BACKGROUND // MARCH 2023

Air Quality 2022

Preliminary Evaluation

German Environment Agency

Umwelt Bundesamt

Imprint

Publisher:
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Design:
Atelier Hauer + Dörfler GmbH

Publications as a pdf:
www.umweltbundesamt.de/publikationen

Photo credits:
Cover: Shutterstock/Katho Menden
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As at: March 2023

ISSN 2363-829X

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I Air Quality in 2022: Data basis and evaluation methodology

1 Air quality and air pollutants

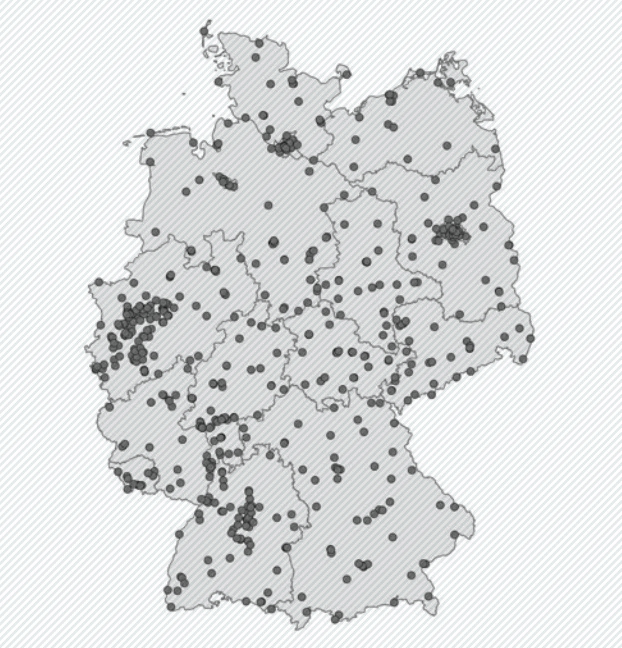
Air quality is monitored throughout Germany by the individual federal states and the UBA (German Environment Agency/*Umweltbundesamt*). In this respect, air quality is determined on the basis of the amount of air pollutants it contains, which means substances which have a harmful impact on human health and/or the environment. These include, primarily, particulate matter, nitrogen dioxide and ozone.

The pollutant concentrations in the air are measured several times a day at over 600 air monitoring stations throughout Germany (Figure 1). It is the task of the individual federal states to monitor the air quality, therefore most of the data come from their monitoring networks. For the Germany-wide assessment of the air quality, the data gathered by the federal states is collected and evaluated at the UBA. The evaluation and assessment of the air quality takes place in terms of the limit and target values as defined by the Directive on Ambient Air Quality and Cleaner Air for Europe[1].

1 EU Directive 2008/50/EC, which became German law with the 39th Ordinance Implementing the Federal Immission Control Act (Ordinance on Air Quality Standards and Emission Ceilings – 39. BImSchV).

Figure 1

Overview of the monitoring stations in Germany



Source: German Environment Agency (UBA) 2023

Particulate Matter (PM_{10}, $PM_{2.5}$)
is defined as particles which pass through the size-selective air inlet of a monitoring device, which demonstrates a 50 percent efficiency cut-off for an aerodynamic diameter of 10 (PM_{10}) and 2.5 ($PM_{2.5}$) micrometres (µm) respectively. Above all, particulate matter is propagated by combustion processes in motor vehicles, power stations and small-scale furnaces and during the production of metals and steel. It is also propagated by soil erosion and precursors such as sulphur dioxide, nitrogen oxides and ammonia. Particulate matter has been proven to have a negative impact on human health.

Nitrogen dioxide (NO_2)
is a reactive nitrogen compound which occurs in the form of a by-product during combustion processes, particularly in motor vehicles, and can have several negative effects on the environment and health. Nitrogen dioxide affects the respiratory mucous membrane, influences the respiratory function and can lead to a Bronchoconstriction, which may be worsened by the impact of allergens.

Ozone (O_3)
is a colourless and toxic gas which forms a natural layer in the upper atmosphere (stratosphere) and protects the earth from the harmful ultraviolet radiation from the sun (the ozone layer). During intense sunlight, however, it also arises at ground-level due to complex photochemical processes between ozone precursors – primarily nitrogen oxides and volatile organic compounds. High concentrations of ozone can cause people to suffer coughs, headaches and respiratory tract irritations.

The results are also compared with the considerably stricter air quality guideline (AQG) levels of the World Health Organization (WHO), which were published in September 2021 as global air quality guidelines[2]. Basis of these AQG levels are up-to-date research results of

2 World Health Organization (2021). WHO global air quality guidelines: particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://apps.who.int/iris/handle/10665/345329. Lizenz: CC BY-NC-SA 3.0 IGO

epidemiological studies, meta-analysis and reviews. Thereby the AQG levels of the year 2006 are replaced and the research findings of the last 15 years on the health impact of air pollution are considered.

