Magazine of the German Environment Agency
1/2019

WHAT MATTERS

Healthy Air

For our Environment

Umwelt Bundesamt

FOREWORD

Healthy air – don't we have it already?

Maria Krautzberger, President,
German Environment Agency

Unlike a few decades ago, there is virtually nothing to smell or taste when we step outside and take a deep breath nowadays. The situation is different in many metropolitan areas around the world, so in this respect we have achieved a lot. Nevertheless, not everywhere in Germany is the air free of risks to human health. This is a known fact, based on high-quality air measurements taken by the federal government and the states (Länder) throughout the year in locations where high levels of pollution are suspected.

So just how good should air quality be? The World Health Organization has evaluated many studies on the topic and issued compliance values that often go beyond what current legislation requires. Unfortunately, compliance with these WHO recommendations is often lacking.

Of course we all want to be able to breathe clean air everywhere. So what can be done? There are many reasons for health-damaging air pollution: beside transport there are the particulates formed by pollutants used in agriculture, solvents which produce ozone, coal power plants and other industrial installations which increase nitrogen dioxide and particulate pollution, and also wood-fired heating units. All of these sources and causes must make a contribution to improving air quality.

Germany and all the other Member States of the European Union made commitments to cut air pollutant emissions significantly over the next ten years. This alone will make a marked improvement, but the EU must agree on tighter and binding air pollutant limits and take action when these limits are exceeded to ensure that healthier air is everywhere.

And what can you as do an individual? As with other environmental concerns, our lifestyles play a key role in air pollution control. Everyone can do something for healthy air: take fewer car trips, use solvent-free cosmetics and paints, or do without the cozy fireplace – and thus help to make the air even better.

Maria Krautzberger

CONTENT

TOPIC

MOBILE APP

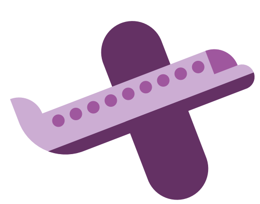
How good is the air you breathe?

Visualising the invisible – you can soon do that using our app "Air Quality". It contains air quality data from over 300 measuring stations including those in your area and is updated hourly. The quickest overview is provided by the "Air Quality Index (LQI)", which covers the pollutants particulate matter, nitrogen dioxide and ozone. Thus you are always informed about the air quality outdoors at the measuring points in your area, and obtain important health tips.

The app is available for mobile devices running Android and iOS operating systems.

STUDY

Fuel dumping of airplanes is noncritical for humans and the environment



For safety, aircraft sometimes have to dump fuel if they have to make an emergency landing shortly after take-off. A recent UBA study estimates the impact of these rapid fuel dumps on humans and the environment as noncritical. As a precaution, the operating instructions for the German Air Traffic Control System (Deutsche Flugsicherung) should stipulate that the same areas are not always allocated for fuel dumping.

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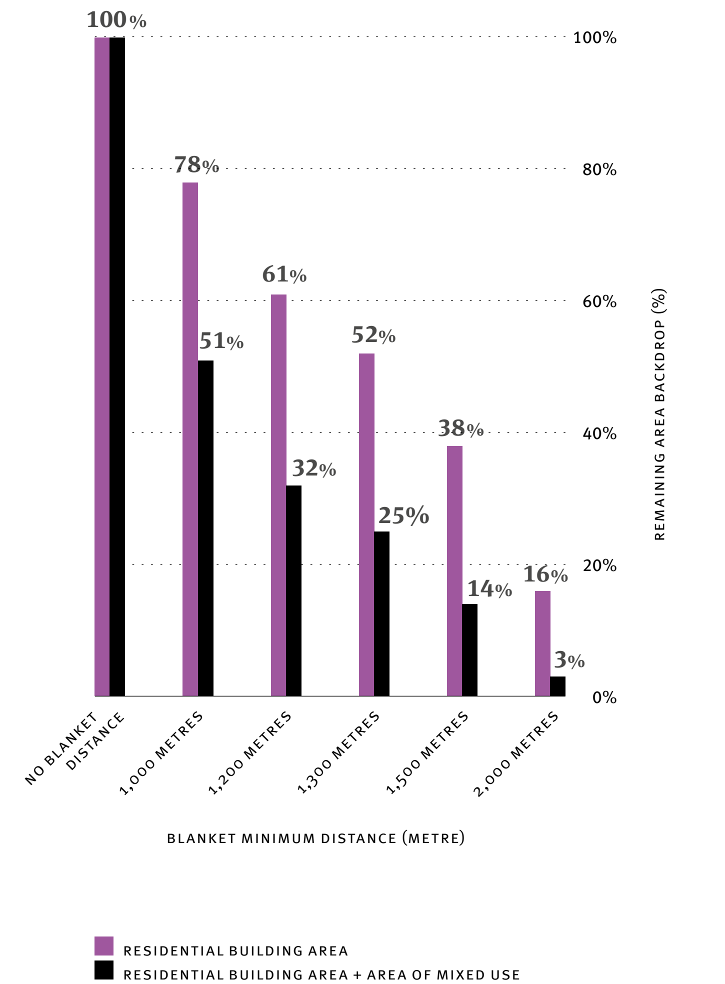
Figure 1

Remaining area backdrop as a function of blanket settlement distance:



POSITION

Minimum distances from wind turbines damage the energy transition

The minimum distances for wind turbines to residential areas would stall the expansion of wind energy. This is shown by a recent UBA study. Even at a blanket distance of 1,000 metres, the available areas would be reduced by 20 to 50 percent. An increase in wind energy capacity compared to the status quo would actually not be possible in the case of this comparatively small minimum distance. Instead of blanket distances, a site-specific examination of health and environmental concerns makes more sense.

Position Paper "Effects of Minimum Distances between Wind Turbines and Settlements"
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As of June 2019

2.8 billion

disposable cups for coffee and other hot beverages are used **every year** in Germany. This is:

7.6 million
per day

320,000
per hour

5,300
per minute

89
per second

And all of these cups end up, if we are lucky, in waste bins and, if we are not lucky, in the environment. Anyone who walks through the city with open eyes can see how big the problem is. There are empty disposable cups on every corner, and waste bins overflow – which leads to more litter in the environment when these bins cannot hold any more. The volume of thousands of disposable cups almost overwhelms city cleaning services. In Berlin the cups fill 15 percent of the municipal waste bins every day – and the trend continues to rise.

All disposable cups consist partly or completely of plastic due to the coating or the lid. They are virtually non-recyclable, and are generally incinerated. If disposable cups end up in the landscape rather than in the garbage, this plastic also gets into soils and water. Moreover, the production of these cups also harms the environment, as it consumes both energy and raw materials.

And last but not least, disposable cups are among the ten most commonly found disposable products containing plastic on the beaches and in the seas of Europe.

Reusable cups for a clean environment

We need a solution, and we have one: reusable cups. These are far more environmentally friendly than disposable cups. They consume less energy and produce (almost) no waste. The requirement is of course that the cups are used often. A recent study by the German Environment Agency has looked into this more closely: A cup should be used ten times to offset production costs. After that its life cycle assessment keeps getting better. This applies to reusable cups that can be handed out at cafés. For cups brought from home, the study calculated that they should be used at least 50 times. In this case it does not matter what the cup is made of, as with frequent use it is the washing process that matters most for the life cycle assessment. It is also best if the dishwasher runs on electricity from renewable energy sources.

The German Environment Agency worked out some ideas in the recent study on how to cut in half the consumption of disposable cups in Germany within the next three years. On the one hand, agreements should be made with industry to have reusable cups become the standard cups given out in the takeaway sector. This means that disposable cups would only be used when asked for explicitly. In addition, coffee and other hot beverages should be more expensive when sold in disposable cups rather than in reusable cups. The study also shows that lids consume a high proportion of energy in their production and cause pollution. It makes sense therefore not to use disposable lids on reusable cups. Guidelines by the Blue Angel should be followed for reusable cup systems (more on this below). Money from the “littering fund” is intended to be used both for cleaning public spaces and for information campaigns.

The German Environment Agency, together with the German Federal Ministry for the Environment, has now for the first time awarded the Blue Angel for reusable cup systems – to FairCup, a company founded in Göttingen. Its story is a beautiful one: FairCup was created in 2016 on the initiative of teacher Sibylle Meyer and her former students at the Vocational School II in Göttingen. Since then the company spread throughout Germany. The special feature of FairCup cups is that they can be returned very easily in reverse vending machines in participating supermarkets.

The Blue Angel for reusable cup systems guarantees that the coffee is consumed in an environmentally friendly manner. The cups themselves are made without materials that are environmentally harmful and dangerous to health. If they are made of plastic, then only of unmixed plastic and without coating. In this way, when they are disposed of, they can be recycled quite easily. Moreover, the cups must achieve a lifetime of 500 wash cycles.

So we already have good examples of the use of reusable cups and how we can reduce environmental impact while we enjoy our daily coffee to go. What remains to do is to implement these suggestions - and, as coffee drinkers, to use reusable cups more often.

Gerhard Kotschik
Packaging waste expert

For more information: “Investigation into the environmental impact of disposable cups outside the home and possible measures to reduce consumption”
www.umweltbundesamt.de/publikationen/oekologische-bedeutung-einweggetraenkebecher

TOPIC

The air you breathe

Photos by **Michael Kerstgens**

A healthy adult breathes in and out about eight litres of air every minute. During physical activity, it can be three to four times more, and for well-trained athletes it can even be as high as 15 times the baseline.

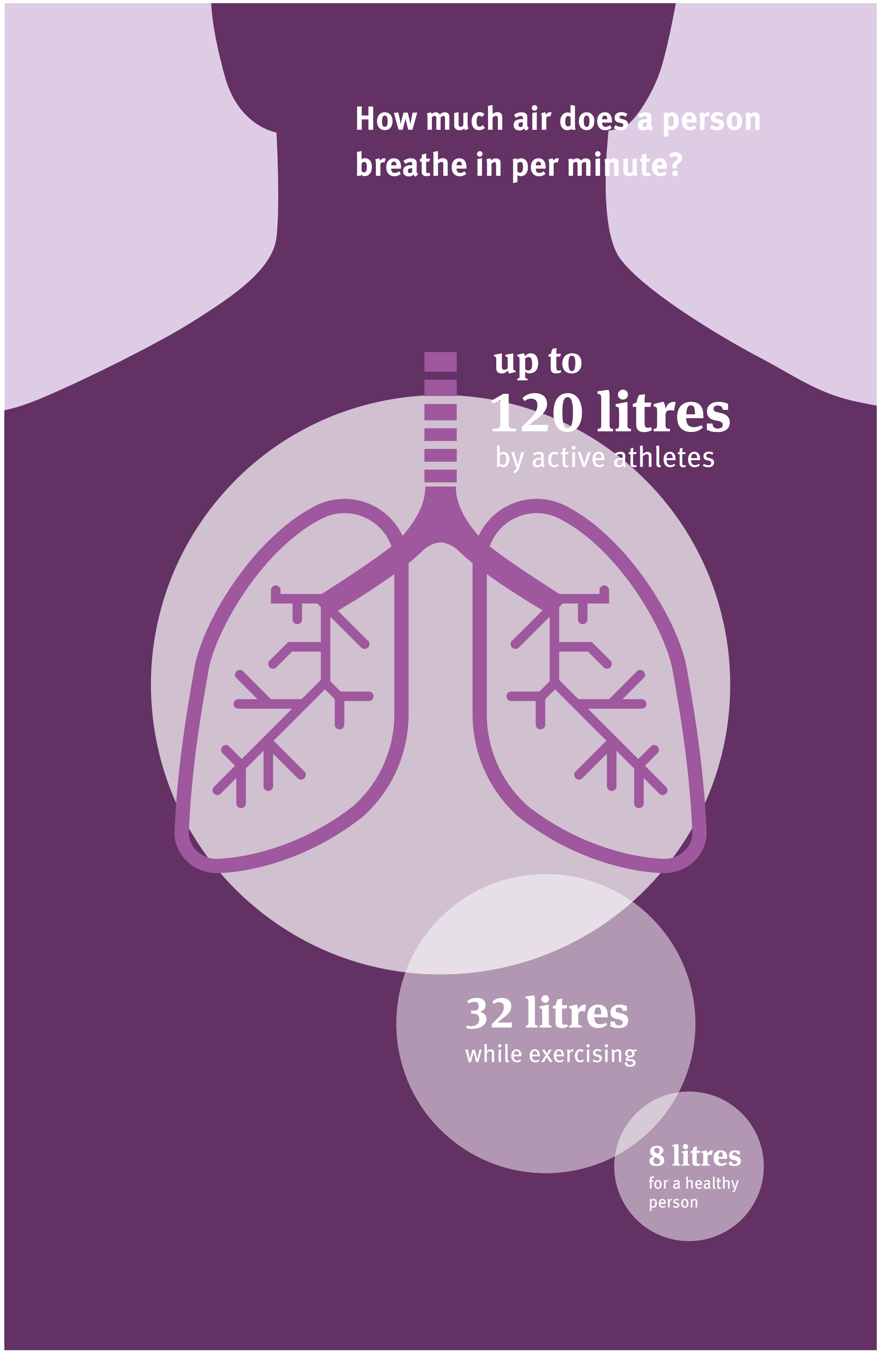
Without breathing we can usually survive for only a few minutes before the central nervous system is permanently damaged. Oxygen contained in the air is essential for the metabolism of all human cells, which makes air irreplaceable for our survival.

