	32%

Table 382: Comparison of emissions, as reported in the 2022 and 2023 submissions, for the mineral soils pool (in [kt CO_2-eq])

	4.A.1 Forest Land remaining Forest Land Submission				4.A.2 Land converted to Forest Land Submission			
Year	2022	2023	Difference	in %	2022	2023	Difference	in %
1990	-15,549.64	-14,411.02	1,138.61	-7%	705.20	66.42	-638.79	-91%
1995	-15,625.03	-14,483.72	1,141.31	-7%	607.54	14.22	-593.32	-98%
2000	-15,700.44	-14,556.40	1,144.04	-7%	491.85	-34.55	-526.40	-107%
2005	-15,731.38	-14,591.65	1,139.73	-7%	297.97	-90.37	-388.34	-130%
2010	-15,779.90	-12,422.55	3,357.35	-21%	94.69	-155.26	-249.95	-264%
2015	-15,836.53	-12,849.23	2,987.30	-19%	-14.04	-197.23	-183.19	1305%
2016	-15,845.80	-12,413.56	3,432.24	-22%	-38.29	-215.49	-177.20	463%
2017	-15,855.06	-9,192.16	6,662.90	-42%	-62.29	-232.49	-170.20	273%
2018	-15,864.33	-8,304.57	7,559.76	-48%	-86.67	-249.50	-162.84	188%
2019	-15,873.61	-12,778.65	3,094.97	-19%	-111.01	-265.24	-154.22	139%
2020	-15,882.89	-9,055.83	6,827.06	-43%	-135.09	-280.85	-145.76	108%

Table 383: Comparison of emissions (methane and nitrous oxide), as reported in the 2022 and 2023 submissions, for wildfires (in [kt CO_2-eq. pursuant to IPCC AR5])

Wildfires	4.A.1 Forest Land remaining Forest Land Submission			
Year	2022	2023	Difference	in %
1990	11.55	15.07	3.52	30.5%
1995	4.28	5.53	1.25	29.1%
2000	4.22	5.40	1.17	27.8%
2005	1.35	1.71	0.35	26.3%
2010	3.98	4.95	0.97	24.2%
2015	4.23	5.19	0.96	22.8%
2016	2.30	2.82	0.52	22.7%
2017	3.23	3.96	0.73	22.6%
2018	19.41	23.77	4.36	22.5%
2019	22.61	27.66	5.05	22.3%
2020	3.10	3.78	0.69	22.2%

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**4 B, Cropland**		**CO_2**	14,722.3	1.2 %	15,556.9	2.0 %	5.7 %
-/-	4 B, Cropland		CH_4	109.5	0.0 %	95.0	0.0 %	-13.2 %
-/-/2	**4 B, Cropland**		**N_2O**	**208.3**	**0.0 %**	**396.8**	**0.1 %**	**90.5 %**

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 345). A stratified, itemized list of the emissions-calculations results for these sub-categories is provided 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 method 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, 2006b), 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 (Bundesanzeiger Verlag, 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 384 and in CRF tables 4, 4.B, 4(II).B, 4(III).B and 4(IV).2. The total emissions from Cropland in 2021 in Germany amounted to 16,049 kt CO_2 equivalents pursuant to IPCC AR5. The main emissions sources are soils, especially organic soils under cultivation (72.7 %). Mineral soils contributed 20.3 % 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 (7.0 %). The sub-categories Orchards and Tree nurseries were slight sinks in 2021. 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 (1.6%) of the total emissions from Cropland than annual crops (98.0 %) do. In 2021, the sub-category Tree nurseries was a slight net sink; all other sub-categories of Cropland functioned as net sources (Table 384).

The predominating greenhouse gas in the Cropland sector is CO_2, accounting for 15,556.89 Gg CO_2 equivalents (96.7 %). 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 (total of 396.8 kt CO_2-eq. pursuant to IPCC AR5 ≙ 2.8 %, consisting of direct (323.9 kt CO_2-eq. pursuant to IPCC AR5 (CRF 4(III)) and indirect emissions (72.9 kt CO_2-eq. pursuant to IPCC AR5 (CRF 4(IV)); this also applies to methane emissions (95.0 kt CO_2-eq. pursuant to IPCC AR5 ≙ 0.5 % (CRF 4(II).B)) from use of organic soils).

Table 384: CO_2, N_2O and CH_4 emissions [kt CO_2-eq. pursuant to IPCC AR5] from Cropland, 2021. The table includes both the relevant sums and the upper and lower bounds of the 95 % confidence interval.

Source category	GHG	Cropland, emissions, 2021 [kt CO_2-eq.] Emission	2.5 perc.	97.5 perc.	[%] 2.5 perc.	97.5 perc.
Cropland$_{annual}$ 1)	∑	**15,730.2**	12,388.8	18,771.4	21.24	19.33
Mineral soils	CO_2 2)	**2,759.0**	2,702.9	3,130.5	2.04	13.46
	$N_2O_{indirect}$ 4)	**71.8**	-2.0	256.4	102.73	257.18
	N_2O_{direct} 3)	**319.0**	118.9	892.3	62.73	179.68
Organic soil	CO_2 2)	**11,490.1**	7,821.1	13,160.5	31.93	14.54
	N_2O 5)	**IE**	IE	IE	IE	IE
	CH_4 6)	**93.8**	56.4	153.6	39.87	63.75
Biomass	CO_2 2)	**996.2**	638.4	1,359.8	35.92	36.50
Litter / dead wood	CO_2 2)	**0.2**	0.0	0.5	103.07	103.07
		Hops, emissions, 2021				
Source category	**GHG**	**[kt CO_2-eq.]**			**[%]**	
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Hops 1)	∑	**10.70**	6.03	15.36	43.65	43.47
Mineral soils	CO_2 2)	**-0.92**	-0.75	-1.11	18.42	20.29
	$N_2O_{indirect}$ 4)	**0.02**	0.01	0.06	75.01	173.55
	N_2O_{direct} 3)	**0.09**	0.05	0.21	52.14	123.48
Organic soil	CO_2 2)	**6.77**	0.10	13.19	98.48	94.95
	N_2O 5)	**IE**	IE	IE	IE	IE
	CH_4 6)	**0.07**	0.00	0.15	101.60	112.50
Biomass	CO_2 2)	**4.67**	2.99	6.37	35.92	36.50
Litter / dead wood	CO_2 2)	**0.00**	0.00	0.00	0.00	0.00
		Vineyards, emissions, 2021				
Source category	**GHG**	**[kt CO_2-eq.]**			**[%]**	
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Vineyards 1)	∑	**25.7**	21.13	30.72	18.16	18.98
Mineral soils	CO_2 2)	**13.5**	12.02	15.22	11.05	12.62
	$N_2O_{indirect}$ 4)	**0.1**	0.05	0.39	66.31	163.38
	N_2O_{direct} 3)	**0.7**	0.41	1.35	37.71	103.93
Organic soil	CO_2 2)	**0.22**	0.08	0.35	65.28	59.16
	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)	**11.17**	5.94	16.45	46.81	47.34
Litter / dead wood	CO_2 2)	**0.00**	0.00	0.00	0.00	0.00
		Orchards, emissions, 2021				
Source category	**GHG**	**[kt CO_2-eq.]**			**[%]**	
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Orchards 1)	∑	**25.07**	22.04	28.17	12.26	12.12
Mineral soils	CO_2 2)	**-20.28**	-19.15	-22.07	5.56	8.83
	$N_2O_{indirect}$ 4)	**0.1**	0.01	0.50	96.46	240.42
	N_2O_{direct} 3)	**0.7**	0.27	1.76	59.40	168.13
Organic soil	CO_2 2)	**50.73**	30.93	67.50	39.03	33.04
	N_2O 5)	**IE**	IE	IE	IE	IE
	CH_4 6)	**0.42**	0.23	0.67	45.77	60.58
Biomass	CO_2 2)	**-6.61**	-5.72	-7.51	13.43	13.54
Litter / dead wood	CO_2 2)	**0.00**	0.00	0.00	0.00	0.00

Tree nurseries, emissions, 2021						
Source category	GHG	[kt CO_2-eq.]			[%]	
		Emission	2.5 perc.	97.5 perc.	2.5 perc.	97.5 perc.
Tree nurseries[1)]	∑	**-13.43**	-11.84	-14.92	11.78	11.24
Mineral soils	CO_2 [2)]	**6.46**	5.99	7.10	7.26	9.94
	$N_2O_{indirect}$ [4)]	**0.05**	0.01	0.13	69.99	173.65
	N_2O_{direct} [3)]	**0.21**	0.12	0.47	42.98	121.53
Organic soil	CO_2 [2)]	**24.31**	16.67	28.65	31.43	17.86
	N_2O [5)]	**IE**	IE	IE	IE	IE
	CH_4 [6)]	**0.15**	0.09	0.24	40.42	60.25
Biomass	CO_2 [2)]	**-44.62**	-38.03	-51.21	14.77	14.77
Litter / dead wood	CO_2 [2)]	**0.00**	0.00	0.00	0.00	0.00
Christmas tree plantations, emissions, 2021						
Source category	**GHG**	**[kt CO_2-eq.]**			**[%]**	
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Christmas-tree plantations[1)]	∑	**176.75**	148.15	205.88	16.31	16.31
Mineral soils	CO_2 [2)]	**34.14**	31.78	37.33	6.90	9.36
	$N_2O_{indirect}$ [4)]	**0.45**	0.09	1.36	80.27	200.39
	N_2O_{direct} [3)]	**2.02**	1.02	4.84	49.27	140.08
Organic soil	CO_2 [2)]	**42.12**	28.38	49.43	32.61	17.35
	N_2O [5)]	**IE**	IE	IE	IE	IE
	CH_4 [6)]	**0.42**	0.25	0.66	40.81	57.71
Biomass	CO_2 [2)]	**97.61**	71.13	124.44	27.13	27.49
Litter / dead wood	CO_2 [2)]	**0.00**	0.00	0.00	0.00	1.00
Short-rotation plantations, emissions, 2021						
Source category	**GHG**	**[kt CO_2-eq.]**			**[%]**	
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
KUPs[1)]	∑	**93.70**	76.12	112.10	18.92	19.40
Mineral soils	CO_2 [2)]	**19.97**	17.92	22.70	10.26	13.64
	$N_2O_{indirect}$ [4)]	**0.29**	-0.02	1.06	107.60	268.56
	N_2O_{direct} [3)]	**1.27**	0.43	3.67	66.09	187.74
Organic soil	CO_2 [2)]	**2.78**	0.43	4.94	84.40	77.72
	N_2O [5)]	**IE**	IE	IE	IE	IE
	CH_4 [6)]	**0.08**	0.00	0.17	102.20	123.65
Biomass	CO_2 [2)]	**69.30**	53.32	85.60	23.06	23.52
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 72 and Figure 73 show the trends over time in emissions from Cropland. The total emissions in 2021 were 6.9 % lower than in the base year 1990. This general trend is due primarily to increases of emissions from mineral soils (64.2%), 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). The emissions resulting from land-use changes from Wetlands to Cropland (0.6 %) are low, absolutely. At the same time, they exhibit an increase of 1,582 %, with respect to 1990, which is tied mainly to the organic soils pool, followed by the biomass pool. In 2021, conversion of Settlement areas led to negative emissions of 218.33 kt CO_2-Eq. No consistent trend is apparent (Figure 72).

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, 2020 and 2021 (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 (2006b): 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 72: GHG emissions from Cropland (sum of CO_2, CH_4 and N_2O) [kt CO_2-eq. pursuant to IPCC AR5] as a result of land use and land-use changes, 1990-2021, by sub-categories (with uncertainties shown only for the total)

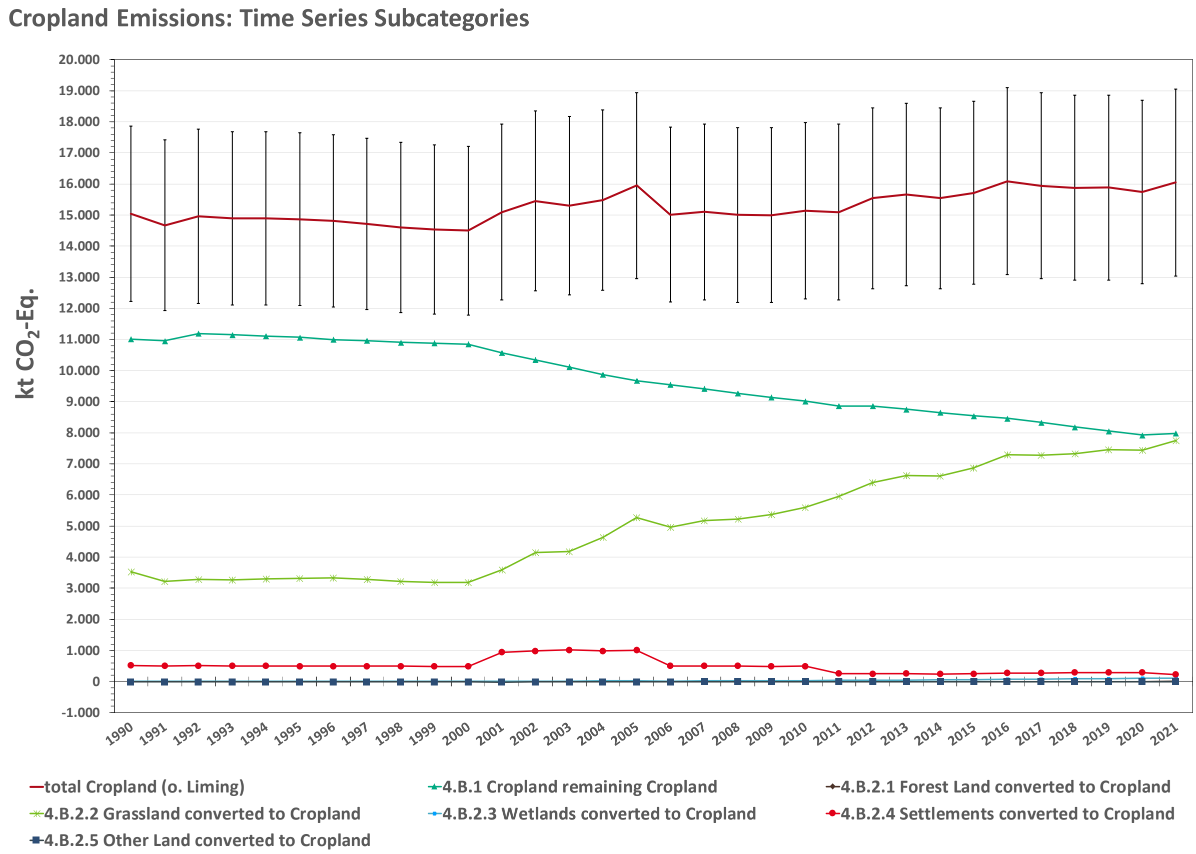
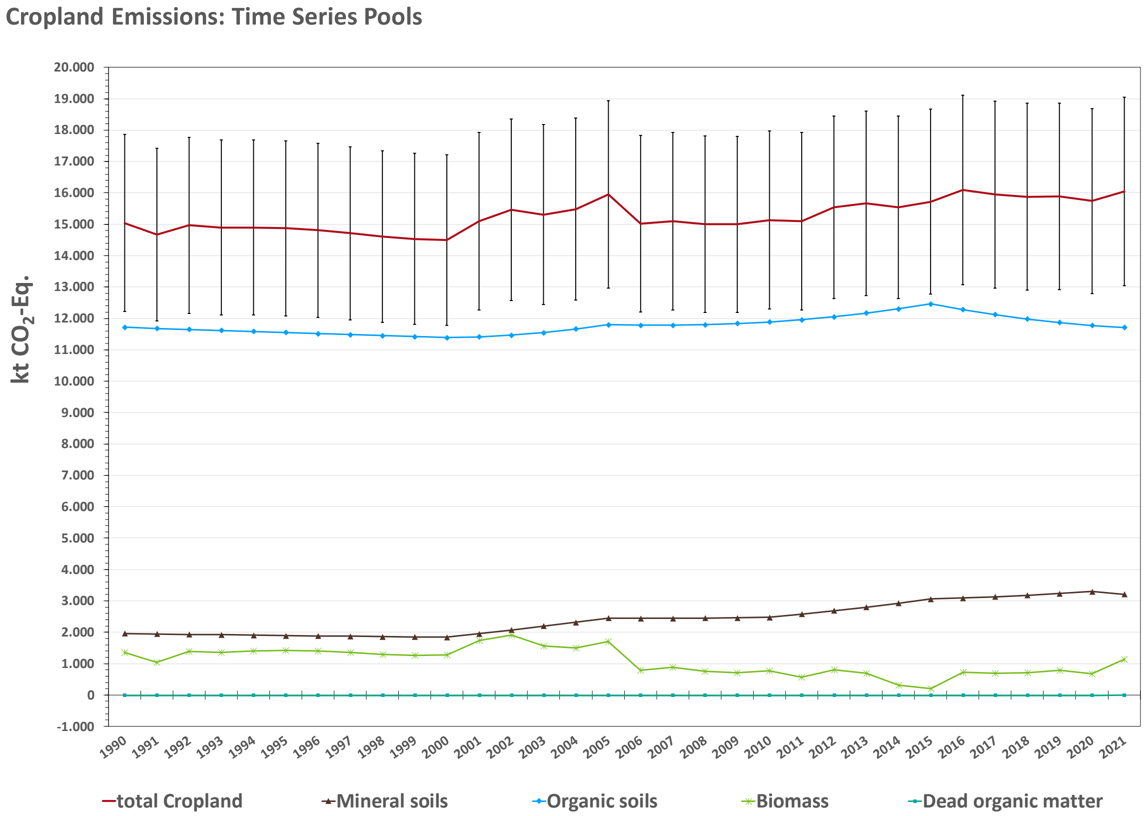


Figure 73: Greenhouse-gas emissions from Cropland, (sum of CO_2, CH_4 and N_2O) [kt CO_2-Eq. pursuant to IPCC AR5] as a result of land use and land-use changes, 1990-2021, by pools (with uncertainties shown only for the total)



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, 2006b)

- "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 the basic characteristics of the plants involved (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 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 ($Cropland_{annual}$) in Chapter 6.1.2.3.3,
- for Hops, in Chapter 6.1.2.3.5.6,
- for Orchards, in Chapter 6.1.2.3.5.1;
- 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 direct nitrous oxide emissions are shown in Table 342 (Chapter 6.1.2.7), while those for indirect N_2O emissions are shown in Table 343 (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 386 (Chapter 6.5.3). 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, 2006b), 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 Bayerisches Landesamt für Umwelt BLfU (2011)) 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 humus balancing" (VDLUFA-Humusbilanzierung) 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,
4. The estimation of carbon-stock changes in the remaining category $Cropland_{annual}$ using the Tier 1 method of the 2006 IPCC Guidelines.

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:

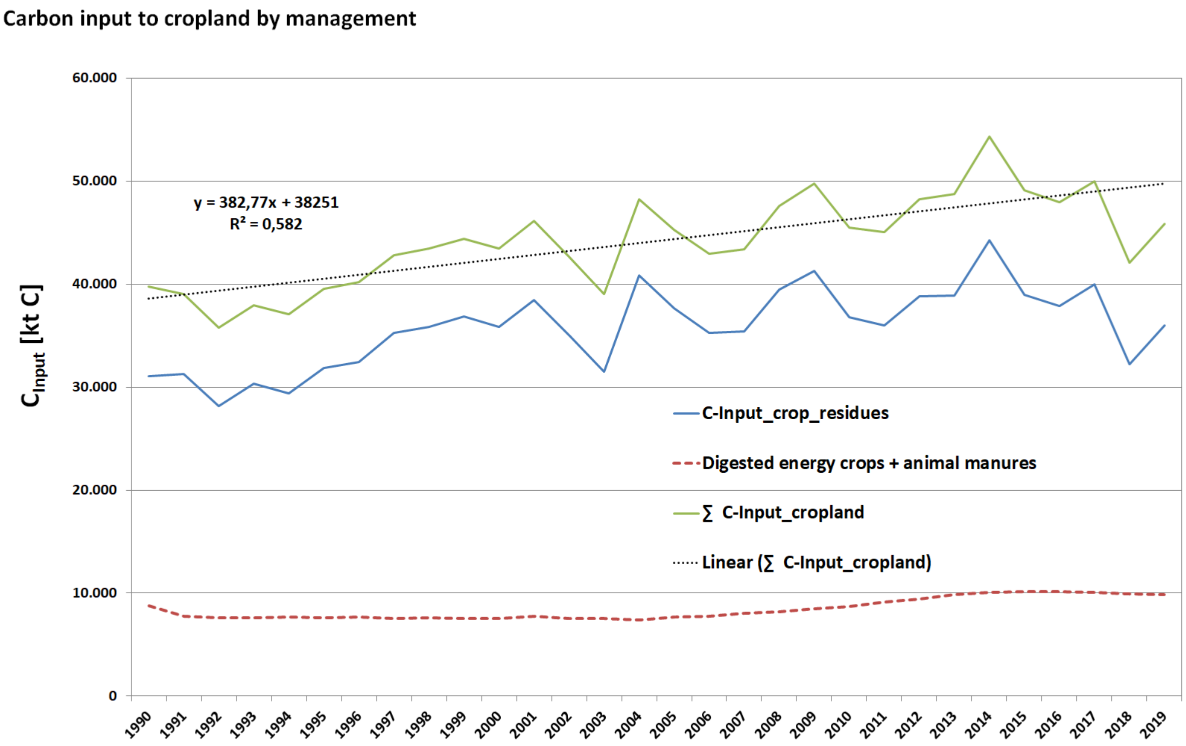
- The nationwide evaluation of the long-term soil monitoring sites, with respect to carbon-stock changes, has confirmed the findings drawn to date at the Länder level. The shares of sites at which no statistically proven changes have occurred clearly predominate. For example, 77 % of the cultivated mineral 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 74 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 74: 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.

Regarding 4.) At the ERT's recommendation, the emissions of the remaining category for annual cropland were estimated using the Tier 1 method of the 2006 IPCC Guidelines. This was to be followed by confirmation of the conservative nature of the assumption that the carbon balance of mineral soils under annual cropland is approximately in an equilibrium state.

For this reason, a conservative scenario for this assumption was chosen. In addition, the input factor (F_I high) was excluded from the outset, even though the relevant marginal data (some of which are given above) indicate that a probably not insignificant part of Germany's cropland area is subject to such inputs. The scenario was also based on the following:

- The results of the Agricultural Soil Inventory (BZE-LW) with regard to the current state of the carbon stocks of Germany's mineral soils (JACOBS et al. 2018), for determination of the land-use factor (FLU).
- Data from official statistics, for determination of the management factor (FM) for cropland cultivation (full tillage, 57 %; reduced, 42 %; direct seed, 1 %)
- The results of long-term soil monitoring (see above: SOC decrease on 13 % of the cropland area; an increase to 10 % and 77 % remain unchanged (MARX et al., 2016)).

Table 385 shows the results of this estimation. Even when the a priori conservative assumptions are applied, the estimation using the Tier 1 method of the 2006 IPCC Guidelines shows an increase in soil carbon stocks in the remaining category for Germany's mineral cropland soils. This result supports the thesis that the following assumption is a conservative one: that the carbon stocks of mineral soils under cropland on which annual crops have been cultivated for many years are approximately in equilibrium.

Table 385: Calculation steps, and results of use of the Tier 1 method of the 2006 IPCC Guidelines on the remaining category of Germany's cropland soils (*Cropland*$_{annual}$)

Management factor (F_{MG})					
	Share in Cropland Area	SOC - Stock		SOC - Stock Change	
	[%]	IPCC default	[kt C]	[kt C 20 a^{-1}]	[kt C a^{-1}]
SOC - Stock 2020			660,184		
full tillage	57	1	376,305		
reduced	42	1.08	299,459		
direct seed	1	1.15	7,592		
∑			683,356	23,172	1,159
Input factor (F_I)					
	Share in Cropland Area	SOC - Stock		SOC - Stock Change	
	[%]	IPCC default	[kt C]	[kt C 20 a^{-1}]	[kt C a^{-1}]
low input	13	0.92	78,958		
medium	77	1	508,341		
high	10	1.1	72,620		
∑			659,919	-264	-13
SOC - Stock Difference (∑ - SOC - Stock 2020)				22,908	1,145.4

In the remaining category for Cropland, carbon-stock changes in mineral soils are registered nonetheless. Such changes are due to "usage transitions" between the different 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).

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 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, 2006b). Additional relevant information is provided in Chapter 6.1.2.1. Table 386 through Table 393 show the uncertainties in the emission factors for the Cropland category, by pools and sub-categories.

The tables highlight the fact that the EF for mineral soils and biomass mainly have standard normal distributions and near-normal distributions. The majority of the uncertainties in connection with soils exhibit a log-normal distribution, while the CO^2 emissions from organic soils exhibit a triangular distribution. 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 the framework of Gaussian calculation of uncertainties propagation, a few uncertainties > 100 % were calculated for the lower bound of the 95 % confidence interval. While the calculation method used conforms to the rules, it is not effective in the present context, in which certain processes cannot lead to removals. This is the case, for example, for direct/indirect N_2O emissions from mineral soils as a result of decomposition of organic soil substance. 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 0.05 – 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 0.05 % [half of the 95% confidence interval].

The total uncertainty for the land-use category Cropland, for the year 2021, is 20.47 % [2.5 % percentile] and 18.63 % [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).

The following tables show the implied emission factors [t C ha^{-1} a^{-1}] for calculation of GHG emissions from Germany's cropland sub-categories, 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 2021.

Table 386: Implied emission factors [t C ha^{-1} a^{-1}] and their uncertainties from annual cropland

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$_{annual}$	-1.9606	99.9	113.86
Hops		-0.1609	5.75	14.2
Vineyards		0.2466	17.96	17.96
Orchards		-0.6737	11.43	11.43
Short-rotation plantations		-0.2550	22.40	25.89
Tree nurseries		-0.0578	10.27	16.56
Christmas tree plantations		0.0401	12.54	18.05
Grassland (in the strict sense)		-0.6833	2.21	14.84
Woody Grassland		-0.7986	4.58	15.37
Hedges		-0.7973	9.52	17.49
Terr. Wetlands		-1.2640	40.10	41.21
Waters		0.0000	3.27	26.01
Settlements		0.2090	3.88	12.88
Other Land		1.9424	48.33	52.33
Mineral soil, N_2O_{direct} [2)]		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Cropland$_{annual}$	5.0000	99.9	230.14
Grassland (in the strict sense)		1.0862	70.05	200.66
Woody Grassland		1.2017	70.16	200.70
Hedges		1.1195	70.65	200.87
Terr. Wetlands		1.8078	82.25	204.83
Mineral soil, $N_2O_{indirect}$ [2)]		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Cropland$_{annual}$	1.0943	99.9	308.52
Grassland (in the strict sense)		0.2444	99.9	287.20
Woody Grassland		0.2704	99.9	287.23
Hedges		0.2519	99.9	287.35
Terr. Wetlands		0.4068	99.9	290.13

Cropland$_{annual}$		Implied emission factor	Uncertainty bounds	
Initial land use	Final land use		lower	upper
Biomass [3]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Cropland$_{annual}$	-35.6849	99.9	115.57
Hops		0.0396	10.08	10.08
Vineyards		-0.0248	19.31	19.31
Orchards		-0.2526	12.88	12.88
Short-rotation plantations		-1.7918	22.84	23.61
Tree nurseries		-0.3370	21.57	21.57
Christmas tree plantations		-1.0421	28.76	28.76
Grassland (in the strict sense)		0.0026	16.28	16.28
Woody Grassland		-3.7841	51.75	52.55
Hedges		-53.1307	52.39	53.19
Terr. Wetlands		-0.9820	49.14	50.25
Waters		0.0000	12.08	12.08
Peat extraction		0.0154	19.77	19.77
Settlements		-0.8869	45.90	47.36
Other Land		0.0086	42.62	42.62
Dead organic matter [3]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Cropland$_{annual}$	-20.6215	99.9	103.70

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 387: Implied emission factors [t C ha^{-1} a^{-1}] and their uncertainties from hops cultivation

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	7.78	7.78
Cropland$_{annual}$		0.1164	12.01	17.69
Vineyards		0.6795	99.9	196.23
Orchards		-0.4121	74.56	74.56
Short-rotation plantations		0.0000	7.84	7.84
Tree nurseries		0.0000	99.9	196.16
Christmas tree plantations		0.0053	99.9	196.16
Grassland (in the strict sense)		-0.5864	33.98	35.31
Woody Grassland		-0.7440	99.9	113.68
Hedges		0.0000	4.97	10.81
Terr. Wetlands		0.0000	9.33	9.33
Waters		0.0000	11.09	11.09
Settlements		0.4687	99.9	138.70
Other Land		0.0000	16.52	16.52
Mineral soil, N_2O_{direct} [2]		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Hops	0.0000	70.29	200.40
Grassland (in the strict sense)		0.7493	77.69	203.45
Woody Grassland		0.9317	99.9	230.37
Hedges		0.0000	70.04	200.66
Terr. Wetlands		0.0000	72.30	201.04

Hops Initial land use	Final land use	Implied emission factor	Uncertainty bounds lower	upper
Mineral soil, $N_2O_{indirect}$ 2)		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	**Hops**	0.0000	99.9	287.02
Grassland (in the strict sense)		0.1686	99.9	289.16
Woody Grassland		0.2096	99.9	308.69
Hedges		0.0000	70.04	200.66
Terr. Wetlands		0.0000	99.9	287.47
Biomass 3)		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	**Hops**	0.0000	23.47	23.47
$Cropland_{annual}$		-0.1264	14.49	14.49
Vineyards		0.0000	99.9	196.44
Orchards		-2.0305	75.08	75.08
Short-rotation plantations		0.0000	7.77	9.83
Tree nurseries		0.0000	99.9	197.06
Christmas tree plantations		0.0000	99.9	197.94
Grassland (in the strict sense)		-0.2282	37.40	37.40
Woody Grassland		-3.5332	99.9	124.94
Hedges		0.0000	43.20	19.64
Terr. Wetlands		0.0000	42.49	43.84
Waters		0.0000	16.54	16.54
Peat extraction		0.0000	16.54	16.54
Settlements		-4.3689	99.9	146.71
Other Land		0.0000	16.54	16.54
Dead organic matter 3)		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	**Hops**	0.0000	0.00	0.00

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 388: Implied emission factors [t C ha-1 a-1] and their uncertainties from vineyards

Vineyards Initial land use	Final land use	Implied emission factor	Uncertainty bounds lower	upper
Mineral soil, CO_2-C 1)		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	**Vineyards**	0.0000	8.99	8.99
$Cropland_{annual}$		-0.2909	14.63	20.63
Hops		-0.7374	74.68	74.68
Orchards		-1.0647	31.16	31.16
Short-rotation plantations		0.0000	9.41	9.41
Tree nurseries		-0.6795	99.9	113.55
Christmas tree plantations		-0.6726	99.9	138.91
Grassland (in the strict sense)		-0.9889	18.78	21.56
Woody Grassland		-0.8548	31.60	33.32
		0.0000	6.16	12.24
Terr. Wetlands		-1.2246	99.9	196.28
Waters		0.0000	16.07	16.07
Settlements		0.2770	51.05	51.05
Other Land		0.0000	20.61	20.61

Vineyards		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}]**	**[%]**	**[%]**
Forest Land	**Vineyards**	0.0000	70.29	200.40
Grassland (in the strict sense)		1.1030	72.25	201.44
Woody Grassland		0.9456	76.59	203.04
Hedges		0.0000	70.04	200.66
Terr. Wetlands		0.8750	99.9	280.77
Mineral soil, $N_2O_{indirect}$ 2)		**[kg N_2O ha^{-1} a^{-1}]**	**[%]**	[%]
Forest Land	**Vineyards**	0.0000	99.9	287.02
Grassland (in the strict sense)		0.2482	99.9	287.75
Woody Grassland		0.2128	99.9	288.87
Hedges		0.0000	99.9	287.20
Terr. Wetlands		0.1969	99.9	347.93
Biomass 3)		**[t C ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	**Vineyards**	0.0000	22.91	22.91
$Cropland_{annual}$		0.0280	17.32	17.32
Hops		-0.0757	75.24	75.24
Orchards		-0.5242	31.83	31.83
Short-rotation plantations		0.0000	7.66	9.66
Tree nurseries		0.1200	99.9	114.81
Christmas tree plantations		0.1486	99.9	140.97
Grassland (in the strict sense)		0.0176	24.65	24.65
Woody Grassland		-4.1529	59.62	60.30
		0.0000	50.94	51.73
Terr. Wetlands		0.1632	99.9	200.35
Waters		0.0000	18.95	18.95
Peat extraction		0.0000	18.95	18.95
Settlements		-1.5096	67.58	68.53
Other Land		0.0000	18.95	18.95
Dead organic matter 3)		**[t C ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	**Vineyards**	0.0000	0.00	0.00

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 389: Implied emission factors [t C ha^{-1} a^{-1}] and their uncertainties from Orchards

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	8.17	8.17
Cropland$_{annual}$		0.4492	18.48	30.52
Hops		0.3885	99.9	113.48
Vineyards		0.9546	45.49	45.49
Short-rotation plantations		0.3822	57.21	57.21
Tree nurseries		0.4205	29.53	29.53
Christmas tree plantations		0.3950	25.92	25.92
Grassland (in the strict sense)		-0.4637	13.21	16.02
Woody Grassland		-0.2564	31.18	32.47
		-0.6122	99.9	139.02
Terr. Wetlands		-1.8440	99.9	196.23
Waters		0.0000	12.54	12.54
Settlements		1.0757	34.22	34.22
Other Land		0.0000	16.18	16.18
Mineral soil, N_2O_{direct} [2]		**[kg N_2O ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	**Orchards**	0.0000	70.29	200.40
Grassland (in the strict sense)		0.5894	71.03	201.00
Woody Grassland		0.2100	76.44	202.98
		0.1470	99.9	243.87
Terr. Wetlands		1.3604	99.9	280.77
Mineral soil, $N_2O_{indirect}$ [2]		**[kg N_2O ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	**Orchards**	0.0000	99.9	287.02
Grassland (in the strict sense)		0.1326	99.9	287.45
Woody Grassland		0.0473	99.9	288.83
		0.0331	99.9	318.89
Terr. Wetlands		0.3061	99.9	347.93
Biomass [3]		**[t C ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	**Orchards**	0.0000	17.68	17.68
Cropland$_{annual}$		0.4912	13.25	13.25
Hops		0.6881	99.9	113.82
Vineyards		0.6406	45.95	45.95
Short-rotation plantations		-4.1578	57.03	57.26
Tree nurseries		-0.5804	31.88	31.88
Christmas tree plantations		-0.7985	29.78	29.78
Grassland (in the strict sense)		0.4452	17.48	17.48
Woody Grassland		-7.1716	53.55	54.13
		-26.4244	99.9	145.76
Terr. Wetlands		-9.8175	99.9	198.48
Waters		0.0000	14.41	14.41
Peat extraction		5.3809	99.9	139.34
Settlements		-1.3695	49.11	49.94
Other Land		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	0.00	0.00

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 390: Implied emission factors [t C ha^{-1} a^{-1}] and their uncertainties from tree nurseries

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	7.78	7.78
Cropland$_{annual}$		-0.1157	7.76	15.13
Hops		0.0000	7.84	7.84
Vineyards		0.5982	88.16	88.16
Orchards		-0.3712	30.27	30.27
Short-rotation plantations		0.0000	7.84	7.84
Christmas tree plantations		0.0000	7.84	7.84
Grassland (in the strict sense)		-0.9584	14.52	17.41
Woody Grassland		0.0000	4.97	10.81
Hedges		-1.6948	99.9	196.30
Terr. Wetlands		-2.3085	99.9	196.22
Waters		0.0000	11.09	11.09
Settlements		0.5116	23.48	23.48
Other Land		0.0000	16.52	16.52
Mineral soil, N_2O_{direct} [2]		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Tree nurseries	0.0000	70.29	200.40
Grassland (in the strict sense)		0.8422	71.36	201.12
Woody Grassland		0.0000	70.04	200.66
Hedges		1.0429	99.9	280.50
Terr. Wetlands		1.9170	99.9	280.77
Mineral soil, $N_2O_{indirect}$ [2]		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Tree nurseries	0.0000	99.9	287.02
Grassland (in the strict sense)		0.1895	99.9	287.53
Woody Grassland		0.0000	99.9	287.20
Hedges		0.2347	99.9	347.71
Terr. Wetlands		0.4313	99.9	347.93
Biomass [3]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Tree nurseries	0.0000	18.15	18.15
Cropland$_{annual}$		1.1479	20.51	20.51
Hops		0.0000	20.45	20.45
Vineyards		1.7922	89.78	89.78
Orchards		-3.0235	32.69	32.69
Short-rotation plantations		0.0000	8.47	9.70
Christmas tree plantations		0.0000	19.47	19.47
Grassland (in the strict sense)		4.1842	24.33	24.33
Woody Grassland		0.0000	41.50	42.14
Hedges		-57.2581	99.9	200.48
Terr. Wetlands		3.2447	99.9	141.53
Waters		0.0000	23.39	23.39
Peat extraction		0.0000	23.39	23.39
Settlements		-0.6491	39.59	40.40
Other Land		0.0000	23.39	23.39
Dead organic matter [3]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Tree nurseries	0.0000	0.00	0.00

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 391 Implied emission factors [t C ha⁻¹ a⁻¹] and their uncertainties from Christmas tree plantations

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	7.78	7.78
$Cropland_{annual}$		-0.2069	8.18	15.35
Hops		0.0000	7.84	7.84
Vineyards		0.6795	99.9	138.91
Orchards		-0.3998	28.98	28.98
Tree nurseries		0.0000	7.84	7.84
Christmas tree plantations		0.0000	7.84	7.84
Grassland (in the strict sense)		-0.9958	11.53	15.00
Woody Grassland		-0.8944	10.19	14.00
Hedges		0.0000	4.97	10.81
Terr. Wetlands		0.0000	99.9	196.22
Waters		0.0000	11.09	11.09
Settlements		0.7261	39.56	39.56
Other Land		0.0000	16.52	16.52
Mineral soil, N_2O_{direct} [2)]		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Christmas tree plantations	0.0000	70.29	200.40
Grassland (in the strict sense)		0.8349	70.81	200.93
Woody Grassland		0.8431	70.60	200.85
Hedges		0.0000	70.04	200.66
Terr. Wetlands		0.0000	99.9	280.77
Mineral soil, $N_2O_{indirect}$ [2)]		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Christmas tree plantations	0.0000	99.9	287.02
Grassland (in the strict sense)		0.1879	99.9	287.39
Woody Grassland		0.1897	99.9	287.34
Hedges		0.0000	99.9	287.20
Terr. Wetlands		0.0000	99.9	347.93
Biomass [3)]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Christmas tree plantations	0.0000	20.94	20.94
$Cropland_{annual}$		-2.3289	27.25	27.25
Hops		0.0000	27.63	27.63
Vineyards		-3.3691	99.9	140.97
Orchards		-2.7410	33.32	33.32
Tree nurseries		0.0000	9.36	10.62
Christmas tree plantations		0.0000	19.47	19.47
Grassland (in the strict sense)		1.0786	29.06	29.06
Woody Grassland		-3.4071	44.96	45.62
Hedges		0.0000	44.09	44.76
Terr. Wetlands		2.1883	99.9	170.42
Waters		0.0000	32.85	32.85
Peat extraction		0.0000	32.85	32.85
Settlements		-3.6937	52.24	52.98
Other Land		0.0000	32.85	32.85
Dead organic matter [3)]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Christmas tree plantations	0.0000	0.00	0.00

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 392: Implied emission factors [t C ha^{-1} a^{-1}] and their uncertainties from short-rotation plantations

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	7.78	7.78
$Cropland_{annual}$		-0.0693	12.24	17.85
Hops		0.0000	99.9	196.16
Vineyards		0.6795	88.16	88.16
Orchards		-0.4903	36.20	36.20
Tree nurseries		0.0001	16.69	16.69
Christmas tree plantations		0.0000	7.84	7.84
Grassland (in the strict sense)		-0.9355	23.17	25.08
Woody Grassland		-0.9026	10.93	14.55
Hedges		0.0000	4.97	10.81
Terr. Wetlands		0.0000	9.33	9.33
Waters		0.0000	11.09	11.09
Settlements		0.3823	59.34	59.34
Other Land		0.0000	16.52	16.52
Mineral soil, N_2O_{direct} [2]		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Short-rotation plantations	0.0000	70.29	200.40
Grassland (in the strict sense)		0.8213	73.61	201.93
Woody Grassland		0.8134	70.71	200.89
Hedges		0.0000	70.04	200.66
Terr. Wetlands		0.0000	72.30	201.04
Mineral soil, $N_2O_{indirect}$ [2]		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Short-rotation plantations	0.0000	99.9	287.02
Grassland (in the strict sense)		0.1848	99.9	288.09
Woody Grassland		0.1830	99.9	287.37
Hedges		0.0000	99.9	287.20
Terr. Wetlands		0.0000	99.9	287.47
Biomass [3]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Short-rotation plantations	0.0000	9.57	10.60
$Cropland_{annual}$		4.0746	13.18	14.46
Hops		4.0746	99.9	196.25
Vineyards		4.0746	87.99	88.18
Orchards		4.0746	35.92	36.28
Tree nurseries		4.0746	16.96	17.61
Christmas tree plantations		0.0000	9.36	10.62
Grassland (in the strict sense)		4.0746	23.67	24.42
Woody Grassland		-4.6290	29.50	30.07
Hedges		0.0000	27.89	28.49
Terr. Wetlands		0.0000	14.71	15.77
Waters		0.0000	8.12	10.30
Peat extraction		0.0000	8.12	10.30
Settlements		4.0746	62.02	62.32
Other Land		0.0000	8.12	10.30
Dead organic matter [3]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Short-rotation plantations	0.0000	0.00	0.00

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 393: Implied emission factors for organic soils under Cropland [t CO2-eq. IPCC AR5 ha^{-1} a^{-1}], and their uncertainties (2.5 % and 97.5% percentile [%]), for the year 2021

Land use	GHG	Emission factor	Uncertainty bounds	
			lower	upper
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Cropland$_{annual}$	CO_2	35.09	43.20	19.64
	N_2O 2)	IE	83.78	264.87
	CH_4	0.32	57.08	91.29
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Hops	CO_2	35.06	99.9	139.98
	N_2O 2)	IE	99.9	298.93
	CH_4	0.37	99.9	165.96
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Vineyards	CO_2	55.04	71.18	59.89
	N_2O 2)	IE	99.9	270.84
	CH_4	0.41	80.37	107.40
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Orchards	CO_2	45.18	43.63	20.58
	N_2O 2)	IE	84.01	264.94
	CH_4	0.37	57.41	91.49
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Tree nurseries	CO_2	37.00	43.71	20.74
	N_2O 2)	IE	84.05	264.95
	CH_4	0.22	57.47	91.53
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Christmas-tree plantations	CO_2	34.84	43.44	20.18
	N_2O 2)	IE	83.91	264.91
	CH_4	0.35	57.27	91.40
Organic soil 1)		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Short-rotation plantations	CO_2	33.93	51.33	33.97
	N_2O 2)	IE	88.25	266.31
	CH_4	0.93	63.45	95.40

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, 1990-2021.

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 2022 Submission to the Climate Secretariat (UNFCCC NIR Submission 2022 – Inventory year 2020, (UNFCCC, 2021)), were used for this comparison. The values for Germany, 2021, were obtained from the current 2023 submission. The comparison is problematic from the outset, because the values to be compared were not all obtained with the same methods (in come cases, the methods differ widely) and, especially, because the demarcations of the systems differ – in some cases, markedly. In view of this fact, and taking account of the major uncertainties, and of the scattering seen in the reported values (cf. Chapter 6.5.3), in none of the compared pools does the comparison show implied emission factors (IEF) that must clearly be considered outliers. Most of the EF are similar, in terms of both absolute size and trends, to those of various central European neighbouring countries.

Table 394: Carbon-stock changes in living biomass, in croplands of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	0.000	-0.047	-3.160	NO	NO	NO	NO
Denmark	-0.015	-0.086	-1.744	0.230	NA	NA	NA
France	-0.002	-0.270	-4.218	-0.096	NA	-0.034	NA
UK	0.000	0.074	NO,IE	0.072	NO	0.342	NO
Netherlands	NA	-0.221	-4.160	-0.198	0.549	0.385	0.608
Austria	-0.001	0.015	-1.255	0.046	NO	NO	NO
Poland	0.034	NO	NO	NO	NO	NO	NO
Switzerland	0.033	0.095	-1.995	0.093	0.166	0.230	0.259
Czech Republic	0.001	-0.243	-2.258	-0.201	0.177	NO	NO
Germany, 2020	-0.0003	-0.204	NO	-0.164	-0.099	-1.050	0.133
Germany, 2021	-0.0007	-0.136	NO	-0.091	-0.63	-1.086	0.159

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2022b)

Table 395: Carbon-stock changes in dead organic matter, in croplands of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-0.003	-0.180	NO	NO	NO	NO
Denmark	NA	-0.298	-1.878	NO,NA	NA	NA	NA
France	NA	-0.020	-0.455	NA	NA	NA	NA
UK	NA	NO,IE	NO	IE	NO	NO,IE	NO
Netherlands	NA	-0.012	-1.214	NA	NA	NA	NA
Austria	NO	-0.017	-0.696	NO	NO	NO	NO
Poland	NA	NO	NO	NO	NO	NO	NO
Switzerland	NO	-0.001	-0.548	NO	NO	NO	NO
Czech Republic	NO	-0.013	-0.224	NO	NO	NO	NO
Germany, 2020	IE	NO	NO	IE	IE	IE	IE
Germany, 2021	IE	NO	NO	IE	IE	IE	IE

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2022b)

Table 396: Carbon-stock changes in mineral soils, in croplands of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-0.014	-1.274	-2.435	-1.272	NO	NO	NO
Denmark	0.011	-0.080	-0.356	NO,IE	-1.774	NA	NA
France	0.131	-1.094	-1.244	-1.171	NO	0.061	NA
UK	-0.337	-1.202	-2.397	-1.226	NO	2.700	NO
Netherlands	NA	-0.472	0.184	-0.483	-0.971	-0.206	2.619
Austria	0.015	-0.984	-0.759	-0.989	NO	NO	NO
Poland	-0.008	-0.112	NO	-1.139	NO	NO	NO
Switzerland	0.245	-0.215	-0.475	-0.343	0.836	1.920	2.568
Czech Republic	0.001	-0.261	-0.261	-0.477	NO	0.058	NO
Germany, 2020	-0.001	-0.986	NO	-1.100	-0.311	1.184	0.277
Germany, 2021	-0.001	-0.657	NO	-0.699	-1.261	0.169	1.926

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2022b)

Table 397: Carbon-stock changes in organic soils, in croplands of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-10.000	NO	NO	NO	NO	NO	NO
Denmark	-7.532	-0.179	IE	-5.002	IE	NA	NA
France	IE	NO	NO	NO	NO	NO	NO
UK	-8.184	-5.135	-8.193	-5.000	NO	NO	NO
Netherlands	-3.515	-3.624	-3.476	-3.625	-3.784	-3.719	-3.102
Austria	NO	NO	NO	NO	NO	NO	NO
Poland	-1.000	-1.000	NO	-1.000	NO	-1.000	NO
Switzerland	-9.520	-8.977	-9.520	-9.520	-9.520	-1.233	2.480
Czech Republic	NO	NO	NO	NO	NO	NO	NO
Germany, 2020	-9.425	-9.160	NO	-9.147	-9.408	-9.469	-9.203
Germany, 2021	-9.681	-9.539	NO	-9.528	-9.851	-9.737	-9.604

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2022b)

6.5.5 Category-specific recalculations (4.B)

This year's submission includes category-specific recalculations for the entire period 1990 through 2021. 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:

- Complete reimplementation of the LULUCF calculation model in the programming languages R and C++
- Thematic, spatial and chronological 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)
- Introduction of new, regionalised emission factors for mineral soils in the sub-category *buildings and open areas* of the land-use category *Settlements* (cf. Chapter 6.1.2.1.6) and the land-use category *Other Land* (cf. Chapter 6.1.2.1.7)

- Implementation of complete-coverage, high-resolution maps of regionalised mineral-soil carbon and nitrogen stocks, for the land-use categories *Cropland$_{annual}$*, *Grassland* and *Forest Land*, within the method for determining GHG emissions from mineral soils (cf. Chapter 6.1.2.1ff)
- For the mineral soils pool on Forest Land, the “stock-difference” method was used. In addition, modelling with YASSO was carried out, and the “overlap method” was used (cf. Chapter 6.4.2.5ff)

In Table 398 (areas) and Table 399 (emissions), the results of the current recalculations for the Cropland category are compared with the corresponding results in the previous year's submission.

The slight differences between the area data of the current submission and those of the previous year's submission are due mainly to correction algorithms. They became necessary in connection with reprogramming of the calculation model, and with updating of the map data for determination of activity data, via integration of the 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 with regard to GHG emissions are due to numerous causal factors, with impacts that overlap in multiple ways in the combined presentation; these factors include the following:

- Minor changes in the areas
- Differences in water levels in organic soils (CH_4 emissions (cf. Table 399))
- In particular, the introduction of maps of the carbon and nitrogen stocks of mineral soils. The mean carbon stocks shown in the soil map are 2.14 t C ha^{-1} below the average value given by the Agricultural Soil Inventory (BZE-LW) (cf. Table 327 and Chapter 6.1.2.1.4). This leads to increasingly lower CO_2 emissions in the 2023 submission, tied to the absolute area increases in the conversion categories leading to Cropland (cf. Table 399)
- Regionalisation effects from introduction of the soil maps

Table 398: 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	2020
4.B	Cropland	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	12,593.81
		2023	13,518.13	13,535.53	13,552.90	13,199.65	12,943.26	12,735.88	12,706.09	12,676.35	12,646.63	12,616.91	12,587.20
		Absolute difference	-71.04	-67.91	-64.78	-37.00	-20.82	-12.44	-11.32	-10.16	-8.98	-7.80	-6.61
		in %	-0.53%	-0.50%	-0.48%	-0.28%	-0.16%	-0.10%	-0.09%	-0.08%	-0.07%	-0.06%	-0.05%

Table 399: Comparison of greenhouse-gas emissions [kt CO_2-eq with GWP pursuant to IPCC AR5] in the Cropland 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	2020
4.B	Cropland	CO_2	2022	13,762.4	13,942.4	13,723.4	15,879.7	15,182.3	16,777.7	16,876.4	16,755.9	16,945.3	16,748.9	16,656.0
			2023	14,722.3	14,565.0	14,208.6	15,571.8	14,743.6	15,242.9	15,609.2	15,453.8	15,384.2	15,388.2	15,238.3
			Difference	960.0	622.6	485.2	-307.9	-438.6	-1,534.8	-1,267.2	-1,302.1	-1,561.1	-1,360.7	-1,417.8
			in %	7.0%	4.5%	3.5%	-1.9%	-2.9%	-9.1%	-7.5%	-7.8%	-9.2%	-8.1%	-8.5%
		CH_4	2022	163.2	151.0	139.1	144.6	147.5	155.1	156.0	155.4	152.2	147.6	140.9
			2023	109.5	101.4	93.3	96.8	99.7	103.5	106.4	107.1	105.4	101.7	95.4
			Difference	-53.8	-49.6	-45.8	-47.8	-47.8	-51.6	-49.7	-48.2	-46.9	-45.9	-45.5
			in %	-32.9%	-32.8%	-32.9%	-33.1%	-32.4%	-33.3%	-31.8%	-31.0%	-30.8%	-31.1%	-32.3%
		N_2O	2022	207.9	203.9	202.2	339.0	373.0	520.0	528.8	538.8	549.6	561.4	574.1
			2023	208.3	203.2	199.9	283.5	290.9	372.3	377.7	383.8	390.5	397.9	406.0
			Difference	0.5	-0.7	-2.3	-55.6	-82.1	-147.7	-151.1	-155.0	-159.1	-163.6	-168.2
			in %	0.2%	-0.4%	-1.1%	-16.4%	-22.0%	-28.4%	-28.6%	-28.8%	-29.0%	-29.1%	-29.3%

6.5.6 Category-specific planned improvements (4.B)

In addition to the planned measures listed in Chapter 6.1.2.1.9, most of which are medium-term measures, no specific measures for improvement of methods in the area of Cropland are currently planned.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**4 C, Grassland**		**CO_2**	29,121.2	2.3 %	25,045.9	3.3 %	-14.0 %
-/-/2	**4 C, Grassland**		**CH_4**	**841.6**	**0.1 %**	**919.3**	**0.1 %**	**9.2 %**
-/-	4 C, Grassland		N_2O	62.2	0.0 %	36.7	0.0 %	-41.0 %

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 2021, the net anthropogenic GHG emissions from *Grassland*, in keeping with IPCC AR5, amounted to 26,001.9 kt CO_2 equivalents. Drainage of organic grassland soils resulted in emissions, in keeping with IPCC AR5, of 27,236.0 kt CO_2, 919.3 kt CO_2-eq. of methane, and 32.5 kt CO_2-eq. of nitrous oxide. Mineral soils (-4,591.8 kt CO_2) served as a carbon sink in the Grassland sector.

These emissions consist of the sum of the emissions from the sub-categories *Grassland (in the strict sense)*, *Woody Grassland*, and *Hedges*. GHG emissions in each of these three sub-categories differ considerably from those in the other sub-categories, both quantitatively and qualitatively. As Table 400 and Figure 75 and Figure 76 show, *Grassland (in the strict sense)* is a significant CO_2 source. Its absolute emissions level, 28,153.4 kt CO_2-eq., is determined primarily by emissions from organic soils (27,754.1 kt CO_2-eq. ≙ 98.9 %), with the fraction for CO_2 emissions (97.1 %) greatly exceeding that for methane (2.9 %). While biomass also functions as a source, and contributes only slightly (13.7%) to the gross emissions of 32,327 kt CO_2-Eq., mineral soils under Grassland (in the strict sense) are an ongoing sink for carbon (Table 400). They reduce the gross emissions in the sub-category Grassland (in the strict sense) by 12.9 %.

Table 400: CO_2, N_2O and CH_4 emissions [kt CO_2-eq. pursuant to IPCC AR5] from Grassland, 2021, 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	Emission [kt CO_2-eq.]	2.5 perc. [kt CO_2-eq.]	97.5 perc. [kt CO_2-eq.]	2.5 perc. [%]	97.5 perc. [%]
Grassland (in the strict sense) Emissions, 2021						
Grassland i.t.s.s.$_{total}$ 1)		**28,055.6**	13,325.7	36,503.2	52.50	30.11
Mineral soils	**CO_2 2)**	**-4,173.4**	-4,096.4	-4,691.4	1.85	12.41
	$N_2O_{indirect}$ 4)	**0.58**	0.26	1.36	54.81	136.52
	N_2O_{direct} 3)	**2.56**	1.70	5.00	33.75	95.45
Organic soil	**CO_2 2)**	**26,936.2**	6,596.2	36,430.6	75.51	35.25
	N_2O 5)	**IE**	IE	IE	IE	IE
	CH_4 6)	**916.0**	447.24	1,304.56	51.17	377.68
Biomass	**CO_2 2)**	**4,410.9**	2,569.3	6,282.1	41.75	42.42
Dead organic matter	**CO_2 2)**	**60.49**	55.56	65.42	8.15	8.15
Woody Grassland, emissions, 2021						
Woody Grassland$_{total}$ 7)		**-2,185.8**	-1,637.7	-2,735.4	24.95	25.35
Mineral soils	**CO_2 2)**	**-420.10**	-408.77	-450.88	2.70	7.33
	$N_2O_{indirect}$ 4)	**0.18**	0.06	0.48	64.70	161.24
	N_2O_{direct} 3)	**0.81**	0.48	1.74	40.87	115.70
Organic soil	**CO_2 2)**	**286.2**	247.7	330.7	13.47	15.55
	N_2O 3)	**31.07**	7.7	53.9	75.14	73.59
	CH_4 6)	**3.2**	1.82	4.16	42.76	65.90
Biomass	**CO_2 2)**	**-2,104.8**	-1,461.6	-2,758.0	30.56	31.03
Dead organic matter	**CO_2 2)**	**17.62**	15.48	19.75	12.11	12.11
Hedges, emissions, 2021						
Hedges$_{total}$ 7)		**34.3**	29.1	40.1	15.55	16.21
Mineral soils	**CO_2 2)**	**-2.27**	-1.96	-2.64	13.83	16.26
	$N_2O_{indirect}$ 4)	**0.00**	0.00	0.01	93.24	210.16
	N_2O_{direct} 3)	**0.01**	0.00	0.02	66.79	150.08
Organic soil	**CO_2 2)**	**13.58**	10.77	16.83	20.72	23.96
	N_2O 3)	**1.48**	-0.25	3.16	116.61	114.19
	CH_4 6)	**0.14**	0.05	0.29	64.67	99.69

Biomass	**CO_2 2)**	**20.6**	15.7	25.7	24.02	24.30
Dead organic matter	**CO_2 2)**	**0.76**	0.35	1.16	54.05	54.05

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 2021, the time series for total emissions from *Grassland (in the strict sense)* includes emissions that have decreased by -2.7 % with respect to the base year 1990. 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 323 % 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, 2020 and 2021 (cf. Chapter 6.3). This applies especially to the sub-category Woody Grassland.

Figure 75: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq. pursuant to IPCC AR5] as a result of land use and land-use changes in Grassland (in the strict sense), 1990-2021, by sub-categories

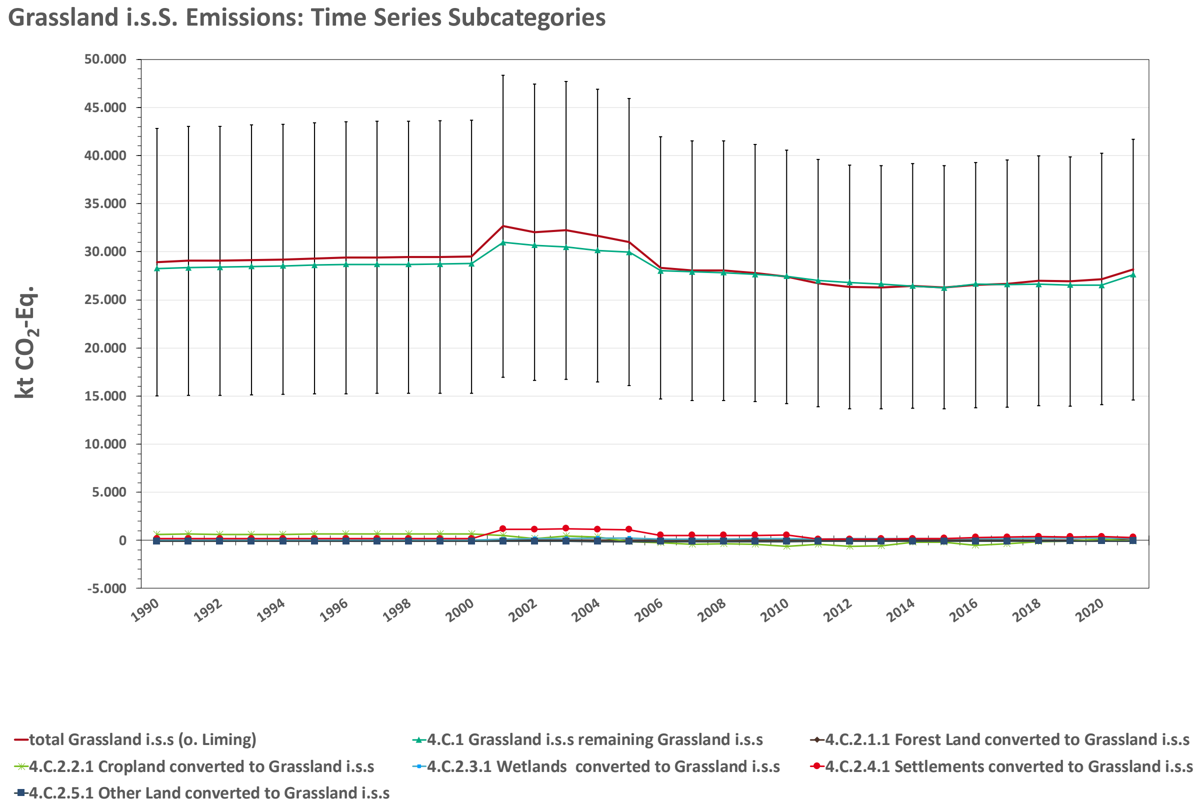
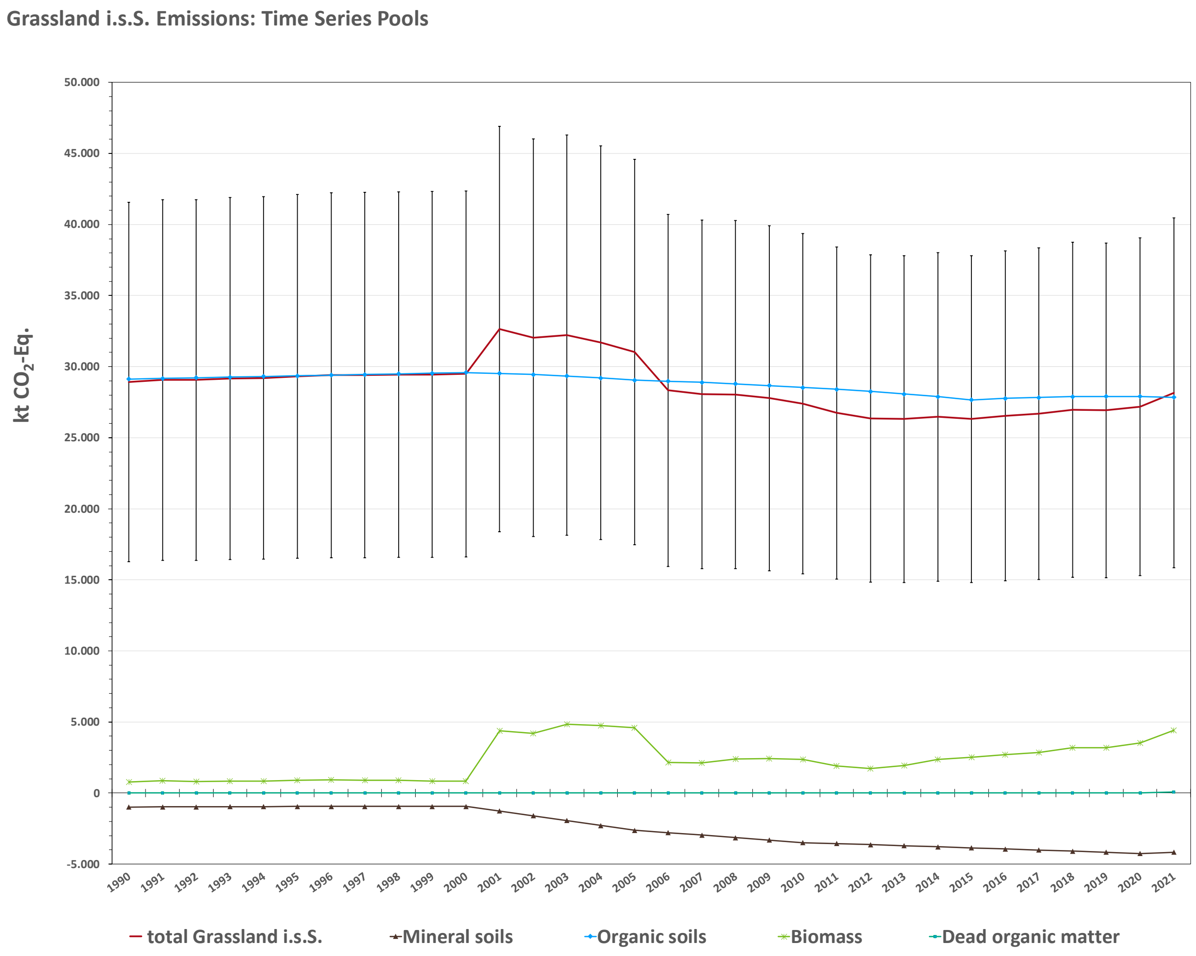


Figure 76: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq. pursuant to IPCC AR5] as a result of land use and land-use changes in Grassland (in the strict sense), 1990-2021, by pools



The net emissions in the sub-category Woody Grassland are shaped primarily by emissions from the biomass pool. In 2021, that pool functioned as a sink, with emissions of -2,104.8 kt CO_2-eq., as did the mineral soils pool (-420.1 kt CO_2-eq.) . The pools' sink effects more than offset the positive emissions from organic soils soils (320.5 kt CO_2-eq.), with the result that the sub-category *Woody Grassland* was a net carbon sink in 2021 (-2,185.8 kt CO_2-eq.; Table 400 and Figure 77 and Figure 78).

The curve progressions of the time series in Figure 77 and Figure 78 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 77: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq. pursuant to IPCC AR5] as a result of land use and land-use changes in woody grassland areas and hedges, 1990-2021, by sub-categories

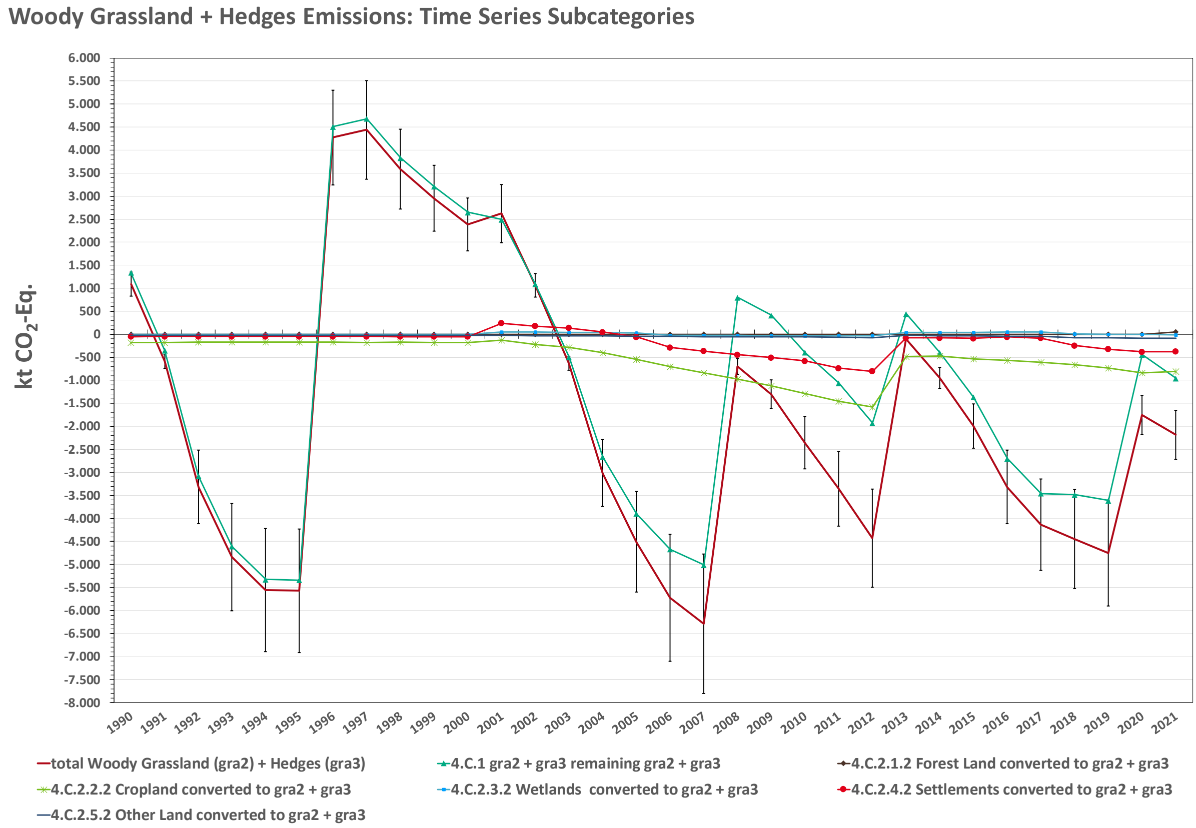
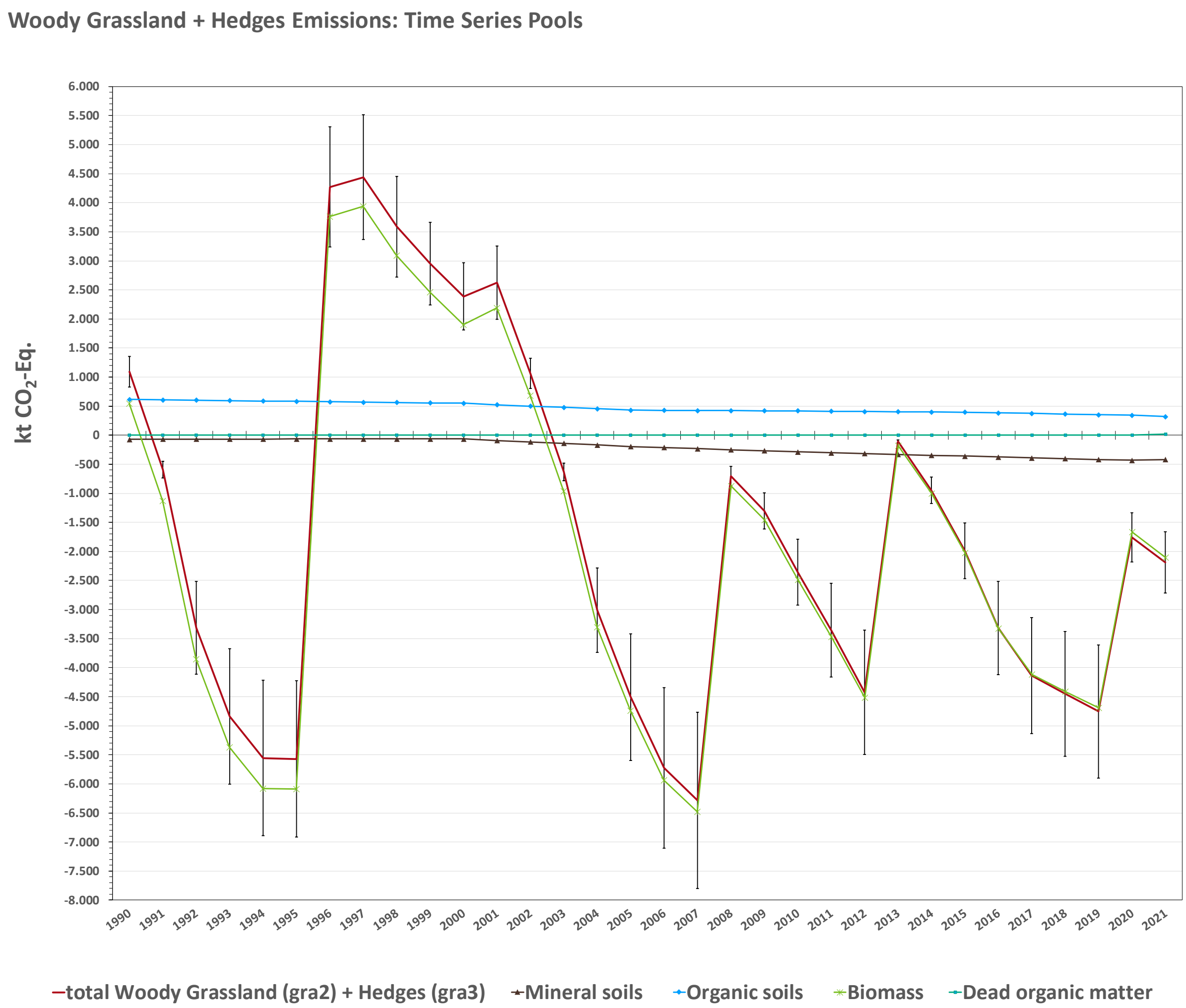


Figure 78: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq. pursuant to IPCC AR5] as a result of land use and land-use changes in woody grassland areas and hedges, 1990-2021, by pools



In 2021, the sub-category *Hedges*, with net emissions of 34.3 kt CO_2-eq. pursuant to IPCC AR5, contributed only slightly to the net emissions in the land-use category *Grassland* (0.1 %). Emissions in the *Hedges* category are shaped by the continuing high emissions of organic soils (2021: 15.2 kt CO_2-eq. pursuant to IPCC AR5 (Table 400)). On the other hand, the net-emissions curve in the time series is shaped by the extremely variable emissions from biomass, which depend strongly on age distribution and rotation periods. They average -0.033 kt CO_2-eq. throughout the entire reporting period, and have an enormous range (-9.2 kt CO_2-eq. through 20.6 kt CO_2-eq.).

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, 2006b)
- "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 345 in Chapter 6.3.2.1)

- herbaceous plants (sub-category Grassland (in the strict sense))
- perennial woody plants in hedges and field copses (sub-categories *Woody Grassland* and *Hedges*)

The GHG emissions from plant biomass of perennial hedge and field copse plants in the sub-categories *Woody Grassland* and *Hedges* are determined as follows: 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 6.1.2.3ff, while the specific methods and emission-factor derivations for *Woody Grassland* and *Hedges* 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-categories *Woody Grassland* and *Hedges*, 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. In addition, the constancy of the carbon stocks can be substantiated with monitoring data from Germany's long-term soil-monitoring areas, although not to the same degree it can be substantiated for Cropland (cf. Chapter 6.5.2.3.2). Results are available for only 42 sites in Lower Saxony and Bavaria (Höper and Schäfer (2012), Fortmann et al. (2012) and BLfU (2011)). These are Germany's two largest Länder, in terms of area, and they have the country's largest absolute shares of grassland areas. In addition, they exhibit large climatic differences. As a result, the results may be assumed to be representative for Germany, on average. 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 Lower Saxony, a majority of the study areas (72 %) exhibited no significant changes with respect to mineral-soil carbon stocks during the study period. A total of 14 % exhibited a significant increase or decrease (Fortmann et al. (2012)). In Bavaria, and over the course of 25 years (4 sampling dates per area), no significant changes overall were found in carbon stocks under permanent grassland (BLfU (2011)).

The ERT had encouraged further review of the thesis that the soil carbon stocks in Germany's mineral soils under permanent grassland (remaining category) are approximately in equilibrium. In an approach similar to that used for Cropland, the Tier 1 method of the 2006 IPCC Guidelines was used for this purpose. The following was assumed for the Tier 1 method:

a. The results of the Agricultural Soil Inventory (BZE-LW) with regard to the current state of the carbon stocks of Germany's mineral soils (JACOBS et al. 2018) may be used for determination of the land-use factor (F_{LU}).

b. The majority of Germany's grasslands are intensively managed, and improvement measures are used throughout (as a rule, more organic fertiliser is applied to such areas than is applied to cropland).

c. Grassland is classified on the basis of a requirement imposed by German official statistics, which differentiate permanent grassland by types of use (Statistisches Bundesamt, 2022c):

- 4.75 % of the grassland area is low-yielding grassland (F_{MG}, nominally managed)
- About 55 % of the area is normally used grassland, which in Germany is always subjected to at lease one improvement measure (F_{MG}, improved grassland; F_I medium)
- About 40 % is intensive used grassland (up to 6 instances of mowing)(F_{MG}, improved grassland, F_I high)

Table 401 shows the results of use of the Tier 1 method. A marked increase in the organic carbon stocks in mineral soils under grassland results. Even when the highest input factor (F_I high) is ignored, or when all classes are set one level lower, the following happens: The result would still be an increase in carbon stocks in mineral soils under grassland. Consequently, the result supports the estimation that the assumption that carbon stocks of mineral soils under grassland in Germany are approximately in equilibrium is a conservative one.

Table 401: Calculation steps, and results of use of the Tier 1 method of the 2006 IPCC Guidelines on the remaining category of Germany's grassland mineral soils

Factor	Level	IPCC default	Share [%]	FI	IPCC default	Area [kha]	C stock [kt]	∑ [kt]
FMG	Nominally	1	4.75			173,716	15,532	
FMG	Improved	1.14	55.08	Medium	1	2,013,189	205,199	
FMG	Improved	1.14	40.17	High	1.1	1,468,394	166,133	386,864
2020_NIR_total						3,655,299		326,820
Difference [kt C a^{-20}								60,044
Difference [kt C a^{-1}								3,002

In CRF Table 4.C.1, "NA" has thus been entered in the spaces "carbon-stock changes in mineral soils" in the remaining categories of *Grassland (in the strict sense)*, *Woody Grassland* and *Hedges* (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*and *Hedges*, is described in Chapter 6.1.2.1, while the pertinent emission factors and their uncertainties are described in Table 403 and Table 404 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-categories *Woody Grassland* and *Hedges*, 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)*. The same holds for emissions from organic soils following land-use changes leading to *Woody Grassland* and *Hedges*. 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-categories *Woody Grassland* and *Hedges*, are listed in CRF Table 4(II).C.

6.6.3 Uncertainties and time-series consistency (4.C)

The uncertainties for the activity data of the land-use category *Grassland* have a normal distribution, with values between 0.05 – 196.0 % for half of the 95 % confidence interval. Here as well, the uncertainty depends on the sample size; the smaller the area, the larger the uncertainty. 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 47.0 % [2.5 % percentile] and 27.1 % [97.5 % percentile], while that for the sub-category *Grassland (in the strict sense)* is 52.5 % [2.5 % percentile] and 30.1 % [97.5 % percentile]; that for the sub-category *Woody Grassland* is 25.0 % [2.5 % percentile] and 25.4 % [97.5 % percentile]; and that for the sub-category *Hedges* is 15.6 % [2.5 % percentile] and 16.2% [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). The contributions of the sub-categories *Woody Grassland* and *Hedges* to the uncertainty of the total inventory are marginal.

Table 402 through Table 407 show the uncertainties relative to the implied emission factors for the sub-categories *Grassland (in the strict sense)*, *Woody Grassland* and *Hedges*.