2 Provisional nature of the information

This evaluation of air quality in Germany in the year 2022 is based on preliminary data which has not yet been conclusively audited from the air monitoring networks of the federal states and the UBA, valid on 31th January 2023. Due to the comprehensive quality assurance within the monitoring networks, the final data will only be available in mid-2023.

The currently available data allows for a general assessment of the past year. The following pollutants were subject to consideration: particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2) and ozone (O_3), since, the measured concentrations are either slightly higher or lower than the limit and target values for the protection of human health for such pollutants.

3 Causes of air pollution

The primary sources of the air pollutants are road traffic and combustion processes in industry, the energy sector and households. Agriculture also contributes to particulate matter emissions due to the formation of what are known as “secondary particles”, which are particles that arise from complex chemical reactions between gaseous substances. The degree of the pollution level is also influenced by the weather conditions. In cold weather, emissions (quantity of a pollutant released to the ambient air) often increase because for example heating systems go into increased use. High-pressure weather during the winter, which is often characterised by low wind speeds and a limited vertical exchange of air, means that air pollutants become concentrated in the lower atmospheric strata. High-pressure weather in the summer, with intense sunlight and high temperatures, acts to boost the formation of ground-level ozone.

At high wind speeds and under strong mixing conditions, the levels of pollution fall, however. Inter-year variations in the levels of air pollution are primarily caused by different weather conditions of this kind. They therefore affect the influence of the more long-term development of the emissions.

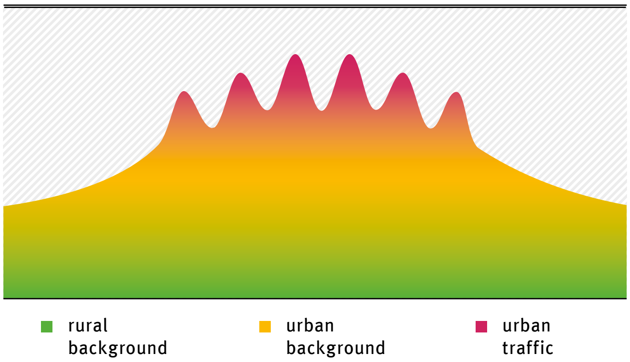
4 Influence of environmental conditions

In the following sections, the concentration values recorded at the individual air monitoring stations are summarised in the form of what are referred to as “pollution regimes”. Pollution regimes group air monitoring stations together with similar environmental conditions. The “rural background” regime relates to areas in which the air quality is largely uninfluenced by local emissions. The air monitoring stations in this regime therefore represent the regional pollution level, which is also referred to as the regional background. The “urban background” regime is characterised by areas in which the measured pollutant concentrations can be seen as being typical for the air quality in the city. In this respect, the pollution results from emissions in the city itself (road traffic, heating systems, industry, etc.) and that in the regional background. The air monitoring stations in the “urban traffic” regime are typically located on busy roads. As a result of this, the urban background pollution is joined by a contribution which arises due to the direct road traffic emissions. Figure 2 provides a diagrammatic representation of the contributions by the individual pollution regimes, although it only provides the approximate proportions. Another pollution regime relates to measurements in the vicinity of industrial areas, which are used to assess the contribution of industrial emissions to the air quality in nearby residential areas.

Figure 2

Diagrammatic presentation of the pollution regimes for particulate matter and nitrogen dioxide

Modified according to Lenschow*



* Lenschow et. al., Some ideas about the sources of PM_{10}, Atmospheric Environment 35 (2001) S23–S33

II Particulate Matter: No exceedances of the EU limit values, but exceedances of the WHO AQG levels

1 PM_{10}-Annual mean values

In 2022 the annual mean PM_{10} values were on a similar level as in the year before Figure 3).

Accompanied by the regional decrease of the PM_{10} emissions, the annual mean PM_{10} values also show a clear decrease in all pollution regimes throughout the entire period of observation. The progression is also characterised by strong inter-year variations, however, particularly due to the different weather conditions. The PM_{10} limit of 40 µg/m³ as the annual mean value was complied with throughout Germany. 47 percent of the air monitoring stations recorded values that infringed the AQG level proposed by the WHO. Next to air monitoring stations in urban traffic locations also stations in urban and rarely in rural background locations exceed this value.