But how can we define healthy air? At first this sounds easy: inhaling does not cause any health damage. However, air can contain harmful substances and cause illness. The concentrations of such air pollutants must be low enough to be harmless to humans, even during long-term exposure. This applies to healthy people as well as to the elderly, children and people with illnesses, for example asthma.

What exactly is air?

The air around us consists of 78 percent nitrogen and 21 percent oxygen. Other components in very low concentrations are, for example, water vapour and carbon dioxide, a greenhouse gas, which has been steadily increasing since the 19th century through human activities such as the burning of fossil fuels (from 0.03 percent in pre-industrial times to around 0.04 percent today). In addition, there are trace substances such as nitrogen monoxide, hydrogen and various noble gases, which occur naturally in such low concentrations in the atmosphere that they do not harm human health. Human activities such as the burning of fossil fuels or intensive animal husbandry, however, create a whole range of airborne pollutants, which may cause high levels of air pollution and disease. These include, for example, particulate matter, ozone, nitrogen dioxide (NO_2) or sulphur dioxide (SO_2). These air pollutants can also be caused by volcanic eruptions, thunderstorms or forest fires. However, it was only through human influence that concentration levels were reached – especially in cities – that could permanently damage our health. Historical sources give evidence to problems with urban air pollution since antiquity. But it was not until industrialisation that air pollution reached levels so high as to not only affect people in the immediate vicinity of the source of pollution, but also caused people in more remote regions to feel its effects.

A billowing smokestack was still symbolic of economic growth at the onset of industrialisation. Subsequently, negative aspects of air pollution such as damage to health and nutrient inputs in ecosystems requiring protection came ever more into focus. Therefore, from 1950 onwards, measures were taken such as the control of small combustion plants and the prohibition of certain fuels in order to improve air quality.



Air pollution control in Germany is based on three pillars

The **first pillar** sets **emission limit values.** The regulated sectors include, for example, transport, industry, small combustion plants or agriculture. For limit values, as a rule, the 'precautionary principle' applies, according to which the emissions should not cause harmful concentrations in areas where people live. These emission limit values are also based on state-of-the-art techniques and are therefore constantly monitored and adjusted.

The **second pillar** limits **total national emissions** of air pollutants. The Convention on Long-range Transboundary Air Pollution is an international agreement to mitigate transnational air pollution, which was signed in 1979 under the auspices of the UN Economic Commission for Europe. Air pollutants know no national borders; international agreements can therefore ensure that clean air policies are coordinated between countries and have international impact. The Gothenburg Protocol, adopted under the Convention on Long-range Transboundary Air Pollution, set national ceilings for the four pollutants SO_2, nitrogen oxides, non-methane volatile organic compounds (NMVOC) and ammonia in 2010. By 2030 and in subsequent years, the national emissions of these four pollutants and of $PM_{2.5}$ must be further reduced to satisfy Germany's obligations under European law.

This reduction cannot always be achieved by tightening the emission limit values set in the first pillar. Voluntary activities also make an important contribution to the reduction of pollutant emissions: For all of us, this can mean, for example, eating less meat voluntarily and thus decreasing ammonia emissions by reducing fatstock. Or heating less often with wood, or foregoing more often a campfire, an Easter fire or private fireworks on New Year's Eve and thereby releasing less particulate matter. Or driving a car (with an internal combustion engine) less often to emit less particulate matter and nitrogen oxides. All of this helps make our air cleaner and healthier.

The **third pillar** is aimed directly at the **protection of human health**. Here, concentrations of pollutants in the ambient air are measured and limited. These limits have been set at the EU level and apply to all Member States. Limit values or target values are defined for short-term as well as for longer-term exposure situations. The short-term limit values refer to exposures on an hourly to daily basis and are intended to minimise short-term exposure situations that may be associated with acute health conditions. As examples, for particulate matter (PM_{10}[1]), a daily limit of 50 micrograms/m³ and, for nitrogen dioxide (NO_2), a limit of 200 micrograms/m³ per hour is specified. In order to reduce the long-term exposure to air pollutants and thus damage to health, which often does not occur before many years of continuous exposure, limit values were set based on an annual mean. These are lower than the short-term limits and, for example, are 40 micrograms/m³ on an annual average for both PM_{10} and NO_2.

Limit values are determined in a political process. These include, on the one hand, scientific findings on concentration values in which no significant health effects can be observed. These are for example compiled in the recommendations of the World Health Organization (WHO). On the other hand, there are the costs or other societal challenges associated with air pollution control to reduce concentrations of air pollutants. Costs arise, for example, when new filter systems or catalysts have to be developed and implemented. Passive measures such as the construction of moss walls or active systems for filtering outdoor air are, on the other hand, less efficient and have not resulted in any demonstrable reduction in ambient concentrations beyond the immediate range of a few metres.

The three pillars of air pollution control have caused, for example, concentrations of sulphur dioxide (SO_2) or lead-containing particles to decrease significantly.

Nevertheless, even today some of our air pollutants are at a level that is above the WHO recommendations, at least in heavily polluted areas. To protect our health in the long term, further efforts are needed to ensure clean and healthy air.

1 For a definition see Chapter "Air pollutants".

Success of Air Pollution Control

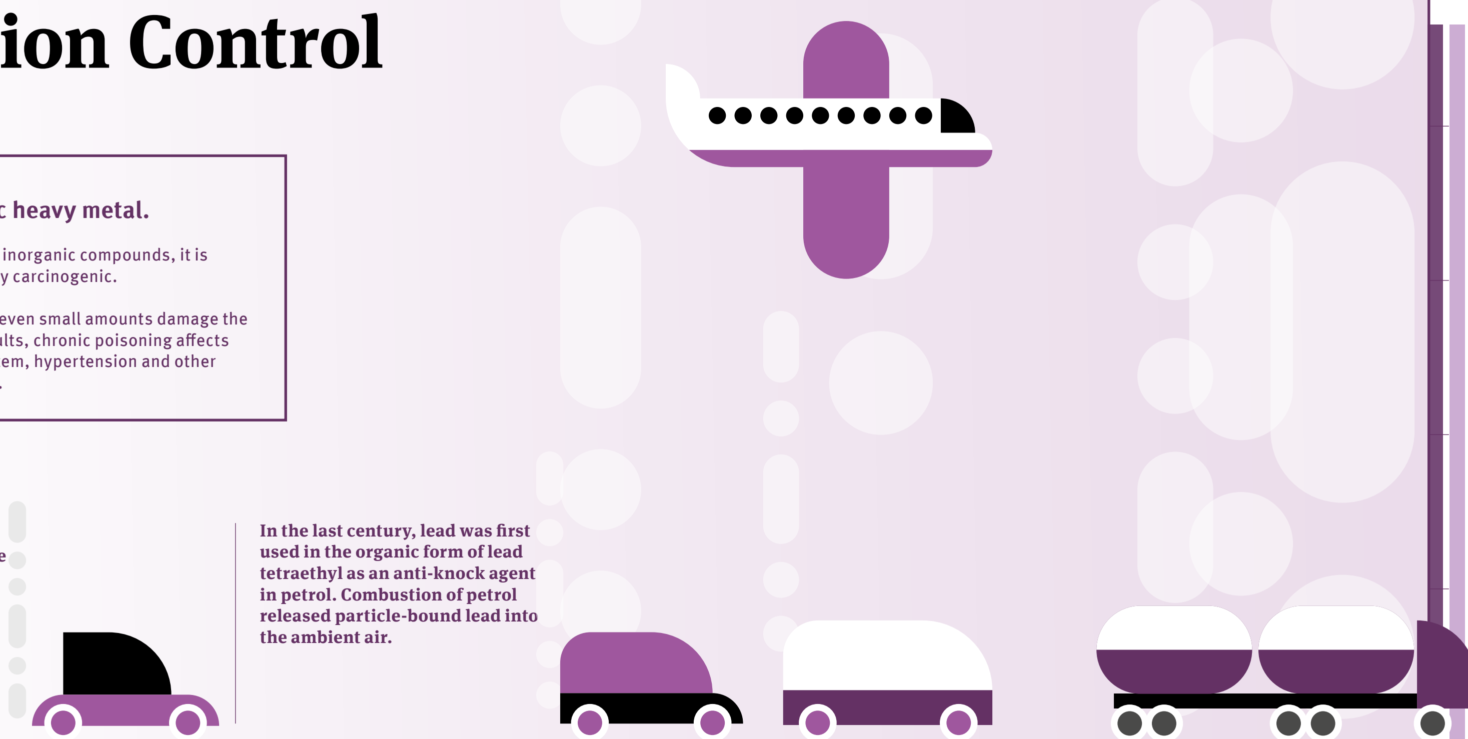
LEAD is a toxic heavy metal.

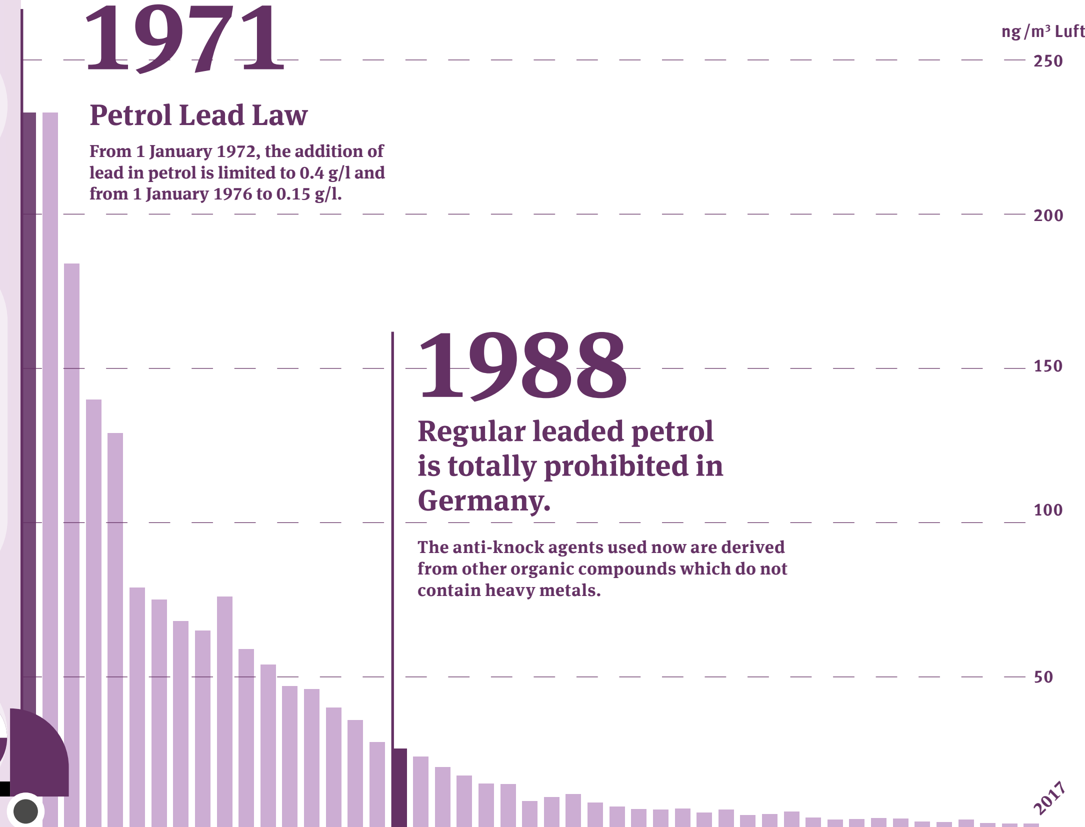
In its pure form and its inorganic compounds, it is classified as potentially carcinogenic.

Especially in children, even small amounts damage the nervous system. In adults, chronic poisoning affects the blood-forming system, hypertension and other nonspecific symptoms.

1877
The first petrol engine was produced

In the last century, lead was first used in the organic form of lead tetraethyl as an anti-knock agent in petrol. Combustion of petrol released particle-bound lead into the ambient air.





1971

Petrol Lead Law

From 1 January 1972, the addition of lead in petrol is limited to 0.4 g/l and from 1 January 1976 to 0.15 g/l.