Table 402: Emission factors [t C ha^{-1} a^{-1}], with uncertainties [% of central tendency], as used for calculation of 2021 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		-0.0635	8.48	11.83
Cropland$_{annual}$		0.7114	2.15	14.83
Hops		0.7903	45.29	46.29
Vineyards		1.3305	12.41	16.31
Orchards		0.4862	9.36	13.03
Short-rotation plantations		0.6247	39.51	40.66
Tree nurseries		1.0884	18.57	20.91
Christmas tree plantations	Grassland$_{i.t.s.s.}$	1.0604	18.61	20.94
Woody Grassland		0.0448	2.96	12.25
Hedges		0.0027	14.52	18.76
Terr. Wetlands		-0.7731	17.52	18.98
Waters		0.0000	2.52	16.99
Peat extraction		0.0000	0.00	0.00
Settlements		1.1574	2.52	9.49
Other Land		3.1895	17.74	22.48
Biomass [2)]		**[t C ha^{-1} a^{-1}]**	**[t C ha^{-1} a^{-1}]**	**[%]**
Forest Land		-34.4819	24.63	24.63
Cropland$_{annual}$		-0.0017	16.27	16.27
Hops		-2.6219	0.00	0.00
Vineyards		-0.0362	20.22	20.22
Orchards		-0.2547	14.85	14.85
Short-rotation plantations		-4.6799	39.23	39.68
Tree nurseries		-0.7834	26.89	26.89
Christmas tree plantations	Grassland$_{i.t.s.s.}$	-0.8265	32.16	32.16
Woody Grassland		-5.6229	51.68	52.48
Hedges		-56.4371	53.34	54.12
Terr. Wetlands		-1.3190	42.72	44.00
Waters		0.0000	30.25	30.25
Peat extraction		0.0425	37.69	37.69
Settlements		-1.4062	45.93	47.39
Other Land		0.0656	33.14	33.14
Dead organic matter [2)]		**[t C ha^{-1} a^{-1}]**	**[t C ha^{-1} a^{-1}]**	**[%]**
Forest Land	Grassland$_{i.t.s.s.}$	-20.6215	8.15	8.15

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 403: Uncertainties for emission factors [2.5 % and 97.5 % percentile, in % of central tendency] for emissions from organic soils under Grassland in the strict sense, in 2021, pursuant to IPCC AR5

Land use Organic soil 1)	GHG	Emission factor [t CO_2-eq. ha^{-1} a^{-1}]	Uncertainty bounds lower [%]	 upper [%]
Grassland in the strict sense	CO_2	28.6810	89.18	41.62
Grassland in the strict sense	CH_4	0.9753	59.89	442.02
Grassland in the strict sense	N_2O	1.8829	93.48	382.61

1) Annual calculation; emission: positive ≙ source; negative ≙ sink

Table 404: Emission factors [t C ha^{-1} a^{-1}], with uncertainties [% of central tendency], as used for calculation of GHG emissions in 2021 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		0.2342	12.99	15.38
$Cropland_{annual}$		0.8993	4.11	15.24
Hops		0.0000	99.9	196.30
Vineyards		1.2749	16.67	19.75
Orchards		0.4625	19.07	21.11
Short-rotation plantations		0.5494	80.17	80.74
Tree nurseries		0.9894	32.18	33.58
Christmas tree plantations	Woody Grassland	0.8998	30.66	32.12
Grassland in the strict sense		0.1320	2.67	12.18
Hedges		0.0129	29.27	31.59
Terr. Wetlands		-0.8727	31.90	32.73
Waters		0.0000	2.52	16.99
Peat extraction		0.0000	0.00	0.00
Settlements		1.1015	4.25	10.09
Other Land		3.7423	22.59	26.48

Woody Grassland Initial land use	Final land use	Emission factor	Uncertainty bounds upper	 lower
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	0.0019	70.07	200.67
Hedges	Woody Grassland	0.0000	75.89	61.99
Terr. Wetlands	Woody Grassland	0.8572	78.66	203.42
Mineral soil, $N_2O_{indirect}$ 3)		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Grassland in the strict sense	Woody Grassland	0.0004	99.9	287.21
Hedges	Woody Grassland	0.0000	99.9	288.69
Terr. Wetlands	Woody Grassland	0.1929	99.9	289.14
Biomass 2)		[t C ha^{-1} 1 a^{-1}]	[t C ha^{-1} 1 a^{-1}]	[%]
Forest Land	Woody Grassland	-38.6065	42.05	42.64
$Cropland_{annual}$	Woody Grassland	3.2033	51.71	52.51
Hops	Woody Grassland	-3.1044	99.9	203.03
Vineyards	Woody Grassland	-0.0173	53.24	54.00
Orchards	Woody Grassland	2.8988	47.93	48.57
Short-rotation plantations	Woody Grassland	1.7417	84.74	84.94
Tree nurseries	Woody Grassland	6.4327	52.16	52.66
Christmas tree plantations	Woody Grassland	6.0326	52.24	52.81
Grassland in the strict sense	Woody Grassland	3.2636	51.67	52.47
Hedges	Woody Grassland	-55.3343	61.23	61.99
Terr. Wetlands	Woody Grassland	4.6817	47.37	48.01
Waters	Woody Grassland	0.0000	54.73	55.58
Peat extraction	Woody Grassland	8.3769	92.10	92.61
Settlements	Woody Grassland	2.0432	39.95	40.70
Other Land	Woody Grassland	7.1576	58.10	58.91
Dead organic matter 2)		[t C ha^{-1} 1 a^{-1}]	[t C ha^{-1} 1 a^{-1}]	[%]
Forest Land	Woody Grassland	-20.6215	12.11	12.11

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 405: Uncertainties for emission factors [2.5 and 97.5 percentile, in % of location scale] for emissions from organic soils under Woody Grassland, 2021

Land use Organic soil[115]	GHG	Emission factor [t CO_2-eq. ha^{-1} a^{-1}]	Uncertainty bounds lower [%]	 upper [%]
Woody Grassland	CO_2	-80.6895	20.77	24.22
Woody Grassland	CH_4	-15.5338	68.74	106.19
Woody Grassland	N_2O	0.0076	99.9	117.86

115 Annual calculation; emission: positive ≙ source; negative ≙ sink

Table 406: Emission factors [t C ha^{-1} a^{-1}], with uncertainties [% of central tendency], as used for calculation of GHG emissions in 2021 from Hedges

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	Hedges	-0.1940	62.23	62.78
Cropland$_{annual}$		0.8225	9.71	17.59
Hops		0.0000	4.97	10.81
Vineyards		1.4010	99.9	139.13
Orchards		0.5885	99.9	126.34
Short-rotation plantations		0.0000	4.97	10.81
Tree nurseries		1.4431	49.25	50.18
Christmas tree plantations		1.5292	74.25	74.87
Grassland in the strict sense		0.1819	15.41	19.46
Woody Grassland		0.2346	50.64	52.01
Terr. Wetlands		0.0000	7.58	10.52
Waters		0.0000	2.52	16.99
Peat extraction		0.0000	0.00	0.00
Settlements		1.2113	39.23	40.29
Other Land		0.0000	11.40	17.90
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	Hedges	0.0063	71.69	201.24
Woody Grassland		0.0446	86.41	206.94
Terr. Wetlands		0.0000	72.30	201.04
Mineral soil, $N_2O_{indirect}$ 3)		[kg N_2O ha^{-1} a^{-1}]	[%]	[%]
Grassland in the strict sense	Hedges	0.0014	99.9	287.61
Woody Grassland		0.0100	99.9	291.63
Terr. Wetlands		0.0000	99.9	287.47
Biomass 2)		[t C ha^{-1} 1 a^{-1}]	[t C ha^{-1} 1 a^{-1}]	[%]
Forest Land	Hedges	-38.6065	71.58	71.92
Cropland$_{annual}$		-4.2857	52.44	53.23
Hops		0.0000	52.14	52.95
Vineyards		-8.1875	99.9	147.93
Orchards		-2.6189	99.9	133.72
Short-rotation plantations		0.0000	27.89	28.49
Tree nurseries		-10.3061	64.21	64.63
Christmas tree plantations		-10.6613	86.21	86.55
Grassland in the strict sense		-3.3242	53.54	54.32
Woody Grassland		-25.2845	71.62	72.28
Terr. Wetlands		0.0000	41.70	42.42
Waters		0.0000	54.73	55.58
Peat extraction		0.0000	54.73	55.58
Settlements		-18.0099	54.81	55.36
Other Land		0.0000	54.73	55.58
Dead organic matter 2)		[t C ha^{-1} 1 a^{-1}]	[t C ha^{-1} 1 a^{-1}]	[%]
Forest Land	Hedges	-20.6215	54.05	54.05

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 the 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 407: Uncertainties for emission factors [2.5 % and 97.5 % percentile, in % of central tendency] for emissions from organic soils for Hedges, in 2021

Land use	GHG	Emission factor	Uncertainty bounds	
			lower	upper
Organic soil[116]		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Hedges	CO_2	10.5931	21.44	24.80
Hedges	CH_4	0.1001	68.95	106.32
Hedges	N_2O	1.2948	99.9	117.98

For *Grassland (in the strict sense)*, *Woody Grassland* and *Hedges*, the calculations are spatially and chronologically consistent and complete for the entire reporting period, 1990-2021.

6.6.4 Source-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.

The following tables (Table 408, Table 409, Table 410) present an intra-European comparison of implied emission factors (IEF) for various pools. For this comparison, values of neighbouring countries, obtained from the 2022 Submission to the Climate Secretariat (UNFCCC NIR Submission 2022: Inventory year 2020, UNFCCC, 2022). The values for Germany, 2021, were obtained from the current 2023 submission.

The comparison is problematic from the outset, because the values to be compared were not all obtained with the same methods (in come cases, the methods differ widely) and, especially, because the demarcations of the systems differ – in some cases, markedly. In this comparison, Grassland in Germany always refers to the sum of the sub-categories *Grassland (in the strict sense)*, *Woody Grassland* and *Hedges*. Such system demarcations are defined very differently from country to country, and thus the relevant mean emission factors of different countries often cannot be directly compared. In view of this fact, and taking account of the major uncertainties, and of the scattering seen in the reported values (cf. Chapter 6.6.3), in none of the compared pools does the comparison show implied emission factors (IEF) that must clearly be considered outliers. Most of the EF are similar, in terms of both absolute size and trends, to those of various central European neighbouring countries.

[116] Annual calculation; emission: positive ≙ source; negative ≙ sink

Table 408: Carbon-stock changes in living biomass, in grassland of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-1.238	-7.219	NO	NO	NO	NO
Denmark	-0.084	-0.110	-0.363	-0.097	NA	NA	NA
France	0.044	-0.105	-1.320	0.050	NA	0.470	NA
UK	-0.001	-0.109	-1.578	-0.071	NO	0.042	NO
Netherlands	0.009	0.062	-3.214	0.164	0.395	0.584	1.164
Austria	NA	-0.597	-1.351	-0.047	NO	NO	NO
Poland	NA	0.184	NO	0.220	NO,IE	NO,IE	NO
Switzerland	0.019	-0.699	-3.485	-0.079	0.577	0.144	0.535
Czech Republic	NO	0.047	-3.805	0.125	0.550	NO	NO
Germany, 2020	-0.018	0.070	NO	0.135	0.369	-0.652	1.688
Germany, 2021	-0.092	-0.026	NO	0.051	-0.571	-0.794	1.742

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

Table 409: Carbon-stock changes in dead organic matter, in grassland of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-0.113	-0.658	NO	NO	NO	NO
Denmark	NO,NA	-0.014	-0.296	NA	NA	NA	NA
France	NA	-0.022	-0.153	NA	NA	NA	NA
UK	NA	-0.014	-0.524	IE	NO	IE,NA	NO
Netherlands	NA	-0.069	-1.349	NA	NA	NA	NA
Austria	NO	-0.361	-0.858	NO	NO	NO	NO
Poland	NA	NO	NO	NO	NO	NO	NO
Switzerland	NO	-0.198	-0.873	NO	NO	NO	NO
Czech Republic	NO	-0.006	-0.385	NO	NO	NO	NO
Germany, 2020	IE	NO	NO	IE	IE	IE	IE
Germany, 2021	IE	NO	NO	IE	IE	IE	IE

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

Table 410: Carbon-stock changes in mineral soils, in grassland of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-0.102	1.061	-1.033	1.529	-0.976	0.907	NO
Denmark	NO,IE,NA	0.011	0.241	IE	-1.067	NA	NA
France	0.000	0.910	0.036	1.011	NO	1.892	NA
UK	0.130	0.690	-1.054	0.679	NO,IE	2.753	NO
Netherlands	0.004	0.715	0.533	0.743	0.111	0.585	3.286
Austria	0.002	0.923	0.822	0.997	NO	NO	NO
Poland	-0.001	0.726	NO	0.789	NO	NO	NO
Switzerland	-0.063	0.369	-1.205	0.346	1.832	2.024	1.590
Czech Republic	0.091	0.441	-0.076	0.470	NO	0.349	NO
Germany, 2020	0.008	1.354	NO	1.271	0.023	2.247	1.377
Germany, 2021	0.006	0.775	NO	0.724	-0.795	1.114	3.314

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

Table 411: Carbon-stock changes in organic soils, in grassland of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-1.891	NO	NO	NO	NO	NO	NO
Denmark	-5.671	-9.652	-9.652	IE	NA	NA	NA
France	IE	NO	NO	NO	NO	NO	NO
UK	-0.588	-2.291	-2.291	NO	NO	NO	NO
Netherlands	-4.072	-3.778	-2.618	-3.779	-4.151	-3.904	-3.025
Austria	-6.402	NO	NO	NO	NO	NO	NO
Poland	-0.250	-0.250	NO	-0.250	-0.250	-0.250	-0.250
Switzerland	-9.087	-8.879	-7.919	-9.347	-7.779	-1.429	3.772
Czech Republic	NO	NO	NO	NO	NO	NO	NO
Germany, 2020	-7.39	-7.80	NO	-7.95	-6.47	-7.18	-6.68
Germany, 2021	-7.634	-7.930	NO	-8.029	-7.014	-7.234	6.959

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

6.6.5 Category-specific recalculations (4.C)

This year's submission includes category-specific recalculations for the entire period 1990 through 2021. 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:

- Complete reimplementation of the LULUCF calculation model in the programming languages R and C++
- Introduction of the new land-use sub-category *Hedges*
- Introduction of new, regionalised emission factors for mineral soils in the sub-category *buildings and open areas* of the land-use category *Settlements* (cf. Chapter 6.1.2.1.6) and the land-use category *Other Land* (cf. Chapter 6.1.2.1.7)
- Implementation of complete-coverage, high-resolution maps of regionalised mineral-soil carbon and nitrogen stocks, for the land-use categories *Cropland*$_{annual}$, *Grassland* and *Forest Land*, within the method for determining GHG emissions from mineral soils (cf. Chapter 6.1.2.1ff)

In Table 412 (areas) and Table 413 (emissions), the results of the current recalculations for the Grassland category are compared with the corresponding results in the previous year's submission.

The slight differences between the area data of the current submission and those of the previous year's submission are due mainly to correction algorithms. They became necessary in connection with reprogramming of the calculation model, and with updating of the map data for determination of activity data, via integration of the 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 with regard to CO_2 and N_2O emissions are very slight (Table 413). Several mutually opposed processes overlap in such a manner that the large differences between the submissions, with regard to biomass and mineral soils, are nearly cancelled out overall. The causal factors with impacts that multiply overlap in a combined presentation include the following:

- Minor changes in the areas (Table 412)
- Differences in water levels in organic soils (CH_4 emissions (cf. Table 413))
- In particular, the introduction of maps of the carbon and nitrogen stocks of mineral soils. The mean carbon stocks in the soil map are 1.64 t C ha^{-1} below the measured average value (cf. Table 328) and Chapter 6.1.2.1.5). This reduces the sink function in the 2023 submission, to a growing degree that depends on the absolute area increases in the conversion categories leading to Cropland.
- Regionalisation effects from introduction of the soil maps

Table 412: 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	2020
4.C	Grassland	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	6,771.03
		2023	6,756.74	6,676.96	6,597.29	6,712.63	6,781.40	6,764.55	6,761.34	6,758.11	6,754.89	6,751.67	6,748.46
		Difference	-49.50	-50.30	-50.98	-51.51	-46.40	-34.42	-32.06	-29.72	-27.35	-24.95	-22.56
		in %	-0.7%	-0.8%	-0.8%	-0.8%	-0.7%	-0.5%	-0.5%	-0.4%	-0.4%	-0.4%	-0.3%

Table 413: Comparison of greenhouse-gas emissions [kt CO_2-eq with GWP pursuant to IPCC AR5] 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	2020
4.C	Grass land	CO_2	2022	26,383.5	27,186.9	27,185.9	25,931.2	18,542.7	18,966.2	19,437.0	19,297.1	18,812.7	18,590.8	18,068.7
			2023	29,121.2	22,855.4	30,975.8	25,604.2	24,087.9	23,363.1	22,258.6	21,595.2	21,582.2	21,228.8	24,470.7
			Difference	2737.72	-4331.54	3789.89	-327.06	5545.18	4396.89	2821.59	2298.10	2769.52	2638.01	6401.91
			in %	10.4%	-15.9%	13.9%	-1.3%	29.9%	23.2%	14.5%	11.9%	14.7%	14.2%	35.4%
		CH_4	2022	977.5	988.1	998.6	1,032.4	1,070.5	1,082.2	1,078.7	1,075.8	1,075.4	1,076.3	1,078.2
			2023	841.6	849.4	857.2	887.6	922.0	934.0	930.2	927.6	927.2	928.4	931.4
			Difference	-135.88	-138.69	-141.38	-144.80	-148.54	-148.23	-148.53	-148.21	-148.20	-147.94	-146.77
			in %	-13.9%	-14.0%	-14.2%	-14.0%	-13.9%	-13.7%	-13.8%	-13.8%	-13.8%	-13.7%	-13.6%
		N_2O	2022	2,120.61	2,135.09	2,149.54	2,108.11	2,077.30	2,017.31	2,022.07	2,025.61	2,028.25	2,029.90	2,030.10
			2023	2,117.25	2,131.00	2,144.78	2,106.14	2,077.73	2,019.22	2,024.57	2,028.69	2,031.94	2,034.25	2,035.04
			Difference	-3.36	-4.09	-4.76	-1.97	0.43	1.91	2.50	3.08	3.70	4.35	4.94
			in %	-0.2%	-0.2%	-0.2%	-0.1%	0.0%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%
		N_2O	2022	59.48	55.6	52.3	70.7	91.6	100.7	102.0	103.5	105.2	107.0	108.9
			2023	62.15	59.0	56.0	45.9	45.3	43.0	42.1	41.2	40.3	39.3	38.3
			Difference	2.67	3.41	3.69	-24.74	-46.31	-57.64	-59.88	-62.36	-64.92	-67.65	-70.55
			in %	4.5%	6.1%	7.1%	-35.0%	-50.6%	-57.3%	-58.7%	-60.2%	-61.7%	-63.3%	-64.8%

6.6.6 Category-specific planned improvements (4.C)

In addition to the planned, soil-relevant measures listed in Chapter 6.1.2.1.9, most of which are medium-term measures, no specific measures for improvement of methods in the area of Grassland are currently planned.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	**4 D, Wetlands**		**CO_2**	**3,692.2**	**0.3 %**	**4,713.8**	**0.6 %**	**27.7 %**
L/T	**4 D, Wetlands**		**CH_4**	**5,325.9**	**0.4 %**	**5,498.0**	**0.7 %**	**3.2 %**
-/-	4 D, Wetlands		N_2O	30.2	0.0 %	39.0	0.0 %	29.2 %

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 source category *Wetlands* is a key category for CO_2 and CH_4 emissions in terms of emissions level and trend.

The Wetlands category includes Germany's peatlands and other wetlands that cannot be allocated to any of the other land-use categories. In the present report, these lands are combined under the umbrella term *Terrestrial wetlands* (other wetlands), and *Natural water bodies, Standing man-made water bodies*, such as fish-breeding points and reservoirs, *Flowing man-made water bodies*, such as drainage ditches and canals for water-resources management, and areas for *Peat extraction*, 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 conversion categories that, pursuant to the 2006 IPCC Guidelines (IPCC, 2006b), the 2013 IPCC Wetland Supplements (IPCC et al., 2014b) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019), are to be reported on, are presented in Chapter 6.2.4.

The results of the emissions calculations, and the upper and lower bounds of the 95 % confidence intervals, for the year 2021 are shown in Table 414, while the emissions trends, differentiated by categories and sub-categories, are presented in Figure 79 and Figure 80.

Table 414: CO_2, N_2O and CH_4 emissions [kt CO_2-eq. pursuant to IPCC AR5] from Germany's Wetlands, 2021.

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$_{total}$		**2,903.2**	1,641.6	4,201.7	42.44	47.31
Mineral soils	CO_2	**-29.2**	-25.78	-32.30	10.85	11.69
	$N_2O_{indirect}$ 1)	**0.04**	0.00	0.14	105.70	260.38
	N_2O_{direct}	**0.18**	0.06	0.50	66.45	182.32
Organic soil	CO_2	**2,169.1**	823.94	3,652.1	62.01	68.37
	N_2O	**32.28**	7.88	97.68	75.60	202.57
	CH_4	**524.94**	197.05	950.30	62.46	81.03
Biomass	CO_2	**144.7**	143.22	146.16	1.01	1.03
Litter / dead wood	CO_2	**61.2**	54.50	67.84	10.90	10.90
Sub-category / Pool	**GHG**	**Natural water bodies [kt CO_2-eq.] Emission**	**2.5 perc.**	**97.5 perc.**	**[%] 2.5 perc.**	**97.5 perc.**
Waters$_{total}$		**45.0**	17.58	62.44	56.05	56.05
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)	**44.81**	19.69	69.94	56.05	56.05
Biomass	CO_2	NO	NO	NO	NO	NO
Litter / dead wood	CO_2	NO	NO	NO	NO	NO

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$_{total}$		**2,377.5**	1,481.4	3,275.6	36.71	36.71
Mineral soils	CO_2	NO	NO	NO	NO	NO
	N_2O_{direct}	NO	NO	NO	NO	NO
Organic soil	CO_2	**2,328.6**	1,456.0	3,201.3	37.48	37.48
	N_2O	**6.51**	3.26	9.76	49.92	49.92
	CH_4	**2.88**	1.21	5.26	57.83	82.85
Biomass	CO_2	**37.3**	20.12	54.86	46.03	47.17
Litter / dead wood	CO_2	**2.2**	0.59	3.79	73.0	73.0
Man-made standing water bodies						
Sub-category / Pool	**GHG**	**[kt CO_2-eq.]**	**[%]**			
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Man-made standing water bodies$_{total}$		**4,651.2**	1,705.2	6,391.8	58.94	53.91
Mineral soils	CO_2	**NO**	NO	NO	NO	NO
	N_2O_{direct}	**NO**	NO	NO	NO	NO
	CH_4	**4,648**	1,702.94	6,389.50	58.97	53.94
Organic soil	CO_2	**NO**	NO	NO	NO	NO
	N_2O	**NO**	NO	NO	NO	NO
	CH_4	**2.57**	2.57	2.57	0.02	0.02
Biomass	CO_2	**NO**	NO	NO	NO	NO
Litter / dead wood	CO_2	**NO**	NO	NO	NO	NO
Man-made flowing water bodies						
Sub-category / Pool	**GHG**	**[kt CO_2-eq.]**	**[%]**			
		Emission	**2.5 perc.**	**97.5 perc.**	**2.5 perc.**	**97.5 perc.**
Man-made flowing water bodies$_{total}$		**274.2**	121.1	414.9	50.54	69.49
Mineral soils	CO_2	**NO**	NO	NO	NO	NO
	N_2O_{direct}	**NO**	NO	NO	NO	NO
	CH_4	**274.16**	135.60	464.67	50.54	69.49
Organic soil	CO_2	**NO**	NO	NO	NO	NO
	N_2O	**NO**	NO	NO	NO	NO
	CH_4	**NO**	NO	NO	NO	NO
Biomass	CO_2	**NO**	NO	NO	NO	NO
Litter / dead wood	CO_2	**NO**	NO	NO	NO	NO

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 2021, a total of 10,251 kt CO_2-Eq. pursuant to IPCC AR5 was released from *Wetlands*. As Table 414 shows, the emissions in the land-use category *Wetlands* consist mainly of CO_2 releases from organic soils (46.5 %) and of methane emissions from flowing and standing man-made water bodies (45.9 %). The CO_2 releases consist of two major components of about equal size: CO_2 emissions from peat extraction (51.8 %) and CO_2 emissions from drainage of terrestrial organic soils (48.2 %). Releases of nitrous oxide (0.45 %) are low, relative to the sum total of all emissions, as are CO_2 releases from biomass (1.9 %). Emissions from mineral soils are negative and, therefore, function as a sink. Their share of overall emissions is very small, however (- 0.3 %).

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 2021, the latter amounted to 2,226.1 ± 896.6 kt CO_2-eq. pursuant to IPCC AR5, and thus were the main factor responsible for the magnitude of total emissions from peat extraction (93.6 %). The on-site emissions, at 87.1 kt CO_2-eq. pursuant to IPCC AR5, are low by comparison. They are dominated by CO_2 (91.8 %), followed by methane (2.4 %) and nitrous oxide (5.8 %).

As the time series in Figure 79 and Figure 80 show, total emissions increased in 2021 with respect to the base year (14.0 %), as the result of an interim intensification of conversion of grassland, forest land and settlement areas. The emissions increase is due mainly to increases in the pools a) organic soils and b) methane from *Flowing man-made water bodies* and *Standing* *man-made water bodies* (Figure 79). The trend curve is shaped primarily by emissions from peat extraction, from man-made water bodies, and from organic soils, in the sub-category *Terrestrial Wetlands*. While the former emissions reflect the annual quantities of peat that are produced, and – like the methane emissions from water bodies – have remained about the same over the years, emissions from organic soils in the sub-category *Terrestrial Wetlands* have increased sharply (+41.4 %).

Figure 79: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq. pursuant to IPCC AR5] as a result of land use and land-use changes in Wetlands, 1990-2021, by sub-categories

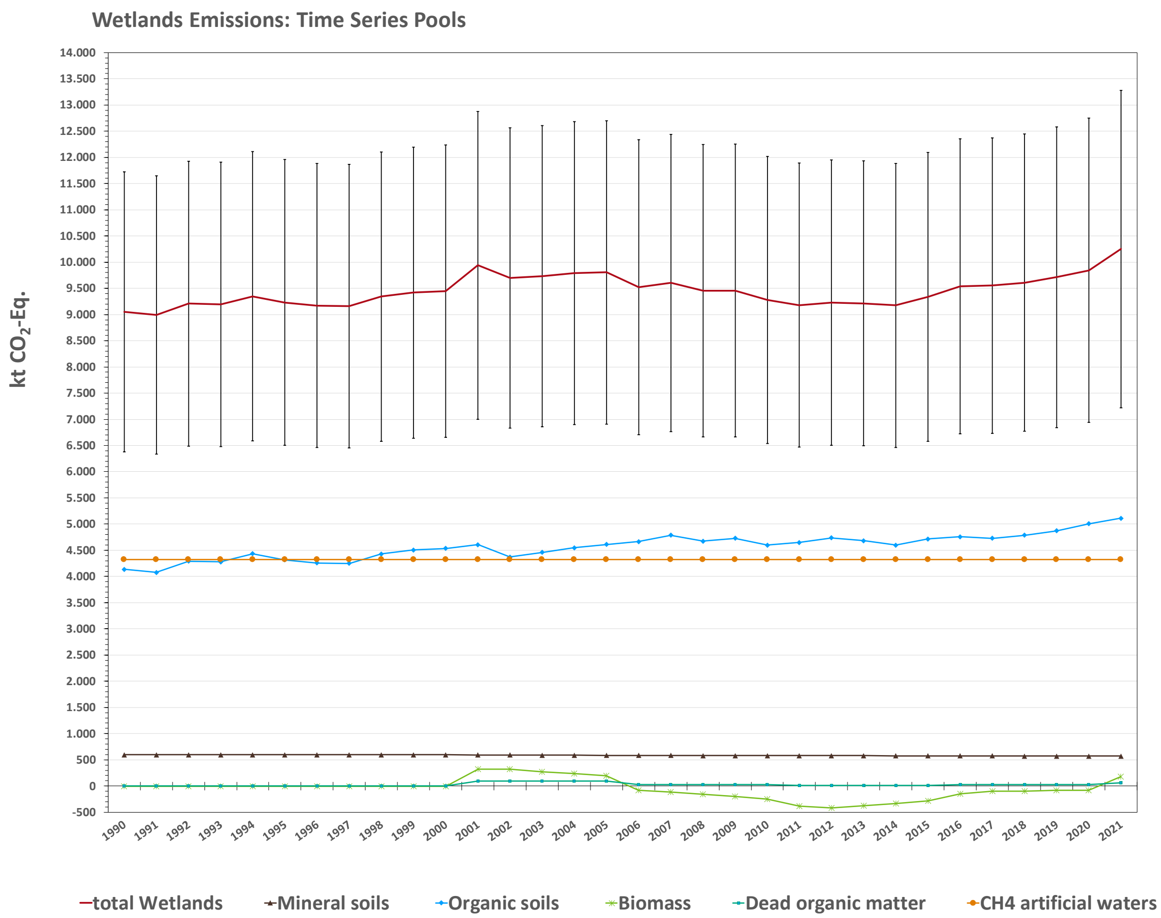
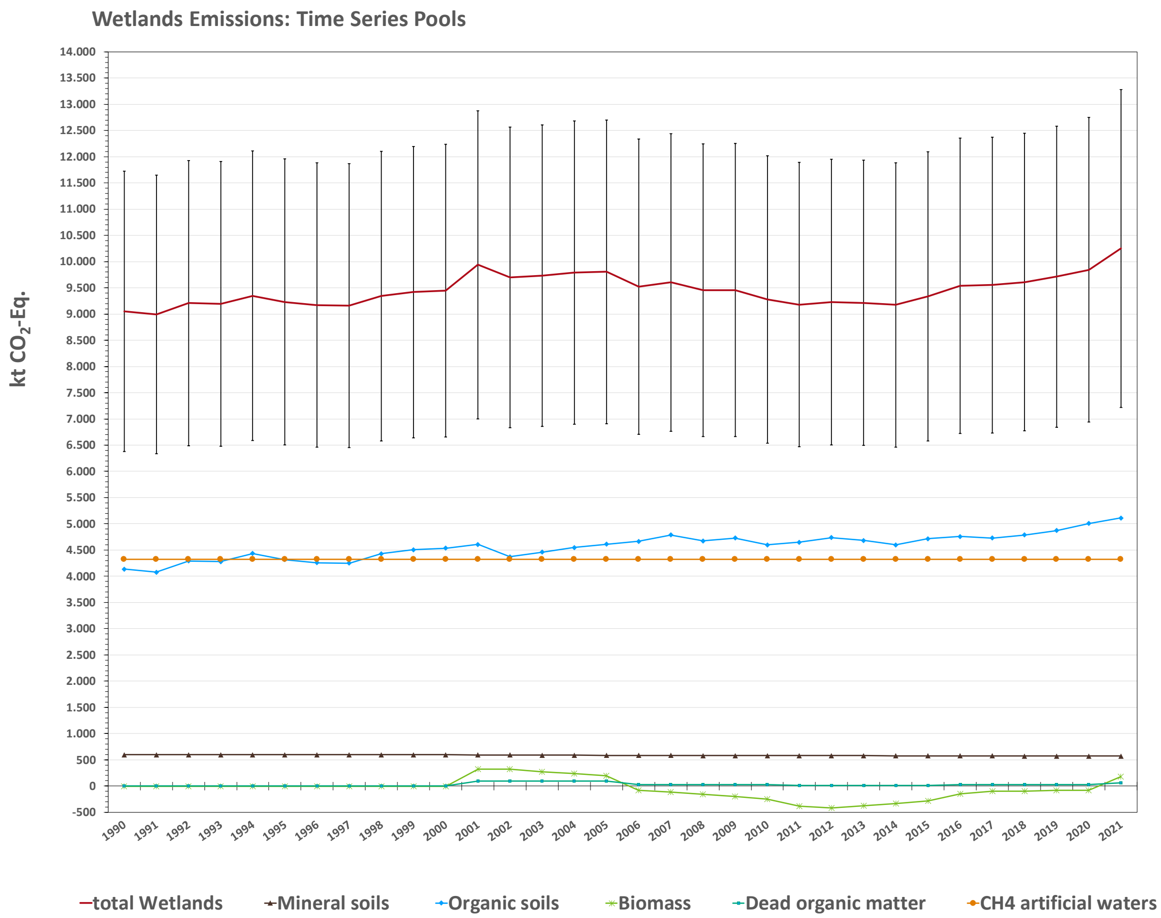


Figure 80: Greenhouse-gas emissions (total of CO_2, CH_4 and N_2O) [kt CO_2-eq. pursuant to IPCC AR5] as a result of land use and land-use changes in Wetlands, 1990-2021, by pools



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 6.1.2ff, Chapter 6.2.4 and Chapter 6.3.2.

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 6.1.2.3ff.

The implied emission factors and pertinent uncertainties are presented in Table 416 (Chapter 6.7.2.6).

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 416 (Chapter 6.7.2.6).

6.7.2.4 Organic soils

The emissions have been calculated in keeping with the methods described in Chapter 6.1.2.2.

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, 2006b). 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, 2006b)

$$CO_2\text{-eq.}_{peat\ extraction} = CO_2\text{-eq.}_{on\text{-}site} + CO_2\text{-eq.}_{off\text{-}site}$$

$CO_2\text{-eq.}_{peat\ extraction}$: GHG emissions from peat extraction [t CO^2-eq. a^{-1}]

$CO_2\text{-eq.}_{on\text{-}site}$: GHG emissions that occur on-site, during production [t CO_2-eq. a^{-1}]

$CO_2\text{-eq.}_{off\text{-}site}$: 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, 2006b) was modified in the following manner:

$$CO_2\text{-eq.}_{on\text{-}site} = A_{peat,\ oligotrophic} \times (EF_{peat,\ oligotrophic\_CO2} + EF_{peat,\ oligotrophic\_N2O} + EF_{peat,\ oligotrophic\_CH4})$$

$CO_2\text{-eq.}_{on\text{-}site}$: 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, 2006b):

$$CO_2\text{-eq.}_{off\text{-}site} = Vol_{peat\_dry} \times Cfraction_{vol\_peat}$$

$CO_{2off\text{-}site}$: 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 (2006b), Tab. 7.5)]

The emission factors for the on-site emissions are listed in Table 419 (Chapter 6.7.2.6). The off-site emissions, calculated from the quantities of peat produced, and the IEF for the off-site emissions, are shown in Table 415.

Table 415: 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	97.90	2,029.5 ± 795.6
1995	106.25	2,203.9 ± 863.9
2000	116.43	2,416.2 ± 947.2
2005	104.97	2,179.6 ± 854.4
2010	101.17	1,991.5 ± 780.7
2011	105.42	2,030.5 ± 796.0
2012	111.82	2,106.0 ± 825.6
2013	110.87	2,042.0 ± 800.5
2014	108.50	1,952.7 ± 765.5
2015	117.52	2,066.4 ± 810.0
2016	122.71	2,069.5 ± 811.2
2017	124.30	2,007.6 ± 787.0
2018	131.82	2,035.9 ± 798.1
2019	142.50	2,097.2 ± 822.1
2020	157.89	2,212.9 ± 867.5
2021	164.75	2,226.1 ± 896.6

6.7.2.6 Waters

In this submission, methane emissions from *Standing man-made water bodies* and *Flowing man-made water bodies* are being reported for the first time, The reporting is in keeping with the 2006 IPCC Guidelines (IPCC, 2006a) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019b).

Chapter 6.1.2.6 and Chapter 6.2.4 outline the manner in which the land-use category *Waters* is subdivided, and present descriptions of the relevant sub-categories and of the methods used to obtain activity data and derive emission factors.

In keeping with the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019b), only methane emissions are reported. They are determined only for the sub-categories *Standing man-made water bodies* and *Flowing man-made water bodies*. The results are recorded in CRF Table 4.(II).D. Emissions from *Natural water bodies* do not have to be reported. For this reason, the notation key NO is entered into the relevant fields in CRF Table 4.(II).D.

Pursuant to the reporting rules, emissions from drainage ditches on organic soils do not fall within the land-use category *Flowing man-made water bodies*. In keeping with the current utilisation of drained peatlands, they are listed in CRF Tables 4.(II).A/B/C or H.

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 416 and Table 419, 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 0.38 %.

The total uncertainty for emissions in the land-use category *Wetlands* is -27.4 % / +29.6 % [95% percentile], while that for the sub-category *Terrestrial Wetlands* is -42.4 % / +47.3 %; that for *Wetlands* is -56.1 % / +56.1 %; and that for *Peat extraction* is +37.1% / +37.1%.

The *Wetlands* category's contribution to the total uncertainty in the LULUCF sector, at 2 %, is small. Nonetheless, the relevant values in connection with methane emissions from water bodies, and emissions from *Peat extraction* and organic soils, in the sub-category *Terrestrial wetlands*, are clearly noticeable.

Table 416: Implied emission factors and uncertainties [in % of central tendency] used for calculation of GHG emissions from Terrestrial Wetlands for 2021, 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[117]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land		0.7405	23.12	23.12
$Cropland_{annual}$		1.7085	45.75	46.73
Hops		0.0000	9.33	9.33
Vineyards		0.0000	10.41	10.41
Orchards		0.4703	99.99	196.23
Short-rotation plantations		0.0000	9.33	9.33
Tree nurseries		0.0000	9.33	9.33
Christmas tree plantations	$Wetlands_{terrestrial}$	0.0000	9.33	9.33
$Grassland_{i.t.s.s.}$		1.0632	14.66	16.37
Woody Grassland		1.0980	26.02	27.02
Hedges		0.0000	7.58	10.52
Waters		0.0000	13.25	13.25
Peat extraction		/	/	/
Settlements		2.0488	62.51	62.51
Other Land		2.6900	3.69	4.69
Mineral soil, N_2O_{direct}[118]		[kg N_2O ha^{-1} a^{-1}]	[kg N_2O ha^{-1} a^{-1}]	[%]
$Grassland_{i.t.s.s.}$	$Wetlands_{terrestrial}$	0.0712	66.45	182.32
Mineral soil, $N_2O_{indirect}$[119]		[kg N_2O ha^{-1} a^{-1}]	[kg N_2O ha^{-1} a^{-1}]	[%]
$Grassland_{i.t.s.s.}$	$Wetlands_{terrestrial}$	0.0160	99.99	260.38

117 Calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

118 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink,

119 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink,

Wetlands$_{terrestrial}$ Initial land use	Final land use	Implied emission factors	Uncertainty bounds lower	upper
Mineral soils CO_2-C[117]		[t C ha^{-1} a^{-1}]	[%]	[%]
Biomass[120]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Wetlands$_{terrestrial}$	-2.0832	29.49	30.12
Cropland$_{annual}$		0.5859	53.67	54.69
Hops		0.0000	42.49	43.84
Vineyards		0.0000	40.26	41.54
Orchards		2.2290	99.99	198.48
Short-rotation plantations		0.0000	14.71	15.77
Tree nurseries		0.0000	27.94	28.70
Christmas tree plantations		-6.3989	99.99	142.35
Grassland (in the strict sense)		1.1837	42.02	43.32
Woody Grassland		-9.5297	42.92	43.62
Hedges		-42.5599	90.23	90.56
Wetlands$_{terrestrial}$		0.0000	0.00	0.00
Waters		0.0000	47.94	49.47
Peat extraction		2.9168	50.31	51.76
Settlements		0.3998	51.06	51.86
Other Land		0.0000	99.99	162.30
Dead organic matter		[t C ha^{-1} a^{-1}]	[t C ha^{-1} a^{-1}]	[%]
Forest Land	Wetlands$_{terrestrial}$	-1.7009	10.90	10.90

Positive: sink; negative: Source

Table 417: Emission factors and uncertainties [in % of central tendency] used for calculation of GHG emissions from peat extraction in 2021, for the pertinent biomass

Peat extraction Initial land use	Final land use	Implied emission factors	Uncertainty bounds upper	lower
Biomass[121]		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Peat extraction	-3.1937	84.51	84.51
Cropland$_{annual}$		-0.7570	31.32	31.32
Hops		0.0000	16.54	16.54
Vineyards		0.0000	18.95	18.95
Orchards		0.0000	14.41	14.41
Short-rotation plantations		0.0000	8.12	10.30
Tree nurseries		0.0000	23.39	23.39
Christmas tree plantations		-2.7884	99.99	114.13
Grassland (in the strict sense)		-0.5864	33.52	33.52
Woody Grassland		-3.1555	99.99	149.32
Hedges		0.0000	99.99	203.73
Wetlands$_{terrestrial}$		-5.2946	53.02	54.40
Waters		0.0000	0.00	0.00
Settlements		-4.2429	99.99	107.36
Other Land		0.0000	0.00	0.00
Dead organic matter		[t C ha^{-1} a^{-1}]	[%]	[%]
Forest Land	Peat extraction	-3.1937	73.00	73.00

Positive: sink; negative: Source

120 Calculation only for the first year following the pertinent land-use change

121 Calculation only for the first year following the pertinent land-use change

Table 418: Uncertainties for emission factors [2.5 and 97.5 percentile, in % of central tendency] for emissions from water bodies, 2021, pursuant to IPCC AR5

Land use	GHG	Implied emission factor	Uncertainty bounds	
			upper	lower
		[t CO_2-eq. ha^{-1} a^{-1}]	[%]	[%]
Man-made standing water bodies	CH_4	382.3546	15.67	19.18
Fish ponds	CH_4	5,533.92	63.39	57.98

Table 419: Uncertainties for emission factors [2.5 and 97.5 percentile, in % of central tendency] for emissions from organic soils, for Wetlands and Peat extraction, 2021, pursuant to IPCC AR5

Land use	GHG	Emission factor	Uncertainty bounds	
			lower	upper
Organic soil[122]		[t CO_2-eq. ha^{-1} a^{-1}]	%	%
Wetlands$_{terrestrial}$	CO_2	19.1803	62.01	68.37
Wetlands$_{terrestrial}$	N_2O	0.2855	75.60	202.57
Wetlands$_{terrestrial}$	CH_4	4.6418	62.46	81.03
Peat extraction	CO_2	133.6362	8.14	9.25
Peat extraction	N_2O	0.3736	49.92	49.92
Peat extraction	CH_4	0.1651	57.83	82.85

The calculations are spatially and chronologically consistent and complete for the entire reporting period, 1990 – 2021.

6.7.4 Category-specific QA/QC 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.

Table 420 presents an intra-European comparison of implied emission factors (IEF) for various pools of the category *Wetlands*. For this comparison, values of neighbouring countries, obtained from the 2022 Submission to the Climate Secretariat (UNFCCC NIR Submission 2022: Inventory year 2020, (UNFCCC, 2022b)), were used. The values for Germany, 2021, were obtained from the current 2023 submission.

The comparison is problematic from the outset, because the values to be compared were not all obtained with the same methods (in come cases, the methods differ widely) and, especially, because the demarcations of the systems differ – in some cases, markedly. In Germany*,* and in the context of this comparison*, Wetlands* refers to the sum of the sub-categories *Terrestrial wetlands*, *Natural water bodies*, *Standing man-made water bodies*, *Flowing man-made water bodies* and *Peat extraction*. This category composition is not found consistently in all of the countries concerned, and thus comparisons of average emission factors are problematic. Nonetheless: Most of the EF

122 Annual calculation; emission: positive ≙ source; negative ≙ sink

are similar, in terms of both absolute size and trends, to those of various central European neighbouring countries.

Table 420: Carbon-stock changes in various pools, in wetlands of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-1.121	-0.068	1.505	NO
Denmark	NO,NA	NO,NA	-0.478	NO	NO	NO	NE
France	NA	NA	NE,NA	-0.484	-0.054	NO	NE
UK	0.000	NO,NE,NA	-0.103	NA	NA	NA	NE
Netherlands	NO,NA	NO,NA	NO	NA	NA	0.001	NO
Austria	NO,NE	NO,NE	NO,NE	-0.468	-0.153	NO	NO
Poland	NO	NO	-0.194	-0.227	-7.974	NO,NA	NO,NA
Switzerland	0.000	NO,IE	-4.853	0.004	NO	0.047	-5.300
Czech Republic[1)]	NA	NA	NA	NA	NA	NA	NA
Germany, 2020	0.01	IE	-6.63	-0.24	-0.10	0.11	-3.88
Germany, 2021	0.007	IE	-3.503	0.347	-0.142	1.041	-4.756

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

[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 2021. 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:

- Complete reimplementation of the LULUCF calculation model in the programming languages R and C++
- Thematic, spatial and chronological 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)
- Introduction of the new land-use sub-categories *natural water bodies, standing man-made water bodies, flowing man-made water bodies*, and *hedges*
- Introduction of new, regionalised emission factors for mineral soils in the sub-category *buildings and open areas* of the land-use category *Settlements* (cf. Chapter 6.1.2.1.6) and the land-use category *Other Land* (cf. Chapter 6.1.2.1.7)
- Implementation of complete-coverage, high-resolution maps of regionalised mineral-soil carbon and nitrogen stocks, for the land-use categories *Cropland$_{annual}$*, *Grassland* and *Forest Land*, within the method for determining GHG emissions from mineral soils (cf. Chapter 6.1.2.1ff)

In Table 421 (areas) and Table 422 (emissions), the results of the current recalculations for the Wetlands category are compared with the corresponding results in the previous year's submission.

The differences between the area data of the current submission and those of the previous year's submission are due mainly to the following two factors:

- Introduction of the new land-use sub-categories

Reprogramming of the calculation model, along with updating of the map data for determination of activity data, via integration of the 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 with regard to emissions, between the current submission and the previous year's submission, are more pronounced in the *Wetlands* category than they are in other categories. As Table 422 shows, methane emissions in particular are many times higher. This is due to the introduction of new water-body categories, and to first-time recording of emissions these new categories.

The differences with regard to N_2O emissions, which are also pronounced, are due mainly to the introduction of maps of the carbon and nitrogen stocks in mineral soils. The carbon stocks of mineral soils in other land-use categories are no longer consistently smaller than they are in the sub-category *Terrestrial wetlands*. For this reason, N_2O emissions related to land-use changes leading to *Terrestrial wetlands* are being determined for the first time. This effect is multiply offset, however, as are the effects with regard to CO emissions, for which this overlapping leads to only small changes in the sum total of emissions. The causal factors with impacts that overlap in a combined presentation include the following, for example:

- Minor changes in the areas (Table 421),
- Differences in water levels in organic soils,
- Regionalisation effects from introduction of the soil maps.

Table 421: 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	2020
4.D	Wetlands	2022	648.15	649.78	651.45	676.47	707.20	728.30	730.99	733.68	736.41	739.15	741.86
		2023	777.84	777.85	777.84	791.64	798.74	801.15	802.34	803.53	804.71	805.90	807.08
		Difference	129.69	128.07	126.39	115.17	91.54	72.86	71.35	69.84	68.30	66.75	65.22
		in %	20.0%	19.7%	19.4%	17.0%	12.9%	10.0%	9.8%	9.5%	9.3%	9.0%	8.8%

Table 422: Comparison of greenhouse-gas emissions [kt CO_2-eq with GWP pursuant to IPCC AR5] 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	2020
4.D	Wetlands	CO_2	2022	1,607.78	1,614.01	1,620.04	2,053.76	2,028.24	1,992.79	2,036.03	2,058.72	2,083.26	2,103.80	2,120.29
			2023	1,670.74	1,677.42	1,683.56	2,011.37	2,070.80	2,079.62	2,132.63	2,157.62	2,177.48	2,190.15	2,194.03
			Difference	62.96	63.41	63.52	-42.38	42.56	86.83	96.60	98.90	94.22	86.35	73.74
			in %	3.9%	3.9%	3.9%	-2.1%	2.1%	4.4%	4.7%	4.8%	4.5%	4.1%	3.5%
		CH_4	2022	335.1	336.0	337.1	453.6	547.0	608.5	619.0	632.0	647.1	664.3	683.7
			2023	4,755.2	4,756.0	4,756.8	4,818.0	4,853.2	4,865.1	4,865.7	4,868.7	4,874.3	4,882.2	4,891.7
			Difference	4,420.2	4,420.0	4,419.7	4,364.4	4,306.2	4,256.5	4,246.7	4,236.8	4,227.2	4,217.9	4,208.0
			in %	1,319.2%	1,315.3%	1,311.2%	962.1%	787.2%	699.5%	686.0%	670.4%	653.2%	635.0%	615.5%
		N_2O	2022	102.54	117.53	120.67	640.77	252.55	136.91	62.96	115.48	131.61	149.94	161.25
			2023	25.85	26.73	25.11	222.42	-213.84	-251.79	-110.87	-59.92	-59.41	-37.43	-35.04
			Difference	-76.69	-90.80	-95.56	-418.35	-466.39	-388.70	-173.83	-175.40	-191.02	-187.38	-196.29
			in %	-74.8%	-77.3%	-79.2%	-65.3%	-184.7%	-283.9%	-276.1%	-151.9%	-145.1%	-125.0%	-121.7%

6.7.6 Category-specific planned improvements (4.D)

The following short-term measures for inventory improvement are planned for the land-use category *Wetlands*:

- Implementation of regionalised carbon and nitrogen stocks for mineral soils in the land-use category *Terrestrial wetlands*

- Consolidation of activity data sets for the sub-categories *Standing man-made water bodies* and *Flowing man-made water bodies*

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/T	**4 E, Settlements**		**CO_2**	**1,251.4**	**0.1 %**	**1,472.9**	**0.2 %**	**17.7 %**
-/-	4 E, Settlements		CH_4	18.8	0.0 %	28.4	0.0 %	50.9 %
-/-/2	**4 E, Settlements**		**N_2O**	**122.7**	**0.0 %**	**255.8**	**0.0 %**	**108.4 %**

* 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 source category *Settlements*is a key category for CO_2 emissions in terms of trend, and a key category for N_2O emissions pursuant to method 2 analysis.

It is subdivided into the sub-categories *Buildings and open areas* und *Roads* (Chapter 6.2.5). Emissions are reported only from *Buildings and open areas*, since the sub-category *Roads* only include fully sealed, vegetation-free areas.

Reporting for the land-use category Buildings and open areas covers 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 423 and in Figure 81 and Figure 82.

Table 423: CO_2, N_2O and CH_4 emissions [kt CO_2-eq. pursuant to IPCCAR5] from Germany's Settlements, 2021. The table includes both the relevant sums and the upper and lower bounds of the 95 % confidence interval.

Category	GHG	Emissions, Settlements, 2021 [kt CO_2-eq.] Emission	2.5 perc.	97.5 perc.	[%] 2.5 perc.	97.5 perc.
$Settlements_{total}$ 1)		**1,757.1**	1,376.0	2,264.4	15.64	15.04
Mineral soils	CO_2 2)	**1,318.7**	1,173.9	1,519.6	10.98	15.24
	$N_2O_{indirect}$ 4)	**27.00**	9.65	70.43	64.25	160.84
	N_2O_{direct} 3)	**120.00**	72.90	254.88	39.25	112.39
Organic soil	CO_2 2)	**1,940.6**	1,288.2	2,266.5	33.62	16.79
	N_2O 5)	**108.77**	44.37	372.21	59.21	242.19
	CH_4 5)	**28.40**	18.96	43.27	33.26	52.35
Biomass	CO_2 2)	**-2,252.94**	-1,682.94	-2,840.70	25.30	26.09
Litter / dead wood	CO_2 2)	**466.5**	437.11	495.94	6.30	6.30

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 2021, the greenhouse-gas emissions emitted from Germany's settlement and transport areas, as a result of land use and land-use changes, amounted to 1,757,1 kt CO_2-Eq. pursuant to IPCC AR5 (Table 423). This figure represents the sum of positive emissions (source) from soils (3,543.5 kt CO_2-Eq. pursuant to IPCC AR5; fraction for organic soils: 58.5 %; fraction for mineral soils: 41.5 %) and dead organic matter (466.5 kt CO_2-Eq.) and of negative emissions (sink) from biomass (-2,252.9 kt CO_2-Eq.), which functioned as a powerful sink in 2021.

With respect to the base year, emissions in 2021 show a net increase of -27 % (Figure 81, Figure 82). 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 conversion between data sources (repeatedly described above) – CORINE (1990 - 2000), B-DLM of ATKIS® (2000 - 2021) (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 81: GHG emissions [kt CO_2-eq. pursuant to IPCC AR5] resulting from land use and land-use changes, from Settlements, 1990 – 2021, by sub-categories

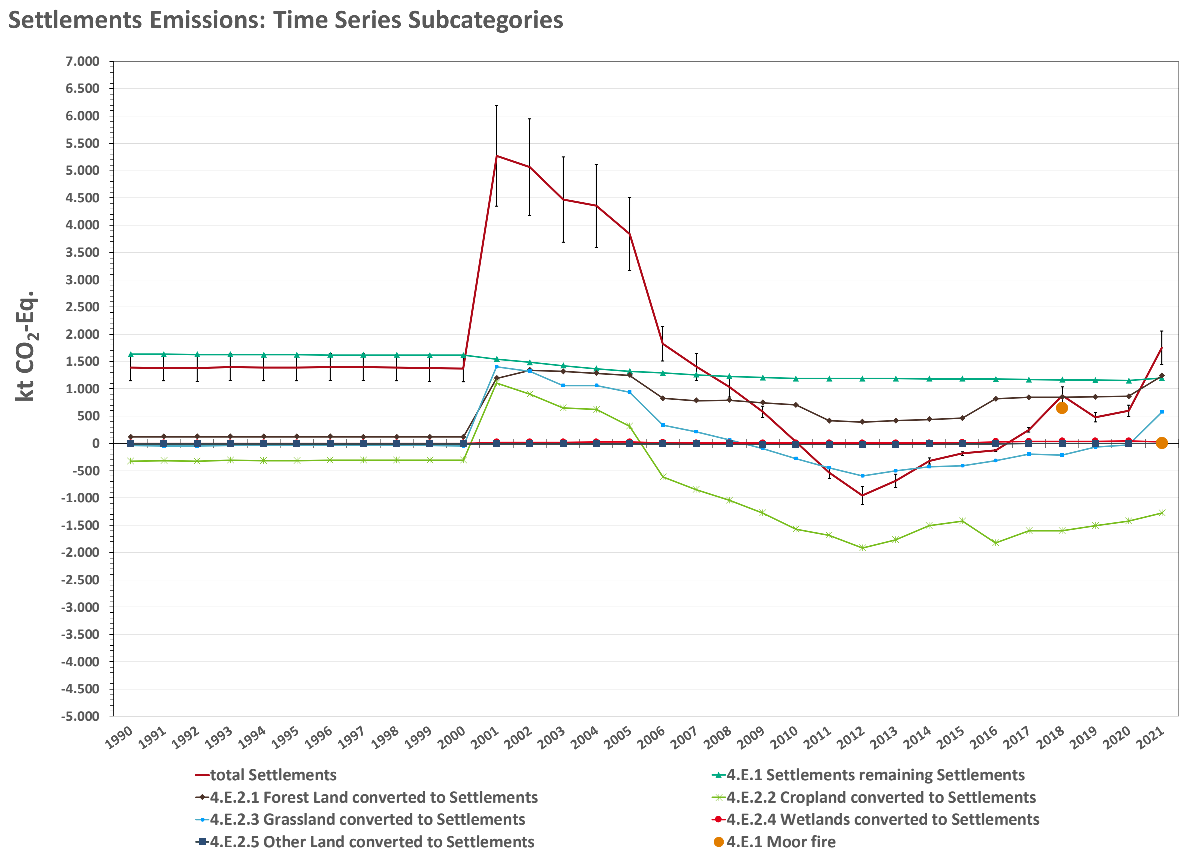
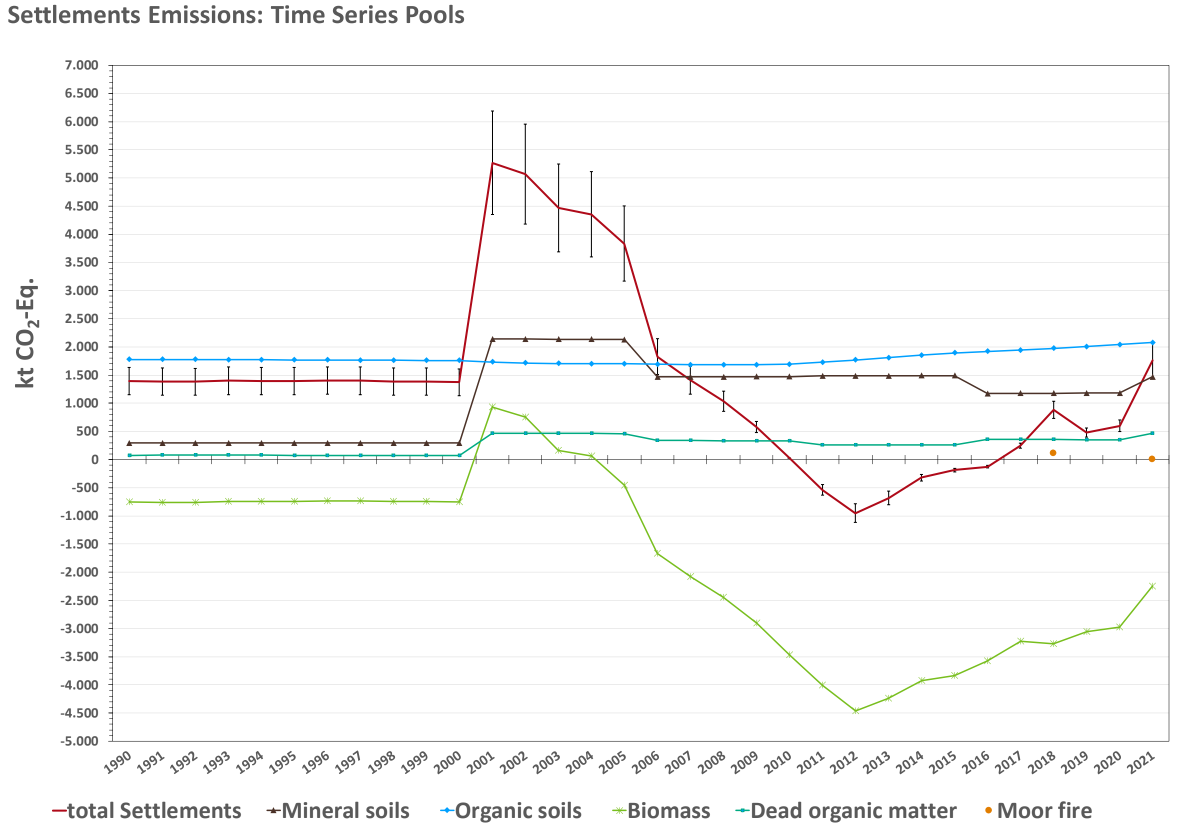


Figure 82: GHG emissions [kt CO_2-eq. pursuant to IPCC AR5] resulting from land use and land-use changes, from Germany's Settlements, 1990 – 2021, by pools



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

The method for calculation of biomass 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 *Buildings and open areas*, 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.

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). 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 %. For this reason, the CO_2 and CH_4 emissions from organic soils that have been calculated for *Buildings and open areas* have been reduced only by 15 %, and the emission factor for nitrous oxide, with the new area factor, has been corrected to 3.91 kg N_2O-N ha^{-1}.

In the case of land-use conversions to *Buildings and open areas*, the value for remaining *Buildings and open areas* is immediately applied.

6.8.2.5 Wildfires

No human-caused wildfires occurred in 2021 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 *Buildings and open areas* are shown in Table 424 and Table 425.

The uncertainties for the activity data, for the year 2021, range from 0.1% to 98 %, depending on the size of the area concerned. The total uncertainty for the activity data in the Settlements category is 0.09 %.

The total uncertainty for the land-use category *Settlements* is -15.6 % / +15.0% (95-% percentile). It is shaped primarily by the uncertainty for emissions from organic soils.

Table 424: Implied emission factors, and their uncertainties [in % of central tendency], used for calculation of GHG emissions from Buildings and open areas for 2021, by pools and sub-categories

Settlements Initial land use Mineral soils CO_2-C[123]	Area Final land use	Emission factor [t C ha^{-1} a^{-1}]	Uncertainty bounds upper [%]	 lower [%]
Forest Land	Buildings and open areas	-0.6517	21.79	21.79
Cropland$_{annual}$		-0.2040	19.07	32.08
Hops		-0.4748	90.32	90.32
Vineyards		-0.2033	32.12	32.12
Orchards		-0.2287	27.53	27.53
Short-rotation plantations		-0.2326	49.29	49.29
Tree nurseries		-0.5412	26.41	26.41
Christmas tree plantations		-0.3547	25.26	28.41
Grassland in the strict sense		-0.4754	18.97	25.34
Woody Grassland		-0.8771	19.47	25.72
Hedges		-8.3778	32.70	36.76
Terr. Wetlands		-0.8112	55.57	55.57
Waters		0.0000	18.74	18.74
Other Land		-0.0046	69.60	69.60

123 Calculation covers a 20-year period; stock change: positive ≙ sink; negative ≙ source

Settlements **Initial land use**	**Area** **Final land use**	**Emission factor**	**Uncertainty bounds** **upper**	**lower**
Mineral soil, N_2O_{direct}[124]		**[kg N_2O ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	Buildings and open areas	0.1280	99.99	287.04
$Cropland_{annual}$		0.0599	99.99	287.57
Hops		0.1553	99.99	300.35
Vineyards		0.0686	99.99	288.53
Orchards		0.0740	99.99	287.86
Short-rotation plantations		0.0728	99.99	291.62
Tree nurseries		0.1720	99.99	288.53
Christmas tree plantations		0.1125	99.99	288.52
Grassland (in the strict sense)		0.1435	99.99	287.21
Woody Grassland		0.2662	99.99	287.24
Hedges		2.4455	99.99	288.44
Terr. Wetlands		0.2303	99.99	291.89
Other Land		0.0016	99.99	301.48
Mineral soil, $N_2O_{indirect}$[125]		**[kg N_2O ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	Buildings and open areas	0.5690	70.35	200.42
$Cropland_{annual}$		0.2661	70.10	201.18
Hops		0.6902	99.99	219.06
Vineyards		0.3048	77.01	202.56
Orchards		0.3288	74.45	201.60
Short-rotation plantations		0.3238	86.89	206.93
Tree nurseries		0.7645	75.89	202.55
Christmas tree plantations		0.4998	75.86	202.54
Grassland (in the strict sense)		0.6377	70.06	200.66
Woody Grassland		1.1831	70.19	200.71
Hedges		10.8688	74.95	202.42
Terr. Wetlands		1.0234	88.25	207.31
Other Land		0.0073	99.99	220.61
Biomass[126]		**[kt C ha^{-1} a^{-1}]**		**[%]**
Forest Land	Buildings and open areas	-1.4803	32.09	32.99
$Cropland_{annual}$		1.1223	45.80	47.25
Hops		1.9993	99.29	100.00
Vineyards		1.9993	99.29	100.00
Orchards		0.9541	49.28	50.58
Short-rotation plantations		1.6207	52.49	52.85
Tree nurseries		1.1613	40.93	41.71
Christmas tree plantations		1.1094	43.51	44.39
Grassland in the strict sense		1.0333	45.91	47.37
Woody Grassland		-3.5984	40.03	40.77
Hedges		-53.3542	47.49	48.12
Terr. Wetlands		0.4450	46.21	47.10
Waters		0.0000	50.92	52.55
Peat extraction		1.9281	99.99	102.20
Other Land		0.5625	55.98	57.47
Dead organic matter[127]		**[kt C ha^{-1} a^{-1}]**	**[%]**	**[%]**
Forest Land	Buildings and open areas	-1.4230	6.30	6.30

Table 425: Uncertainties for emission factors [2.5 and 97.5 percentile, in % of central tendency] for emissions from organic soils under settlements, 2021, pursuant to IPCC AR5

Land use **Organic soil**[128]	**GHG**	**Emission factor** **[t CO_2-eq. ha^{-1} a^{-1}]**	**Uncertainty bounds** **lower** **[%]**	**upper** **[%]**
Buildings and open areas	CO_2	28.8162	33.62	16.79
Buildings and open areas	CH_4	0.4218	33.26	52.35
Buildings and open areas	N_2O	1.6152	59.21	242.19

124 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

125 Calculation covers a 20-year period; emission: positive ≙ source; negative ≙ sink

126 Calculation only for first year of land-use change, stock change: positive ≙ sink; negative ≙ source

127 Calculation only for first year of land-use change; stock change: positive ≙ sink; negative ≙ source

128 Annual calculation; emission: positive ≙ source; negative ≙ sink

6.8.4 Category-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 2022 submissions to the Climate Secretariat. The values for Germany were obtained from the 2022 and 2023 submissions.

The biomass IEF given in the present submission show the conversion categories to be a sink overall; only the "from Forest Land" conversion 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.

Basically, the IEF for the other pools do not differ widely, in terms of trend and level, from those of neighbouring countries. In cases where they are at the edge of the relevant range, an equivalent figure in at least one other central European neighbouring country can always be found.

Table 426: Carbon-stock changes in living biomass in Settlements of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-0.551	-5.146	NO	NO	NO	NO
Denmark	NO,NA	-0.222	-1.583	-0.183	-0.075	-0.005	NO,NA
France	-0.031	-0.688	-3.636	-0.033	-0.336	NA	NA
UK	NA	-0.885	-4.363	-0.248	-0.076	-3.179	NO
Netherlands	NA	-0.499	-2.725	-0.196	-0.399	NO,NE	NO,NE
Austria	NA	0.406	-0.851	0.454	0.526	NO	NO
Poland	0.048	-0.412	-1.144	-0.032	-0.900	NO	NO
Switzerland	0.001	-0.535	-4.603	-0.186	-0.135	0.103	0.016
Czech Republic	NO	-0.314	-3.749	NO	NO	NO	NO
Germany, 2020	NO	0.738	-1.008	1.069	0.727	0.751	NO
Germany, 2021	NO	0.807	-0.829	1.126	0.791	-2.675	0.528

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

Table 427: Carbon-stock changes in dead organic matter in Settlements of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-0.021	-0.198	NO	NO	NO	NO
Denmark	NO,NA	-0.065	-1.695	NO	NA	NA	NO,NA
France	NA	-0.065	-0.442	NA	NA	NA	NA
UK	NA	-0.228	-1.287	IE,NA	IE,NA	-0.370	NO
Netherlands	NA	-0.057	-0.794	NA	NA	NA	NA
Austria	NO	-0.026	-0.585	NO	NO	NO	NO
Poland	NA	-0.001	-0.018	NO	NO	NO	NO
Switzerland	NO	-0.074	-0.861	NO	NO	NO	NO
Czech Republic	NO	-0.030	-0.354	NO	NO	NO	NO
Germany, 2020	IE	-0.10	-1.09	IE	IE	IE	IE
Germany, 2021	IE	-0.096	-1.079	IE	IE	IE	IE

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

Table 428: Carbon-stock changes in mineral soils, in Settlements of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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	-0.944	-2.204	NO	-1.362	-2.329	NO
Denmark	NO,NA	-0.872	-1.480	-0.805	-1.464	0.003	NO,NA
France	NA	-0.974	-1.526	-0.150	-1.675	NO	NA
UK	-0.255	-4.689	-7.911	-2.178	-5.108	NO	NO
Netherlands	NA	-0.210	-0.376	0.499	-0.481	-0.264	1.968
Austria	NA	-0.746	-2.957	-0.522	-1.522	NO	NO
Poland	NO	-1.392	-2.544	-1.409	-1.650	NO	NO
Switzerland	0.057	-0.509	-0.939	-0.360	-0.527	0.100	0.402
Czech Republic	NO	-0.131	-0.281	-0.054	-0.405	NO	NO
Germany, 2020	NO	-0.312	-0.385	-0.200	-0.435	-0.029	NO
Germany, 2021	NO	-0.378	-0.652	-0.205	-0.520	-0.811	-0.005

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

Table 429: Carbon-stock changes in organic soils, in Settlements of various countries (Germany, for 2020 & 2021; other countries, for 2020)

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,NA	NO,NA	NA	NA	NO,NA	NA	NO,NA
France	NO	NO	NO	NO	NO	NO	NO
UK	-1.011	-2.342	-1.614	NO	-5.000	-7.900	NO
Netherlands	-4.079	-3.996	-3.963	-3.850	-4.016	-4.282	-3.296
Austria	NO	NO	NO	NO	NO	NO	NO
Poland	-1.000	-1.000	-1.000	-1.000	-1.000	-1.000	NO
Switzerland	-2.551	-5.120	-7.435	-5.091	-5.136	-7.007	NO
Czech Republic	NO	NO	NO	NO	NO	NO	NO
Germany, 2020	-7.28	-7.38	-6.90	-7.61	-7.39	-6.34	-6.87
Germany, 2021	-5.163	-7.793	-7.394	-7.872	-7.844	-7.114	-8.102

Positive: carbon removal by sink; negative: carbon emission by source; Source: (UNFCCC, 2021)

6.8.5 Category-specific recalculations (4.E)

This year's submission includes category-specific recalculations for the entire period 1990 through 2021. 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:

- Complete reimplementation of the LULUCF calculation model in the programming languages R and C++
- Thematic, spatial and chronological 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)
- Introduction of the new land-use sub-categories *roads, natural water bodies, standing man-made water bodies, flowing man-made water bodies*, and *hedges*
- Introduction of new, regionalised emission factors for mineral soils in the sub-category *buildings and open areas* of the land-use category *Settlements* (cf. Chapter 6.1.2.1.6) and the land-use category *Other Land* (cf. Chapter 6.1.2.1.7)
- Implementation of complete-coverage, high-resolution maps of regionalised mineral-soil carbon and nitrogen stocks, for the land-use categories *Cropland*$_{annual}$, *Grassland* and *Forest Land*, within the method for determining GHG emissions from mineral soils (cf. Chapter 6.1.2.1ff)

In Table 430 (areas) and Table 431 (emissions), the results of the current recalculations for the Settlements category are compared with the corresponding results in the previous year's submission.

The differences between the area data of the current submission and those of the previous year's submission are due mainly to the following two factors:

- Introduction of the new land-use sub-categories

- Reprogramming of the calculation model, along with updating of the map data for determination of activity data, via integration of the 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 emissions data of the 2023 submission exhibit considerable differences, with respect to the data of the previous year's submission, for all greenhouse gases. There are numerous causal factors for this, and their impacts overlap in multiple ways; in some cases, they reinforce each other, and in others, they tend to cancel each other out. The causal factors with impacts that overlap in a combined presentation include the following, for example:

- area changes – in this context, especially the introduction of the sub-category *Roads* – and their equilibria
- changes in area-ratio factors (such as sealed/unsealed) for *Buildings and open areas*
- Regionalisation effects from introduction of the soil maps
- Differences in water levels in organic soils

Table 430: 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	2020
4.E	Settlement	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	4,628.96
		2023	3,864.96	3,879.18	3,893.36	4,121.11	4,284.84	4,496.31	4,520.22	4,544.13	4,568.01	4,591.88	4,615.74
		Difference	24.39	22.01	19.58	-0.67	-0.07	-3.03	-5.04	-7.07	-9.10	-11.15	-13.22
		in %	0.6%	0.6%	0.5%	0.0%	0.0%	-0.1%	-0.1%	-0.2%	-0.2%	-0.2%	-0.3%

Table 431: Comparison of greenhouse-gas emissions [kt CO_2-eq with GWP pursuant to IPCC AR5] 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	2020
4.E	Settlement	CO_2	2022	1,776.57	1,812.06	1,806.38	4,529.69	471.74	351.63	303.79	704.13	764.13	932.21	1,075.87
			2023	1,251.39	1,252.84	1,233.74	3,511.62	-229.01	-462.07	-370.69	0.64	-15.41	228.14	346.22
			Difference	-525.17	-559.21	-572.65	-1,018.07	-700.76	-813.70	-674.48	-703.49	-779.54	-704.07	-729.65
			in %	-29.6%	-30.9%	-31.7%	-22.5%	-148.5%	-231.4%	-222.0%	-99.9%	-102.0%	-75.5%	-67.8%
		CH_4	2022	53.8	52.3	50.8	59.1	63.8	69.4	71.1	72.8	177.1	73.9	73.1
			2023	18.8	17.9	17.1	19.6	21.8	26.0	27.3	28.3	132.2	28.5	27.8
			Difference	-34.97	-34.45	-33.69	-39.43	-41.94	-43.35	-43.75	-44.49	-44.94	-45.34	-45.28
			in %	-65.0%	-65.8%	-66.4%	-66.7%	-65.7%	-62.5%	-61.6%	-61.1%	-25.4%	-61.4%	-61.9%
		N_2O	2022	152.01	168.6	167.9	404.1	310.9	325.9	280.4	282.9	285.4	287.8	290.2
			2023	122.73	121.8	121.0	302.9	236.5	249.9	217.1	219.0	220.7	222.6	224.1
			Difference	-29.28	-46.75	-46.83	-101.24	-74.36	-75.99	-63.22	-63.93	-64.66	-65.26	-66.07
			in %	-19.3%	-27.7%	-27.9%	-25.1%	-23.9%	-23.3%	-22.5%	-22.6%	-22.7%	-22.7%	-22.8%

6.8.6 Category-specific planned improvements (4.E)

In addition to the planned measures listed in Chapter 6.1.2.1.9, most of which are medium-term measures, no specific measures for improvement of methods in the area of Settlements are currently planned.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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.

6.9.2 Methodological issues (4.F)

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.

6.9.3 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, 2006b). Additional relevant information is provided in Chapter 6.1.2.1.

The time series is complete and consistent.

6.9.4 Category-specific quality assurance / control and verification (4.F)

Details regarding this year's reviews are provided in Chapter 6.1.3.

6.9.5 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 measures affected the results of the land-area calculations for the land-use category *Other Land*:

- Complete reimplementation of the LULUCF calculation model in the programming languages R and C++
- Thematic, spatial and chronological 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)

The slight differences between the area data of the current submission and those of the previous year's submission are due mainly to correction algorithms. They became necessary in connection with reprogramming of the calculation model, and with updating of the map data for determination of activity data, via integration of the 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).

Table 432: 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	2020
4.F	Other Land	2022	67.59	62.36	57.14	46.06	41.22	38.66	38.16	37.66	37.16	36.66	36.16
		2023	66.80	61.46	56.31	46.64	41.96	39.69	39.22	38.78	38.34	37.91	37.50
		Difference	-0.80	-0.91	-0.83	0.58	0.74	1.03	1.06	1.12	1.18	1.25	1.34
		in %	-1.2%	-1.5%	-1.5%	1.2%	1.8%	2.6%	2.7%	2.9%	3.1%	3.3%	3.6%

6.9.6 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	4 G, Harvested Wood Products		CO_2	-1,330.4	-0.1 %	-8,651.3	-1.1 %	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 (HWP) is a key category in terms of emissions level and trend.

The contribution of HWP in land-use sectors in Germany, in terms of greenhouse emissions by sources and removals by sinks, was estimated with the WoodCarbonMonitor model (Rüter, 2017), via an approach based on production data for wood products, and using the prescribed calculation approach. 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[129] (UNFCCC, 2014b), the approach chosen (approach B) may refer either to the 2006 IPCC Guidelines (IPCC, 2006b) 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, 2006b) as "variable 2A" (production approach for wood products for material use).

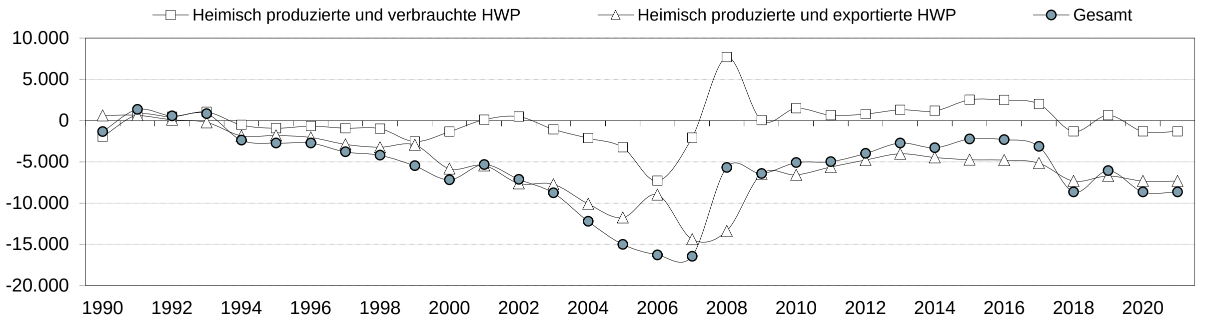
In the interest of transparency, pursuant to CRF Table 4.Gs1, wood products for material use are divided into products that, following their production, are consumed in Germany, and products that have subsequently been exported. The carbon storage effect of wood in solid waste disposal sites is not taken into account. The biomass from short-rotation plantations is used exclusively for energy purposes in Germany (cf. category 1.A, Chapter 3.2), and is thus not reported under Harvested Wood Products (HWP).

At the time this report was prepared (09/2022), the defined routine inventory-preparation procedure (cf. Chapter 1.2.3) had not yet reached the point at which the activity data needed for

129 Footnote 12 of CRF table sheet 4.G-s1

calculation of HWP would be available (cf. (FAO, 2022a)). For this reason, the time series for CO_2 emissions and removals in HWP were carried forward for the year 2021 (cf. Figure 83).