EU limit value

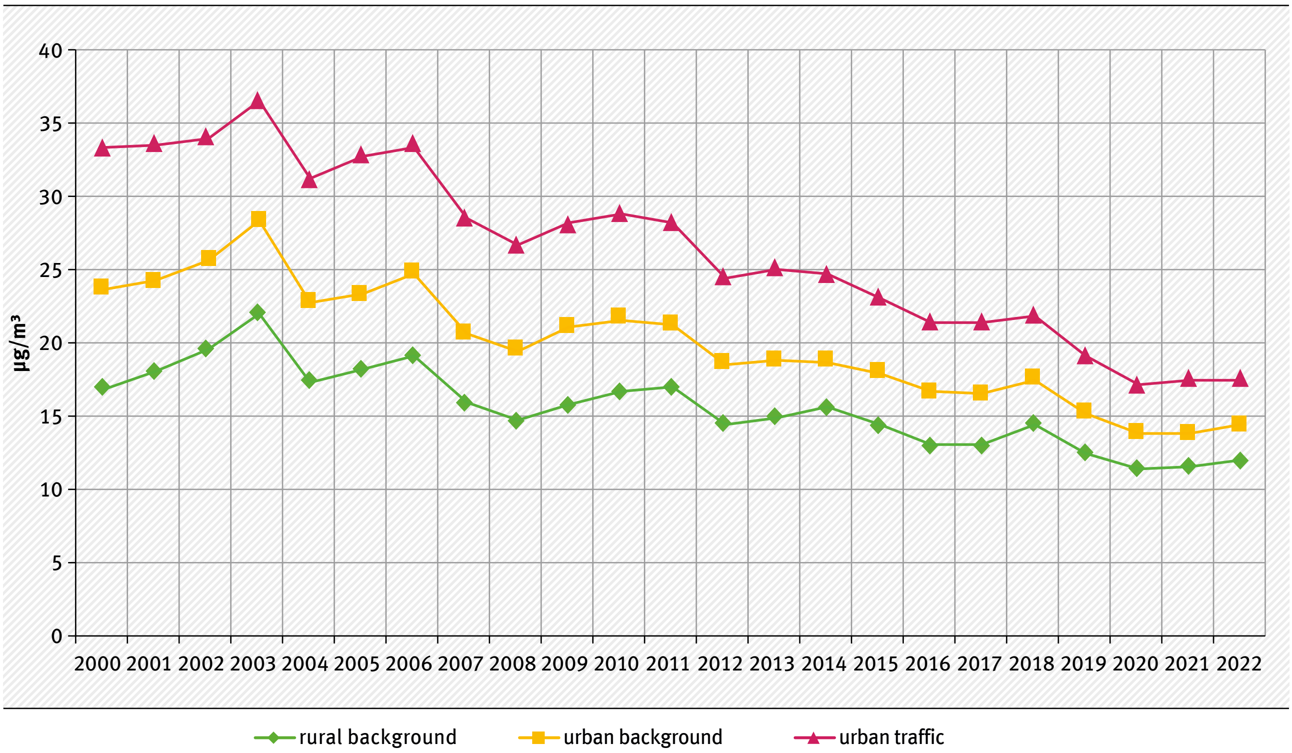
The annual mean PM_{10} value must not exceed 40 µg/m³.

WHO AQG level 2021

The annual mean PM_{10} value should not exceed 15 µg/m³.

Figure 3

Development of the annual mean PM_{10} values
via selected air monitoring stations in the corresponding pollution regime, time frame 2000–2022



Source: German Environment Agency (UBA) 2023

The interannual variations of the PM_{10} annual means are mainly caused by meteorological variations and to a lesser extend by emission variations (see also Chapter I/3 Causes of air pollution). This meteorological influence is illustrated in Figure 4, which shows the monthly mean PM_{10} values of the last five years.