1988

Regular leaded petrol is totally prohibited in Germany.

The anti-knock agents used now are derived from other organic compounds which do not contain heavy metals.

SULPHUR DIOXIDE is a colourless, pungent smelling, sour tasting, poisonous gas.

Sulphur dioxide irritates the mucous membrane and can cause eye irritation and respiratory problems.

1952

In conjunction with other air pollutants, sulphur dioxide was a major contributor to the smog event in London (Page 21, Air pollutants).

Sulphur dioxide can form various acids and particulate matter in the atmosphere.

The entry of these acids into the highland forests made sulphur dioxide one of the major causes of tree decline.

Therefore, the emission limit values of sulphur dioxide from incineration plants in the old Federal Republic of Germany were gradually tightened over the years.

The ordinance on large combustion plants (13th BImSchV), in its first version, sets a general emission limit value for sulphur dioxide for solid fuels fixed at 400 mg/m³.

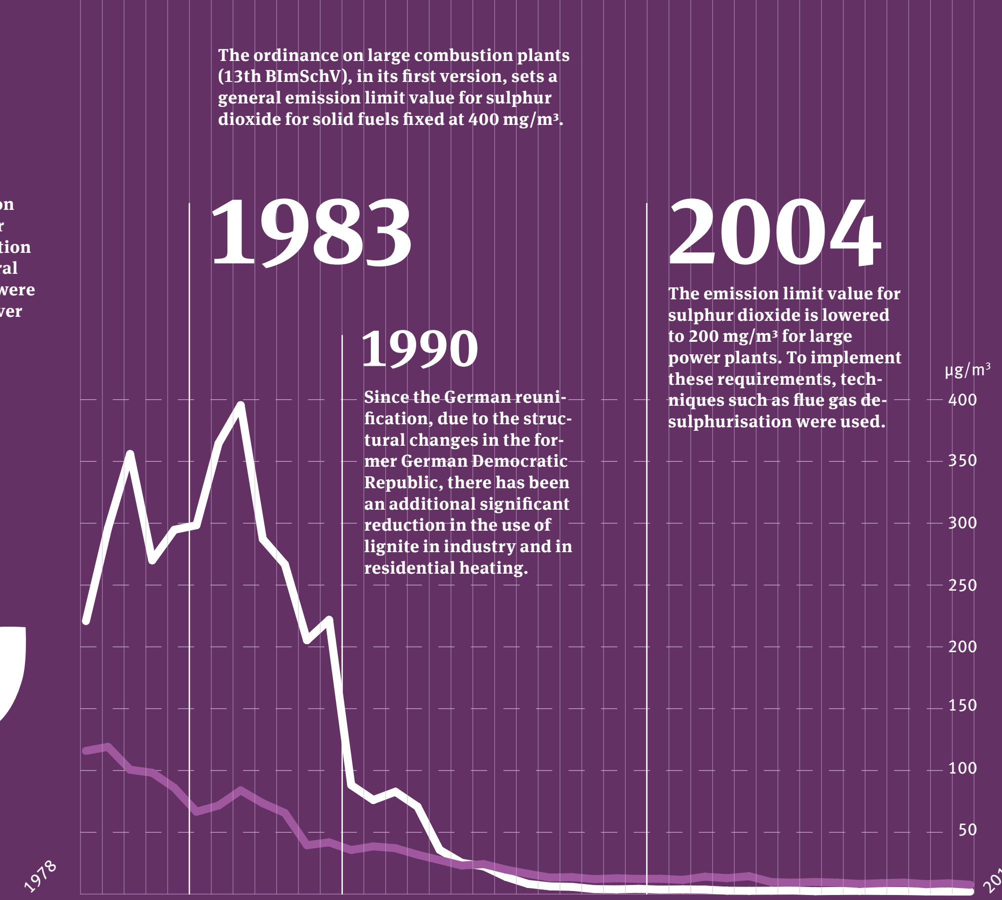
1983

1990

Since the German reunification, due to the structural changes in the former German Democratic Republic, there has been an additional significant reduction in the use of lignite in industry and in residential heating.

2004

The emission limit value for sulphur dioxide is lowered to 200 mg/m³ for large power plants. To implement these requirements, techniques such as flue gas desulphurisation were used.



Air Poll-utants

In December 1952, the smog in London was literally so thick that you could not see your hand in front of your face. A temperature inversion and the smoke from coal fires and industrial chimneys plunged the British capital into impenetrable smog. Over four days, at times the smog caused the visibility to drop to less than 30 centimetres. The consequences of this air pollution were significant: thousands of people died. As well as an extremely high concentration of particulate matter, high sulphur dioxide concentrations (SO_2) were also responsible for the disaster.

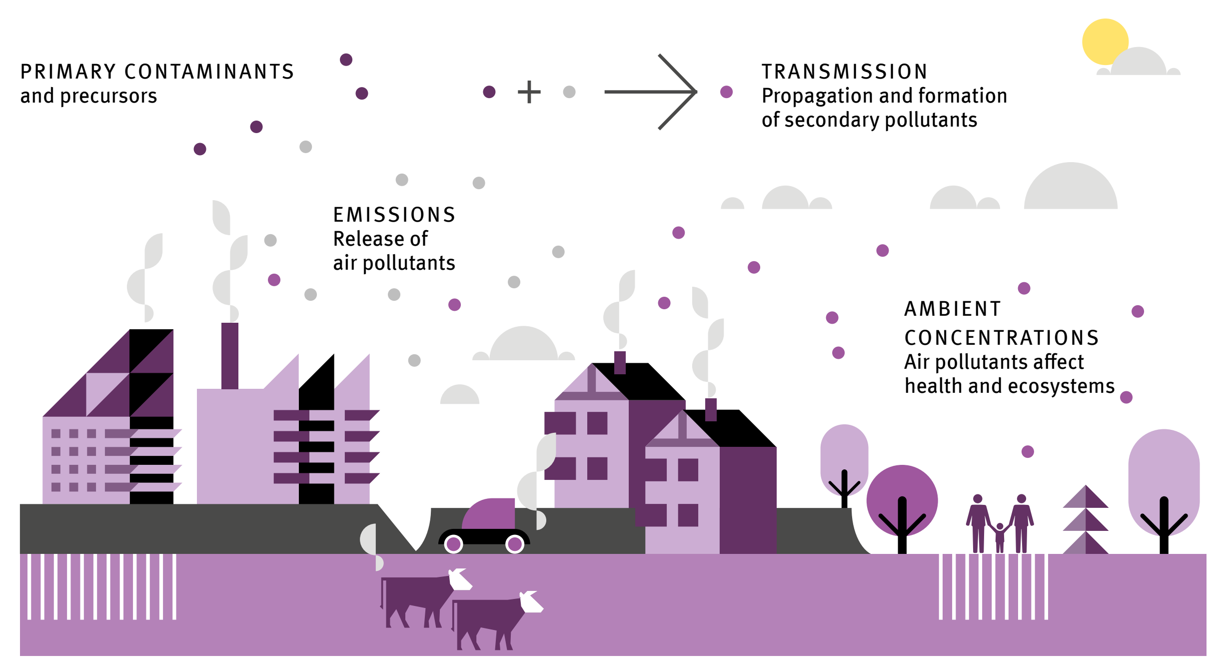
SO_2 still played a major role in Western industrialised countries in the middle of the last century, mainly due to industrial emissions and residential heating. However, flue gas desulphurisation in power plants and the use of low sulphur fuels have led to a significant reduction in the emissions so that health-damaging SO_2 concentrations are now a thing of the past in Germany.

Air pollution control always poses two fundamental questions: where do relevant air pollutants come from and how can we reduce harmful concentrations? The focus shifts again and again:

After the sulphur dioxide, leaded particles from petrol were a major health and environmental problem in the 1980s. The ban on lead in fuels effectively solved this problem.

Later, the particulate matter pollution from exhaust fumes became more prevalent. Here, too, filters could make the air cleaner.

With regard to health in Germany, there are currently three air pollutants in particular that cause problems: particulate matter, nitrogen dioxide (NO_2) and ozone. These regularly exceed the EU limits or the guidelines recommended by the World Health Organization (WHO).



Particulate Matter

Particles occur in the atmosphere in a variety of sizes and shapes. With regard to particulate matter, the particles are so small that they can reach the respiratory tract in humans. These small particles are differentiated according to their size (see Figure 3).

Figure 2

EU limits ↔ WHO recommendations

Figure 3

Size of particulate matter in comparison

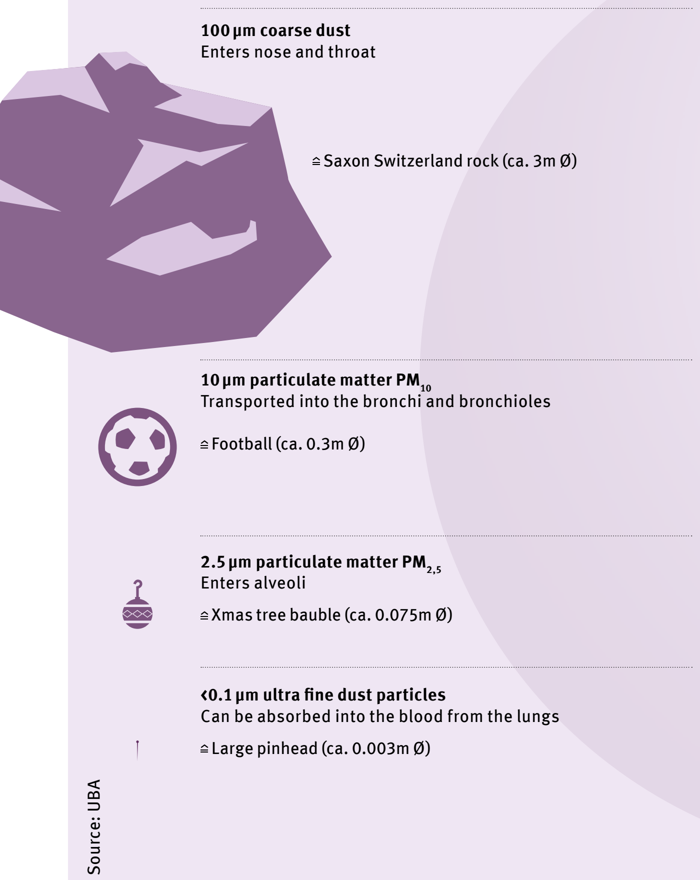
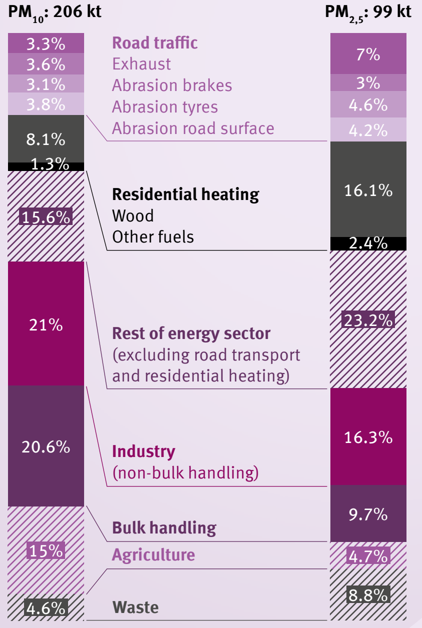
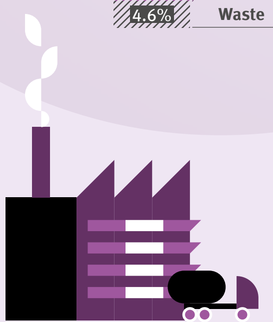


Figure 4

PM Emissions 2017





Particulate matter can be emitted directly; it is then known as primary particulate matter. But it can also originate from gaseous precursors in the atmosphere forming secondary particulate matter. In Germany, humans are the cause of the largest amounts of particulate matter. We speak of anthropogenic sources (ancient Greek ánthrōpos = human). The largest of these anthropogenic sources are road traffic, use of (wood) fires for residential heating, power plants, industrial plants and agriculture as well as the handling of bulk goods. However, primary particulate matter is also released from natural sources. These include disturbance of soil material, plant material such as spores and pollen, sea salt particles and particles from volcanic eruptions and forest/vegetation fires. The essential precursor gases that lead to the formation of secondary particulate matter are nitrogen oxides, ammonia and sulphur dioxide. The size of the particles is closely related to how they are formed. While $PM_{2.5}$ is mainly formed as a secondary product or arises during combustion, larger particles of particulate matter are more likely to develop due to abrasion or disturbance.