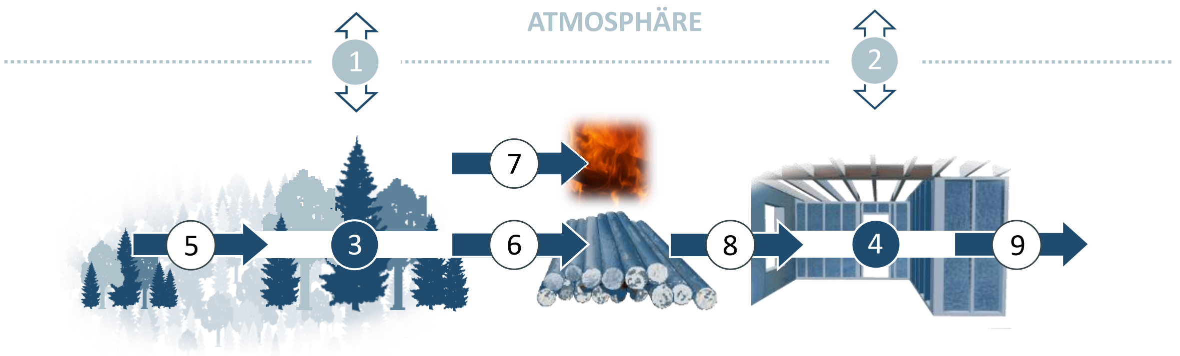
Figure 83: Net CO_2 emissions and removals in HWP (in kt CO_2)



(Domestically produced and used HWP; Domestically produced and exported HWP; Total)

Figure 84 presents an overview, of the 2020 report year, of the carbon flows linked to forest and wood use that are reported as "gains" and "losses" in the defined carbon pools for forests (here: only living biomass (3); cf. 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 84: Carbon flows and carbon stocks, and their CO_2 emissions and removals throughout the Forest Land / harvested wood products chain



CO_2-Emissionen und ihre Einbindung in den Kohlenstoffspeichern WALD[a] und HOLZPRODUKTE	[in kt CO_2e]
1 WALD[a]	-29.334
2 HOLZPRODUKTE	-8.651
Größe der definierten Kohlenstoffspeicher[e]	[in kt C]
3 WALD[a]	1.230.070
4 HOLZPRODUKTE	293.029

Kohlenstoffflüsse[b] zu und aus den Kohlenstoffspeichern	[in kt C]
5 Zunahme (WALD)	43.264
6 Abnahme (WALD) *(Rohholz[c] für stoffliche Nutzung)*	-18.429
7 Abnahme (WALD) *(Rohholz für vornehmlich energetische Nutzung[d])*	-16.835
8 Zunahme (HOLZPRODUKTE)	13.776
9 Abnahme (HOLZPRODUKTE)	-11.417

[a] hier nur lebende Biomasse
[b] während des Berichtsjahres (Zunahme positiv, Abnahme negativ)
[c] basierend auf der StBA-Holzeinschlagstatistik (Stamm- und Industrieholz) in Erntefestmeter (m³)
[d] basierend auf Differenz zw. StBA-Holzeinschlagstatistik (Stamm- und Industrieholz) und inventurdatenkalibriertem Gesamtholzeinschlag in Vorratsfestmeter (Vfm) (vgl. Abb. 70)
[e] am Ende des Berichtsjahres (WALD: basierend auf den Daten der Kohlenstoffinventur 2017 (CI 2017), s. www.bwi.info) WoodCarbonMonitor © S. Rüter, 2021

Furthermore, both increases (5) of living biomass stocks in forests (i.e. on existing Forest Land and on forest lands subject to land-use changes) and their decreases are shown. The related carbon flows differentiate between roundwood harvest for the subsequent manufacturing of HWP (6) and b) removals of biomass which are primarily due to an energetic use (7) of wood.

Carbon-stock decreases due to roundwood harvest for its material use are estimated on the basis of logging data (Statistisches Bundesamt, FS 3, R 3.3.1) on the production of stem-wood (i.e. sawlogs and veneer logs) and further industrial roundwood. The data are broken down into five main tree-species / wood-type groups and are reported in cubic metres of harvested timber. Carbon-stock decreases of the living biomass pool in forests that are primarily due to wood energy use and which are not reported under HWP (production approach), in addition to logging-statistics data on the production of fuel wood, also comprise data on non-commercialised wood and standing timber losses of reserve solid cubic metres that are not covered in this statistics. The latter (timber losses), which were determined within the scope of the 2017 Carbon Inventory (CI2017), serve as a basis for the calibration of the logging statistics, by main-tree-species groups, that is described in Chapter 6.10.2.1.

The calculation of the carbon flows (8 and 9) associated with the carbon stock in HWP as well as the resulting changes of the stock that are reported in CRF Table 4.Gs1 are described in the following Chapter 6.10.2.

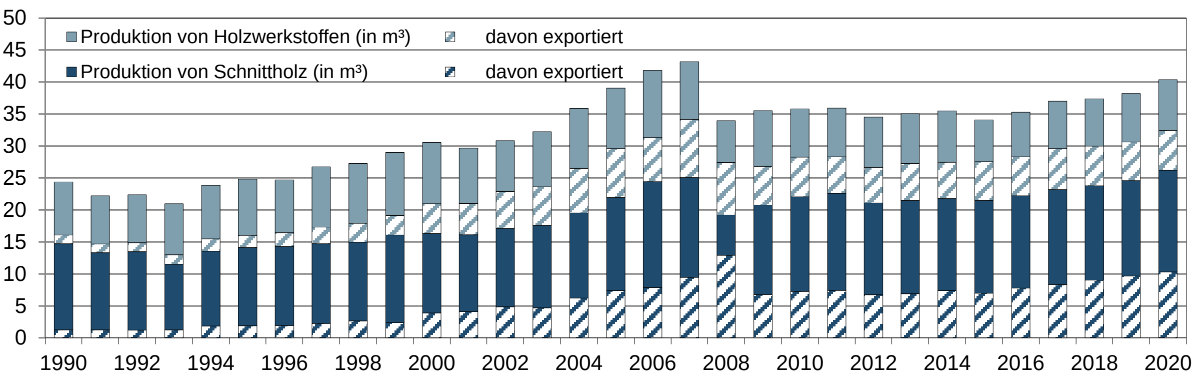
6.10.2 Methodological issues (4.G)

6.10.2.1 Activity data

At the time this report was prepared (09/2022), the activity data necessary for calculation relative to HWP for the year 2021 were not yet available in the FAOSTAT database (FAO, 2022a). For this reason, the previous year's data were used in describing the method applied to the time series from that source.

Figure 85 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, 2022b). These time series correspond to the data proposed in the 2006 IPCC Guidelines (IPCC, 2006b) for estimation of the HWP contribution following the Tier 1 methodology (Chapter 12.2.1 IPCC (2006b): 12.9).

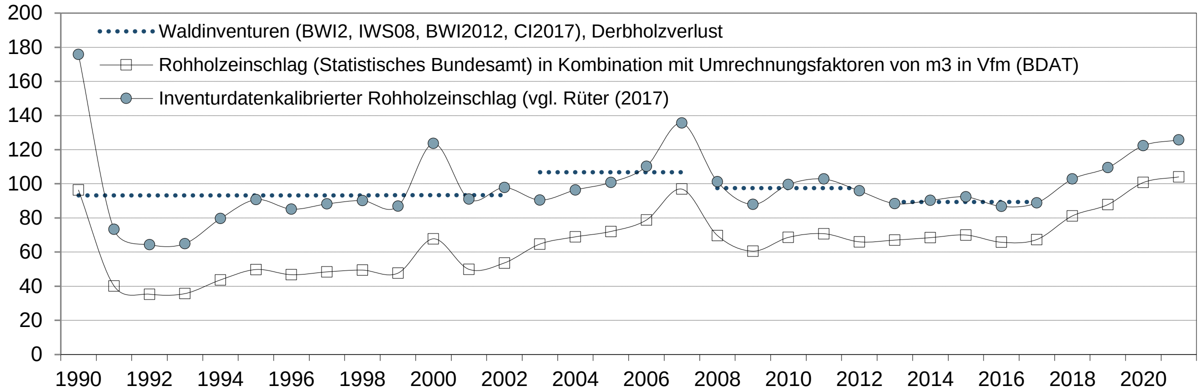
Figure 85: Sawn wood and wood-based panels produced in Germany [Mm³] (FAO, 2022b)



(Production of wood-based panels (in m³); Production of sawn wood (in m³); of this, quantity exported)

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 86), since the statistics underestimate the annual roundwood production by about 30 %. The reasons for this statistical underestimation of the wood harvest include the fact that some harvested raw wood is lost or is not used, and that some wood is used for 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. 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 keeping with the provisions of IPCC et al. (2014a), are provided in Rüter (2017).

Figure 86: National harvest statistics, and their calibration with forest-inventory data on solid-wood losses [in millions of solid cubic metres], (Statistisches Bundesamt, FS 3, R 3.3.1) and Chapter 6.4.2.1.1



At the time this report was prepared (09/2022), the activity data necessary for calculation relative to industrial roundwood for the year 2021 were also not yet available in the FAOSTAT database. For this reason, a domestic feedstock factor $f_{DP}(i)$ for the semi-finished product categories sawnwood and wood-based panels was not determined.

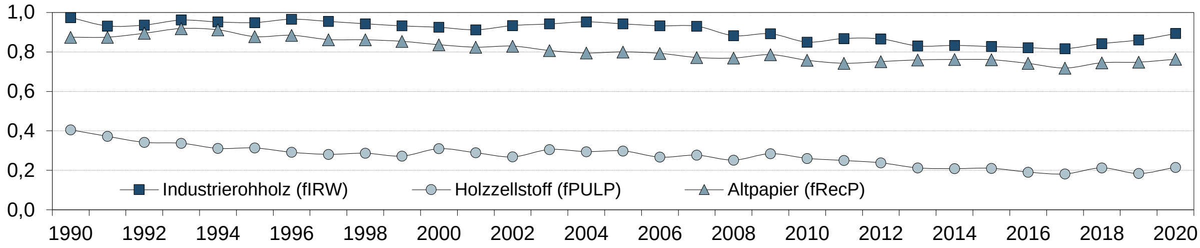
In a second step, a domestic feedstock factor $f_{DP}(i)$ was then determined that, for the semi-finished product categories sawnwood and wood-based panels, is based on FAO data on the feedstock category industrial roundwood. For the calculation of the fraction of the feedstock coming from domestic harvest 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 (f_{IRW}) and wood pulp (f_{PULP}), 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 (f_{RecP}) (Figure 87). 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

$$f_{DP}(i) = \{f_{IRW}(i) * (1-p) * f_{PULP}(i)\} + p * f_{RecP}(i)$$

'paper and paperboard.'

Figure 87: Development of the domestic feedstock factor fDP(i) for the feedstock categories considered (FAO, 2022b)



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 433). In line with IPCC requirements, HWP from deforestation are taken into account on the basis of instantaneous oxidation (cf. Chapter 2.8.2. IPCC 2014a). In keeping with IPCC requirements, HWP from deforestation are taken into account on the basis of instantaneous oxidation (cf. Chapter 2.8.3 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 433: 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 (2006b): 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 product 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. At the time this report was prepared (09/2022), the defined routine inventory-preparation procedure (cf. Chapter 1.2.3) had not yet reached the point at which the activity data needed for calculation of HWP would be available (cf. (FAO, 2022a)). For this reason, the time series for CO_2 emissions and removals in HWP were carried forward for the year 2021.

6.10.4 Category-specific quality assurance / control and verification (4.G)

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 relevant involved experts and the Single National Entity.

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 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)

At the time this report was prepared (09/2022), the activity data needed for calculation of HWP were not yet available in the FAOSTAT database (FAO, 2022a). For this reason, no category-specific recalculations were carried out.

6.10.6 Category-specific planned improvements (4.G)

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

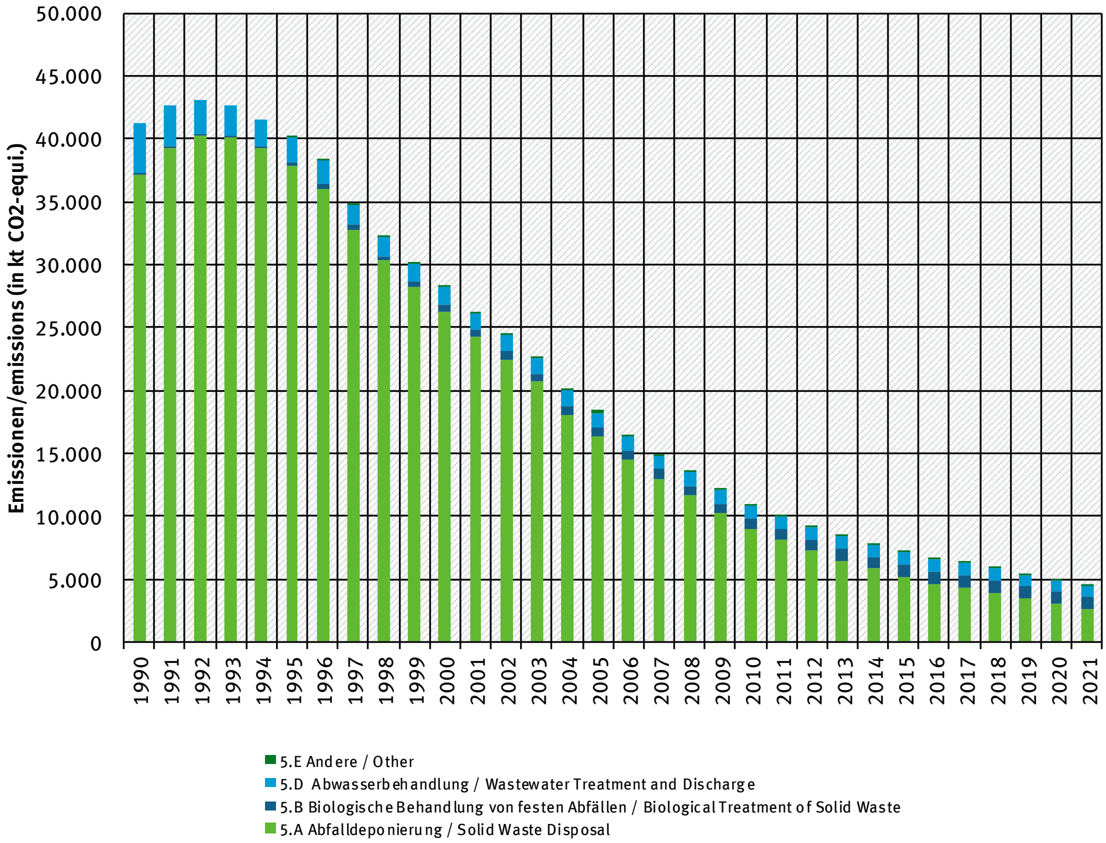
6.11 Other sectors (4.H)

In 4.H, N_2O emissions caused by cultivation of organic soils, and originating in the category *Settlements* (108.8 kt CO_2-eq. for 2021), 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).

7 Waste and Waste Water (CRF Sector 5)

7.1 Overview (CRF Sector 5)

Figure 88: 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
L/T	5 A, Solid Waste Disposal		CH_4	37,191.3	2.9 %	2,574.2	0.3 %	-93.1 %

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.

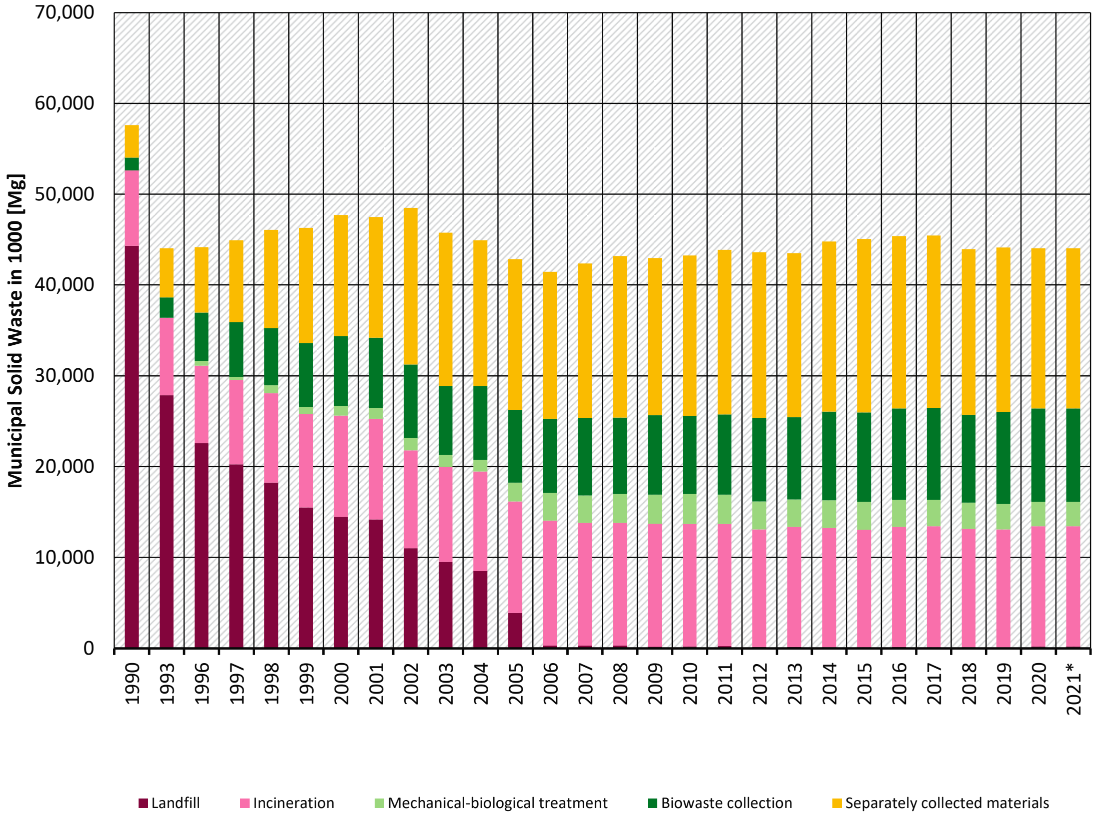
7.2.1 Managed disposal in landfills – landfilling of settlement waste (5.A.1)

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 89). 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 89: 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 90 kt in 2021, 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, 2006b): *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 59: (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 60: (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, 2006b). 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 61: (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 62: (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, 2006b):

Equation 63: *(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, 2006b) 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 of landfilled settlement waste should be differentiated in keeping with the different waste-type fractions contained in such waste, since the further emissions-calculation procedure is based on the fact that different waste types have different DOC, DOC_f and k 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 published by (Statistisches Bundesamt, jährlich - FS 19, R. 1). 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 published by the Federal Statistical Office in GENESIS-Online and, at the same time, provided to the German Environment Agency in an unchanged table format, for reporting purposes. 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.

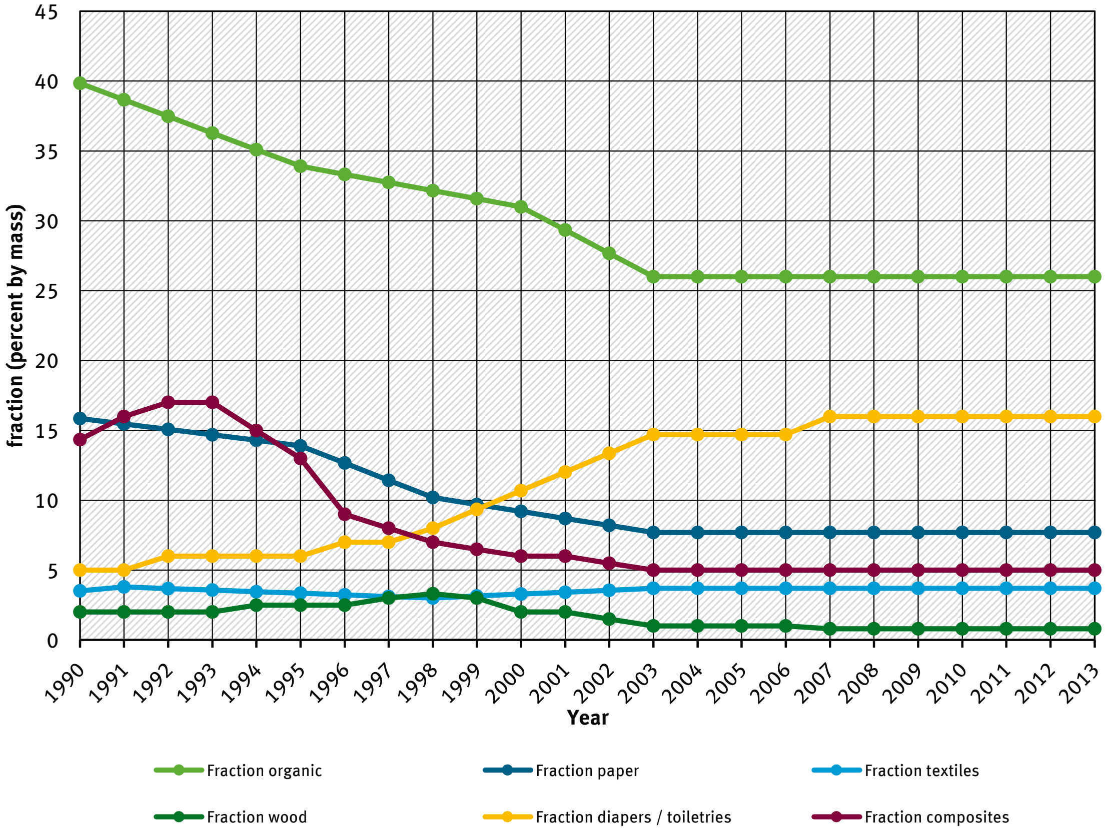
For the entire period as of 1950, and for all relevant types of waste, including sewage sludges, complete and seamless data series are thus available that are based on the best-available sources for the various sub-periods concerned.

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 90) 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 90: 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 434 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 434 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 434: Quantities of biologically degradable waste, by waste fractions

Waste fraction	Units	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
Organic waste	[kt]	16,844	7,515	3,202	813	6	1	2	1	0	0	1	2
Garden and park waste	[kt]	0	0	54	26	0	0	0	0	2	0	0	0
Paper	[kt]	9,095	4,372	1,421	426	7	1	4	9	8	5	5	6
Wood	[kt]	2,658	1,889	1,037	238	0	0	0	0	0	0	0	0
Diapers + textiles	[kt]	3,572	2,082	2,241	519	5	2	3	2	2	1	2	2
Composite materials	[kt]	5,587	2,644	621	155	1	0	0	0	0	0	0	0
Sewage sludge	[kt]	2,494	1,024	452	634	27	81	57	16	26	40	29	30
Output from MBT facilities	[kt]	0	0	370	1170	991	714	618	610	515	508	505	502

In 2011/12, the residual-gas emissions from landfill storage of mechanically and biologically treated waste were quantified in an expert assessment (Stegmann, 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 435 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 435: Per-capita quantities of landfilled household waste

	Units	1990	1995	2000	2005	2010
Per-capita quantities of landfilled waste	kg/capita/day	1.60	0.85	0.55	0.18	0.04
	Units	**2015**	**2016**	**2017**	**2018**	**2019**
Per-capita quantities of landfilled waste	kg/capita/day	0.03	0.02	0.02	0.02	0.02
	Units	**2020**	**2021**			
Per-capita quantities of landfilled waste	kg/capita/day	0.02	0.03			

Table 436: Per-capita quantities of settlement waste

	Units	1995	2000	2005	2010	2015
Production of settlement waste per capita	kg/capita/day	1.71	1.78	1.57	1.68	1.72
	Units	**2016**	**2017**	**2018**	**2019**	**2020**
Production of settlement waste per capita	kg/capita/day	1.73	1.71	1.66	1.67	1.68
		2021				
Production of settlement waste per capita	kg/capita/day	1.69				

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, 2006b). 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, 2006b). 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.

Current results regarding the biological decomposition processes in landfills (Stegmann et al., 2018), pp. 172 - 173) indicate that aerobic carbon degradation in particular tends to reduce methane formation noticeably, and that greater consideration could be given to such processes – possibly via the factor MCF (Stegmann et al., 2018), Chapter 4.1.4, p. 68ff). The effects are relatively slight, however, and could only be roughly estimated. For this reason, no adjustments to the factor MFC can be made. Instead, this aspect is being taken suitably into account in the uncertainties of the MCF.

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 437 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 437:

- 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, 2006b)). 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.
- Until the 2022 report, a national value of 18% was used for the DOC for the organic fraction (Wallmann, 1999). More-recent studies of landfills (Stegmann et al., 2018), pp. 172 - 173) have shown that the default value of 15% is in better accordance with actual landfill-gas formation. As of the 2023 report, therefore, a DOC of 15% is being used in calculations.
- 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, 2006b)) 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, 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.

Recent research results (Stegmann et al., 2018), pp. 172 - 173) largely confirm the DOC values; an adjustment is recommended only for the DOC value for the organic fraction. Through the 2022 report, a national DOC value of 18% was used for the organic fraction. As of the 2023 report, the DOC has been adjusted to the IPCC default value of 15%, in keeping with the relevant recommendation.

Table 437: DOC values used

Fraction	DOC values			Source
	IPCC 2006 default (wet waste)	used		
		through the 2022 NIR	as of the 2023 NIR	
Organic waste	15 %	18%	**15%**	(Wallmann, 1999) (Stegmann et al., 2018), pp. 172 - 173)
Garden and park waste	20 %	**20%**		Table 2.4, Chap. 2.3.1, (IPCC, 2006b)
Paper and paperboard	40 %	**40%**		Table 2.4, Chap. 2.3.1, (IPCC, 2006b)
Wood and straw	43 %	**43%**		Table 2.4, Chap. 2.3.1, (IPCC, 2006b)
Textiles	24 %	**24%**		Table 2.4, Chap. 2.3.1, (IPCC, 2006b)
Diapers	24 %	**24%**		Table 2.4, Chap. 2.3.1, (IPCC, 2006b)
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, 2012);

7.2.1.2.5 DOC_F

Through the 2022 report, DOC_F, the DOC fraction that can be converted into landfill, was assumed to be 50 %, for all waste fractions. That value is in keeping with the IPCC default of 0.5 (Chapter 3.2.3, (IPCC, 2006b)).

In the 2023 report, DOC_f for the wood and straw fraction has been adjusted in keeping with recent studies and evaluations (Stegmann et al. (2018)Stegmann et al, 2018, pp. 68-73). For the other fractions, it has been kept at the existing value of 0.5, which is in keeping with the IPCC default values. The reference sources referred to indicate that wood has a gas-formation potential in the range 21 – 57 m^3/Mg per cubic metre of roundwood, while the default values previously used in the NIR correspond to a gas-formation potential for wood of 402 m^3/Mg per cubic metre of roundwood. Consequently, the biological availability and carbon degradation under anaerobic environmental conditions are so low that the DOC_f value for wood (straw quantities are of lesser importance in connection with landfilling) has been reduced from a level of 50 % to a level of 10 % (Stegmann et al., 2018), p. 26). The study has confirmed the DOC for the organic fraction, and for garden and park waste, paper and cardboard, textiles, diapers, composite materials, sewage sludge and MBT waste.

Table 438: DOC_F values used

<table>
<tr><th rowspan="3">Fraction</th><th colspan="3">DOC_F values</th><th rowspan="3">Source</th></tr>
<tr><th rowspan="2">IPCC 2006 default (wet waste)</th><th colspan="2">used</th></tr>
<tr><th>through the 2022 NIR</th><th>as of 2023 NIR</th></tr>
<tr><td>Organic fraction</td><td rowspan="9">0.5</td><td colspan="2">0.5</td><td>(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999)(Wallmann, 1999) (Stegmann et al., 2018), pp. 172 - 173)</td></tr>
<tr><td>Garden and park waste</td><td colspan="2">0.5</td><td>Chap. 3.2.3, (IPCC, 2006b) and (Stegmann et al., 2018), pp. 172 - 173)</td></tr>
<tr><td>Paper and paperboard</td><td colspan="2">0.5</td><td>Chap. 3.2.3, (IPCC, 2006b) and (Stegmann et al., 2018), pp. 172 - 173)</td></tr>
<tr><td>Wood and straw</td><td>0.5</td><td>0.1</td><td>(Stegmann et al., 2018), pp. 172 - 173)</td></tr>
<tr><td>Textiles</td><td colspan="2">0.5</td><td>Chap. 3.2.3, (IPCC, 2006b) and (Stegmann et al., 2018), pp. 172 - 173)</td></tr>
<tr><td>Diapers</td><td colspan="2">0.5</td><td>Chap. 3.2.3, (IPCC, 2006b) and (Stegmann et al., 2018), pp. 172 - 173)</td></tr>
<tr><td>Composite materials</td><td colspan="2">0.5</td><td>Chap. 3.2.3, (IPCC, 2006b) and (Stegmann et al., 2018), pp. 172 - 173)</td></tr>
<tr><td>Sewage sludge</td><td colspan="2">0.5</td><td>Chap. 3.2.3, (IPCC, 2006b) and (Stegmann et al., 2018), pp. 172 - 173)</td></tr>
<tr><td>Waste from MBT facilities</td><td colspan="2">0.5</td><td>Chap. 3.2.3, (IPCC, 2006b) and (Stegmann et al., 2018), pp. 172 - 173)</td></tr>
</table>

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 439: Fraction of CH_4 in landfill gas

Fraction of CH_4 in landfill gas	2004	2006	2008	2010	2012	2014	2016	2018	2020
Landfills in the operational and closure phases	49 %	50 %	49 %	48 %	48 %	47 %	45 %	42	41%
Landfills in the aftercare phase	N. e.	N. e.	N. e.	42 %	40 %	38 %	32 %	32 %	32%

Source: (Statistisches Bundesamt, 2018), Table 1.5

In recent years, the methane concentrations in recovered landfill gas (Table 439) have been decreasing, however. Presumably, this decrease in methane concentrations is due to oxidation effects caused by 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, and of the k values (methane-generation rates) derived from those half-lives, for the various waste fractions. Table 440 shows the half-lives and the methane-formation rate (k value) 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 64.

As a result of recent studies and evaluations, it has become necessary to adjust the existing half-lives and resulting k values for the paper / cardboard and wood fractions (Stegmann et al., 2018); Chapter 8.3, p. 145). For example, as a rule, the paper fraction has biograded considerably more rapidly in landfills than would be expected in light of the default half-life of 12 years. Numerous studies of landfills in Germany have confirmed that the bodies of landfills contain much less paper than they should contain, or than would be expected, in light of the quantities of paper placed in them, and of the rate of degradation determined by the half-life used under the existing NIR approach. As a result, the half-life of paper has been reduced from 12 years to 7 years, to bring it into line with the conditions found to prevail in landfill bodies. This, in turn, changes the pertinent k value from 0.058 to 0.099 bedeutet (Stegmann et al. 2018).

Exploratory drilling and digging at landfills, and laboratory studies, have shown that the wood fraction hardly degrades at all under anaerobic conditions. This is especially true when large pieces of wood are involved that are not accessible for microorganisms. According to recent findings, and to supplementary laboratory studies, biodegradation of wood takes considerably longer than would be expected in light of the existing half-life of 23 years. The half-lives for degradation of wood are very long – assuming that wood can degrade at all in anaerobic environments. For this reason, the relevant half-life has been increased from 23 years to 50 years, which entails a change in the k value from 0.030 to 0.014 (Stegmann et al., 2018).

For calculation purposes, national values, oriented to the IPCC default values, continue to be used for food waste, garden/park waste, textiles/diapers and sewage sludge, throughout the entire time series. For composite materials and waste from mechanical biological treatment (MBT facilities), national values are used, since the Guidelines provide no default values. Current research projects (Stegmann et al., 2018) have confirmed these national values. Due to mathematical imprecision in the relationship between half-lives and k values (for the organic fractions and sewage sludge) in Table 3.3 and Table 3.4 of the 2006 IPCC Guidelines, small differences occur between calculation of methane formation using k values and calculation using half-lives. In the 2022 ARR, the German approach to this aspect was confirmed as correct.

Equation 64: (2006 IPCC Guidelines)

$$k = \ln 2 / t_{1/2}$$

Table 440: 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	
		through the 2022 NIR	as of the 2023 NIR		through the 2022 NIR	as of the 2023 NIR
Organic waste	4	**4**		0,185	**0.173**	
Garden/park waste	7	**7**		0.1	**0.099**	
Paper / cardboard	12	12	**7**	0.06	0.058	**0.099**
Wood	23	23	**50**	0.030	0.030	**0.013**
Textiles / diapers	12	**12**		0.06	**0.058**	
Composite materials	--	**12**		---	**0.058**	
Sewage sludge	4	**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[130] 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.

[130] Technical instructions on recycling, treatment and other management of settlement waste (Third general administrative provision on the Waste Act (Abfallgesetz)) of 14 May 1993

The quantities of methane listed in Table 441 include both the landfill-gas quantities used for energy generation and those flared off.

Table 441: Methane collection in landfills

Year	Methane formation in Gg	Collected quantity of methane, in Gg			Recovery rate in %
		Landfilling and decommissioning phases, in Gg	After-closure phase, in Gg	Total quantity, in Gg	
1990	1567			91	5.8
1991	1662			101	6.1
1992	1709			111	6.5
1993	1714			120	7.0
1994	1685			129	7.7
1995	1640			138	8.4
1996	1581			150	9.5
1997	1507			206	13.6
1998	1423			221	15.5
1999	1343			222	16.6
2000	1265			223	17.6
2001	1183			221	18.7
2002	1109			218	19.7
2003	1035			215	20.8
2004	965	236	11	247	25.6
2005	897			247	27.6
2006	818	231	11	242	29.6
2007	735			220	30.0
2008	662	190	11	201	30.4
2009	597			191	32.0
2010	539	171	11	181	33.6
2011	487			167	34.3
2012	441	140	14	154	35.0
2013	401			143	35.9
2014	364	121	13	134	36.8
2015	332			126	37.9
2016	303	107	11	118	39.0
2017	277			107	38.6
2018	253	85	12	97	38.2
2019	232			96	41.4
2020	213			95	44.6
2021	196			94	47.8

Source: (Statistisches Bundesamt, jährlich - FS 19, R. 1)

The data include gaps, since official statistical data are available only for certain single years; such gaps were closed via interpolation / 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 2020, a total of 95 Gg methane was collected, together with landfill gas. Of that quantity, a fraction of about 24 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 %. In the assessment of experts of the German Environment Agency (UBA), formation of N_2O in the combustion process is not expected, due to the high temperatures involved, and the emissions of nitrogen oxides occur under these reaction conditions as NO and NO_2.

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, 2006b). 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 0.67 kt CO_2 equivalent. In addition, a compilation of all sources listed as "not estimated" is presented in Annex 5 (Annex Chapter 18) 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.

Uncertainties for the selected methane-formation parameters

In keeping with the extensive country-specific analyses that have been carried out, and with the adjusted methane-formation parameters, the uncertainties relative to gas formation can be estimated as follows (Stegmann et al., 2018), Chapter 9, p. 161):

- Uncertainties relative to DOC_f:
- ± 20% for default values, ± 10 % after adjustment of values
- Uncertainties relative to methane formation potential DDOCM (Equation 65)
- ± 20% for default values, up for -40% for wood, depending on the type of wood
- Uncertainties relative to MCF = 1 for the Federal Republic of Germany after 1972 and for the entire national territory as of 1990: -38%, + 0%
- Uncertainties relative to MCF = 0.6 for the Federal Republic of Germany until 1972 and for the entire national territory until 1989: ± 25%
- Uncertainties relative to the methane fraction in landfill gas F = 0.5: + 30%, - 0%
- Uncertainties relative to k value:
  - Organic fraction (food waste) and sewage sludge: + 25%, - 0%
  - Paper and paperboard: + 45%, - 0%
  - Wood and straw: + 45%, - 0%
  - Textiles, disposable nappies/diapers, composite materials: + 40%, - 0%

According to well-founded estimates by estimates of the German Environment Agency (UBA), the uncertainties for the total methane emissions from landfills amount to ± 20 %

7.2.1.4 Category-specific quality assurance / control and verification (5.A.1)

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 relevant involved experts and the Single National Entity.

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 2022 reporting shows that Germany had the second-highest value, 0.47. 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).

Internationally, 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. In the IEF comparison, Austria and Japan rank third and fourth, respectively. With values of 0.28 and 0.20, respectively, their values are about as large as that of Germany.

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.

In recent years, there have been growing indications in Germany that calculation of landfill-gas formation, and of the resulting methane emissions, with the IPCC's FOD model has produced significant overestimations with regard to actual landfill behaviour. For this reason, the German Environment Agency commissioned two research projects that studied this issue and determined national DOC and DOC_f values, half-lives and k values. The key results of these two research projects have entered into the present 2023 National Inventory Report (Stegmann et al., 2018).

In keeping with the extensive evaluations and studies carried out at landfills in Germany, the DOC and DOC_f values, half-lives and k values have been adjusted as follows for several fractions:

Organic fraction:	Adjustment of DOC from 0.18 to 0.15
Wood and straw fraction:	Adjustment of DOC from 0.5 to 0.1
	Adjustment of half-life $t_{½}$ from 23 to 50 years
	With that, adjustment of the k value from 0.030 to 0.014
Paper fraction:	Adjustment of half-life $t_{½}$ from 12 to 7 years
	With that, adjustment of the k value from 0.058 to 0.099

With the use of these values, the annual methane formation calculated for the year 2020 has decreased, with respect to the 2022 report, from 383 Gg/a to 213 Gg/a, and methane emissions have decreased from 271 Gg/a to 106 Gg/a. The changes in the time series as of 1990 are shown in the following tables.

Table 442: Recalculation: Methane formation in landfills [kt]

Year	1990	1995	2000	2005	2010	2015	2020	2021
2022 NIR	1614	1738	1423	1094	741	523	383	-
2023 NIR	1567	1640	1265	897	539	332	213	196

Table 443: Recalculation: Methane emissions from landfills [kt]

Year	1990	1995	2000	2005	2010	2015	2020	2021
2022 NIR	1368	1433	1056	762	504	357	271	-
2023 NIR	1328	1352	938	584	322	185	106	92

7.2.1.6 Planned improvements, category-specific (5.A.1)

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/T	5 B, Biological Treatment of Solid Waste		CH_4	59.4	0.0 %	791.0	0.1 %	1232.0 %
-/-/2	5 B, Biological Treatment of Solid Waste		N_2O	19.7	0.0 %	184.3	0.0 %	837.1 %

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 method 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 the Federal Republic of Germany, biodegradable waste is 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, 2006b). 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 (Federal Statistical Office, GENESIS-Online, Table 32111-0003)[131]. 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 (Federal Statistical Office, direct data transfer), 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

[131] https://www-genesis.destatis.de/genesis//online?operation=table&code=32111-0003&bypass=true&levelindex=0&levelid=1630573034654#abreadcrumb

composting systems is extrapolated, on the basis of the trend for the previous 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-CH_4 = 1,400 g CH_4/ t biowaste

EF-N_2O = 49 g N_2O/ 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.

Following a transition in the framework of the 2023 report, the national emission factors now contain only the emissions from treatment in composting facilities. Since that transition, the emissions that occur in connection with spreading of compost are reported in categories 3.D.a.2.c and 3.D.b. This change addresses review result A.8 (Table 5, 2020 ARR), which had led to multiple discussions between the responsible experts in the areas of agriculture and composting. As a result of those discussions, it was decided that, from a technical standpoint, emissions from spreading of compost should be reported in the agricultural sector, and not under composting per se. The emission factor for methane has not changed as a result of this change, since the methane emissions that occur during and after compost spreading are generally negligible. As described above, the new emission factor for nitrous oxide applies only for treatment. It is considerably lower than the previously used factor, which also included spreading of compost. Emissions from storage of compost on the premises of the treatment facility are included in the emission factors used here.

Pursuant to Cuhls et al., the N_2O emission factor for composting of biowaste amounts to 49 g N_2O/t biowaste, which is slightly below the range of the IPCC default factor, 60 - 600 g. The IPCC default factor for composting is 300 g N_2O/t biowaste (Vol. 5, Chapter 4.1.3.1).

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 figures given in the literature and by other countries vary widely. The uncertainties were determined on the basis of the measurement results of the aforementioned research project ((Cuhls et al., 2015) p. 120), from which a log-normal distribution can be derived. The following uncertainties were determined: for CH_4, +272 % to -87 %; for N_2O, +123.5 % to -64 %.

7.3.1.4 Source-specific quality assurance / control and verification (5.B.1)

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 relevant involved experts and the Single National Entity.

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 & 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 0.049 g N_2O/kg waste, is also lower than the relevant default value, 0.3 g, and it lies slightly below the range for the default value, 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 2022). The IEF for methane is on the same order as the values of Italy and Austria, and it is higher than Belgium's value. The IEF for nitrous oxide is the lowest of the values given by the reporting countries. The reasons for this were explained in the previous paragraph.

A comparison, carried out for the 2022 report, of Germany's emission factors (cf. Table 444) and those of technologically comparable countries (Austria, Belgium, Switzerland and Italy) shows that Germany's CH_4 EF lies in the middle of the range. For nitrous oxide, its EF is somewhat lower, but still on the same order of magnitude, than/as those of Belgium and Switzerland.

Table 444: Comparison of emission factors for composting

EF in g/t	Germany	Austria	Belgium	Switzerland	Italy
Methane CH_4	1400	1820	750	1840	1630
Nitrous oxide N_2O	49	250	100	90	600

Source: For Germany, current submission; for other countries, the 2022 submission (UNFCCC, 2020)

7.3.1.5 Category-specific recalculations (5.B.1)

The conversion of the N_2O emission factor described in 7.3.1.2 leads to a considerable reduction – from 74 g N_2O/t biowaste to 49 g N_2O/t biowaste. This has prompted a recalculation of the entire time series for N_2O emissions from composting of biowaste. This, in turn, has reduced the N_2O emissions by approximately one-third, throughout the entire time series.

In each case, when the inventory data for the current year are being prepared, the most recent available statistical data 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, the current report year is extrapolated, as described above. In the relevant subsequent year, the data so extrapolated are replaced with the data obtained via statistical survey. For this reason, the previous year's figures have to be recalculated each year.

During the annual quality assurance process, a transfer error was detected – the value for input biowaste in 1990 had erroneously been entered in the year 1991. That error was corrected. For 1991 and 1992, no statistical data are available, and thus the figures for those years are interpolated. The correction has resulted in a considerable increase in the emissions for 1990 (cf. the following table).

Table 445: Recalculations, CRF 5.B.1

Designation	Units	NIR	1990	1991	1992	1995	2000	2005	2010	2015	2020
Waste quantities managed in composting systems (TOTAL)	[kt]	2023	1,515	1,809	2,103						9133.5
		2022	724	1,515	1,956						8807.6
Nitrous oxide emission factor	[g/t]	2023	49	49	49	49	49	49	49	49	49
		2022	74	74	74	74	74	74	74	74	74
CH_4 emissions	[t]	2023	2,121.00	2,532.60	2,944.20						12786.90
		2022	1,013.60	2,121.00	2,738.40						12330.70
N_2O emissions	[t]	2023	74.24	88.64	103.05	253.25	442.45	435.40	421.82	433.67	447.54
		2022	53.58	112.11	144.74	382.45	668.19	657.54	637.04	654.94	651.76

7.3.1.6 Category-specific planned improvements (5.B.1)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 the Federal Republic of Germany, biodegradable waste is 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, however, since their emissions are already included in CRF category 3 B.

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 are shown in the annual waste statistics (Federal Statistical Office, direct data transfer, 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.

The resulting digestates are used in either agriculture or horticulture. 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. 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 (Federal Statistical Office, direct data transfer, 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 (Federal Statistical Office, GENESIS-Online, Table 32111-0003)[132]. 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 (Federal Statistical Office, direct data transfer), is applied to the input 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 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

[132] https://www-genesis.destatis.de/genesis//online?operation=table&code=32111-0003&bypass=true&levelindex=0&levelid=1630573034654#abreadcrumb

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 = 45 g N_2O/ t biowaste

Following a transition in the framework of the 2023 report, the national emission factors now contain only the emissions from treatment in digesting systems. Since that transition, the emissions that occur in connection with spreading of digestates are reported in categories 3.D.a.2.c and 3.D.b. This change addresses review result A.8 (Table 5, 2020 ARR), which had led to multiple discussions between the responsible experts in the areas of agriculture and digestion. As a result of those discussions, it was decided that, from a technical standpoint, emissions from spreading of digestates should be reported in the agricultural sector, and not under digestion per se. The emission factor for methane has not changed as a result of this change, since the methane emissions that occur during and after spreading of digestates are generally negligible. As described above, the new emission factor for nitrous oxide applies only for treatment. It is considerably lower than the previously used factor, which also included spreading of digestates. Emissions from storage of liquid digestates, and of composted solid digestates, on the premises of the treatment facility are included in the emission factors used here. . Pursuant to Cuhls et al., the N_2O emission factor for anaerobic digestion of biowaste amounts to a total of 45 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.

Information on emissions from digestion of energy crops and manure 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 figures given in the literature and by other countries vary widely. The uncertainties were determined on the basis of the measurement results of the aforementioned research project ((Cuhls et al., 2015) p. 120), from which a log-normal distribution can be derived. The following uncertainties were determined: for CH_4, +179 % to -76 %; for N_2O, +185.5 % to -77 %.

7.3.2.4 Source-specific quality assurance / control and verification (5.B.2)

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 relevant involved experts and the Single National Entity.

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 2022) – the values exhibit an extremely wide range, and they do not lend themselves to comparison.

A comparison, carried out for the 2022 report, of the German emission factor for methane emissions from biowaste-digestion plants and the corresponding factors of technologically comparable countries (Italy and Portugal) found that those countries' emission factors, each at 2,000 g per tonne of biowaste, are slightly below the value used in Germany, 2,800 g per tonne.

None of the countries reports on nitrous oxide emissions from digestion plants.

Table 446: Comparison of emission factors for digestion

EF in g/t	Germany	Italy	Portugal
Methane CH_4	2800 (5.7%)	2000	2000
Nitrous oxide N_2O	45	-	-

Source: For Germany, current submission; for other countries, the 2022 submission (UNFCCC, 2020)

7.3.2.5 Category-specific recalculations (5.B.2)

The conversion of the N_2O emission factor described in 7.3.2.2 leads to a considerable reduction – from 67 g N_2O/t biowaste to 45 g N_2O/t biowaste. This has prompted a recalculation of the entire time series for N_2O emissions from digestion of biowaste. This, in turn, has reduced the N_2O emissions by approximately one-third, throughout the entire time series.

In each case, when the inventory data for the current year are being prepared, the most recent available statistical data 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, the current report year is extrapolated, as described above. 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.

Table 447: Recalculations, CRF 5.B.2

Designation	Units	NIR	1998	2000	2005	2010	2015	2020
Waste quantities managed in biogas and digestion plants (TOTAL)	[kt]	2023						5570.0
		2022						5792.2
Nitrous oxide emission factor	[g/t]	2023	45	45	45	45	45	45
		2022	67	67	67	67	67	67
CH_4	[t]	2023						15596.00
		2022						16218.22
N_2O	[t]	2023	13.49	41.21	113.44	153.76	244.60	250.65
		2022	20.08	61.35	168.90	228.93	364.19	388.08

7.3.2.6 Category-specific planned improvements (5.B.2)

No improvements are planned at present.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 3.2.3). 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 (Statistisches Bundesamt, 2022h). Cremations have been accounting for a growing share of all funerals (BDB, 2022), and thus the absolute numbers of cremations have been growing as well (cf. Table 448). 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 448: Calculatory number of cremations in Germany

Cremations	1990	1995	2000	2005	2010	2015	2020	2021
Number (in thousands)	169	316	328	365	427	574	710	752

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, and of prohibitions designed to guard against high wildfire risks, a model entailing considerably fewer numbers of traditional events was developed. Unlike campfires, which tend to be used in private settings, Easter bonfires take place in more-public settings. The calculations are carried out separately for these two types of fire situations, and a model incorporating a continuing decrease in campfires is used. The approach for modelling Easter bonfires calls for general percentage-wise reductions, and includes deductions to take account of various cancellations.

No recalculations were required.

No further improvements are planned at present.

7.5 Wastewater handling (5.D)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/T	**5 D 1, Domestic Wastewater**		**CH_4**	**2,870.8**	**0.2 %**	**487.0**	**0.1 %**	**-83.0 %**
-/-/2	**5 D 1, Domestic Wastewater**		**N_2O**	**1,029.3**	**0.1 %**	**348.2**	**0.1 %**	**-66.2 %**
-/-	5 D 2, Industrial Wastewater		CH_4	10.4	0.0 %	53.8	0.0 %	419.4 %
-/-	5 D 2, Industrial Wastewater		N_2O	28.1	0.0 %	23.8	0.0 %	-15.2 %

The category *Wastewater treatment – Domestic wastewater handling* is a key category for CH_4 emissions in terms of trend, and a key category for N_2O emissions pursuant to method 2 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 handling (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 449: 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 handling)

7.5.1.1.1 Category description (5.D.1 domestic wastewater handling)

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 handling* 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, dreijährlich - FS 19, R. 2.1.3). 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 Domestic wastewater handling)

Equation 6.1 (IPCC (2006d): 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 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. As of 2020, the emission factor used, 0.2 kg per year and inhabitant, is being carried forward, since, as the aforementioned study indicates, it is not realistic to expect unending improvements via plant optimisations. 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 (BMLFUW, 1991). The IPCC default value for Germany, at 62 g, is of the same order of magnitude (2006 IPCC Guidelines, (IPCC, 2006d): 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 (2006d): 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 & 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 & 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 & BLU, 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 et al., 2020a), 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:

$$CH_4 = BOD_{5Y}\ x\ B_o\ x\ MCF$$

$$BOD_{5Y} = P_{cesspool,\ septic\ tanks}\ x\ BOD_5\ x\ 365\ x\ 0.001$$

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

$P_{cesspools,\ septic\ tanks}$ = *Number of persons connected to cesspools or septic 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 450: Inhabitants of Germany as a whole, and inhabitants connected to cesspools and septic tanks

Inhabitants [1000s of persons]	1990	1995	2000	2005	2010	2015	2019	2020	2021
Cesspools and septic tanks	8234.425	6434.800	1266.667	875.667	575.000	448.609	367.773	347.564	327.355
Germany as a whole	79753.227	81307.715	81456.617	81336.663	80284.071	82175.684	83166.711	83155.031	83237.124

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, dreijährlich - FS 19, R. 2.1.3). 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.

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 quality assurance 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.

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 in this area (Gibbs & Woodbury, 1993) 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 on the basis of the considerations and information provided in the IPCC Refinements (2019) (IPCC, 2019b), which has not yet entered into force, and with use 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 & Tchobanoglous, 2011), 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 & Tchobanoglous, 2011) 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 & Tchobanoglous, 2011) 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 & Tchobanoglous, 2011) were confirmed, in the following year, by (Diaz-Valbuena et al., 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 451: Verification of CH_4 from cesspools and septic tanks

CH_4 from cesspools and septic tanks [kt]	2016	2017	2018	2019	2020	2021
via BOD5 load / inhabitant (Gujer)	0.974	0.928	0.882	0.836	0.790	0.744
via BOD5 concentration and wastewater production (BDZ)	1.010	0.963	0.915	0.867	0.820	0.772

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 2022) 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 Category-specific recalculations (5.D.1 Wastewater treatment)

No recalculations are required.

7.5.1.1.6 Planned improvements, category-specific (5.D.1 Wastewater treatment)

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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.[133]. 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,

[133] In 2016, digester gas was recovered in a total of 1,258 wastewater treatment facilities (Statistisches Bundesamt, 2017).

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):

- Thermal utilisation: no methane emissions occur. Thermal utilisation requires energy inputs and thus is allocated to CRF 1.
- 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 452: Use of digested sewage sludge

Sewage sludge Dry matter DM [t]	2017	2018	2019	2020	2021
Total quantity	1,713,185	1,747,230	1,740,089	1,740,556	1,740,556
Thermal utilisation	1,190,156	1,295,188	1,293,246	1,334,994	1,334,994
- Mono-incineration	478,493	496,463	490,141	507,929	507,929
- Co-incineration	648,108	761,959	768,961	795,819	795,819
- Unknown	63,555	36,766	34,144	31,246	31,246
Landfill	0	0	0	0	0
Recycling for substance recovery	516,158	436,146	433,723	388,886	388,886
- Agriculture	311,905	280,325	287,484	259,851	259,851
- Landscaping-related measures	171,633	122,615	58,597	25,181	25,181
- Composting	0	0	0	0	0
- Other	32,620	33,206	87,642	103,854	103,854
Other direct utilisation	6,871	15,896	13,120	16,676	16,676

The activity data for sewage-sludge utilisation are based on data of the Federal Statistical Office (Statistisches Bundesamt, jährlich). 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")[134].

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:

$$M_{methane} = V_{raw\ gas} \times 0.65 \times \sigma \times 0.000001$$

[134] This includes provision to drying facilities in cases in which further disposal steps are not known.

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)

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).[135] 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 %

[135] 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.

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.

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 quality assurance 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.

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 Category-specific recalculations (5.D.1 Sludge treatment)

Data on sewage-sludge production and losses are available through 2020. The figures for 2021 were obtained by carrying forward the figures for 2020.

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 (2006d): 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 (BMLFUW, 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, dreijährlich - FS 19, R. 2.1.3). 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 (2006d): 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, in %/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, dreijährlich - FS 19, R. 2.1.3), amounting to about 30%, $F_{IND\text{-}COMM}$ 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, 2006): 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[136] 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:

$$N_{EFFLUENT} = (P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM})$$

[136] 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.

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:

$$N_{EFFLUENT\ with} = (P \times Protein \times F_{NPR} \times F_{NON-CON} \times F_{IND-COM}) \times (1 - F_{ELIMINATION}) \times T_{PLANT\ Deni}$$

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 (Köppen et al., 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 Schmidt et al. (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 (2006d): 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 (2006d): 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 quality assurance 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.

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 (Köppen et al., 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 453: 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 & Souci, 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)[137] 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[138] 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 (Noleppa & Cartsburg, 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 (Noleppa & Cartsburg, 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 2022) 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.

[137] The nutrition report is published every four years.
[138] 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 years 2018 and 2019, the emissions from effluent – and, thus, the total emissions – have increased slightly. The values for 2019 have been carried forward for the years 2020 and 2021.

Publication of new values for the wastewater quantities for the year 2019 led to changes in the values previously extrapolated for the period as of 2016 (until the 2022 NIR, the value for that year was the last firm value). The wastewater quantities have decreased slightly as a result, and the share of wastewater treatment with denitrification (the splitting factor) has increased slightly. The increased share for denitrification has slightly increased the direct emissions. Emissions from the effluent of wastewater treatment plants have decreased as a result of decreases in wastewater quantities and in the relevant FAO data. Nitrous oxide emissions have decreased slightly overall.

Table 454: Recalculation of N_2O emissions

Protein intake	Units		2017	2018	2019	2020
Protein supply	[g/capita/d]	2023 NIR	104.05	105.50	104.24	104.24
Protein supply	[g/capita/d]	2022 NIR	104.05	105.40	105.40	105.40
per capita and year	[kg/capita/a]	2023 NIR	30.383	30.806	30.438	30.438
per capita and year	[kg/capita/a]	2022 NIR	30.383	30.777	30.777	30.777
Nutrient removal	**Units**		**2017**	**2018**	**2019**	**2020**
Total quantity of wastewater	[1000 m³]	2023 NIR	9,403,349	9,225,645	9,047,942	8,870,239
Total quantity of wastewater	[1000 m³]	2022 NIR	9,499,670	9,418,288	9,336,906	9,255,524
Quantity of wastewater that is treated with denitrification	[1000 m³]	2023 NIR	8,948,327	8,812,106	8,675,884	8,539,662
Quantity of wastewater that is treated with denitrification	[1000 m³]	2022 NIR	8,965,049	8,845,549	8,726,049	8,606,549
Splitting factor (the share of wastewater treatment with denitrification)	[-]	2023 NIR	0.951611	0.955175	0.958879	0.962732
Splitting factor (the share of wastewater treatment with denitrification)	[-]	2022 NIR	0.943722	0.939189	0.934576	0.929882
N2O Indirect (effluent)	**Units**		**2017**	**2018**	**2019**	**2020**
NEFFLUENT Real	[kt]	2023 NIR	130.814	131.307	128.227	126.398
NEFFLUENT Real	[kt]	2022 NIR	134.501	138.771	141.211	143.423
N_2O emissions	[kt]	2023 NIR	1.028	1.032	1.008	0.993
N_2O emissions	[kt]	2022 NIR	1.057	1.090	1.110	1.127
N_2O, direct	**Units**		**2017**	**2018**	**2019**	**2020**
N_2O emissions	[kt]	2023 NIR	0.328	0.330	0.332	0.333
N_2O emissions	[kt]	2022 NIR	0.325	0.324	0.323	0.322
N_2O, total	**Units**		**2017**	**2018**	**2019**	**2020**
Total N_2O	[kt]	2023 NIR	1.356	1.362	1.339	1.326
Total N_2O	[kt]	2022 NIR	1.382	1.415	1.433	1.449

7.5.1.3.6 Planned improvements, category-specific (5.D.1 Nitrous oxide from municipal wastewater)

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

7.5.2 Industrial wastewater handling (5.D.2)

7.5.2.1 Methane emissions from industrial wastewater handling (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 handling are not a key category.

The CH_4 emissions reported here relate only, in keeping with (IPCC, 2006b), 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 (U. Austermann-Haun & 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 ((U. Austermann-Haun & 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 (U. 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, 2006b): 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, jährlich - 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.[139] For 6 industrial sectors (Manufacture of grain mill products (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, 2006b): Vol. 5, Chapter 6.2.3.1, Equation 6.4). The total methane emissions from industrial wastewater treatment are calculated with the following formula:

[139] 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.

$$CH_4\ Emissions\ = \sum_i \left[\left(TOW_i \cdot \omega_{ANR,i} \cdot \omega_{CSB,i} \cdot EF_{CH4,gelöst,i}\right) + E_{CH4,GS,i} + E_{CH4,PS,i} + E_{CH4,AT,i}\right]$$

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, 2006b): 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 455: 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 %
2021	1,030,958	116%

The TOW figures for the individually considered sub-sectors are shown in Table 9 in (U. Austermann-Haun & 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 457). Until 2016, the underlying wastewater statistics were updated every three years. In 2019, no updating was carried out, for the first time. For this reason, the data as of 2017 are extrapolated. For this purpose, an annual wastewater-quantity reduction of 1 % is assumed for the chemical industry, and an annual wastewater-quantity reduction of 1.5 % is assumed for paper and paperboard production. For the food industry, the value continues to be assumed as constant. The extrapolation (expert assessment) was carried out on the basis of the developments of the previous years. This total-TOW figure from the formula $TOW_i = P_i \cdot W_i \cdot COD_i$ has <u>not</u> 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 TOW_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 TOW_i. The sector-specific parameters are listed in the following Table 456 (cf. also Table 12 in (U. Austermann-Haun & Witte, 2014)).

The various sub-sectors differ in terms of the fractions of wastewater (cf. $\omega_{ANR,i}$ in Table 456) 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 456: 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, 2006b): Vol. 5, Chapter 6) refers to precursors. The reporting to date thus already includes the required additional product categories. (IPCC, 2006b) notes that the default values have to be used with care, since they are industry-specific, process-specific and country-specific.

Table 457: Calculation of the TOW for 2021, direct discharges

Industrial sector	Average COD [kg/m³]	Wastewater quantity (2021) [m³]	TOW (2021 [t COD/year]
Chemical industry	3 1)	244,370,857	733,113
Food industry	3 2)	59,802,282	179,407
Paper and pulp industry	2 2)	185,440,445	370,881
			1,283,400

1) 2006 IPCC Guidelines, (IPCC, 2006b): 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 quality assurance, 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.

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, 2006b), 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)

Recalculations of the TOW were carried out. They were needed in that the statistics on which the values had been based were not continued from 2017 onward. This had made it necessary to rely on extrapolation as of that year (cf. also Chapter 7.5.2.1.2).

Table 458: Recalculation of the TOW on the basis of wastewater quantities for the years 2017 through 2020

Wastewater quantity [m³] Industrial sector	Inventory	2017	2018	2019	2020
Chemicals	2023 NIR	254,395,036	251,851,086	249,332,575	246,839,249
Chemicals	2022 NIR	256,964,683	256,964,683	256,964,683	256,964,683
Paper & paperboard	2023 NIR	196,996,966	194,042,012	191,131,382	188,264,411
Paper & paperboard	2022 NIR	199,996,920	199,996,920	199,996,920	199,996,920
TOW [kt]					
Total	2023 NIR	1,337	1,323	1,310	1,296
Total	2022 NIR	1,350	1,350	1,350	1,350

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

7.5.2.2 Nitrous oxide emissions from industrial wastewater handling (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, 2006b), 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 ((Ute Austermann-Haun & 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, 2006b): 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 (Ute Austermann-Haun & 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 (Ute 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 - 90 % / + 310 %.

The mean specific nitrogen loads in the various relevant sectors have the uncertainties shown in (Table 459). 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 459: 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 quality assurance, 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.

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.

(Ute Austermann-Haun & 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, 2006b), 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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

7.6 Other sectors (5.E)

KC	Category	Activity	EM of	1990 (kt CO_2-eq.)	(fraction)	2021 (kt CO_2-eq.)	(fraction)	Trend 1990-2021
-/-	5 E, Other		CH_4	0.0	0.0 %	2.6	0.0 %	-
-/-	5 E, Other		N_2O	0.0	0.0 %	29.0	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[140].

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 (BFJ & BMJ, 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 460). The emissions limits

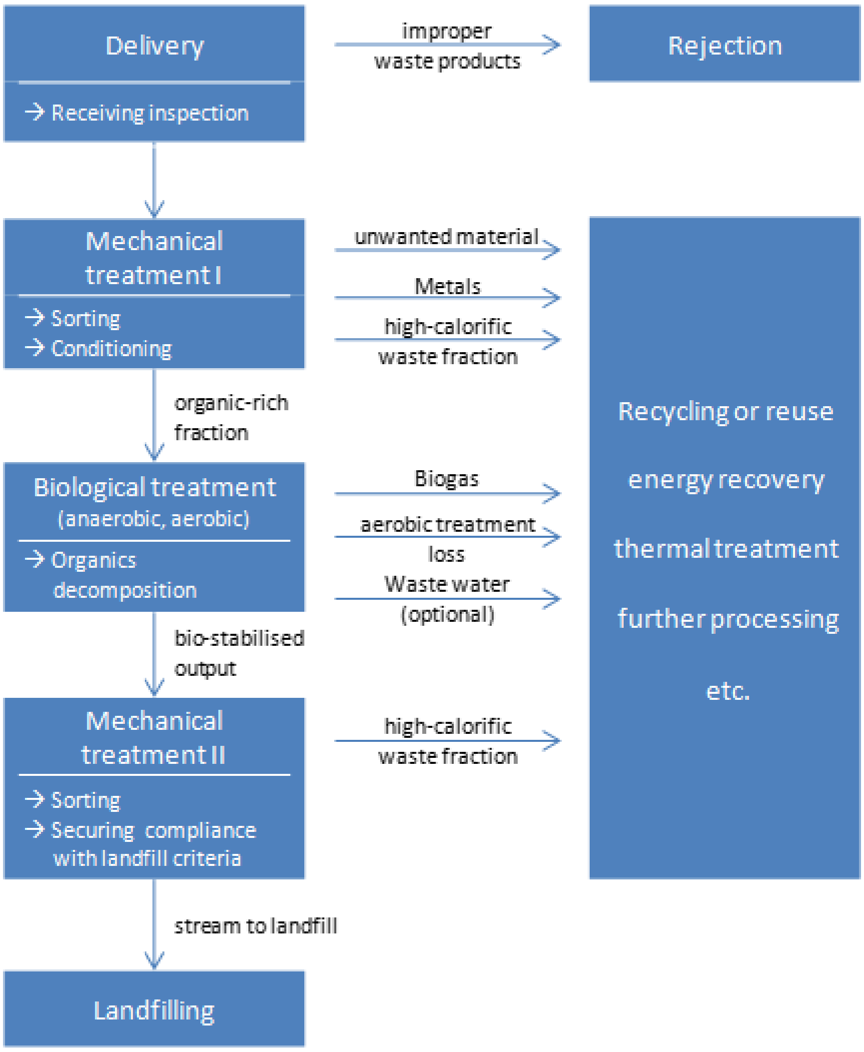
[140] Informative Inventory Report (IIR): www.iir.umweltbundesamt.de

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 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 3.68 million t of waste are treated annually in mechanical-biological waste treatment plants in Germany. In treatment, about 3.23 million t of residues occur. Of these, 0.72 million t are declared as waste for disposal (with a large fraction for storage in landfills); 2,37 million t are declared as waste for recycling (largely, for use as substitute fuels); and 0.35 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 0.44 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 91: Substance-flow scheme for mechanical biological waste treatment (MBT)[141]



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

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. 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, 2019). As of 2020, publication has been discontinued, and the Federal Statistical Office has been providing the activity data via GENESIS-ONLINE ((Statistisches Bundesamt, ohne Jahresangabe), 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 (Detzel et al., 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-

[141] Source: VDI 3475 Blatt 3, Emisssionsminderung - Anlagen zur mechanisch-biologischen Behandlung von Siedlungsabfällen, 2006-12 (amended)

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 requirements (BFJ & BMJ, 2017), all MBT in operation are closed facilities with 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 460).

Table 460: 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.:

$EF\text{-}N_2O$ = 30.3 g N_2O / t waste

$EF\text{-}CH_4$ = 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 quality assurance, 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.

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 461: Recalculation of data for MBT

Designation	Units	NIR	2020
Waste quantities treated	[kt]	2023	3,679.5
		2022	3,718
CH_4	[kg]	2023	96,035
		2022	97040
N_2O	[kg]	2023	111,489
		2022	112,655

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 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 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 462: 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

Indirect CO_2 emissions from CO and NMVOC are not explicitly calculated in the inventory. In the following CRF, they are taken indirectly into account as CO_2, however, via the prescribed/utilised calculation method:

- 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 CO_2 and reported as such in CRF Table2(I).A-Hs2.

On the basis of the 2018 ARR result (G.11, Table 6), and of its reiteration in the 2020 ARR (G7, Table 3 2020), the indirect CO_2 emissions of the energy and IPPU sectors are reported in CRF Table 6 using the notation key "NE." This procedure is also followed for the agriculture, LULUCF and waste sectors.

Only in a very few individual cases are indirect N_2O emissions from NO_X and NH_3 listed as such in the national inventory. These include:

- CRF 3: Indirect N_2O emissions from atmospheric deposition and leaching / surface runoff are reported in CRF Tables 3.B(b) and 3.D.

- CRF 4: Indirect N_2O emissions from leaching / surface runoff are reported in CRF Table 4(IV).

On the basis of the 2018 ARR result (G.11, Table 6), the indirect N_2O emissions of the agriculture and LULUCF sectors are reported using the notation key “IE.” The validity of this procedure was confirmed in the 2020 Review. “NE” is reported for the energy, IPPU and waste sectors.

10 Recalculations and improvements (GWP pursuant to IPCC AR4)

In the recalculations chapters, all emissions figures given in CO_2 equivalents have been calculated using the Global Warming Potentials (GWP) given in the Fourth IPCC Assessment Report, In order to ensure comparability with the inventories of the last report round. Any exceptions have been clearly marked as such.

10.1 Explanation and justification of the recalculations

10.1.1 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.

10.1.2 Recalculations in the 2023 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 2020 became available, the following recalculations for the various relevant fuels were carried out:

(in millions of tonnes of CO_2-equivalents; GWP pursuant to AR4)	2022 Submission	2023 Submission	Change with respect to 2022 Submission	
Total emissions, CRF 1.A	604.7	612.4	7.7	1.3%
Petroleum	229.4	233.1	3.7	1.6%
Natural gas and mine gas	164.3	167.9	3.5	2.2%
Lignite	106.5	107.0	0.4	0.4%
Hard coal	79.3	80.3	0.9	1.2%
Other fuels / fuels	25.1	24.2	-0.8	-3.4%

Source: Own calculations

With respect to the 2022 submission, major changes for petroleum and gases resulted, in part as a result of methodological adjustments. For the year 2020, emissions were upwardly corrected by about 7.7 millions of tonnes of carbon dioxide equivalents. Changes in allocations also play a role in this context, and details regarding the recalculations made are provided especially in the chapters for the CRF categories 1.A.1.b and 1.A.2.g viii.

(Additional, on an excerpt basis)

- mobile emission sources in 1.A: Revision of the CO_2 emission factor for gasoline (2020)

- 1.A.3.a, 1.D.1.a: Correction of the breakdown of flights by domestic and international flights (as of 1990)
- 1.A.3.a, 1.D.1.a: Implementation of a country-specific CO_2 emission factor for avgas (as of 1990)
- 1.A.3.d: First-time inclusion of LNG seagoing vessels (as of 2015)
- 1.A.3.d, 1.D.1.b: Revision of the CO_2 emission factor for heavy fuel oil (as of 1990)
- 1.B.1.b: Revision of the activity data for hard-coal-coke production (2020)
- 1.B.2.b: Adjustment of activity data and methods (as of 1990)

Industrial processes & product use

- 2.A.4.b / 2.B.7: Change in the data source for soda production
- 2.C.1: Implementation of the 2020 final Energy Balance
- 2.D.1: Revision in the area of co-combusted lubricant quantities in mobile emission sources (as of 1990)
- 2.D.2, 2.G.4: Adjustment of foreign-trade statistics (2020)

Agriculture

- 3.A, 3.B, 3.D: Inclusion of data from 2020 agricultural census (as of 2000)
- 3.A, 3.B, 3.D: Correction of ration calculation (as of 1990), and correction of milk yield / weight at slaughter for dairy cows (2020)
- 3.A, 3.B, 3.D: Updating of feeding data for fattening pigs (as of 2011)
- 3.B, 3.D: Cattle/swine: Change in indirect N_2O for deep-bedding housing systems, and consideration of field-edge storage of solid manure, and of indirect N_2O via leaching
- 3.B, 3.D: Correction of the weight at slaughter for heifers (2020)
- 3.B, 3.D: Correction of the age at slaughter / weight at slaughter for male beef cattle
- 3.A, 3.B, 3.D: Correction of the numbers of piglets per sow (as of 2015)
- 3.B, 3.D: Correction of the total gross meat quantity obtained at slaughter, for broilers (2020)
- 3.D, 3.J: Updating of the digested N quantities in connection with digestion of energy crops (as of 2019)
- 3.D: Updating of sewage-sludge quantities (2020)
- 3.D: First-time inclusion of digestates of waste, and of compost of biowaste and garden waste (as of 1990)
- 3.B, 3.D: Introduction of grazing for laying hens
- 3.D: Updating of N quantities for crop residues (as of 2000)
- 3.D: Updating of N quantities from N mineralisation in mineral soils (as of 1990)
- 3.D: Updating of areas and emissions for cultivated organic soils (as of 1990)
- 3.B, 3.D: Revision of activity data for manure digestion (as of 1990)

Land use, land-use change and forestry:

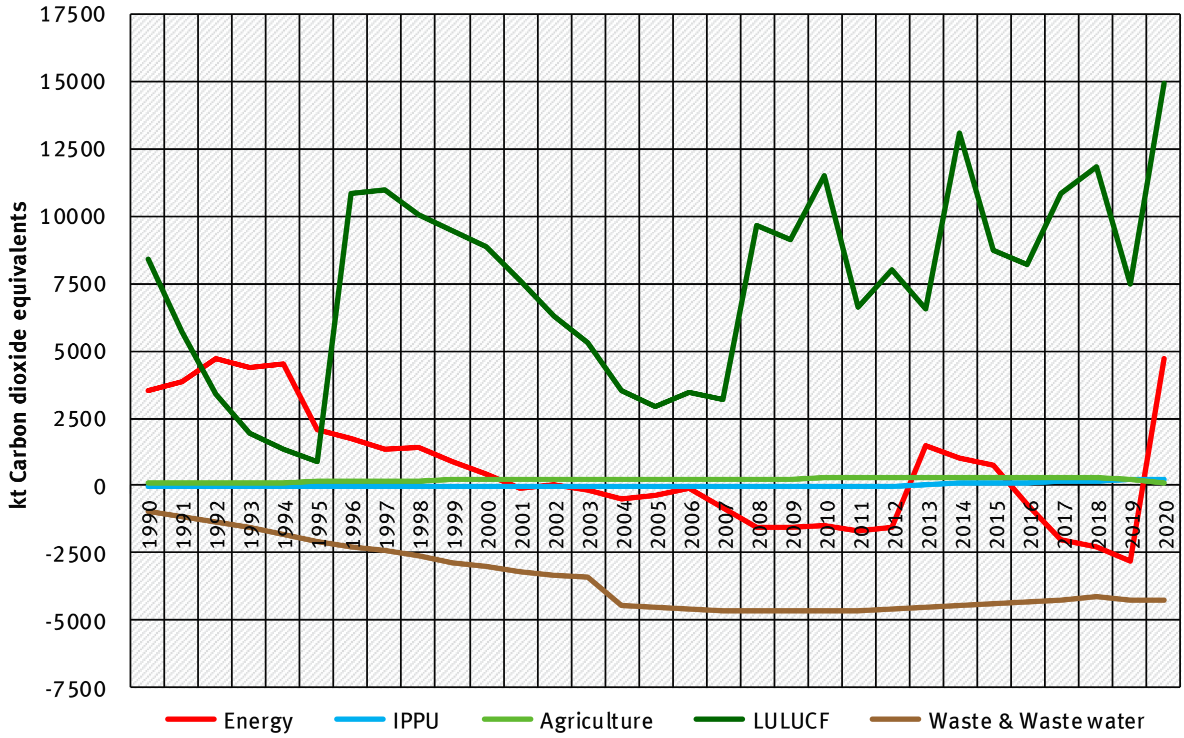
- New implementation of the LULUCF calculation model in the R and C++ programming languages
- Adjustment of the sampling network for determination of land use and land-use changes
- Wildfires: First-time inclusion of biomass comprising dead wood and litter
- Mineral forest soils: Use of the “overlap method,” based on the “stock-difference-method,” and modelling with YASSO
- Regionalisation of the carbon and nitrogen stocks of mineral soils
- Introduction of the land-use sub-categories “hedges,” “natural water bodies,” “standing man-made water bodies,” “flowing man-made water bodies,” and “roads”

- Introduction of regionalised emission factors for mineral soils in the sub-category "Buildings and open areas" of the land-use categories "Settlements" and *"Other Land"*

Waste and wastewater:

- 5.A.1, 5.B.1, 5.B.2, 5.E.1: Routine updating of statistical data for the year before last year
- 5.A.1, CH_4: Revision of emissions parameters (DOC, DOCf, half-life), on the basis of a research project
- 5.A.1, CH_4: Revision of gas quantities collected in landfilling and decommissioning phases (2020)
- 5.B.1: Correction of erroneous activity data (1990 through 1992)
- 5.B.1, 5.B.2: Revision of the emission factor for N_2O (as of 1990)
- 5.D.1: Updating of protein-supply data pursuant to FAO (2018-2020)
- 5.D.1: Updating of the annual wastewater quantity for 2019 and earlier years (as of 2017)
- 5.D.2: Extrapolation of TOW following the elimination of statistics (as of 2018)

Figure 92: Change in total emissions, throughout all categories, with respect to the 2021 submission (GWP pursuant to IPCC AR4)



10.1.3 Recalculations in the 2023 inventory, by substances

Recalculations were carried out in the following source categories (cf. also the specifications in 10.1.2):

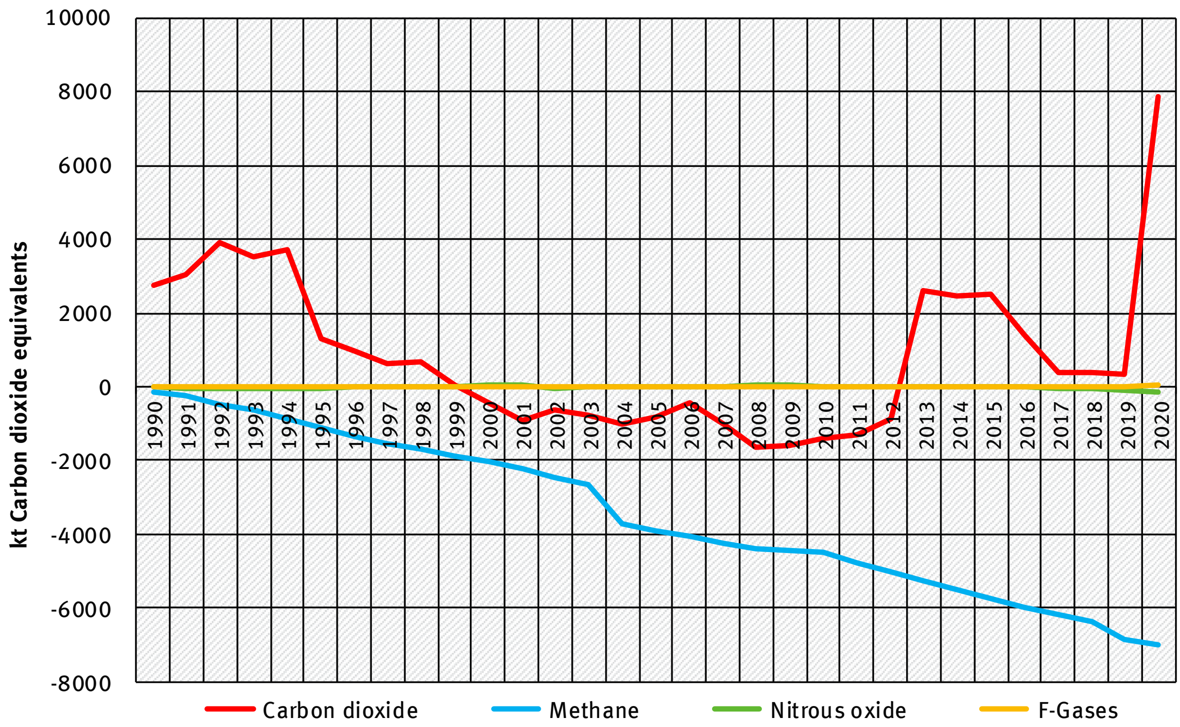
Table 463: Overview of the main CRF categories affected by recalculations

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 464: Percentage changes with respect to last year's report

		Base year	2005	2020
Total (CO_2 equiv.)		0.21%	-0.48%	0.10%
CO_2	1990:	0.26%	-0.10%	1.23%
CH_4		-0.13%	-5.68%	-14.3%
N_2O		0.0%	0.00%	-0.6%
F gases	1995:	0.00%	0.00%	0.39%

Figure 93: Recalculation of total emissions of individual GHG, throughout all source categories, with respect to the 2022 submission (GWP pursuant to IPCC AR4)



With respect to the 2022 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.

10.2 Impact on emissions levels

The changes with respect to the 2022 submission, at plus 0.21 % for 1990, and minus 0.48 % and plus 0.10 % for 2020, are smaller than the corresponding changes in the previous submission.

Table 467 and Table 469 show the changes in emissions as reported for 1990, 2005 and 2020, for the various CRF sectors.

The inventory has been further improved with regard to completeness and accuracy.

Table 465: Recalculation of total national GHG emissions (without LULUCF; GWP pursuant to IPCC AR4)

	2022 Submission	2023 Submission	Change with respect to 2020 Submission	
1990	1,241,919	1,244,508	2,589	0.21%
1995	1,115,305	1,115,458	152	0.01%
2000	1,036,926	1,034,503	-2,423	-0.23%
2005	986,709	981,974	-4,735	-0.48%
2010	935,768	929,904	-5,865	-0.63%
2011	911,244	905,194	-6,049	-0.66%
2012	916,901	911,026	-5,875	-0.64%
2013	933,987	931,311	-2,677	-0.29%
2014	894,465	891,439	-3,026	-0.34%
2015	897,954	894,768	-3,186	-0.35%
2016	901,442	896,840	-4,602	-0.51%
2017	885,729	879,876	-5,853	-0.66%
2018	850,542	844,513	-6,029	-0.71%
2019	799,734	793,139	-6,595	-0.82%
2020	728,738	729,495	758	0.10%

Source: Own calculations

The emissions data for memo items were corrected with respect to the previous report.