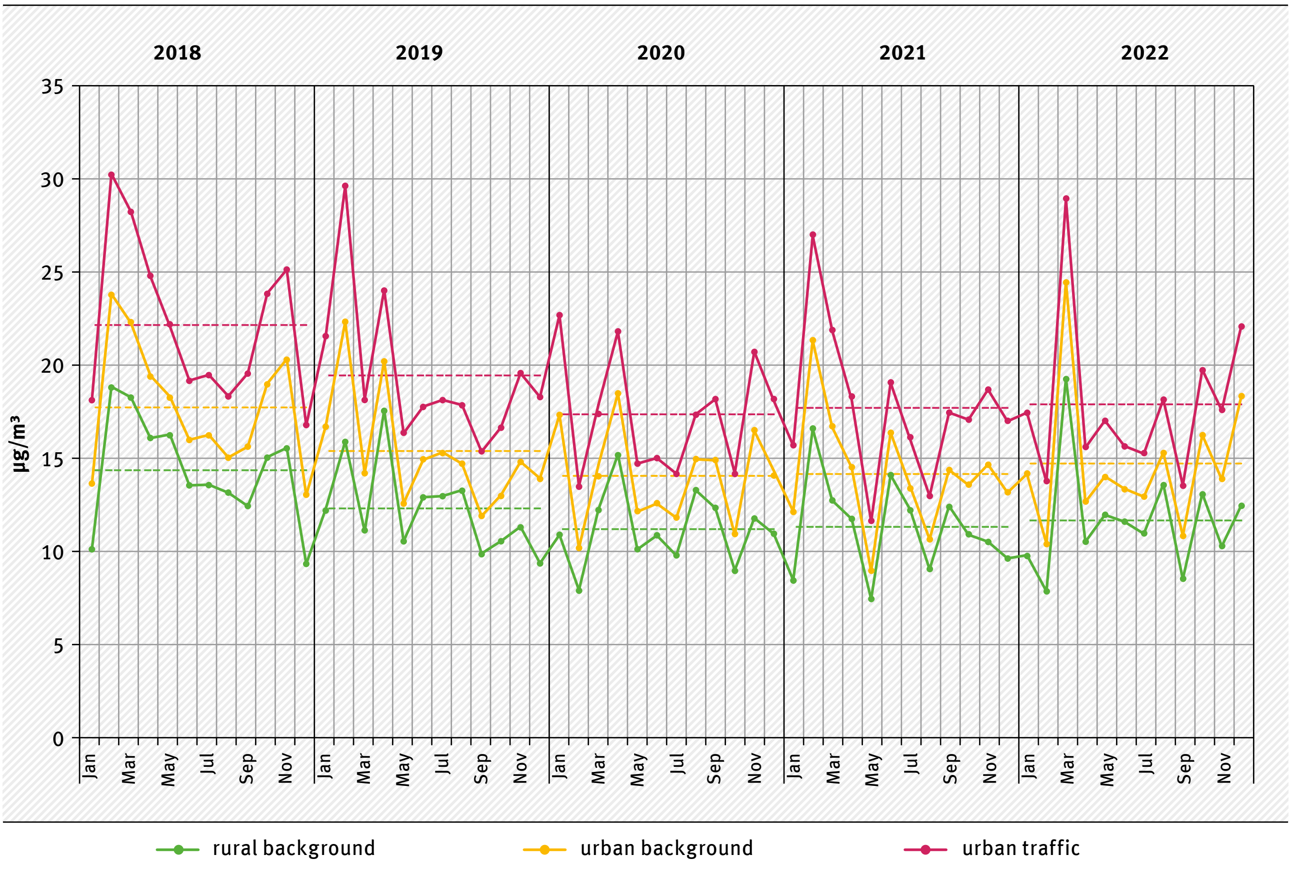
The year 2022 was again very sunny and too warm. It belongs to the warmest years since the start of recording with a significantly too dry summer[3]. In contrast, the months February and September were considerably too wet, which lead to a lower PM_{10} pollution in those months. On the other hand, the sunniest March since the start of recording[4] led to very dry weather and therefore to considerably high PM_{10} concentrations.

3 Deutschlandwetter im Jahr 2022, Pressemitteilung des DWD, https://www.dwd.de/DE/presse/pressemitteilungen/DE/2022/20221230_deutschlandwetter_jahr2022_news.html?nn=495078

4 Deutschlandwetter im März 2022, Pressemitteilung des DWD, https://www.dwd.de/DE/presse/pressemitteilungen/DE/2022/20220330_deutschlandwetter_maerz2022.pdf?__blob=publicationFile&v=3