How particulate matter affects your health

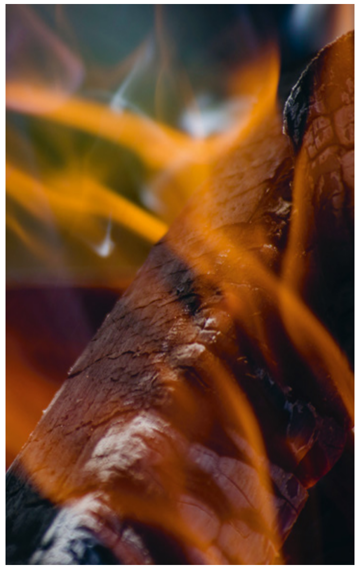
The smaller the particles, the further they are able to penetrate into the respiratory tract. The health effects of particulate matter vary depending on the depth of penetration. They range from mucosal irritation and local inflammation in the trachea or the lung alveoli to increased deposition of arteriosclerotic plaques in the blood vessels, increased tendency for thrombosis and increased mortality from cardiovascular diseases and lung cancer.

The statutory limit values for particulate matter are met in Germany, with a few exceptions. However, this is no reason to give the all-clear because even lower loads can harm your health.

Particulate matter damages the health of the population significantly more than other air pollutants.

The limit values are not strict enough for adequate health protection: For PM_{10}, the annual mean limit is 40 µg/m³, but the WHO considers half this amount as reasonable: 20 µg/m³.

As particulate matter comes from many different sources, there is no single measure that can be taken to reduce the load. For this reason, many parties need to play their part: in agriculture, wood burning in private homes, transport and industry.

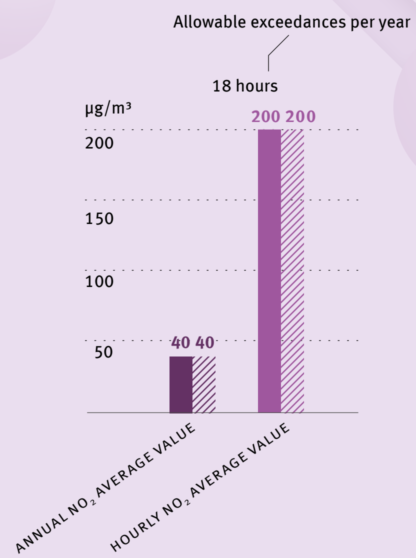


Nitrogen dioxide

Nitrogen dioxide (NO_2) is an air pollutant that belongs to the nitrogen oxides. It is produced by natural processes such as lightning and forest fires as well as by microbiological formation in soils. However, humans contribute to the formation to a much higher degree, as nitrogen oxides are released in all combustion processes in cars, in coal-fired power plants or in domestic gas heating.

Figure 5

EU limit values ■ ↔ WHO recommendations



Compilation: German Environment Agency

Figure 6

Exceedances of annual NO_2 limit value

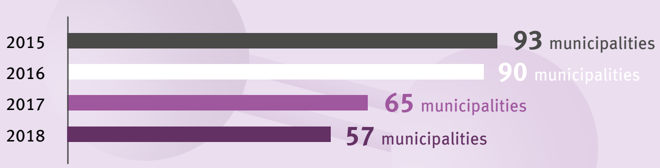
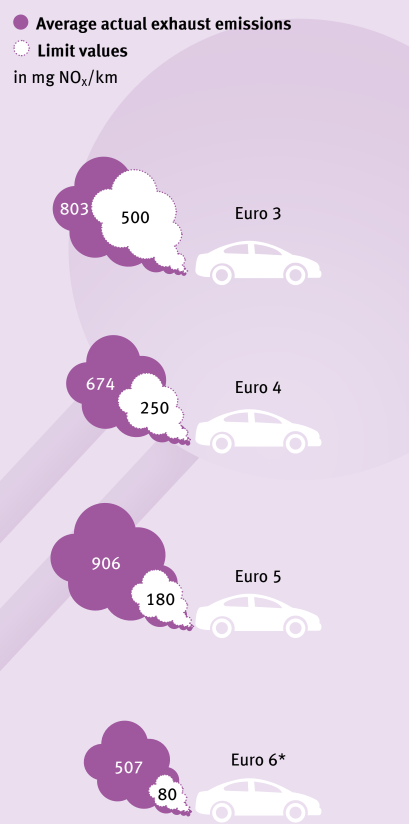


Figure 7

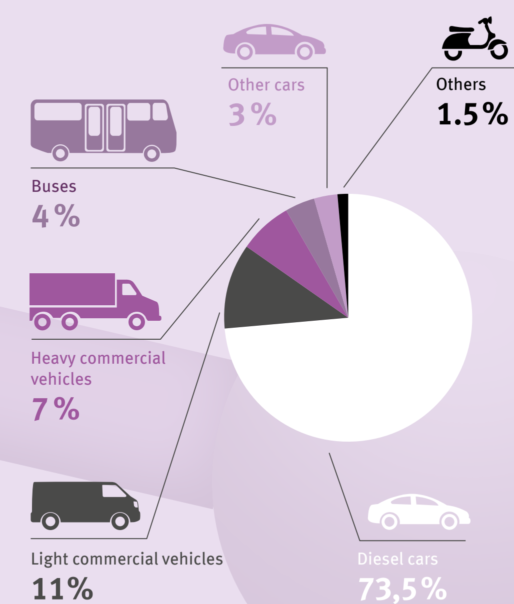
Diesel cars of various pollutant classes



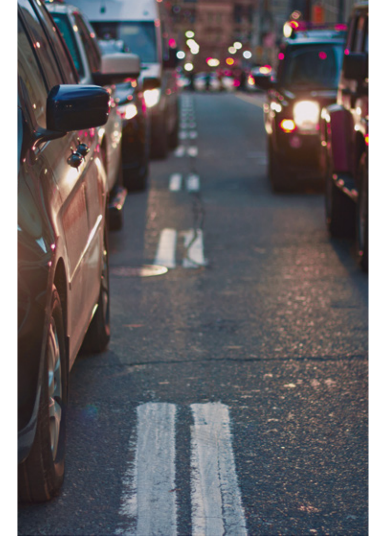
*For vehicles without verification of lower nitrogen oxides emissions in practical operation on the road (Euro 6a-c). For vehicles with obligation to provide proof of compliance of limit values exclusively in roller test bench measurements (Euro 6a-c).
Source: HBEFA 3.3 (24.04.2017)

Figure 8

Diesel cars contribute the most to the NO_2 pollution in cities and towns



Source: UBA/TREMOD 5.82/HBEFA 3.3, As of 2017



These combustion processes initially produce around 90 percent NO and only around 10 percent NO_2 directly. Most of the NO_2 is subsequently formed secondarily in the atmosphere by the conversion of NO into NO_2.

NO_2 concentrations can vary widely even on a small spatial scale. High concentrations can usually be found along busy roads. From analyses of NO_2 concentrations near the road in the inner-city, it is known that road traffic accounts for around 60 percent of the pollution. As for road traffic, diesel cars once again are the major source and account for over 70 percent.

How NO_2 makes you sick

As a strong oxidising agent, NO_2 causes inflammations in the respiratory tract and increases the irritant effect of other air pollutants. As a consequence, at high exposure, symptoms such as difficulty in breathing, coughing, bronchitis and a decrease in lung function can occur.

If the NO_2 concentration of the surrounding air increases, it is mostly individuals with a previously damaged respiratory tract who are affected. During long lasting (which sometimes occurs in Germany) or very high exposure (which may occur in big cities in other countries of the world), an increase in cardiovascular diseases and mortality rate can also be observed statistically.

Within the European Union, and thus also in Germany, the WHO-recommendations were adopted for the stipulation of limit values for NO_2. Human health is by law better protected against NO_2 compared to fine particulate matter – provided that the limit values are met.

Newer diesel cars, as from emissions standard Euro 6d-TEMP on, emit a much lower amount of nitrogen oxides than older vehicles do. On average, diesel cars of Euro Class 5 and older diesels of Class 6 showed exceedances of the allowed emissions at a level around five or six times higher in actual operation. Due to newer legal specifications, modern diesels may in an initial period also exceed the current limit values at a maximum of 2.1 times higher in actual operation.

Nevertheless, the associated reductions of NO_2 concentrations are not enough to comply with the limit values in effect since 2010 in heavily polluted locations in the near future.

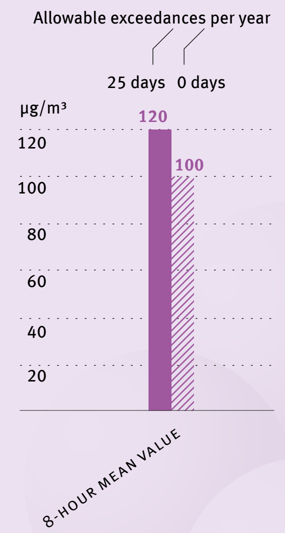
Therefore, further measures are required that can also cover traffic restrictions for older diesel cars, provided it is done proportionally.

Ozone

Ozone, a molecule made up of three oxygen atoms (O_3), is formed in the atmosphere through chemical reactions in which nitrogen oxides, volatile organic compounds (VOC) and other substances are involved. The latter are released in particular from solvents (from paints and varnishes, adhesives or cleaning products), from unburned fuel components or from the natural transpiration of higher plants.

Figure 9

EU target values ↔ WHO guideline values

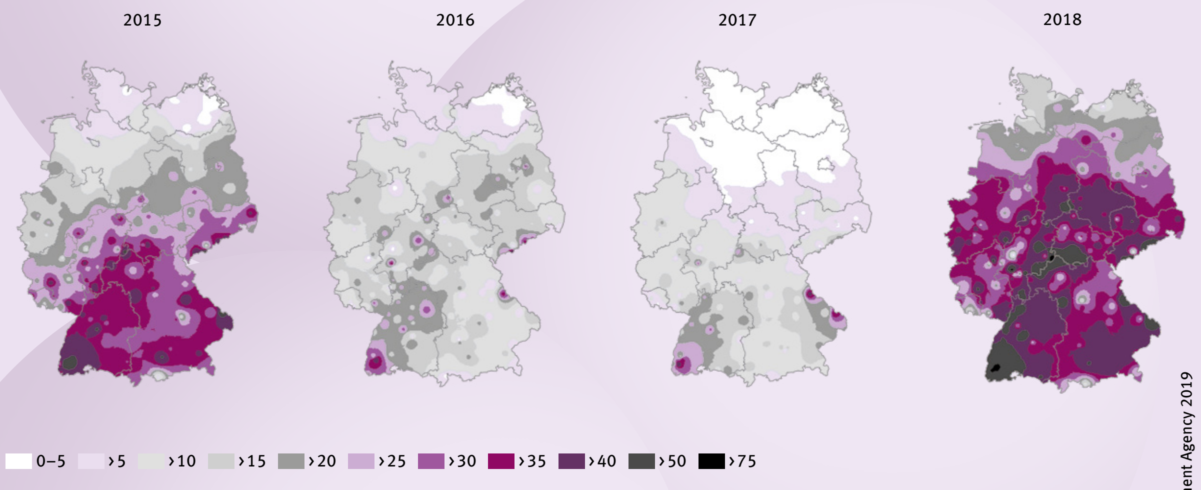


Compilation: German Environment Agency

Figure 10

Spatial distribution of the exceedance days of a long-term objective for the protection of health

Number of days with maximum 8-hour average values › 120 µg/m³



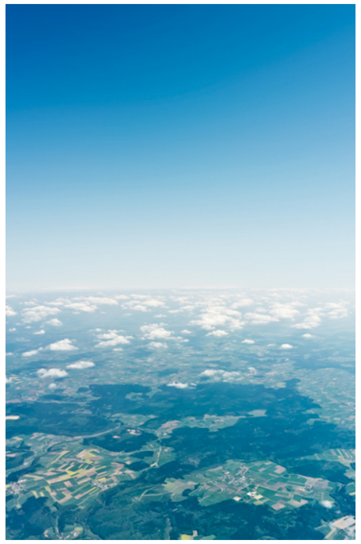
Source: German Environment Agency 2019

The ozone formation from these precursor substances is favoured by solar (ultra-violet) radiation and high temperatures. This is why ozone pollution is always particularly high in summer. The highest ozone values arise away from the sources of the precursor substances in suburban and in adjoining rural areas. This sounds paradoxical, but stems from the fact that the nitrogen monoxide (NO) from automobile emissions reacts with ozone. Ozone is broken down in the process, leading to a significantly lower ozone pollution in the city centre, a result caused in effect by other air pollutants. On the other hand, winds transport precursor substances away from the cities and thus contribute to ozone formation at other locations.

How ozone makes you sick

The health effects of ozone consist of decreased lung function, inflammatory reactions in the respiratory tract and respiratory symptoms. If in summer ozone values rise over the information threshold (180 µg/m³ as hourly value) or even over the alert threshold (240 µg/m³ as hourly value), information and behavioural recommendations are reported over the media.