Of these changes, those for international civil air and maritime transports were the most pronounced.

Table 466: Recalculations of inventory memo items (GWP pursuant to IPCC AR4)

	1990	2005	2020
Emissions reported as memo items:	**0.94%**	**0.06%**	**0.64%**
From international transports	-0.22%	0.18%	-0.06%
of which: international civil air transport	1.26%	1.08%	0.50%
of which: international maritime navigation	-2.68%	-2.54%	-2.18%
From multilateral military missions	NE	NE	NE
CO_2 from combustion of biomass	0.00%	0.00%	-0.76%
captured CO_2 (CCS)	NO	NO	NO

Source: Own calculations

10.2.1 Impacts on emissions levels of categories in 1990

Total emissions (not including LULUCF) for 1990 were upwardly corrected, by a total of about 0.21 %, or 2,589 kt CO_2 equivalents (cf. Table 467).

The key inventary-relevant corrections were made in opposing directions – in the sectors *Energy* (+3.534 kt | +0.34 %) and *Waste & wastewater* (-960 kt | -2.54 %)

In addition, relatively slight corrections – also in opposing directions – were made in the sectors *Industrial processes and product use* (-52 kt) and *Agriculture* (+67 kt).

The net CO_2 emissions for the *LULUCF* sector have again been upwardly corrected, to a noticeable degree – by +4,169 kt, (+17 %). At the same time, the pertinent methane and nitrous oxide emissions increased by 4,236 kt, or 176 %.

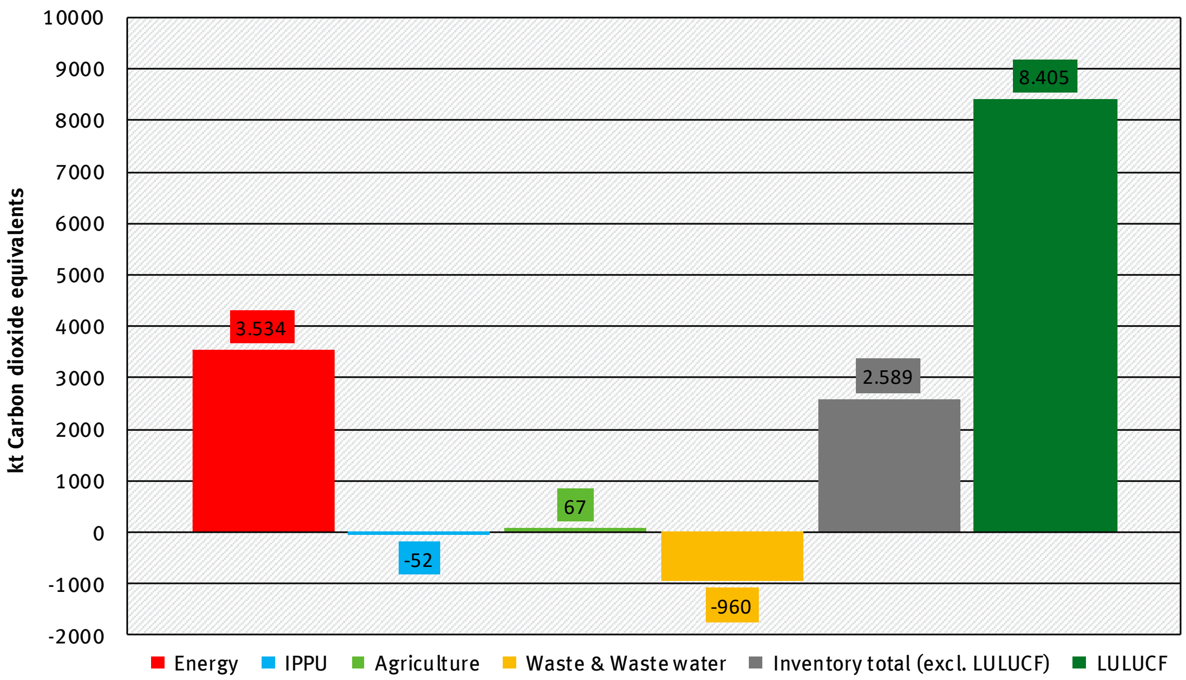
More-detailed pertinent information, in addition to that provided in the following table, is available in CRF tables 8(a)s1 through 8(a)s4.

Table 467: Recalculation of CRF-specific total GHG emissions for 1990, in kt CO_2 equivalents. (GWP pursuant to IPCC AR4)

	2022 Submission	2023 Submission	Change with respect to 2022	
Total national emissions (without LULUCF)	**1,241,919**	**1,244,508**	**2,589**	**0.21%**
1. Energy	1,036,444	1,039,977	3,534	0.34%
2. IPPU	96,891	96,840	-52	-0.05%
3. Agriculture	70,581	70,648	67	0.09%
4. Land-use changes and forestry	27,003	35,408	8,405	-31.1%
CO_2 (net emissions / removals)	*24,591*	*28,760*	*4,169*	*17.0%*
N_2O + CH_4 (emissions)	*2,412*	*6,647*	*4,236*	*176%*
5. Waste & wastewater	38,003	37,043	-960	-2.53%

Source: Own calculations

Figure 94: Absolute changes in CRF sectors and the inventory as a whole, for the year 1990 (GWP pursuant to IPCC AR4)



10.2.2 Impacts on emissions levels of categories in 2005

With regard to the 2022 submission, the total emissions (not including LULUCF) reported for 2005 were downwardly corrected by 4,735 kt CO_2 equivalents, or by 0.48 % (cf. Table 469).

The key correction in this regard was made in the *Waste & wastewater* sector (-4,536 kt | -21.4 %).

In addition, relatively minor corrections were made in the sectors *Energy* (-382 kt), *Industrial processes and product use* (-40 kt) and *Agriculture* (+223 kt).

In the *LULUCF* sector, CO_2 emissions decreased by 1,098 kt in 2005. On the other hand, the combined methane and nitrous oxide emissions in this sector are now nearly three times as high as was reported in the 2022 submission (+4.031 kt | +137 %).

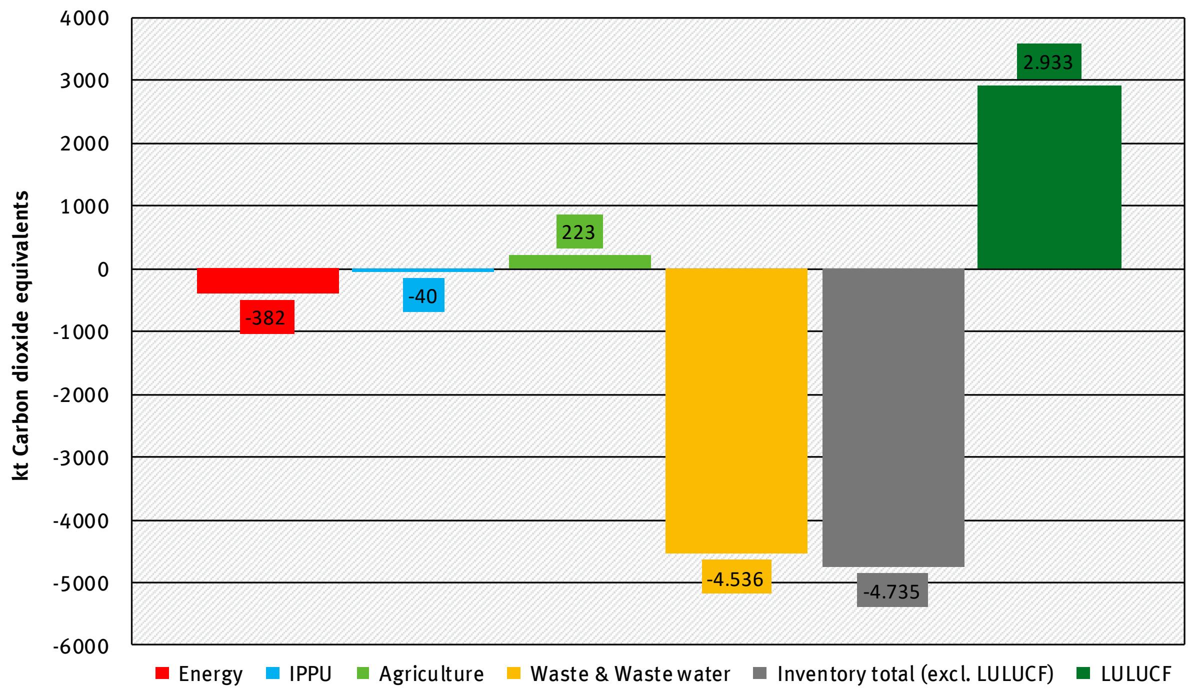
More-detailed pertinent information, in addition to that provided in the following table, is available in CRF tables 8(a)s1 through 8(a)s4.

Table 468: Recalculation of CRF-specific total GHG emissions for 2005, in kt CO_2 equivalents. (GWP pursuant to IPCC AR4)

	2022 Submission	2023 Submission	Change with respect to 2022	
Total national emissions (without LULUCF)	**986,709**	**981,974**	**-4,735**	**-0.48%**
1. Energy	831,839	831,456	-382	-0.05%
2. IPPU	75,602	75,562	-40	-0.05%
3. Agriculture	58,081	58,304	223	0.38%
4. Land-use changes and forestry	4,348	7,281	2,933	-67.4%
CO_2 (net emissions / removals)	*1,406*	*307*	*-1,098*	*-78.1%*
N_2O + CH_4 (emissions)	*2,942*	*6,973*	*4,031*	*137%*
5. Waste & wastewater	21,188	16,652	-4,536	-21.41%

Source: Own calculations

Figure 95: Absolute changes in CRF sectors and the inventory as a whole, for the year 2005 (GWP pursuant to IPCC AR4)



10.2.3 Impacts on emissions levels of categories in 2020

With regard to the 2022 submission, the total emissions (not including LULUCF) reported for the year 2020 were upwardly corrected, very slightly, by 758 kt CO_2 equivalents, or by 0.10 % (cf. Table 469).

The key corrections were made in opposing directions – in the sectors *Energy* (+4.728 kt | +0.78 %) and *Waste & wastewater* (-4,258 kt | -48.6 %).

In addition, minor changes were made in the sectors *Industrial processes and product use* (+199 kt) and *Agriculture (*+88 kt).

In the *LULUCF* sector, CO_2 sink performance decreased dramatically – by 11,140 kt – in 2020. The combined methane and nitrous oxide emissions in this sector are now more than twice as high as was reported in the 2022 submission (+3.762 kt | +111 %).

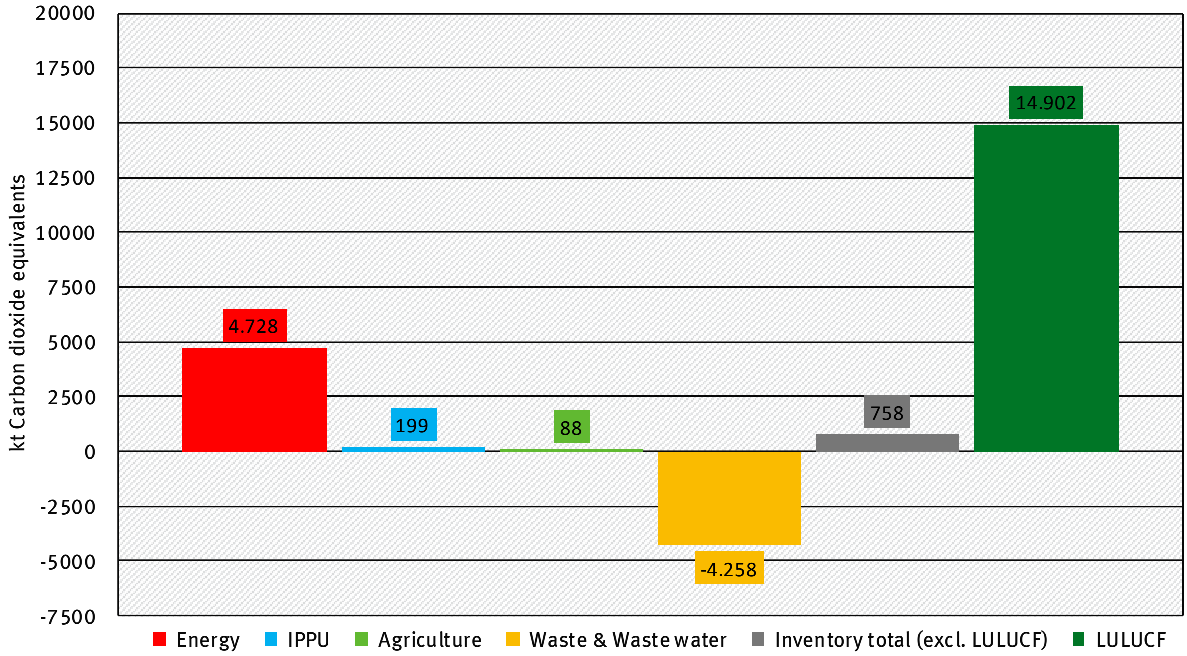
More-detailed pertinent information, in addition to that provided in the following table, is available in CRF tables 8(a)s1 through 8(a)s4.

Table 469: Recalculation of CRF-specific total GHG emissions for 2020, in kt CO_2 equivalents. (GWP pursuant to IPCC AR4)

	2022 Submission	2023 Submission	Change with respect to 2022	
Total national emissions (without LULUCF)	**728,738**	**729,495**	**758**	**0.10%**
1. Energy	608,399	613,128	4,728	0.78%
2. IPPU	55,473	55,672	199	0.36%
3. Agriculture	56,095	56,183	88	0.16%
4. Land-use changes and forestry	-11,265	3,637	14,902	132%
CO_2 (net emissions / removals)	*-14,650*	*-3,511*	*11,140*	*76.0%*
N_2O + CH_4 (emissions)	*3,385*	*7,147*	*3,762*	*111%*
5. Waste & wastewater	8,770	4,513	-4,258	-48.6%

Source: Own calculations

Figure 96: Absolute changes in CRF sectors and the inventory as a whole, for the year 2020 (GWP pursuant to IPCC AR4)



10.3 Impacts on emissions trends and on time-series consistency

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 39 % with respect to the current base year. (For comparison: The reduction for the year 2020, in which the pandemic had a stronger effect, amounted to more than 41 %.)

In 2021, the CO_2-only emissions in 2021 were nearly 5 % above the values of the previous year.

At minus 4.9 % and minus 2.9 %, respectively, emissions of methane and nitrous oxide continued to decrease.

Emissions of F gases overall decreased by a full 4.7 %, although it should be noted that the trends for the individual F gases continue to develop heterogeneously.

10.4 Inventory improvements

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. The table lists only aspects that were not already resolved during the Review.

Table 470: Compilation of the Review recommendations successfully addressed as of the current report

CRF	Review Findings	Improvement	Report [year]	Reference	Reference of reitteration	Resolved in …
0.	ARR 2015/2016:In the NIR (page 768) Germany calculates its commitment period reserve (CPR) to be 4 381 287 024 t CO2 eq. This value has not been updated from the 2014 NIR (page 721) and is not calculated based on the current calculated assigned amount for Germany (3 592 699 888 t CO2 eq). Based on the assigned amount for the second commitment period of the Kyoto Protocol, the ERT calculates the CPR to be 3 233 429 900 t CO2 eq.. ERT: Finding is an issue and/or a problem: Yes	Closed, due to the ending of Kyoto commitment period.	2015, 2016	G.5, Table 5	G.6, 2015; G.5, 2018; G.3, Table 3, 2020 G.1, Table 3, 2022	-
1.A.3.b.	The Party reported in NIR table 59 the CO2 EF for fossil-based gasoline as being up to 75.29 tg/TJ (e.g. for 2017 and 2018), which is higher than the upper value of the default range in the 2006 IPCC Guidelines (vol. 2, chap. 2) (73.00 t/TJ). In the NIR (p.216), Germany indicated that the comparatively high CO2 EF for gasoline is the result of an adjustment. During the review, the Party clarified that the adjustment was related to the average annual country-specific net calorific value (in kJ/kg fuel), which was lowered significantly after 2014 by the responsible mineral oil authority (until 2014 it was 43.542 kJ/kg; as of 2015 it is 42.281 kJ/kg) resulting in a significantly higher energy-related CO2 EF for gasoline (in t CO2/TJ). Is finding an issue/problem?: Yes. Transparency	Resolved	2020	E.5, Table 5	E.3, Table 3, 2022	see NIR chapter 15.7.3
2.C.3.a.	Germany reported that the SF6 EF for secondary aluminium has been reduced to 1.5 per cent owing to “structural conversions” (NIR, section 4.4.3.2). During the review, the ERT requested clarification of what is meant by “structural conversions”. In response, Germany explained that construction changes in the aluminium plant were the cause of the decreased EF. The details of the construction changes were not provided owing to confidentiality concerns. The Party explained that a confidential measurement protocol provided by the plant to the German Environment Agency justified the change in EF, and that the responsible regulatory authority had checked and approved the measurement protocol of the plant. Is finding an issue and/or a problem?: Yes. Transparency	Resolved	2018	I.20, Table 6	I.11, Table 3, 2020; I.6, Table 3, 2022	NIR 2022, chap. 4.4.3.2, p.344
4(V)	The Party reported above-ground biomass stocks as fuel for estimating GHG emissions from biomass burning in NIR table 411. The ERT noted that this is not in accordance with the 2006 IPCC Guidelines (vol. 4, equation 2.27) because fuel also includes litter and deadwood. During the review, the Party acknowledged the missing stocks while noting that biomass burning is an insignificant contributor to national total GHG emissions. The ERT acknowledged this insignificance. Is finding an issue/problem?: Yes. Completeness	Resolved. For forest fire, biomass from the deadwood and litter pools will also be considered for burning as of this submission.	2020	L.16, Table 5	L.12, Table 3, 2022	see NIR chapter 6.4.5, 6.4.2.7.5 and 6.4.2.7.2, Tab 369,

CRF	Review Findings	Improvement	Report [year]	Reference	Reference of reitteration	Resolved in …
4.	The Party applied a country-specific methodology for estimating SOC changes in mineral soils associated with changes in the use of land, as reported in its NIR (section 6.1.2.1, pp.532–541); that is, it calculated a single national average SOC content for each land-use category and subcategory, as shown in NIR table 534. The ERT noted that this is not in accordance with the good practice established in the 2006 IPCC Guidelines (vol. 4, chaps. 2, 4, 5 and 6, and equation 2.25), which requires stratification of the entire population (SOC in mineral soils across the entire national territory) by climate zone, soil type, use of land and management practice of land with the aim of minimizing, so far as practicable, the variability of the average factors to avoid any biases, so far as can be judged, and minimizing uncertainties, so far as practicable. The methodology applied by Germany does not stratify SOC values by climate zone, soil type or management practice. The ERT noted that the Party's limited stratification of SOC compared with the IPCC default stratification means that uncertainty is not reduced as far as practicable. A method that uses the average SOC values of national conditions for each reported category or subcategory can only be valid if land-use conversions are assumed to occur for each land category in equal proportion to the spatial distribution of the SOC content within that category. The NIR does not provide evidence for the assumption that the distribution of SOC values, and associated mean, in each land category corresponds to the distribution, and associated mean, of the areas within the relevant land-use change category. It is therefore not possible to state that the SOC change estimates are accurate, as for instance when land-use changes occur preferentially in a subset of the land category population; for example, the conversion of grassland to forest land is very likely to occur on the less productive land, which very likely has a lower SOC content than the average calculated across the entire area of the grassland. During the review, the Party clarified that the problem is known and the solution is progressing under the stepwise implementation of a new German soil reporting system, as follows: step 1, implementation of new nationwide EFs derived from the results of nationwide soil inventories; step 2, implementation of a new reporting method; step 3, full automation of the German LULUCF reporting system; and step 4, regionalization of the soil inventory results. While the implementation of steps 1 to 3 will inform the next inventory submission, step 4 is expected to be implemented later. The new soil reporting system, once completed, will stratify SOC according to use and natural and site-specific conditions (e.g. geomorphology, parent material, regional climate zone). Is finding an issue/problem?: Yes. Accuracy	Resolved. "With this submission, Germany implemented the ERT recommendation from the 2020 review process (ARR 2020: L.8, Table 5) and regionalized the carbon and nitrogen stocks of mineral soils. "	2020	L.8, Table 5	L.1, Table 3, 2022; L.2, Table 3, 2022	see NIR chapter 6.4.2.5, 6.1.2.1.9
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 (CO_2) (see ID# L.13 in table 5); (b) 4(V) biomass burning – DOM stocks (CH_4 and N_2O) (see ID# L.16 in table 5); (c) FM (CO_2 and N_2O) (see ID# KL.15 in table 5); (d) CM (CO_2) (see ID# KL.18 in table 5).	Resolved. Description is given in the resp. chapter.	2020	Annex III		see NIR 2022, chapter: 6.1.2.1

CRF	Review Findings	Improvement	Report [year]	Reference	Reference of reitteration	Resolved in …
5.A.1.	During the review, Germany outlined plans for future improvement to the estimates of solid waste disposal through research into the decay profiles of individual waste types and decay rates (DOCf and k). According to the information provided during the review, when completed, this work will enable Germany to more accurately report its landfill emissions. The ERT commends Germany for its efforts to further improve the solid waste emission estimates in the inventory, especially given their diminishing significance in terms of the contribution to overall national emissions. ERT: Finding is an issue and/or a problem: Not an issue	Resolved. The DOCf for the wood and straw fraction is adjusted in the 2023 reporting according to recent studies and evaluations ((Stegmann et al, 2018, pp. 68-73). According to the same study, the DOCF is assumed to be 0.5 for the other fractions as before, which corresponds to the IPCC Defaults.	2015, 2016	W.7, Table 5		see NIR-Chapter 7.2.1.2.5
5.A.1.	Table 430 of the NIR presents half-lives and CH4 formation rates (k-values). The k-values do not match the IPCC defaults to which references are made in the table. For example, for food waste, a k-value of 0.173 is given in the table while the IPCC default is 0.185 (2006 IPCC Guidelines, volume 5, table 3.3). For some of the other waste fractions, there are slight differences. It is clear that this issue has arisen from rounding when converting between half-lives and k-values. However, the k-values are being used in the emission calculations, and the 2006 IPCC Guidelines state that the half-lives are based on k-values and not the other way around. During the review, Germany explained that an earlier version of the IPCC spreadsheet model for solid waste disposal on land used half-lives rather than k-values and that the Party had continued to apply this model. Germany informed the ERT that two research projects are under way to determine national k-values. The ERT noted that given that the landfilling of food waste has decreased significantly since 2005, there is an overestimation of emissions in the most recent years. Is finding an issue and/or a problem?: Yes. Accuracy	Resolved. The k-Values have been updated with emission reporting 2023.	2018	W.11, Table 6	W.2, Table 3, 2020; W.1, Table 3, 2022	see NIR 2023 chapter 7.2.1.2.7
KP-CM	see ARR 2020 L.9, L.10 and L.12 (Laufende Nr.: 6571 + 6572 + 6574) Is finding an issue/problem?: Yes. Completeness	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.18, Table 5	KL.11, Table 3, 2022	-
KP-CM - GM	see ARR 2020 L.14 (Laufende Nr.: 6576) Is finding an issue/problem?: Yes. KP reporting adherence	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.19, Table 5	KL.12, Table 3, 2022	-
KP-Deforestation	The Party reported in the information item of CRF table 4(KP-I)A.2 the area of deforested lands disaggregated by final land use, although it did not report the annual carbon stock changes in each carbon pool. Is finding an issue/problem?: Not a problem	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.12, Table 5		-

CRF	Review Findings	Improvement	Report [year]	Reference	Reference of reitteration	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	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.13, Table 5	KL.4, Table 3, 2022	-
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	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.14, Table 5	KL.5, Table 3, 2022	-
KP-FM	see ARR 2020 L.9 Is finding an issue/problem?: Yes. Transparency	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.16, Table 5	KL.7, Table 3, 2022	-
KP-LULUCF	see ARR 2020 L.8 Is finding an issue/problem?: Yes. Accuracy	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.10, Table 5	KL.2, Table 3, 2022	-

CRF	Review Findings	Improvement	Report [year]	Reference	Reference of reitteration	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 2013–2018, 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	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.14, Table 5	KL.5, Table 3, 2022	-
KP-FM	see ARR 2020 L.9 Is finding an issue/problem?: Yes. Transparency	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.16, Table 5	KL.7, Table 3, 2022	-
KP-LULUCF	see ARR 2020 L.8 Is finding an issue/problem?: Yes. Accuracy	Closed - as KP-Inventory-Reporting is no longer carried out.	2020	KL.10, Table 5	KL.2, Table 3, 2022	-

All measures are aimed at achieving complete consistency with the UNFCCC report guidelines and the IPCC Guidelines.

The following table summarises the information provided in the various category chapters of the inventory reports (since 2011) relative to planned improvements. The 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 471: 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	Year of reporting	Reference NIR-chapter	Resolved in
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.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.B.2	Additional measurement campaigns for determination of emissions from natural gas networks are currently underway in Germany. 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). Tentative plans call for integration of the relevant finding within future reports. In the area of end-user emissions (1.B.2.b.vi), some overlapping with emissions from 1.A.1., 1.A.2 and 1.A.4 occurs. Review is thus needed to determine whether any double-counting is occurring in this area.	The reporting is to be updated based on the results of the measurement campaigns.	[2024]	open	ongoing	2023	3.3.2.6	
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]	done	Resolved. Results of the measurement campaigns have been included in the NIR	2021	3.3.2.6	see NIR chapter 3.3.2.2.4 - 3.3.2.2.6

CRF	Planned improvement	Data quality objective	Deadline	STATUS	Comment	Year of reporting	Reference NIR-chapter	Resolved in
2.B.2	The emissions data for the one small producer who was unable to carry out measurements completely in 2021 are to be corrected in the next submission.	The emission data for the one small producer who was unable to carry out measurements completely in 2021 should be corrected in the next submission.	[2024]	open	ongoing	2023	4.3.2.6	
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]	overdue	Germany is continuing to work on that issue.	2022	4.3.7.6	
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.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]	overdue	Germany is continuing to work on that issue.	2021	4.9.2.6	
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]	done	Resolved. "With this submission, Germany implemented the ERT recommendation from the 2020 review process (ARR 2020: L.8, Table 5) and regionalized the carbon and nitrogen stocks of mineral soils."	2022	6.1.2.1.9	see NIR chapters 6.4.2.5 & 6.1.2.1.9
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]	done	Resolved. The calculation of carbon stock change for mineral soils is based on the overlap method and uses a Tier 2 and Tier 3 approach of (2006 IPCC Guidelines - Equ. 2.25, IPCC (2006a)). Detailed description is given in the resp. chapters.	2022	6.1.4	see NIR chapters: chapter 6.1.2.1.3, 6.4.2.5.1, 6.4.2.5.3 and 6.4.2.5.4
4.	The planned improvements for the coming years include the following: Introduction of models for calculation of carbon and nitrogen stocks in mineral soils in the land-use category Cropland. This will have to be preceded by the development of a model for derivation of complete-coverage, regionalised cultivation data from the database of the EU's Integrated Administration and Control System (IACS) (in progress).	Introduction of models for calculation of carbon and nitrogen stocks in mineral soils in the land-use category Cropland. This will have to be preceded by the development of a model for derivation of complete-coverage, regionalised cultivation data from the database of the EU's Integrated Administration and Control System (IACS) (in progress).	[2026]	open	ongoing	2023	6.1.2.1.9	

CRF	Planned improvement	Data quality objective	Deadline	STATUS	Comment	Year of reporting	Reference NIR-chapter	Resolved in
4.	The planned improvements for the coming years include the following: Introduction of model-based calculation of carbon and nitrogen stocks in mineral soils in the land-use category Grassland. No truly reliable data sets are available for validation of models in the area of Grassland. Development of such calculation, therefore, will depend on the availability of results of repeat soil-inventory sampling (this commenced in 2022).	Introduction of model-based calculation of carbon and nitrogen stocks in mineral soils in the land-use category Grassland. No truly reliable data sets are available for validation of models in the area of Grassland. Development of such calculation, therefore, will depend on the availability of results of repeat soil-inventory sampling (this commenced in 2022).	[2028]	open	ongoing	2023	6.1.2.1.9	
4., 4.D	The planned improvements for the coming years include the following: Implementation of regionalised carbon and nitrogen stocks for mineral soils in the land-use category Terrestrial wetlands	Implementation of regionalised carbon and nitrogen stocks for mineral soils in the land-use category Terrestrial wetlands	[2024]	open	ongoing	2023	6.1.2.1.9 + 6.7.6	
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]	done	Resolved. Detailed description is given in the resp. chapters.	2022	6.5.6	see NIR chapter 6.1.2.1.4 & 6.5.2.3.2
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]	done	Resolved. Detailed description is given in the resp. chapters.	2022	6.6.6	see NIR chapter 6.1.2.1.4 & 6.6.2.3.2
4.D	The following short-term measures for inventory improvement are planned for the land-use category Wetlands: Consolidation of activity data sets for the sub-categories Standing man-made water bodies and Flowing man-made water bodies	Consolidation of activity datasets for the Standing man-made water bodies and Flowing man-made water bodies.	[2024]	open	ongoing	2023	6.1.4, 6.7.6	
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]	done	Resolved. Detailed description is given in the resp. chapters.	2022	6.7.6	see NIR chapters 6.1.2.1.7 & 6.7.2.3

CRF	Planned improvement	Data quality objective	Deadline	STATUS	Comment	Year of reporting	Reference NIR-chapter	Resolved in
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]	done	Resolved. Detailed description is given in the resp. chapters.	2022	6.8.6	see NIR chapter 6.1.2.1.6 & 6.8.2.3
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]	done	Resolved. Due to the differences between the statistically recorded values and the estimated landfill gas quantity, several research projects have been initiated by UBA in recent years. With the adoption of the research-results (Stegmann et al, 2018) as of the 2023 report, this difference have dissolved.	2013	8.2.1.6	see NIR chapter 7.2.1.2.3 ff
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]	done	Resolved. The results of the research projects have been adopted with the emission reporting 2023.	2019	7.2.1.6	see NIR chapter 7.2.1.2.3 ff
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 DOCf 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]	done	Resolved. The results of the research projects have been implemented with the emission reporting 2023	2020	7.2.1.6	see NIR chapter 7.2.1.2.3 ff

CRF	Planned improvement	Data quality objective	Deadline	STATUS	Comment	Year of reporting	Reference NIR-chapter	Resolved in
5.D.1.	In the area of wastewater treatment, only CH_4 emissions from open cesspools and N_2O 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.	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]	overdue	Germany is continuing to work on that issue.	2022	7.5.1.1.6 + 7.5.1.3.6	

10.4.1 Implementing Regulation Article 9: Reporting on implementation of recommendations and adjustments

Table 472: Implementing Regulation Article 9: Reporting on implementation of recommendations and adjustments, Article 9.1

Member State:	Germany			
Reporting year:	UNFCCC Annual Review Report 2022			
CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Chapter/section in the NIR
The ARR 2022 was issued in March 2023, which was too late to implement its recommendations into the 2023 reporting.				

11 Information relative to accounting for Kyoto units

11.1 Background information

Chapter 11 and 0 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 0.

11.2 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.

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.

11.3 Discrepancies and Notifications

15/CMP.1 annex I.E paragraph 12 List of discrepant transactions	No discrepant transactions occurred in 2022.
15/CMP.1 annex I.E paragraph 13 and 14 List of CDM notifications	No CDM notifications occurred in 2022.
15/CMP.1 annex I.E paragraph 15 List of non-replacements	No non-replacements occurred in 2022.
15/CMP.1 annex I.E paragraph 16 List of invalid units	No invalid units exist as at 31 December 2022.
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.

11.4 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	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.

Joint implemention project information	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 2022, 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**

11.5 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_{2eq} equivalent) calculated pursuant to Article 3 paragraphs 7 and 8 of the Kyoto Protocol as this yields less than eight times of its most recently reviewed inventory. The emissions in 2020 where 728,737,600 tonnes CO_{2eq}. Eight times his amount yields 5,829,901,000 tonnes CO_{2eq}.

The initial CPR of the current commitment period did not change and is still 3,233,429,900 tonnes CO_{2eq} (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 Information on changes in the national registries

The following changes to the national registry of Germany have occurred in 2022. Note that the 2022 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	No change regarding the cooperation arrangement occurred during the reported period..
15/CMP.1 annex II.E paragraph 32.(c) Change to database structure or the capacity of national registry	There has been 3 new EUCR releases (versions 13.6.1, 13.7.1 and 13.8.2) after version 13.5.2 (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 13.6.1, 13.7.1 and 13.8.2 compared with version 13.5.2 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) Change to list of publicly available information	No change to the list of publicly available information occurred during the reporting period.
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 has been opened on 6.10.2020 in the Union Registry.
Annual Review report Previous Expert Review Team recommendations	The last available report (FCCC/ARR/2022/DEU published 2.3.2022) contains no recommendations regarding the registry. Recommendations from former annual review reports (specifically FCCC/ARR/2020/DEU) have been addressed in the last NIR.

13 Other information

This chapter is currently not required.

14 Annex 1: Key categories of 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.

14.1 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 5 in Chapter 1.5. In this context, we call attention to the description of the underlying methods in the *2006 IPCC GL* (IPCC (2006b): Vol. 1).

14.1.1 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) gases) in the base year (1990; 1995 for the F gases) 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 (2006b): 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 (2006b): Vol. 1).

The following table presents a complete list of all of the sub-categories covered by the analysis.

Table 473: Key categories for Germany pursuant to the Approach 1 method (complete list, calculated with IPCC AR5-GWP)

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2021	Level 2021 + LULUCF	Trend 2021	Trend 2021 + 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	-	-	-	-	-	-	-	-	-/-

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2021	Level 2021 + LULUCF	Trend 2021	Trend 2021 + LULUCF	KCA decision
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
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	-	-	-	-	-	-	•	-	-/T
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/T
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/-
2 B 2, Nitric Acid Production		N_2O	-	-	-	-	-	-	•	•	-/T
2 B 3, Adipic Acid Production		N_2O	•	•	•	•	-	-	•	•	L/T

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2021	Level 2021 + LULUCF	Trend 2021	Trend 2021 + LULUCF	KCA decision
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	-	-	-	-	-	-	-	-	-/-
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 Chemical Industry		CH_4	-	-	-	-	-	-	-	-	-/-
2 B 10, Other Chemical Industry		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-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 2021	Level 2021 + LULUCF	Trend 2021	Trend 2021 + 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	-	-	-	-	-	-	•	•	-/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/-
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/-
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 and leaching	N_2O	-	-	-	-	-	-	-	-	-/-
3 D, Agricultural Soils		N_2O	•	•	•	•	•	•	•	•	L/T
3 G, Liming		CO_2	-	-	-	-	•	•	•	•	L/T

IPCC Categories	Activity	Emissions of	Level Base Year	Level Base Year + LULUCF	Level 1990	Level 1990 + LULUCF	Level 2021	Level 2021 + LULUCF	Trend 2021	Trend 2021 + LULUCF	KCA decision
3 H, Urea Application		CO_2	-	-	-	-	-	-	-	-	-/-
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	-	•	-	•	-	•	-	•	L/T
4 D, Wetlands		N_2O	-	-	-	-	-	-	-	-	-/-
4 E, Settlements		CO_2	-	-	-	-	-	-	-	•	-/T
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	-	-	-	-	-	-	-	-	-/-

14.1.2 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 6, Chapter 1.5.1, also have to be considered, however.

14.1.3 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 (2006b): 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.

15 Annex 2: Detailed discussion of the methodology and data for calculating CO_2 Emissions from combustion of fuels

15.1 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 Climate Action (BMWK). The most important data source for the Energy Balance is the *Federal Statistical Office (Statistisches Bundesamt).* Data on renewable energy sources are collected and provided 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.

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 476: Federal Statistical Office surveys used in preparation of Energy Balances for the Federal Republic of Germany . The final Energy Balance continues to include data from the following associations: Nuclear Technology Germany (KernD); the Federal German association of lignite-producing companies and their affiliated organisations (DEBRIV); the Federal German association of the energy and water-resources industries (bdew); the

Gesamtverband Steinkohle association of the German hard-coal-mining industry (GVSt); and the Fuels and Energy industry association (en2x).

Also, experts personally provide relevant data in a number of specific cases – such as on non-energy-related consumption by the chemical industry.

Furthermore, the then Federal Ministry for Economic Affairs and Energy (BMWi) 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 German 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.

In recent years, German experts on energy statistics have expended considerable efforts on the task of minimizing the differences between the provisional and final Energy Balances. In 2020, the Federal Statistical Office obtained the EU grant "improvement of timeliness of energy statistics" from EUROSTAT. In the framework of a dedicated project, this funding is expected to enable the Federal Statistical Office to provide data for year x-1, to the AGEB, as early as August of the relevant year. The pertinent project was launched in 2020, and it includes the statistical offices of the Länder, which are responsible for the concrete surveys involved. Key surveys for the preparation of the Energy Balance and the emissions inventories have been given temporal priority. As a result, the Federal Statistical Office, working on the basis of the data collected by the reference date, and using imputation procedures, was able – in July 2020 – to extrapolate a complete data set for the year 2019. In July 2021, the so-developed methods were used in routine operations for the first time. In October 2021, quality assurance for the methods was carried out by comparing the extrapolated results with the final 2020 survey data. In the 2022 survey year, the resulting methodological improvements made it possible to prepare a considerably improved provisional Energy Balance, now based, for the first time, on extrapolations – the 2021 provisional Energy Balance. The participating institutions coordinated their scheduling for the relevent data flow so carefully that a number of process steps are being carried out in the shortest-possible processing time, and the relevant data can be available for inventory preparation in 2023.

15.2 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, and
- 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 description of **final energy consumption** (by energy sources / fuels) shows the potential scope of energy consumption in the final consumption sectors. (The energy that is ultimately required (for applications such as work, lighting, space heat and process heat) has to be differentiated from final energy consumption. It is not listed in the EB (AGEB, 2015).) 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 sources / fuels. 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),
- electrical power, and other energy sources (non-renewable waste, waste heat).

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 sources 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 meet the need for emissions reporting to be as up to date as possible, the following procedure will be carried out on an annual basis as of 2022 for purposes of inventory preparation: at the end of August, the Working Group on Energy Balances (AGEB) will provide the German Environment Agency (UBA) with a complete provisional Energy Balance, based on extrapolated statistics of the Federal Statistical Office, for the year x-1. The AGEB will then deliver the final Energy Balance to UBA in the following February (at that point, the EB will be for the year x-2). Publication will then take place in about the following April.

15.3 Methodological issues: Energy-related activity rates

Essentially, the inventories for air pollutants and greenhouse gases prepared by the German 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 3.2.6.2.
- Natural gas inputs in compressors, for the years 1995-2002, were taken 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 NIR 2022’s 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 Balances through 2012; it 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, for energy production, of the blast-furnace gas produced in pig-iron 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.

15.4 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 for the Energy Balance somewhat, the dynamic development of the energy sector soon necessitated an amendment of that Act. The currently valid amendment of the Act on Energy Statistics of 6 March 2017 (Federal Law Gazette (BGBl) I p. 392) introduces improvements in statistical coverage, updates the survey groups involved and adds 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 covered survey year 2018.

The data structures of the Energy Balance are adjusted on an ongoing basis, in order to ensure that the best-possible data are provided.

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 [142]
- Remarks regarding changes in the Energy Balances 2003 through 2007 [143]
- Revision of the Energy Balances 2003 through 2009 [144]
- Methodological changes in the 2012 Energy Balance [145]
- Explanations relative to the Energy Balances (updated as of November 2015) [146]

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 time series will be revised in 2023, as part of the implementation of the proposals made in that report.

15.4.1 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. As of 2020, and in the framework of the contract for the Energy Balances – and as a quality-assurance measure – the Energy Balances are being prepared and provided in a time-series format. This facilitates detection of time-series jumps during compilation of the data.

The following section presents the content of the current report, in its original wording (marked with a different typeface).

15.4.1.1.1 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. The Energy Balances for the Federal Republic of Germany, which the Working Group on Energy Balances (AGEB) has been commissioned to prepare,

142 http://www.ag-energiebilanzen.de/#revision_der_eb_2003_bis_2006
143 http://www.ag-energiebilanzen.de/#aktualisierungen_der_energiebilanzen_2003_bis
144 http://www.ag-energiebilanzen.de/#revision_der_energiebilanzen_2003_bis_2009_05
145 http://www.ag-energiebilanzen.de/#methodische_aenderungen_der_eb_2012
146 http://www.ag-energiebilanzen.de/index.php?article_id=29&fileName=vorwort.pdf

are among the most important data sets for determination of greenhouse-gas emissions. 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 2020 Energy Balance.

15.4.1.1.2 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)

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 Energy Balances for the following energy sources / 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. 066K (Monatserhebung über die Elektrizitäts- und Wärmeerzeugung der allgemeinen Versorgung; Monthly survey of electricity and heat generation for the public sector) 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.

15.4.1.1.3 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.htm l[147]; last checked on 2 February 2022.

In addition, data from the *Official Mineral Oil Statistics (AMS)* of the Federal Office of Economics and Export Control (BAFA) are used:

BAFA - Energie - Amtliche Mineralöldaten Dezember 2020, last checked on 2 February 2022.

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:

[147] 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.

"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*
- *LPG: 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 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, transformation 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, transformation 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; they are now listed 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 onshore and offshore wind energy production, and energy production via photovoltaics, are derived from
- the relevant electricity feed-in and compensation, as certified by auditors for transmission system operators (TSO), in keeping with 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.

15.4.1.1.4 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 (broken down by fuels) for the public supply and for industry.

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-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.[148]

15.4.1.1.5 Checking and verification of results

Measures for quality assurance and control cover the following areas:

- Assurance of data quality / transparency of methods and procedures,
- 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 Methodi”" – AKM) sited within the Federal Ministry for Economic Affairs and Climate Action (BMWK).

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

[148] 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. Energy statistics are being brought into line with the
changed framework conditions 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.

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.

15.4.1.1.6 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 the organisations themselves and by the Federal Ministry for Economic Affairs and Climate Action (BMWK) and the German Environment Agency (UBA). 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 a 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).

15.4.1.1.7 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.

15.4.1.1.8 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 2020, became available in May 2021. Other annual surveys became available as follows: 064 (heat generation), December 2021; 067 (electricity generation systems of industry), October 2021; 070 (electricity feed-in), December 2021; 073 (sewage gas), September 2021; 082 (gas), December 2021. The results of survey 062 (geothermal energy), and the results of survey 063 (biofuels), became available in December 2021. 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 December 2021. 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, are 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.

Table 474: Data for the year 2020:

Surveying institution	Statistics no.	Publication date
Federal Statistical Office	060	Dec. 2021
	062	Dec. 2021
	063	Dec. 2021
	064	Dec. 2021
	066	Dec. 2021
	067	Oct. 2021
	070	Dec. 2021
	073	Sept. 2021
	075	Sept. 2021
	082	Dec. 2021
BAFA	Official Mineral Oil Statistics (Amtliche Mineralölstatistik)	Monday, June 14, 2021

Table 475: Data for the year 2019:

Surveying institution	Statistics no.	Publication date
Federal Statistical Office	Energy tax 2019, Tab. 2.3 Natural gas	Monday, June 21, 2021

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 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 (EN2X) 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 from 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 petroleum coke for use in metallurgical coking plants are provided by the relevant German Länder (states), for the

national Energy Balance, on the basis of an agreement between the 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 476: 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	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 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 Figures for heat networks Heat balance		All operators of heating plants with installed rated capacity of 1 MW_{th}, 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	Number, net nominal capacity, and electricity and heat generation by generating unit Fuel inputs, fuel stocks, and electricity and heat generation by the installation, in the report month Sales of heat in the report month Storage systems	Operators of plants for generation of electricity, including CHP systems, with net nominal capacity of at least 1 MW_{el} in each case; and systems for storage of electricity with net nominal capacity of at least 1 MW_{el} or with 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 MW_{el} 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	Number, net nominal capacity, and electricity and heat generation, broken down by generating units; and bottleneck capacity by type of installation; primary energy savings 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 MW_{el}
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.

Survey	No.	Survey period	Currentness, pursuant to quality report	Type of data	Group surveyed	Units surveyed
Annual survey of generation and use of heat and of heating-network operations	064	Annually	End of the following year	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 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 Figures for heat networks Heat balance		All operators of heating plants with installed rated capacity of 1 MW_{th}, 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	Number, net nominal capacity, and electricity and heat generation by generating unit Fuel inputs, fuel stocks, and electricity and heat generation by the installation, in the report month Sales of heat in the report month Storage systems	Operators of plants for generation of electricity, including CHP systems, with net nominal capacity of at least 1 MW_{el} in each case; and systems for storage of electricity with net nominal capacity of at least 1 MW_{el} or with 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 MW_{el} 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	Number, net nominal capacity, and electricity and heat generation, broken down by generating units; and bottleneck capacity by type of installation; primary energy savings 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 MW_{el}
Monthly survey of gas supply	068	Monthly	42 days after the end of the report month	Production and own consumption of natural gas (upper net calorific value) Feed-in and withdrawal of natural gas, biogas; own consumption 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	Monthly survey of gas supply
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	Grid utilisation charges for customers with special contracts Grid feed-in, by fuels Removals from the grid 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 electricity feed-in, and electricity demand, as recorded by electricity grid operators,
Annual survey of production, use and supply of sewage gas	073	Annually	8 weeks after the end of the reporting period	Production, use and supply of sewage gas Use of sewage sludge, at wastewater treatment plants, for generation of electricity and heat Installed capacity of installations for generation of electricity and heat Electricity and heat generation from sewage gas 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	Annual survey of production, use and supply of sewage gas
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 deliveries of LP gas
Annual survey of gas sales and income in the gas-supply sector	082	Annually	As a rule, the national results become available 12 weeks after the end of the reporting period	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 Deliveries and exports of gas, and relevant revenue Gas production, by gas types Gas deliveries, and revenue, by Länder	All operators of systems in the gas supply sector	Annual survey of gas sales and income 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 [149]

[149] On its website, the Federal Statistical Office only publishes 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.

15.5 REGULAR COMPARISONS OF ENERGY BALANCES

15.5.1 Comparison of the 2020 Energy Balance with the 2020 estimated Energy Balance

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 2020 Energy Balance with the 2020 estimated Energy Balance yields 19 positions (including sum fields). These are shown in the overview below and explained in the following.

Table 477: Overview: Positions of note in the comparison of the 2020 Energy Balance with the 2020 estimated Energy Balance

EB column	EB line	TJ	%	Explanatory remarks:
Hard coal	Statistical differences	-34,855	-90.5	Difference between production and use
Hard coal	FINAL ENERGY CONSUMPTION	-47,378	-23.2	Calculated
Hard coal	Metals production	-51,277	-30.2	Estimation error
Hard coal	Mining, non-metallic minerals, manufacturing sector overall	-47,378	-23.2	Estimation error
Coke	DOMESTIC PRIMARY ENERGY CONSUMPTION	10,518	59.6	Calculated
Other lignite production	Statistical differences	12,038	114.2	Difference between production and use
Other lignite production	FINAL ENERGY CONSUMPTION	12,420	22.4	Calculated
Other lignite production	Processing of non-metallic minerals	15,988	39.0	Estimation error
Other lignite production	Mining, non-metallic minerals, manufacturing sector overall	12,420	22.4	Estimation error
HEL	Statistical differences	50,204	-100.0	Difference between production and use
HEL	Commercial and institutional, and other consumers	56,912	51.1	Estimation error
HS	Statistical differences	10,038	-38.0	Difference between production and use
Natural gas	Manufacture of refined petroleum products	18,935	41.3	Estimation error
Natural gas	Total energy consumption in the transformation sector	19,591	23.9	Total
Natural gas	Statistical differences	50,852	-53.5	Difference between production and use
PET	**Manufacture of refined petroleum products**	**18,947**	**41.2**	**Total**
SET	**Statistical differences**	**79,468**	**-95.8**	**Total**
SET	**Processing of non-metallic minerals**	**24,209**	**28.3**	**Total**
Total	**Statistical differences**	**86,392**	**-64.2**	**Total**

15.6 Energy-Data Action Plan for inventory improvement

Since 2012, the German Environment Agency, working in cooperation with the Federal Ministry for Economic Affairs and Climate Action (BMWK), 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 478: 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 Climate Action (BMWK) / 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	Federal Ministry for Economic Affairs and Climate Action (BMWK) / Working Group on Energy Balances (AGEB) / Federal Statistical Office / Statistical offices of the Länder	BMWK	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	Federal Ministry for Economic	BMWK/AGEB (not for official data) /	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	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
	the final Energy Balance	Affairs and Climate Action (BMWK) / Working Group on Energy Balances (AGEB) / Federal Statistical Office / Statistical offices of the Länder	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	Federal Ministry for Economic Affairs and Climate Action (BMWK) / Working Group on Energy Balances (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. As of issuance of the contract for preparation of the Energy Balances for the years 2018 through 2020, established procedures call for the existing estimation procedures and	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
							transition models to be continually 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 for Economic Affairs and Climate Action (BMWK) / 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;	Annual energy data workshops held since 2010	Ongoing since 2010	
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	Federal Ministry for Economic Affairs and Climate Action (BMWK), AGEB, persons responsible for questionnaires	BMWK	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 the report of the EEFA research institute to the AGEB and the Federal Ministry for Economic	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
								Affairs and Climate Action (BMWK). 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 2023		
6.2	Discrepancies between EB and IEA data	Federal Ministry for Economic Affairs and Climate Action (BMWK), AGEB, persons responsible for questionnaires	BMWK	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 its inventory data and the corresponding IEA data in its next annual submission.*		To be jointly defined in the framework of the action plan	See 6.1	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
6.3	Discrepancies between EB and IEA data	Federal Ministry for Economic Affairs and Climate Action (BMWK), AGEB	BMWK		*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 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	Federal Ministry for Economic Affairs and Climate Action (BMWK) / Federal Statistical Office	Federal Statistical Office	39	*significant amount of flaring/losses of natural gas in the NEB that were not transparently accounted for*	NIR, EB	Meeting involving all participating energy experts; review and adjustment of the data source		Completed as of April 12	

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								
7.2	Improvement of the balance sheet for gases	Federal Ministry for Economic Affairs and Climate Action (BMWK) / 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	Revision of the NEB	Completed	

15.7 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, 2006b).

A more-detailed is provided in the following report: CO_2-Emissionsfaktoren für fossile Brennstoffe - Aktualisierung 2022 (CO_2 emission factors for fossil fuels – 2022 update) (Juhrich, 2022).

15.7.1 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:

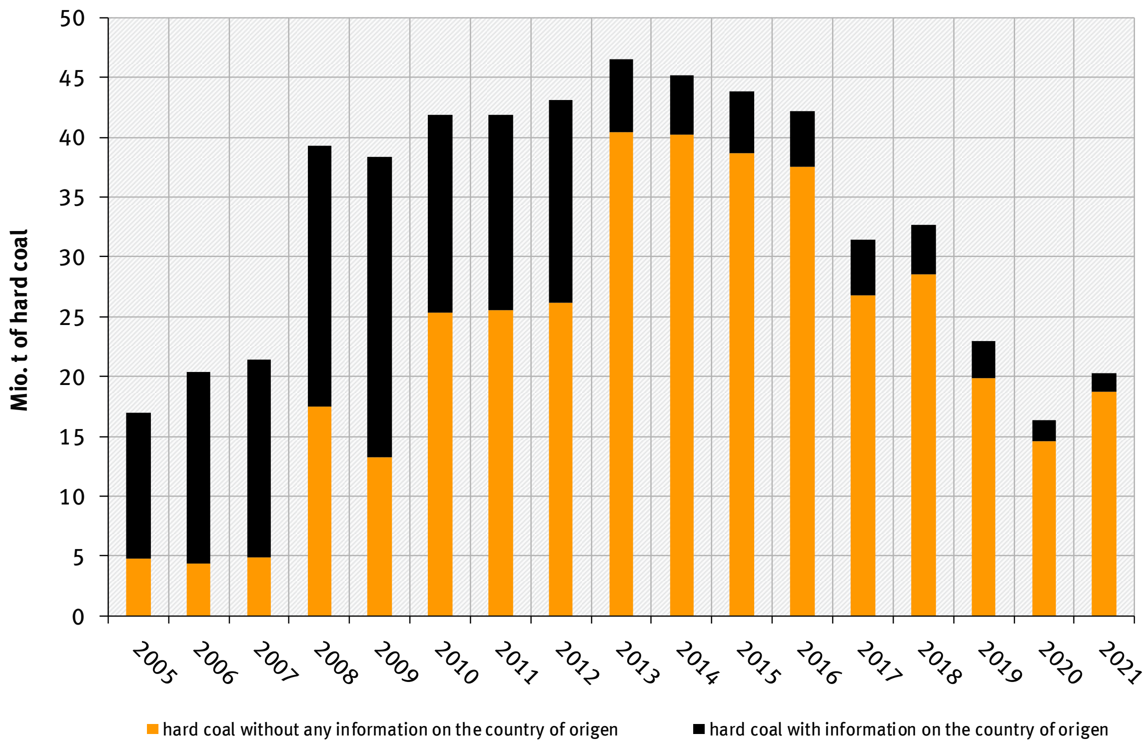
Table 479: Comparison of CO_2 emission factors for hard coal

[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.

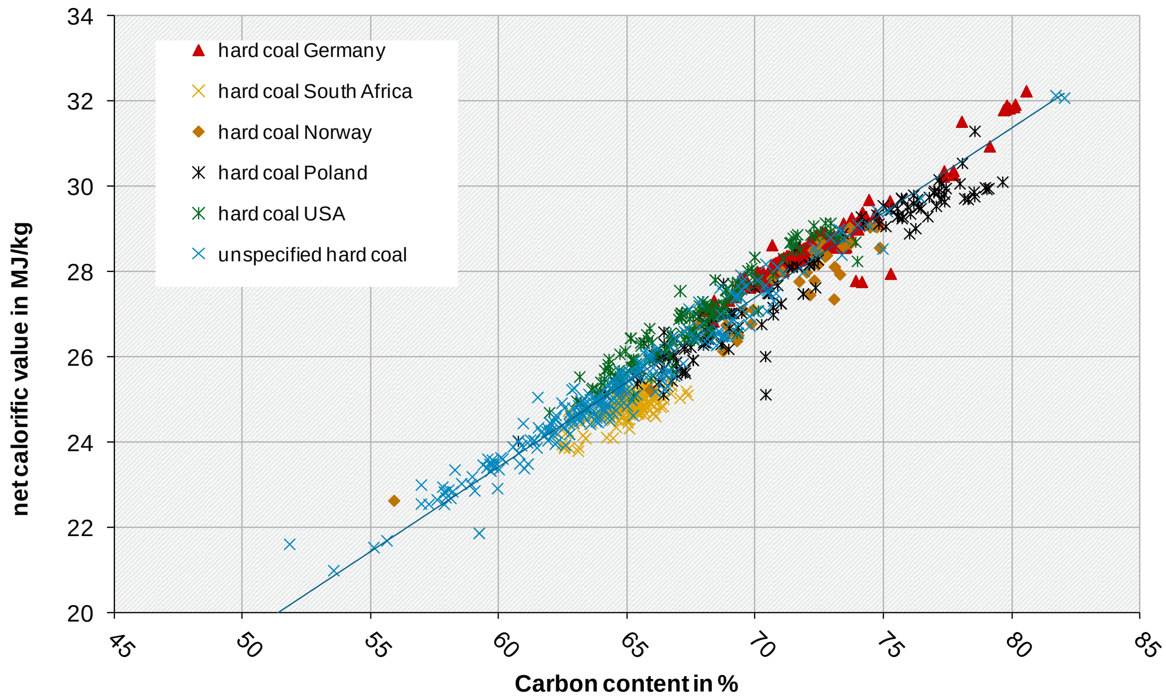
Figure 97: Hard-coal quantities for which emission factors and calorific values measured in the emissions trading framework are available



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 98: 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**.

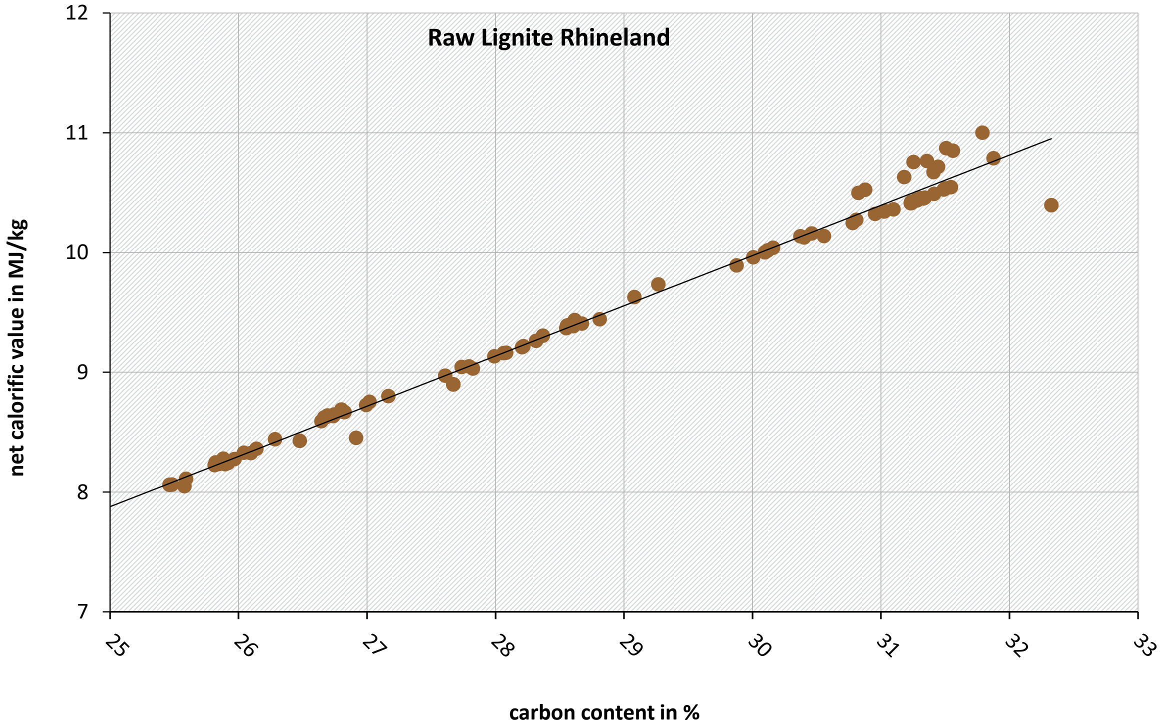
With regard to **hard-coal coke**, an average, energy-based CO_2 emission factor was calculated, for all other industrial sectors, from the emissions trading data for the years 2005 – 2013. The emission factors for the subsequent years differ only slightly, and thus calculations can continue to use the 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.

15.7.2 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 99: 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 99 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.

15.7.3 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") was comprehensively evaluated (DGMK, 2002). 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. From those carbon-content levels, mass-based emission factors were then derived.

The factors were reviewed and updated in 2020, by PetroLab, in the framework of the project "Analyse von Ottokraftstoffen und Flugbenzin zur Validierung der Faktoren" ("Analysis of gasolines and avgas, for validation of factors"). The results, which refer only to the fossil fuel fractions, are similar to those obtained in the DGMK study. The following table shows the mean values of the factors, as obtained in projects to date:

Table 480: Comparison of CO_2 emission factors for fossil fuel fractions

	Units	Regular	Super (premium)	Super leaded	Super plus (premium plus)
Petrolab 2022	t CO_2/ t	-	3.171	-	3.137
DGMK 2002	t CO_2/ t	3.183	3.185	-	3.141
DGMK 1994	t CO_2/ t	3.179	3.188	3.193	3.156
max. difference	%	0.129	-0.551		-0.618

The magnitude of the emission factor depends mainly on the fractions of aromatic compounds, kerosenes, ethers and other oxygen compounds involved, which differ in terms of their carbon content.

At the time the DGMK study was being carried out, gasolines did not yet contain any biogenic fractions. For this reason, it was not necessary to differentiate between the various fuel fractions involved. In the 2022 PetroLab study, on the other hand, differentiation between biogenic and fossil fuel fractions was required, since the fractions now have to be reported separately.

The energy-related emission factor used in the inventories is derived on the basis of the net calorific values annually published by the Working Group on Energy Balances (AGEB). (AGEB, 2021c)

From 2014 to 2015, that implied net calorific value, which is derived from the quantities reported by producers, in units of metric tonnes and terajoules, decreased from 43,542 to 42,281 kJ / kg. As a result, the derived energy-related emission factor increased from 73,091 to 75,287 kg CO_2 / TJ – which is outside of the range given by the IPCC Guidelines. The factor has remained outside of that range since then.

Juhrich (2022) recently carried out a review and update of the country-specific CO_2 emission factors for fossil fuels. In this context, an implied mass-based emission factor of 3.169 kg CO_2 / kg was obtained for the year 2020. From it, in turn, an energy-related emission factor of 74,952 kg CO_2 / TJ was derived. With regard to recurring review remarks concerning the country-specific value, which is noticeably high in comparison to IPCC defaults and international values, the report concludes that "*the default value given in the 2066 IPCC Guidelines, 69.3 t CO2/TJ, is too low"* and that its used within the "*German inventory would lead to a considerable underestimation*."

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.

15.7.4 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 is calculated from emissions trading data for the chemical industry. In the process, the total consisting of the CO_2 emissions from use of other gases in the EU Emissions Trading System (ETS) is obtained. Fuel input quantities cannot be determined from emissions trading data, since some operators give fuel inputs in tonnes, while others give them in m^3. Only in individual cases are net calorific values given. The energy statistics give relatively low fuel input figures, and the figures' annual changes do not always seem plausible. For this reason, the fuel quantities given in reporting for large combustion plants are used. This procedure ensures consistency with the air pollutant emission inventory. Finally, the CO_2 quantity determined from the ETS – the quantity resulting from combustion of other gases – is divided by the fuel input figure from reporting for large combustion plants, in order to obtain a CO_2 emission factor. The so-determined CO_2 factors are roughly similar to those for refinery gas. This seems plausible, because the other gases produced by the chemical industry are similar to refinery gas. For this reason, in energy statistics, many operators list those gases as refinery gas.

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.

15.7.5 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, Nanning, Hillebrand, et al. (2006), 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.

15.7.6 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, Nanning, Hillebrand, et al. (2006), 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.

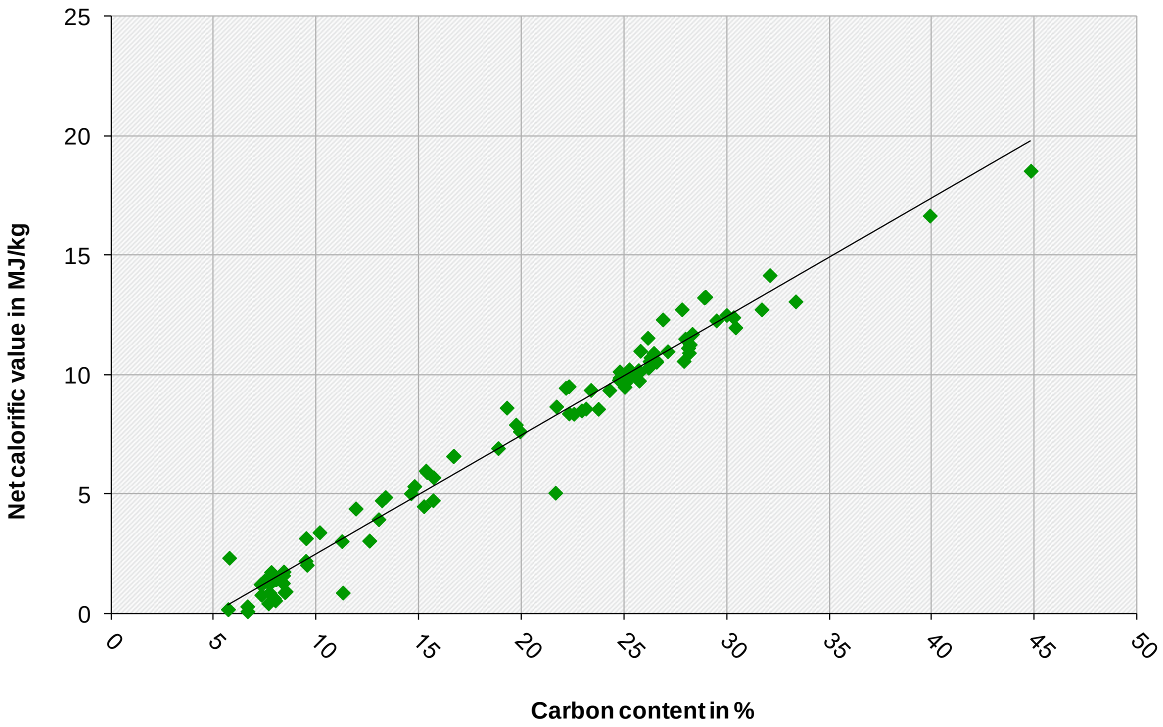
The process for calculation of the CO_2 emission factors for **biogas, landfill gas** and **sewage gas** began with evaluation of relevant net calorific values from energy statistics. Averages of those calorific values were then calculated for each category from the values for the years 2009 – 2011. 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, 2006b) 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 100: 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.

15.7.7 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 481: CO_2 emission factors derived for emissions reporting for the period as of 1990; energy

Fuel-based emission factors	Units	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Coal																	
Hard coal																	
Raw hard coal (power stations, industry)	t CO2/TJ	93.1	93.1	93.5	93.9	94.0	94.2	93.7	93.4	93.6	93.5	93.6	93.4	93.1	93.7	93.6	93.9
Hard-coal briquettes	**t CO2/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
Hard-coal coke (not including that for the iron & steel industry)	**t CO2/TJ**	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	107.8
Hard-coal coke for the iron & steel industry	t CO2/ t	3.29	3.26	3.23	3.19	3.18	3.17	3.17	3.20	3.19	3.17	3.17	3.18	3.18	3.18	3.19	3.17
Anthracite (heat market for households, commerce, trade, services)	t CO2/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
Ballast hard coal, *old German Länder*	t CO2/TJ	95.2															
Coking coal, *Germany*	t CO2/ t	2.96	2.93	2.90	2.87	2.86	2.85	2.86	2.85	2.89	2.90	2.88	2.87	2.88	2.89	2.89	2.88
Hard coal for the iron & steel industry	t CO2/ t	2.92	2.92	2.92	2.95	2.89	2.89	2.91	2.96	2.97	2.90	2.88	2.94	2.90	2.93	2.94	2.92
Other hard-coal products	t CO2/ t	3.30	3.30	3.30	3.30	3.29	3.30	3.30	3.32	3.32	3.32	3.32	3.33	3.32	3.31	3.32	3.32
Hard-coal tar	t CO2/ t	3.27	3.27	3.27	3.28	3.27	3.27	3.28	3.31	3.31	3.30	3.31	3.31	3.31	3.30	3.31	3.30
Benzene	t CO2/ t	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	3.36

Fuel-based emission factors	**Units**	**1990**	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Lignite																	
Raw lignite																	
Public district heating stations, *Germany*	t CO2/TJ		111.7	110.8	111.1	110.7	110.7	111.0	110.7	110.9	111.0	111.2	111.4	110.8	110.6	110.6	110.8
Old German Länder	*t CO2/TJ*	113.8															
New German Länder	*t CO2/TJ*	110.0															
Industry, commercial and institutional and residential ("small consumers"), *Germany*	t CO2/TJ		106.0	109.8	108.2	106.3	106.0	105.0	105.1	103.8	104.0	105.8	106.2	106.4	106.5	105.9	105.8
Old German Länder	*t CO2/TJ*	114.7															
New German Länder	*t CO2/TJ*	107.7															
Public power stations; coalfield:																	
Rheinland	t CO2/TJ	114.8	113.9	113.1	113.2	113.3	113.3	113.2	113.0	113.1	113.1	113.0	113.0	112.7	112.9	113.3	113.1
Helmstedt	t CO2/TJ	98.7	98.7	98.7	98.7	96.7	101.7	97.9	103.3	101.1	99.5	97.9	NO	NO	NO	NO	NO
Hesse	t CO2/TJ	112.2	103.2	103.5	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Lausitz	t CO2/TJ	111.2	111.3	111.5	111.2	110.6	109.9	111.0	110.3	111.2	110.9	111.3	111.5	110.6	109.9	110.2	111.0
Mitteldeutschland	t CO2/TJ	105.7	103.9	102.9	104.0	103.4	103.4	102.8	102.9	102.8	102.9	103.9	104.3	104.2	104.2	103.6	103.2
Lignite briquettes, Germany	**t CO2/TJ**		98.3	99.0	99.3	99.0	99.3	99.3	99.1	99.6	99.4	99.5	99.3	99.0	99.0	99.2	99.2
Old German Länder	*t CO2/TJ*	99.5															
New German Länder	*t CO2/TJ*	96.6															
Lignite tar, *New German Länder*	**t CO2/TJ**	82.9															
Lignite tar oil, *New German Länder*		78.6															
Lignite dust and fluidised bed coal, *Germany*	**t CO2/TJ**		97.6	98.1	98.1	98.0	98.1	98.0	98.0	98.1	98.0	98.1	98.1	97.5	97.5	97.5	97.5
Old German Länder	*t CO2/TJ*	98.3															
New German Länder	*t CO2/TJ*	96.1															
Lignite coke, *Germany*	**t CO2/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
Old German Länder	*t CO2/TJ*	109.6															
New German Länder	*t CO2/TJ*	100.2															
Peat, *old German Länder, Germany*		101.8	101.8	101.8	101.8	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Meta-lignite ("hard lignite")	**t CO2/TJ**	96.4	96.4	96.5	NO	94.9	94.8	94.9	94.2	95.6	94.5	94.8	94.6	95.1	94.7	94.4	93.6

Fuel-based emission factors	Units	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Petroleum																	
Crude oil 4)	**t CO2/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
Gasoline	**t CO2/t**	3.181	3.182	3.183	3.183	3.184	3.180	3.182	3.183	3.183	3.183	3.183	3.183	3.183	3.183	3.169	3.169
Naphtha, *Germany 4)*	**t CO2/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
Old German Länder[4)]	*t CO2/TJ*	73.3															
New German Länder[4)]	*t CO2/TJ*	73.3															
Kerosene[4)]	**t CO2/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
Avgas	**t CO2/TJ**	71.2	71.2	71.2	71.2	71.2	71.2	71.2	71.2	71.2	71.2	71.2	71.2	71.2	71.2	71.2	71.2
Diesel fuel, *Germany*	**t CO2/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
Old German Länder	*t CO2/TJ*	74.0															
New German Länder	*t CO2/TJ*	74.0															
Light heating oil, *Germany*	**t CO2/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
Old German Länder	*t CO2/TJ*	74.0															
New German Länder	*t CO2/TJ*	74.0															
Heavy fuel oil	**t CO2/TJ**	79.8	79.8	79.8	79.6	79.7	79.9	80.1	80.0	81.3	80.9	81.6	80.8	79.9	79.4	79.7	79.5
Petroleum	**t CO2/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
Petroleum coke (not including coke burn-off in catalyst regeneration)	**t CO2/TJ**	94.8	94.8	94.8	94.8	94.6	95.4	94.7	95.1	95.7	97.6	103.8	104.3	104.0	104.3	103.4	101.8
LP gas, *Germany (energy-related consumption)*	**t CO2/TJ**		65.3	64.4	65.3	65.3	65.4	65.4	65.4	65.5	66.3	66.3	66.3	66.3	66.3	66.3	66.3
Old German Länder	*t CO2/TJ*	65.6															
New German Länder	*t CO2/TJ*	65.6															
Refinery gas, *Germany*	**t CO2/TJ**		56.9	56.7	57.0	66.4	61.6	62.3	60.8	60.1	62.0	52.9	69.8	57.1	57.3	57.2	57.1
Old German Länder	*t CO2/TJ*	54.6															
New German Länder	*t CO2/TJ*	54.6															
Other petroleum products, *Germany*	**t CO2/TJ**		82.1	82.1	82.1	82.5	82.8	82.9	82.6	82.7	82.3	80.9	83.0	80.4	80.1	80.4	81.9
Old German Länder	*t CO2/TJ*	82.1															
New German Länder	*t CO2/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
Gases																	
Coke oven gas, *Germany*	**t CO2/TJ**		41.0	41.0	40.7	40.3	41.6	41.2	41.8	41.2	41.3	41.1	40.7	40.9	40.8	41.0	41.5
Old German Länder	*t CO2/TJ*	41.0															
New German Länder	*t CO2/TJ*	43.6															
Coking-plant and city gas, *Germany*	**t CO2/TJ**		42.6														
Old German Länder	*t CO2/TJ*	43.2															
New German Länder	*t CO2/TJ*	58.3															
Top gas and converter gas, Germany	**t CO2/TJ**		257.1	258.7	252.9	259.7	264.7	263.5	259.5	256.8	261.3	256.7	258.6	259.6	259.2	256.4	254.5
Old German Länder	*t CO2/TJ*	264.6															
New German Länder	*t CO2/TJ*	264.6															
Fuel gas, *New German Länder*	**t CO2/TJ**	118.4															
Other produced gases, *Germany*	**t CO2/TJ**	63.6	63.6	63.6	63.6	63.6	63.6	63.6	65.3	66.2	63.5	58.2	59.3	63.6	68.9	60.8	65.2

Fuel-based emission factors	Units	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Natural gases																	
Natural gas, *Germany*	**t CO2/TJ**		55.8	55.8	55.9	55.9	55.9	55.9	55.9	55.9	55.9	55.8	55.8	55.7	55.7	55.8	55.8
Old German Länder	*t CO2/TJ*	55.7															
New German Länder	*t CO2/TJ*	55.5															
Petroleum gas	**t CO2/TJ**	61.9	61.9	61.9	61.9	61.4	61.5	61.5	63.2	62.0	61.6	61.9	62.5	63.6	62.2	61.0	61.1
Pit gas	**t CO2/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
Waste 2)																	
Household waste / municipal waste	**t CO2/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
Industrial waste, *Germany*	**t CO2/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
Old German Länder	*t CO2/TJ*	73.9															
New German Länder	*t CO2/TJ*	74.9															
Special waste, Germany	**t CO2/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
Special fuels 1)																	
Used oil	t CO2/TJ	75.7	75.7	75.7	75.7	75.9	75.9	77.3	75.6	75.5	75.3	76.3	75.4	75.1	77.6	76.9	82.4
Waste plastics	t CO2/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
Waste tyres	t CO2/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
Bleaching clay	t CO2/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
Sewage sludge (2 MJ/kg)	t CO2/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
Sewage sludge (4 MJ/kg)	t CO2/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
Sewage sludge (6 MJ/kg)	t CO2/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
Sewage sludge (8 MJ/kg)	t CO2/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
Sewage sludge (10 MJ/kg)	t CO2/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
Solvents (waste)	t CO2/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
Biomass fuels[3)]																	
Spent liquors from pulp production	t CO2/TJ	121.1	121.1	110.3	104.8	98.3	98.0	98.2	97.9	97.5	97.8	97.9	97.4	97.8	97.5	95.4	97.8
Fibre/de-inking residues	t CO2/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
Firewood, untreated	t CO2/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
Waste wood, wood scraps (industry)	t CO2/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
Waste wood, wood scraps (commercial/institutional)	t CO2/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
Bark	t CO2/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
Animal meals and fats	t CO2/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
Biogas	t CO2/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
Landfill gas	t CO2/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
Sewage gas	t CO2/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
Bioethanol	t CO2/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
Biodiesel[4)]	t CO2/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

Fuel-based emission factors	Units	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
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

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 482: 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	2021
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	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	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	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	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	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	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	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	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	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	115.82	117.51
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	53.61
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	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	1387.44
2.B.5 Production of calcium carbide	C	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	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	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	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	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	440.00
2.C.2 Ferroalloys production	1500.00	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	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	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	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	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.

16 Annex 3: Other detailed methodological descriptions for individual source or sink categories

16.1 Other detailed methodological descriptions for the source category "Energy" (1)

16.1.1 Energy industry (1.A.1)

16.1.1.1 Methodological aspects of determination of emission factors (Chapter 3.2.4.2)

This section in the 2022 NIR describes the key steps in the research projects of Rentz et al. (2002) and Fichtner et al. (2011) for determination of emission factors other than CO_2 emission factors.

16.1.2 Transport (1.A.3)

16.1.2.1 Transport – Civil aviation (1.A.3.a)

16.1.2.1.1 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 (2006b) 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[150] (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.

[150] Personal e-mail communication with Dr. Feuerhelm, FAM Hamburg, 9 June 2009

Avgas

As was done for kerosene, the emission factors are taken from the TREMOD AV model (Knörr, 2022).

Table 483: Emission factors for avgas, 2018

	1.A.3.a		1.D.1.a	
	LTO	Cruise	LTO	Cruise
CO_2	71,199			
CH_4	165	0.00	137	0.00
N_2O	2.30			
SO_2	0.46			
NO_X	90.5	143	89.9	128
NMVOC	656	558	645	551
CO	17,396	20,957	17,472	22,916

Source: (Gores, 2021)

Table 484: Overview of emission factors for kerosene; in kg/TJ

	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
CO_2	**73,256**															
SO_2	19.7	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
Kerosene, L/TO, national (1.A.3.a)																
CH_4	7.09	7.23	7.63	8.11	8.07	7.99	8.00	8.71	9.25	9.23	9.11	9.58	9.78	10.15	14.49	16.42
N_2O	2.81	2.79	2.79	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
NO_X	295	324	287	277	304	309	312	311	310	312	321	322	316	312	291	280
NMVOC	28.4	28.9	30.5	32.4	32.3	31.9	32.0	34.9	37.0	36.9	36.5	38.3	39.1	40.6	58.0	65.7
CO	212	211	275	291	260	254	252	260	265	265	252	255	262	268	349	383
Kerosene, cruise, national (1.A.3.a)																
CH_4	0.00															
N_2O	2.34	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
NO_X	337	375	348	340	374	376	381	383	381	386	397	400	396	396	370	365
NMVOC	14.4	16.0	16.6	18.9	19.9	19.9	20.2	21.7	22.7	22.0	17.7	18.1	17.7	19.4	26.1	30.5
CO	147	149	186	203	197	197	201	212	219	214	154	151	152	159	241	294
Kerosene, L/TO, international (1.D.1.a)																
CH_4	14.94	9.03	6.42	5.72	5.31	5.19	5.12	5.08	4.97	5.12	5.06	5.19	5.36	4.85	4.79	4.60
N_2O	2.11	2.09	2.09	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
NO_X	297	306	303	324	342	345	346	349	353	352	357	358	355	358	368	367
NMVOC	59.7	36.1	25.7	22.9	21.2	20.8	20.5	20.3	19.9	20.5	20.2	20.8	21.4	19.4	19.2	18.4
CO	249	227	236	219	203	199	199	197	194	196	192	192	195	187	185	187
Kerosene, cruise, international (1.D.1.a)																
CH_4	0.00															
N_2O	2.34	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
NO_X	313	317	329	338	352	354	360	362	362	366	370	372	373	376	379	378
NMVOC	13.3	8.96	5.98	5.27	4.66	4.53	4.39	4.39	4.71	4.35	4.17	4.23	4.32	4.26	4.29	4.09
CO	73.8	61.6	47.7	42.4	37.8	37.3	37.0	36.8	40.1	36.2	34.2	34.2	34.7	34.1	34.4	34.6

Source: (Gores, 2021)

[a] pursuant to IPCC (2006b): Volume 2, Chapter 3.6, Table 3.6.5: Methane emissions during cruise flight are negligibly low.