Figure 4

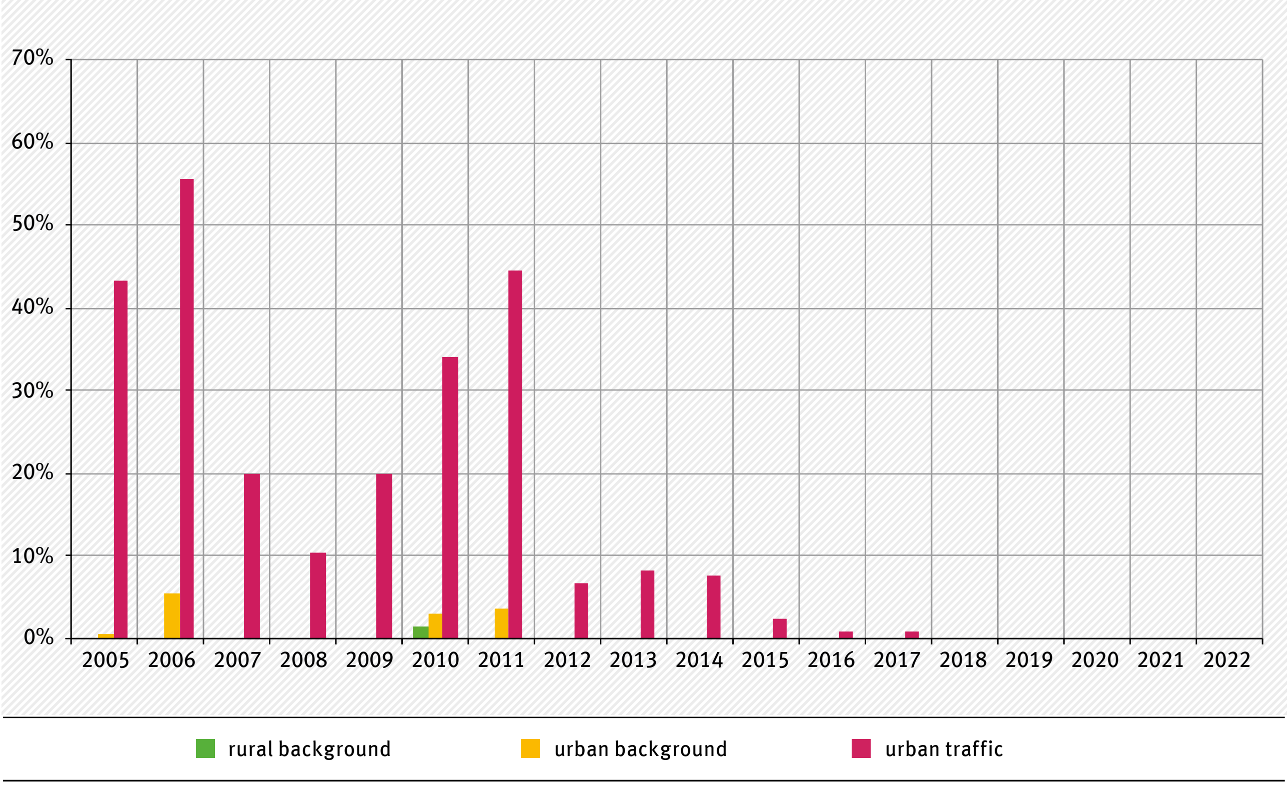
PM_{10} monthly mean values of the period 2018–2022
annual means as dahed lines



Source: German Environment Agency (UBA) 2023

Figure 5

Percentage share of air monitoring stations exceeding the PM_{10} limit value
for the 24-hour values in the corresponding pollution regime, time frame 2005–2022



Source: German Environment Agency (UBA) 2023

2 PM_{10}-24-hour values

Like in the year before, none of the 360 stations measured PM_{10} 24-hour values above 50 µg/m³ at more than 35 days. Thus, the positive trend of the past years continues. In the past, most of the exceedances occured at traffic stations (in 2006 up to more than half of those stations). Since 2012 the shares of traffic stations with exceedances have been below 10 percent, and no exceedances at background stations have occured anymore (see Figure 5, yellow bars).

The AQG level of the World Health Organization (WHO) was not complied with at 24 percent of all air monitoring stations.