The protection against elevated ozone concentrations is rather low, as the EU does not specify any legally binding limit values, but only target values in addition to the information and alert thresholds. In complying with the target values, harmful effects on human health should be avoided. This compliance must be achieved whenever possible within a specified time period. However, for an exceedance of a target value for ozone, in contrast to exceedances of the limit values for fine particulate matter and NO_2, the authorities are not obliged to draw up local air quality plans with concrete measures for achieving the target value. In order to achieve lower ozone concentrations, it is necessary above all to further reduce the emissions of the precursor gases.

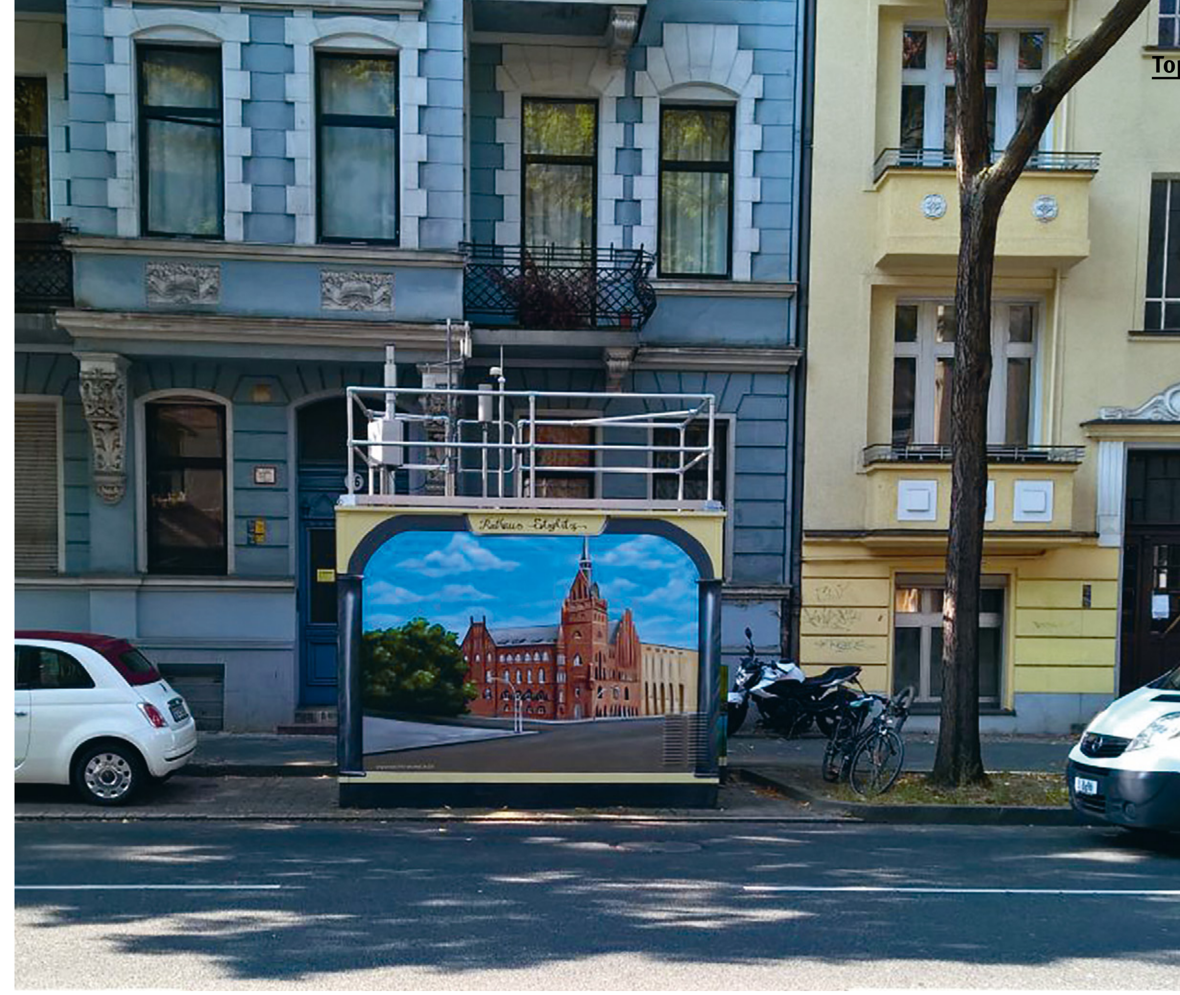


AIR POLLUTANTS AND ECOSYSTEMS

Air pollutants are not only a health risk – they can also harm plants, soils, and ecosystems on land or in waters. Therefore, it is not only the concentration of pollutants in the air that is decisive, but also the amount of pollutants transported into sensitive ecosystems over a certain period of time. The effects on these ecosystems are complex and long-term. High inputs of e.g. nitrogenous or sulphurous compounds or direct damage, e.g. from ozone, threaten biodiversity and destabilise systems. This can result in increased vulnerability to drought or pests. Not only are the ecosystems themselves an asset worth protecting, but also their diverse functions in the ecological balance, such as buffer and filtration capacities, that are of vital importance to humans. One important goal of emissions reduction is therefore the protection of ecosystems. Monitoring programs for air-pollutant load of ecosystems, the success of reduction measures and the conditions of ecosystems are in place throughout Europe.

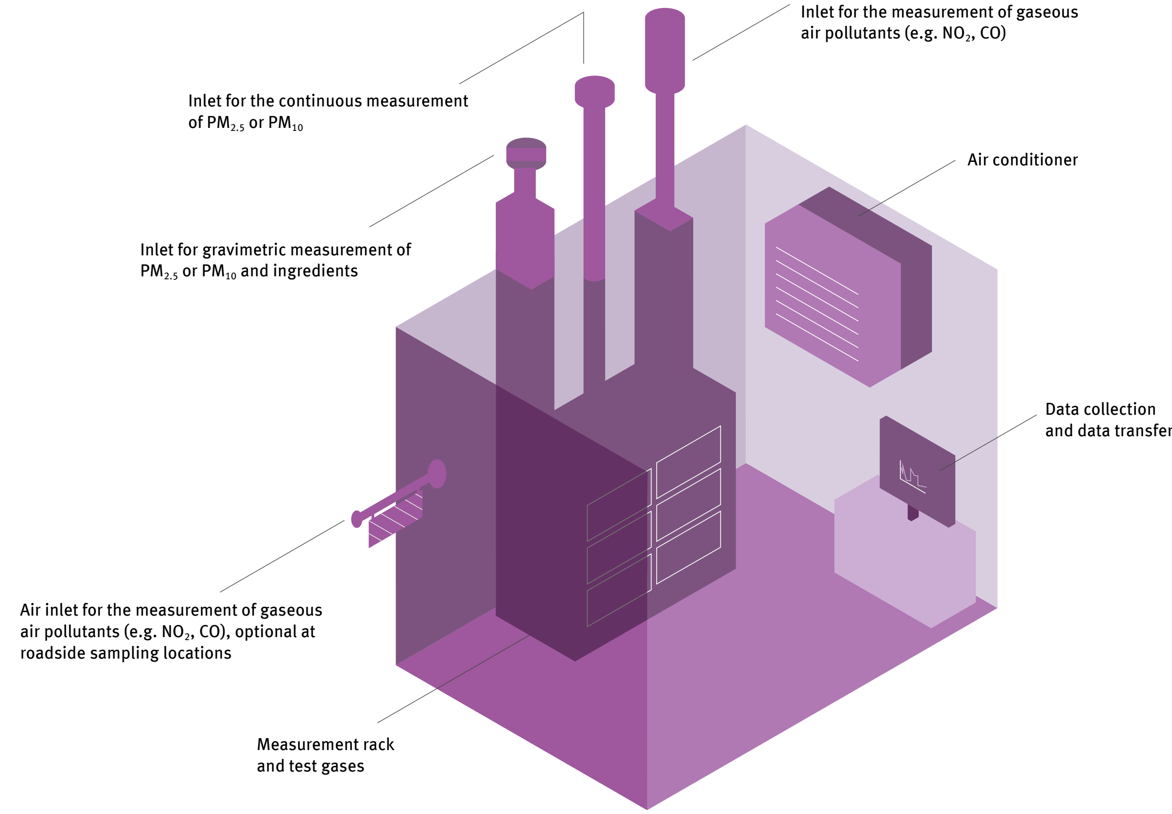
This is how Germany's air is measured

What do measurements tell us?
Air quality is recorded in Germany using various measuring instruments. The unit used is always the mass of the pollutant in one cubic metre of air, for example micrograms per cubic metre (µg/m³).



The measured values give information about the health-threatening concentrations humans are exposed to through air pollutants. Based on this data, it is checked whether or not limit and guideline values for the protection of health are met. In addition, measurement data also document the trend of air-pollutant concentrations over long time periods. They show whether or not air pollution control measures achieve their intended objectives. Measuring air-pollutant concentrations in every location in the country is not possible – but also not necessary. Often, measured concentrations are transferable to other locations. For example, values measured close to a road can be transferred to adjacent road stretches, provided that traffic and other conditions such as building development do not change significantly. Values from monitoring stations in remote rural areas are valid even for similarly characterised areas within 100 kilometres or more. However, if comprehensive concentrations of air pollutants are to be determined, they must be modelled.

Scientists consider numerous influencing factors for these calculations: firstly, the emissions of pollutants, secondly, their transport in the atmosphere through wind and turbulence, and thirdly, chemical processes that occur between the air pollutants. How well these chemistry transport models used work can be demonstrated by comparing them with actual measurements. By means of such calculations, the air quality in different areas can be evaluated even if not measured. Models are also used to understand pollutant transport routes and to identify sources of pollution. A further field of application is scenario calculations. These calculations show how modifications of the sources of pollution or of climate change can affect the future concentration of air pollutants. Air pollution levels can also be predicted by models, as is done for weather. This can be helpful for the planning of sports events or leisure activities outdoors.



When are measurement data comparable?

Only if the measurement methods and time periods of the recorded measurements are comparable, will the determined measurement results also be comparable. For that reason, the methods by which the air is measured are "reference measurement methods" specified throughout Europe in the directive for air quality. If other measurement processes for the implementation come up, a comprehensive testing programme is performed for the verification of their equivalence. Moreover, the required accuracy of the measured values is specified in the directive. One speaks of a measurement uncertainty. For air pollutants, this uncertainty amounts to ± 15 percent of a single measured value for gaseous air pollutants and ± 25 percent for particles.2 A further requirement of the directive is that at least 90% of the measured values must be valid for one year.

The air monitoring networks have quality management systems at their disposal in which regular maintenance and measuring devices calibrations are provided. These systems are checked by the national reference laboratories at least once every five years. These laboratories are accredited for the implementation of these processes as testing and calibration laboratories and participate in EU-wide quality assurance programmes. The German Environment Agency reference laboratory produces test gases with which every monitoring network in Germany calibrates their own equipment (see p. 45 "UBA insights").

2 Measurements can never be 100 percent accurate. There is no true value without measurement uncertainty. This measurement uncertainty indicates how certain it is that the true value is determined of what is measured.