16.1.2.2 Derivation of activity rates for road transport (1.A.3.b)

16.1.2.2.1 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 485 below.

Table 485: Energy inputs in road transports, since 1990

	Gasoline	Diesel fuel	Biofuels [a]	CNG, LPG and	Petroleum	Lubricants [b]
Energy inputs pursuant to Energy Balances 1990-2021 (last revision: 10/2022), in TJ						
1990	1,330,479	735,920	0	138	0	2,543
1995	1,299,982	964,013	1,504	138	610	455
1996	1,299,879	964,580	2,046	115	638	372
1997	1,297,487	979,586	3,652	106	357	266
1998	1,300,463	1,022,794	4,081	106	637	206
1999	1,300,602	1,097,036	5,370	100	637	116
2000	1,237,055	1,108,105	12,276	94.0	414	82.7
2001	1,199,318	1,097,416	16,740	98.0	471	74.5
2002	1,166,381	1,105,842	20,460	607	472	77.3
2003	1,108,989	1,078,352	29,948	694	0	72.6
2004	1,072,720	1,110,931	40,042	1,887	0	75.0
2005	992,377	1,078,620	78,897	5,484	0	78.5
2006	930,834	1,082,042	143,881	9,051	0	77.4
2007	892,982	1,073,987	155,752	14,787	0	79.9
2008	854,002	1,102,624	126,181	22,796	0	81.3
2009	829,227	1,114,939	113,765	32,285	0	87.4
2010	791,416	1,168,063	120,129	30,591	0	82.6
2011	787,803	1,197,252	115,828	32,384	0	80.9
2012	742,000	1,223,719	120,513	32,437	0	76.5
2013	741,150	1,283,637	109,358	30,507	0	78.1
2014	744,661	1,296,828	113,957	28,983	0	78.1
2015	708,672	1,348,789	105,764	26,422	0	78.0
2016	709,179	1,393,481	106,054	22,710	0	78.1
2017	719,580	1,425,424	108,049	21,329	0	77.4
2018	692,694	1,377,104	112,594	21,543	0	75.9
2019	699,835	1,390,837	111,781	21,280	0	76.5
2020	629,435	1,239,658	134,891	17,974	0	80.4
2021	634,080	1,254,201	120,477	21,202	0	73.0

Sources: Evaluation tables of the Energy Balances, "Mineralöl-Zahlen" ("Petroleum Data") of the Association of the German Petroleum Industry (MWV, 2020) and "Amtliche Mineralöldaten" ("Official Mineral Oil Statistics") (BAFA, 2022c).

[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 486).

Table 486: 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 487: Correction factors for harmonisation with the Energy Balance

	Gasoline fuels[a]	Diesel fuels [a]	
	automobiles, light utility vehicles, motorcycles	*automobiles, light utility vehicles,*	*heavy utility vehicles, buses*
1990	1.086	1.086	0.983
1995	1.046	1.046	0.931
2000	0.995	0.995	0.956
2005	0.938	0.938	0.784
2006	0.914	0.914	0.836
2007	0.899	0.899	0.800
2008	0.896	0.896	0.802
2009	0.885	0.885	0.845
2010	0.871	0.871	0.894
2011	0.879	0.879	0.875
2012	0.858	0.858	0.935
2013	0.879	0.879	0.943
2014	0.894	0.894	0.883
2015	0.890	0.890	0.898
2016	0.900	0.900	0.889
2017	0.912	0.912	0.877
2018	0.877	0.877	0.843
2019	0.873	0.873	0.869
2020	0.901	0.901	0.890
2021	0.921	0.921	0.848

[a] In each case, including biogenic admixtures

Source: (Knörr, Heidt, Gores, et al., 2021)

16.1.2.2.2 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.

16.1.2.2.3 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.

16.1.2.3 Derivation of emission factors

16.1.2.3.1 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 486) 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].

$$IEF\ [kg\ per\ TJ]_{inventory} = EM\ [kg]_{specific,TREMOD} \div AR\ [TJ]_{specific\ consumption,TREMOD}$$

A similar procedure is used for the implied emission factors for evaporation:

$$IEF\ [kg\ per\ t]_{inventory} = EM\ [kg]_{specific,TREMOD} \div AR\ [t]_{specific\ consumption,TREMOD}$$

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.

$$EM_{corr.} \div AR_{corr.} = EM_{TREMOD} \div AR_{TREMOD}$$

.

16.1.2.3.2 Emission factors for biodiesel, bioethanol, petroleum, natural gas and LP gas

The emission factors for biodiesel and petroleum are set, throughout, to the same values as those for conventional diesel fuel. Those for bioethanol, on the other hand, 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 (2006b): 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)).

16.1.2.3.3 International comparison of (implied) emission factors

The following tables compare the following values as derived for the German emissions inventory and for 2021 with the relevant implied emission factors of other reporting countries, pursuant to their 2022 submissions: implied emission factors for methane and nitrous oxide from automobiles (1.A.3.b i), light (1.A.3.b ii) and heavy duty vehicles (1.A.3.b iii, including buses) and motorised two-wheel vehicles (1.A.3.b iv). The corresponding international values were taken from the GHG Locator (UNFCCC, 2022a).

Table 488: Implied emission factors for CH_4 and N_2O from automobiles, in kg/TJ

	Gasoline		Diesel		CNG		LPG	
	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O
Germany	4.86	0.31	3.54	3.39	17.3	0.23	2.19	0.85
Belgium	6.11	0.44	0.05	2.52	20.9	0.35	7.35	0.90
Denmark	4.04	0.63	0.06	2.77	12.9	0.37	10.3	2.66
France	11.9	0.98	0.25	3.36	30.1	0.72	11.7	0.90
Italy	9.88	0.91	0.10	2.74	20.2	0.47	8.69	0.73
Netherlands	8.93	0.73	0.35	2.21	92.0	3.00	2.33	0.84
Spain	7.73	0.81	0.19	3.31	22.1	0.55	8.13	0.64
EU-27	7.35	0.72	0.91	3.16	21.4	0.51	9.37	1.40
UK	5.68	0.60	0.08	2.99	IE	IE	IE	IE

Table 489: Implied emission factors for CH_4 and N_2O from light duty vehicles, in kg/TJ

	Gasoline		Diesel		CNG		LPG	
	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O
Germany	9.88	0.71	1.74	2.58	7.04	0.17	NA	NA
Belgium	5.02	0.75	0.05	1.78	IE	IE	IE	IE
Denmark	5.37	2.02	0.08	2.01	12.8	0.40	3.4	0.77
France	11.7	0.94	0.10	2.47	21.9	0.71	11.2	0.68
Italy	6.09	1.46	0.11	1.84	NO	NO	NO	NO
Netherlands	4.04	1.86	0.68	1.48	92.0	3.00	0.9	0.86
Spain	18.8	1.74	0.24	2.11	NO	NO	NO	NO
EU-27	10.6	1.64	0.46	2.29	26.0	0.89	7.4	0.78
UK	3.92	0.97	0.05	2.29	IE	IE	IE	IE

Table 490: Implied emission factors for CH_4 and N_2O from heavy duty vehicles, in kg/TJ

	Diesel		CNG	
	CH_4	N_2O	CH_4	N_2O
Germany	0.09	4.17	17.7	NA
Belgium	0.69	4.04	50.1	NE
Denmark	0.63	4.60	26.8	3.08
France	0.58	2.38	60.3	NO
Italy	1.94	3.23	56.4	NO
Netherlands	0.43	3.99	92.0	3.00
Spain	1.59	3.46	49.6	NO
EU-27	1.18	3.47	57.8	1.24
UK	0.77	4.52	53.20	0.10

Table 491: Implied emission factors for CH_4 and N_2O from motorised two-wheel vehicles, in kg/TJ

	Gasoline	
	CH_4	N_2O
Germany	133	1.18
Belgium	41.3	1.25
Denmark	71.5	1.22
France	24.0	1.16
Italy	61.0	1.35
Netherlands	99.3	1.10
Spain	69.0	1.43
EU-27	72.1	1.29
UK	41.5	1.21

16.1.3 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):

$$r_{E\%} = r_{V\%} \times \frac{\rho_{lubricant}}{\rho_{fuel}} \times \frac{\mathrm{H_{i_{lubricant}}}}{\mathrm{H_{i_{fuel}}}}$$

$$r_{E\%} = 2\ \% \times \frac{0.875\ \frac{\mathrm{kg}}{\mathrm{l}}}{0.750\ \frac{\mathrm{kg}}{\mathrm{l}}} \times \frac{40.000\ \frac{\mathrm{kJ}}{\mathrm{kg}}}{43.543\ \frac{\mathrm{kJ}}{\mathrm{kg}}} = 2.1435\ \%$$

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 3.2.8.2 & 16.1.2.2). 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 3.2.10). 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, 2006b): 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 492: 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	2021
Gasoline, fossil	73,069	73,075	73,094	73,103	73,119	75,287	75,285	75,285	75,285	75,284	74,952	74,950
Gasolione, biogenic (bioethanol)						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	74,919	74,917
biogenic						71,641						

Source: Own calculations

[a] Default emission factor pursuant to IPCC (2006b): Volume 2, Chapter 2 – *Stationary Combustion*, page 2.20, Table 2.4

Table 493: CO_2 from lubricants co-incinerated in two-stroke gasoline engines, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021
1.A.3.b	186	33.3	6.06	5.75	6.05	5.72	5.72	5.67	5.57	5.61	5.90	5.35
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	1.09	1.05
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	4.19	4.33
Total	**193**	**39.6**	**12.3**	**11.4**	**9.74**	**9.85**	**9.70**	**9.65**	**9.84**	**9.74**	**11.2**	**10.7**

Source: Own calculations, based on (Knörr, Heidt, & Bergk, 2021; Knörr, Heidt, Gores, et al., 2021)

Recalculations with respect to the 2022 Submission

The fuel consumption figures for road vehicles with two-stroke engines have been recalculated, for all years. 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 494: Revised quantities of co-combusted lubricants, in terajoules

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
2023 Submission	2,637	541	167	155	133	133	131	130	133	131	151
2022 Submission	2,585	529	161	151	130	130	128	128	130	129	139
Absolute change	52.1	12.5	6.31	4.24	2.68	2.96	2.85	2.39	2.51	2.40	12.0
Relative change	2.01%	2.37%	3.92%	2.81%	2.06%	2.27%	2.22%	1.87%	1.93%	1.86%	8.65%

Source: Own calculations

Table 495: Revised carbon dioxide emissions, in kilotonnes

	1990	1995	2000	2005	2010	2015	2016	2017	2018	2019	2020
2023 Submission	193	39.6	12.3	11.4	9.74	9.85	9.70	9.65	9.84	9.74	11.2
2022 Submission	189	38.7	11.8	11.0	9.54	9.63	9.49	9.47	9.66	9.56	10.3
Absolute change	3.81	0.92	0.46	0.31	0.20	0.22	0.21	0.18	0.19	0.18	0.88
Relative change	2.01%	2.37%	3.92%	2.81%	2.06%	2.29%	2.24%	1.89%	1.95%	1.88%	8.51%

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)

16.1.4 Calculation of the fossil fractions of biofuels used, as well as of the carbon dioxide emissions resulting from their use

The following section presents the procedure used for calculation of the fossil fractions of the biofuels used, as well as of the carbon dioxide emissions resulting from their use.

Methodological issues

The basis for the calculation consists of the CO_2 emissions resulting, in the various source categories, from use of biodiesel and biogasoline.

Table 496: CO_2 emissions resulting from use of biodiesel and bioethanol, in kilotonnes

	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019	2020	2021
from bioethanol	0	0	83.1	496	2,224	2,240	2,244	2,208	2,267	2,196	2,096	2,200
from biodiesel	106	895	2,976	5,518	6,894	5,689	5,712	5,841	6,124	6,067	7,975	6,747
TOTAL	**106**	**895**	**3,059**	**6,015**	**9,118**	**7,929**	**7,956**	**8,049**	**8,391**	**8,263**	**10,071**	**8,947**

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.[151]
- 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.[152]

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.

The fossil-based carbon dioxide quantities shown in the following table are obtained on the basis of the total emissions shown above. These carbon dioxide quantities are allocated to the total national emissions.

Table 497: CO_2 emissions from fossil fractions of biofuels used, in kilotonnes

	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019	2020	2021
from bioethanol	0.00	0.00	5.54	33.1	148	149	150	147	151	146	140	147
from biodiesel	5.86	49.3	164	304	379	313	314	321	337	334	439	371
TOTAL	**5.86**	**49.3**	**169**	**337**	**527**	**462**	**464**	**468**	**488**	**480**	**578**	**518**

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

[151] WG I – Note on fossil carbon content in biofuels; Calculating the fossil fuel content of biofuels that replace fossil diesel (biodiesel)
[152] WG I – Note on fossil carbon content in biofuels; Table 1 – Carbon content and fossil fraction of carbon content of biogasoline

assurance will not be carried until the pertinent country-specific method has been successfully implemented.

Specific recalculations

With respect to the 2022 submission, recalculations were carried out to take account of corrections, within the individual CRF categories, of the biofuel quantities used.

Table 498: Revised indirect CO_2 emissions from biofuels, in kilotonnes

	1995	2000	2004	2005	2010	2015	2016	2017	2018	2019	2020
fossil CO_2 from bioethanol											
2023 Submission			5.54	33.1	148	149	150	147	151	146	140
2022 Submission			5.54	33.1	148	149	150	147	151	146	140
Absolute change			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Relative change			0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
fossil CO_2 from biodiesel											
2023 Submission	5.86	49.3	164	304	379	313	314	321	337	334	439
2022 Submission	5.86	49.3	164	304	379	312	312	321	337	334	439
Absolute change	0.00	0.00	0.00	0.00	0.0	1.05	1.78	0.00	0.00	0.00	-0.07
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.34%	0.57%	0.00%	0.00%	0.00%	-0.02%
total fossil CO_2 from biofuels											
2023 Submission	5.86	49.3	169	337	527	462	464	468	488	480	578
2022 Submission	5.86	49.3	169	337	527	461	462	468	488	480	578
Absolute change	0.00	0.00	0.00	0.00	0.0	1.05	1.78	0.00	0.00	0.00	-0.06
Relative change	0.00%	0.00%	0.00%	0.00%	0.00%	0.23%	0.39%	0.00%	0.00%	0.00%	-0.01%

Source: Own calculations

Planned improvements

Currently, no improvements in addition to the annual revision of the underlying models are planned.

Chapter 10.4, Inventory Improvements (Table 471), presents an overview of the improvements that previous reports have listed in this chapter. Improvements that have been completed are listed in Table 470 in the same chapter.

16.2 Other detailed methodological descriptions for the category "industrial processes" (2)

This chapter is currently not required.

16.3 Other detailed methodological descriptions for the category "Agriculture" (3)

16.3.1 Calculation of the emissions for additional animal categories

The CRF tables in IPCC (2006c 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 499 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 18.

Table 499: 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

16.3.1.1 Animal-place figures

In Germany, no official counts are taken of populations of deer, rabbits, ostriches and fur-bearing animals. Table 500 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 500: 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)

16.3.1.2 CH_4 emissions from enteric fermentation

No CH_4 emissions from enteric fermentation are calculated for ostriches, since IPCC (2006b 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 (2006b Vol 4, 10.28, Table 10.10) is used (20 kg pl^{-1} a^{-1}).

IPCC (2006c Vol 4) does not provide an emission factor for rabbits. Pursuant to footnote 1 to Table 10.10 on p. 10.28 in IPCC (2006c 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 a power of 0.75. 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 (2006c 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 (2006c 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 501 shows, by way of example, the annual emissions from enteric fermentation calculated for deer, rabbits and fur-bearing animals.

Table 501: 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

16.3.1.3 CH_4 emissions from manure management

The default emission factors in IPCC (2006c Vol 4, 10.83, Table 10A-9) are used. The resulting emissions are shown in Table 502.

Table 502: 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

16.3.1.4 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 16.3.1.4.1. The resulting N_2O emissions are listed in Chapter 16.3.1.4.2.

16.3.1.4.1 N excretions

Neither IPCC (2006c Vol 4) nor EMEP/EEA (2019b) 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 (2022b)), 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 (2006c 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 66:

Equation 66: 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 66 then yields an N-excretion value of 0.8 kg pl^{-1} a^{-1}.

For ostriches, neither IPCC (2006c Vol 4) nor EMEP/EEA (2019b) specifies default values for N excretions. For the German calculations in this category, we again use the relevant Danish value (UNFCCC, 2022b): 15.6 kg pl^{-1} a^{-1}.

For mink, IPCC (2006c Vol 4, 10.59, Table 10.19) specifies a default N-excretion value of 4.59 kg pl^{-1} a^{-1}.

16.3.1.4.2 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 16.3.1.6.

Table 503: 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

16.3.1.5 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 16.3.1.4.2). 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 (2019b-3B-31) have been used for those animals. The data ultimately used are listed in Table 504, 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 504: 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 (2019b-3B-31)
Ostriches	70	0.57	0.16	Default for geese, EMEP/EEA (2019b-3B-31)
Fur-bearing animals (mink)	60	0.27	0.09	Default, EMEP/EEA (2019b-3B-31)

The resulting deposition of reactive nitrogen (N_{reac}), and the then-resulting indirect N_2O emissions, are given in Table 505. Pursuant to IPCC (2006c 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 505: 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

16.3.1.6 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 (2006c 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 (2019b-3B-31) (50 %) is used. In keeping with IPCC (2006c 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 506 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 506: 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

16.3.1.7 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 508 shows the emission factors that are used to calculate the NH_3 emissions.

Table 507: 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 (2019b-3B-31)
Rabbits		0.90	Default for horses, EMEP/EEA (2019b-3B-31)
Ostriches		0.45	Default for geese, EMEP/EEA (2019b-3B-31)
Fur-bearing animals (mink)		0.90	Default for horses, EMEP/EEA (2019b-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 resulting indirect N_2O emissions, are given in Table 508. In keeping with IPCC (2006c 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 508: 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 (2006c 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 (2006c Vol 4, 11.24, Table 11.3).

Table 509: 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

16.3.2 Distributions of housing, storage and application procedures, and of grazing data (CRF 3.B, 3.D)

Table 510 through Table 513 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 510 through Table 513, but with the data underlying those data. Those underlying data have state-level (German-Länder-level) resolution. Cf. Chapter 2.5 in Rösemann et al. (2023). The tables also include information relative to emission factors (including that for NH_3).

Table 510: 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	2021	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	6	6	5	4	4	3	3	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	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	7	7	7	6	6	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	66	67	69	70	72	74	75	77	78	78	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	2	2	2	3	3	4	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	10	10	10	9	9	9	9	8	8	8	7	7	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	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	10	10	9	9	9	9	8	8	8	8	8		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	48	42	37	32	26	21	16	11	5	5	5		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	33	39	45	50	56	62	68	73	79	79	79	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	3	3	3	4	4	4	4	5	5	5	5	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	5	6	6	7	8	9	9	10	11	11	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	8	8	7	6	6	5	5	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	9	9	8	8	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	45	45	46	47	48	49	50	51	51	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	25	24	22	21	19	18	18	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	7	9	10	12	14	16	17	19	19	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	17	17	17	16	16	16	16	15	15	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	7	7	6	6	5	4	4	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	7	7	7	6	6	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	49	50	50	51	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	30	29	27	25	24	22	21	19	19	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	2021	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	9	11	12	14	16	18	20	20	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	19	19	19	18	18	18	17	17	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	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	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	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	10	10	9	8	8	7	7	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	3	3	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	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	47	46	44	43	41	40	38	37	35	35	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	29	31	33	35	37	39	39	39	8.0	0.197
	time spent on pastures (in % of year)	43	42	43	43	43	43	44	44	45	45	45	45	46	45	46	46	46	47	47	48	49	50	50	51	52	53	54	55	56	56	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	11	11	10	9	8	8	7	6	6	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	4	4	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	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	32	31	30	29	28	27	27	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	18	20	22	24	26	29	31	33	33	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	35	36	37	38	40	41	42	43	44	46	45	45		

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	2021	bedding material (straw) kg place d^{-1}	NH3-N EF for housing, kg NH3-N per kg TAN in excreta
fattening pigs	fully slatted floor, slurry	49	49	49	49	57	57	57	57	62	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	79	80	81	81	81		0.3
	partly slatted floor, slurry	40	40	40	40	34	34	34	34	31	31	30	30	29	28	27	26	25	24	23	22	22	21	20	19	19	18	17	16	16	15	15	15		0.3
	plane floor with bedding	8	8	8	8	6	6	6	6	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	3	3	3	3	2	2	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	1	1	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	1	1	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	0		
weaners	fully slatted floor, slurry	45	45	45	45	57	57	57	57	62	62	63	64	65	66	66	67	68	69	70	71	72	73	74	75	76	76	77	78	79	80	80	80		0.3
	partly slatted floor, slurry	41	41	41	41	33	33	33	33	28	28	28	27	27	26	26	25	24	24	23	23	22	21	21	20	19	18	18	17	16	16	16	16		0.3
	plane floor with bedding	10	10	10	10	7	7	7	7	6	6	6	6	6	6	6	5	5	5	5	5	5	4	4	4	4	3	3	3	3	2	2	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	1	1	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	1	1	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	0		
sows	straw based	42	42	42	42	26	26	26	26	24	24	23	22	21	20	19	18	17	17	16	15	14	13	12	12	11	10	10	9	8	8	8	8	0.5	0.34
	slurry based	58	58	58	58	74	74	74	74	76	76	77	78	79	80	81	82	83	83	84	85	86	87	88	88	89	90	90	91	92	92	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	0		
boars	straw based	32	32	32	32	23	23	23	23	21	21	21	20	20	19	19	18	18	17	17	16	16	15	14	13	12	11	10	9	9	8	8	8	0.5	0.34
	slurry based	68	68	68	68	77	77	77	77	79	79	79	80	80	81	81	82	82	83	83	84	84	85	86	87	88	89	90	91	91	92	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	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	5		*)
	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	63	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	32	0.5 kg per place and year	*)
	time spent on pastures (in % of year)	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3		
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	100	1.4 kg per place and year	0.09 kg per kg of total N excreted

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	2021	bedding material (straw) kg place d^{-1}	NH3-N EF for housing, kg NH3-N per kg TAN in excreta
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	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	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	100	5.6 kg per place and year	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	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	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	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	21		
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	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	56		
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	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	56		
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	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	34		

*) s. Table 513: Laying hens, housing-specific partial NH_3 emission factors

Table 511: 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	2021	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	5	5	6	6	7	7	8	8	9	9	10	10	11	11	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	24	25	26	26	27	27	28	29	28	27	26	25	25	24	23	22	21	21	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	38	37	36	35	34	33	32	31	30	30	31	31	32	32	33	33	34	34	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	3	3	3	3	3	4	4	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	1	1	1	1	1	1	1	1	1	0.030		0,000		17.0	0.23
	storage below animal confinements > 1 month (% of total untreated slurry)	42	42	42	42	36	36	36	36	36	36	36	35	35	34	34	34	33	33	33	32	32	32	31	31	31	30	30	30	29	29	29	29	0,045		0.002		17.0	0.23
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	22	24	26	27	27	27	28	27	26	27	27						
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	2	3	4	4	5	5	5	5	5	5	5	6	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	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	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	63	0,000		0,000		1.198	0.23
cattle, storage of	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	37	0,045		0,005		1.611	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	2021	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
digestates																																							
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	96	94	90	87	84	80	76	71	67	67	67	0.600	0.013	0,005	0,005	2.0	0.23
	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	4	6	10	13	16	20	24	29	33	33	33	0,000		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	15	12	10	9	7	6	5	4	4	4	4	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	78	81	83	85	87	88	89	90	91	91	91	0,600	0.013	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	7	7	6	6	6	6	6	6	6	6	6	0,000		0,010		17.0	0.23
female beef cattle, solid manure	heap (% of total solid manure)	100	100	100	100	100	100	100	100	100	100	99	98	98	97	96	96	95	94	94	93	93	89	85	81	76	72	68	63	59	54	54	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	4	5	6	6	7	7	11	15	19	24	28	32	37	41	46	46	46	0,000		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	85	81	76	72	68	63	59	54	54	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	15	19	24	28	32	37	41	46	46	46	0,000		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	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	100	0,000		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	70	68	65	62	59	57	54	51	51	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	30	32	35	38	41	43	46	49	49	49	0,000		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	2021	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
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	72	69	66	63	59	56	53	50	50	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	28	31	34	37	41	44	47	50	50	50	0,000		0,010		17.0	0.23
pigs, untreated slurry	open tank (% of total untreated slurry)	47	47	47	47	27	27	27	27	27	27	25	23	22	20	19	17	15	14	12	10	9	9	9	10	10	10	11	11	11	12	12	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	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	15	17	18	19	21	22	24	25	26	28	27	26	25	24	23	22	21	20	20	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	7	7	7	7	7	7	7	8	8	8	9	9	10	10	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	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	34	34	34	34	35	35	36	36	36	37	37	38	38	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	16	16	18						
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	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	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	70	71	71	71	72	72	72	73	72	71	70	68	67	65	64	62	60	60	60	0,600	0,030	0,005	0,005	3.0	0.30
	deep bedding	25	25	25	25	30	30	30	30	31	31	31	30	30	30	29	29	29	28	28	28	27	28	29	30	32	33	35	36	38	40	40	40	0,000		0,010		25.0	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	2021	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
	(% of total solid manure)																																						
sows / boars, solid manure	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	100	0,600	0,030	0,005	0,005	3.0	0.30
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	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	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	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	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	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	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	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	14	14	15	14	14	14	14	15	15						
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	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	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	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	100	0,320		0,005		2.0	0.19
goats	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	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	2021	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
	solid manure)																																						
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	1.04	1.48	2.13	2.53	3.29	8.86	12.37	16.88	19.70	25.28	31.81	39.68	43.49	52.62	55.06	57.20	56.88	55.94	55.14	55.13	56.29	56.29						
	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	66	66	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	34	34	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 512: 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	2021	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	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	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	5	4	3	3	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	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	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	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	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	0.50
	broadcast, vegetation	0	0	0	0	0	0	0	0	0	0	2	3	5	6	8	9	11	12	14	16	17	17	17	16	16	15	13	10	8	6	0	0	0.50
	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	44	42	40	40	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	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	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	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	0.20

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	2021	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	0	0	0	0	0	0	1	1	1	1	1	0	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	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	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	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	4	4	4	5	10	10	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	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	3	3	3	3	4	4	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	3	4	4	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	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	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	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	6	9	12	15	19	19	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	3	3	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	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	0.04
cattle, solid manure	broadcast, without incorporation	14	14	14	14	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	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	14	14	14	14	14	14	15	15	15	15	15	0.09
	broadcast, incorporation < 4h	0	0	0	0	9	9	9	9	9	9	10	11	12	14	15	16	17	18	20	21	22	23	25	26	27	28	30	31	33	35	35	35	0.45
	broadcast, incorporation < 12h	11	11	11	11	28	28	28	28	29	29	29	29	29	28	28	28	28	28	27	27	27	27	27	26	26	26	23	21	18	15	15	15	0.81
	broadcast, incorporation < 24h	43	43	43	43	24	24	24	24	25	25	23	22	20	19	17	15	14	12	11	9	8	6	5	3	2	0	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	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	31	31	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	2	1	1	0	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	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	2	1	1	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	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	0.13
	broadcast, incorporation < 12h	0	0	0	0	29	29	29	29	28	28	25	23	20	18	16	13	11	8	6	3	1	1	0	0	0	0	0	0	0	0	0	0	0.16
	broadcast, incorporation < 24h	49	49	49	49	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	0.21

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	2021	NH_3-N EF for application, kg NH_3-N per kg TAN applied
	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	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	12	8	4	0	0	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	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	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	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	3	3	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	0.08
	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	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	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	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	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	38	38	43	43	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	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	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	4	5	5	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	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	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	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	12	16	19	19	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	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	5	5	5	6	6	6	7	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	19	17	15	13	11	9	7	6	4	2	3	3	4	5	5	5	0.90
	broadcast, incorporation < 1 h	4	4	4	4	15	15	15	15	15	15	15	16	16	16	16	16	16	16	16	16	16	16	16	16	17	17	17	17	18	18	18	18	0.09
	broadcast, incorporation < 4h	0	0	0	0	2	2	2	2	2	2	4	6	8	10	12	14	16	18	20	22	24	27	29	31	33	35	36	36	37	37	37	37	0.45
	broadcast, incorporation < 12h	0	0	0	0	20	20	20	20	21	21	21	21	21	21	21	22	22	22	22	22	22	22	22	23	23	23	19	16	13	9	9	9	0.81
	broadcast, incorporation < 24h	52	52	52	52	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	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	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	27	29	31	31	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	2021	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	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	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	8	6	5	4	4	4	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	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	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	12	10	9	8	0	0	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	48	47	46	46	46	46	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	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	2	3	3	4	4	4	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	2	2	2	2	2	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	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	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	10	11	11	12	20	20	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	4	4	5	6	6	6	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	1	1	1	1	1	1	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	0	0	0	0	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	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	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	5	6	7	8	8	8	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	1	2	2	2	2	2	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	2	3	3	3	3	3	0.01
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	25	27	29	29	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	16	17	18	20	21	23	24	25	27	28	28	28	0.00
	broadcast, incorporation < 4h	0	0	0	0	0	0	0	0	0	0	3	6	9	12	15	18	21	24	26	29	32	35	38	41	44	47	45	43	41	38	38	38	0.18
	broadcast, incorporation < 12h	0	0	0	0	11	11	11	11	21	21	20	20	19	18	18	17	16	16	15	14	14	13	12	12	11	10	9	7	6	4	4	4	0.40
	broadcast, incorporation < 24h	92	92	92	92	84	84	84	84	71	71	66	62	57	53	49	44	40	35	31	26	22	18	13	9	4	0	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	24	26	29	29	29	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	2021	NH_3-N EF for application, kg NH_3-N per kg TAN applied
	broadcast, incorporation < 1 h	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	29	29	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	43	41	39	39	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	6	5	3	3	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	0.45
other animals (horses, sheep, goats), solid manure	broadcast, without incorporation	100	100	100	100	100	100	100	100	100	100	96	92	88	84	80	76	72	68	64	60	56	52	48	44	40	36	37	38	39	40	40	40	0.90
	broadcast, incorporation < 1 h	0	0	0	0	0	0	0	0	0	0	1	1	2	3	3	4	5	5	6	7	7	8	9	9	10	11	11	12	12	13	13	13	0.09
	broadcast, incorporation < 4h	0	0	0	0	0	0	0	0	0	0	2	3	5	7	9	10	12	14	16	17	19	21	22	24	26	28	29	29	30	31	31	31	0.45
	broadcast, incorporation < 12h	0	0	0	0	0	0	0	0	0	0	2	3	5	6	8	10	11	13	14	16	18	19	21	22	24	26	23	20	18	15	15	15	0.81
	broadcast, incorporation < 24h	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	0.90
Digested manure and digested energy crops	broadcast, 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	0.50
	broadcast, incorporation < 1 h	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	7	7	7	6	5	5	5	5	0.10
	broadcast, incorporation < 4h	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	16	12	9	5	4	3	2	2	2	2	0.26
	broadcast, incorporation < 8h	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	0	0	0	0	0	0	0	0	0	0	0.40
	broadcast, incorporation < 12h	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0.43
	broadcast, vegetation	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	12	11	10	8	6	5	3	0	0	0.50
	broadcast, grassland	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	11	10	9	8	8	7	6	6	6	0.60
	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	0.46
	trailing hose, incorporation < 1 h	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	5	7	9	9	8	8	8	8	8	0.04
	trailing hose, incorporation < 4h	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	13	10	8	5	4	4	4	3	3	3	0.15
	trailing hose, incorporation < 8h	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0.24
	trailing hose, incorporation < 12h	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0.30
	trailing hose, vegetation	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	17	17	17	17	17	17	17	19	19	0.35
	trailing hose, grassland	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	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	1	2	2	3	4	5	6	6	6	0.04
	trailing shoe, incorporation < 4 h	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	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	0.24

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	2021	NH_3-N EF for application, kg NH_3-N per kg TAN applied
	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	0.30
	trailing shoe, grassland	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	6	9	11	14	17	20	20	20	0.36
	injection (open slot)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	7	8	8	9	9	9	9	9	0.24
	grubber and injection	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	13	14	14	15	15	16	16	16	0.04

Table 513: Laying hens, housing-specific partial NH_3 emission factors

[in kg NH_3-N per excreted kg N]	≤ 2000	2001 - 2009	≥2010	2011 - 2019	≥2020
cage housing; as of 2010: small-group housing	0.164	0.164	0.066	0.066	0.066
floor management, aviary	0.351	linear interpolation	0.090	linear interpolation	0.071
intensive outdoor management, free-range management, organic production	0.351	linear interpolation	0.090	linear interpolation	0.071

16.4 Other detailed methodological descriptions for the source/sink category "Land-use change and forestry" (4)

This chapter is currently not required.

16.5 Other detailed methodological descriptions for the category "Waste and wastewater" (6)

This chapter is currently not required.

17 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.

17.1 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 2021, this approach yields a non-energy-related consumption of about 989 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.

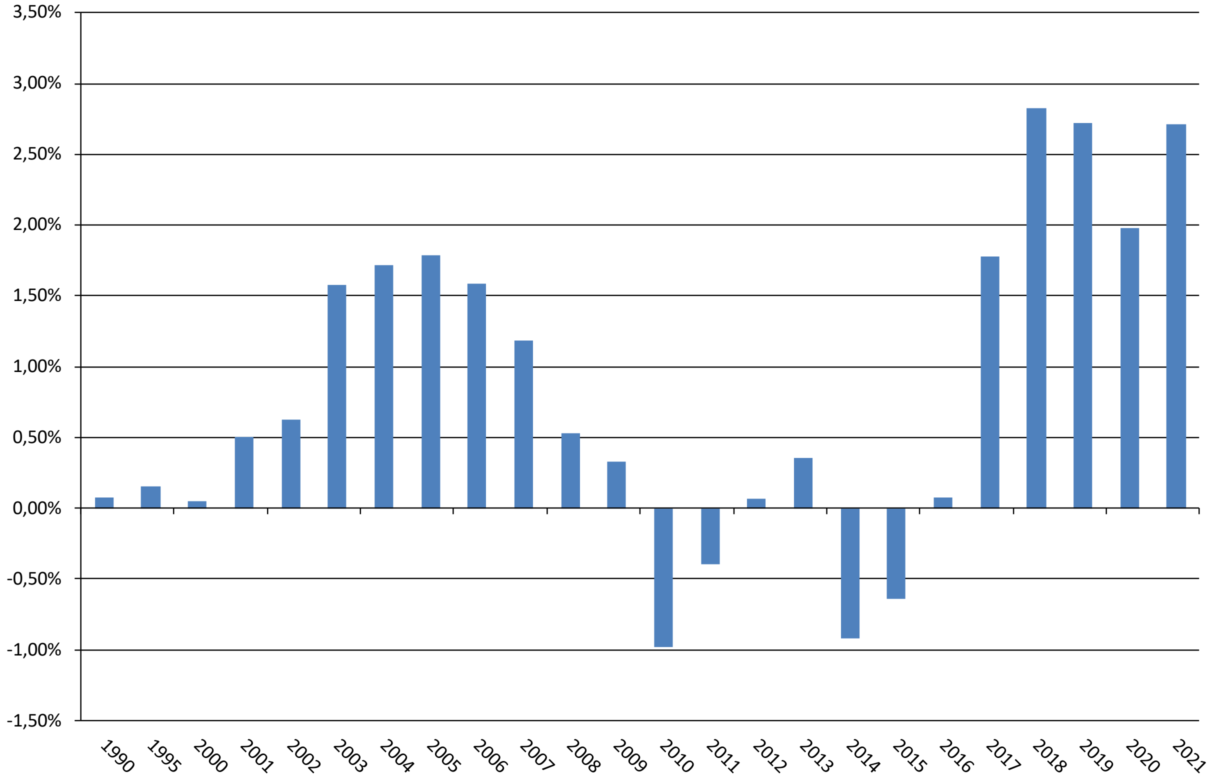
The following tables present further sample results of the comparison between the Sectoral Approach and the Reference Approach. For 2021, the Reference Approach yields fuel inputs that are 2.71 % higher and reference emissions that are 0.52 % higher (cf. Chapter 3.2.1.1).

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 514: 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	**11,751**	**12,915**	**11,759**	**9**	**0.07%**
1995	10,980	12,115	10,997	17	0.15%
2000	10,586	11,838	10,591	5	0.05%
2001	10,856	12,094	10,910	54	0.50%
2002	10,641	11,892	10,708	67	0.63%
2003	10,633	11,997	10,801	168	1.58%
2004	10,440	11,822	10,619	179	1.72%
2005	10,228	11,683	10,410	182	1.78%
2006	10,372	11,767	10,536	164	1.58%
2007	9,950	11,232	10,068	118	1.19%
2008	10,102	11,292	10,155	53	0.53%
2009	9,445	10,522	9,476	31	0.33%
2010	9,896	10,955	9,799	-97	-0.98%
2011	9,507	10,611	9,470	-38	-0.40%
2012	9,567	10,661	9,573	6	0.07%
2013	9,855	10,976	9,889	35	0.35%
2014	**9,295**	**10,326**	**9,209**	**-86**	**-0.92%**
2015	9,371	10,396	9,311	-60	-0.64%
2016	9,554	10,664	9,561	7	0.07%
2017	9,323	10,645	9,489	166	1.78%
2018	**9,013**	**10,227**	**9,268**	**255**	**2.83%**
2019	8,607	9,756	8,841	234	2.72%
2020	8,003	9,060	8,161	158	1.98%
2021	**8,275**	**9,489**	**8,500**	**225**	**2.71%**

Figure 101: Percentage discrepancies between annual total activity data under the Reference Approach and the corresponding total quantities under the Sectoral Approach



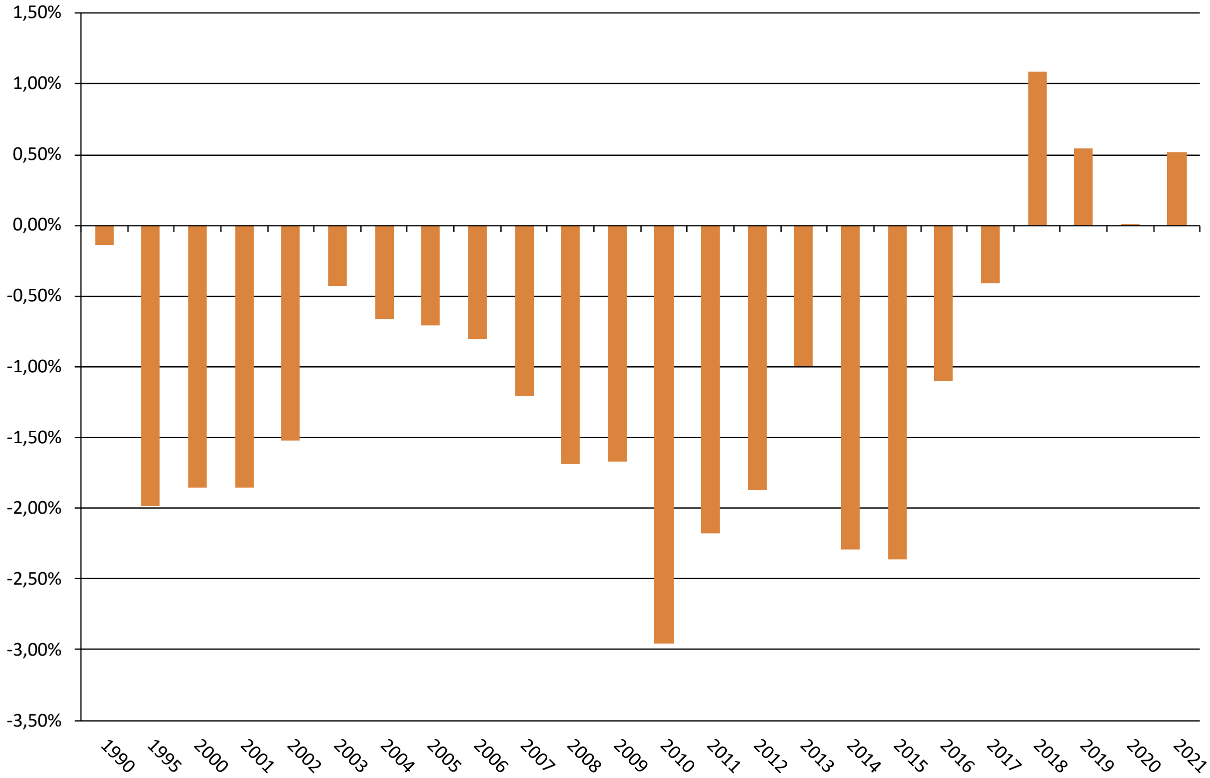
The situation is turned around for the carbon dioxide emissions calculated with the Reference Approach: In almost all cases, they tend to be lower than those calculated with the Sectoral Approach. The values for the years 2019 through 2021 are the sole exceptions in this regard. (Cf. Chapter 3.2.1.1).

Table 515: 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	**988,066**	**986,673**	**-1,393**	**-0.14%**
1995	878,962	861,544	-17,419	-1.98%
2000	835,832	820,372	-15,460	-1.85%
2001	858,116	842,240	-15,877	-1.85%
2002	843,725	830,886	-12,839	-1.52%
2003	840,331	836,728	-3,603	-0.43%
2004	826,119	820,616	-5,503	-0.67%
2005	807,930	802,219	-5,711	-0.71%
2006	819,448	812,846	-6,602	-0.81%
2007	793,645	784,069	-9,576	-1.21%
2008	798,607	785,129	-13,478	-1.69%
2009	742,652	730,232	-12,420	-1.67%
2010	**780,112**	**757,035**	**-23,077**	**-2.96%**
2011	756,371	739,874	-16,497	-2.18%
2012	762,265	747,969	-14,296	-1.88%
2013	783,343	775,523	-7,820	-1.00%
2014	744,334	727,301	-17,033	-2.29%

	1.AA	1.AB (excluding non-energy-related consumption)	1.AB (excluding non-energy-related consumption) minus 1.AA	
2015	749,201	731,532	-17,669	-2.36%
2016	751,142	742,863	-8,279	-1.10%
2017	731,653	728,654	-2,999	-0.41%
2018	702,782	710,391	7,609	1.08%
2019	**657,793**	**661,385**	**3,592**	**0.55%**
2020	600,779	600,811	32	0.01%
2021	**629,640**	**632,884**	**3,244**	**0.52%**

Figure 102: Percentage discrepancies between the annual carbon dioxide emissions as calculated with the Reference Approach and as calculated with the Sectoral Approach



18 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 516: Overview, for completeness, of sources and sinks whose emissions are not estimated (NE)

Emissions 2020			
kt CO_2 equiv	**national total (without LULUCF)**	**749.254**	
kt CO_2 equiv	thereof 0.1 %	749	
kt CO_2 equiv	thereof 0.05 %	375	
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	< 15.9	see NIR Chapter 4.3.4.2
2.B.6	Titan dioxid 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	148	see NIR Chapter 16.3.1
3.A.4	Rabbits	4.44	see NIR Chapter 16.3.1
3.A.4	Fur-bearing animals	0.18	see NIR Chapter 16.3.1
3.B(a).4	Deer	1.63	see NIR Chapter 16.3.1
3.B(a).4	Fur-bearing animals	1.21	see NIR Chapter 16.3.1
3.B(a).4	Rabbits	0.99	see NIR Chapter 16.3.1
3.B(a).4	Ostrich	1.21	see NIR Chapter 16.3.1
3.B(b).4	Fur-bearing animals	0.60	see NIR Chapter 16.3.1
3.B(b).4	Rabbits	0.73	see NIR Chapter 16.3.1
3.B(b).4	Ostrich	0.05	see NIR Chapter 16.3.1
3.B(b).5	Indirect emissions	0.90	see NIR Chapter 16.3.1
3.D	Other animals	35.88	The entries for other animals are not shown in CRF Reporter under 3 D., see NIR Chapter 16.3.1
5.A	Flaring	0.67	see NIR Chapter 7.2.1.2.9
5.E.	accidental fires (buildings, cars ...)	< 100	see NIR Chapter 7.6
Sum		**716**	

Table 517: 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.

19 Annex 6: Additional information to be considered as part of the NIR submission (where relevant) or other useful reference information

19.1 Additional information relative to inventory preparation and to the National System

19.1.1 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 Climate Action (BMWK); 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[153] "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*

[153] 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.*

19.1.2 Additional information about the Quality System of Emissions Inventories

19.1.2.1 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.

19.1.2.1.1 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.

19.1.2.1.2 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.

19.1.2.1.3 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).

19.1.2.1.4 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 the annual inventory review under the UN Framework Convention on Climate Change
- 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.

19.1.2.1.5 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.

19.1.2.1.6 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.

19.1.2.1.7 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.

19.1.2.1.8 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.

19.1.2.1.9 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.

19.1.2.1.10 Annex 1: Minimum requirements pertaining to quality control and quality assurance in emissions reporting in the Federal Environment Agency

19.1.2.1.10.1 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.

19.1.2.1.10.2 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. 19.1.2.1.10.3). That work has led to the development of the Quality System for Emissions Inventories (QSE), via which the points mentioned in Chapter 19.1.2.1.2 have been implemented.

19.1.2.1.10.2.1 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.

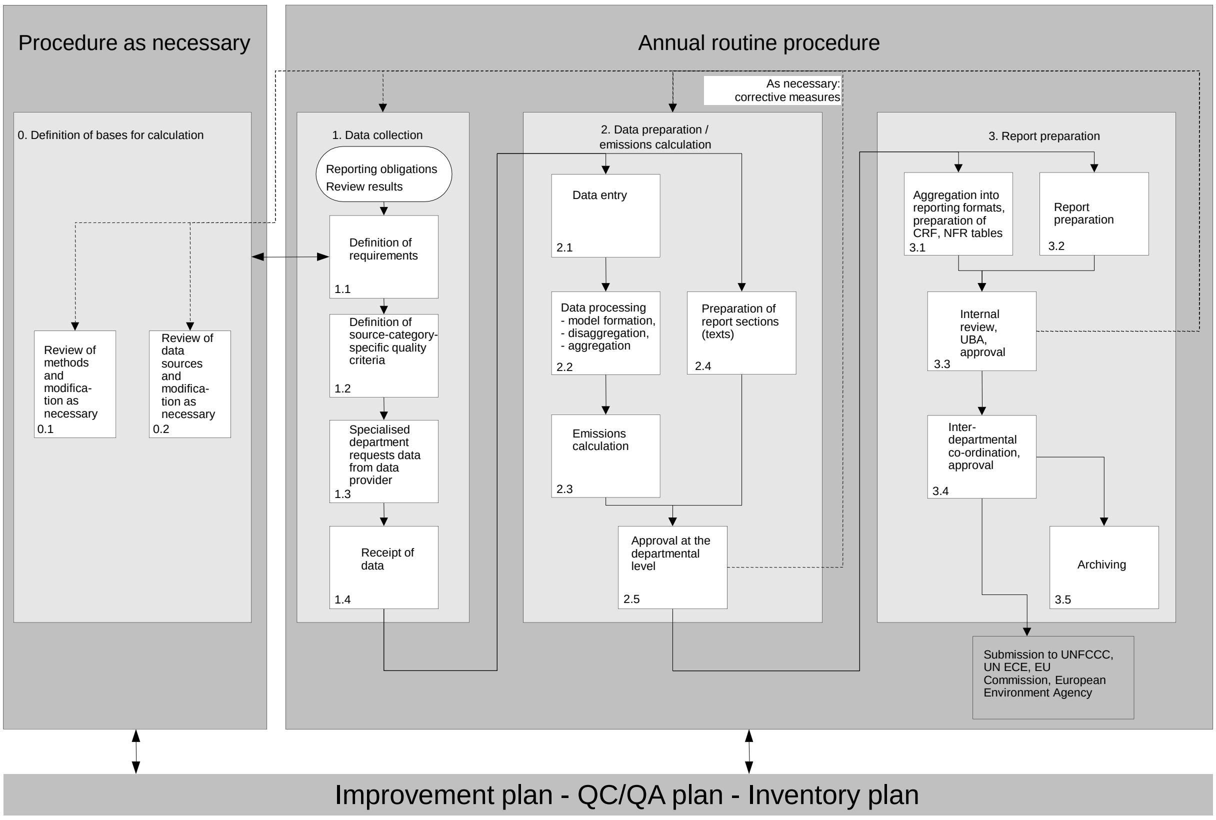
19.1.2.1.10.2.2 Reporting procedures

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 103). Additional relevant information is provided in the QSE manual, Chapter 4.3.

Figure 103: 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 19.1.2.1.2), 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.

19.1.2.1.10.3 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 104), 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)

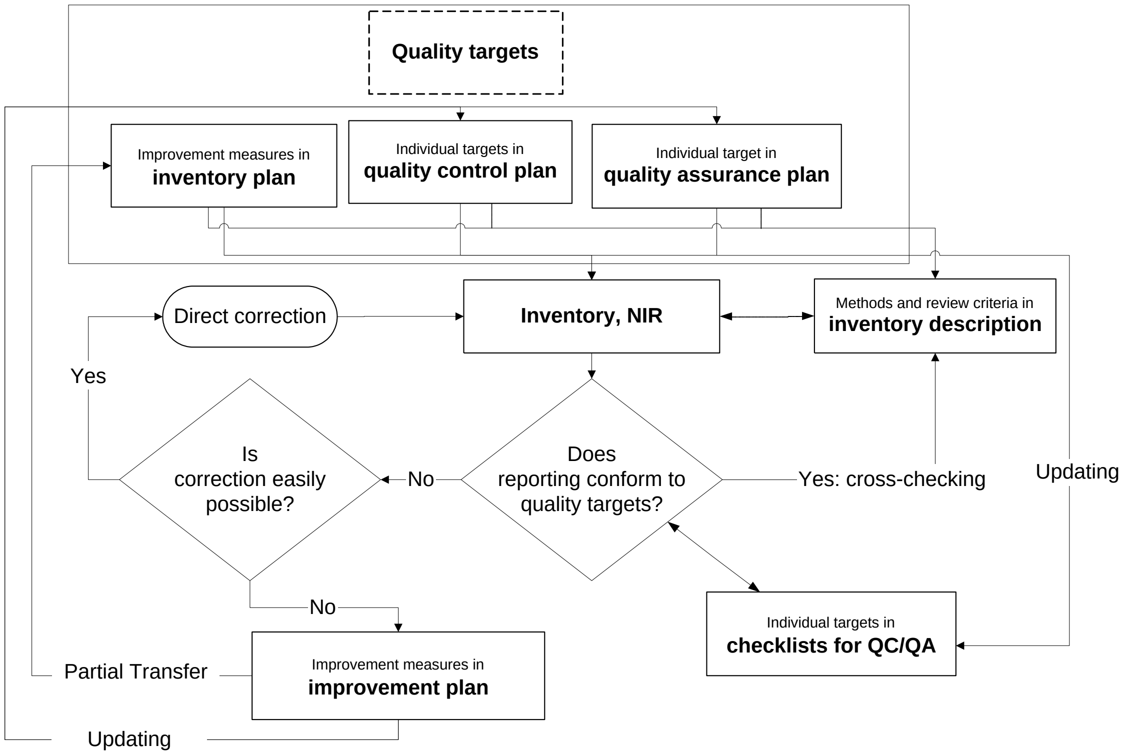
WHAT: This provides the reference to the object that is to be improved – for example, the CO_2 calculation in category xy needs to be improved

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 104: 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).

19.1.2.1.10.4 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 19.1.2.1.10.2.2), 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.

19.1.2.1.10.5 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.

19.1.2.1.10.6 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 518. 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 518: 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).

19.1.2.1.11 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 519: General checklist for responsible experts

Process No.	Sub-process name	Individual goal	Optional goal
Main process: 0. Definition of bases for calculation			
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.

Process No.	Sub-process name	Individual goal	Optional goal
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

Process No.	Sub-process name	Individual goal	Optional goal
			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.

19.1.3 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.

19.1.4 Verification of the German Greenhouse Gas Inventory

19.1.4.1 Introduction

In 2021 4 independent set 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).

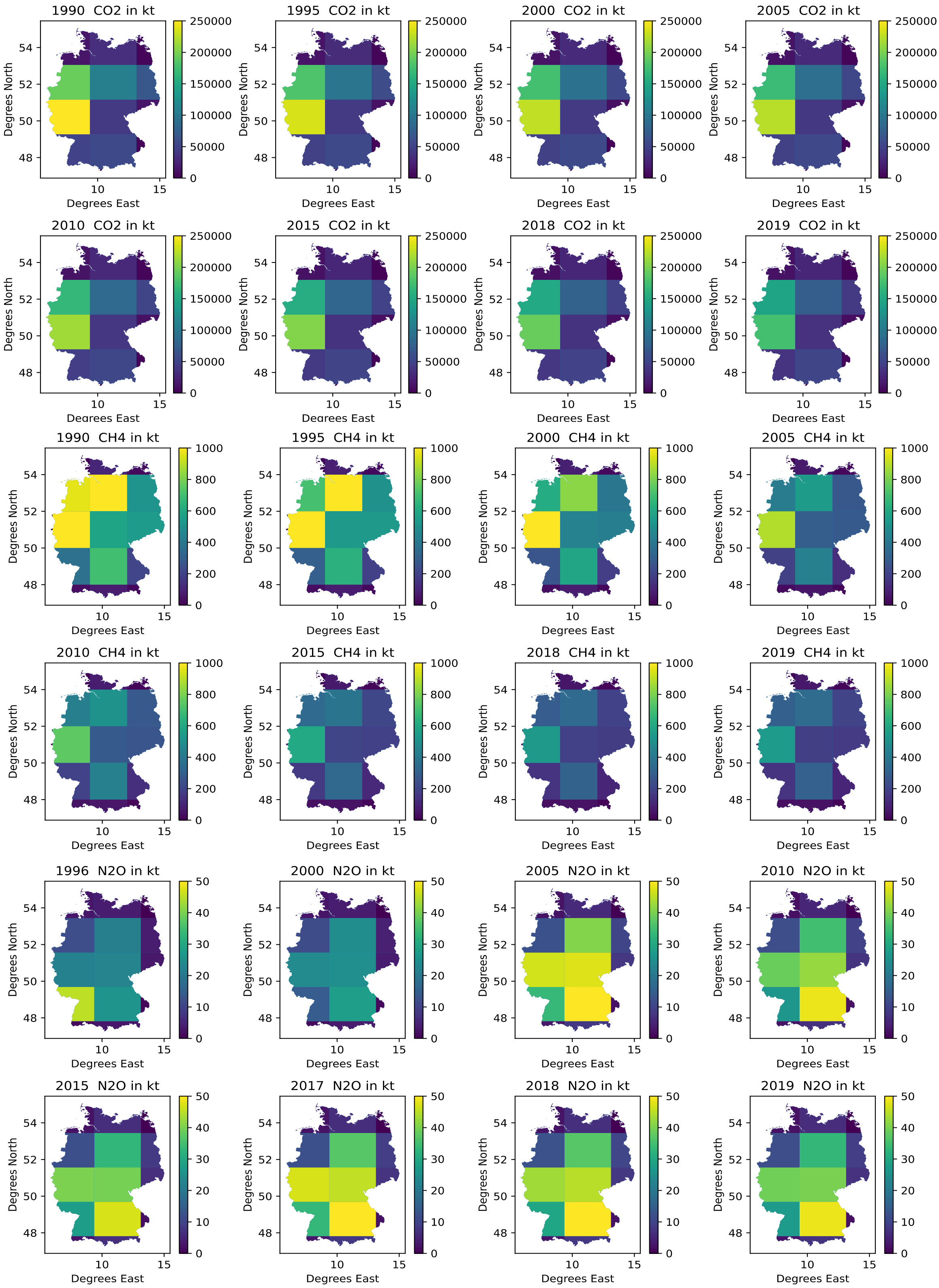
The last two independent sources of data that will be used for verification are not explicitly listed by the IPCC 2019 refinements (Romano *et al.*, 2019). These are the database of the Pollution Release and Transfer Register (PRTR) (Umweltbundesamt, 2022) and the data from the European Emission Trade 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).

19.1.4.2 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 105: Time Slice Emission data for Germany from the CAMS data store



19.1.4.2.1 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.

19.1.4.2.2 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 105 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.

19.1.4.2.3 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 106 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.

19.1.4.2.4 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).

19.1.4.3 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 105 and Figure 106 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 107. These two mathematical similarity measures were computed, in order to quantify the similarity between the temporal trends visible in Figure 107, for trend verification purposes. The results are shown in Table 520.

19.1.4.3.1 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 107 shows the EDGAR data in orange, whilst the national inventory data is plotted as thick blue line.

19.1.4.3.2 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 107.

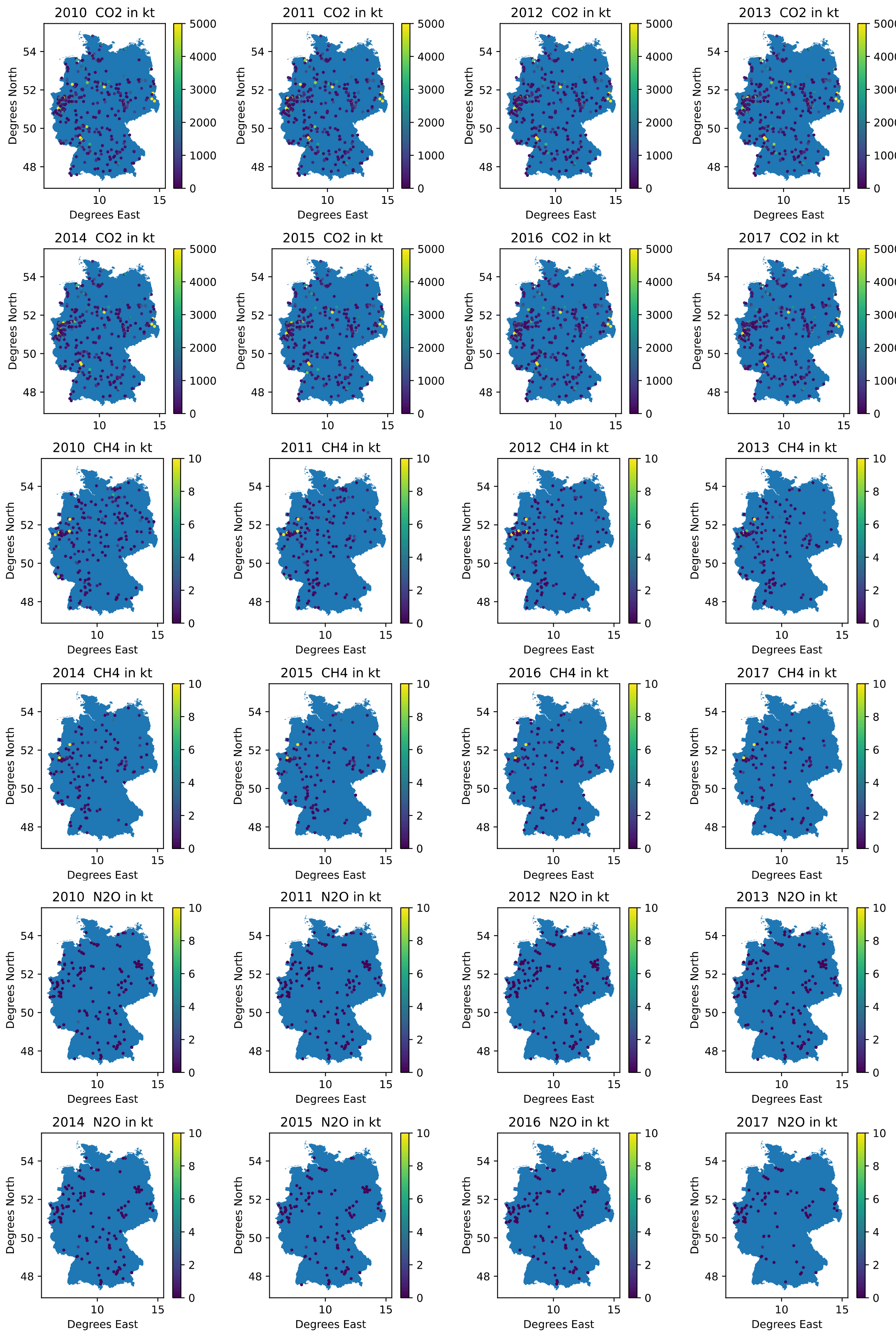
19.1.4.3.3 The Pollution Release and Transfer Register

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 106 for visualisation. The yearly sums, plotted as red line in Figure 107, were directly extracted from the database file.

19.1.4.3.4 The European Emission Trade System

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 107. 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 520.

Figure 106: Time Slice Emission data for Germany from the EPRTR Database



19.1.4.4 Results and Discussion

The trend data in Figure 107 shows very different patterns for each of the three GHG, which is also visible in Table 520. 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 520: 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

19.1.4.4.1 The EDGAR Inventory

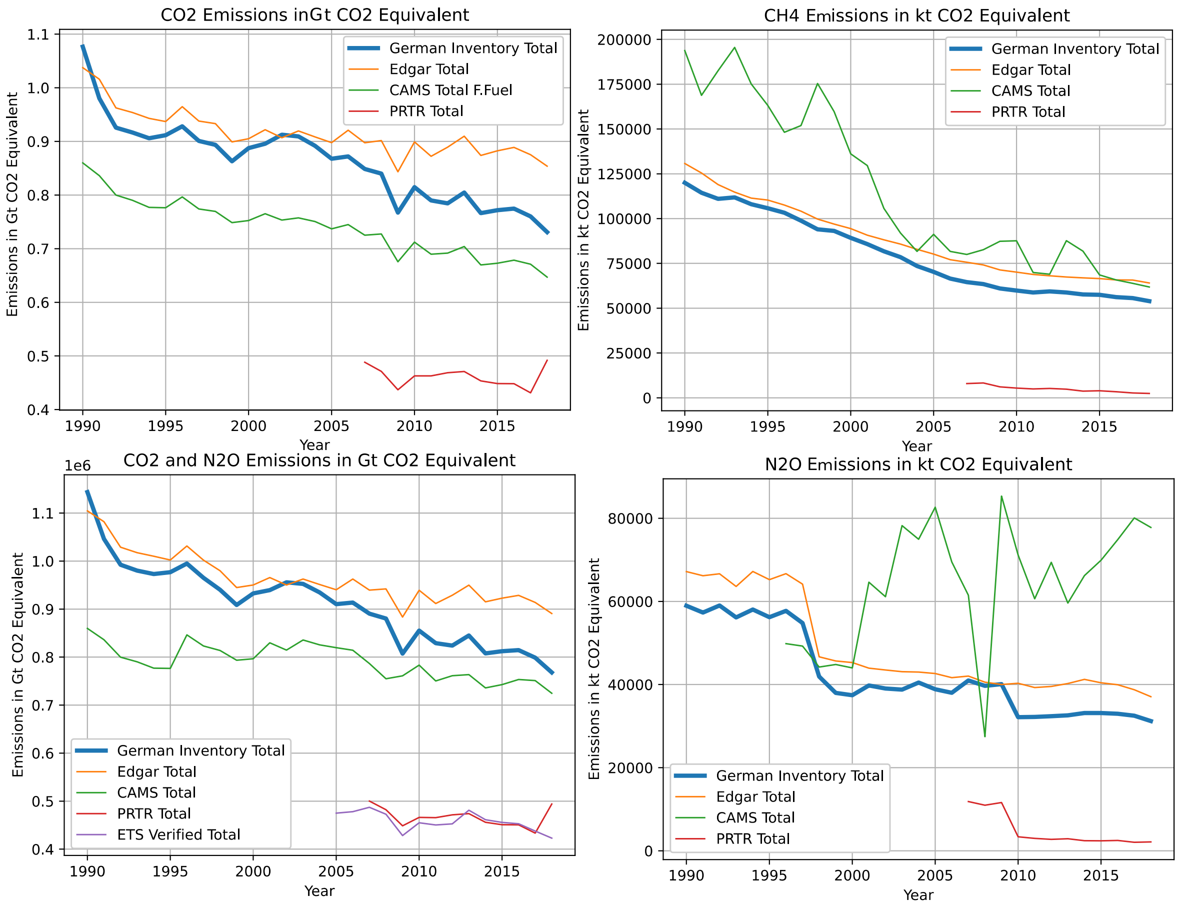
The EDGAR inventory usually is in good agreement with the national inventory data with high correlation values to the national inventory totals, as shown in Table 520 and as visible by the orange line, which is always in close agreement with the reported national totals (thick blue line) in Figure 107. 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.

19.1.4.4.2 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 107 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 107, 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 107, shows a good agreement of the trend to the inventory data, as also visible by the high correlation scores in Table 520. The green curve in Figure 107 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 520. Remarkable is the large dip around 2008, which shows a strong contrast in the data if compared to the bottom-up inventories.

Figure 107: Trend plots for CO_2 CH_4 and N_2O emission totals over the years 1990-2018



19.1.4.4.3 The Pollution Release and Transfer Register

The PRTR data matches the trends of the reported national GHG gases quite well, as highlighted in Table 520. 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.

19.1.4.4.4 The European Emission Trade System

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 520. 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.

19.1.5 Past and Present Verification Activities of Greenhouse Gas Emissions in National and International Projects

In the following text, all emission data in CO2 equivalents are still calculated with the greenhouse gas potentials (GWP) of the Fourth IPCC Assessment Report (IPCC AR4).

19.1.5.1 Introduction

Multidisciplinary scientific projects are usually set up as temporal research initiatives with clearly set goals and tasks for the participating members. They develop tools and data within a project frame of 3 to 4 years and are discontinued after their completion. This places certain constraints on the development and usage of the developed data and tools for inventory agencies:

1. It is necessary to have a fixed set of coordinating personnel within the inventory agencies to use the results and tools for emission reporting.
2. Inventory staff needs to be actively involved in the design and development of these tools and sets of data.
3. The inventory team members should act as a scientific relay between the emission inventory world and e.g. the modeling community and the atmospheric science community in order to express their specific verification needs to improve the emission inventory or identify problematic source categories.

This can be done at the country and specific level with source specific bottom-up data research projects, which yield emission factors and activity data for very specific single sources. The bigger picture (sector wide goals, LULUCF/AFOLU or modeling of national totals for stakeholders), however, require the involvement of larger expert groups from various fields of academic research. This was established for the first time in for GHG research in Europe with the VERIFY project (https://verify.lsce.ipsl.fr/). The aim of the verify project was to assemble European inventory agencies such as RVIM (Netherlands), ISPRA and CMCC (Italy), UBA (Germany) and CITEPA (France) to collaborate with academic partners in order to establish a "common language" between inventory agencies and a large consortium of climate research specialists in order to answer to the 2019 IPCC refinements[154] on QA/QC and verification, which suggest just such a collaboration.

The nature of the project offers only a temporal limited set of data in the form of the report data below, which has been part of the VERIFY project, which has ended. All plots presented below are available from the following VERIFY resource page as fact sheets: http://webportals.ipsl.jussieu.fr/VERIFY/FactSheets/. Detailed reports on the methodology used in the production of the data may be found here: https://verify.lsce.ipsl.fr/index.php/repository/key-reports-verify.

19.1.5.2 Fossil Fuel CO_2 data

The fossil fuel CO_2 comparison data from the VERIFY project has been published by Petrescu et al.[155] figure V1 shows the UNFCCC fossil fuel data, labeled as CRF encompassing different sectors, compared to other sets of data. An in-depth description of the other individual sets of data may be found in Petrescu et al.[155], or in Minx et al.[156], which deliver an in-depth analysis of the features of different sets of data. Figure 108 shows that the reported greenhouse gas data is well in the envelope of the other independent bottom-up set of data, which shows that the trend as well as the overall magnitude of the reported emissions totals in Germany are in agreement with these external sets of data. An interesting aspect of these bottom-up inventories is their direct

[154] Romano, D. et al. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories — IPCC General Guidance and Reporting. https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/ (2019).

[155] Petrescu, A. M. R. et al. The consolidated European synthesis of CO_2 emissions and removals for the European Union and United Kingdom: 1990–2018. Earth Syst. Sci. Data 13, 2363–2406 (2021).

[156] Minx, J. C. et al. A comprehensive and synthetic dataset for global, regional, and national greenhouse gas emissions by sector 1970–2018 with an extension to 2019. Earth Syst. Sci. Data 13, 5213–5252 (2021).

link to the economy, where it is possible to see e.g. the economic crisis in 2008-2009 as well as the Eurozone crisis around 2012. The steep decline in 2020 is also remarkable.

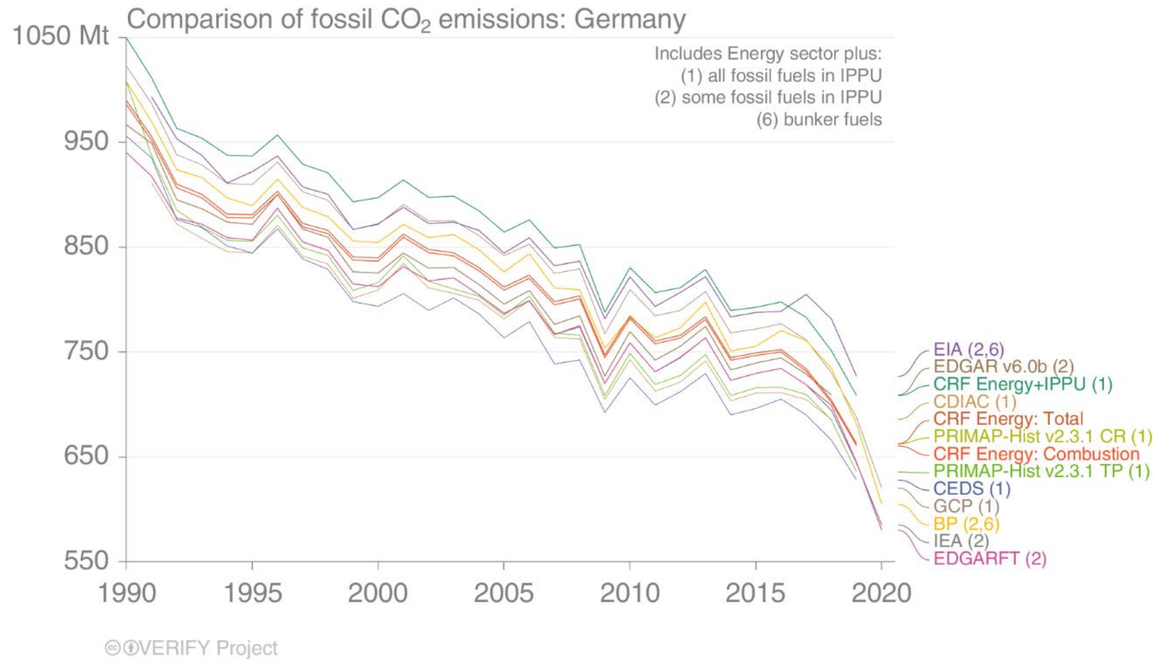


Figure 108: Fossil CO_2 emissions for Germany from bottom-up inventories, CRF depicts the reported emissions to the UNFCCC. The trend as well as the order of magnitude are in good agreement between the different sets of data.

Figure 109 from Petrescu et al.[155] shows the mean of the CO_2 data in the three decades (1990-1999, 2000-2009, 2010-2019) across individual sectors as well as the corresponding trend in each sector. Here we see that the energy related sectors contributed to a large extent to the reduction across the decades, whilst e.g. the transport sector decreased in CO_2 emissions by only a small portion. The large drop in the manufacturing industries may have been caused by closure of large manufacturing plants in the 1990s due to a restructuring of the industry, which took part in Germany at that time. The growth in the 2000s in emissions in that sector shows the economic upsurge in this specific sector.

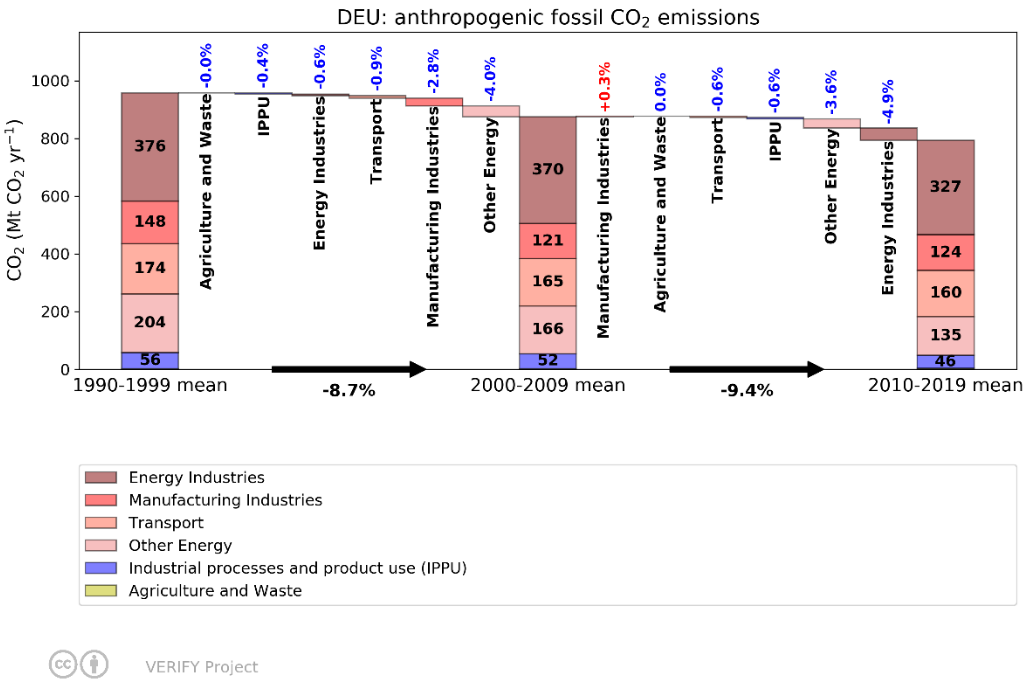


Figure 109: Fossil CO_2 emissions for Germany as mean over the three respective decades. Energy related emissions in Germany have dropped quite significantly between the decades, whilst transport related emissions decreased slower.

19.1.5.3 Methane

The data presented here is part of VERIFYs methane data which has also been published by Petrescu et al.[157] Figure 110 shows anthropogenic methane in different sectors, compared to different bottom-up datasets. We see that the CH_4 total is in good agreement with the other bottom-up set of data, together with the energy, waste and agricultural sectors. Only the IPPU sector deviates slightly, which may be caused by methodological differences in the EDGAR data. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the mean CH_4 emissions over t he three decades (1990-1999, 2000-2009, 2010-2019) across individual sectors as well as the corresponding trend in each sector. We see that the energy and the waste sector have contributed substantially to the methane emission reductions, whilst agricultural emissions decreased only slowly. Figure 112 shows methane data from global inversions and from the GOSAT satellite. We see that the error bar for both methods is larger than from the reported UNFCCC emissions. However, both methods verify the trend of the reported UNFCCC data and envelope the reported UNFCCC methane data. Data from VERIFY for countries with lesser days of cloud cover, e.g. in southern Europe, show even better results for the top-down methane data, with smaller error bars, due to the higher availability of data from spaceborne sensors Petrescu et al.[157].

[157] Petrescu, A. M. R. *et al.* The consolidated European synthesis of CH_4 and N_2O emissions for EU27 and UK: 1990–2020. *Earth Syst. Sci. Data Discuss.* 1–97 (2022) doi:10.5194/essd-2022-287.

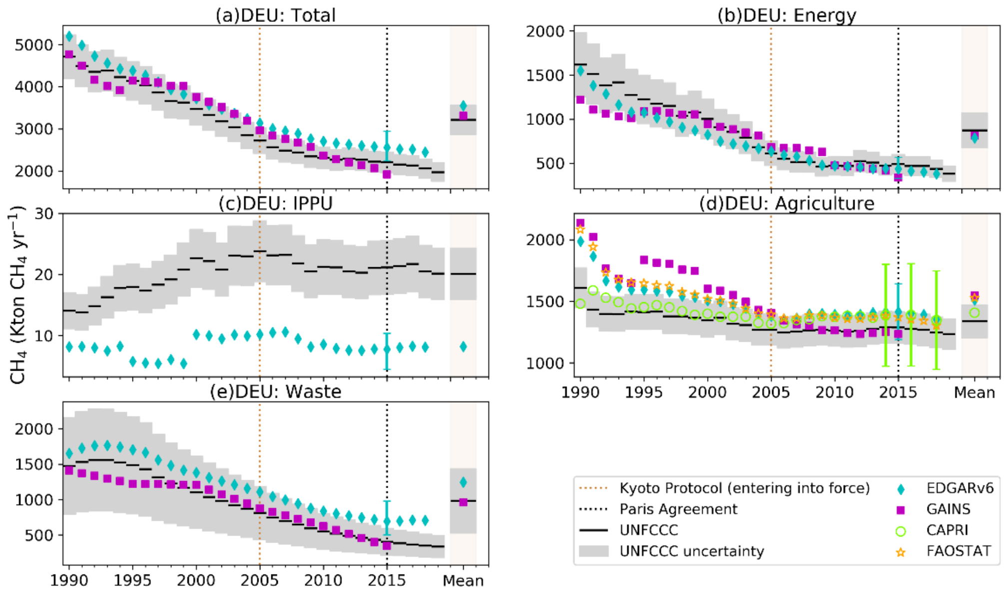


Figure 110: Anthropogenic CH_4 data for the reported UNFCCC data as well as selected bottom-up datasets.