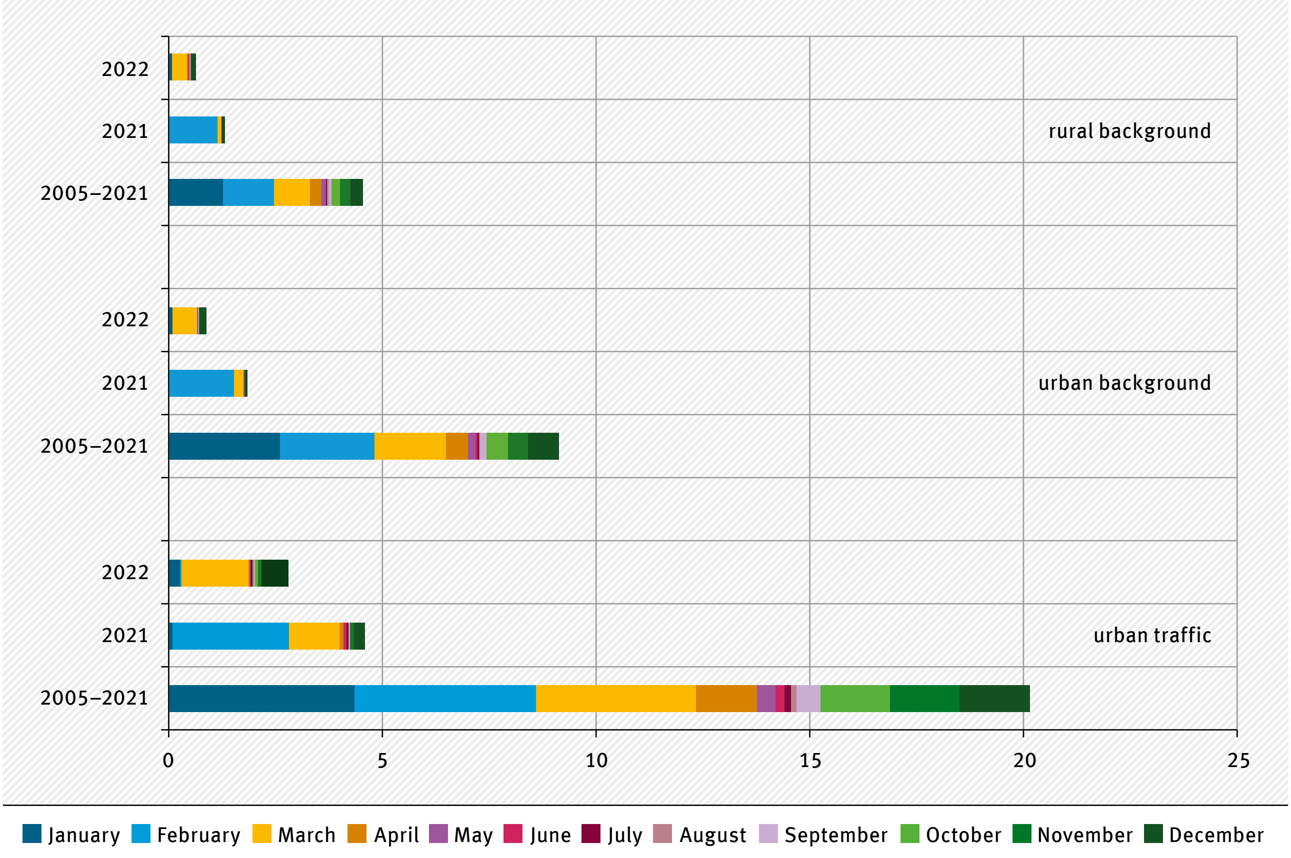
EU-limit value
The 24-hour PM_{10} value must not exceed 50 µg/m³ more than 35 times per year.

WHO AQG level 2021
For the short-term concentration the 99th percentile of the 24-hour PM_{10} value should not exceed 45 µg/m³.

Figure 6

Average number of days on which the PM_{10} limit was exceeded

(24-hour values › 50 µg/m³) per month in the corresponding pollution regime, shown for the years 2022, 2021 and the period 2005–2021



Source: German Environment Agency (UBA) 2023

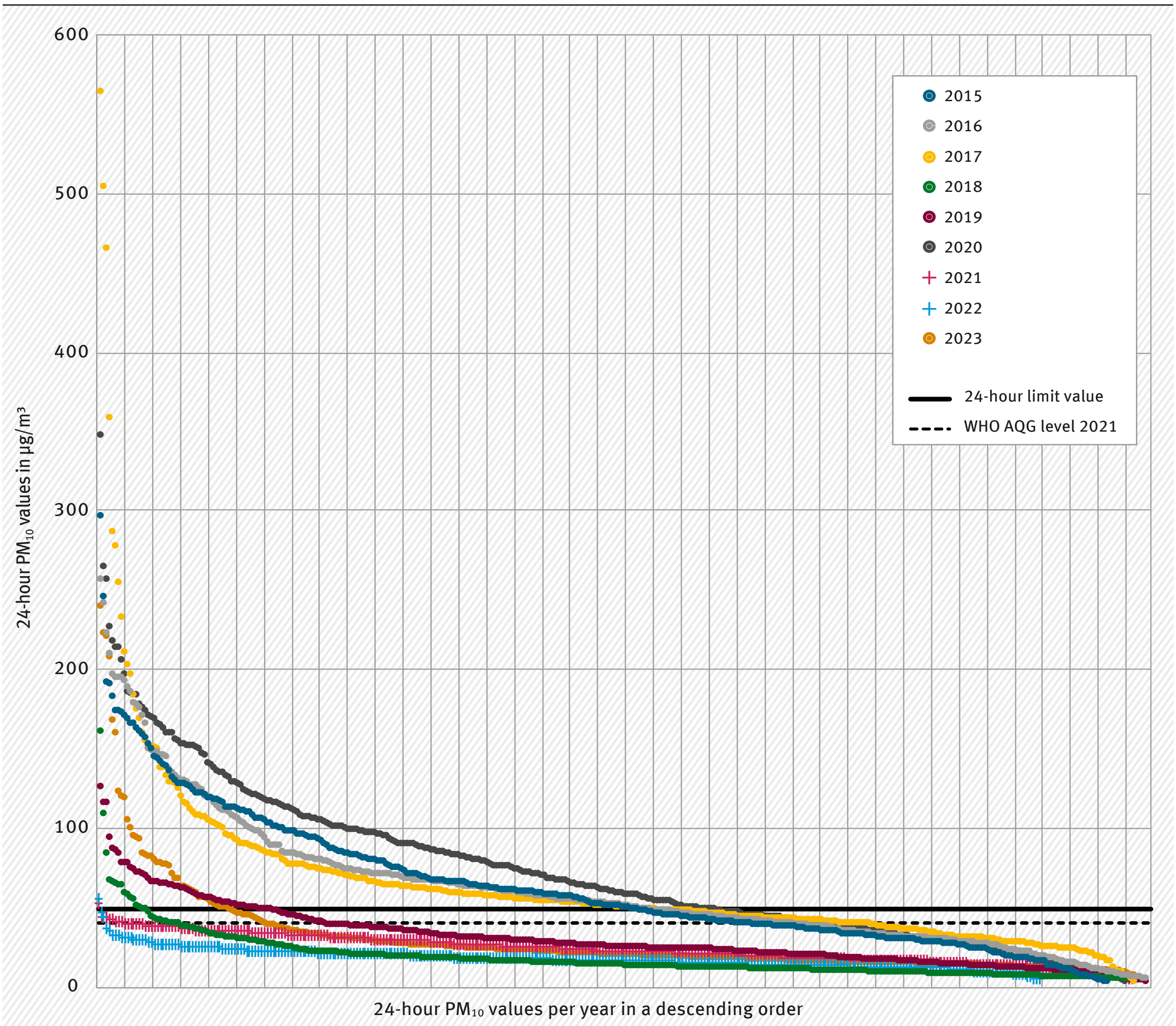
Figure 6 shows how many days were recorded on which the limits were exceeded, on average, per month. In this case, 2022 is compared with the previous year (2021) and an extended reference period (2005–2021). It can be seen that, compared to the reference period, in 2022 there were only very few days on which the limits were exceeded. But, in contrast to the slightly higher polluted previous year 2021, less exceedances occurred in 2022. The majority of exceedances occurred in March which was much too dry.