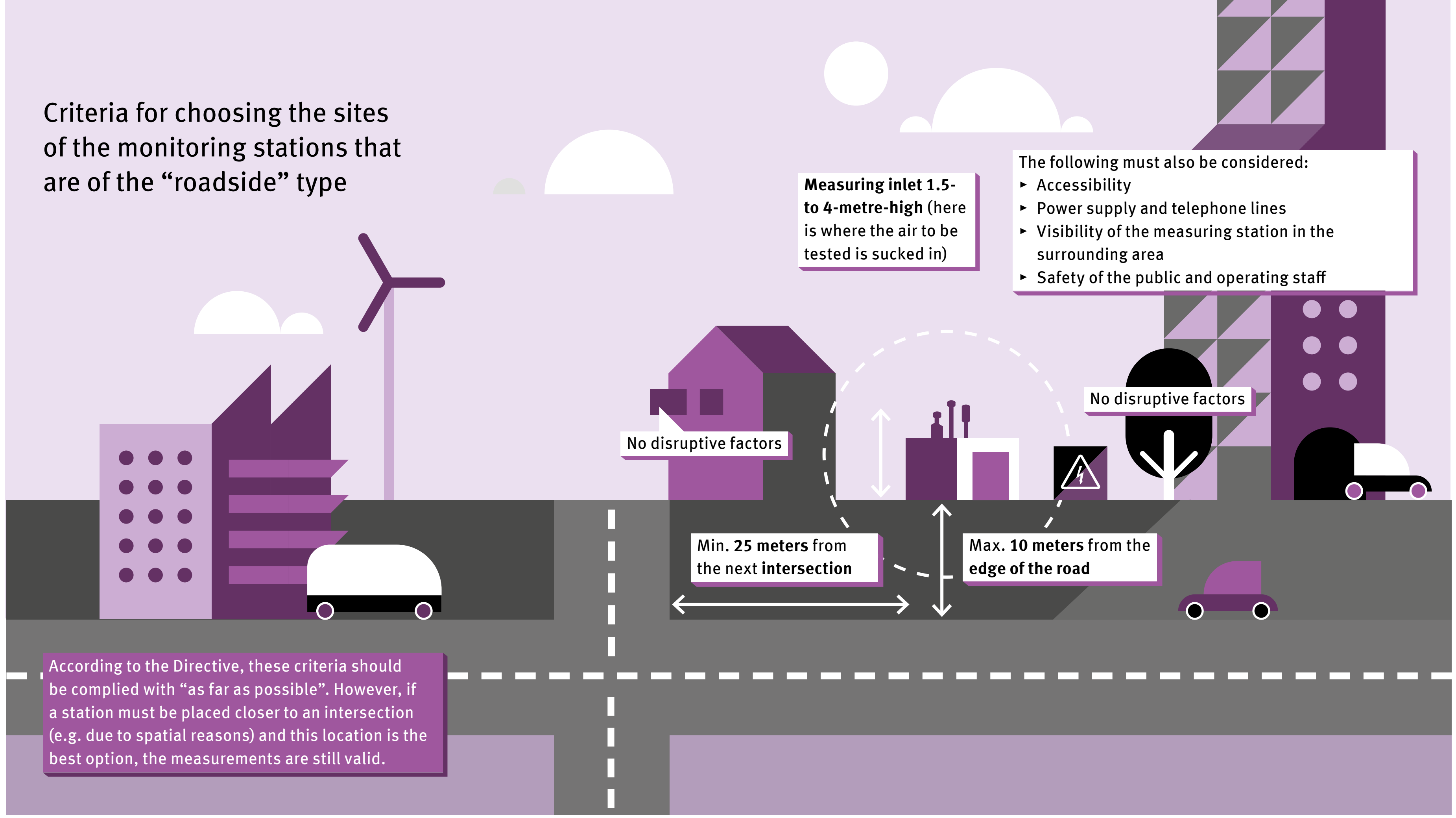
Where are monitoring stations placed?

The location of the monitoring stations is also important for obtaining comparable measurement results. There are basically four different site types for monitoring stations:

- Rural background: these monitoring stations are located in areas where large-scale air quality is the most unaffected by man-made sources.
- Urban background: these stations measure air quality in urban and suburban residential areas off the main roads.
- Roadside: these stations measure directly beside roads.
- Close to industrial facilities: these stations measure in the direct vicinity of industrial installations.

A large and growing part of the population lives in cities and conurbations where air quality is influenced by a variety of human activities: heating, industry, commerce or transport. In order to determine the impact on a large part of the urban population, air pollutants are measured in typical urban and suburban residential areas away from major roads. However, the air pollution affecting the population living on busy roads is also monitored. This is because the basic principle of the European Directive is the certain compliance with the limits set for the protection of human health everywhere.

Therefore, the monitoring stations must be placed in such a way that they also determine the highest concentrations to which the population is directly or indirectly exposed – for example, by the roads (directly) or when ventilating their homes (indirectly). For pollutants such as nitrogen dioxide, which stem predominantly from traffic, this means that monitoring stations have to be placed by busy roads.



39th Ordinance on the Implementation of the Federal Immission Control Act (39th BImSchV)

The European Directive on air quality was transposed by Germany 1:1 into German law in the form of the 39th BImSchV.

The Ordinance specifies limit and target values for a large number of air pollutants. In addition, it regulates the assessment methods, such as measurements and model calculations, the number and location of the monitoring stations, the measuring technique to be used, the quality assurance of the measurements, the development of air pollution control plans in case the limit values are exceeded and public information.

Citizen Science – good for home use

“How clean is the air you breathe?” This is one of the questions that projects use to encourage citizens to measure air pollutants in their immediate environment. Frequently, citizen science projects of this type offer easy-to-use sensors and compile the measured data on Internet platforms. This data can provide information about the spatial distribution of air pollutants in a city and can show where the main loads are found (e.g. busy roads) or indicate short-term peak loads (e.g. New Year’s Eve fireworks). With this knowledge of where and when the air quality is good or bad, everyone can adapt their behaviour in order to breathe in the best possible air. However, since these sensors measure significantly less accurately than professional devices, the measurement results are not equivalent. For example, simple sensors cannot determine whether limits are adhered to or not.

Bad air and poor health

Is it possible to calculate how the environment affects our health?

Which (environmental) risks should be reduced to improve the health of the entire population? To answer this question, national and international studies are carried out to estimate the 'burden of disease'.

The Global Burden of Disease study (GBD study) was developed in the 1990s by the World Health Organization (WHO) in collaboration with the World Bank and the Harvard School of Public Health. Now, for the first time it became possible to comprehensively present the health of the world's population and to compare it at the state level (Murray and Lopez 1996). The first study identified previously underestimated or neglected health outcomes and assessed their relevance to public health, for example mental illnesses and injuries resulting from traffic accidents.

What does 'burden of disease' mean?

To quantify health impacts, years of life are used as the unit of measure for population health: first, the years of life that people lose if they die before reaching the statistical life expectancy (Years of Life Lost due to premature mortality, YLL). Secondly, the years of life that people live with poor health due to diseases (Years Lived with Disability, YLD). The so-called Disability-Adjusted Life Year (DALY) unites the two components (YLL and YLD) and has since been used to quantify the burden of disease in populations.

DALY = YLL + YLD
YLL = Number of deaths in an age group times the remaining life expectancy at the time of death
YLD = Number of ill people times a weighting factor for the severity of the disease

The DALY is an indicator for the health of a population as a whole. DALYs also offer the opportunity to compare different diseases: Can more diseases or deaths be ascribed to smoking or to air pollution? Is it alcohol abuse that causes more illness or rather the lack of physical exercise? Thus, policymakers can weigh the evidence to determine which priorities should be set for health protection, preventive measures or the allocation of taxes.

The GBD study is regularly updated by the Institute for Health Metrics and Evaluation, a Washington University research facility based in Seattle, USA. It provides burden of disease data almost annually at a national level, even for Germany. The results are available online.[3]

3 http://www.healthdata.org/data-visualization/gbd-compare.

Which diseases are caused by a polluted environment?

Anyone who wants to protect the population against diseases first needs to know what causes the greatest burden of disease – for example, whether more people die of cancer or cardiovascular diseases. Secondly, it is important to know what causes the respective diseases – whether smoking, lack of physical exercise or other factors are among the reasons for the disease. These are called risk factors.

In its work, the German Environment Agency investigates the effects of environmental risk factors on human health, for example the effects of air pollutants such as particulate matter and nitrogen dioxide, but also those of environmental noise. There is an established method developed by the WHO for calculating the burden of disease due to environmental risks: the Environmental Burden of Disease (EBD) concept (Prüss-Üstün, Mathers et al., 2003), which is based on the more fundamental burden of disease approach.

This concept combines health-related and environmental data from different sources. These include population-based observational studies on health ("epidemiological studies"), cause-of-death statistics and data from environmental monitoring. Linking this information makes it possible to approximately determine the share of the disease burden that can be attributed to an environmental risk factor (attributable fraction of the overall disease burden).

Many diseases are linked to environmental pollution, as demonstrated by toxicological (animal studies) and epidemiological studies. Thus, it has become common knowledge, for example, that the body's exposure to lead can adversely affect the mental development of children, and that particulate matter can lead to lung cancer.

There is a function that is used to illustrate the mathematical association between the increasing pollutant concentration and the resulting health complaints. Together with information on the distribution of the considered environmental risk factor in the total population (exposure), it can thus be determined how much higher the risk of developing a disease or dying from a disease is in areas with a higher concentration of certain air pollutants.

Interpretation of the (environmental) burden of disease

To calculate the environmental burden of disease, various assumptions need to be made – for example, from which pollutant concentration the risk of disease or death increases. In addition, data is needed on the concentration of air pollutants and how many people die or become ill with certain diseases. All these assumptions are combined in mathematical models.

However, models can only be an approximation of reality. Moreover, the results of model calculations strongly depend on the quality of the input data and the chosen assumptions. The transparent disclosure of assumptions and the presentation of the uncertainty in the results is therefore an important prerequisite for an appropriate interpretation.

Example of use:

COMPARISON OF THE BURDEN OF DISEASE FOR NITROGEN DIOXIDE AND PARTICULATE MATTER IN GERMANY

UBA calculations for 2014 show that nearly 49,700 years of life lost (YLL) can be attributed to nitrogen dioxide and about 409,900 YLL to particulate matter. In the case of attributable deaths, the figures are about 6,000 (1) and 41,100 (2). This shows that particulate matter is a considerably more important risk factor than NO_2.

Only data from urban and rural monitoring stations were used to estimate the exposure. Due to methodological reasons, particularly high concentrations, as found at roadsides in cities, cannot be considered.

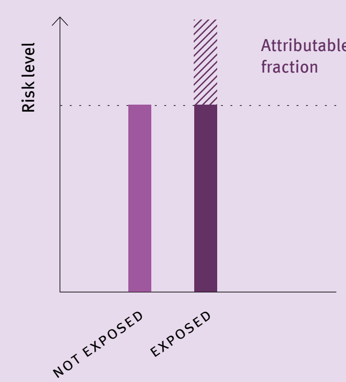
(1) www.umweltbundesamt.de/no2-krankheitslasten
(2) www.umweltbundesamt.de/daten/umwelt-gesundheit/gesundheitsrisiken-durch-feinstaub

Figure 11

Calculation of the burden of disease for air pollutants
according to the Environmental Burden of Disease approach

Figure 12

What is the share of environmental risk factors in the burden of disease?



Source: UBA's own illustration according to (Prüss-Üstün, Mathers et al. 2003, p.13)

Results of burden of disease studies do not provide precise numbers but rather present estimates within a reliable scale.

The health effects of air pollutants are discussed intensively in politics, in the media and in public. Results from burden of disease studies are also used as arguments in those discussions. In most cases, isolated estimates from burden of disease assessments were used as discussion points, such as ‘attributable deaths’ or ‘years of life lost’. However, isolating single estimates from burden of disease is not adequate because the results of burden of disease studies are usually designed for relative comparisons of different risks, as shown in the GBD studies. Calculating the burdens of disease for different environmental risk factors enables comparisons between them and makes it possible to identify which risk factors should be reduced as a priority.

Another challenge in interpreting burden of disease studies is that results for individual pollutants are produced by different institutions that use the same measurement units but base their calculations on different assumptions and input data. As an example, in its report on air quality in Europe for Germany in 2014, the European Environment Agency (EEA) presented disease burden of 12,860 attributable deaths and 133,800 years of life lost (YLL) due to exposure to nitrogen dioxide (EEA 2017). In contrast, a research project commissioned by UBA for the same year estimated the disease burden of approximately 6,000 attributable deaths and about 49,700 years of life lost (YLL) (Schneider, Cyrys et al., 2018). A key difference between these two studies is that the EEA assumed that nitrogen dioxide is associated with all natural deaths. This does not apply to UBA’s research project, in which the main analysis limited the burden of disease exclusively to deaths that occurred as a result of cardiovascular diseases; but not lung cancer, since there are contradictory study results for this disease. In its baseline analysis, the EEA assumed that adverse health effects only occur above 20 µg/m³ nitrogen dioxide on an annual average, whereas UBA’s study set this value at 10 µg/m³, since epidemiological studies indicate adverse health effects already at values between 10 and 20 µg/m³.

The direct comparison of disease burden from different studies is only appropriate if the assumptions in the models used for the calculation correspond.

Another important prerequisite for the interpretation of data on the burden of disease is the relative comparison with other risk factors in order to be able to assess the importance of the selected environmental risk factor for the health of the population. If these conditions are met, estimates of the burden of disease provide important information for the appraisal of air pollutant effects on health.

Due to the above-mentioned methodological concerns, the results of such studies should always only be evaluated at the level of the entire population.

By no means do studies on the burden of disease allow a statement on whether a person contracted his disease due to bad air.

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INTERVIEW

"You cannot choose the air you breathe".

Interview with Dr. Maria Neira, WHO Director, Department of Public Health, Environmental and Social Determinants of Health, World Health Organization (WHO).

Dr Neira, when did you last breathe unhealthy air?
Unfortunately I have to do that very often. Very recently in India, I'm afraid, in Shanghai and in Beijing – there are many examples where you are forced to breathe very bad air. I believe the worst was in Beijing a few years ago. I felt really even sick. My eyes and my throat hurt and I was coughing all the time. It was a terrible feeling.