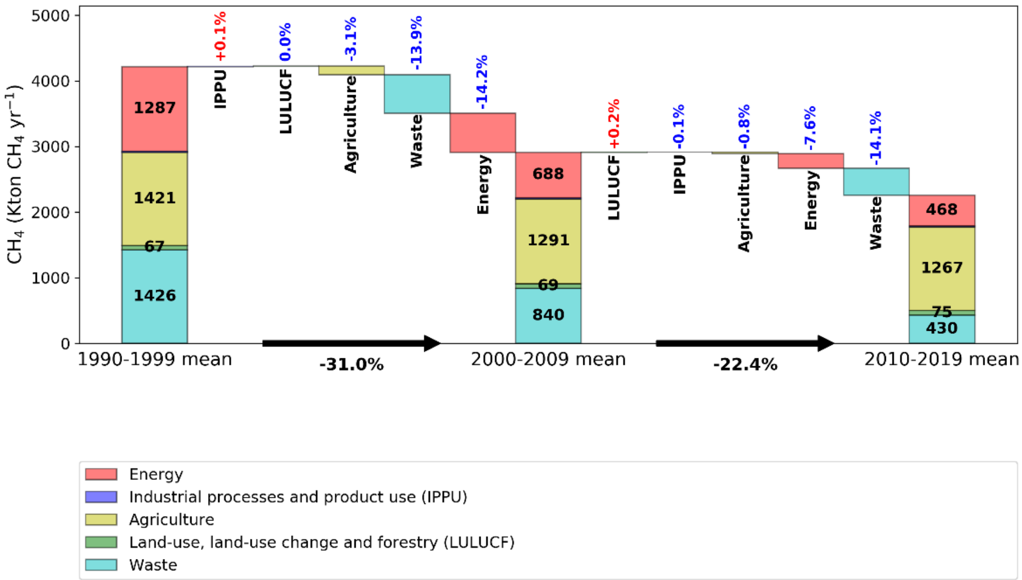


Figure 111: Anthropogenic CH_4 data for the reported UNFCCC data as well as selected bottom-up datasets.

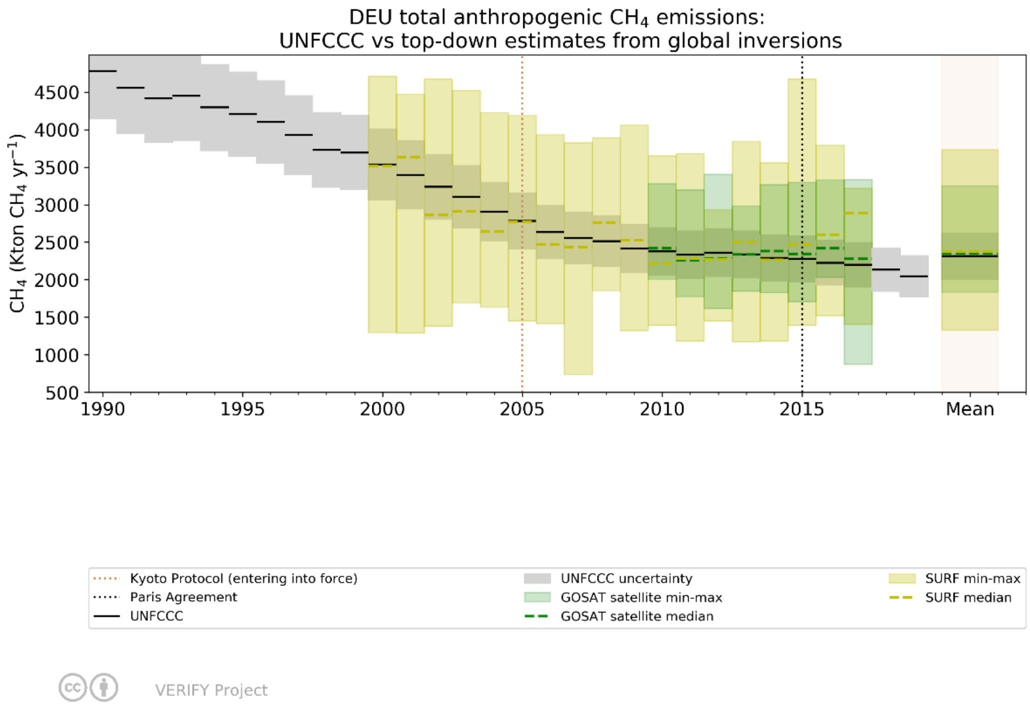


Figure 112: **Top down anthropogenic CH_4 emissions from the GOSAT satellite as well as from global inversions.**

19.1.5.4 N_2O

The N_2O data is also described in Petrescu et al. [157]. Figure 113 shows the N_2O trend in the different sectors compared to the UNFCCC data. The trend as well as the magnitude of the N_2O data in the individual sectors fit quite well, given the large error bars in the different sectors, such as the agricultural and waste sector. The three decadal plot of Figure 114 shows that the largest cuts in emissions have been achieved by the IPPU sector, whilst energy, LULUCF and agriculture have seen a slight increase of N_2O in the last two decades.

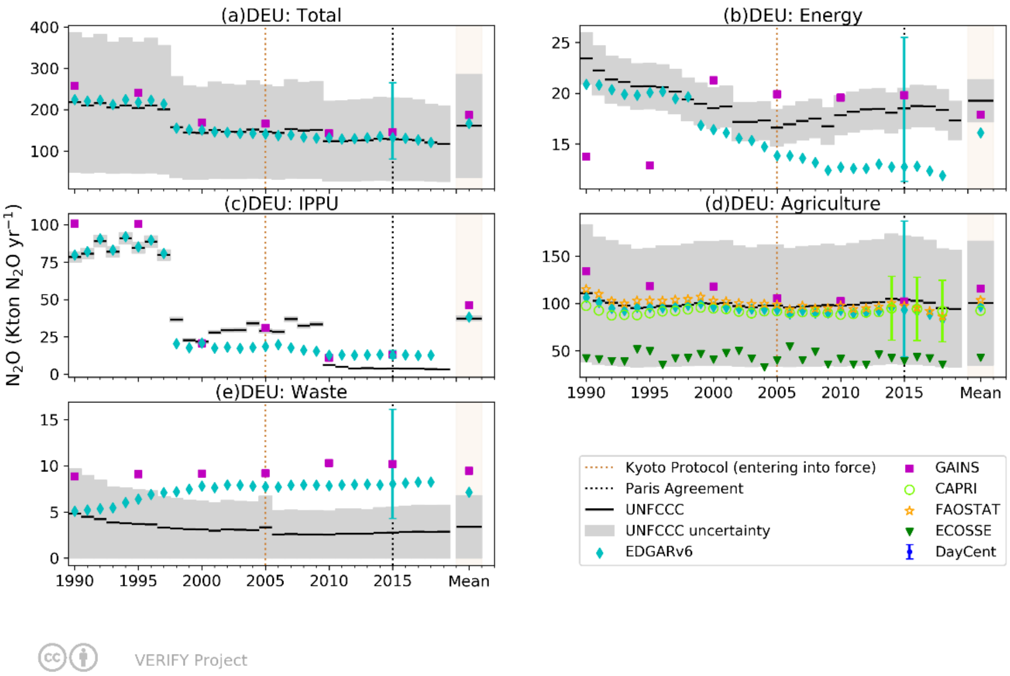


Figure 113: Anthropogenic N_2O data for the reported UNFCCC data as well as selected bottom-up datasets.

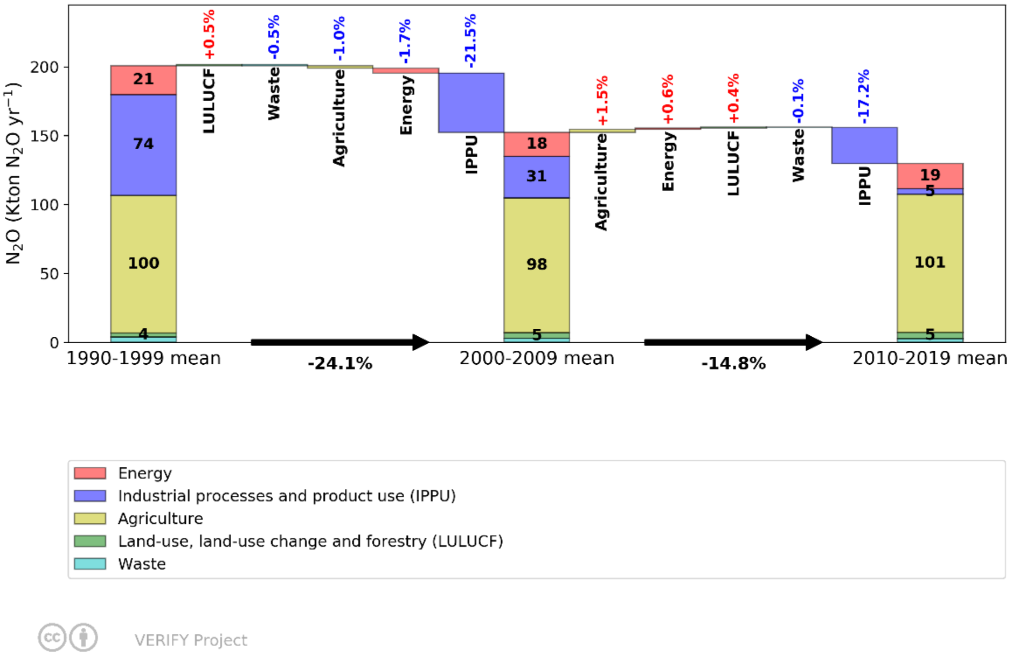


Figure 114: Trends in N_2O data for the reported UNFCCC data over three decades.

19.1.6 Detailed sector time series analysis

Time series analysis of the Emission Database for Global Atmospheric Research (EDGAR) in greater sector detail is shown in figure V8. EDGAR is one of the key sets of data which has been recommended by the IPCC 2019 refinements on QA/QC & verification for GHG reporting by Romano et al.[154]. The data by Crippa et al.[158] of version 7 may be retrieved from the EDGAR project page: https://edgar.jrc.ec.europa.eu/report_2022#intro. It is available as separate excel or ".csv" files from the JRC. All sector data for the three gases shown in Figure 115 illustrates that the trend between the EDGAR 7.0 data and the inventory data is very similar, as shown by the other, more, coarser sectoral VERIFY analysis above. The major emitting sectors are also in the same order of magnitude in the EDGAR 7.0 and the UNFCCC data. This shows that there is a high correlation between the two sets of data for all the three major greenhouse gases. Smaller deviations between the two sets of data may be due to country specific differences in the reporting (higher tier reporting in the national UNFCCC data due to an improved level of dis-aggregation and more complex models vs. more generic approaches) in case of EDGAR.

[158] Crippa, M., Guizzardi, D., Banja, M., Solazzo, E., Muntean, M., Schaaf, E., Pagani, F., Monforti-Ferrario, F., Olivier, J., Quadrelli, R., Risquez Martin, A., Taghavi-Moharamli, P., Grassi, G., Rossi, S., Jacome Felix Oom, D., Branco, A., San-Miguel-Ayanz, J. and Vignati, E., CO2 emissions of all world countries - 2022 Report, EUR 31182 EN, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/730164, JRC130363

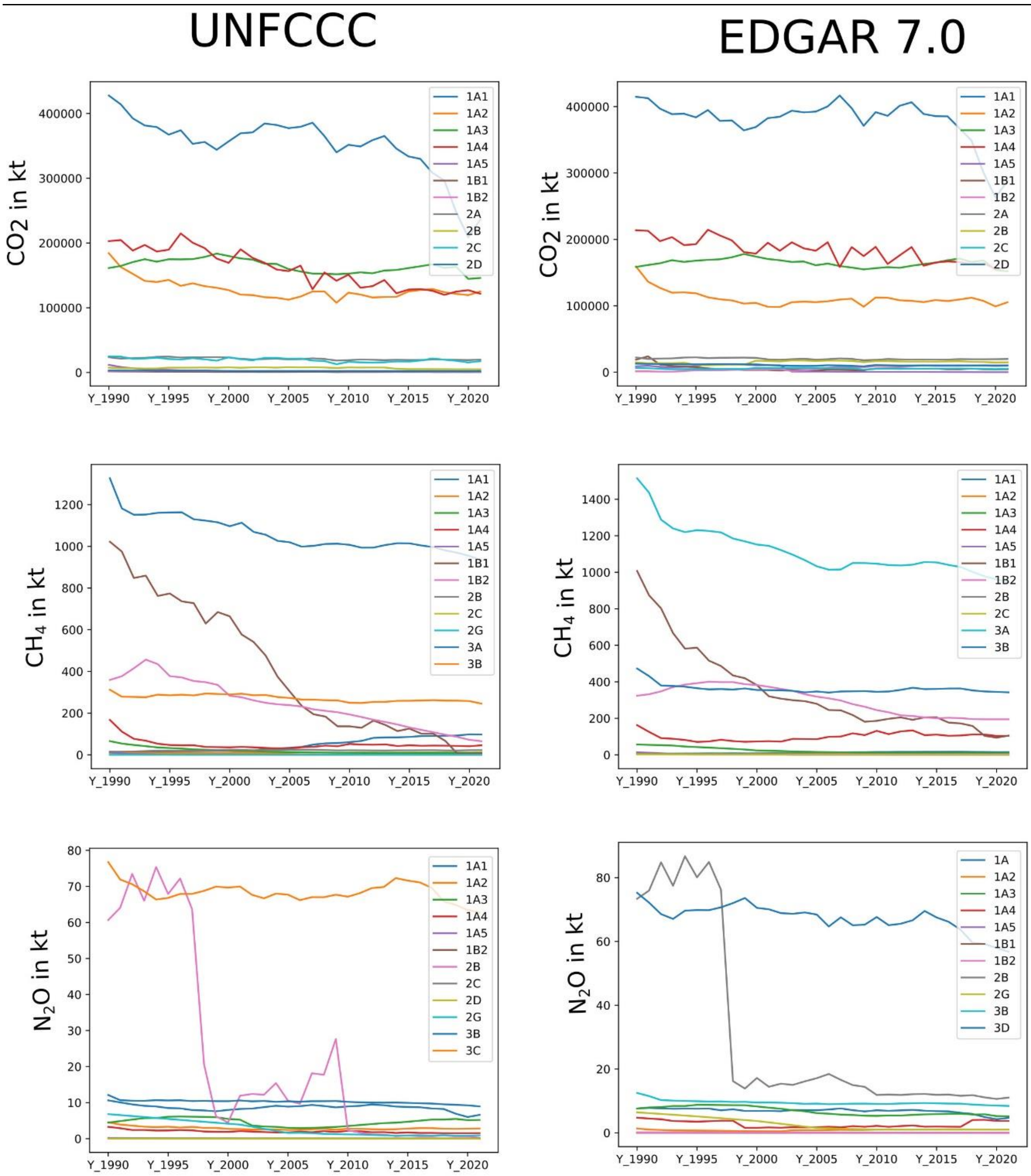


Figure 115: Trend data from the German GHG inventory (left) vs. EDGAR 7.0 data for Germany (right).

19.2 Supplementary information

19.2.1 Standard Electronic Format (SEF) Tables

The SEF tables are appended as separate Excel files.

19.2.2 Detailed information about the National System, and about changes within the National System

All of this information has been provided in the preceding chapters.

19.2.3 Further detailed information about the National Registries and about accounting of Kyoto units

The required documents are confidential and accessible for assessors only.

19.3 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 521: 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)	**1,054,741**	**1,016,870**	**969,474**	**959,367**	**943,185**	**939,897**	**959,653**	**931,487**	**923,467**	**895,402**	**898,938**	**915,242**	**898,835**	**899,858**	**885,633**
Net CO_2 emissions/removals	1,083,501	984,708	928,857	917,822	906,668	909,585	935,737	908,329	900,181	868,154	891,603	898,206	913,893	909,740	890,217
CH_4 (with LULUCF)	**132,606**	**126,231**	**122,193**	**122,909**	**118,429**	**115,632**	**112,544**	**107,422**	**101,789**	**100,616**	**96,046**	**91,918**	**87,213**	**83,234**	**76,469**
CH_4 (without LULUCF)	138,936	132,556	128,543	129,238	124,756	121,955	118,872	113,746	108,112	106,938	102,370	98,250	93,562	89,612	82,866
N_2O (with LULUCF)	**51,554**	**50,074**	**51,577**	**49,022**	**50,730**	**49,111**	**50,462**	**47,854**	**36,439**	**32,963**	**32,472**	**34,300**	**33,553**	**33,336**	**34,810**
N_2O (without LULUCF)	52,440	50,954	52,467	49,900	51,604	49,981	51,333	48,720	37,302	33,824	33,332	35,356	34,619	34,417	35,898
F gases, total	**12,324**	**11,890**	**12,382**	**15,008**	**15,449**	**16,021**	**15,209**	**15,424**	**15,909**	**14,200**	**12,735**	**13,409**	**13,437**	**12,962**	**13,380**
Total emissions, without LULUCF	**1,251,225**	**1,205,065**	**1,155,626**	**1,146,307**	**1,127,793**	**1,120,661**	**1,137,869**	**1,102,187**	**1,077,604**	**1,043,181**	**1,040,192**	**1,054,869**	**1,033,038**	**1,029,390**	**1,010,291**
Total emissions / removals, with LULUCF	1,287,200	1,180,109	1,122,249	1,111,968	1,098,477	1,097,542	1,121,151	1,086,218	1,061,504	1,023,116	1,040,041	1,045,221	1,055,511	1,046,730	1,022,360

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)	**865,471**	**877,498**	**850,230**	**852,858**	**788,286**	**831,130**	**807,614**	**812,816**	**833,804**	**794,739**	**798,085**	**801,745**	**785,986**	**754,811**	**707,491**
Net CO_2 emissions/removals	865,778	870,903	846,710	843,916	770,500	820,839	791,170	787,704	809,946	778,062	779,213	780,350	767,606	739,346	692,963
CH_4 (with LULUCF)	**72,574**	**68,159**	**65,670**	**64,296**	**61,477**	**60,100**	**58,551**	**58,893**	**57,899**	**56,368**	**55,895**	**54,178**	**53,339**	**51,098**	**48,261**
CH_4 (without LULUCF)	78,999	74,601	72,125	70,769	67,968	66,607	65,061	65,409	64,421	62,898	62,436	60,719	59,883	57,762	54,832
N_2O (with LULUCF)	**33,367**	**32,702**	**35,332**	**34,203**	**34,545**	**27,449**	**27,458**	**27,584**	**27,718**	**28,202**	**28,155**	**28,019**	**27,548**	**26,383**	**25,669**
N_2O (without LULUCF)	34,466	33,734	36,361	35,232	35,697	28,576	28,582	28,712	28,841	29,350	29,314	29,145	28,679	27,526	26,805
F gases, total	**13,576**	**13,539**	**13,634**	**13,618**	**14,028**	**13,701**	**13,880**	**14,056**	**14,085**	**14,085**	**14,523**	**14,619**	**14,710**	**13,879**	**13,212**
Total emissions, without LULUCF	**984,987**	**991,897**	**964,865**	**964,974**	**898,336**	**932,379**	**907,502**	**913,348**	**933,505**	**893,394**	**896,658**	**898,560**	**881,583**	**846,171**	**794,634**
Total emissions / removals, with LULUCF	992,819	992,776	968,830	963,536	888,193	929,723	898,693	895,881	917,293	884,395	885,486	884,832	870,878	838,514	787,811

GHG emissions / sinks, in CO_2 equivalents (kt)	2020	2021
CO_2 emissions (without LULUCF)	**647,252**	**678,799**
Net CO_2 emissions/removals	643,742	675,066
CH_4 (with LULUCF)	**47,051**	**45,688**
CH_4 (without LULUCF)	53,613	52,255
N_2O (with LULUCF)	**24,922**	**24,767**
N_2O (without LULUCF)	26,068	25,931
F gases, total	**11,697**	**11,104**
Total emissions, without LULUCF	**730,923**	**760,358**
Total emissions / removals, with LULUCF	735,120	764,356

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	**1,044,156**	**1,007,215**	**958,785**	**949,524**	**926,793**	**922,578**	**943,004**	**911,145**	**901,164**	**876,231**	**872,552**	**892,180**	**875,825**	**870,547**	**853,172**
2. Industrial processes	**93,227**	**89,560**	**89,541**	**90,804**	**96,329**	**94,758**	**92,869**	**93,460**	**81,007**	**73,404**	**76,658**	**73,025**	**71,464**	**75,462**	**77,199**
3. Agriculture	**72,632**	**65,681**	**64,228**	**63,329**	**63,179**	**63,189**	**63,734**	**62,750**	**63,202**	**63,368**	**62,732**	**63,457**	**61,259**	**60,682**	**59,802**
4. Land use, land-use changes & forestry	**35,976**	**-24,956**	**-33,376**	**-34,339**	**-29,316**	**-23,118**	**-16,718**	**-15,969**	**-16,100**	**-20,064**	**-151**	**-9,648**	**22,473**	**17,339**	**12,069**
CO_2	28,760	-32,162	-40,617	-41,545	-36,517	-30,312	-23,917	-23,158	-23,286	-27,248	-7,335	-17,036	15,058	9,881	4,585
N_2O & CH_4	7,215	7,206	7,241	7,207	7,201	7,194	7,199	7,189	7,186	7,184	7,183	7,388	7,415	7,458	7,485
5. Waste	**41,209**	**42,608**	**43,072**	**42,650**	**41,492**	**40,136**	**38,262**	**34,832**	**32,230**	**30,178**	**28,250**	**26,208**	**24,491**	**22,699**	**20,118**

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	**832,819**	**842,705**	**815,735**	**820,513**	**762,431**	**800,320**	**776,304**	**783,203**	**803,522**	**762,833**	**767,815**	**768,841**	**748,982**	**718,460**	**671,198**
2. Industrial processes	**74,091**	**74,303**	**75,199**	**71,560**	**64,038**	**61,850**	**61,816**	**60,925**	**60,750**	**60,674**	**59,700**	**61,518**	**65,453**	**62,549**	**59,534**
3. Agriculture	**59,623**	**58,506**	**59,063**	**59,424**	**59,768**	**59,355**	**59,394**	**60,052**	**60,852**	**62,108**	**61,967**	**61,546**	**60,867**	**59,265**	**58,525**
4. Land use, land-use changes & forestry	**7,832**	**879**	**3,965**	**-1,439**	**-10,143**	**-2,656**	**-8,809**	**-17,467**	**-16,213**	**-8,999**	**-11,172**	**-13,727**	**-10,705**	**-7,657**	**-6,822**
CO_2	307	-6,595	-3,520	-8,942	-17,786	-10,290	-16,444	-25,111	-23,859	-16,677	-18,872	-21,395	-18,380	-15,465	-14,529
N_2O & CH_4	7,525	7,473	7,484	7,503	7,643	7,635	7,634	7,644	7,646	7,677	7,700	7,667	7,675	7,808	7,707
5. Waste	**18,454**	**16,383**	**14,868**	**13,478**	**12,099**	**10,853**	**9,987**	**9,167**	**8,381**	**7,780**	**7,175**	**6,655**	**6,281**	**5,897**	**5,377**

GHG emissions / sinks, by source and sink categories, in CO_2 equivalents (kt)	2020	
1. Energy	**613,329**	**642,351**
2. Industrial processes	**55,140**	**57,180**
3. Agriculture	**57,552**	**56,333**
4. Land use, land-use changes & forestry	**4,197**	**3,998**
CO_2	-3,511	-3,733
N_2O & CH_4	7,708	7,731
5. Waste	**4,901**	**4,494**

Table 522: 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	2021
CO_2 emissions*	84.30	84.38	83.89	83.69	83.63	83.87	84.34	84.51	85.70	85.83	86.42	86.76	87.01	87.42	87.66	87.87	88.47	88.12	88.38	87.75	89.14	88.99	88.99	89.32	88.96	89.01	89.23	89.16	89.20	89.03	88.55	89.27
CH_4*	10.60	10.47	10.57	10.72	10.50	10.32	9.89	9.75	9.45	9.65	9.23	8.71	8.44	8.09	7.57	7.37	6.87	6.81	6.66	6.84	6.45	6.45	6.45	6.20	6.31	6.23	6.03	6.05	6.04	6.07	6.44	6.01
N_2O*	4.12	4.16	4.46	4.28	4.50	4.38	4.43	4.34	3.38	3.16	3.12	3.25	3.25	3.24	3.45	3.39	3.30	3.66	3.54	3.85	2.94	3.03	3.02	2.97	3.16	3.14	3.12	3.12	3.12	3.23	3.41	3.26
F gases, total	0.98	0.99	1.07	1.31	1.37	1.43	1.34	1.40	1.48	1.36	1.22	1.27	1.30	1.26	1.32	1.38	1.36	1.41	1.41	1.56	1.47	1.53	1.54	1.51	1.58	1.62	1.63	1.67	1.64	1.66	1.60	1.46
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**	**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	2021
1. Energy	83.45	83.58	82.97	82.83	82.18	82.32	82.87	82.67	83.63	84.00	83.88	84.58	84.78	84.57	84.45	84.55	84.96	84.54	85.03	84.87	85.84	85.54	85.75	86.08	85.39	85.63	85.56	84.96	84.91	84.47	83.91	84.48
2. Industrial processes	7.45	7.43	7.75	7.92	8.54	8.46	8.16	8.48	7.52	7.04	7.37	6.92	6.92	7.33	7.64	7.52	7.49	7.79	7.42	7.13	6.63	6.81	6.67	6.51	6.79	6.66	6.85	7.42	7.39	7.49	7.54	7.52
4. Agriculture	5.80	5.45	5.56	5.52	5.60	5.64	5.60	5.69	5.87	6.07	6.03	6.02	5.93	5.89	5.92	6.05	5.90	6.12	6.16	6.65	6.37	6.54	6.57	6.52	6.95	6.91	6.85	6.90	7.00	7.37	7.87	7.41
5. Waste	3.29	3.54	3.73	3.72	3.68	3.58	3.36	3.16	2.99	2.89	2.72	2.48	2.37	2.21	1.99	1.87	1.65	1.54	1.40	1.35	1.16	1.10	1.00	0.90	0.87	0.80	0.74	0.71	0.70	0.68	0.67	0.59
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**	**100.0**

* Not including emissions from Land Use, Land Use Change and Forestry (LULUCF).

Table 523: 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)	**1,054,741**	**1,016,870**	**969,474**	**959,367**	**943,185**	**939,897**	**959,653**	**931,487**	**923,467**	**895,402**	**898,938**	**915,242**	**898,835**	**899,858**	**885,633**
Net CO_2 emissions / removals	1,083,501	984,708	928,857	917,822	906,668	909,585	935,737	908,329	900,181	868,154	891,603	898,206	913,893	909,740	890,217
CH_4 (without LULUCF)	**4,736**	**4,508**	**4,364**	**4,390**	**4,230**	**4,130**	**4,019**	**3,836**	**3,635**	**3,593**	**3,430**	**3,283**	**3,115**	**2,973**	**2,731**
CH_4 (with LULUCF)	4,962	4,734	4,591	4,616	4,456	4,356	4,245	4,062	3,861	3,819	3,656	3,509	3,342	3,200	2,959
N_2O (without LULUCF)	**195**	**189**	**195**	**185**	**191**	**185**	**190**	**181**	**138**	**124**	**123**	**129**	**127**	**126**	**131**
N_2O (with LULUCF)	198	192	198	188	195	189	194	184	141	128	126	133	131	130	135
F gases, total (CO_2-equivalents)	**12,324**	**11,890**	**12,382**	**15,008**	**15,449**	**16,021**	**15,209**	**15,424**	**15,909**	**14,200**	**12,735**	**13,409**	**13,437**	**12,962**	**13,380**
NO_x	**2,847**	**2,620**	**2,469**	**2,364**	**2,232**	**2,172**	**2,087**	**2,012**	**1,983**	**1,946**	**1,868**	**1,812**	**1,752**	**1,709**	**1,664**
SO_2	**5,464**	**3,964**	**3,237**	**2,902**	**2,416**	**1,743**	**1,476**	**1,226**	**978**	**798**	**643**	**622**	**559**	**532**	**492**
NMVOC	**3,949**	**3,427**	**3,105**	**2,916**	**2,494**	**2,363**	**2,263**	**2,206**	**2,147**	**1,982**	**1,814**	**1,718**	**1,625**	**1,543**	**1,539**
CO	**13,354**	**11,083**	**9,553**	**8,637**	**7,603**	**7,234**	**6,659**	**6,416**	**5,900**	**5,484**	**5,146**	**4,946**	**4,642**	**4,311**	**4,094**

Emissions development (kt)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO_2 emissions (without LULUCF)	**865,471**	**877,498**	**850,230**	**852,858**	**788,286**	**831,130**	**807,614**	**812,816**	**833,804**	**794,739**	**798,085**	**801,745**	**785,986**	**754,811**	**707,491**
Net CO_2 emissions / removals	865,778	870,903	846,710	843,916	770,500	820,839	791,170	787,704	809,946	778,062	779,213	780,350	767,606	739,346	692,963
CH_4 (without LULUCF)	**2,592**	**2,434**	**2,345**	**2,296**	**2,196**	**2,146**	**2,091**	**2,103**	**2,068**	**2,013**	**1,996**	**1,935**	**1,905**	**1,825**	**1,724**
CH_4 (with LULUCF)	2,821	2,664	2,576	2,527	2,427	2,379	2,324	2,336	2,301	2,246	2,230	2,169	2,139	2,063	1,958
N_2O (without LULUCF)	**126**	**123**	**133**	**129**	**130**	**104**	**104**	**104**	**105**	**106**	**106**	**106**	**104**	**100**	**97**
N_2O (with LULUCF)	130	127	137	133	135	108	108	108	109	111	111	110	108	104	101
F gases, total (CO_2-equivalents)	**13,576**	**13,539**	**13,634**	**13,618**	**14,028**	**13,701**	**13,880**	**14,056**	**14,085**	**14,085**	**14,523**	**14,619**	**14,710**	**13,879**	**13,212**
NO_x	**1,617**	**1,631**	**1,585**	**1,530**	**1,439**	**1,458**	**1,437**	**1,432**	**1,435**	**1,391**	**1,366**	**1,332**	**1,276**	**1,188**	**1,104**
SO_2	**473**	**474**	**457**	**451**	**393**	**403**	**388**	**369**	**357**	**336**	**334**	**310**	**301**	**290**	**260**
NMVOC	**1,490**	**1,486**	**1,424**	**1,361**	**1,247**	**1,363**	**1,274**	**1,258**	**1,213**	**1,173**	**1,147**	**1,139**	**1,143**	**1,096**	**1,066**
CO	**3,863**	**3,831**	**3,790**	**3,767**	**3,225**	**3,536**	**3,457**	**3,206**	**3,168**	**3,000**	**3,102**	**2,973**	**2,981**	**2,863**	**2,756**

Emissions development (kt)	2020	2021
CO_2 emissions (without LULUCF)	**647,252**	**678,799**
Net CO_2 emissions / removals	643,742	675,066
CH_4 (without LULUCF)	**1,680**	**1,632**
CH_4 (with LULUCF)	1,915	1,866
N_2O (without LULUCF)	**94**	**93**
N_2O (with LULUCF)	98	98
F gases, total (CO_2-equivalents)	**11,697**	**11,104**
NO_x	**974**	**966**
SO_2	**241**	**254**
NMVOC	**1,029**	**1,044**
CO	**2,454**	**2,587**

Table 524: 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**	**-8.1**	**-9.0**	**-10.6**	**-10.9**	**-9.0**	**-11.7**	**-12.4**	**-15.1**	**-14.8**	**-13.2**	**-14.8**	**-14.7**	**-16.0**
Net CO_2 emissions / removals		-9.1	-14.3	-15.3	-16.3	-16.1	-13.6	-16.2	-16.9	-19.9	-17.7	-17.1	-15.7	-16.0	-17.8
CH_4 (without LULUCF)		**-4.8**	**-7.9**	**-7.3**	**-10.7**	**-12.8**	**-15.1**	**-19.0**	**-23.2**	**-24.1**	**-27.6**	**-30.7**	**-34.2**	**-37.2**	**-42.3**
N_2O (without LULUCF)		**-2.9**	**+0.0**	**-4.9**	**-1.6**	**-4.7**	**-2.1**	**-7.2**	**-29.3**	**-36.1**	**-37.0**	**-33.5**	**-34.9**	**-35.3**	**-32.5**
F gases, total							**-5.1**	**-3.7**	**-0.7**	**-11.4**	**-20.5**	**-16.3**	**-16.1**	**-19.1**	**-16.5**
Total emissions, without LULUCF		**-3.7**	**-7.6**	**-8.4**	**-9.9**	**-10.4**	**-9.1**	**-11.9**	**-13.9**	**-16.6**	**-16.9**	**-15.7**	**-17.4**	**-17.7**	**-19.3**
Total emissions / removals, with LULUCF		-8.3	-12.8	-13.6	-14.7	-14.7	-12.9	-15.6	-17.5	-20.5	-19.2	-18.8	-18.0	-18.7	-20.6
Total emissions, without LULUCF, with respect to base year*		*-4.0*	*-7.9*	*-8.7*	*-10.1*	*-10.7*	*-9.3*	*-12.2*	*-14.1*	*-16.9*	*-17.1*	*-15.9*	*-17.7*	*-18.0*	*-19.5*
NO_X		**-8.0**	**-13.3**	**-17.0**	**-21.6**	**-23.7**	**-26.7**	**-29.3**	**-30.3**	**-31.6**	**-34.4**	**-36.3**	**-38.5**	**-40.0**	**-41.5**
SO_2		**-27.5**	**-40.8**	**-46.9**	**-55.8**	**-68.1**	**-73.0**	**-77.6**	**-82.1**	**-85.4**	**-88.2**	**-88.6**	**-89.8**	**-90.3**	**-91.0**
NMVOC		**-13.2**	**-21.4**	**-26.2**	**-36.8**	**-40.2**	**-42.7**	**-44.1**	**-45.6**	**-49.8**	**-54.1**	**-56.5**	**-58.8**	**-60.9**	**-61.0**
CO		**-17.0**	**-28.5**	**-35.3**	**-43.1**	**-45.8**	**-50.1**	**-52.0**	**-55.8**	**-58.9**	**-61.5**	**-63.0**	**-65.2**	**-67.7**	**-69.3**

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)	**-17.9**	**-16.8**	**-19.4**	**-19.1**	**-25.3**	**-21.2**	**-23.4**	**-22.9**	**-20.9**	**-24.7**	**-24.3**	**-24.0**	**-25.5**	**-28.4**	**-32.9**
Net CO_2 emissions / removals	-20.1	-19.6	-21.9	-22.1	-28.9	-24.2	-27.0	-27.3	-25.2	-28.2	-28.1	-28.0	-29.2	-31.8	-36.0
CH_4 (without LULUCF)	**-45.3**	**-48.6**	**-50.5**	**-51.5**	**-53.6**	**-54.7**	**-55.8**	**-55.6**	**-56.3**	**-57.5**	**-57.8**	**-59.1**	**-59.8**	**-61.5**	**-63.6**
N_2O (without LULUCF)	**-35.3**	**-36.6**	**-31.5**	**-33.7**	**-33.0**	**-46.8**	**-46.7**	**-46.5**	**-46.2**	**-45.3**	**-45.4**	**-45.7**	**-46.6**	**-48.8**	**-50.2**
F gases, total	**-15.3**	**-15.5**	**-14.9**	**-15.0**	**-12.4**	**-14.5**	**-13.4**	**-12.3**	**-12.1**	**-12.1**	**-9.4**	**-8.8**	**-8.2**	**-13.4**	**-17.5**
Total emissions, without LULUCF	**-21.3**	**-20.7**	**-22.9**	**-22.9**	**-28.2**	**-25.5**	**-27.5**	**-27.0**	**-25.4**	**-28.6**	**-28.3**	**-28.2**	**-29.5**	**-32.4**	**-36.5**
Total emissions / removals, with LULUCF	-22.9	-22.9	-24.7	-25.1	-31.0	-27.8	-30.2	-30.4	-28.7	-31.3	-31.2	-31.3	-32.3	-34.9	-38.8
Total emissions, without LULUCF, with respect to base year*	*-21.5*	*-21.0*	*-23.1*	*-23.1*	*-28.4*	*-25.7*	*-27.7*	*-27.2*	*-25.6*	*-28.8*	*-28.5*	*-28.4*	*-29.7*	*-32.6*	*-36.7*
NO_X	**-43.2**	**-42.7**	**-44.3**	**-46.3**	**-49.5**	**-48.8**	**-49.5**	**-49.7**	**-49.6**	**-51.1**	**-52.0**	**-53.2**	**-55.2**	**-58.3**	**-61.2**
SO_2	**-91.3**	**-91.3**	**-91.6**	**-91.8**	**-92.8**	**-92.6**	**-92.9**	**-93.2**	**-93.5**	**-93.9**	**-93.9**	**-94.3**	**-94.5**	**-94.7**	**-95.2**
NMVOC	**-62.3**	**-62.4**	**-64.0**	**-65.5**	**-68.4**	**-65.5**	**-67.7**	**-68.2**	**-69.3**	**-70.3**	**-71.0**	**-71.2**	**-71.1**	**-72.3**	**-73.0**
CO	**-71.1**	**-71.3**	**-71.6**	**-71.8**	**-75.9**	**-73.5**	**-74.1**	**-76.0**	**-76.3**	**-77.5**	**-76.8**	**-77.7**	**-77.7**	**-78.6**	**-79.4**

Emissions trend Trend with respect to 1990/1995 (%)	2020	2021
CO_2 emissions (without LULUCF)	**-38.6**	**-35.6**
Net CO_2 emissions / removals	-40.6	-37.7
CH_4 (without LULUCF)	**-64.5**	**-65.5**
N_2O (without LULUCF)	**-51.7**	**-52.0**
F gases, total	**-27.0**	**-30.7**
Total emissions, without LULUCF	**-41.6**	**-39.2**
Total emissions / removals, with LULUCF	-42.9	-40.6
Total emissions, without LULUCF, with respect to base year*	*-41.8*	*-39.4*
NO_x	**-65.8**	**-66.1**
SO_2	**-95.6**	**-95.3**
NMVOC	**-74.0**	**-73.6**
CO	**-81.6**	**-80.6**

* 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 525: 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**	**-4.7**	**-1.0**	**-1.7**	**-0.3**	**+2.1**	**-2.9**	**-0.9**	**-3.0**	**+0.4**	**+1.8**	**-1.8**	**+0.1**	**-1.6**
Net CO_2 emissions / removals		-9.1	-5.7	-1.2	-1.2	+0.3	+2.9	-2.9	-0.9	-3.6	+2.7	+0.7	+1.7	-0.5	-2.1
CH_4 (without LULUCF)		**-4.8**	**-3.2**	**+0.6**	**-3.6**	**-2.4**	**-2.7**	**-4.6**	**-5.2**	**-1.2**	**-4.5**	**-4.3**	**-5.1**	**-4.6**	**-8.1**
N_2O (without LULUCF)		**-2.9**	**+3.0**	**-5.0**	**+3.5**	**-3.2**	**+2.8**	**-5.2**	**-23.9**	**-9.5**	**-1.5**	**+5.6**	**-2.2**	**-0.6**	**+4.4**
F gases, total							**-5.1**	**+1.4**	**+3.1**	**-10.7**	**-10.3**	**+5.3**	**+0.2**	**-3.5**	**+3.2**
Total emissions, without LULUCF		**-3.7**	**-4.1**	**-0.8**	**-1.6**	**-0.6**	**+1.5**	**-3.1**	**-2.2**	**-3.2**	**-0.3**	**+1.4**	**-2.1**	**-0.4**	**-1.9**
Total emissions / removals, with LULUCF		-8.3	-4.9	-0.9	-1.2	-0.1	+2.2	-3.1	-2.3	-3.6	+1.7	+0.5	+1.0	-0.8	-2.3
NO_x		**-8.0**	**-5.7**	**-4.3**	**-5.6**	**-2.7**	**-3.9**	**-3.6**	**-1.5**	**-1.9**	**-4.0**	**-3.0**	**-3.3**	**-2.4**	**-2.6**
SO_2		**-27.5**	**-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		**-13.2**	**-9.4**	**-6.1**	**-14.5**	**-5.3**	**-4.2**	**-2.5**	**-2.7**	**-7.7**	**-8.5**	**-5.3**	**-5.4**	**-5.1**	**-0.3**
CO		**-17.0**	**-13.8**	**-9.6**	**-12.0**	**-4.9**	**-7.9**	**-3.7**	**-8.0**	**-7.0**	**-6.2**	**-3.9**	**-6.1**	**-7.1**	**-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**	**+1.4**	**-3.1**	**+0.3**	**-7.6**	**+5.4**	**-2.8**	**+0.6**	**+2.6**	**-4.7**	**+0.4**	**+0.5**	**-2.0**	**-4.0**	**-6.3**
Net CO_2 emissions / removals	-2.7	+0.6	-2.8	-0.3	-8.7	+6.5	-3.6	-0.4	+2.8	-3.9	+0.1	+0.1	-1.6	-3.7	-6.3
CH_4 (without LULUCF)	**-5.1**	**-6.1**	**-3.7**	**-2.1**	**-4.4**	**-2.2**	**-2.6**	**+0.6**	**-1.7**	**-2.6**	**-0.8**	**-3.1**	**-1.5**	**-4.2**	**-5.6**
N_2O (without LULUCF)	**-4.1**	**-2.0**	**+8.0**	**-3.2**	**+1.0**	**-20.5**	**+0.0**	**+0.5**	**+0.5**	**+1.7**	**-0.2**	**-0.5**	**-1.7**	**-4.2**	**-2.7**
F gases, total	**+1.5**	**-0.3**	**+0.7**	**-0.1**	**+3.0**	**-2.3**	**+1.3**	**+1.3**	**+0.2**	**+0.0**	**+3.1**	**+0.7**	**+0.6**	**-5.6**	**-4.8**
Total emissions, without LULUCF	**-2.5**	**+0.7**	**-2.7**	**+0.0**	**-6.9**	**+3.8**	**-2.7**	**+0.6**	**+2.2**	**-4.3**	**+0.4**	**+0.2**	**-1.9**	**-4.0**	**-6.1**
Total emissions / removals, with LULUCF	-2.9	-0.0	-2.4	-0.5	-7.8	+4.7	-3.3	-0.3	+2.4	-3.6	+0.1	-0.1	-1.6	-3.7	-6.0
NO_x	**-2.9**	**+0.9**	**-2.8**	**-3.5**	**-5.9**	**+1.3**	**-1.4**	**-0.4**	**+0.2**	**-3.0**	**-1.8**	**-2.5**	**-4.2**	**-6.9**	**-7.1**
SO_2	**-3.8**	**+0.2**	**-3.6**	**-1.3**	**-12.8**	**+2.6**	**-3.9**	**-4.8**	**-3.2**	**-6.0**	**-0.5**	**-7.3**	**-2.8**	**-3.8**	**-10.2**
NMVOC	**-3.1**	**-0.3**	**-4.2**	**-4.4**	**-8.3**	**+9.3**	**-6.6**	**-1.3**	**-3.6**	**-3.2**	**-2.3**	**-0.6**	**+0.3**	**-4.1**	**-2.7**
CO	**-5.6**	**-0.8**	**-1.1**	**-0.6**	**-14.4**	**+9.6**	**-2.3**	**-7.3**	**-1.2**	**-5.3**	**+3.4**	**-4.1**	**+0.3**	**-4.0**	**-3.7**

Emissions trend Emissions trend with respect to the previous year in each case (%)	2020	
CO_2 emissions (without LULUCF)	**-8.5**	**+4.9**
Net CO_2 emissions / removals	-7.1	+4.9
CH_4 (without LULUCF)	**-2.5**	**-2.9**
N_2O (without LULUCF)	**-2.9**	**-0.6**
F gases, total	**-11.5**	**-5.1**
Total emissions, without LULUCF	**-8.0**	**+4.0**
Total emissions / removals, with LULUCF	-6.7	+4.0
NO_x	**-11.8**	**-0.9**
SO_2	**-7.4**	**+5.4**
NMVOC	**-3.5**	**+1.5**
CO	**-11.0**	**+5.4**

Table 526: 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		-3.5%	-8.2%	-9.1%	-11.2%	-11.6%	-9.7%	-12.7%	-13.7%	-16.1%	-16.4%	-14.6%	-16.1%	-16.6%	-18.3%	-20.2%	-19.3%	-21.9%	-21.4%	-27.0%
2. Industrial processes		-3.9%	-4.0%	-2.6%	3.3%	1.6%	-0.4%	0.2%	-13.1%	-21.3%	-17.8%	-21.7%	-23.3%	-19.1%	-17.2%	-20.5%	-20.3%	-19.3%	-23.2%	-31.3%
3. Agriculture		-9.6%	-11.6%	-12.8%	-13.0%	-13.0%	-12.3%	-13.6%	-13.0%	-12.8%	-13.6%	-12.6%	-15.7%	-16.5%	-17.7%	-17.9%	-19.4%	-18.7%	-18.2%	-17.7%
5. Waste		3.4%	4.5%	3.5%	0.7%	-2.6%	-7.2%	-15.5%	-21.8%	-26.8%	-31.4%	-36.4%	-40.6%	-44.9%	-51.2%	-55.2%	-60.2%	-63.9%	-67.3%	-70.6%

Emissions change with respect to 1990 (%)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Energy	-23.4%	-25.7%	-25.0%	-23.0%	-26.9%	-26.5%	-26.4%	-28.3%	-31.2%	-35.7%	-41.3%	-38.5%
2. Industrial processes	-33.7%	-33.7%	-34.6%	-34.8%	-34.9%	-36.0%	-34.0%	-29.8%	-32.9%	-36.1%	-40.9%	-38.7%
3. Agriculture	-18.3%	-18.2%	-17.3%	-16.2%	-14.5%	-14.7%	-15.3%	-16.2%	-18.4%	-19.4%	-20.8%	-22.4%
5. Waste	-73.7%	-75.8%	-77.8%	-79.7%	-81.1%	-82.6%	-83.9%	-84.8%	-85.7%	-87.0%	-88.1%	-89.1%

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		-3.5%	-4.8%	-1.0%	-2.4%	-0.5%	2.2%	-3.4%	-1.1%	-2.8%	-0.4%	2.2%	-1.8%	-0.6%	-2.0%	-2.4%	1.2%	-3.2%	0.6%	-7.1%
2. Industrial processes		-3.9%	0.0%	1.4%	6.1%	-1.6%	-2.0%	0.6%	-13.3%	-9.4%	4.4%	-4.7%	-2.1%	5.6%	2.3%	-4.0%	0.3%	1.2%	-4.8%	-10.5%
3. Agriculture		-9.6%	-2.2%	-1.4%	-0.2%	0.0%	0.9%	-1.5%	0.7%	0.3%	-1.0%	1.2%	-3.5%	-0.9%	-1.4%	-0.3%	-1.9%	1.0%	0.6%	0.6%
5. Waste		3.4%	1.1%	-1.0%	-2.7%	-3.3%	-4.7%	-9.0%	-7.5%	-6.4%	-6.4%	-7.2%	-6.6%	-7.3%	-11.4%	-8.3%	-11.2%	-9.2%	-9.3%	-10.2%

Emissions change, in each case with respect to the previous year; change in %	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Energy	5.0%	-3.0%	0.9%	2.6%	-5.1%	0.7%	0.1%	-2.6%	-4.1%	-6.6%	-8.6%	4.7%
2. Industrial processes	-3.4%	-0.1%	-1.4%	-0.3%	-0.1%	-1.6%	3.0%	6.4%	-4.4%	-4.8%	-7.4%	3.7%
3. Agriculture	-0.7%	0.1%	1.1%	1.3%	2.1%	-0.2%	-0.7%	-1.1%	-2.6%	-1.2%	-1.7%	-2.1%
5. Waste	-10.3%	-8.0%	-8.2%	-8.6%	-7.2%	-7.8%	-7.2%	-5.6%	-6.1%	-8.8%	-8.8%	-8.3%

19.4 Recalculations: detailed consideration on the basis of CRF Table 8 (GWP IPCC AR 4)

The following tables provide a numerical overview of the revised emissions figures for the years 1990 and 2020, pursuant to CRF tables 8s1 through 8s4 of the current CRF submission. The explanatory remarks regarding the recalculations shown are provided in Chapter 10.1 of the present report and in the relevant category-specific chapters.

19.4.1 Overview for report year 1990

Table 527: Revised carbon dioxide emissions, 1990 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
	[kt]			[%]		
National total emissions and removals	**1,076,569.85**	**1,083,500.88**	**6,931.03**	**0.644**	**0.557**	**0.542**
1. Energy	**989,092.98**	**991,906.29**	**2,813.30**	**0.284**	**0.226**	**0.220**
A. Combustion of fuels	985,252.52	988,065.64	2,813.11	0.286	0.226	0.220
1. Energy generation	423,905.78	427,842.82	3,937.04	0.929	0.316	0.308
2. Manufacturing	185,165.00	184,187.46	-977.54	-0.528	-0.079	-0.076
3. Transport	161,503.89	161,352.10	-151.79	-0.094	-0.012	-0.012
4. Other sectors	202,924.95	202,918.64	-6.31	-0.003	-0.001	0.000
5. Other	11,752.90	11,764.62	11.72	0.100	0.001	0.001
B. Fugitive emissions from fuels	3,840.46	3,840.65	0.19	0.005	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	2,007.85	0.19	0.009	0.000	0.000
2. Industrial processes & product use	**59,694.09**	**59,642.33**	**-51.76**	**-0.087**	**-0.0042**	**-0.0040**
A. Mineral industry	23,522.38	23,522.38	0.00	0.000	0.000	0.000
B. Chemical industry	8,109.38	8,057.63	-51.75	-0.638	-0.004	-0.004
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	2,982.45	2,982.44	-0.01	-0.001	0.000	0.000
3. Agriculture	**3,192.03**	**3,192.03**	**0.00**	**0.000**	**0.000**	**0.000**
4. Land use, land-use changes, forestry	**24,590.75**	**28,760.24**	**4,169.49**	**16.956**		**0.326**
A. Forest land	-19,707.07	-18,696.50	1,010.57	-5.128		0.079
B. Cropland	13,762.36	14,722.32	959.96	6.975		0.075
C. Grassland	26,383.49	29,121.21	2,737.71	10.377		0.214
D. Wetlands	3,705.75	3,692.17	-13.58	-0.366		-0.001
E. Settlements	1,776.57	1,251.39	-525.17	-29.561		-0.041
G. Harvested wood products	-1,330.35	-1,330.35	0.00	0.000		0.000
5. Waste & wastewater	**NO,NE,NA**	**NO,NE,NA**				
6. Other	**NA**	**NA**				
Reported only as memo items:						
International transports	**19,032.74**	**18,990.05**	**-42.70**	**-0.224**	**-0.003**	**-0.003**
International air transports	11,922.23	12,072.65	150.42	1.262	0.012	0.012
International sea transports	7,110.51	6,917.39	-193.12	-2.716	-0.016	-0.015
Multilateral operations	IE, NE	NE				
CO_2 from biomass	22,101.38	22,101.38	0.00	0.000	0.000	0.000

Table 528: Revised methane emissions, 1990 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
	[kt CO_2-eq.]				[%]	
National total emissions and removals	**119,996.41**	**124,049.81**	**4,053.39**	**3.38**	**0.326**	**0.317**
1. Energy	**40,382.00**	**41,182.08**	**800.08**	**1.98**	**0.064**	**0.063**
A. Combustion of fuels	6,587.64	6,645.37	57.73	0.88	0.005	0.005
1. Energy generation	280.21	280.21	0.00	0.00	0.000	0.000
2. Manufacturing	251.63	252.13	0.50	0.20	0.000	0.000
3. Transport	1,588.62	1,645.90	57.28	3.61	0.005	0.004
4. Other sectors	4,187.75	4,187.70	-0.05	0.00	0.000	0.000
5. Other	279.42	279.42	0.00	0.00	0.000	0.000
B. Fugitive emissions from fuels	33,794.37	34,536.72	742.35	2.20	0.060	0.058
1. Solid fuels	25,553.44	25,553.44	0.00	0.00	0.000	0.000
2. Oil and natural gas	8,240.93	8,983.28	742.35	9.01	0.060	0.058
2. Industrial processes & product use	**351.46**	**410.97**	**59.51**	**16.93**	**0.005**	**0.005**
3. Agriculture	**40,964.31**	**40,972.80**	**8.49**	**0.02**	**0.001**	**0.001**
A. Enteric fermentation	33,161.69	33,161.70	0.00	0.00	0.000	0.000
B. Manure management	7,802.34	7,810.83	8.49	0.11	0.001	0.001
J. Other	0.28	0.28	0.00	0.00	0.000	0.000
4. Land use, land-use change and forestry	**1,441.09**	**5,651.95**	**4,210.86**	**292.20**		**0.329**
A. Forest land	39.47	30.70	-8.77	-22.21		-0.001
B. Cropland	145.74	97.74	-48.00	-32.94		-0.004
C. Grassland	872.79	751.46	-121.32	-13.90		-0.009
D. Wetlands	335.07	4,755.24	4,420.18	1319.20		0.345
E. Settlements	48.03	16.80	-31.23	-65.01		-0.002
5. Waste & wastewater	**36,798.04**	**35,832.00**	**-966.04**	**-2.63**	**-0.078**	**-0.075**
A. Landfilling of solid waste	34,200.20	33,206.48	-993.72	-2.91	-0.080	-0.078
B. Biological treatment of solid waste	25.34	53.03	27.69	109.25	0.002	0.002
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	6.97	6.64	-0.33	-4.67	0.000	0.000
International air transports	5.00	4.67	-0.33	-6.52	0.000	0.000
International sea transports	1.97	1.97	0.00	0.00	0.000	0.000
Multilateral operations	IE, NE	**IE, NE**				

Table 529: Revised nitrous oxide emissions, 1990 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
	[kt CO_2-eq.]				[%]	
National total emissions and removals	**58,960.11**	**58,969.76**	**9.65**	**0.02**	**0.001**	**0.001**
1. Energy	**6,968.73**	**6,889.08**	**-79.65**	**-1.14**	**-0.006**	**-0.006**
A. Combustion of fuels	6,966.37	6,886.80	-79.57	-1.14	-0.006	-0.006
1. Energy generation	3,167.08	3,167.08	0.00	0.00	0.000	0.000
2. Manufacturing	1,350.36	1,352.50	2.15	0.16	0.000	0.000
3. Transport	1,410.78	1,329.15	-81.63	-5.79	-0.007	-0.006
4. Other sectors	977.26	977.18	-0.08	-0.01	0.000	0.000
5. Other	60.89	60.89	0.00	0.00	0.000	0.000
B. Fugitive emissions from fuels	2.36	2.28	-0.09	-3.60	0.000	0.000
2. Oil and natural gas	2.36	2.28	-0.09	-3.60	0.000	0.000
2. Industrial processes & product use	**23,390.92**	**23,390.92**	**0.00**	**0.00**	**0.000**	**0.000**
3. Agriculture	**26,424.71**	**26,483.16**	**58.45**	**0.22**	**0.005**	**0.005**
B. Manure management	3,656.06	3,611.05	-45.01	-1.23	-0.004	-0.004
D. Agricultural soils	22,768.53	22,871.98	103.46	0.45	0.008	0.008
J. Other	0.12	0.12	0.00	0.00	0.000	0.000

	Submission 2022	Submission 2023	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
	[kt CO_2-eq.]				[%]	
4. Land use, land-use change and forestry	**970.73**	**995.43**	**24.70**	**2.54**		**0.002**
A. Forest land	443.53	488.31	44.78	10.10		0.003
B. Cropland	190.82	191.26	0.43	0.23		0.000
C. Grassland	65.22	69.71	4.49	6.88		0.000
D. Wetlands	34.10	33.94	-0.15	-0.45		0.000
E. Settlements	20.36	26.92	6.56	32.20		0.001
H. Other	146.00	105.04	-40.96	-28.05		-0.003
5. Waste & wastewater	**1,205.02**	**1,211.18**	**6.16**	**0.51**	**0.000**	**0.000**
B. Biological treatment of solid waste	15.97	22.12	6.16	38.56	0.000	0.000
D. Wastewater treatment	1,189.05	1,189.05	0.00	0.00	0.000	0.000
6. Other	**NA**	**NA**				
Reported only as memo items:						
International transports	204.70	206.19	1.49	0.73	0.000	0.000
International air transports	112.65	114.14	1.49	1.32	0.000	0.000
International sea transports	92.05	92.05	0.00	0.00	0.000	0.000
Multilateral operations	**IE, NE**	**IE, NE**				
Indirect N_2O	**NO,IE**	**NE,IE**				

Table 530: Revised HFC emissions, 1990 (GWP IPCC AR 4)

	Submission 2023	Submission 2023	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**

Table 531: Revised PFC emissions, 1990 (GWP IPCC AR 4)

	Submission 2023	Submission 2023	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
	[kt CO_2-eq.]				[%]	
Total national emissions	**3,060.23**	**3,060.23**	**0.00**	**0.000**	**0.000**	**0.000**

Table 532: Revised SF_6 emissions, 1990 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	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**	**0.000**	**0.000**	**0.000**

Table 533: Revised *unspecified-mix* emissions, 1990 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	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**	**0.000**	**0.000**	**0.000**

Table 534: Revised NF_3 emissions, 1990 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	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**

19.4.2 Overview for report year 2020

Table 535: Revised carbon dioxide emissions, 2020 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
	[kt CO_2-eq.]			[%]		
National total emissions and removals	**624,730.54**	**643,741.66**	**19,011.12**	**3.04**	**2.606**	**2.593**
1. Energy	**594,884.82**	**602,585.74**	**7,700.92**	**1.29**	1.056	1.050
A. Combustion of fuels	593,069.88	600,779.46	7,709.58	1.30	1.057	1.052
1. Energy generation	208,312.43	208,824.61	512.18	0.25	0.070	0.070
2. Manufacturing	115,336.65	119,509.43	4,172.78	3.62	0.572	0.569
3. Transport	145,263.81	144,567.77	-696.05	-0.48	-0.095	-0.095
4. Other sectors	123,413.66	127,134.90	3,721.24	3.02	0.510	0.508
5. Other	743.34	742.76	-0.58	-0.08	0.000	0.000
B. Fugitive emissions from fuels	1,814.93	1,806.28	-8.66	-0.48	-0.001	-0.001
1. Solid fuels	629.55	631.77	2.22	0.35	0.000	0.000
2. Oil and natural gas	1,185.39	1,174.51	-10.88	-0.92	-0.001	-0.001
C. Transport and storage of CO_2	NA	NA				
2. Industrial processes & product use	**41,886.59**	**42,038.09**	**151.50**	**0.36**	**0.021**	**0.021**
A. Mineral industry	19,043.42	19,201.70	158.28	0.83	0.022	0.022
B. Chemical industry	5,291.40	5,380.59	89.19	1.69	0.012	0.012
C. Metal production	15,625.10	15,528.69	-96.41	-0.62	-0.013	-0.013
D. Non-energy-related fuel use & solvent use	1,926.68	1,927.12	0.44	0.02	0.000	0.000
3. Agriculture	**2,609.60**	**2,628.50**	**18.90**	**0.72**	**0.003**	**0.003**
G. Liming	1,963.28	2,009.78	46.50	2.37	0.006	0.006
H. Urea application	456.65	433.27	-23.38	-5.12	-0.003	-0.003
I. Other C-containing fertilisers	189.68	185.46	-4.22	-2.22	-0.001	-0.001
4. Land use, land-use change and forestry	**-14,650.47**	**-3,510.67**	**11,139.80**	**-76.04**		**1.519**
A. Forest land	-46,252.00	-39,243.83	7,008.17	-15.15		0.956
B. Cropland	16,656.04	15,238.27	-1,417.77	-8.51		-0.193
C. Grassland	18,068.74	24,470.65	6,401.91	35.43		0.873
D. Wetlands	4,452.15	4,329.29	-122.86	-2.76		-0.017
E. Settlements	1,075.87	346.22	-729.64	-67.82		-0.100
G. Harvested wood products	-8,651.28	-8,651.28	0.00	0.00		0.000
5. Waste & wastewater	**NO,NE,NA**	**NO,NE,NA**				
6. Other	**NO**	**NA**				
Reported only as memo items:						
International transports	**17,220.91**	**17,209.51**	**-11.40**	**-0.07**	**-0.002**	**-0.002**
International air transports	13,622.91	13,691.24	68.32	0.50	0.009	0.009
International sea transports	3,598.00	3,518.27	-79.73	-2.22	-0.011	-0.011
Multilateral operations	IE, NE	IE, NE				
CO_2 from biomass	107,259.95	106,438.90	-821.05	-0.77	-0.113	-0.112
collected CO_2	**NO**	**NO**				
Long-term C storage in landfills	**NA**	**NA**				
Indirect CO_2	**NO,NE,IE**	**NO,NE,IE**				

Table 536: Revised methane emissions, 2020 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
	[kt CO_2-eq.]			[%]		
National total emissions and removals	**50,888.63**	**47,868.60**	**-3,020.03**	**-5.93**	**-0.414**	**-0.412**
1. Energy	8,803.55	5,933.66	-2,869.89	-32.60	-0.393	-0.391
A. Combustion of fuels	3,884.36	3,992.50	108.14	2.78	0.015	0.015
1. Energy generation	2,355.68	2,457.82	102.14	4.34	0.014	0.014
2. Manufacturing	271.95	279.33	7.38	2.71	0.001	0.001
3. Transport	214.71	219.72	5.01	2.33	0.001	0.001
4. Other sectors	1,040.69	1,034.25	-6.43	-0.62	-0.001	-0.001
5. Other	1.33	1.38	0.05	3.75	0.000	0.000
B. Fugitive emissions from fuels	4,919.18	1,941.16	-2,978.02	-60.54	-0.408	-0.406
1. Solid fuels	136.68	136.77	0.09	0.06	0.000	0.000
2. Oil and natural gas	4,782.50	1,804.39	-2,978.11	-62.27	-0.408	-0.406

	Submission 2022	Submission 2023	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
	[kt CO_2-eq.]				[%]	
2. Industrial processes & product use	**592.21**	**592.25**	**0.03**	**0.01**	**0.000**	**0.000**
B. Chemical industry	562.90	562.90	0.00	0.00	0.000	0.000
C. Metal production	5.98	5.99	0.01	0.21	0.000	0.000
G. Other product use	23.33	23.35	0.02	0.08	0.000	0.000
3. Agriculture	**31,651.05**	**31,635.00**	**-16.05**	**-0.05**	**-0.002**	**-0.002**
A. Enteric fermentation	23,867.42	23,846.96	-20.47	-0.09	-0.003	-0.003
B. Manure management	6,470.71	6,448.58	-22.13	-0.34	-0.003	-0.003
J. Other	1,312.93	1,339.47	26.55	2.02	0.004	0.004
4. Land use, land-use change and forestry	**1,873.29**	**5,858.42**	**3,985.13**	**212.73**		**0.544**
A. Forest land	35.87	25.08	-10.79	-30.09		-0.001
B. Cropland	125.81	85.22	-40.59	-32.26		-0.006
C. Grassland	962.64	831.60	-131.05	-13.61		-0.018
D. Wetlands	683.70	4,891.68	4,207.98	615.47		0.574
E. Settlements	65.27	24.85	-40.42	-61.93		-0.006
5. Waste & wastewater	**7,968.53**	**3,849.28**	**-4,119.25**	**-51.69**	**-0.565**	**-0.562**
A. Landfilling of solid waste	6,769.63	2,654.55	-4,115.08	-60.79	-0.564	-0.561
B. Biological treatment of solid waste	713.72	709.57	-4.15	-0.58	-0.001	-0.001
C. Waste incineration	482.76	482.76	0.00	0.00	0.000	0.000
E. Other	2.43	2.40	-0.03	-1.04	0.000	0.000
6. Other	**NO**	**NA**				
Reported only as memo items:						
International transports	**2.65**	**2.55**	**-0.10**	**-3.61**	**0.000**	**0.000**
International air transports	1.76	1.64	-0.12	-6.62	0.000	0.000
International sea transports	0.89	0.91	0.02	2.34	0.000	0.000
Multilateral operations	IE, NE	IE, NE				

Table 537: Revised nitrous oxide emissions, 2020 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions *Without LULUCF*	*including LULUCF*
	[kt CO_2-eq.]				[%]	
Total national emissions	**29,694.28**	**29,314.69**	**-379.59**	**-1.28**	**-0.052**	**-0.052**
1. Energy	4,711.05	4,608.35	-102.70	-2.18	-0.014	-0.014
A. Combustion of fuels	4,710.11	4,607.41	-102.70	-2.18	-0.014	-0.014
1. Energy generation	1,807.39	1,790.08	-17.31	-0.96	-0.002	-0.002
2. Manufacturing	779.73	827.09	47.37	6.08	0.006	0.006
3. Transport	1,672.96	1,533.30	-139.66	-8.35	-0.019	-0.019
4. Other sectors	446.85	453.65	6.80	1.52	0.001	0.001
5. Other	3.18	3.28	0.10	3.19	0.000	0.000
B. Fugitive emissions from fuels	0.94	0.94	0.00	0.31	0.000	0.000
2. Oil and natural gas	0.94	0.94	0.00	0.31	0.000	0.000
2. Industrial processes & product use	**834.75**	**834.75**	**0.00**	**0.00**	**0.000**	**0.000**
3. Agriculture	**21,834.42**	**21,919.50**	**85.08**	**0.39**	**0.012**	**0.012**
B. Manure management	2,908.44	2,756.52	-151.92	-5.22	-0.021	-0.021
D. Agricultural soils	18,673.22	18,907.30	234.08	1.25	0.032	0.032
J. Other	252.76	255.69	2.92	1.16	0.000	0.000
4. Land use, land-use changes, forestry	**1,512.14**	**1,288.80**	**-223.34**	**-14.77**		**-0.030**
A. Forest land	372.55	470.22	97.67	26.22		0.013
B. Cropland	527.05	372.66	-154.39	-29.29		-0.021
C. Grassland	105.12	42.38	-62.74	-59.69		-0.009
D. Wetlands	42.36	42.63	0.27	0.63		0.000
E. Settlements	133.92	107.75	-26.17	-19.54		-0.004
H. Other	162.23	120.00	-42.23	-26.03		-0.006
5. Waste & wastewater	**801.92**	**663.28**	**-138.64**	**-17.29**	**-0.019**	**-0.019**
B. Biological treatment of solid waste	309.87	208.06	-101.81	-32.86	-0.014	-0.014
D. Wastewater treatment	458.48	422.00	-36.48	-7.96	-0.005	-0.005
E. Other	33.57	33.22	-0.35	-1.04	0.000	0.000
6. Other	**NO**	**NA**				

	Submission 2022	Submission 2023	Change		Impacts on total national emissions Without LULUCF	including LULUCF
	[kt CO_2-eq.]				[%]	
Reported as memo items:						
International transports	**176.23**	**176.94**	**0.72**	**0.41**	**0.000**	**0.000**
International air transports	128.46	129.18	0.72	0.56	0.000	0.000
International sea transports	47.77	47.77	0.00	0.00	0.000	0.000
Multilateral operations	**NE**	**NE**				
Indirect N_2O	**NO,IE**	**NE,IE**				

Table 538: Revised HFC emissions, 2020 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions Without LULUCF	including LULUCF
	[kt CO_2-eq.]				[%]	
Total national emissions	**8,792.42**	**8,840.96**	**48.54**	**0.55**	**0.007**	**0.007**
2.C.4. Magnesium production	8.26	8.26	0.00	0.00	0.000	0.000
2.E.1. Electronics industry	14.05	14.05	0.00	0.00	0.000	0.000
2.F.1. Air-conditioning and refrigeration systems	7,985.23	7,968.02	-17.21	-0.22	-0.002	-0.002
2.F.2. Foam production	324.10	389.93	65.83	20.31	0.009	0.009
2.F.3. Fire extinguishers	104.68	104.68	0.00	0.00	0.000	0.000
2.F.4. Aerosols	341.86	341.86	0.00	0.00	0.000	0.000
2.F.5. Solvents	IE	IE				
2.G.4. Other	14.24	14.15	-0.09	-0.62	0.000	0.000

Table 539: Revised PFC emissions, 2020 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions Without LULUCF	including LULUCF
	[kt CO_2-eq.]				[%]	
Total national emissions	**207.25**	**207.14**	**-0.11**	**-0.05**	**0.000**	**0.000**
2.C.3. Aluminium production	76.70	76.70	0.00	0.00	0.000	0.000
2.E.1. Electronics industry	126.60	126.60	0.00	0.00	0.000	0.000
2.F.1. Air-conditioning and refrigeration systems	3.95	3.84	-0.11	-2.74	0.000	0.000

Table 540: Revised SF_6 emissions, 2020 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions Without LULUCF	including LULUCF
	[kt CO_2-eq.]				[%]	
Total national emissions	**3,008.03**	**3,008.03**	**0.00**	**0.00**	**0.000**	**0.000**
2.B.9. Production of PFC & SF_6	0.89	0.89	0.00	0.00	0.000	0.000
2.C.4. Magnesium production	51.56	51.56	0.00	0.00	0.000	0.000
2.E.1. Electronics industry	27.18	27.18	0.00	0.00	0.000	0.000
2.G.1. Electrical equipments	218.86	218.86	0.00	0.00	0.000	0.000
2.G.2. SF_6 and PFC from other product use	2,709.54	2,709.54	0.00	0.00	0.000	0.000

Table 541: Revised *unspecified-mix* emissions, 2020 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions Without LULUCF	including LULUCF
	[kt CO_2-eq.]				[%]	
Total national emissions	**140.66**	**139.91**	**-0.74**	**-0.529**	**0.000**	**0.000**
2.B.9. Production of PFC & SF_6	44.70	44.70	0.00	0.000	0.000	0.000
2.H. Other	95.95	95.21	-0.74	-0.776	0.000	0.000

Table 542: Revised NF_3 emissions, 2020 (GWP IPCC AR 4)

	Submission 2022	Submission 2023	Change		Impacts on total national emissions	
					Without LULUCF	*including LULUCF*
	[kt CO_2-eq.]				[%]	
Total national emissions	**10.80**	**10.80**	**0.00**	**0.00**	**0.000**	**0.000**
2.E.1. Electronics industry	10.80	10.80	0.00	0.00	0.000	0.000

20 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, 2006b), in Table 543 and Table 544.