The New Year's Day represents a special case for the PM_{10} 24-hour values. As a result of the emission due to fireworks the PM_{10} pollution during the first hours of the day is exceptionally high. These high 1-hour values have an impact on the PM_{10} 24-hour values.

The 24-hour PM_{10} values of all monitoring stations at the New Year's Days plotted in descending order (Figure 7) show that the pollution in the last years varies with the meteorological situation and many of the monitoring stations are above the daily limit value. This is different in 2021 and 2022, here the peak concentrations are missing. This is due to the exceptionally small amount of emitted PM_{10} mass as a result of the measures to contain the Corona pandemic. In those both years only some single monitoring stations exceed the limit value of 50 µg/m³. The New Year's Day in 2023 was again typically polluted as there were no more restrictions for fireworks.

Figure 7

24-hour PM_{10} values of all air monitoring stations at the New Year's Days 2015–2023



Source: German Environment Agency (UBA) 2023

Saharan dust event on Germany's highest mountain
Natural sources may lead to high particulate matter concentrations. As an example, extraordinary high PM_{10} concentrations were measured at UBA's monitoring station Zugspitze/Schneefernerhaus between 15th and 18th March, which were caused by transboundary transport of Saharan dust. Starting at noon of 15th March hourly concentrations exceeded 1,000 µg/m³ and decreased in the afternoon again. On the following days hourly means were repeatedly above 400 µg/m³. Finally, on Friday, 18th March the concentrations normalized. The highest PM_{10} daily mean within this episode was 218 µg/m³ (17th March). For comparison, approx. 4 µg/m³ is the typical annual mean PM_{10} concentration there. In general, Zugspitze/Schneefernerhaus is the monitoring station with the lowest PM pollution in Germany. Between 2011 and 2020 no comparably high values were recorded at this mountain station. In contrast to other episodes like in February 2021 when Saharan dust and therefore high PM_{10} values were monitored throughout Germany, the 2022's dust event did not cause exceedances of the daily limit value on a large scale.

3 $PM_{2.5}$-Air pollution

From 1st January 2015, for the smaller fraction of particulate matter which only contains particles with a maximum diameter of 2.5 micrometres (µm), an annual mean limit of 25 µg/m³ applies throughout Europe. In Germany, since 2015 and also in 2022, this value was not exceeded at any air monitoring station. The annual mean $PM_{2.5}$ values decrease during the entire period and for all pollution regimes (Figure 8). The Figure shows that the concentrations at monitoring stations, in more polluted urban and traffic locations, are on a similar level as rural background stations a few years ago. However, the WHO AQG level is exceeded at almost every (99.5 %) of the about 200 monitoring stations.