So you experienced immediate health effects?
Absolutely. And when you see people around you wearing masks, coughing with red eyes, you realise that their daily live is painful.

You just mentioned the health effects you experienced yourself. How big is the influence of air pollutants on human health compared to other influences like chemicals from food or consumer products or self-inflicted toxins like alcohol or cigarette smoke? Or infectious diseases?
You can't choose the quality of the air you breathe. If you live in New Delhi you breathe the air you have. It is not a personal choice. Air pollution is the most important environmental risk factor for human health and the fourth worst factor among all health risk factors in general. It causes diseases like lung cancer, stroke, heart diseases, pneumonia, and chronic respiratory diseases. We estimate that air pollution causes 7 million premature deaths worldwide every year. It is clear that bad air is really a major public health issue and one of the most important ones we need to respond to, tackle and act immediately. Maybe in a few years people will ask politicians: Why didn't you do more to protect people's health when you already knew this was doing a lot of damage?

"Air quality has definitely improved in the European Union countries, no doubt about that."

How should governments act in face of this knowledge and do governments use these facts properly?
Well obviously they do not show the level of ambition and act at the speed we would like to see. As a public health officer your ambition is to reduce the number of deaths by one hundred per cent and to do it tomorrow. So if you look at that standard – which would be mine, of course –, the current action taken is too slow and not ambitious enough. I have to say that we all, the medical community, the public health community, we were really getting very impatient with this situation. However, in the last two years things are taking a different dimension and direction. We finally see some new hope.

In what respect do you see a different direction?
Well, when you look at China – China has declared a war on air pollution and declared it a national priority. And we already see some effects. The trend of increasing air pollution has now stabilised or even started to go down. That is important because China has such a big share of the world's population. We would like to see India to follow suit.

So China sees the risk from air pollution. They looked at the facts and acted accordingly. But elsewhere – do you find politics is more susceptible to science than in the past or less?
Political decisions are often hampered by economic conflicts of interest. To me it is absolutely clear that tackling air pollution will have a fantastic economic benefit in the medium and long term. But political action often is too short-sighted. But since we are creating political pressure and making sure that the citizens understand that when they have asthma this is related to the

“My hope is that countries will realise even more that bad air is affecting their economy as well.”

air quality, and when they are developing chronic respiratory diseases or even lung cancer – that is something that creates the right political pressure and then the decisions are taken for right political reasons – namely to protect the health of our citizens and mitigate the financial costs incurred by our health services.

You worked at the WHO on a European level for a long time. Tell us about the advances in air quality over the past decades in Europe?
Air quality has definitely improved in the European Union countries, no doubt about that. In particular there has been an important decrease in exposure to particulate matter. In 2016 the percentage of the population exposed to PM_{10} and $PM_{2.5}$ levels above the limit values of the WHO guidelines was the lowest since 2000. And between 2000 and 2014 we saw decreasing trends in PM_{10} and NO_2 concentrations for 75 % of the EU air monitoring stations. Those are positive signals, but: There is still a huge part of the population that is exposed to concentrations clearly exceeding WHO recommendations. We have several hundred thousand premature deaths every year in the EU which is absolutely unacceptable. As you probably know the WHO guidelines for particulate matter are stricter than the ones set by the EU legislation. In our opinion more needs to be done to push for legislation to take on board our recommendations and therefore better protect public health which is the goal we all have.

What should the EU do?
I encouraged everyone for a long time that the WHO air quality guidelines should be a basis for legislation for cleaner air. I believe the EU is moving in this direction. At least those are the signals that we are receiving. Looking at the advances: I think EU regulations and emissions control have played a very important role. It also creates a kind of positive competition among the European countries. Many countries are not there yet but clean air is in everyone’s interest, not only for public health, it is also a social question.

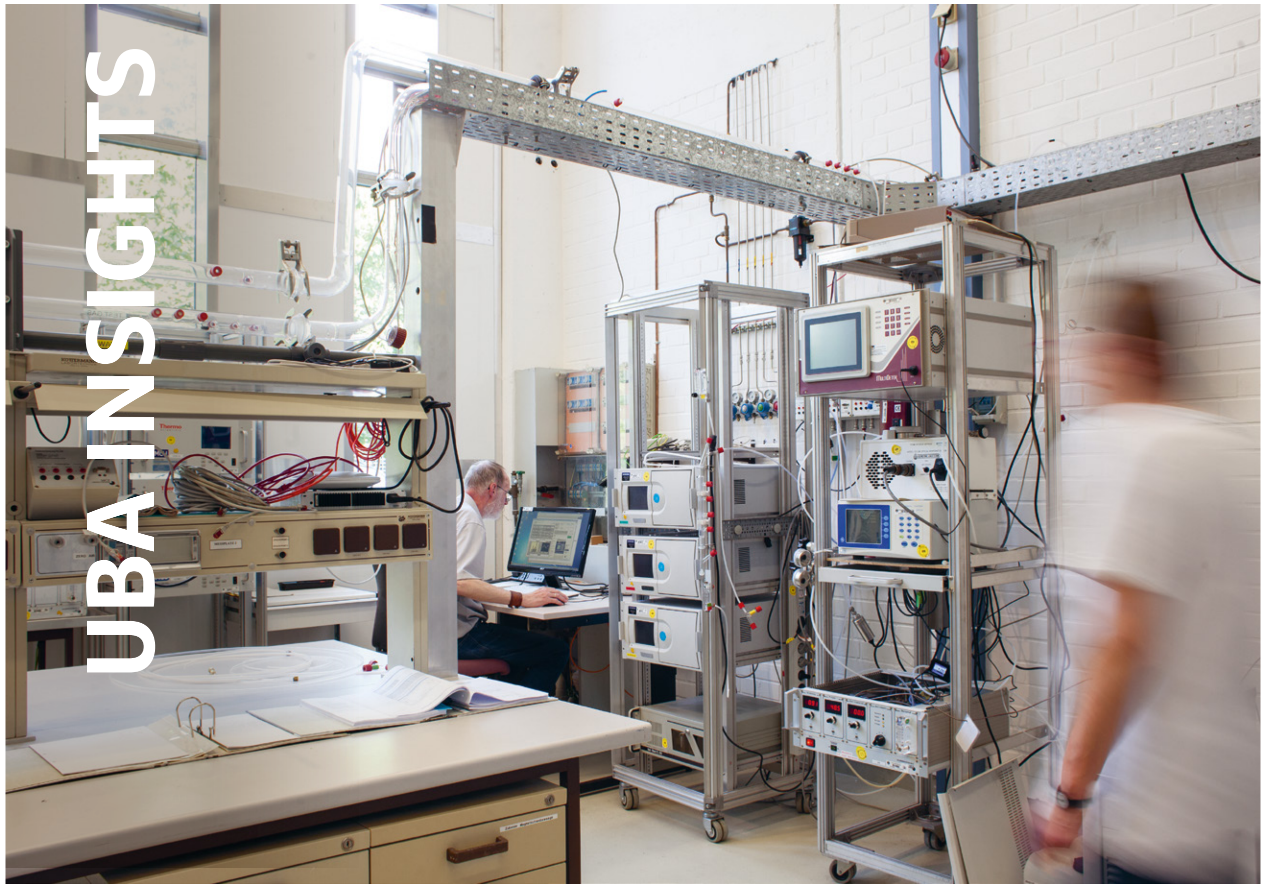
The WHO is currently working on new Air Quality Guidelines. How strict will they be?
In public health there are no limits for ambition. You cannot impose low standards for yourself. We need to make sure that we take all necessary measures to ensure people’s health. Whatever is needed.

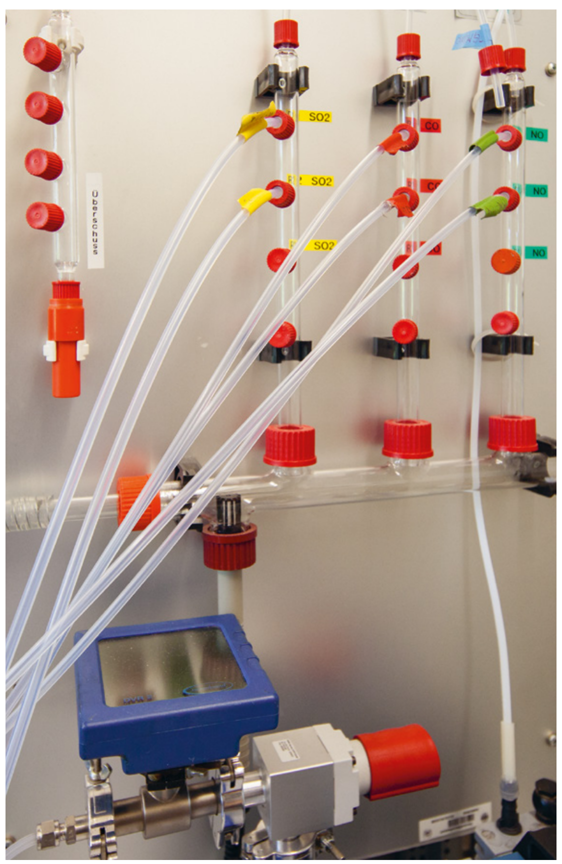
When will the new guidelines be published?
I cannot give you a date but we are trying to publish them as soon as possible. It is a very strict process that requires a very methodical approach and sound science.

Do you feel optimistic for clean air in the future? In Germany, the EU and worldwide?
I am pathologically optimistic. My hope is that countries will realise even more that bad air is affecting their economy as well. I think that China’s decision to declare air pollution a big enemy was wise. And the demand of the citizens, the science community, and the many children going on strike because they want us to tackle climate change – those movements are giving me hope that things are going to change.

Dr Neira, thank you for your time.

The German Environment Agency





The UBA office building in Langen, Hesse, is the headquarters of the air monitoring network.

How much is one microgram of NO_2?

For more than 20 years, UBA has been ensuring that air pollutants are measured everywhere based on the same reference criteria. The UBA Reference Laboratory produces gases that are used by all measuring institutes to calibrate their instruments.

The 'International Prototype Metre' for air quality measurements

If someone wanted to know how long one metre was two hundred years ago, they had to travel to Paris. There, securely locked in a steel cabinet, the 'International Prototype Metre' was stored – a rod of pure platinum, exactly one metre long, defined as the ten millionth part of the distance between the equator and the pole.

This archaic 'prototype meter' has long been history. One metre today is defined by the speed of light on a much more scientific footing: it is the distance the light travels in a vacuum in 1/299 792 458 seconds. However, just as all length measurements were traced back to the 'prototype metre' in Paris, all concentration measurements must also have a fixed reference figure. This international standard unit is given in grams per mole and it tells how much 6x1023 particles of a substance weigh. It is 46.1 g for nitrogen dioxide, for example. In order to be able to carry out comparable measurements, gas mixtures with a precisely specified number of particles must be produced – the 'prototype metre' of air measurements, also called 'measuring standard' or 'reference gases'.

Basically, the National Metrology Institute of Germany (PTB) in Brunswick is responsible for providing the 'National Measurement Standards' for air pollutants. However, PTB has commissioned the German Environment Agency with the provision of these standards. That is why the German reference gas is being produced in a UBA laboratory in Langen (Hesse) – in accordance with internationally established regulations and with the utmost accuracy. The quality of these gases is ensured by regular comparative measurements organised by the European Reference Laboratory in Ispra, Italy.

If someone wants to measure air pollutants in Germany, they must go to Langen in Hesse to compare their gas mixtures with the UBA reference gases. After a successful 'follow-up measurement', these measuring institutes will receive a certificate from UBA confirming that the gas mixture is traceable to the national standard and suitable for air quality measurements. The institutes take home their own reference gas. The states (Länder) use these 'transfer standards' to ensure that the accuracy of their pollutant measurements adhere to air quality limiting figures.

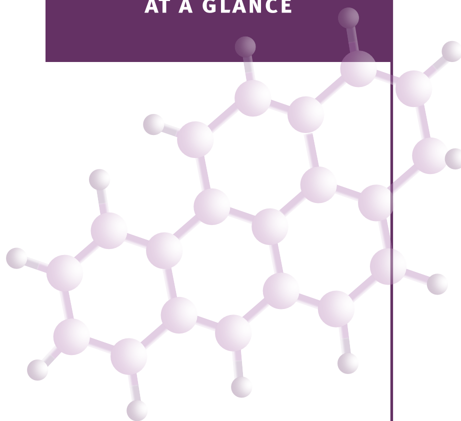
ENVIRONMENTAL DATA

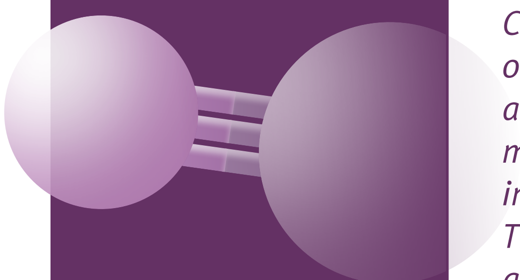
FURTHER AIR POLLUTANTS AT A GLANCE

Benzo(a)pyrene

IN PARTICULATE MATTER

Benzo(a)pyrene is a polycyclic aromatic hydrocarbon (PAH). It has a carcinogenic effect when inhaled or ingested. Since 2007 only four out of about 120 stations, three of them close to the road, exceeded the 9 times target value of 1 nanogram per cubic metre of air (ng/m³) as an annual average. The highest values were measured in proximity to traffic.