Table 543: Uncertainties by categories (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	$\mid\frac{D}{\sum C}\mid$	*I * F* Note C	*J * E ** Note D	$\sqrt{2}\,K^2+L^2$
		t CO_2 equivalent	t CO_2 equivalent	%	%	%		%	%	%	%	%
Sum	**GHG**	**1,290,897.4**	**764,356.4**			**3.22**						**3.63**
1 A 1 a, Public Electricity and Heat Production	CO_2	338,451.16	207,344.83	3.43	1.29	3.67	0.77	0.00	0.16	0.79	0.30	0.72
1 A 1 a, Public Electricity and Heat Production	CH_4	192.83	2,579.15	7.86	53.82	54.39	0.03	0.00	0.00	0.02	0.15	0.02
1 A 1 a, Public Electricity and Heat Production	N_2O	2,140.86	1,590.75	3.17	18.77	19.03	0.00	0.00	0.00	0.01	0.03	0.00
1 A 1 b, Petroleum Refining	CO_2	24,102.60	19,983.95	2.74	4.29	5.09	0.01	0.00	0.02	0.06	0.10	0.01
1 A 1 b, Petroleum Refining	CH_4	17.99	14.61	2.24	17.37	17.51	0.00	0.00	0.00	0.00	0.00	0.00
1 A 1 b, Petroleum Refining	N_2O	89.27	48.01	2.65	31.62	31.73	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	8,645.46	4.60	3.36	5.69	0.00	0.02	0.01	0.04	0.03	0.00
1 A 1 c, Manufacture of Solid Fuels and Other Energy	CH_4	103.02	139.83	22.87	114.33	116.59	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	586.23	114.02	5.73	22.65	23.36	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 a, Iron and steel	CO_2	35,269.33	37,835.23	4.61	3.28	5.65	0.06	0.01	0.03	0.19	0.14	0.06
1 A 2 a, Iron and steel	CH_4	69.95	78.31	8.06	23.95	25.27	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 a, Iron and steel	N_2O	137.93	101.52	4.85	35.48	35.81	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 b, Non-ferrous metals	CO_2	1,629.22	1,444.70	11.05	0.94	11.09	0.00	0.00	0.00	0.02	0.00	0.00
1 A 2 b, Non-ferrous metals	CH_4	1.55	1.79	11.16	69.68	70.57	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 b, Non-ferrous metals	N_2O	15.25	6.68	10.25	64.12	64.93	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 d, Pulp, Paper and Print	CO_2	3.65	10.78	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	0.73	2.69	3.96	42.43	42.62	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 d, Pulp, Paper and Print	N_2O	2.50	9.18	3.96	50.63	50.78	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	$\left\lvert\frac{D}{\sum C}\right\rvert$	*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 e, Food Processing, Beverages and Tobacco	CO_2	2,015.91	230.96	5.76	1.31	5.91	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 e, Food Processing, Beverages and Tobacco	CH_4	5.02	0.19	7.12	45.12	45.68	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 e, Food Processing, Beverages and Tobacco	N_2O	21.92	1.75	5.47	55.39	55.66	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 f, Non-Metallic Minerals	CO_2	18,507.38	12,149.78	3.69	0.90	3.79	0.00	0.00	0.01	0.05	0.01	0.00
1 A 2 f, Non-Metallic Minerals	CH_4	56.31	16.32	3.36	23.47	23.71	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 f, Non-Metallic Minerals	N_2O	182.53	98.74	2.86	27.63	27.78	0.00	0.00	0.00	0.00	0.00	0.00
1 A 2 g, Other	CO_2	126,761.98	73,315.62	0.00	3.54	3.54	0.09	0.01	0.06	0.00	0.29	0.08
1 A 2 g, Other	CH_4	148.81	237.51	3.11	30.28	30.44	0.00	0.00	0.00	0.00	0.01	0.00
1 A 2 g, Other	N_2O	842.61	530.01	2.96	14.62	14.92	0.00	0.00	0.00	0.00	0.01	0.00
1 A 3 a, Domestic Aviation	CO_2	2,263.44	732.35	6.67	3.67	7.61	0.00	0.00	0.00	0.01	0.00	0.00
1 A 3 a, Domestic Aviation	CH_4	2.82	1.67	19.76	75.54	78.08	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 a, Domestic Aviation	N_2O	20.27	6.60	0.00	21.45	21.45	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 b, Road Transport	CO_2	151,889.81	142,140.84	0.00	5.35	5.35	0.77	0.02	0.11	0.00	0.85	0.72
1 A 3 b, Road Transport	CH_4	1,812.75	231.45	6.96	10.51	12.61	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 b, Road Transport	N_2O	1,123.44	1,351.50	6.57	13.25	14.80	0.00	0.00	0.00	0.01	0.02	0.00
1 A 3 c, Railways	CO_2	3,122.15	853.29	0.00	10.05	10.05	0.00	0.00	0.00	0.00	0.01	0.00
1 A 3 c, Railways	CH_4	19.72	0.33	8.67	29.29	30.55	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 c, Railways	N_2O	6.81	1.89	8.84	65.66	66.26	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 d, Domestic Navigation	CO_2	2,993.44	1,449.85	25.24	2.07	25.33	0.00	0.00	0.00	0.04	0.00	0.00
1 A 3 d, Domestic Navigation	CH_4	2.17	5.61	5.61	133.58	133.70	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 d, Domestic Navigation	N_2O	18.56	10.84	12.54	98.82	99.61	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 e, Other Transportation	CO_2	1,083.27	836.22	2.75	0.92	2.90	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 e, Other Transportation	CH_4	5.95	4.59	2.75	68.73	68.78	0.00	0.00	0.00	0.00	0.00	0.00
1 A 3 e, Other Transportation	N_2O	12.88	6.44	2.87	47.88	47.97	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	$\sqrt{2K^2+L^2}$
		t CO_2 equivalent	t CO_2 equivalent	%	%	%		%	%	%	%	%
1 A 4 a, Commercial/Institutional	CO_2	64,110.78	33,306.72	0.00	8.29	8.29	0.10	0.00	0.03	0.00	0.31	0.10
1 A 4 a, Commercial/Institutional	CH_4	1,637.12	97.22	15.58	106.10	107.24	0.00	0.00	0.00	0.00	0.01	0.00
1 A 4 a, Commercial/Institutional	N_2O	131.10	91.96	6.96	75.05	75.37	0.00	0.00	0.00	0.00	0.01	0.00
1 A 4 b, Residential	CO_2	128,635.75	82,296.47	0.00	9.14	9.14	0.76	0.01	0.06	0.00	0.84	0.71
1 A 4 b, Residential	CH_4	2,782.86	991.02	14.60	136.28	137.06	0.02	0.00	0.00	0.02	0.15	0.02
1 A 4 b, Residential	N_2O	683.71	256.39	9.86	88.90	89.44	0.00	0.00	0.00	0.00	0.03	0.00
1 A 4 c, Agriculture/Forestry/Fishing	CO_2	10,172.11	6,082.93	0.00	12.88	12.88	0.01	0.00	0.00	0.00	0.09	0.01
1 A 4 c, Agriculture/Forestry/Fishing	CH_4	270.25	190.19	7.97	50.35	50.98	0.00	0.00	0.00	0.00	0.01	0.00
1 A 4 c, Agriculture/Forestry/Fishing	N_2O	54.15	60.34	13.24	93.86	94.78	0.00	0.00	0.00	0.00	0.01	0.00
1 A 5, Other: Military	CO_2	11,764.62	980.27	0.00	5.35	5.35	0.00	0.00	0.00	0.00	0.01	0.00
1 A 5, Other: Military	CH_4	312.95	2.00	4.38	46.78	46.98	0.00	0.00	0.00	0.00	0.00	0.00
1 A 5, Other: Military	N_2O	54.14	4.00	3.65	99.01	99.08	0.00	0.00	0.00	0.00	0.00	0.00
1 B 1, Solid Fuels	CO_2	1,832.80	634.18	0.00	35.96	35.96	0.00	0.00	0.00	0.00	0.03	0.00
1 B 1, Solid Fuels	CH_4	28,619.85	159.47	0.00	23.92	23.92	0.00	0.01	0.00	0.00	0.00	0.00
1 B 2 a, Oil	CO_2	477.63	406.35	0.00	24.92	24.92	0.00	0.00	0.00	0.00	0.01	0.00
1 B 2 a, Oil	CH_4	270.87	22.05	0.00	16.18	16.18	0.00	0.00	0.00	0.00	0.00	0.00
1 B 2 a, Oil	N_2O	0.28	0.22	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	986.70	492.29	0.00	22.31	22.31	0.00	0.00	0.00	0.00	0.01	0.00
1 B 2 b, Natural Gas	CH_4	9,788.56	1,811.35	0.00	23.47	23.47	0.00	0.00	0.00	0.00	0.05	0.00
1 B 2 c, Venting and Flaring	CO_2	543.52	298.20	0.00	145.68	145.68	0.00	0.00	0.00	0.00	0.05	0.00
1 B 2 c, Venting and Flaring	CH_4	1.85	0.59	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	1.74	0.60	0.00	68.06	68.06	0.00	0.00	0.00	0.00	0.00	0.00
2 A 1, Cement Production	CO_2	15,297.27	13,640.22	2.50	1.00	2.69	0.00	0.00	0.01	0.04	0.02	0.00
2 A 2, Lime Production	CO_2	5,986.62	4,524.94	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	916.91	3.13	11.48	11.90	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	816.37	6.68	10.93	12.81	0.00	0.00	0.00	0.01	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	%	%	%		%	%	%	%	%
2 B 1, Ammonia Production	CO_2	6,025.00	4,012.00	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	2,896.77	344.34	0.55	2.09	2.16	0.00	0.00	0.00	0.00	0.00	0.00
2 B 3, Adipic Acid Production	N_2O	16,074.90	66.27	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	5.88	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	615.50	457.81	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	861.57	11.17	13.97	17.89	0.00	0.00	0.00	0.01	0.01	0.00
2 B 8, Petrochemical and Carbon Black Production	CH_4	373.73	569.98	15.69	15.19	21.84	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	164.50	0.95	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
2 B 10, Other Chemical Industry	CH_4	66.65	65.04	0.00	38.73	38.73	0.00	0.00	0.00	0.00	0.00	0.00
2 B 10, Other Chemical Industry	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	16,418.95	0.00	9.35	9.35	0.03	0.00	0.01	0.00	0.17	0.03
2 C 1, Iron and Steel Production	CH_4	5.22	5.52	0.00	68.50	68.50	0.00	0.00	0.00	0.00	0.00	0.00
2 C 1, Iron and Steel Production	N_2O	23.60	11.92	8.46	70.39	70.90	0.00	0.00	0.00	0.00	0.00	0.00
2 C 2, Ferroalloys Production	CO_2	429.00	5.97	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	9.61	1.82	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	696.07	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	1,385.67	49.04	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	233.10	9.93	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	7.51	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	64.37	5.53	39.47	39.86	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 C 6, Zinc Production	CO_2	670.80	289.16	0.00	42.51	42.51	0.00	0.00	0.00	0.00	0.01	0.00
2 D 1, Lubricant Use	CO_2	188.63	198.33	0.00	17.72	17.72	0.00	0.00	0.00	0.00	0.00	0.00
2 D 2, Paraffin Wax Use	CO_2	242.70	502.29	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	0.62	1.28	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	1,328.78	0.00	9.21	9.21	0.00	0.00	0.00	0.00	0.01	0.00
2 E, Electronics Industry	SF_6	48.73	33.28	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	NF_3	4.95	13.72	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	HFC-23	14.34	12.34	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	0.04	0.00	17.00	17.00	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	CF_4	92.06	64.81	0.00	13.90	13.90	0.00	0.00	0.00	0.00	0.00	0.00
2 E, Electronics Industry	C_2F_6	147.83	43.89	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	14.14	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	5.79	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}	21.57	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	13.62	63.25	0.00	17.19	17.19	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	HFC-32	0.76	244.39	0.00	7.68	7.68	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	135.75	1,874.60	0.00	6.45	6.45	0.00	0.00	0.00	0.00	0.01	0.00
2 F, Product Uses as Substitutes for ODS	HFC-134a	2,062.03	4,216.88	0.00	5.64	5.64	0.00	0.00	0.00	0.00	0.03	0.00
2 F, Product Uses as Substitutes for ODS	HFC-143a	76.60	1,233.25	0.00	10.62	10.62	0.00	0.00	0.00	0.00	0.01	0.00
2 F, Product Uses as Substitutes for ODS	HFC-152a	100.24	23.55	0.00	4.41	4.41	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	HFC-227ea	0.67	81.41	0.00	3.68	3.68	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	9.35	9.35	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	8.97	8.97	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	2.43	0.00	21.33	21.33	0.00	0.00	0.00	0.00	0.00	0.00
2 F, Product Uses as Substitutes for ODS	C_3F_8	20.07	0.91	0.00	19.09	19.09	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	5.07	23.71	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	43.77	43.77	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	9.03	9.03	0.00	0.00	0.00	0.00	0.03	0.00
2 G, Other Product Manufacture and Use	HFC-134a	0.00	0.18	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	13.29	0.00	21.01	21.01	0.00	0.00	0.00	0.00	0.00	0.00
2 G, Other Product Manufacture and Use	HFC-365mfc	0.00	0.71	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	24.91	24.91	0.00	0.00	0.00	0.00	0.00	0.00
3 A, Enteric Fermentation	CH_4	19,844.44	15,114.31	4.00	20.00	20.40	0.13	0.00	0.01	0.07	0.34	0.12
3 A, Enteric Fermentation	CH_4	15,699.01	9,814.70	2.16	10.82	11.03	0.02	0.00	0.01	0.02	0.12	0.01
3 A, Enteric Fermentation	CH_4	1,597.65	1,212.25	3.56	12.51	13.01	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	2,468.76	2,494.33	4.00	20.00	20.40	0.00	0.00	0.00	0.01	0.06	0.00
3 B, Manure Management	CH_4	2,683.77	1,548.32	2.24	11.20	11.42	0.00	0.00	0.00	0.00	0.02	0.00
3 B, Manure Management	CH_4	3,426.57	2,621.87	3.26	16.29	16.62	0.00	0.00	0.00	0.01	0.05	0.00
3 B, Manure Management	CH_4	169.02	219.12	4.70	10.35	11.36	0.00	0.00	0.00	0.00	0.00	0.00
3 B, Manure Management	N_2O	849.94	623.56	4.00	100.00	100.08	0.01	0.00	0.00	0.00	0.07	0.00
3 B, Manure Management	N_2O	874.03	625.75	2.07	51.82	51.86	0.00	0.00	0.00	0.00	0.04	0.00
3 B, Manure Management	N_2O	356.42	286.02	3.10	77.39	77.45	0.00	0.00	0.00	0.00	0.02	0.00
3 B, Manure Management	N_2O	112.84	120.76	4.99	49.90	50.15	0.00	0.00	0.00	0.00	0.01	0.00
3 B, Manure Management	N_2O	1,017.94	716.42	39.99	399.94	401.93	0.11	0.00	0.00	0.03	0.32	0.10
3 D, Agricultural Soils	N_2O	20,339.18	16,619.88	32.08	70.57	77.52	2.22	0.00	0.01	0.60	1.31	2.07
3 G, Liming	CO_2	2,200.53	2,006.37	3.95	2.92	4.91	0.00	0.00	0.00	0.01	0.01	0.00
3 H, Urea Application	CO_2	481.05	399.48	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	182.16	3.00	3.00	4.24	0.00	0.00	0.00	0.00	0.00	0.00
3 J, Other	CH_4	0.31	1,500.21	10.00	20.00	22.36	0.00	0.00	0.00	0.02	0.03	0.00
3 J, Other	N_2O	0.11	227.37	9.52	97.10	97.57	0.00	0.00	0.00	0.00	0.02	0.00
4 A , Forest Land	CO_2	-18,696.50	-41,870.91	0.00	8.08	8.08	0.15	0.01	0.04	0.00	0.45	0.20
4 A , Forest Land	CH_4	34.39	26.65	0.00	97.35	97.35	0.00	0.00	0.00	0.00	0.00	0.00
4 A , Forest Land	N_2O	461.78	435.50	0.00	86.82	86.82	0.00	0.00	0.00	0.00	0.04	0.00
4 B, Cropland	CO_2	14,722.32	15,556.89	0.00	22.39	22.39	0.16	0.00	0.01	0.00	0.41	0.17
4 B, Cropland	CH_4	109.46	94.96	0.00	62.99	62.99	0.00	0.00	0.00	0.00	0.01	0.00
4 B, Cropland	N_2O	208.34	396.84	0.00	157.92	157.92	0.01	0.00	0.00	0.00	0.07	0.00
4 C, Grassland	CO_2	29,121.21	25,045.89	0.00	50.49	50.49	2.13	0.01	0.03	0.00	2.31	5.36
4 C, Grassland	CH_4	841.64	919.32	0.00	376.32	376.32	0.16	0.00	0.00	0.00	0.39	0.15
4 C, Grassland	N_2O	62.15	36.68	0.00	64.26	64.26	0.00	0.00	0.00	0.00	0.00	0.00
4 D, Wetlands	CO_2	3,692.17	4,713.81	0.00	29.26	29.26	0.03	0.00	0.00	0.00	0.17	0.03
4 D, Wetlands	CH_4	5,325.87	5,498.00	0.00	67.39	67.39	0.18	0.00	0.00	0.00	0.41	0.17
4 D, Wetlands	N_2O	30.18	39.01	0.00	167.86	167.86	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	1,251.39	1,472.89	0.00	16.62	16.62	0.00	0.00	0.01	0.00	0.15	0.02
4 E, Settlements	CH_4	18.82	28.40	0.00	52.35	52.35	0.00	0.00	0.00	0.00	0.00	0.00
4 E, Settlements	N_2O	122.73	255.78	0.00	118.34	118.34	0.00	0.00	0.00	0.00	0.03	0.00
4 G, Harvested Wood Products	CO_2	-1,330.35	-8,651.28	0.00	29.85	29.85	0.09	0.01	0.01	0.00	0.31	0.10
5 A, Solid Waste Disposal	CH_4	37,191.25	2,574.15	0.00	20.00	20.00	0.00	0.02	0.00	0.00	0.06	0.00
5 B, Biological Treatment of Solid Waste	CH_4	59.39	791.04	1.42	157.26	157.26	0.02	0.00	0.00	0.00	0.14	0.02
5 B, Biological Treatment of Solid Waste	N_2O	19.67	184.34	1.47	103.42	103.43	0.00	0.00	0.00	0.00	0.02	0.00
5 D 1, Domestic Wastewater	CH_4	2,870.84	486.96	3.15	23.98	24.19	0.00	0.00	0.00	0.00	0.01	0.00
5 D 1, Domestic Wastewater	N_2O	1,029.29	348.22	31.85	3,726.56	3,726.70	2.25	0.00	0.00	0.01	1.45	2.10
5 D 2, Industrial Wastewater	CH_4	10.36	53.83	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	28.09	23.84	50.00	310.00	314.01	0.00	0.00	0.00	0.00	0.01	0.00
5 E, Other	CH_4	0.00	2.64	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	29.02	2.00	20.00	20.10	0.00	0.00	0.00	0.00	0.00	0.00

Table 544: 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 2021**	**Activity data uncertainty**		**Emission factor uncertainty**		**Combined uncertainty**		**Contribution to variance 2021**		**Inventory trend in national emissions for 2021; increase with respect to base year**	
			t CO_2 equivalent	**t CO_2 equivalent**	**-%**	**+%**	**-%**	**+%**	**-%**	**+%**	**fraction**	**% of base year**	**-%**	**+%**
Sum		**GHG**	**1,290,897.43**	**764,356.41**					**2.93**	**3.26**		**-40.79**	**10.20**	**10.89**
1 A 1 a, Public Electricity and Heat Production	fossil fuels	CO_2	338,451.16	207,344.83	7.28	7.54	2.46	2.46	3.61	3.68	0.10	-38.74	12.50	13.13
1 A 1 a, Public Electricity and Heat Production		CH_4	192.83	2,579.15	26.45	41.72	47.41	112.58	28.54	38.30	0.00	1,237.54	47.39	63.81
1 A 1 a, Public Electricity and Heat Production		N_2O	2,140.86	1,590.75	24.62	23.33	50.15	44.99	21.81	22.06	0.00	-25.70	203.48	282.06
1 A 1 b, Petroleum Refining	fossil fuels	CO_2	24,102.60	19,983.95	10.71	11.33	9.29	10.54	4.96	5.11	0.00	-17.09	51.35	54.05
1 A 1 b, Petroleum Refining		CH_4	17.99	14.61	45.66	56.35	27.67	43.44	18.74	18.87	0.00	-18.82	133.70	163.40
1 A 1 b, Petroleum Refining		N_2O	89.27	48.01	61.71	53.32	34.60	36.03	35.04	35.12	0.00	-46.22	258.70	361.63
1 A 1 c, Manufacture of Solid Fuels and Other Energy	fossil fuels	CO_2	65,289.06	8,645.46	10.86	11.54	11.04	11.51	5.54	5.79	0.00	-86.76	2.09	2.16
1 A 1 c, Manufacture of Solid Fuels and Other Energy		CH_4	103.02	139.83	31.46	41.51	59.29	127.30	50.07	85.83	0.00	35.73	854,943.30	1,567,876.01
1 A 1 c, Manufacture of Solid Fuels and Other Energy		N_2O	586.23	114.02	16.03	18.08	49.51	62.51	26.83	27.58	0.00	-80.55	17.87	22.02
1 A 2 a, Iron and steel	fossil fuels	CO_2	35,269.33	37,835.23	13.47	14.94	10.29	10.86	5.33	5.70	0.01	7.28	53.70	56.95
1 A 2 a, Iron and steel		CH_4	69.95	78.31	12.18	11.32	30.77	34.20	24.29	24.61	0.00	11.96	227.80	313.40
1 A 2 a, Iron and steel		N_2O	137.93	101.52	44.88	39.60	72.24	91.99	38.33	38.57	0.00	-26.39	2,482.48	3,907.34
1 A 2 b, Non-ferrous metals	fossil fuels	CO_2	1,629.22	1,444.70	9.67	10.39	1.34	1.32	8.31	8.86	0.00	-11.33	23.55	25.10
1 A 2 b, Non-ferrous metals		CH_4	1.55	1.79	18.66	13.36	69.42	77.06	69.71	71.66	0.00	15.60	1,200.22	2,533.66
1 A 2 b, Non-ferrous metals		N_2O	15.25	6.68	31.72	19.84	57.06	53.30	64.45	66.51	0.00	-56.17	100.71	178.00
1 A 2 d, Pulp, Paper and Print	fossil fuels	CO_2	3.65	10.78	8.55	8.85	3.01	3.13	5.64	5.67	0.00	195.64	21.55	22.82
1 A 2 d, Pulp, Paper and Print		CH_4	0.73	2.69	43.91	43.73	54.58	65.70	47.49	47.69	0.00	267.79	94.33	136.22
1 A 2 d, Pulp, Paper and Print		N_2O	2.50	9.18	10.77	11.19	10.28	11.83	6.88	7.26	0.00	267.79	15.51	16.50
1 A 2 e, Food Processing, Beverages and Tobacco	fossil fuels	CO_2	2,015.91	230.96	11.24	12.84	3.30	3.59	4.21	4.34	0.00	-88.54	0.74	0.78
1 A 2 e, Food Processing, Beverages and Tobacco		CH_4	5.02	0.19	49.76	38.88	46.12	63.36	45.49	45.85	0.00	-96.27	5.09	7.98
1 A 2 e, Food Processing, Beverages and Tobacco		N_2O	21.92	1.75	27.47	43.20	60.78	74.53	42.39	46.71	0.00	-92.01	7.39	13.77
1 A 2 f, Non-Metallic Minerals	fossil fuels	CO_2	18,507.38	12,149.78	12.50	14.32	1.88	1.95	2.92	3.01	0.00	-34.35	8.67	8.89
1 A 2 f, Non-Metallic Minerals		CH_4	56.31	16.32	45.85	54.86	36.68	42.54	27.11	27.34	0.00	-71.03	162.08	217.26
1 A 2 f, Non-Metallic Minerals		N_2O	182.53	98.74	31.86	45.24	29.99	39.80	21.66	22.42	0.00	-45.91	68.42	105.34
1 A 2 g, Other	fossil fuels	CO_2	126,761.98	73,315.62	15.05	16.84	3.77	4.04	2.83	2.94	0.01	-42.16	20.08	20.69
1 A 2 g, Other		CH_4	148.81	237.51	41.03	51.54	66.67	159.05	18.34	22.43	0.00	59.60	72.86	90.87
1 A 2 g, Other		N_2O	842.61	530.01	40.93	48.78	31.44	30.03	13.01	13.24	0.00	-37.10	176.27	198.67

A1	A2	B	C	D	E-	E+	F-	F+	G-	G+	H	I	J-	J+
IPCC category	Qualifier	gas	Base year emissions or removals t CO_2 equivalent	Emissions or removals 2021 t CO_2 equivalent	Activity data uncertainty -%	+%	Emission factor uncertainty -%	+%	Combined uncertainty -%	+%	Contribution to variance 2021 fraction	% of base year	Inventory trend in national emissions for 2021; increase with respect to base year -%	+%
1 A 3 a, Domestic Aviation	fossil fuels	CO_2	2,263.44	732.35	12.10	12.50	4.79	5.09	7.51	7.69	0.00	-67.64	5.14	5.56
1 A 3 a, Domestic Aviation		CH_4	2.82	1.67	25.05	10.61	62.77	259.48	48.96	77.54	0.00	-40.62	297.17	563.85
1 A 3 a, Domestic Aviation		N_2O	20.27	6.60	16.33	19.11	20.79	21.99	21.13	21.78	0.00	-67.43	13.72	17.15
1 A 3 b, Road Transport	fossil fuels	CO_2	151,889.81	142,140.84	25.16	35.27	4.25	5.31	4.61	4.93	0.08	-6.42	46.66	48.46
1 A 3 b, Road Transport		CH_4	1,812.75	231.45	32.63	61.68	29.69	39.91	9.90	11.67	0.00	-87.23	6.98	7.99
1 A 3 b, Road Transport		N_2O	1,123.44	1,351.50	35.19	54.54	28.34	50.41	11.86	13.76	0.00	20.30	151.19	171.62
1 A 3 c, Railways	fossil fuels	CO_2	3,122.15	853.29	10.43	10.32	3.20	3.21	10.01	10.02	0.00	-72.67	7.11	7.89
1 A 3 c, Railways		CH_4	19.72	0.33	13.28	12.77	53.57	92.82	30.08	30.95	0.00	-98.34	1.01	1.32
1 A 3 c, Railways		N_2O	6.81	1.89	14.92	13.92	39.70	64.30	38.10	55.68	0.00	-72.29	30.99	50.14
1 A 3 d, Domestic Navigation	fossil fuels	CO_2	2,993.44	1,449.85	24.29	45.39	3.14	4.55	25.49	25.46	0.00	-51.57	59.69	90.89
1 A 3 d, Domestic Navigation		CH_4	2.17	5.61	68.61	163.67	81.39	195.73	66.94	157.71	0.00	158.14	99.79	246.38
1 A 3 d, Domestic Navigation		N_2O	18.56	10.84	11.82	14.46	48.23	75.31	33.02	43.78	0.00	-41.61	166.35	247.88
1 A 3 e, Other Transportation	fossil fuels	CO_2	1,083.27	836.22	1.23	1.79	1.09	1.09	1.47	1.74	0.00	-22.81	3.44	3.62
1 A 3 e, Other Transportation		CH_4	5.95	4.59	8.24	5.65	43.30	66.85	38.91	57.31	0.00	-22.96	89.83	141.73
1 A 3 e, Other Transportation		N_2O	12.88	6.44	5.64	3.67	51.82	51.89	47.84	47.60	0.00	-50.03	42.77	68.90
1 A 4 a, Commercial/Institutional	fossil fuels	CO_2	64,110.78	33,306.72	10.00	10.95	1.39	1.38	5.71	5.88	0.01	-48.05	14.00	15.20
1 A 4 a, Commercial/Institutional		CH_4	1,637.12	97.22	41.26	47.74	46.88	103.81	35.87	52.83	0.00	-94.06	39.74	76.15
1 A 4 a, Commercial/Institutional		N_2O	131.10	91.96	38.29	46.14	37.96	55.86	30.12	35.19	0.00	-29.86	67.94	91.51
1 A 4 b, Residential	fossil fuels	CO_2	128,635.75	82,296.47	9.88	10.65	1.40	1.50	6.06	6.30	0.05	-36.02	15.55	16.97
1 A 4 b, Residential		CH_4	2,782.86	991.02	19.92	21.49	45.70	68.66	40.65	58.04	0.00	-64.39	7,051.05	11,289.30
1 A 4 b, Residential		N_2O	683.71	256.39	32.38	49.39	54.63	74.68	34.48	41.61	0.00	-62.50	75.00	106.42
1 A 4 c, Agriculture/Forestry/Fishing	fossil fuels	CO_2	10,172.11	6,082.93	27.06	27.64	7.89	7.31	12.95	12.84	0.00	-40.20	61.45	66.52
1 A 4 c, Agriculture/Forestry/Fishing		CH_4	270.25	190.19	23.27	26.06	46.69	81.61	29.64	40.99	0.00	-29.62	69.50	100.52
1 A 4 c, Agriculture/Forestry/Fishing		N_2O	54.15	60.34	32.82	34.49	47.11	76.30	29.65	40.72	0.00	11.43	186.56	268.22
1 A 5, Other: Military	fossil fuels	CO_2	11,764.62	980.27	7.25	8.16	1.52	1.55	3.71	3.83	0.00	-91.67	1.53	1.60
1 A 5, Other: Military		CH_4	312.95	2.00	18.25	40.45	59.94	85.72	46.40	46.32	0.00	-99.36	8.00	11.50
1 A 5, Other: Military		N_2O	54.14	4.00	27.53	29.24	72.01	200.06	46.30	92.05	0.00	-92.61	12.02	22.99
1 B 1, Solid Fuels	fossil fuels	CO_2	1,832.80	634.18	2.99	2.98	24.85	30.88	31.56	31.96	0.00	-65.40	90.99	130.09
1 B 1, Solid Fuels		CH_4	28,619.85	159.47	25.52	24.05	33.69	41.27	25.71	25.94	0.00	-99.44	1.33	2.22
1 B 2 a, Oil		CO_2	477.63	406.35	35.86	48.38	30.37	30.99	26.01	28.48	0.00	-14.92	362.79	482.83
1 B 2 a, Oil		CH_4	270.87	22.05	10.98	11.10	21.27	21.33	16.17	17.16	0.00	-91.86	3.38	3.90
1 B 2 a, Oil		N_2O	0.28	0.22	0.00	0.00	0.00	0.00	29.88	30.13	0.00	-21.41	319.41	438.11
1 B 2 b, Natural Gas		CO_2	986.70	492.29	0.00	0.00	0.00	0.00	22.28	22.34	0.00	-50.11	22.13	28.91
1 B 2 b, Natural Gas		CH_4	9,788.56	1,811.35	24.96	31.47	58.31	80.14	18.84	21.93	0.00	-81.50	1.73	2.07
1 B 2 c, Venting and Flaring		CO_2	543.52	298.20	3.01	2.99	10.05	9.97	16.24	16.35	0.00	-45.14	49.55	58.81
1 B 2 c, Venting and Flaring		CH_4	1.85	0.59	0.00	0.00	0.00	0.00	19.29	19.12	0.00	-67.78	30.19	39.45
1 B 2 c, Venting and Flaring		N_2O	1.74	0.60	3.01	2.99	24.98	25.03	67.68	67.79	0.00	-65.44	98.01	156.95

A1 IPCC category	A2 Qualifier	B gas	C Base year emissions or removals t CO_2 equivalent	D Emissions or removals 2021 t CO_2 equivalent	E- Activity data uncertainty -%	E+ +%	F- Emission factor uncertainty -%	F+ +%	G- Combined uncertainty -%	G+ +%	H Contribution to variance 2021 fraction	I % of base year	J- Inventory trend in national emissions for 2021; increase with respect to base year -%	J+ +%
2 A 1, Cement Production		CO_2	15,297.27	13,640.22	2.52	2.50	1.00	1.00	2.71	2.71	0.00	-10.83	26.71	27.32
2 A 2, Lime Production		CO_2	5,986.62	4,524.94	2.69	2.68	7.33	5.90	7.16	6.14	0.00	-24.42	26.34	28.32
2 A 3, Glass Production		CO_2	780.48	916.91	7.38	8.54	25.65	29.83	11.66	11.82	0.00	17.48	367.15	409.19
2 A 4, Other Process Uses of Carbonates		CO_2	1,458.01	816.37	11.55	11.34	9.62	10.63	12.40	12.55	0.00	-44.01	14.39	17.57
2 B 1, Ammonia Production		CO_2	6,025.00	4,012.00	0.00	0.00	0.00	0.00	1.01	1.00	0.00	-33.41	2.28	2.29
2 B 2, Nitric Acid Production		N_2O	2,896.77	344.34	1.70	1.72	3.45	3.72	2.16	2.19	0.00	-88.11	0.41	0.43
2 B 3, Adipic Acid Production		N_2O	16,074.90	66.27	2.02	2.01	6.00	6.05	6.33	6.43	0.00	-99.59	0.03	0.03
2 B 5, Carbide Production		CO_2	443.16	5.88	9.93	9.94	10.01	9.99	13.75	14.40	0.00	-98.67	5.50	6.43
2 B 7, Soda Ash Production		CO_2	615.50	457.81	0.00	0.00	0.00	0.00	2.52	2.51	0.00	-25.62	43.14	43.93
2 B 8, Petrochemical and Carbon Black Production		CO_2	973.97	861.57	46.09	58.15	22.07	22.77	17.45	18.37	0.00	-11.54	3,017.71	3,678.12
2 B 8, Petrochemical and Carbon Black Production		CH_4	373.73	569.98	25.32	26.32	14.18	15.22	19.33	20.16	0.00	52.51	147.76	180.91
2 B 9 a, By-product Emissions		HFC-23	C	C	0.00	0.00	0.00	0.00	2.95	2.98	0.00	-99.96	0.00	0.00
2 B 9 b, Fugitive Emissions		SF_6	164.50	0.95	0.00	0.00	0.00	0.00	2.98	2.97	0.00	-99.42	0.02	0.02
2 B 9 b, Fugitive Emissions		HFC-134a	C	C	0.00	0.00	0.00	0.00	2.99	2.98	0.00	-45.74	4.98	5.07
2 B 9 b, Fugitive Emissions		HFC-227ea	C	C	0.00	0.00	0.00	0.00	2.99	3.03	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 Chemical Industry		CH_4	66.65	65.04	0.00	0.00	0.00	0.00	38.71	38.78	0.00	-2.42	2,772.56	4,267.84
2 B 10, Other Chemical Industry		N_2O	C	C	20.05	20.13	62.64	62.72	63.57	68.20	0.00	0.00	557.42	1,242.05
2 C 1, Iron and Steel Production		CO_2	22,810.29	16,418.95	20.64	22.95	8.50	8.58	9.22	9.57	0.00	-28.02	69.29	75.71
2 C 1, Iron and Steel Production		CH_4	5.22	5.52	1.01	0.99	77.41	78.88	68.02	67.69	0.00	5.60	262.46	473.11
2 C 1, Iron and Steel Production		N_2O	23.60	11.92	19.72	13.35	71.29	75.80	70.55	72.76	0.00	-49.49	2,651.77	6,304.50
2 C 2, Ferroalloys Production		CO_2	429.00	5.97	50.09	50.02	7.02	6.91	50.33	51.08	0.00	-98.61	149.47	263.13
2 C 2, Ferroalloys Production		CH_4	9.61	1.82	50.10	50.04	49.42	50.33	62.27	80.54	0.00	-81.04	252.46	560.57
2 C 3, Aluminium Production		CO_2	1,011.92	696.07	0.98	1.00	50.05	50.00	50.03	50.13	0.00	-31.21	3,855.08	6,520.09
2 C 3, Aluminium Production		SF_6	C	C	0.00	0.00	0.00	0.00	10.07	10.75	0.00	-76.60	4.30	4.75
2 C 3, Aluminium Production		CF_4	1,385.67	49.04	0.00	0.00	0.00	0.00	14.96	14.84	0.00	-96.46	0.73	0.85
2 C 3, Aluminium Production		C_2F_6	233.10	9.93	0.00	0.00	0.00	0.00	15.03	15.08	0.00	-95.74	0.88	1.02
2 C 4, Magnesium Production		SF_6	C	C	0.00	0.00	0.00	0.00	17.23	10.90	0.00	-73.15	7.91	9.44
2 C 4, Magnesium Production		HFC-134a	0.00	7.51	0.00	0.00	0.00	0.00	20.56	12.94	0.00		0.00	0.00
2 C 5, Lead Production		CO_2	157.87	64.37	22.44	18.39	38.08	46.92	39.92	39.73	0.00	-59.22	62.54	90.15
2 C 6, Zinc Production		CO_2	670.80	289.16	0.00	0.00	0.00	0.00	42.46	42.55	0.00	-56.89	48.30	75.97
2 D 1, Lubricant Use		CO_2	188.63	198.33	24.89	25.07	9.98	9.99	17.35	18.38	0.00	5.14	235.33	285.04
2 D 2, Paraffin Wax Use		CO_2	242.70	502.29	0.00	0.00	0.00	0.00	70.66	70.34	0.00	106.95	151.32	295.30
2 D 2, Paraffin Wax Use		N_2O	0.62	1.28	0.00	0.00	0.00	0.00	60.31	60.25	0.00	106.95	356.44	1,853.50
2 D 3, Other		CO_2	2,551.10	1,328.78	19.80	20.00	9.96	10.02	9.09	9.26	0.00	-47.91	22.60	24.66

A1 IPCC category	A2 Qualifier	B gas	C Base year emissions or removals t CO_2 equivalent	D Emissions or removals 2021 t CO_2 equivalent	E- Activity data uncertainty -%	E+ +%	F- Emission factor uncertainty -%	F+ +%	G- Combined uncertainty -%	G+ +%	H Contribution to variance 2021 fraction	I % of base year	J- Inventory trend in national emissions for 2021; increase with respect to base year -%	J+ +%
2 E, Electronics Industry		SF_6	48.73	33.28	0.00	0.00	0.00	0.00	7.02	7.41	0.00	-31.72	21.07	22.84
2 E, Electronics Industry		NF_3	4.95	13.72	0.00	0.00	0.00	0.00	6.96	7.40	0.00	177.04	15.39	16.47
2 E, Electronics Industry		HFC-23	14.34	12.34	0.00	0.00	0.00	0.00	7.02	7.32	0.00	-13.95	61.51	65.66
2 E, Electronics Industry		HFC-32	0.00	0.04	0.00	0.00	0.00	0.00	6.95	7.43	0.00		0.00	0.00
2 E, Electronics Industry		CF_4	92.06	64.81	0.00	0.00	0.00	0.00	6.43	6.73	0.00	-29.60	21.52	22.95
2 E, Electronics Industry		C_2F_6	147.83	43.89	0.00	0.00	0.00	0.00	7.01	7.39	0.00	-70.31	4.12	4.46
2 E, Electronics Industry		C_3F_8	0.00	14.14	0.00	0.00	0.00	0.00	7.07	7.43	0.00		0.00	0.00
2 E, Electronics Industry		c-C_4F_8	0.00	5.79	0.00	0.00	0.00	0.00	7.01	7.37	0.00		0.00	0.00
2 E, Electronics Industry		C_6F_{14}	21.57	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	13.62	63.25	0.00	0.00	0.00	0.00	17.20	17.25	0.00	364.49	28.03	33.86
2 F, Product Uses as Substitutes for ODS		HFC-32	0.76	244.39	0.00	0.00	0.00	0.00	7.62	7.64	0.00	32,133.17	13.44	15.73
2 F, Product Uses as Substitutes for ODS		HFC-43-10mee	C	C	0.00	0.00	0.00	0.00	1.98	2.00	0.00		0.00	0.00
2 F, Product Uses as Substitutes for ODS		HFC-125	135.75	1,874.60	0.00	0.00	0.00	0.00	6.40	6.46	0.00	1,280.96	17.02	21.22
2 F, Product Uses as Substitutes for ODS		HFC-134a	2,062.03	4,216.88	0.00	0.00	0.00	0.00	5.63	5.57	0.00	104.50	19.21	21.25
2 F, Product Uses as Substitutes for ODS		HFC-143a	76.60	1,233.25	0.00	0.00	0.00	0.00	10.63	10.53	0.00	1,510.09	15.08	16.82
2 F, Product Uses as Substitutes for ODS		HFC-152a	100.24	23.55	0.00	0.00	0.00	0.00	4.38	4.34	0.00	-76.51	3.76	4.45
2 F, Product Uses as Substitutes for ODS		HFC-227ea	0.67	81.41	0.00	0.00	0.00	0.00	3.67	3.67	0.00	12,001.49	17.84	24.03
2 F, Product Uses as Substitutes for ODS		HFC-236fa	C	C	0.00	0.00	0.00	0.00	9.90	10.02	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	9.38	9.28	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	8.84	8.92	0.00		0.00	0.00
2 F, Product Uses as Substitutes for ODS		C_2F_6	0.00	2.43	0.00	0.00	0.00	0.00	21.42	21.36	0.00		0.00	0.00
2 F, Product Uses as Substitutes for ODS		C_3F_8	20.07	0.91	0.00	0.00	0.00	0.00	18.99	18.97	0.00	-95.48	1.30	1.73
2 F, Product Uses as Substitutes for ODS		C_6F_{14}	C	C	0.00	0.00	0.00	0.00	19.91	19.86	0.00		0.00	0.00
2 G, Other Product Manufacture and Use		CH_4	5.07	23.71	19.95	19.82	19.97	20.01	26.82	29.75	0.00	367.41	73.04	98.01
2 G, Other Product Manufacture and Use		N_2O	C	C	89.04	110.17	44.55	71.88	43.43	43.64	0.00	-88.94	9.27	15.89
2 G, Other Product Manufacture and Use		SF_6	C	C	0.00	0.00	0.00	0.00	9.05	9.01	0.00	-60.80	32.17	33.83
2 G, Other Product Manufacture and Use		HFC-134a	0.00	0.18	0.00	0.00	0.00	0.00	22.41	22.46	0.00		0.00	0.00
2 G, Other Product Manufacture and Use		HFC-245fa	0.00	13.29	0.00	0.00	0.00	0.00	21.10	20.99	0.00		0.00	0.00
2 G, Other Product Manufacture and Use		HFC-365mfc	0.00	0.71	0.00	0.00	0.00	0.00	22.38	22.19	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	25.08	25.02	0.00		0.00	0.00
3 A, Enteric Fermentation	Dairy cows	CH_4	19,844.44	15,114.31	3.99	4.00	20.14	20.01	20.37	20.45	0.02	-23.84	174.85	218.25
3 A, Enteric Fermentation	non-dairy cattle	CH_4	15,699.01	9,814.70	11.45	11.85	13.21	14.29	10.97	11.09	0.00	-37.48	40.03	45.10
3 A, Enteric Fermentation	other animals	CH_4	1,597.65	1,212.25	16.71	17.31	34.25	44.02	12.90	13.18	0.00	-24.12	91.37	106.79

A1	A2	B	C	D	E-	E+	F-	F+	G-	G+	H	I	J-	J+
IPCC category	**Qualifier**	**gas**	**Base year emissions or removals $t\ CO_2$ equivalent**	**Emissions or removals 2021 $t\ CO_2$ equivalent**	**Activity data uncertainty**		**Emission factor uncertainty**		**Combined uncertainty**		**Contribution to variance 2021**		**Inventory trend in national emissions for 2021; increase with respect to base year**	
					-%	**+%**	**-%**	**+%**	**-%**	**+%**	**fraction**	**% of base year**	**-%**	**+%**
3 B, Manure Management	Dairy cows	CH_4	2,468.76	2,494.33	4.01	3.96	19.88	19.99	20.27	20.60	0.00	1.04	304.83	372.88
3 B, Manure Management	non-dairy cattle	CH_4	2,683.77	1,548.32	10.11	10.73	18.00	20.39	11.48	11.47	0.00	-42.31	34.36	38.53
3 B, Manure Management	swine	CH_4	3,426.57	2,621.87	7.19	6.77	20.89	22.05	16.55	16.70	0.00	-23.48	278.30	330.70
3 B, Manure Management	other animals	CH_4	169.02	219.12	14.60	16.02	49.30	59.82	11.21	11.51	0.00	29.64	75.84	88.55
3 B, Manure Management	Dairy cows	N_2O	849.94	623.56	4.01	3.96	56.96	98.88	57.06	99.50	0.00	-26.64	1,672.57	3,576.68
3 B, Manure Management	non-dairy cattle	N_2O	874.03	625.75	30.12	42.20	44.65	93.45	33.72	48.35	0.00	-28.41	258.58	392.83
3 B, Manure Management	swine	N_2O	356.42	286.02	28.92	21.29	52.12	97.14	45.41	76.01	0.00	-19.75	1,291.42	2,336.87
3 B, Manure Management	other animals	N_2O	112.84	120.76	45.87	59.91	77.28	171.61	32.72	47.48	0.00	7.02	1,266.37	1,928.30
3 B, Manure Management	deposition and leaching	N_2O	1,017.94	716.42	40.02	40.58	94.91	397.09	95.25	405.26	0.01	-29.62	138.90	794.60
3 D, Agricultural Soils		N_2O	20,339.18	16,619.88	78.76	161.30	75.88	329.51	35.78	81.62	0.20	-18.29	5,816.16	10,213.17
3 G, Liming		CO_2	2,200.53	2,006.37	3.93	3.57	3.81	3.53	4.51	4.83	0.00	-8.82	41.78	33.21
3 H, Urea Application		CO_2	481.05	399.48	1.00	1.00	1.00	1.00	1.40	1.41	0.00	-16.96	13.42	13.70
3 I, Other carbon-containing fertilisers		CO_2	510.45	182.16	3.03	3.02	3.00	2.99	4.21	4.28	0.00	-64.31	5.15	5.38
3 J, Other		CH_4	0.31	1,500.21	10.05	10.00	20.19	19.99	21.97	22.94	0.00	485,379.35	28.30	36.28
3 J, Other		N_2O	0.11	227.37	95.17	383.34	60.27	104.40	56.15	98.11	0.00	205,276.50	70.59	150.43
4 A , Forest Land		CO_2	-18,696.50	-41,870.91	0.00	0.00	0.00	0.00	9.75	9.74	0.03	123.95	18.85	20.64
4 A , Forest Land		CH_4	34.39	26.65	0.00	0.00	0.00	0.00	66.09	150.45	0.00	-22.52	472.45	1,263.89
4 A , Forest Land		N_2O	461.78	435.50	0.00	0.00	0.00	0.00	65.22	64.75	0.00	-5.69	690.90	1,566.55
4 B, Cropland		CO_2	14,722.32	15,556.89	0.00	0.00	0.00	0.00	15.86	13.86	0.01	5.67	291.23	388.32
4 B, Cropland		CH_4	109.46	94.96	0.00	0.00	0.00	0.00	43.01	65.50	0.00	-13.25	1,166.82	2,139.02
4 B, Cropland		N_2O	208.34	396.84	0.00	0.00	0.00	0.00	52.99	110.88	0.00	90.47	123.53	261.64
4 C, Grassland		CO_2	29,121.21	25,045.89	0.00	0.00	0.00	0.00	63.55	53.97	0.30	-13.99	261.36	1,103.83
4 C, Grassland		CH_4	841.64	919.32	0.00	0.00	0.00	0.00	51.52	93.58	0.00	9.23	337.17	706.46
4 C, Grassland		N_2O	62.15	36.68	0.00	0.00	0.00	0.00	50.82	50.31	0.00	-40.99	50.82	289.39
4 D, Wetlands		CO_2	3,692.17	4,713.81	0.00	0.00	0.00	0.00	34.81	114.43	0.04	27.67	241.56	447.01
4 D, Wetlands		CH_4	5,325.87	5,498.00	0.00	0.00	0.00	0.00	70.63	176.67	0.10	3.23	264.67	786.73
4 D, Wetlands		N_2O	30.18	39.01	0.00	0.00	0.00	0.00	8.38	8.33	0.00	29.23	72.35	89.87
4 E, Settlements		CO_2	1,251.39	1,472.89	0.00	0.00	0.00	0.00	147.88	107.00	0.01	17.70	524.86	626.10
4 E, Settlements		CH_4	18.82	28.40	0.00	0.00	0.00	0.00	37.64	56.04	0.00	50.92	137.14	249.94
4 E, Settlements		N_2O	122.73	255.78	0.00	0.00	0.00	0.00	46.21	104.04	0.00	108.40	123.26	255.54
4 G, Harvested Wood Products		CO_2	-1,330.35	-8,651.28	0.00	0.00	0.00	0.00	32.32	32.30	0.01	550.30	53.95	68.99
5 A, Solid Waste Disposal		CH_4	37,191.25	2,574.15	0.00	0.00	0.00	0.00	19.95	20.00	0.00	-93.08	1.92	2.37
5 B, Biological Treatment of Solid Waste		CH_4	59.39	791.04	13.72	42.79	76.05	205.45	69.11	153.03	0.00	1,231.99	104.54	374.96
5 B, Biological Treatment of Solid Waste		N_2O	19.67	184.34	25.14	29.93	62.75	140.53	56.58	100.60	0.00	837.07	105.50	242.91

A1 IPCC category	A2 Qualifier	B gas	C Base year emissions or removals	D Emissions or removals 2021	E- Activity data uncertainty	E+	F- Emission factor uncertainty	F+	G- Combined uncertainty	G+	H Contribution to variance 2021	I	J- Inventory trend in national emissions for 2021; increase with respect to base year	J+
			t CO_2 equivalent	t CO_2 equivalent	-%	+%	-%	+%	-%	+%	fraction	% of base year	-%	+%
5 D 1, Domestic Wastewater		CH_4	2,870.84	486.96	30.23	30.40	36.15	36.20	43.45	51.01	0.00	-83.04	3.07	5.08
5 D 1, Domestic Wastewater		N_2O	1,029.29	348.22	85.15	126.57	97.22	384.14	76.06	242.41	0.00	-66.17	3,280.25	12,858.77
5 D 2, Industrial Wastewater		CH_4	10.36	53.83	0.00	0.00	0.00	0.00	49.99	50.43	0.00	419.43	82.96	148.07
5 D 2, Industrial Wastewater		N_2O	28.09	23.84	49.89	49.89	90.05	306.64	91.32	319.60	0.00	-15.15	159.63	754.96
5 E, Other		CH_4	0.00	2.64	1.99	2.00	19.96	20.04	20.09	20.20	0.00		36.80	45.38
5 E, Other		N_2O	0.00	29.02	2.00	2.01	19.98	20.10	20.05	20.23	0.00		71.51	139.59

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).

21 References

AGEB. (2015). Vorwort zu den Energiebilanzen für die Bundesrepublik Deutschland (pp. 22). Berlin: AGEB - AG Energiebilanzen e.V.

AGEB. (2016). *Umsetzung eines Verfahrens zur regelmäßigen und aktuellen Ermittlung des Energieverbrauchs in nicht von der amtlichen Statistik erfassten Bereichen* (I C 4 - 73/15). Retrieved from https://www.bmwi.de/Redaktion/DE/Downloads/Studien/umsetzung-verfahren-ermittlung-energieverbrauch-nicht-amtliche-statisik-langfassung.html

AGEB. (2021a). Arbeitsgemeinschaft Energiebilanzen: Energieverbrauch in Deutschland - Daten für das 1. bis 4. Quartal 2020 [Press release]. Retrieved from https://ag-energiebilanzen.de/index.php?article_id=29&fileName=quartalsbericht_q4_2020.pdf

AGEB. (2021b). Energieverbrauch in Deutschland im Jahr 2020 [Press release]. Retrieved from www.ag-energiebilanzen.de

AGEB. (2021c). Heizwerte der Energieträger und Faktoren für die Umrechnung von spezifischen Mengeneinheiten in Wärmeinheiten (2005-2019). from AGEB - Arbeitsgemeinschaft Energiebilanzen e.V. https://ag-energiebilanzen.de/index.php?article_id=29&fileName=heizwerte2005bis2019.pdf

AGEB (Ed.) (2003). *Energiebilanzen der Bundesrepublik Deutschland - Jahre 1990-1999*. Frankfurt am Main: Verlags- und Wirtschaftsgesellschaft der Elektrizitätswerke.

Allekotte, M., Heidt, C., & Knörr, W. (2022). *Modellintegration des Transport-Visualisierungsmodells (TraViMo) und dem Transport Emission Model (TREMOD) : Endbericht Texte / Umweltbundesamt* (pp. 1). Retrieved from http://www.umweltbundesamt.de/publikationen/modellintegration-des-transport

http://webde/gruppen/bibliothek/OnlineReports/FB000701.pdf

AMD. (2003). *Umweltbericht*. Retrieved from http://data.theeuropeanlibrary.org/BibliographicResource/3000070766859

Anderl, M., Kampel, E., Köther, T., Muik, B., Pazdernik, K., Schodl, B., Poupa, S., Wappel, D., & Wieser, M. (2008). *Austria's Informative Inventory Report (IIR) 2008 - Submission under the UNECE Convention on Long-range Transboundary Air Pollution* (B. Read Ed.). Wien: UBA - Umweltbundesamt (Österreich).

Andreas, L. (2000). *Langzeitemissionsverhalten von Deponien für Siedlungsabfälle in den neuen Bundesländern.* (Dissertation), Technische Universität, Dresden.

ATV. (2004). *Produktionsspezifische Abwässer und Abfälle aus der Glas- und Mineralfaserindustrie*. Hennef: GFA.

Austermann-Haun, U., & Carozzi, A. (2011). *Bereitstellung einer qualitätsgesicherten Datengrundlage für die Emissionsberichterstattung zur Umsetzung von internationalen Luftreinhalte- und Klimaschutzvereinbarungen für ausgewählte Industriebranchen – hier: N2O Emissionsfaktoren aus der Abwasserreinigung der vier relevantesten Industriebereiche*

Austermann-Haun, U., & Witte, H. (2014). *Liste der großtechnischen Anaerobanlagen zur Industrieabwasserreinigung in Deutschland*. Unveröffentlichtes Werk. Hochschule Ostwestfalen-Lippe. Detmold.

Bachmaier, J., & Gronauer, A. (2007). *Klimabilanz von Biogasstrom*

BAFA. (2022a). Amtliche Mineralöldaten für die Bundesrepublik Deutschland: Bundesamt für Wirtschaft und Ausfuhrkontrolle.

BAFA. (2022b). Entwicklung der Rohöleinfuhr in die Bundesrepublik Deutschland: Bundesamt für Wirtschaft und Ausfuhrkontrolle, Ref. 423.

BAFA. (2022c). Mineralölstatistik. https://www.bafa.de/DE/Energie/Rohstoffe/Mineraloelstatistik/mineraloel_node.html

BAIUDBw. (2020). *Brennstoffeinsatz der Bundeswehr*. Unveröffentlichtes Werk.

Baker, J. M., Ochsner, T. E., Venterea, R. T., & Griffis, T. J. (2007). Tillage and soil carbon sequestration—What do we really know? *Agriculture, Ecosystems & Environment, 118*(1), 5.

Barghorn, M., Gössele, P., & Kaworski, W. (1986). *Laufende Aktualisierung des Datenmaterials aus der Bundesweiten Hausmuellanalyse = Bundesweite Hausmuellanalyse 1983-1985* (U.-. Umweltbundesamt Ed.). Berlin: RGUS - Arbeitsgruppe Umweltstatistik im Institut für Quantitative Methoden der Technischen Universität Berlin.

Bauer, S., Polcher, D. A., & Greßmann, A. (2010). *Evaluierung der Anforderungen der 20. BImSchV für Binnentankschiffe im Hinblick auf die Wirksamkeit der Emissionsminderung klimarelevanter Gase* (FKZ 3709 45 326)

BDB. (2022). Informationen des Bundesverbandes Deutscher Bestatter e.V. zum Anteil der Feuerbestattungen.

BDZ. (2005). *Zement-Jahresbericht 2004/2005*: BDZ - Bundesverband der Deutschen Zementindustrie.

BDZ. (2017). *Betriebs- und Leistungsfähigkeit von vollbiologischen Kleinkläranlagen bis 50 EW - Abschlussbericht 06/2013 – 12/2014*. Retrieved from https://docplayer.org/71803733-Betriebs-und-leistungsfaehigkeit-von-vollbiologischen-kleinklaeranlagen-bis-50-ew.html

Bechtold, M., Tiemeyer, B., Laggner, A., Leppelt, T., Frahm, E., & Belting, S. (2014). Large-scale regionalization of water table depth in peatlands optimized for greenhouse gas emission upscaling. *Hydrology and Earth System Sciences, 18*(9), 21. doi:10.5194/hess-18-3319-2014

Becker, A., Düputell, D., Gärtner, A., Hirschberger, R., & Oberdörfer, M. (2012). Emissionen klimarelevanter Gase aus Kläranlagen. *Immissionsschutz*(4). doi:doi.org/10.37307/j.1868-7776.2012.04.07

Beduco NV. (2020). Nährstoffgehalte von Kaninchenfutter. Retrieved from http://docplayer.org/28662297-Kaninchen-rohfett-rohprotein.html

Bender, M. (2009). *Aufbereitung von Daten der Emissionserklärungen gemäß 11. BImSchV aus dem Jahre 2004 für die Verwendung bei der UNFCC- und UNECE-Berichterstattung - Bereich Lageranlagen* (Bericht Nr. M74 244/7, UBA FKZ 3707 42 103/01)

Bender, M., & Langer, D. (2009). *Inventarverbesserung 2008, Verbesserung und Ergänzung der aktuellen Inventardaten, IPCC-Kategorie (1996) 1.B.2 Diffuse Emissionen aus Erdöl und Erdgas* (UBA FKZ 360 16 012)

Bender, M., & Langer, D. (2012). *Ermittlung von Emissionsfaktoren und Aktivitätsraten im Bereich IPCC (1996) 1.B.2.b.iii* (Bericht Nr. M96023/01, UBA FKZ 360 16 035)

Bender, M., & von Müller, G. (2019). *Emissionsfaktoren zu Raffinerien für die nationale Emissionsberichterstattung* (FKZ 3716 41 107 0)

Betzenbichler, W., Kolmetz, S., & Randall, S. (2016a). *Erarbeitung wissenschaftlich-methodischer Grundlagen zur Umsetzung der Empfehlungen aus den internationalen Inventarüberprüfungen - Verbesserung des Qualitätsmanagements und der Verifikation der deutschen Emissionsinventare*

Betzenbichler, W., Kolmetz, S., & Randall, S. (2016b). *Erarbeitung wissenschaftlich-methodischer Grundlagen zur Umsetzung der Empfehlungen aus den internationalen Inventarüberprüfungen - Verbesserung des Qualitätsmanagements und der Verifikation der deutschen Emissionsinventare*. Freising, Dessau-Roßlau: VERICO.

Beyer, M., Chudy, A., Hoffmann, L., Jentsch, W., Laube, W., Nehring, K., & Schiemann, R. (2004). *Rostocker Futterbewertungssystem: Kennzahlen des Futterwertes und Futterbedarfs auf der Basis von Nettoenergie*. Dummerstorf: Forschungsinstitut für die Biologie landwirtschaftlicher Nutztiere.

30. BImSchV: Dreißigste Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über Anlagen zur biologischen Behandlung von Abfällen - 30. BImSchV), (2017).

bft. (2022). Entwicklung der Tankstellenanzahl in Deutschland. Retrieved from https://www.bft.de/daten-und-fakten/entwicklung-tankstellenanzahl

BGR (Cartographer). (1995 & 1997). Bodenübersichtskarte der Bundesrepublik Deutschland 1: 1 000 000, digitale Version (BÜK 1000/LBA_V2) [Karte]

BGR (Cartographer). (1997). Digitale Bodenübersichtskarte der BRD (BUEK 1000) [Karte]

Biertümpfel, A., Rudel, H., Werner, A., & Vetter, A. (2009). *15 Jahre Energieholzversuche in Thüringen*. Retrieved from http://www.tll.de/ainfo/pdf/ehol1009.pdf

Bittkau, O. (2017, September 2017). [Telefongespräch zu CO2-Emissionen aus Erdölpipelines].

Bittman, S., Dedina, M., Howard, C. M., Oenema, O., & Sutton, M. A. e. (2014). *Options for Ammonia Mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen*. Retrieved from https://www.inms.international/sites/inms.international/files/AGD_final_file.pdf

BKG (Cartographer). (2021). Digitales Landbedeckungsmodell für Deutschland LBM-DE2015 [Karte]. Retrieved from http://gdz.bkg.bund.de/index.php/default/wms-landbedeckungsmodell-fur-deutschland-2015-wms-lbm-2015.html

BLE. (2022a). *Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland 2021*. Retrieved from https://www.ble.de/SharedDocs/Pressemitteilungen/DE/2022/220210_StatistischesJahrbuch.html#:~:text=Das%20Statistische%20Jahrbuch%20%C3%BCber%20Ern%C3%A4hrung,ble%2Dmedienservice.de%20erh%C3%A4ltlich.

BLE. (2022b). *Waldbrandstatistik der*
Bundesrepublik Deutschland
für das Jahr 2021. Retrieved from https://www.ble.de/SharedDocs/Downloads/DE/BZL/Daten-Berichte/Waldbrandstatistik/Waldbrandstatistik-2021.html;jsessionid=A574B0BF8BBE9FCF17176A7D490DFD41.1_cid335?nn=8907034

BLfU. (2011). *Den Boden fest im Blick - 25 Jahre Bodendauerbeobachtung in Bayern*. Retrieved from https://www.bestellen.bayern.de/application/applstarter?APPL=eshop&DIR=eshop&ACTIONxSETVAL(artdtl.htm,APGxNODENR:276767,AARTxNR:lfu_bod_00083,AARTxNODENR:201966,USERxBODYURL:artdtl.htm,KATALOG:StMUG,AKATxNAME:StMUG,ALLE:x)=X

Blum, U., & Heinbach, R. (2006). *Endbericht zum BZE Ringversuch Humus 2006*

Blum, U., & Heinbach, R. (2007). *Endbericht zum BZE Ringversuch Mineralboden 2007 - Teil 1*. Retrieved from https://www.yumpu.com/de/document/read/19086737/teil-1

BMBF, & UBA (Eds.). (1998). *Verbundvorhaben Deponiekörper*. Berlin.

BMEL. (2020). Massive Schäden - Einsatz für die Wälder. Retrieved from https://www.bmel.de/DE/themen/wald/wald-in-deutschland/wald-trockenheit-klimawandel.html

BMELF. (1994). *Der Wald in den neuen Bundesländern - Eine Auswertung vorhandener Daten nach dem Muster der Bundeswaldinventur*

BMELF. (2010). *Aufnahmeanweisung für die Inventurstudie 2008 im Rahmen der Treibhausgasberichterstattung*

BMELV. (2005). *Die zweite Bundeswaldinventur – BWI²: Der Inventurbericht*

BMELV. (2016). *Konzept zur Erstellung von THG Emissions- und Kohlenstoffinventaren der Quell- und Senkengruppen Landwirtschaft und LULUCF durch das Johann Heinrich von Thünen-Institut (TI) im Zuständigkeitsbereich des BMEL*. Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (BMELV). Berlin.

BMJ, & BfJ. (1998). *Gesetz zum Schutz vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten (Bundes-Bodenschutzgesetz - BBodSchG); „Bundes-Bodenschutzgesetz vom 17. März 1998 (BGBl. I S. 502), das zuletzt durch Artikel 101 der Verordnung vom 31. August 2015 (BGBl. I S. 1474) geändert worden ist“*. Bundesamts für Justiz
Bundesministeriums der Justiz und für Verbraucherschutz Retrieved from https://www.gesetze-im-internet.de/bbodschg/BBodSchG.pdf.

20. BImSchV: Zwanzigste Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung zur Begrenzung der Emissionen flüchtiger organischer Verbindungen beim Umfüllen oder Lagern von Ottokraftstoffen,

Kraftstoffgemischen oder Rohbenzin) in der Fassung der Bekanntmachung vom 18. August 2014 (BGBl. I S. 1447), die durch Artikel 2 der Verordnung vom 24. März 2017 (BGBl. I S. 656) geändert worden ist, (2017a).

21. BImSchV: Verordnung zur Begrenzung der Kohlenwasserstoffemissionen bei der Betankung von Kraftfahrzeugen in der Fassung der Bekanntmachung vom 18. August 2014 (BGBl. I S. 1453), die zuletzt durch Artikel 3 der Verordnung vom 24. März 2017 (BGBl. I S. 656) geändert worden ist, (2017b).

Richtlinie des Rates vom 21.Mai 1991 über die Behandlung von kommunalem Abwasser, 91/271/EWG C.F.R. (1991).

BMU (Ed.) (1990). *Eckwerte der oekologischen Sanierung und Entwicklung in den neuen Laendern = Umweltpolitik*: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit.

BNetzA & BKartA, B. f. E., Gas, Telekommunikation, Post und Eisenbahnen & Bundeskartellamt. (2022). *Monitoringbericht 2021*. Retrieved from https://www.bundesnetzagentur.de/SharedDocs/Mediathek/Monitoringberichte/Monitoringbericht_Energie2021.pdf;jsessionid=5318E185692FB157AA6E4572CCC92D6D?__blob=publicationFile&v=7

Boelcke, B. (2007). *Ertragspotenzial und Ertragsaufbau von Weiden (Salix) in Kurzumtriebsplantagen*. Retrieved from https://www.landwirtschaft-mv.de/Fachinformationen/Nawaro/?id=63&processor=processor.sa.lfaforenbeitrag

Bolte, A., Hertel, D., Ammer, C., Schmid, I., Nörr, R., Kuhr, M., & Redde, N. (2003). Freilandmethoden zur Untersuchung von Baumwurzeln. *Forstarchiv, 74*(6), 240-262.

Börjesson, P., & Berglund, M. (2007). Environmental systems analysis of biogas systems—Part II: The environmental impact of replacing various reference systems. *Biomass and Bioenergy, 31*(5), 326-344.

Bösch, B., & Kändler, G. (2013). *Methodenentwicklung für die 3. Bundeswaldinventur: Modul 3 Überprüfung und Neukonzeption einer Biomassefunktion - Abschlussbericht*

Böttcher, C. (2022). *Aktualisierung der Emissionsfaktoren für Methan für die Erdgasbereitstellung*. Umweltbundesamt. Dessau. Retrieved from https://www.umweltbundesamt.de/publikationen/aktualisierung-der-emissionsfaktoren-fuer-methan

Brandes, F. (2022). *Entwicklung der Methanemissionen in der Gasanwendung (G 201908)*. DVGW. Bonn. Retrieved from https://www.dvgw.de/themen/forschung-und-innovation/forschungsprojekte/dvgw-forschungsprojekt-megan

BSRIA Limited. (Versch. Jahrgänge). *World Market for Air Conditioning*.

DirektZahlVerpflV: Direktzahlungen-Verpflichtungenverordnung vom 4. November 2004 (BGBl. I S. 2778), zuletzt geändert durch Artikel 3 der Verordnung vom 15. Dezember 2011 (eBAnz 2011 AT144 V1); Verordnung über die Grundsätze der Erhaltung landwirtschaftlicher Flächen in einem guten landwirtschaftlichen und ökologischen Zustand, (2004).

Baugesetzbuch in der Fassung der Bekanntmachung vom 23.September 2004 (BGBl. I S. 2414), das zuletzt durch Artikel 6 des Gesetzes vom 20. Oktober 2015 (BGBl. I S. 1722) geändert worden ist, (2015).

Bundesgesetzblatt. (2004). *Verordnung über die Grundsätze der Erhaltung landwirtschaftlicher Flächen in einem guten landwirtschaftlichen und ökologischen Zustand*

(Direktzahlungen-Verpflichtungenverordnung - DirektZahlverpflV). Bonn: Bundesgesetzblatt (BGBl) Retrieved from http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl104058.pdf

https://www.bgbl.de/xaver/bgbl/text.xav?SID=&tf=xaver.component.Text_0&tocf=&qmf=&hlf=xaver.component.Hitlist_0&bk=bgbl&start=%2F%2F*%5B%40node_id%3D%27952641%27%5D&skin=pdf&tlevel=-2&nohist=1&sinst=5373C4B6.

Bundesgesetzblatt. (2012). Verordnung über das Inverkehrbingen von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis beim Düngen (Düngeverordnung in der Fassung der Bekanntmachung vom 27. Februar 2007 (BGBl. I S. 221), die zuletzt durch Artikel 5 Absatz 36 des Gesetzes vom 24. Februar 2012 (BGBl. I S. 212) geändert worden ist) *Teil I Nr. 58*: Bonn.

Bundesministerium für Verbraucherschutz, E. u. L. B. (2010). *Aufnahmeanweisung für die Inventurstudie 2008 im Rahmen der Treibhausgasberichterstattung.*

Bundesverband Glasindustrie e.V. (2022). Produktion von Glas und Glaswaren nach Branchensektoren: 2020 und 2021 | Production of glass and glassware by industriall sector 2020 and 2021. In B. G. e. V. (Ed.), Jahresbericht 2021/22: Annual Report (pp. 64). Düsseldorf. Retrieved from https://www.bvglas.de/presse/publikationen/.

Bundesverband Keramische Fliesen (2020). [Telefongespräch des UBA mit Jens Fellhauer (fellhauer@fliesenverband.de vom Bundesverband Keramische Fliesen e.V.) am 19.08.2020].

Burschel, P., Kürsten, E., & Larson, B. C. (1993). *Die Rolle von Wald und Forstwirtschaft im Kohlenstoffhaushalt : eine Betrachtung für die Bundesrepublik Deutschland* (U. M. F. Forstwissenschaft & B. F. V.-u. Forschungsanstalt Eds.). München.

BVEG. (2021). Jahresbericht des Bundesverband Erdgas, Erdöl und Geoenergie e.V., Statistischer Bericht Retrieved from http://www.erdoel-erdgas.de/

BVEG. (2022a). *Jahresbericht 2021*. Retrieved from https://www.bveg.de/der-verband/publikationen/

BVEG. (2022b). Jahresbericht des Bundesverband Erdgas, Erdöl und Geoenergie e.V., Statistischer Bericht Retrieved from https://www.bveg.de/wp-content/uploads/2022/03/BVEG-Jahresbericht-2021.pdf

BVKalk (2021). [Mitteilung per E-Mail von Dr. Werner Fuchs am 5.7.2021].

BVKalk (2022). [Mitteilung per E-Mail vonPhilip Nuyken am 15.7.2022].

BVL, B. f. V. u. L. (2022). *Absatzmengen von Wirkstoffen in Pflanzenschutzmitteln von 1987 bis 2020* [Excelfile]. Retrieved from:

https://www.bvl.bund.de/DE/Arbeitsbereiche/04_Pflanzenschutzmittel/01_Aufgaben/02_ZulassungPSM/03_PSMInlandsabsatzAusfuhr/psm_PSMInlandsabsatzAusfuhr_node.html
Cambou, A., Shaw, R. K., Huot, H., Vidal-Beaudet, L., Hunault, G., Cannavo, P., Nold, F., & Schwartz, C. (2018). Estimation of soil organic carbon stocks of two cities, New York City and Paris. *Science of the total environment, 644*(10), 452-464.
Cech, M., Davis, P., Gambardella, F., Haskamp, A., González, P. H., Spence, M., & Larivé, J.-F. (2017). Performance of European cross-country oil pipelines - Statistical summary of reported spillages in 2015 and since 1971. Retrieved from https://www.concawe.eu/publication/performance-european-cross-country-oil-pipelines-statistical-summary-reported-spillages-2015-since-1971/
Clodic, D., & Barrault, S. (2011). *1990 to 2010 Refrigerant inventories for Europe - Previsions on banks and emissions from 2006 to 2030 for the European Union - Part A 1990 to 2010 refrigerant inventories for Europe*
Clodic, D., Barrault, S., & Saba, S. (2012). *Global inventories of the worldwide fleets of refrigerating and airconditioning equipment in order to determine refrigerant emissions - The 1990 to 2006 Updating*
Cools, N., Verschelde, P., Hinsch Mikkelsen, J., De Vos, B., & Quataert, P. (2006). *Quality assurance and quality control in forest soil analysis:4th fscc interlaboratory comparison*. Geraardsbergen: Instituut voor Natuur- en Bosonderzoek.
Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, L 375/1, European Communities, Pub. L. No. 31 12 (1991).
Cuhls, C., Mähl, B., Clemens, J., & Herrmann, T. (2015). *Ermittlung der Emissionssituation bei der Verwertung von Bioabfällen* (U.-. Umweltbundesamt & g. I. f. W. mbH Eds.). Dessau-Roßlau.
Dämmgen, U., Amon, B., Gyldenkærne, S., Hutchings, N. J., Kleine Klausing, H., Haenel, H.-D., & Rösemann, C. (2011). Reassessment of the calculation procedure for the volatile solids excretion rates of cattle and pigs in the Austrian, Danish and German agricultural emission inventories. *Landbauforschung Völkenrode, 61*, 115-126.
Dämmgen, U., Amon, B., Hutchings, N. J., Haenel, H.-D., & Rösemann, C. (2012). Data sets to assess methane emissions from untreated cattle and pig slurry and solid manure storage systems in the German and Austrian emission inventories. *Landbauforschung, 62*, 1-20.
Dämmgen, U., & Hutchings, N. J. (2005). *The assessment of emissions of nitrogen species from agriculture using the methodology of the atmospheric emission inventory guidebook* (9076998787)
Dämmgen, U., Lüttich, M., Döhler, H., Eurich-Menden, B., & Osterburg, B. (2002). GAS-EM–ein Kalkulationsprogramm für Emissionen aus der Landwirtschaft. *Landbauforschung Völkenrode, 1*(52), 19-42.
Dämmgen, U., Rösemann, C., Haenel, H.-D., & Hutchings, N. J. (2012). Enteric methane emissions from German dairy cows. *Landbauforschung, 62*, 21-31.
Dämmgen, U., Schulz, J., Kleine Klausing, H., Hutchings, N. J., Haenel, H.-D., & Rösemann, C. (2012). Enteric methane emissions from German pigs. *Landbauforschung, 62*, 83-96.
Daschner, R., Faulstich, M., & Quicker, P. (2010). *Überprüfung der Emissionsfaktoren für die Abfallverbrennung* (pp. 93).
DAV. (2016). Anzahl der Asphaltmischwerke in Deutschland.
DAV. (2022). Asphaltproduktion in Deutschland (einzelne Mitteilung).
DBFZ. (2011). *Emissionsanalyse und Quantifizierung von Stoffflüssen durch Biogasanlagen im Hinblick auf die ökologische Bewertung der landwirtschaftlichen Biogasgewinnung und Inventarisierung der deutschen Landwirtschaft*
DBU. (2010). *Kurzumtriebsplantagen : Handlungsempfehlungen zur naturverträglichen Produktion von Energieholz in der Landwirtschaft - Ergebnisse aus dem Projekt NOVALIS*. Retrieved from https://edocs.tib.eu/files/e01fn12/690161034.pdf
De Vries, W., Reinds, G. J., Gundersen, P., & Sterba, H. (2006). The impact of nitrogen deposition on carbon sequestration in European forests and forest soils. *Global Change Biology, 12*(7), 23.
DEBRIV. (2004, 15. September 2004) *Mitteilung vom Deutscher Braunkohlen-Industrie-Verein e.V. an das IKP Stuttgart/Interviewer: I. Stuttgart*. DEBRIV.
Dechow, R., & Freibauer, A. (2011). Assessment of German nitrous oxide emissions using empirical modelling approaches. *Nutrient Cycling in Agroecosystems, 91*(3), 235-254. doi:10.1007/s10705-011-9458-9
DEhSt (2016). [Mitteilung per E-Mail von Detlef Bittner (Fachgebiet E 1.2) am 25.7.2016].
DEhSt (2017). [Mitteilung per E-Mail von Daniela Malsch (Fachgebiet E 1.2) am 2.8.2017].
DEHSt (2018). [Mitteilung per E-Mail von Fachgebiet E 1.2 am 27.07.2018].
DEhSt (2019). [Mitteilung per E-Mail von Daniela Malsch (Fachgebiet V 2.2) am 19.8.2019].
DEhSt (2020). [Mitteilung per E-Mail von Daniela Malsch (Fachgebiet V 2.2) am 6.7.2020].
DEhSt (2021). [Mitteilung per E-Mail von Daniela Malsch (Fachgebiet V 2.2) am 29.6.2021].
DEhSt (2022). [Mitteilung per E-Mail von Daniela Malsch (Fachgebiet V 2.2) am 25.4.2022].
Deichnik, K. (2022). Aktualisierung und Revision des Modells zur Berechnung der spezifischen Verbräuche und Emissionen des von Deutschland ausgehenden Seeverkehrs. from Bundesamts fur Seeschifffahrt und Hydrographie
Detzel, A., Vogt, R., Fehrenbach, H., Knappe, F., & Gromke, U. (2003). *Anpassung der deutschen Methodik zur rechnerischen Emissi-onsermittlung an internationalen Richtlinien (F+E-Vorhaben 299 42 245)*
DGE. (2008). *Ernährungsbericht 2008*. Bonn: DGE - Deutsche Gesellschaft für Ernährung e. V.
DGMK. (1992). *Ansatzpunkte und Potentiale zur Minderung des Treibhauseffektes aus Sicht der fossilen Energieträger*
DGMK. (2002). *Zusammensetzung von Ottokraftstoffen aus deutschen Raffinerien*
Diaz-Valbuena, L. R., L. Leverenz, H., Cappa, C. D., Tchobanoglous, G., Horwath, W. R., & Darby, J. L. (2011). Methane, Carbon Dioxide, and Nitrous Oxide Emissions
from Septic Tank Systems. *Environmental Science and Technology, 45*(7), 7. doi:10.1021/es1036095

DIE PAPIERINDUSTRIE e. V. - Erzeugerpreisindex StaBu. (2022). Ein Leistungsbericht + ausführliche Statistiken - Tabelle N 17. Bonn.

Die Verbraucher Initiative e.V. (2005, 09.01.2013). Distickstoffmonoxid. *Zusatzstoffe-Online.de.* Retrieved from http://www.zusatzstoffe-online.de/zusatzstoffe/284.e942_distickstoffmonoxid.html

DLG (Ed.) (2005). *Bilanzierung der Nährstoffausscheidungen landwirtschaftlicher Nutztiere* (1 ed. Vol. Band 199). Frankfurt/M.: DLG-Verlag.

DLG (Ed.) (2014). *Bilanzierung der Nährstoffausscheidungen landwirtschaftlicher Nutztiere.* (2 ed. Vol. Band 199). Frankfurt/M.: DLG-Verlag.

Döpelheuer, A. (2002). Anwendungsorientierte Verfahren zur Bestimmung von CO, HC und Ruß aus Luftfahrttriebwerken: DLR.

Dowle, M., Srinivasan, A., Gorecki, J., Chirico, M., Stetsenko, P., Short, T., Lianoglou, S., Antonyan, E., Bonsch, M., Parsonage, H., Ritchie, S., Ren, K., Tan, X., Saporta, R., Seiskari, O., Dong, X., Lang, M., Iwasaki, W., Wenchel, S., Broman, K., Schmidt, T., Arenburg, D., Smith, E., Cocquemas, F., Gomez, M., Chataignon, P., Blaser, N., Selivanov, D., Riabushenko, A., Lee, C., Groves, D., Possenriede, D., Parages, F., Toth, D., Yaramaz-David, M., Perumal, A., Sams, J., Morgan, M., Quinn, M., Storey, R., Saraswat, M., Jacob, M., Schubmehl, M., Vaughan, D., Hocking, T., Silvestri, L., Barrett, T., Hester, J., Damico, A., Freundt, S., Simons, D., Sales de Andrade, E., Miller, C., Peder Meldgaard, J., Tlapak , V., Ushey, K., Eddelbuettel, D., & Schwen, B. (2022). Extension of `data.frame`. 127. https://cran.r-project.org/web/packages/data.table/data.table.pdf

Drexhage, M., & Colin, F. (2001). Estimating root system biomass from breast-height diameters. *Forestry, 74*(5), 7.

Drexler, S., Gensior, A., & Don, A. (2021). Carbon sequestration in hedgerow biomass and soil in the temperate climate zone. *Regional Environmental Change, 21*(3), 74. doi:10.1007/s10113-021-01798-8

Dreysse, T. (2015). Vergleich des Bodenkohlenstoffmodells CANDY-Carbon-Balance (CCB) mit der Humusbilanzmethode nach VDLUFA am Beispiel von ausgewählten Ackerstandorten der Bodenzustandserhebung Landwirtschaft. In T.-I. f. A. (Braunschweig) & H. A. (Braunschweig) (Eds.), *Kongressband 2015 Göttingen : Vorträge zum Generalthema: Böden - Lebensgrundlage für Pflanze und Tier* (pp. 792). Darmstadt: VDLUFA-Verlag.

DüV: Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis beim Düngen, (2007).

DüV: Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis beim Düngen (2017).

Düwel, O., Siebner, C. S., Utermann, J., & Krone, F. (2007). *Gehalte an organischer Substanz in Oberböden Deutschlands - Bericht über länderübergreifende Auswertungen von Punktinformationen im FISBo BGR*. Retrieved from https://download.bgr.de/bgr/Boden/HUMUS1000OB/Bericht/humus1000_ob_Bericht.pdf

DWA. (2007). Merkblatt DWA-M 381 - Eindickung von Klärschlamm (Vol. M 381, pp. 39). Hennef DWA – Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.

DWA. (ab 1988 - jährlich). Leistungsvergleich kommunaler Kläranlagen - jährliche Veröffentlichung. *KA - Korrespondenz Abwasser, Abfall*.

DWD (2013, 26.07.2013). [Persönliche Mitteilung von Herrn Lux am 26.07.2013 "Gemittelte Erdbodentemperaturen in 1 m Tiefe in Deutschland"].

Ecofys & Environment Agency Austria. (2017). *Member State recommendations on reporting systems for cropland & grazing land management emissions & removals*

Germany : 2016 and 2017 Submission

Eddelbuettel, D., & François, R. (2011). Rcpp: Seamless R and C++ integration. *Journal of statistical software, 40*(8), 18. doi:10.18637/jss.v040.i08

Edelmann, S. (2013). *Organischer Kohlenstoff in terrestrischen und semiterrestrischen Stadtböden - Eine Bilanzierung der organischen Kohlenstoffgehalte und -mengen in Abhängigkeit von der Flächennutzung im Berliner Stadtgebiet.* (Diploma Dissertation), Humboldt Universität zu Berlin, Berlin.

Edmondson, J. L., Davies, Z. G., McCormack, S. A., Gaston, K. J., & Leake, J. R. (2014). Land-cover effects on soil organic carbon stocks in a European city. *Science of the total environment, 472*, 10. doi:10.1016/j.scitotenv.2013.11.025

Edmondson, J. L., Davies, Z. G., McHugh, N., Gaston, K. J., & Leake, J. R. (2012). Organic carbon hidden in urban ecosystems. *Scientific reports, 2*, 7.

EEA. (2019). *Final Review Report. 2019 annual review of national greenhouse gas inventory data pursuant to Article 19(2) of Regulation (EU) No 525/2013. Germany.*

EEA. (2020). *Final Review Report. 2020 Comprehensive Review of National greenhouse gas inventory data pursuant to Article 4(3) of Regulation (EU) No 2018/842 and to Article 3 of Decision No 406/2009/EC. Germany.*

EEA. (2021). *Final Review Report 2021 - annual review of national greenhouse gas inventory data pursuant to ARticle 19(2) of Regulation (EU) No 525/2013. Germany.*

EEA. (2022). *Final Review Report 2022 - annual review of national greenhouse gas inventory data pursuant to ARticle 19(2) of Regulation (EU) No 525/2013. Germany.*

Einig, K., Jonas, A., & Zaspel, B. (2009). Eignung von CORINE-Geodaten und Daten der Flächenerhebung zur Analyse der Siedlungs-und Verkehrsflächenentwicklung in Deutschland. *Wirtschaft und Statistik*(4), 11.

ElektroG: Gesetz über das Inverkehrbringen, die Rücknahme und die umweltverträgliche Entsorgung von Elektro- und Elektronikgeräten vom 20. Oktober 2015, (2015).