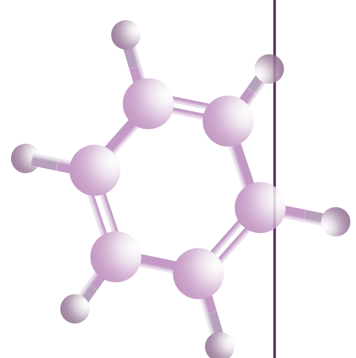


CARBON MONOXIDE

Carbon monoxide is a colourless, odourless and tasteless gas. It is a strong respiratory poison. The main source of carbon monoxide in the air is motor vehicle traffic. The limit value 10 mg/m³ (8-hour average in one day) has applied from 1/1/2005. It has not been exceeded in Germany since then.

Benzene

Benzene is an organic chemical compound with an aromatic odour. Benzene is carcinogenic. The main part of the pollution goes back to road traffic: benzene is a component of the exhaust gases. **None of the measuring stations has reported an exceedance of the limit value of 5 µg/m³ annual average.**



METALS IN PARTICULATE MATTER

74.92

As

33

Arsenic IN PARTICULATE MATTER

Arsenic damages mucous membranes and the respiratory tract and it can cause lung cancer. The annual average target value of 6 ng/m³ has not been exceeded since 2011. The highest concentrations can be measured close to industrial installations. Arsenic is mainly produced by the burning of hard coal and lignite or oil and in the metal industry.

Cadmium

IN PARTICULATE MATTER

Cadmium is toxic and carcinogenic and is mainly absorbed through food. For the most part, cadmium is emitted by combustion processes, but the metal industry is also a major emitter. The last exceedance of the target value of 5 ng/m³ as annual average was registered in 2013.

48

Cd

112.411

58.693

Ni

28

NICKEL IN PARTICULATE MATTER

Nickel compounds are generally classified as carcinogenic to humans and metallic nickel is also thought to be carcinogenic. Nickel enters the air through emissions e.g. from power plants or industrial installations. Nickel has a target value of 20 ng/m³ as an annual average which has been exceeded 13 times at four stations near industrial installations since 2007. One of the stations exhibited concentrations of up to 93 ng/m³, well above the target value.

As of 2017

UBA AIR MONITORING NETWORK

One of the UBA sites is located on the isle of Sylt.

Air monitoring network

The German Environment Agency runs seven measuring stations from the summit of Zugspitze (highest mountain in Germany) to the isle of Sylt (off the German North Sea coast). They are intentionally located outside metropolitan areas meaning as far from potential air pollution sources as possible. These measuring stations monitor a large number of air pollutants and climate parameters which include particulate matter, nitrogen dioxide or carbon dioxide. In addition, air, particulate matter and rainwater samples are regularly collected and centrally analysed for specific ingredients. The measurements performed by the UBA air monitoring network record air quality and its trend in ‘clean air areas’. Thus, UBA fulfils the Federal Republic of Germany’s statutory measuring tasks for airborne contaminants transported over large distances plus their deposition and effects on the environment. These tasks derive from international agreements and current EU legislation*. In addition, the UBA air monitoring network carries out research and development in order to improve the measurement technology and understanding of atmospheric chemical processes.

Differences among the monitoring networks of the states (Länder)

The states (Länder) run a comprehensive air monitoring network that can monitor air quality in cities, agglomerations and rural areas**. The measurement data provide a representative nationwide overview of the current air quality situation. Unlike the UBA air monitoring network, some of these stations are located in places where pollutant concentrations are very high, e.g. adjacent to transport routes or close to industrial facilities (see also ‘This is how Germany’s air is measured’). The air monitoring network of the states (Länder) differs above all in the measuring stations’ location but also in their tasks compared to the UBA air monitoring network.

By contrast, UBA records background concentrations of air pollutants and their transport and trends far away from their sources, especially in terms of climate trends. However, both monitoring networks have the same goal: protecting the environment and humans. Together, they ensure that air quality and its improvement within the Federal Republic of Germany are monitored.

* The measurement obligations for the UBA air monitoring network derive from the Convention on Long-range Transboundary Air Pollution (European Monitoring and Evaluation Programme, EMEP and International Cooperative Programme Integrated Monitoring ICP IM), from the GAW program of the UN WMO, from Germany‘s membership in the OSPAR and HELCOM marine protection commissions and from the EU Air Quality Directive.

** The measurement obligations for the air monitoring network of the states (Länder) derive from the existing Federal Immission Control Act and the 39th Federal Immission Control Ordinance

Examples from the air monitoring network: Everything clean?

The measurement data from the UBA air monitoring network illustrates the air pollutants trend, as shown here by the example of measured particulate matter concentrations at the Waldhof (Lower Saxony) measuring station since the beginning of 2002 (Figure 13).

On average, the particulate matter concentrations at the background stations are decreasing and the air becomes 'cleaner'.

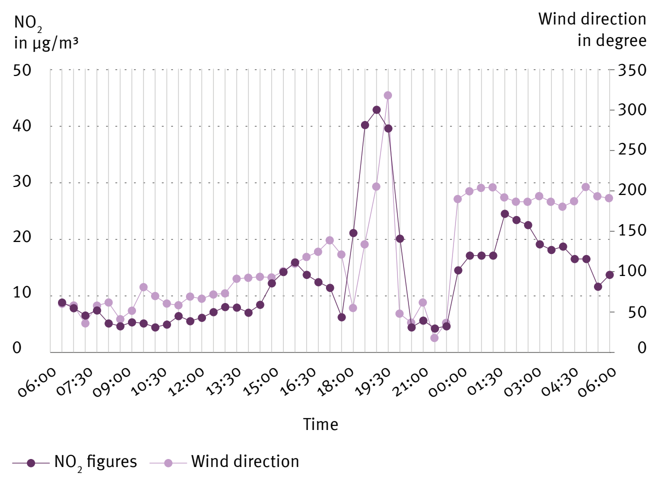
Nevertheless, the Schauinsland NO_2 measurement data helps explain humanity's impact. Wind direction-dependent transport (from the Freiburg conurbation, North-North-West ~ 300°) also causes occasional elevated NO_2 concentrations at the Schauinsland measuring station (here ~ 19:30 h) lying at great distance from all sources (Figure 14).

Figure 13

Annual mean values of the highly correlated PM_{10} and $PM_{2.5}$ concentrations at the Waldhof measuring station

Figure 14

Half-hourly NO_2 average figures and correlation with the wind direction at the Schauinsland measuring station. 08/02 – 09/02/2018.



Air monitoring sites:

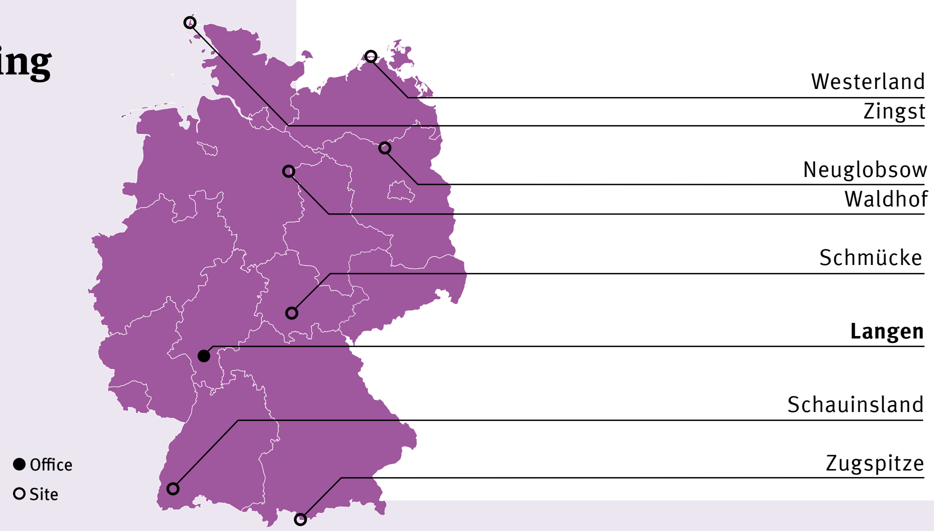


Figure 15

CO_2 concentration trend at the Schauinsland and Zugspitze UBA measuring stations, and comparison at Mauna Loa and according to WMO.

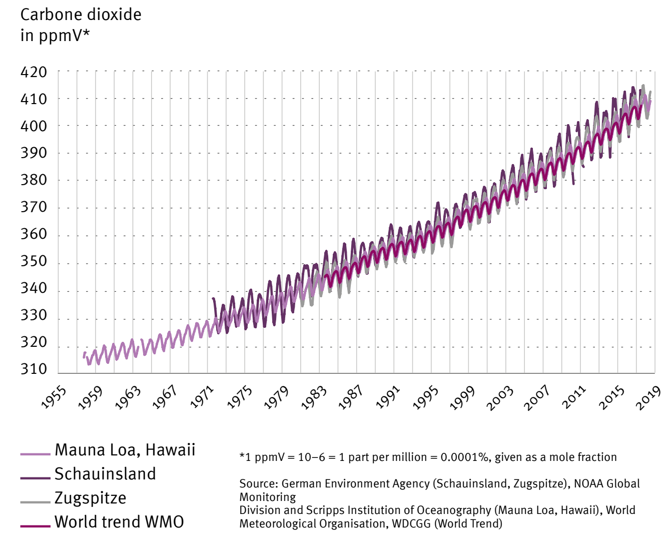
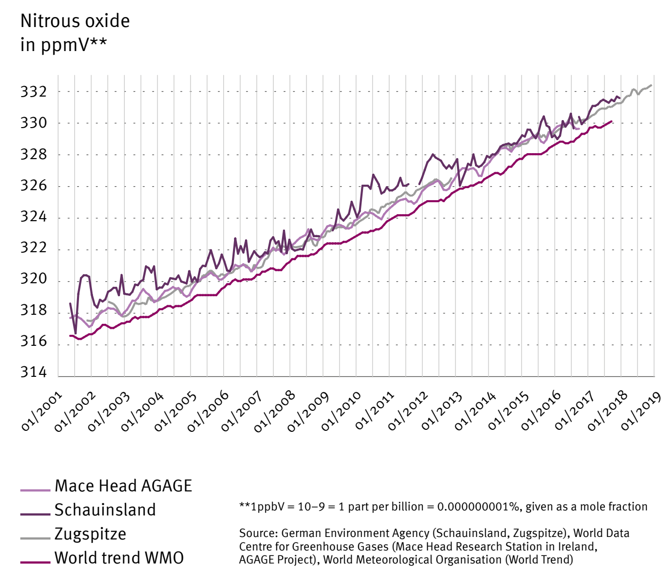


Figure 16

Trend of nitrous oxide concentration at the Schauinsland and Zugspitze measuring stations, and comparison in Mace Head and according to WMO.



Climate gases

Unlike the classic 'air pollutants' such as particulate matter or NO_2, the background concentrations of most climate gases show an increase. For example, long-term atmospheric carbon dioxide measurements at the German Environment Agency's Zugspitze and Schauinsland monitoring stations indicate a steady increase in concentration since the beginning of records in 1971 and 1980 by approximately 70–80 ppm (Figure 15). This increase in CO_2 concentration is in particular due to human use of fossil carbonaceous fuels. During combustion, the carbon contained is oxidised to CO_2 and emitted into the atmosphere where it eventually accumulates. The CO_2 concentrations show seasonal, periodic vegetation fluctuations.

The same applies, for example, to the climate-damaging di-nitric oxide (N_2O), also called nitrous oxide. Since the beginning of measurements at UBA's Zugspitze and Schauinsland air monitoring stations, the concentration of nitrous oxide has risen by about 4% (Figure 16).

Nitrous oxide is produced as an intermediate product in the degradation of organic matter and other substance conversions (nitrification, denitrification) in soils and water. In particular, the use of nitrogen-containing fertilisers in agriculture increases the production of climate-damaging nitrous oxide. In addition, the combustion of biomass also increases the concentration in the atmosphere.

The problem of an increase in climate-damaging gases, as exemplified here by CO_2 and N_2O, lies in the enhancement of the natural greenhouse effect.

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