EMEP. (2009). *EMEP/CORINAIR Emission Inventory Guidebook – 2009*. Retrieved from http://www.eea.europa.eu/publications/emep-eea-emission-inventory-guidebook-2009
EMEP. (2019). *EMEP/EEA air pollutant emission inventory guidebook 2019* (EEA Report No 13/2019). Retrieved from https://www.eea.europa.eu/publications/emep-eea-guidebook-2019
EMEP/EEA. (2019a). *EMEP/EEA air pollutant emission inventory guidebook 2019: Technical guidance to prepare national emission inventories*. Retrieved from https://www.eea.europa.eu/publications/emep-eea-guidebook-2019
EMEP/EEA. (2019b). *EMEP/EEA air pollutant emission inventory guidebook – 2019*
en2x. (2021a). *Klimaschutz braucht Energie Vielfalt - Gründungsbericht 2021*. Retrieved from https://en2x.de/service/publikationen/
en2x. (2021b). *MWV-Jahresbericht 2020*. Retrieved from https://en2x.de/service/publikationen/
en2x (2022). [Persönliche Mitteilung (E-Mail) von Herrn M. Bittkau zu Daten zur Emissionsberichterstattung 2022].
Ernährungsphysiologie, G. f. (2006). *Energie- und Nährstoffbedarf landwirtschaftlicher Nutztiere. Nr. 10. Empfehlungen zur Energie- und Nährstoffversorgung von Schweinen.* Frankfurt/M.: Gesellschaft für Ernährungsphysiologie / Ausschuß für Bedarfsnormen.
European Candle Association. (2017). Consumption of candles in the European Union (EU 28) [Press release]. Retrieved from http://eca.ral-candles.eu/index.php?rubrik=19&topnav=8
European Commission. (2007a). *Reference document on best available techniques (BAT) reference document (BREF) in the ceramic manufacturing industry*. European Commission Retrieved from http://eippcb.jrc.ec.europa.eu/reference/.
European Commission. (2007b). *Reference Document on Best Available Techniques for the Manufacture of Large Volume Inorganic Chemicals - Solids and Others industry*. European Commission Retrieved from http://eippcb.jrc.ec.europa.eu/reference/BREF/lvic-s_bref_0907.pdf.
EUROPEAN COMMISSION DECISION of 27 April 2011 determining transitional Union-wide rules for harmonised free allocation of emission allowances pursuant to Article 10a of Directive 2003/87/EC of the European Parliament and of the Council (2011/278/EU), 2011/278/EU C.F.R. (2011).
European Parliament and Council of the European Union: Regulation (EC) No 1165/2008 concerning livestock and meat statistics and repealing Council directives 93/23/EEC, 93/24/EEC and 93/25/EEC, § Article 4 (2008).
European Parliament and Council of the European Union DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control), Directive 2010/75/EU C.F.R. (2010).
European Parliament and Council of the European Union Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013, Regulation (EU) 2018/842 C.F.R. (2018).
EXXON. (2014). Förderung von Erdgas in Deutschland. Retrieved from http://www.erdgassuche-in-deutschland.de/erkundung_foerderung/produktion_von_erdgas/index.html
F-GasV: Verordnung (EU) Nr. 517/2014 des europäischen Parlaments und des Rates vom 16. April 2014 über fluorierte Treibhausgase und zur Aufhebung der Verordnung (EG) Nr. 842/2006, (2014).
FAO. (1990). *Soil Map of the World: Revised Legend* (92-5-103022-7)
FAO. (2022a). FAOSTAT (Database). Retrieved 21.08.2022, from Food and Agriculture Organization of the United Nations http://www.fao.org/faostat/en/#data/QA
FAO. (2022b). FAOSTAT-Forestry Production and Trade (Database). from FAO - Food and Agriculture Organization of the United Nations https://www.fao.org/home/en
FAOSTAT. (ab 2015). FAOSTAT Protein supply quantity (Online Database). Retrieved 24.10.2022, from FAOSTAT - Food and Agriculture Organization Corporate Statistical Database http://www.fao.org/faostat/en/#data/FBS
Fehrenbach, H., Köppen, S., Markwardt, S., & Vogt, R. (2016). *Aktualisierung der Eingangsdaten und Emissionsbilanzen biogener Energienutzungspfade (BioEm).*
Feller, C., Fink, M., Laber, H., Maync, A., Paschold, P. J., Scharpf, H. C., Schlaghecken, J., Strohmeyer, K., Weier, U., & Ziegler, J. (2011). *Düngung im Freilandgemüsebau* Retrieved from https://www.igzev.de/publikationen/IGZ_Duengung_im_Freilandgemuesebau.pdf
Fichtner, W., Karl, U., & Hartel, R. (2011). *Fortschreibung der Emissionsfaktoren für Feuerungs- und Gasturbinenanlagen nach 13./17. BImSchV und TA Luft : Endbericht* (pp. X, 140).
Finnern, H., Grottenthaler, W., & Kühn, D. (1994). *Bodenkundliche Kartieranleitung : mit 91 Tabellen* (4., verarbeitete und erweiterte Auflage ed. Vol. 4). Hannover: BGR - Bundesanstalt für Geowissenschaften und Rohstoffe / Arbeitsgruppe Bodenkunde.
FOEN. (2010). *Switzerland´s Greenhouse Gas Inventory 1990 - 2008*
Forsell, N., Korosuo, A., Federici, S., Gusti, M., Rincón-Cristóbal, J. J., Rüter, S., Sánchez-Jiménez, B., Dore, C., Brajterman, O., & Gardiner, J. (2018). *Guidance on developing and reporting Forest Reference Levels in accordance with Regulation (EU) 2018/841*. Retrieved from https://op.europa.eu/en/publication-detail/-/publication/5ef89b70-8fba-11e8-8bc1-01aa75ed71a1/language-en
Forsell, N., Korosuo, A., Gusti, M., Rüter, S., Havlik, P., & Obersteiner, M. (2019). Impact of modelling choices on setting the reference levels for the EU forest carbon sinks: how do different assumptions affect the country-specific forest reference levels? *Carbon balance and management, 14*(1), 18. doi:10.1186/s13021-019-0125-9
Fortmann, H., Rademacher, P., Groh, H., & Höper, H. (2012). Stoffgehalte und -vorräte

im Boden und deren
Veränderungen. In H. Höper & H. Meesenburg (Eds.), *Tagungsband 20 Jahre Bodendauerbeobachtung in Niedersachsen* (pp. 257). Hannover: Landesamt für Bergbau, Energie und Geologie.

Franko, U., Kolbe, H., Thiel, E., & Ließ, E. (2011). Multi-site validation of a soil organic matter model for arable fields based on generally available input data. *Geoderma, 166*(1), 16. doi:10.1016/j.geoderma.2011.07.019

Fraver, S., Wagner, R. G., & Day, M. (2002). Dynamics of coarse woody debris following gap harvesting in the Acadian forest of central Maine, USA. *Canadian Journal of Forest research, 32*(12), 12. doi:10.1139/x02-131

Gärtner, S., Münch, J., Reinhardt, G., & Vogt, R. (2008). Materialband E: ÖkobilanzenOptimierungen für einen nachhaltigen Ausbau der Biogaserzeugung und -nutzung in DeutschlandBMU-Bericht.

GASUNIE. (2014). Verdichterstationen. Retrieved from http://www.erdgas-fuer-morgen.de/hoofdmenu/verdichterstationen

Gebauer, A., Sakhaee, A., Don, A., Poggio, M., & Ließ, M. (2022). Topsoil Texture Regionalization for Agricultural Soils in Germany—An Iterative Approach to Advance Model Interpretation. *Frontiers in Soil Science, 1*, 21. doi:10.3389/fsoil.2021.770326

GFZ, D. G. (2018). Pilotstandort Ketzin. Retrieved from http://www.co2ketzin.de/startseite/

Gibbs, M. J., & Woodbury, J. W. (1993). Methane from livestock manure In A. R. v. Amstel (Ed.), *International IPCC workshop methane and nitrous oxide : methods in national emissions inventories and options for control ; proceedings ; EUROASE Hotel, Amersfoort, The Netherlands, 3-5 February, 1993* (pp. 12). Bilthoven: Rijksinstituut voor Volksgezondheid en Milieu.

Gitzhofer, K., Bergmann, G., & Petermann, U. (2008). *Bereitstellung aktueller Emissionsdaten für die Glas- und Mineralfaserindustrie*. Offenbach a.M. [u.a.].

Global Carbon Project. (2022). Global Carbon Project (2022) - Carbon budget and trends 2022. Retrieved from www.globalcarbonproject.org/carbonbudget

Gores, S. (2021). *Inventartool zum deutschen Flugverkehrsinventar 1990-2020, im Rahmen der Aktualisierung des Moduls TREMOD-AV im Transportemissionsmodell TREMOD*.

Gottwald, J., Dobritz, F., & Schneider, L. (2017). *Prüfung der Vollständigkeit der Berichterstattungskategorie 'Keramische Erzeugnisse' insbesondere Emissionsrelevanz feinkeramischer Teilbranchen (Evaluierung in CRF 2.A.4.a/NFR 2.A.6 AR-Keramik) Dokumentationen / Umweltbundesamt (UBA)* (pp. 1). Retrieved from http://www.umweltbundesamt.de/publikationen/pruefung-der-vollstaendigkeit-der

Graf, T., Beck, M., Mauermeier, M., Ismann, D., Portner, J., P., D., & Schmidhalter, U. (2014). Humulus lupulus – The Hidden Half. *BrewingScience, 67*(11-12), 6.

Graf, T. M. (2016). *Tröpfchenbewässerung im Hopfenbau - Feldversuche, Physiologie und Rhizosphäre. .* (Dissertation), Technische Universität München, München. Retrieved from https://mediatum.ub.tum.de/doc/1304504/1304504.pdf

Grebe, S., & Eurich-Menden, B. (2022). *Free-range husbandry of laying hens. Methodology for calculating the nitrogen excreted in the free range area and derivation of the ammonia emission factor.*

Grebe, S., Wulf, S., & Häußermann, U. (2022). *Dokumentation zur Datenaufbereitung der Aktivitätsdaten Biogas für den Nationalen Inventarbericht, Submission 2023*

Greiner, B., Barghoorn, M., & Dobberstein, J. (1983). *Chemisch-physikalische Analyse von Hausmuell* (A.-A. U. Technische Universität Berlin . Institut fuer Quantitative Methoden & U.-. Umweltbundesamt Eds.). Dessau-Roßlau.

Grosse, C. (2021). *Qualitätsprüfung der Texte für den Nationalen Inventarbericht 2022 und Datenerhebung in der Quellgruppe 1.B.2.b* (PNr. 156 527)

Grosse, C. (2022). *Qualitätsprüfung der Texte für die nationalen Inventarberichte 2023 und 2024 und Datenerhebung in der Quellgruppe 1.B.2.b - Zwischenbericht 2022*

Große, C., Eyßer, M., Lehmann, S., Sammueller, J., & Behnke, M. (2022). *Ermittlung von Methanemissionen des Gasverteilnetzes (ME DSO): Inventur der Datenlage zur Abschätzung von Methanemissionen aus dem deutschen Gasverteilnetz, Entwicklung und Durchführung eines repräsentativen Messprogramms zur Erhebung der erforderlichen Daten: Abschlussbericht*

Grün, E., Schmelz, K.-G., & Schild, L. (2013). Klimarelevante Emissionen des Emschersystems. *KA Korespondenz Abwasser, Abfall, 60*(3).

Grundner, F., & Schwappach, A. F. (1952). *Massentafeln zur Bestimmung des Holzgehaltes stehender Waldbäume und Waldbestände* (10. Auflage ed.). Berlin: Verlag von Paul Parey.

Grüneberg, E., Ziche, D., & Wellbrock, N. (2014). Organic carbon stocks and sequestration rates of forest soils in Germany. *Global Change Biology, 20*(8), 19. doi:10.1111/gcb.12558

Gschrey, B., Warncke, K., & Osterheld, S. (2018). *Inventarermittlung der F-Gase 2017/2018 - Daten von HF(C)KW, FKW, SF6, NF3, SF5CF3, H(C)FE und PFPMIE für die nationale Emissionsberichterstattung gemäß Klimarahmenkonvention für die Berichtsjahre 2017 und 2018*

Gschrey, B., Winfried, S., Kimmel, T., Zeiger, B., & Reitz, S. (2015). *Implementierung der ab dem Berichtsjahr 2013 gültigen IPCC Guidelines for National Greenhouse Gas Inventories 2006 in die Inventarerhebung fluorierter Treibhausgase (HFKW, FKW, SF6, NF3)* (1862-4359). Retrieved from https://www.umweltbundesamt.de/publikationen/implementierung-der-ab-dem-berichtsjahr-2013

Gujer, W. (2006). *Siedlungswasserwirtschaft* (3., bearbeitete Auflage ed.). Berlin: Springer.

Gurgel, A. (2011). *Ergebnisse der Versuche mit schnellwachsenden Baumarten nach 18 Jahren Bewirtschaftung in Gülzow*. Paper presented at the Tagungsband. Beitrag zu einer Tagung retrieved from https://www.landwirtschaft-mv.de/Fachinformationen/Nawaro/?id=66&processor=processor.sa.lfaforenbeitrag

Haas, W. (2015). *Kraftstoffpermeation an Zapfsäulen*

Haenel, H.-D., Dämmgen, U., & Rösemann, C. (2011). Estimating numbers of piglets, weaners and fattening pigs for the German agricultural emission inventory. *Landbauforsch, 61*, 229-236.

Haenel, H.-D., Rösemann, C., Dämmgen, U., Döring, U., Wulf, S., Eurich-Menden, B., Freibauer, A., Döhler, H., Schreiner, C., Osterburg, B., & Fuß, R. (2020a). *Berechnung von gas- und partikelförmigen Emissionen aus der deutschen Landwirtschaft 1990 – 2018*. Retrieved from https://www.thuenen.de/media/publikationen/thuenen-report/Thuenen_Report_77.pdf

Haenel, H.-D., Rösemann, C., Dämmgen, U., Döring, U., Wulf, S., Eurich-Menden, B., Freibauer, A., Döhler, H., Schreiner, C., Osterburg, B., & Fuß, R. (2020b). *Calculations of gaseous and particulate emissions from German agriculture 1990 - 2018. Report on methods and data (RMD). Submission 2020. Thünen Report 77*

Haenel, H.-D., & Wulf, S. (2016). *Berechnung von CH_4-, N_2O-, NO-, N_2- und NH_3-Emissionen durch Vergärung von Gülle, Mist und Energiepflanzen ab Emissionsberichterstattung 2015.* Thünen-Institut, Braunschweig, und KTBL, Darmstadt. . Unveröffentlichtes Manuskript.

Hafner, I. A., Gabrielii, C., & Widell, K. (2019). *Refrigeration units in marine vessels: Alternatives to HCFCs and high GWP HFCs*: Nordic Council of Ministers.

Handke, V., Degel, M., Hohlfeld, A., & Kathöfer, V. (2013). *International Workshop "Comparing ETS and NIR Monitoring Data" : 26th and 27th September 2011*. Dessau-Roßlau.

Handke, V., Joerss, W., Pfitzner, R., Brinkschneider, F., & Schollenberger, H. (2004). *Das Qualitäts-System-Emissionsinventare: Handbuch*

Harthan, R. O., Anderson, G., & Böttcher, H. (2017). *Methodische Anpassung der deutschen THG-Emissionsinventare an die überarbeiteten "UNFCCC" reporting guidelines on annual inventories for Parties included in Annex I to the Convention*. Dessau-Roßlau.

Hasenbalg, C., & Sohnke, R. (2021). *Recherche des Festbrennstoffeinsatzes in deutschen Dampfbahnen 2019 & 2020*. Unveröffentlichtes Werk. Probst & Consorten.

Hedel, R., & Kunze, J. (2012). *Recherche des jährlichen Kohleeinsatzes in historischen Schienenfahrzeugen seit 1990*. Unveröffentlichtes Werk. Probst & Consorten Marketing-Beratung. Dresden.

Heilwig, R. (2002). Fahrleistungen und Kraftstoffverbrauch im Straßenverkehr. *DIW Wochenbericht*(51/52), 881.

Henrichsmeyer, W., Cypris, C., Löhe, W., Meudt, M., Sander, R., von Sothen, F.,, Isermeyer, F., Schefski, A., Schleef, K.-H., Neander, E., Fasterding, F., Helmcke, B.,, & Neumann, M., Nieberg, H., Manegold, D., Meier, T. (1996). *Entwicklung des gesamtdeutschen Agrarsektormodells RAUMIS96. Endbericht zum Kooperationsprojekt. Forschungsbericht für das BML (94 HS 021)*

Hensmann, M., Haardt, S., & Ebert, D. (2011). *Emissionsfaktoren zur Eisen- und Stahlindustrie für die Emissionsberichterstattung* (FKZ 3707 42 301). Retrieved from http://www.uba.de/uba-info-medien/4362.html

Hensmann, M., Haardt, S., & Ebert, D. (2012). *Emissionsfaktoren zur Eisen- und Stahlindustrie für die Emissionsberichterstattung* (Stand: Juli 2012 ed.). Dessau-Roßlau.

Herold, A., Anderson, G., & Jörß, W. (2016). *Implications of the changed reporting requirements of the Effort Sharing Decision for the EU ETS and the national GHG inventory : work package 1: comparison of ETS and IPCC Climate Change / Umweltbundesamt* (pp. 1). Retrieved from http://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/climate_change_13_2016_implications_of_changed_reporting_requirements.pdf

http://webde/gruppen/bibliothek/Onlinebuecher/EB012194.pdf

Herold, A., Jörß, W., Koch, M., & Scheffler, M. (2014). *Methodische Anpassung der deutschen THG-Emissionsinventare an die überarbeiteten „UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention“* (FKZ: 3712 41 103-2)

Hoehn, E., Riedmüller, U., Eckert, B., Tworeck, A., & Leßmann, D. (2009). *Ökologische Bewertung von künstlichen und erheblich veränderten Seen sowie Mittelgebirgsseen anhand der biologischen Komponente Phytoplankton nach den Anforderungen der EU-Wasserrahmenrichtlinie - Bewertungsmodul für Mittelgebirgsseen und Verfahrensanpassungen für Baggerseen, pH-neutrale Tagebauseen, Talsperren und Sondertypen im Tiefland - Abschlussbericht zum LAWA-Projekt O 3.06*. Retrieved from https://www.gewaesserfragen.de/pdfs/Abschlbericht_LAWA_O3_06_Feb_09.pdf

Hoffmann, G., Wünsch, C., Schnapke, A., & Sieck, M. (2011). *Nutzung der Potenziale des biogenen Anteils im Abfall zur Energieerzeugung*. Dessau-Roßlau.

Höper, H., & Schäfer, W. (2012). Die Bedeutung der organischen Substanz von Mineralboden fur den Klimaschutz. *Bodenschutz, 3*(12), 72-80.

Horn, H. (Producer). (2013). Ertragspotenziale von Kurzumtriebsplantagen in Sachsen. [PowePoint-Präsentation] Retrieved from https://www.landwirtschaft.sachsen.de/download/2013_11_28_Vortrag_Horn_Nossen.pdf

Houghton, J. T., Meira Filho, L. G., Lim, B., Treanton, K., & Mamaty, I. (1997). *Revised 1996 IPCC guidelines for national greenhouse gas inventories. v. 1: Greenhouse gas inventory reporting instructions.-v. 2: Greenhouse gas inventory workbook.-v. 3: Greenhouse gas inventory reference manual*. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html

Idoine, N. E., Raycraft, E. R., Hobbs, S. F., Shaw, R. A., Everett, P., Evans, E. J., Deady, E. A., & Mills, A. J. (2022). *World Mineral Production 2016-2020*. Keyworth, Nottingham: British Geological Survey (BGS).

Illichmann, S. (2016). *Recherche des Festbrennstoffeinsatzes historischer Schienenfahrzeuge in Deutschland 2015*. Probst & Consorten Marketing-Beratung. Dresden.

Institut für Umweltschutz. (1990). *Umweltbericht der DDR : Information zur Analyse der Umweltbedingungen in der DDR und zu weiteren Massnahmen / Institut für Umweltschutz*

IPCC. (2000). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/gp/english/index.html

IPCC. (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html

IPCC. (2006a). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/

IPCC. (2006b). *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (N. G. G. I. Programme, E. H.S., B. L., M. K., N. T., & T. K Eds.). Japan: IGES.

IPCC. (2006c). *2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 4: Agriculture, Forestry and Other Land Use* (S. Eggleston, L. Buendia, K. Miwa, T. Ngara, & K. Tanabe Eds.). Japan: IGES.

IPCC. (2006d). *Intergovernmental Panel on Climate Change - 2006 IPCC Guidelines for National Greenhouse Gas Inventories*

IPCC. (2014). *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.* Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/03/Wetlands_Supplement_Entire_Report.pdf

IPCC. (2015). *Climate change 2014: synthesis report* (R. K. Pachauri, L. Mayer, & I. P. o. C. Change Eds.). Geneva, Switzerland: Intergovernmental Panel on Climate Change.

IPCC. (2019a). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*

IPCC. (2019b). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories - Chapter 6: Wastewater treatment and discharge*. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/5_Volume5/19R_V5_6_Ch06_Wastewater.pdf

IPCC, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., & Troxler, T. G. (2014a). *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol.* Retrieved from http://www.ipcc-nggip.iges.or.jp/public/kpsg/index.html

IPCC, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M., & Troxler, T. G. (2014b). *2013 Supplement to the IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.* Retrieved from http://www.ipcc-nggip.iges.or.jp/public/wetlands/index.html

Jacobs, A., Flessa, H., Don, A., Heidkamp, A., Prietz, R., Dechow, R., Gensior, A., Poeplau, C., Riggers, C., Schneider, F., Tiemeyer, B., Vos, C., Wittnebel, M., Müller, T., Säurich, A., Fahrion-Nitschke, A., Gebbert, S., Hopfstock, R., Jaconi, A., Kolata, H., Lorbeer, M., Schröder, J., Laggner, A., Weiser, C., & Freibauer, A. (2018). *Landwirtschaftlich genutzte Böden in Deutschland - Ergebnisse der Bodenzustandserhebung*

Jamet, M., & Knörr, W. *Überleitung der Fahrleistungserhebung 2014 nach TREMOD - Entwurf des Endberichts zum Forschungsprojekt 84.0523 der BASt*. Unveröffentlichtes Werk.

JARN. (Versch. Jahrgänge). Special Edition “World Air Conditioner Market". *Japan Air Conditioning, Heating & Refrigeration News, Tokyo 107-0052*.

Järvenpää, M., Repo, A., Akujärvi, A., Kaasalainen, M., & Liski, J. (2018). Soil carbon model Yasso15-Bayesian calibration using worldwide litter decomposition and carbon stock data. *Manuscript in preparation]. Geoscientific Model Development*, 19.

Jarvis, S., & Pain, B. (1994). Greenhouse gas emissions from intensive livestock systems: their estimation and technologies for reduction. *Climate Change: Significance for Agriculture and Forestry, 27*, 27-38.

Joas, D. R., Potrykus, A., Schott, R., & Wenzel, S. (2004). *VOC-Minderungspotenzial beim Transport und Umschlag von Mineralölprodukten mittels Kesselwagen* (FKZ 202 44 372). Retrieved from http://www.umweltdaten.de/publikationen/fpdf-l/2637.pdf

Johansson, T., & Hjelm, B. (2012). Stump and root biomass of poplar stands. *Forests, 3*(2), 166-178.

Jörß, W., & Gronewäller, L. (2010). *Aufbereitung von Daten der Emissionserklärungen gemäß 11. BImSchV aus dem Jahre 2004 für die Verwendung bei der UNFCCC- und UNECE-Berichterstattung : Schlussbericht*. Berlin [u.a.].

Juhrich, K. (2022). *CO2-Emissionsfaktoren für fossile Brennstoffe : Aktualisierung 2022*. Retrieved from http://www.umweltbundesamt.de/publikationen/co2-emissionsfaktoren-fuer-fossile-brennstoffe-0

Juhrich, K., & Wachsmann, U. (2007). *Dokumentation der Datenqualität von Aktivitätsdaten für die Berichte über Emissionen aus stationären Feuerungen im Rahmen des Nationalen Inventarberichtes und des Monitoring Mechanismus nach RL EG 99/296*. Dessau.

Kaltschmitt, M. (2007). *Umwelteffekte einer geothermischen Stromerzeugung - Analyse und Bewertung der klein- und großräumigen Umwelteffekte der geothermischen Stromerzeugung* (FKZ 205 421 10)

Keller, M., Hausberger, S., Matzer, C., Wüthrich, P., & Notter, B. (2017). Handbuch für Emissionsfaktoren des Straßenverkehrs (HBEFA) Version 3.3. from MK Consulting GmbH, INFRAS AG & IVT / TU Graz http://www.hbefa.net/d/documents/HBEFA33_Hintergrundbericht.pdf http://www.hbefa.net/d/documents/HBEFA33_Documentation_20170425.pdf

Kern, J., Hellebrand, H. J., Scholz, V., & Linke, B. (2010). Assessment of nitrogen fertilization for the CO 2 balance during the production of poplar and rye. *Renewable and Sustainable Energy Reviews, 14*(5), 1453-1460.

Kiesel, F. K., Martina. (2019). *139. Gasstatistik 2017*

Kiesel, F. K., Martina. (2020). *140. Gasstatistik 2018*

Kirchgessner, M., Roth, F. X., Schwarz, F. J., & Stangl, G. (2008). *Tierernährung*. Frankfurt am Main, Germany: DLG - Verlags Union Agrar.

Kirchgessner, M., Windisch, W., & Müller, H.-L. (1994). *Methane release from dairy cows and pigs*. Paper presented at the Proc XIII Symp on energy metabolism of farm animals.

Klingenfuß, C., Klein, D.-P., Thrum, T., Fell, H., Klemm, J., & Zeitz, J. (2020). Natürliche Kohlenstoffspeicher in Berlin.

Knörr, W. (2022). *TREMOD Aviation (TREMOD AV) 2022 - Revision des Modells zur Berechnung des Flugverkehrs (TREMOD-AV)*. Heidelberg: Ifeu Institut für Energie- und Umweltforschung GmbH

Öko-Institut e.V.

Knörr, W., Allekotte, M., & Gores, S. (2021). *TREMOD Aviation (TREMOD AV) 2021 - Revision des Modells zur Berechnung des Flugverkehrs (TREMOD-AV)*. Heidelberg: Ifeu - Institut für Energie- und Umweltforschung GmbH

Öko-Institut e.V.

Knörr, W., Heidt, C., & Bergk, F. (2021). *TREMOD Mobile Machinery (TREMOD MM) 2021*. Heidelberg: Ifeu Institut für Energie- und Umweltforschung Heidelberg GmbH.

Knörr, W., Heidt, C., Gores, S., & Bergk, F. (2021). *TREMOD - Daten- und Rechenmodell: Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1960-2035*. Heidelberg: Ifeu Institut für Energie- und Umweltforschung Heidelberg GmbH.

Knörr, W., Heldstab, J., & Kasser, F. (2009). *Ermittlung der Unsicherheiten der mit den Modellen TREMOD und TREMOD-MM berechneten Luftschadstoffemissionen des landgebundenen Verkehrs in Deutschland : Endbericht*

Knörr, W., Höpfner, U., & Lambrecht, U. (2002). *Aktualisierung des "Daten- und Rechenmodells":Energieverbrauch und Schadstoffemissionen des motorisierten Verkehrs in Deutschland 1980-2020 : Endbericht*

Knörr, W., Schacht, A., & Gores, S. (2015). *TREMOD Aviation (TREMOD AV) 2015 - Revision des Modells zur Berechnung des Flugverkehrs (TREMOD-AV)*. Heidelberg: Ifeu Institut für Energie- und Umweltforschung GmbH

Öko-Institut e.V.

Knörr, W., Schacht, A., Gores, S., Kotzulla, M., & Wetzel, F. (2012). *Entwicklung eines eigenständigen Modells zur Berechnung der Energieeinsätze und Emissionen des zivilen Flugverkehrs - (TREMOD-AV)*. Retrieved from https://www.umweltbundesamt.de/publikationen/entwicklung-eines-modells-zur-berechnung

Koj, H. (2021, 08.09.21). [Persönliche Mitteilung Hr. Koj (BAFA) zur Tanklagererhebung].

König, H. C. (2007). *Waldbrandschutz-Kompendium für Forest und Feuerwehr*

König, N., Blum, U., Symossek, F., Bussian, B., Ellinghaus, R., Furtmann, K., Gärtner, A., Gutwasser, F., Hauenstein, M., & Kiesling, G. (2005). *Handbuch forstliche Analytik*. Bonn: Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft.

Köppen, S., Markwardt, S., Fehrenbach, H., & Vogt, R. (2016). *Aktualisierung der Eingangsdaten und Emissionsbilanzen wesentlicher biogener Energienutzungspfade (BioEm)*

Körschens, M., Rogasik, J., Hülsbergen, K.-J., Ellerbrock, R., Franko, U., Schulz, E., Böning, H., Eich, D., Köppen, D., Kolbe, H., Leithold, G., Merbach, I., Peschke, H., Prystav, W., Reinhold, J., & Zimmer, J. (2004). *Humusbilanzierung: Methode zur Beurteilung und Bemessung der Humusversorgung von Ackerland*. Retrieved from https://web.archive.org/web/20141114053919/https://www.vdlufa.de/joomla/Dokumente/Standpunkte/08-humusbilanzierung.pdf

Kraftfahrtbundesamt. (Versch. Jahrgänge). *Fahrzeugzulassungen Bestand an Kraftfahrzeugen und Kraftfahrzeuganhängern nach Fahrzeugalter*.

Kreißig, J. (1996). *Ganzheitliche Bilanzierung von Dachbahnen aus Bitumen : Kurzbericht*. Frankfurt am Main.

KrWG: Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen, 22 C.F.R. (2012).

LAWA. (2019). *Wasserwirtschaftliche Anforderungen an die Lagerung von Silage und Festmist auf landwirtschaftlichen Flächen unter sechs Monaten.* Retrieved from https://www.lawa.de/documents/lawa-merkblatt-lagerung-festmist-und-silage_1578302310.pdf

Lechtenböhmer, S., Nanning, S., Buttermann, H.-G., & Hillebrand, B. (2006a). *Bilanzierung der Gewinnung und Verwendung von Kalkstein und Ausweisung der CO2-Emissionen*. Dessau.

Lechtenböhmer, S., Nanning, S., Buttermann, H.-G., & Hillebrand, B. (2006b). *Bilanzierung der Gewinnung und Verwendung von Kalkstein und Ausweisung der CO2-Emissionen (Forschungsbericht 205 41 217/02, UBA-FB 000949205 41 217/02)* (20/06). Retrieved from http://www.eefa.de/pdf/UBA-Texte_29_06.pdf

Lechtenböhmer, S., Nanning, S., Hillebrand, B., & Buttermann, H.-G. (2006). *Einsatz von Sekundärbrennstoffen : Umsetzung des Inventarplanes und nationale unabhängige Überprüfung der Emissionsinventare für Treibhausgase, Teilvorhaben 02*. Dessau.

Lenk, T., Vogelbusch, F., & Falken, C. (2004). *Auswirkungen des Tanktourismus auf das deutsche Steueraufkommen – eine finanzwissenschaftliche Bestandsaufnahme.* Paper presented at the UNITI Bundesverband mittelständischer Mineralölunternehmen e. V. - Mitgliederversammlung 2004, München.

Leverenz, H., & Tchobanoglous, G. (2011). *Evaluation of Greenhouse Gas Emissions from Septic Systems: WERF Report DEC1R09*. London: IWA Publishing.

LfL, & BLU. (2009). *Wirtschaftsdünger und Gewässerschutz: Lagerung und Ausbringung von Wirtschaftsdüngern in der Landwirtschaft*. Retrieved from https://www.lfl.bayern.de/mam/cms07/publikationen/daten/informationen/p_34348.pdf

LfL Bayern. (2006). Untersuchungen zur tiergerechten Kaninchenmast. Retrieved from https://www.lfl.bayern.de/ilt/tierhaltung/kleintiere/023092/index.php

Linde Gas. (2017). Branchen - Lebensmittel & Getränke - Milchprodukte. Retrieved from http://www.linde-gas.de/de/industries/food_and_beverage/dairy/index.html

Liski, J. (1995). *Variation in soil organic carbon and thickness of soil horizons within a boreal forest stand–effect of trees and implications for sampling* (0037-5330)

Liski, J., Perruchoud, D., & Karjalainen, T. (2002). Increasing carbon stocks in the forest soils of western Europe. *Forest Ecology and Management, 169*(1), 159-175.

Lubenau, U., & Schuetz, S. (2014). *Messungen der Erdgasqualität an verschiedenen Stellen im Netz zur Ableitung bzw. Verifizierung von durchschnittlichen Emissionsfaktoren und Heizwerten von Erdgas*. Unveröffentlichtes Werk. DBI Gas- und Umwelttechnik GmbH. Leipzig.

Luftfahrt-Bundesamt. (Versch. Jahrgänge). *Bestand an Luftfahrzeugen in der Bundesrepublik Deutschland*.

Luo, Z., Wang, E., & Sun, O. J. (2010). Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. *Agriculture, Ecosystems & Environment, 139*(1), 224-231.

Maier, J., & Vetter, R. (2004). *Erträge und Zusammensetzung von Kurzumtriebs-Gehölzen (Weide, Pappel, Blauglockenbaum).* Paper presented at the Energieholzproduktion in der Landwirtschaft : Potenzial, Anbau, Technologie, Ökologie und Ökonomie, Postdam.

Marx, M., Jörg Rinklebe, Kastler, M., Molt, C., Kaufmann-Boll, C., Lazar, S., Lischeid, P. D. G., Schilli, C., & Körschens, M. (2016). *Erarbeitung fachlicher, rechtlicher und organisatorischer Grundlagen zur Anpassung an den Klimawandel aus Sicht des Bodenschutzes: Teil 3: Bestimmung der Veränderungen des Humusgehalts und deren Ursachen auf Ackerböden Deutschlands*. Retrieved from https://www.umweltbundesamt.de/publikationen/erarbeitung-fachlicher-rechtlicher-0

Mathivanan, G. P., Eysholdt, M., Zinnbauer, M., Rösemann, C., & Fuß, R. (2021). New N2O emission factors for crop residues and fertiliser inputs to agricultural soils in Germany. *Agriculture, Ecosystems and Environment, 322*, 12

Matthäi, M., Gutberlet, H., Feller, K.-H., Schimmelpfennig, M., & Stübiger, M. (2010). Messung der Lichtstärke von Kerzen unterschiedlicher Zusammensetzung: Westdeutsche Dochtfabrik GmbH; Sasol Wax GmbH; FH Jena.

Matthäi, M., & Petereit, N. (2004). Die Qualitätskerze *Sonderdruck*. Jahrbuch für den Praktiker 2004: ECA.

Mauersberger, R., & Kopp, D. (2006). *Klassifikation der Seen für die Naturraumerkundung des nordost-deutschen Tieflandes*. Retrieved from https://uckermaerkische-seen.de/files/foerderverein/downloads/Archiv_2006_3_Mauersberger.pdf

Meiners, H. (2005) *persönliche Mitteilung am 28.09.2005 - basierend auf dem Forschungsbericht FKZ 203 41 253/05 "Teilbereich 1 – Prognostische Emissionsfaktoren für Feuerungsanlagen"/Interviewer: M. Hüllenkrämer*. DMT, Gelsenkirchen.

Meiners, H. O., Michael; Kerber, Vitali. (2018). *Vertwerten von Grubengas als Beitrag zur Emissionsvermeidung und zur Gefahrenabwehr*. Retrieved from http://www.grubengas.de/german/DMT_Gutachten%20Emissionsvermeidung+Anlagen.pdf

Mell, W.-D. (2008). *Strukturen im Bootsmarkt*

Metzger, M. J., Bunce, R. G. H., Jongman, R. H. G., Mücher, C. A., & Watkins, J. W. (2005). A climatic stratification of the environment of Europe. *Global Ecology and Biogeography, 14*(6), 549-563. doi:10.1111/j.1466-822x.2005.00190.x

Mokany, K., Raison, R., & Prokushkin, A. S. (2006a). Critical analysis of root: shoot ratios in terrestrial biomes. *Global Change Biology, 12*(1), 84-96.

Mokany, K., Raison, R. J., & Prokushkin, A. S. (2006b). Critical analysis of root: shoot ratios in terrestrial biomes. *Global Change Biology, 12*(1), 84-96.

Molitor, R., Hausberger, S., & Benke, G. (2004). Abschätzung der Auswirkungen des Tanktourismus auf den Treibstoffverbrauch und die Entwicklung der CO2-Emissionen in Österreich. *Endbericht im Auftrag des Lebensministeriums*.

Müller-Using, S., & Bartsch, N. (2009). Decay dynamic of coarse and fine woody debris of a beech (Fagus sylvatica L.) forest in Central Germany. *European Journal of Forest Research, 128*(3), 287-296.

Müller, R. (2016, 25.08.2016). [Anteil Dolomit an der Düngekalkgesamtmenge, Düngekalkhauptgemeinschaft. Persönliche Mitteilung].

MWV. (2019). Jahresbericht 2019. Retrieved from https://www.mwv.de/publikationen/jahresberichte/

MWV. (2020). *Jahresbericht 2020*. Retrieved from https://web.archive.org/web/20210120083826/https://www.mwv.de/wp-content/uploads/2020/09/MWV_Mineraloelwirtschaftsverband-e.V.-Jahresbericht-2020-Webversion.pdf

Nabuurs, G. J., & Schelhaas, M. J. (2002). Carbon profiles of typical forest types across Europe assessed with CO2FIX. *Ecological Indicators, 1*(3), 213-223.

NaSE-Workshop (2004, November 2004). [NaSe Workshop 2004].

Neubauer, M., & Demant, B. (2016). Wurzeln als Kohlenstoffspeicher: Untersuchungen zur unterirdischen Biomasse von Birke, Eiche und Kiefer. Germany, Europe: Universitätsdruckerei Freiburg, Albert-Ludwigs-Universität Freiburg.

Neulicht, R. (1995). *Emission Factor Documentation for AP-42 Section 10.7 "Charcoal"*. Retrieved from https://www3.epa.gov/ttn/chief/ap42/ch10/

Neumann, J., & Wycisk, P. (2002). Mittlere jährliche Grundwasserneubildung *Bundesrepublik Deutschland Nationalatlas – Relief, Boden und Wasser.* (pp. 144-145). Heidelberg: Spektrum Akademischer Verlag.

Nielsen, M., Nielsen, O.-K., & Thomsen, M. (2010). *Emissions from decentralised CHP plants 2007 - Energinet.dk Environmental project no. 07/1882: Project report 5 - Emission factors and emission inventory for decentralised CHP production*. Retrieved from https://web.archive.org/web/20220120070417/http://www.dmu.dk/Pub/FR786.pdf

Noleppa, S., & Cartsburg, M. (2015). *Das große Wegschmeißen Vom Acker bis zum Verbraucher: Ausmaß und Umwelteffekte der Lebensmittelverschwendung in Deutschland*. Berlin: WWF - World Wildlife Foundation.

Notter, B., Keller, M., Althaus, H.-J., Cox, B., Knörr, W., Heidt, C., Biemann, K., Räder, D., & Jamet, M. (2019). *Handbuch für Emissionsfaktoren des Straßenverkehrs (HBEFA) 4.1*. Retrieved from https://www.hbefa.net/d/documents/HBEFA41_Development_Report.pdf

ÖKO-INSTITUT. (2006). *Datenaustausch zwischen Emissionshandel und Nationaler Klimaschutzberichterstattun - Abschlussbericht zum F+E-Vorhaben - FKZ 205 41 521*. Unveröffentlichtes Werk. Berlin.

Oonk, H., & Lambert, C. (2017). *Greenhouse Gas Emissions from Biological Treatment of Waste - Overwiew of Existing Measurements*. Unpublished Work.

Ornellas, D. L. (1982). *Calorimetric Determinations of the Heat and Products of Detonation for Explosives: October 1961 to April 1982*. Technical Report, (AD-A409329; UCRL-52821; NASA/STI Accession number: 20030014092). Livermore.

Osowski, S., Neumann, J., & Fahlenkamp, H. (2004). Nutzung biogener Festbrennstoffe in Vergasungsanlagen. *Chemie Ingenieur Technik, 76*(7), 1004-1012.

Paul, C., Weber, M., & Mosandl, R. (2009). *Kohlenstoffbindung junger Aufforstungsflächen*. Retrieved from https://karlgayer.de/Forschung_Aufforstung.pdf

Penman, J., Kruger, D., & Calbally, I. (Eds.). (2000). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories : IPCC National Greenhouse Gas Inventories Programme*. Kanagawa: Institute for Global Environmental Strategies.

Pistorius, T., Zell, J., & Hartebrodt, C. (2007). *Untersuchungen zur Rolle des Waldes und der Forstwirtschaft im Kohlenstoffhaushalt des Landes Baden-Württemberg*

Plinke, E., & Schonert, M. (2000). *Anwendung des IPCC-Referenzverfahrens zur Ermittlung der verbrennungsbedingten CO2-Emissionen in Deutschland*. Basel.

Poeplau, C., Don, A., Vesterdal, L., Leifeld, J., Van Wesemael, B., Schumacher, J., & Gensior, A. (2011). Temporal dynamics of soil organic carbon after land-use change in the temperate zone -

carbon response functions as a model approach. *Global Change Biology, 17*(7), 2415-2427. doi:10.1111/j.1365-2486.2011.02408.x

Polley, H. (2001). *Aufnahmeanweisung für die Bundeswaldinventur II: (2001-2002)* (2. korrigierte, überarbeitete Ausgabe ed.). Bonn: BMVEL - Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft.

Pöpken, S. (2011). *Obstanbau, Weinanbau und Weihnachtsbaumkulturen in Deutschland: Zwischenbericht des Forschungsprojekts Methodenentwicklung zur Erfassung der Biomasse mehrjährig verholzter Pflanzen außerhalb von Waldflächen"*

Portner, J., Rossbauer, G., & Bauer, M. (2019). [Nährstoffaufnahme des Hopfens.].

Pouyat, R. V., Yesilonis, I. D., & Golubiewski, N. E. (2009). A comparison of soil organic carbon stocks between residential turf grass and native soil. *Urban Ecosystems, 12*(1), 45-62. doi:10.1007/s11252-008-0059-6

Raciti, S. M., Hutyra, L. R., & Finzi, A. C. (2012). Depleted soil carbon and nitrogen pools beneath impervious surfaces. *Environmental Pollution, 164*, 248-251.

Rentz, O., Karl, U., & Peter, H. (2002). *Ermittlung und Evaluierung von Emissionsfaktoren für Feuerungsanlagen in Deutschland für die Jahre 1995, 2000 und 2010*. Karlsruhe.

Riedel, T., Stümer, W., Freibauer, A., Rüter, S., Dunger, K., Steuk, J., & Brötz, J.,, Hennnig, P., Dunger, K., & Bolte, A. (2019). *Wälder in Deutschland sind eine wichtige Kohlenstoffsenke*

Riedmüller, U., Mischke, D. U., Pottgiesser, T., Böhmer, J., Deneke, R., Ritterbusch, D., & Stelzer, D. (2013). Begleittext zu den Steckbriefen der deutschen Seetypen (pp. 25). Freiburg: LBH - Limnologie-Büro-Hoehm.

Röhling, S., Dunger, K., Kändler, G., Klatt, S., Riedel, T., Stümer, W., & Brötz, J. (2016). Comparison of calculation methods for estimating annual carbon stock change in German forests under forest management in the German greenhouse gas inventory. *Carbon balance and management, 11*(1), 12.

Röhling, S., & Kludt, R. (2010). *Ableitung der Kalksteinbilanz aus den statistischen Daten der Bundesanstalt für Geowissenschaften und Rohstoffe für Zwecke der Emissionsberichterstattung nach Klimarahmenkonvention und Kyoto Protokoll (Kategorie CRF 2.A.3)*. Dessau-Roßlau.

Rösemann, C., Haenel, H.-D., Dämmgen, U., Freibauer, A., Wulf, S., Eurich-Menden, B., Döhler, H., Schreiner, C., & Osterburg, B. (2015). *Calculations of gaseous and particulate emissions from German agriculture 1990-2013*. In Thünen-Institut (Series Ed.) *Thünen Report*

Rösemann, C., Vos, C., Haenel, H.-D., Dämmgen, U., Döring, U., Wulf, S., Eurich-Menden, B., Freibauer, A., Döhler, H., Schreiner, C., Osterburg, B., & Fuß, R. (2023). *Calculations of gaseous and particulate emissions from German agriculture 1990 - 2021. Report on methods and data (RMD). Submission 2023.*

Roßkopf, N., Fell, H., & Zeitz, J. (2015). Organic soils in Germany, their distribution and carbon stocks. *Catena, 133*, 157-170. doi:10.1016/j.catena.2015.05.004

Roth, U., Döhler, H., Hartmann, S., & Wulf, S. (2011). Treibhausgasbilanzen und CO2eq-Vermeidungskosten landwirtschaftlicher Biogasanlagen. *Biogas in der Landwirtschaft—Stand und Perspektiven. KTBL-Schrift, 488*, 196-208.

Rothe, B. (2017, 01.06.2017). [Keramik: ETS-Emissionsdaten].

Ruppert, J. S., Wilfried; Schäfer, Stefan. (2009). *Bereitstellung einer qualitätsgesicherten Datengrundlage für die Emissionsberichterstattung zur Umsetzung von internationalen Luftreinhalte- und Klimaschutzvereinbarungen für ausgewählte Industriebranchen: Teilvorhaben 03 Zementindustrie (FKZ 370742301/03)* (FKZ 370742301/03)
Rüter, S. (2011). *Projections of Net-Emissions From Harvested Wood Products in European Countries*. Retrieved from http://literatur.vti.bund.de/digbib_extern/dn048901.pdf
Rüter, S. (2017). *Der Beitrag der stofflichen Nutzung von Holz zum Klimaschutz – Das Modell WoodCarbonMonitor.*, Technische Universität München. Retrieved from https://mediatum.ub.tum.de/doc/1295127/1295127.pdf
Rüter, S., Alfredsen, G., Ximenes, F. d. A., Guendehou, S., Pingoud, K., & Tsunetsugu, Y. (2014). Section 2.8: Harvested Wood Products (HWP). In J. Jenkins & J. Li (Eds.), *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* - (pp. 109-134). Switzerland: IPCC.
Sakhaee, A., Gebauer, A., Ließ, M., & Don, A. (2022). Spatial prediction of organic carbon in German agricultural topsoil using machine learning algorithms. *SOIL, 8*(2), 587-604. doi:10.5194/soil-8-587-2022
Santana, E. J., Rodrigues dos Santos, F., Mastelini, S. M., Melquiades, F. L., & Barbon Jr, S. (2021). Improved prediction of soil properties with multi-target stacked generalisation on EDXRF spectra. *Chemometrics and Intelligent Laboratory Systems, 209*, 104231. doi:10.1016/j.chemolab.2020.104231
Schäfer, S., Ruppert, J., Furth, G., & Kludt, R. (2022). *Überarbeitung der Emissionsfaktoren für Luftschadstoffe in den Branchen Zementklinkerproduktion und Glasherstellung : Teilbericht - Zementklinkerproduktion Texte / Umweltbundesamt* (pp. 1). Retrieved from http://www.umweltbundesamt.de/publikationen/ueberarbeitung-der-emissionsfaktoren-fuer-0
http://webde/gruppen/bibliothek/OnlineReports/FB000678.pdf
Schmidt, T., Schneider, F., Leverenz, D., & Hafner, G. (2019). *Lebensmittelabfälle in Deutschland - Baseline 2015*. Retrieved from https://www.thuenen.de/media/publikationen/thuenen-report/Thuenen_Report_71.pdf
Schmutz, B. I. (2009, 28.09.2009). [Interessengemeinschaft für Esel und Maultiere, persönliche Mitteilung].
Schön, M., Walz, R., Angerer, G., Bätcher, K., Böhm, E., Hillenbrand, T., Hiessl, H., Reichert, J., Paoli, M., & Sartorius, R. (1993). *Emissionen der Treibhausgase Distickstoffoxid und Methan in Deutschland : Emissionsbilanz, Identifikation von Forschungs- und Handlungsbedarf sowie Erarbeitung von Handlungsempfehlungen ; Phase 1*. Berlin: E. Schmidt.
Schöning, I., Totsche, K. U., & Kögel-Knabner, I. (2006). Small scale spatial variability of organic carbon stocks in litter and solum of a forested Luvisol. *Geoderma, 136*(3), 631-642.
Schuhmann, K.-U. (2018). Technische Regel für Gasinstallationen – Die DVGW-TRGI 2018. *Energie- und Wasser-Praxis, 2018*(9), 6.
Schulz, S. (2012). *Einflüsse auf die Bauzeit im Hochbau: Ursachen und Folgen der Einflussfaktoren vor und während der Bauausführung von Neubauten. S. 230.* (Masterarbeit), Brandenburgische Technische Universität Cottbus.
Schulze, E. D., Hogberg, P., Van Oene, H., Persson, T., Harrison, A. R., Read, D., Kj0ller, A., & Matteucci, G. (2000). 21 Interactions Between the Carbon and Nitrogen Cycles and the Role of Biodiversity: A Synopsis of a Study Along a North-South Transect Through Europe. *Ecological studies, 142*, 468-492.
Schwarz, W. (2007). *Daten von H-FKW, FKW und SF6 für die nationale Emissionsberichterstattung gemäß Klimarahmenkonvention für die Berichtsjahre 2004 und 2005 - F-Gas-Emissionen 2004/2005 und Unsicherheitsbestimmung im ZSE*. Retrieved from https://www.umweltbundesamt.de/publikationen/daten-von-h-fkw-fkw-sf6-fuer-nationale?anfrage=Kennummer&Suchwort=3439
Schwarz, W. (2009). *SF6 und NF3 in der deutschen Photovoltaik-Industrie - Inventarverbesserung 2008 – Verbesserung und Ergänzung der Daten für die nationale Emissionsberichterstattung gemäß Klimarahmenkonvention in der Quellgruppe Photovoltaik (2.F.8.h)* (FuE-Vorhaben FKZ 360 16 027)
Schwarz, W., & Harnisch, J. (2003). *Establishing the leakage rates of mobile air conditioners*. Retrieved from https://climate.ec.europa.eu/system/files/2016-11/leakage_rates_final_report_en.pdf
Schwarz, W., Kimmel, T., Gschrey, B., Leisewitz, A., & Sauer, J. (2012). *Modelle für die Inventarerhebung von F-Gasen*
Schwarz, W., & Leisewitz, A. (1996). *Aktuelle und künftige Emissionen treibhauswirksamer fluorierter Verbindungen in Deutschland*
Schwitzgebel, F., Dunger, K., & Polley, H. (2009). Die Inventurstudie 2008. Ergebnisse einer Kohlenstoffinventur auf Bundeswaldinventur-Basis. Hintergrund, Methodik und Durchführung der Studie. *AFZ Waldwirtsch Umweltvorsorge, 64*, 1070-1071.
Schwitzgebel, F., & Riedel, T. (2019). Die Kohlenstoffinventur 2017 – Methode, Durchführung, Kosten. *AFZ Waldwirtsch Umweltvorsorge, 14*, 3.
Seitel, C., & Oberle, M. (2022). Erfassung der Teichflächen in Bayern. *Fachzeitschrift für die Binnenfischerei Fischer und Teichwirt, 73*(Heft 2), 2.
Senser, F., & Souci, S. W. (1991). *Der kleine "Souci-Fachmann-Kraut" : Lebensmitteltabelle für die Praxis* (D. F. f. Lebensmittelchemie Ed. 2., überarbeitete und erwweitete Auflage ed.).
Shahhosseini, M., Hu, G., & Pham, H. (2022). Optimizing ensemble weights and hyperparameters of machine learning models for regression problems. *Machine Learning with Applications, 7*, 10. doi:10.1016/j.mlwa.2022.100251
Siegl, W., J Wallington, T., T Guenther, M., Henney, T., Pawlak, D., & Duffy, M. (2002). R-134a Emissions from Vehicles. *Environ. Sci. & Technol., 36*, 561-566. doi:10.1021/es011108x
SKM Enviros. (2010). *Eco-Efficiency Study of Supermarket Refrigeration - For the European Partnership for Energy and Environment (EPEE)*

Sobotik, M., Graf, T., Himmelbauer, M., Bodner, G., Bohner, A., & Loiskandl, W. (2018). In-situ Beschreibung des Wurzelsystems von Hopfen und Mais über Freilegung am Bodenprofil. . *Die Bodenkultur -Journal of Land Management, Food and Environment, 69*(2), 121-130.

Spiekers, H. (2019, 05.09.2019). [Experteninformation zu Nährstoffgehalten im Rinderfutter, persönliche Mittteilung].

Spielmanns, R. (2020, 20.05.2020). [Tierzahlen Rinder, persönliche Mitteilung].

Sponagel, H. (2005). *Bodenkundliche Kartieranleitung : mit 103 Tabellen* (A.-h.-A. B. d. S. G. D. u. d. B. f. G. u. Rohstoffe Ed. 5., verb. und erw. Aufl. ed.). Hannover: Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

Spörl, R. (2009). *Revision des BVT-Merkblattes für die Papier- und Zellstoffherstellung: Vergleichbarkeit von Berichtsdaten : Teilbericht 2 / bearb.: Rainer Spörl*: Heidenau [u.a.] 2009.

Spyromitros-Xioufis, E., Tsoumakas, G., Groves, W., & Vlahavas, I. (2016). Multi-target regression via input space expansion: treating targets as inputs. *Machine Learning, 104*(1), 55-98. doi:10.1007/s10994-016-5546-z

Statistik der Kohlenwirtschaft. (2022). Herstellung von Braunkohlenbriketts, Braunkohlenkoks, Staub-, Trocken- und Wirbelschichtkohle nach Revieren. Retrieved from http://www.kohlenstatistik.de/3-0-Uebersichten.html

Statistische Ämter des Bundes und der Länder. (2010). Landwirtschaftszählung 2010: Agrarstrukturen in Deutschland – Regionale Ergebnisse der Landwirtschaftszählung 2010. Retrieved from https://www.statistikportal.de/de/veroeffentlichungen/landwirtschaftszaehlung-2010

Statistisches Bundesamt. (1992). *Statistisches Jahrbuch 1992 für die Bundesrepublik Deutschland* (3824602385). Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=cat04356a&AN=fuu.02025892&lang=de&site=eds-live

Statistisches Bundesamt (2017, 28.08.2017). [Persönliche Mitteilung von Herrn Kaiser; E 207: Deutschland - Erhebung über Gewinnung, Verwendung und Abgabe von Klärgas].

Statistisches Bundesamt. (2018). *Abfallentsorgung (ehemals Fachserie 19, Reihe 1: Umwelt, Abfallentsorgung)*. Retrieved from https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/Abfallwirtschaft/_inhalt.html#_b3r77i0vp

Statistisches Bundesamt. (2019). *Abfallentsorgung (ehemals Fachserie 19, Reihe 1: Umwelt, Abfallentsorgung)*. Retrieved from https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/Abfallwirtschaft/_inhalt.html#_b3r77i0vp

Statistisches Bundesamt. (2020). Ausgewählte Zahlen für die Bauwirtschaft. GENESIS-Online Datenbank Retrieved 12.05.2020, from Statistisches Bundesamt, https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Bauen/Tabellen/baufertigstellungen.html

Statistisches Bundesamt. (2021a). Abfallentsorgung (ehemals Fachserie 19, Reihe 1: Umwelt, Abfallentsorgung). from Statistisches Bundesamt

Statistisches Bundesamt. (2021b). *Produktionswert, -menge, -gewicht und Unternehmen der Vierteljährlichen Produktionserhebung: Deutschland, Jahre, Güterverzeichnis (9-Steller), bereit gestellt im Rahmen einer vereinbarten jährlichen Aktualisierung und Fortschreibung*.

Statistisches Bundesamt. (2022a). Aquakulturbetriebe, Anlagengröße: Deutschland, Jahre, Anlagenarten. Wiesbaden.

Statistisches Bundesamt. (2022b). *Erhebung über die Energieverwendung der Betriebe des Verarb. Gewerbes sowie des Bergbaus und der Gewinnung von Steinen und Erden (060)*. Tabelle 2: Energieverbrauch nach Energieträgern. Unveröffentlichtes Werk.

Statistisches Bundesamt. (2022c). Feldfrüchte und Grünland: Dauergrünland nach Art der Nutzung im Zeitvergleich.

Statistisches Bundesamt. (2022d). *Jahreserhebung über die Stromerzeugungsanlagen der Betriebe im Verarbeitenden Gewerbe sowie im Bergbau und in der Gewinnung von Steinen und Erden (067)*. Tabelle 2: Energieverbrauch nach Energieträgern. Unveröffentlichtes Werk. Statistisches Bundesamt.

Statistisches Bundesamt. (2022e). Methoden: Energie - Branchen und Unternehmen. Retrieved from https://www.destatis.de/DE/Methoden/Qualitaet/Qualitaetsberichte/Energie/einfuehrung.html

Statistisches Bundesamt. (2022f). *Produktionswert, -menge, -gewicht und Unternehmen der Vierteljährlichen Produktionserhebung: Deutschland, Jahre, Güterverzeichnis (9-Steller), bereit gestellt im Rahmen einer vereinbarten jährlichen Aktualisierung und Fortschreibung*.

Statistisches Bundesamt. (2022g). Sondererhebung: Proteineinsatz in der Schweinemast im Zeitraum 1. November 2020 bis 31. Oktober 2021. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Tiere-Tierische-Erzeugung/Tabellen/sonderauswertung-schweinemast.html

Statistisches Bundesamt. (2022h). *Statistik der Sterbefälle: Gestorbene (Anzahl)*. Retrieved from: https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/Geburten/Tabellen/lebendgeborene-gestorbene.html

Statistisches Bundesamt. (2022i). Statistischer Bericht - Abfallentsorgung 2020. Wiesbaden.

Statistisches Bundesamt. (2022j). Tabelle 46321-0005 Beförderte Güter, Beförderungsleistung (Binnenschifffahrt): Deutschland, Jahre, Güterverzeichnis (Abteilungen und Gruppen). Available from Destatis Genesis Online https://www-genesis.destatis.de/genesis/online

Statistisches Bundesamt (ab 2012). [Persönliche Mitteilung von DESTATIS-Mitarbeitern aus FG E 207: Deutschland - Erhebung über Gewinnung, Verwendung und Abgabe von Klärgas; jährlich].

Statistisches Bundesamt. (ab 2013). WasserwirtschaftWasser-wirtschaft: Klärschlamm-entsorgung aus der öffentlichen Abwasser-behandlung.

Statistisches Bundesamt. (dreijährlich - FS 19, R. 2.1.3). Fachserie. 19, Umwelt. 2, Wasserversorgung und Abwasserbeseitigung. 1, Öffentliche Wasserversorgung und öffentliche Abwasserentsorgung. 3, Strukturdaten zur Wasserwirtschaft. *Fachserie 19, Umwelt*.

Statistisches Bundesamt. (FS 3, R 3a). Land- und Forstwirtschaft, Fischerei, Landwirtschaftliche Bodennutzung und pflanzliche Erzeugung Retrieved 14.09.2020 https://www.destatis.de/DE/Service/Bibliothek/_publikationen-fachserienliste-3.html

Statistisches Bundesamt. (FS 3, R 3b). Land- und Forstwirtschaft, Fischerei, Landwirtschaftliche Bodennutzung und pflanzliche Erzeugung (div. Jgg.). https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/Bodennutzung/BodennutzungErzeugung.html

Statistisches Bundesamt. (FS 3, R 3.1.2). Land- und Forstwirtschaft, Fischerei,– Bodennutzung der Betriebe (Landwirtschaftlich genutzte Flächen) (div. Jgg.). https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/Bodennutzung/LandwirtschaftlicheNutzflaeche.html

Statistisches Bundesamt. (FS 3, R 3.1.4). Land- und Forstwirtschaft, Fischerei,– Landwirtschaftliche Bodennutzung - Baumobstflächen https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/ObstGemueseGartenbau/Baumobstflaechen.html

Statistisches Bundesamt. (FS 3, R 3.1.7). Land- und Forstwirtschaft, Fischerei, Landwirtschaftliche Bodennutzung - Baumschulerhebung (div. Jgg.). https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/ObstGemueseGartenbau/Baumschulerhebung.html

Statistisches Bundesamt. (FS 3, R 3.2.1). Land- und Forstwirtschaft, Fischerei, Wachstum und Ernte – Feldfrüchte (div. Jgg.). https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/Bodennutzung/LandwirtschaftlicheNutzflaeche.html

Statistisches Bundesamt. (FS 3, R 3.2.2). *Land- und Forstwirtschaft, Fischerei, Wirtschaftsdünger tierischer Herkunft in landwirtschaftlichen Betrieben - Erhebung zur Wirtschaftsdüngerausbringung (div. Jgg.)*

Statistisches Bundesamt. (FS 3, R 3.3.1). Land- und Forstwirtschaft, Forstwirtschaftliche Bodennutzung - Holzeinschlagsstatistik. https://www.destatis.de/DE/Service/Bibliothek/_publikationen-fachserienliste-3.html

Statistisches Bundesamt. (FS 3, R 4). Land- & Forstwirtschaft, Fischerei Viehbestand und tierische Erzeugung (div. Jgg.). https://www.destatis.de/DE/Publikationen/Thematisch/LandForstwirtschaft/ViehbestandTierischeErzeugung/ViehbestandtierischeErzeugung.html

Statistisches Bundesamt. (FS 3, R 4.1). Land- und Forstwirtschaft, Fischerei, Viehbestand. Retrieved 14.09.2020, from Statistisches Bundesamt https://www.destatis.de/DE/Service/Bibliothek/_publikationen-fachserienliste-3.html

Statistisches Bundesamt. (FS 3, R 5.1). *Bodenfläche nach Art der tatsächlichen Nutzung*. Retrieved from https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Landwirtschaft-Forstwirtschaft-Fischerei/Flaechennutzung/Publikationen/Downloads-Flaechennutzung/bodenflaechennutzung-2030510177004.html

Statistisches Bundesamt. (FS 4, R 3.1). Produktion des Verarbeitenden Gewerbes sowie des Bergbaus und der Gewinnung von Steinen und Erden (div. Jgg.). https://www.destatis.de/DE/Publikationen/Thematisch/IndustrieVerarbeitendesGewerbe/Konjunkturdaten/ProduktionJ.html

Statistisches Bundesamt. (FS 4, R 8.1). Produzierends Gewerbe - Eisen und Stahl (div. Jgg. bis 2009). https://www.destatis.de/DE/Startseite.html

Statistisches Bundesamt. (FS 4, R 8.2). Verarbeitendes Gewerbe (Düngemittel / Rohholz) - Düngemittelversorgung. Retrieved 14.09.2020, from Statistisches Bundesamt https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Industrie-Verarbeitendes-Gewerbe/_inhalt.html#_sndpeo3vm

Statistisches Bundesamt. (FS 19, R 2.1.2). Fachserie 19, Reihe 2.1.2, Öffentliche Abwasserbehandlung und -entsorgung; ab 2010: 3-jährig.

Statistisches Bundesamt. (jährlich). Wasser-wirtschaft: Klärschlamm-entsorgung aus der öffentlichen Abwasser-behandlung (Stand: 2021 ed.).

Statistisches Bundesamt. (jährlich - FS 4, R. 3.1). Fachserie. 4, Produzierendes Gewerbe. 3, Produktion im Produzierenden Gewerbe. 1, Produktion des Verarbeitenden Gewerbes sowie des Bergbaus und der Gewinnung von Steinen und Erden. . *Fachserie 4, Produzierendes Gewerbe, Fachserie 4, Reihe 3.1*.

Statistisches Bundesamt. (jährlich - FS 19, R. 1). Fachserie 19, Reihe 1: Umwelt, Abfallentsorgung. *Fachserie 19, Umwelt*.

Statistisches Bundesamt. (o.J.). Außenhandelsstatistik: Zeitreihen aus 51000BJ180. Wiesbaden.

Statistisches Bundesamt. (ohne Jahresangabe). GENESIS Online : Die Datenbank des Statistischen Bundesamtes (Online-Datenbank). from Statistisches Bundesamt https://www-genesis.destatis.de/genesis/online

Stegmann, R. (2012). *Fachgutachten: „Methanemissionen aus der Ablagerung von mechanischbiologisch behandelten Abfällen"*

Stegmann, R., Heyer, K.-U., Hupe, K., Rettenberger, G., & Schneider, R. (2018). *Überprüfung der methodischen Grundlagen zur Bestimmung der Methanbildung in Deponien - Endbericht*

Stehfest, E., & Bouwman, L. (2006). N2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. *Nutrient Cycling in Agroecosystems, 74*(3), 207-228.

StMELF. (diverse Jahrgänge). Herkunftssicherungs- und Informationssystem für Tiere. http://www.hi-tier.de

Stocker, T. F., Qin, D., & Plattner, G.-K. (Eds.). (2014). *Climate Change 2013 - The Physical Science Basis : Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Stolzenburg, K. (2006). Versuchsergebnisse, Weiden, Pappeln und Miscanthus der LAP Forchheim (pp. 63-80). Forchheim: Landesanstalt für Pflanzenbau.

Strauß, K. (1998). *Kraftwerkstechnik : zur Nutzung fossiler, nuklearer und regenerativer Energiequellen* (4. Aufl. ed.). Berlin: Springer.

Struschka, M., Kilgus, D., Springmann, M., & Behnke, A. (2008). *Effiziente Bereitstellung aktueller Emissionsdaten für die Luftreinhaltung*. Dessau-Roßlau.

TA Luft - Technische Anleitung zur Reinhaltung der Luft vom 27. Februar 1986 - Erste Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz, Gemeinsames Ministerialblatt S. 95, ber. S. 202, (1986).

TA Luft - Technische Anleitung zur Reinhaltung der Luft vom 24. Juli 2002 - Erste Allgemeine Verwaltungsvorschrift zum Bundes-Immissionsschutzgesetz, (2002).

Tebert, C., Volz, S., & Töfge, K. (2016). *Ermittlung und Aktualisierung von Emissionsfaktoren für das nationale Emissionsinventar bezüglich kleiner und mittlerer Feuerungsanlagen der Haushalte und Kleinverbraucher*

The R Core Team. (2022). R: A Language and Environment for Statistical Computing - Reference Index: The R Core Team - Version 4.3.0 Under development (unstable). https://www.R-project.org/

Theloke, J., Kampffmeyer, T., Kugler, U., Friedrich, R., Schilling, S., Wolf, L., & Springwald, T. (2013). *Ermittlung von Emissionsfaktoren und Aktivitätsraten im Bereich IPCC (1996) 1.B.2.a. i-vi - Diffuse Emissionen aus Mineralöl und Mineralölprodukten* (Förderkennzeichen 360 16 033)

Theloke, J., Kampffmeyer, T., Kugler, U., Friedrich, R., Wolf, L., Springwald, T., & Voß, A. (2013). *Ermittlung von Emissionsfaktoren und Aktivitätsraten im Bereich IPCC (1996) 1.B.2.a. i-vi - Diffuse Emissionen aus Mineralöl und Mineralölprodukten - Abschlussbericht* - (Förderkennzeichen 360 16 033). Retrieved from http://webde/gruppen/bibliothek/OnlineReports/EF000477.pdf [Zugriff erfolgt über IP-Erkennung]

Theloke, J., Wagner, S., & Jepsen, D. (2008). *Emissionen aus der Nahrungsmittelindustrie / von Jochen Theloke*: Stuttgart [u.a.].

Thünen-Institut. (2016). *Ausführungsbestimmung zur Erstellung von Emissions- und Kohlenstoffinventaren und deren Qualitätsmanagement für den Bereich der Quellgruppen Landwirtschaft und LULUCF. Anlage zum Konzept Emissions- und Kohlenstoffinventare im nachgeordneten Bereich des BMEL vom 14.09.2016. Version 2.01, Stand vom 14.09.2016*. Thünen-Institut.

TI, J. H. v. T.-I. (2016). *Ausführungsbestimmung zur Erstellung von Emissions- und Kohlenstoffinventaren und deren Qualitätsmanagement für den Bereich der Quellgruppen Landwirtschaft und LULUCF. Anlage zum Konzept Emissions- und Kohlenstoffinventare im nachgeordneten Bereich des BMEL vom 14.09.2016. Version 2.01, Stand vom 14.09.2016*. THÜNEN-INSTITUT (Johann Heinrich von Thünen-Institut).

Tiemeyer, B., Freibauer, A., Borraz, E. A., Augustin, J., Bechtold, M., Beetz, S., Beyer, C., Ebli, M., Eickenscheidt, T., Fiedler, S., Förster, C., Gensior, A., Giebels, M., Glatzel, S., Heinichen, J., Hoffmann, M., Höper, H., Jurasinski, G., Laggner, A., Leiber-Sauheitl, K., Peichl-Brak, M., & Drösler, M. (2020a). A new methodology for organic soils in national greenhouse gas inventories: Data synthesis, derivation and application. *Ecological Indicators, 109*, 105838. doi:https://doi.org/10.1016/j.ecolind.2019.105838

Tiemeyer, B., Freibauer, A., Borraz, E. A., Augustin, J., Bechtold, M., Beetz, S., Beyer, C., Ebli, M., Eickenscheidt, T., Fiedler, S., Förster, C., Gensior, A., Giebels, M., Glatzel, S., Heinichen, J., Hoffmann, M., Höper, H., Jurasinski, G., Laggner, A., Leiber-Sauheitl, K., Peichl-Brak, M., & Drösler, M. (2020b). A new methodology for organic soils in national greenhouse gas inventories: Data synthesis, derivation and application. *Ecological Indicators, 109*, 14. doi:10.1016/j.ecolind.2019.105838

Tietge, U., Dornoff, J., Diaz, S., & Jahn, H. (2020). *Erarbeitung einer Methode zur Ermittlung und Modellierung der CO2-Emissionen des Kfz-Verkehrs : Abschlussbericht Texte / Umweltbundesamt* (pp. 1). Retrieved from http://www.umweltbundesamt.de/publikationen/erarbeitung-einer-methode-zur-ermittlung

http://webde/gruppen/bibliothek/OnlineReports/FB000242.pdf

Tuomi, M., Thum, T., Järvinen, H., Fronzek, S., Berg, B., Harmon, M., Trofymow, J. A. T., Sevanto, S. A., & Liski, J. (2009). Leaf litter decomposition—Estimates of global variability based on Yasso07 model. *Ecological Modelling, 220*(23), 19. doi:10.1016/j.ecolmodel.2009.05.016

UBA. (2022). Daten: Atmosphärische Treibhausgas-Konzentrationen. *Daten zur Umwelt.* Retrieved from https://www.umweltbundesamt.de/daten/klima/atmosphaerische-treibhausgas-konzentrationen

UMEG. (2004). Emissionsfaktoren-Handbuch Emissionserklärung 2004 Baden-Württemberg. *Zentrum für Umweltmessung, Umwelterhebungen und Gerätesicherheit Baden-Württemberg (UMEG), 4-02/2004*.

Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its first session, held at Montreal from 28 November to 10 December 2005, § 39 (2006).

UNFCCC. (2010). *National Reports - GHG Inventories (Annex I) - Inventory Review Reports* Retrieved from http://unfccc.int/national_reports/annex_i_ghg_inventories/inventory_review_reports/items/4715.php

UNFCCC. (2011). *Report of the technical assessment of the forest management reference level submission of Germany submitted in 2011*. Retrieved from https://unfccc.int/documents/6826

UNFCCC. (2013a). *Methodological issues under the Convention: Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention*. Retrieved from http://www.unfccc.int/resource/docs/2013/sbsta/eng/l29a01.pdf

UNFCCC. (2013b). Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention, Decision 24/CP.19, Annex I, Guidelines for the preparation of national communications by Parties included in Annex I to the Convention. Retrieved from http://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf#page=2

UNFCCC. (2014a). *Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013. Addendum - Part two: Action taken by the Conference of the Parties at its nineteenth session*. Retrieved from https://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf

UNFCCC. (2014b). *Report of the COP on its nineteenth session, held in Warsaw from 11 to 23 November 2013. Addendum: Decision 24/CP.19 on the Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention.*

UNFCCC. (2020). *National Inventory Submissions 2020*. Retrieved from https://unfccc.int/ghg-inventories-annex-i-parties/2020

UNFCCC. (2021). *National Inventory Submissions 2021*. Retrieved from https://unfccc.int/ghg-inventories-annex-i-parties/2021

UNFCCC. (2022a). GHG Review Tools • Locator. Retrieved from https://rt.unfccc.int/locator

UNFCCC. (2022b). *National Inventory Submissions 2022*. Retrieved from https://unfccc.int/ghg-inventories-annex-i-parties/2022

United Nations Economic Comission for Europe: Convention on Long-range Transboundary Air Pollution (CLRTAP), (1979).

UStatG: Umweltstatistikgesetz vom 16. August 2005 (BGBl. I S. 2446), das zuletzt durch Artikel 2 Absatz 5 des Gesetzes vom 5. Juli 2017 (BGBl. I S. 2234) geändert worden ist, § § 10 Erhebung bestimmter klimawirksamer Stoffe (2005).

Vasenev, I. I., Vasenev, V. I., & Stoorvogel, J. J. (2013). Urban soil organic carbon and its spatial heterogeneity in comparison with natural and agricultural areas in the Moscow region. *Catena, 107*, 7.

VDA. (2013). AdBlue. In V. d. Automobilindustrie (Ed.). Berlin: Verband der Automobilindustrie (VDA).

VDD. (2009). *Berechnung auf Basis des Standes der Technik deutscher Hersteller*.

VDD. (2022). *Jährliche Datenübermittlung des Verbandes* [xlsx]. Retrieved from: Inventarbeschreibung in „Bitumen_AREF_Zeitreihen_und_Unsicherheiten_Archiv.zip“

VDI. (1998). *Emissionsminderung ; Aluminiumschmelzflußelektrolyse : VDI Richtlinie 2286, Bl. 1, Stand: Dezember 1998*: Berlin Beuth-Verlag GmbH 1998.

VDI-Richtlinie 2440: Emissionsminderung - Mineralölraffinerien, (2000).

VDI. (2006). *Emissionsminderung - Keramische Industrie: VDI 2585* (Stand: Februar 2006 ed.). Berlin: Beuth-Verlag GmbH.

VDI. (2017). *Emissionsminderung ; Glashütten : VDI Richtlinie 2578, Stand: Mai 2017*. Berlin: Beuth.

VDMA. (2011). *Energiebedarf für Kältetechnik in Deutschland*

VDZ. (2016). Zement – Produktionsdaten der deutschen Zementindustrie: Verein Deutscher Zementwerke e.V. (VDZ).

Vogel, V., Hans U., & Synowietz, C. (1974). *Chemikerkalender* (2. Auflage ed.). Berlin: Springer-Verlag.

Volk, F. (1986). Detonation gases and residues of composite explosives. *Journal of energetic Materials, 4(1)*, p. 93-113.

von Winkler, M. (2004). Abschätzung von Emissionsfaktoren bei Transport und Lagerung von Mineralölprodukten *Trade Journal, 120*(10).

Wagner, J., & Steinmetzer, S. (2018). *Erhebung der Größen und Zusammensetzung von Brauchtums- und Lagerfeuern durch kommunale Befragungen Texte / Umweltbundesamt* (pp. 1). Retrieved from http://www.umweltbundesamt.de/publikationen/erhebung-der-groessen-zusammensetzung-von

Wallfarth, B. (2014). [E-Mail].

Wallmann, R. (1999). *Ökologische Bewertung der mechanisch-biologischen Restabfallbehandlung und der Müllverbrennung auf Basis von Energie-und Schadgasbilanzen*: ANS.

Walter, K., Don, A., & Flessa, H. (2015). No general soil carbon sequestration under Central European short rotation coppices. *Gcb Bioenergy, 7*(4), 727-740.

Warncke, K., Schwarz, W., & Gschrey, B. (2018). *Emissionen fluorierter Treibhausgase in Deutschland 2016 - Daten von HF(C)KW, FKW, SF6, NF3, SF5CF3, H(C)FE und PFPMIE für die nationale Emissionsberichterstattung gemäß Klimarahmenkonvention für das Berichtsjahr 2016*

WEG. (2008). Erdgas-Erdöl, Entstehung-Suche-Förderung. Retrieved from http://www.erdoel-erdgas.de/Erdgas_Erd%F6l___Entstehung___Suche___F%F6rderung-134-1-68b.html

Wei, Z., Wu, S., Yan, X., & Zhou, S. (2014). Density and stability of soil organic carbon beneath impervious surfaces in urban areas. *PloS one, 9*(10), e109380.

Weilbacher. (1987). *Ausgasung von Zellgasen*

Weiß, M., Neelis, M., & Patel, M. (2006). *Estimating CO2 Emissions from the Non-Energy Use of Fossil Fuels in Germany - Final Report*. Report. Department of Science, Technology, and Society (STS). Utrecht University (UU) - Copernicus Institute. Utrecht.

Weiss, P., Schieler, K., Schadauer, K., & Englisch, M. (2000). *Die Kohlenstoffbilanz des österreichischen Waldes und Betrachtungen zum Kyoto-Protokoll*. Wien: UBA - Umweltbundesamt.

Wellbrock, N., Aydin, C.-T., Block, J., Wolff, B., Evers, J., Gauer, J., Gehrmann, J., Kölling, C., König, N., Liesebach, M., Martin, J., Meiwes, K. J., Riek, W., D., F. K., Milbert, G., Raben, G., Schäffer, W., Bussian, B., Deckert, M., & Diekmann, O. (2006). *Bodenzustandserhebung im Wald (BZE II), Arbeitsanleitung für die Außenaufnahmen*

Wellbrock, N., Bolte, A., & Flessa, H. (2016). *Dynamik und räumliche Muster forstlicher Standorte in Deutschland: Ergebnisse der Bodenzustandserhebung im Wald 2006 bis 2008* (978-3-86576-161-3). Retrieved from https://ideas.repec.org/p/zbw/jhtire/43.html

Wickham, H., & Müller, K. (2022). R Special Interest Group on Databases (R-SIG-DB). https://cran.r-project.org/web/packages/DBI/index.html

Wickham, H., Ooms, J., Müller, K., Nishiyama, T., & Müller, K. (2022). Rcpp Interface to PostgreSQL. 17. https://cran.r-project.org/web/packages/RPostgres/RPostgres.pdf

Wiechmann, B., Dienemann, C., Kabbe, C., Brandt, S., Vogel, I., & Roskosch, A. (2013). *Klärschlammentsorgung in der Bundesrepublik Deutschland* (U.-. Umweltbundesamt Ed.). Dessau-Roßlau: UBA - Umweltbundesamt.

Wirth, C., Schulze, E. D., Schwalbe, G., Tomczyk, S., Weber, G., Weller, E., Böttcher, H., Schumacher, J., & Vetter, J. (2004). *Dynamik der Kohlenstoffvorräte in den Wäldern Thüringens : Abschlussbericht zur 1. Phase des BMBF-Projektes "Modelluntersuchung zur Umsetzung des Kyoto-Protokolls*. Retrieved from https://www.researchgate.net/profile/Christian-Wirth-4/publication/42088487_Dynamik_der_Kohlenstoffvorrate_in_den_Waldern_Thuringens_Abschlussbericht_zur_1_Phase_des_BMBF-Projektes_Modelluntersuchung_zur_Umsetzung_des_Kyoto-Protokolls/links/56196d6708ae78721f9d0172/Dynamik-der-Kohlenstoffvorraete-in-den-Waeldern-Thueringens-Abschlussbericht-zur-1-Phase-des-BMBF-Projektes-Modelluntersuchung-zur-Umsetzung-des-Kyoto-Protokolls.pdf

Wolff, B., & Riek, W. (1997). *Deutscher Waldbodenbericht 1996-Ergebnisse der bundesweiten Bodenzustandserhebung in Wald (BZE) 1987-1993*

World Meteorological Organization. (2018). WMO Statement on the Status of the Global Climate in 2017. Genf: Switzerland: World Meteorological Association.

World Meteorological Organization. (2020). WMO Statement on the Status of the Global Climate in 2019. Geneva: Switzerland: World Meteorological Association.

Wutzler, T., Wirth, C., & Schumacher, J. (2008). Generic biomass functions for Common beech (Fagus sylvatica) in Central Europe: predictions and components of uncertainty. *Canadian Journal of Forest research, 38*(6), 1661-1675. doi:10.1139/X07-194

Zander, F., & Merten, D. (2006). *Teilvorhaben A: Überarbeitung und Dokumentation der Brennstoffeinsätze für stationäre Feuerungsanlagen in den neuen Bundesländern für das Jahr 1990* (FKZ 205 41 115)

Zimmermann, T., & Jepsen, D. (2018). *Entwicklung von Methoden zur Berechnung von Treibhausgas- und Luftschadstoffemissionen aus der Verwendung von Schmierstoffen und Wachsen*. Hamburg, Dessau-Roßlau.

Zöllner, S. (2014). *Überführung der Bestands- und Ereignisdaten des DVGW in die Emissionsdatenbank des Umweltbundesamts*