EU limit value

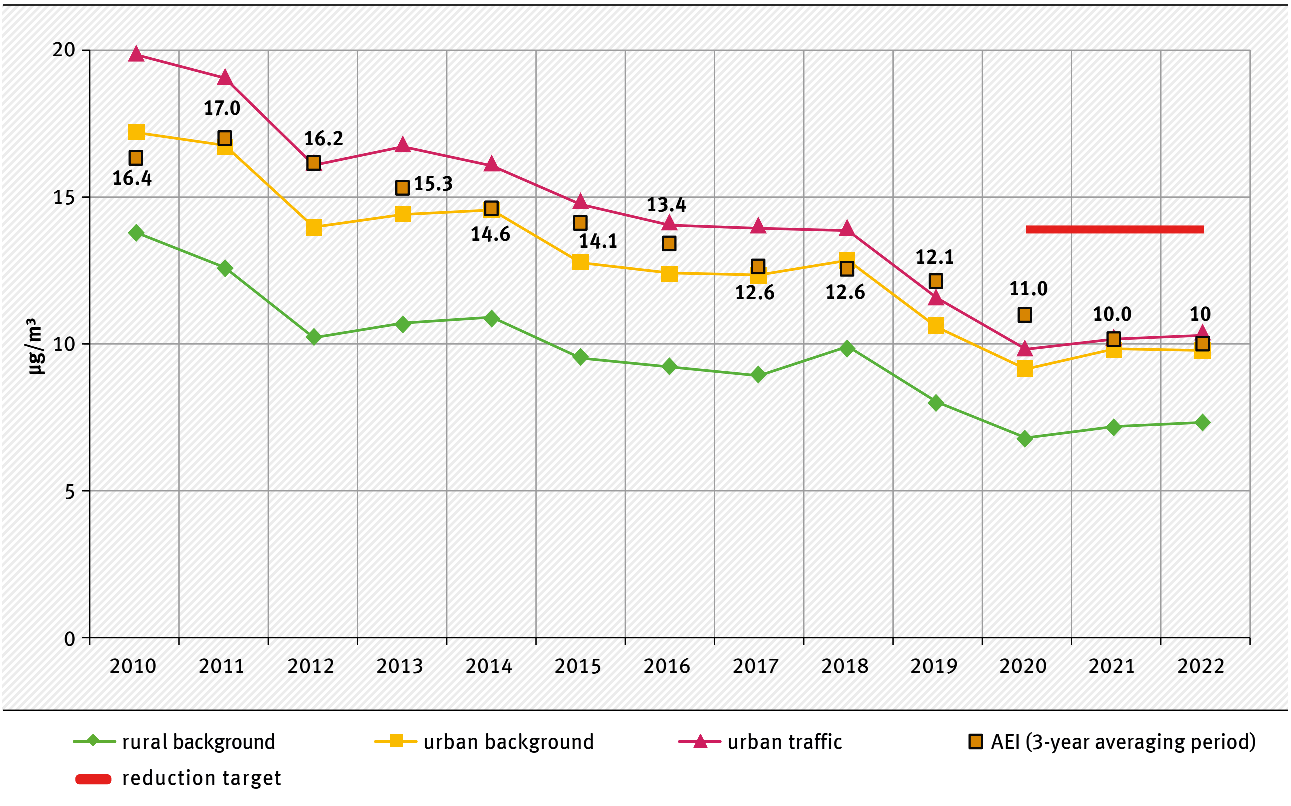
The annual mean $PM_{2.5}$ value must not exceed 25 µg/m³.

WHO AQG level 2021

The annual mean $PM_{2.5}$ value should not exceed 5 µg/m³. For the short-term concentration the 99th percentile of the 24-hour $PM_{2.5}$ value should not exceed 15 µg/m³.

Figure 8

Development of the annual mean $PM_{2.5}$ values and of the Average Exposure Indicator (AEI)
via selected monitoring stations in the corresponding pollution regime, time frame 2010–2022



Source: German Environment Agency (UBA) 2023

The WHO AQG level for the short term pollution was also exceeded at all stations in 2022. The EU Air Quality Directive also requires to reduce the average exposure of the population to $PM_{2.5}$. For this purpose, the Average Exposure Indicator (AEI) was developed. As the initial value for Germany for 2010, an AEI of 16.4 µg/m³ was calculated, this resulted in a national reduction goal of 15 percent until 2020. Accordingly, the AEI calculated from 2020 on may not exceed the value of 13.9 µg/m³. Germany met the reduction target with 11.0 µg/m³ in 2020 and also in the following years.

The AEI for 2022 (average value of the years 2020, 2021 and 2022) is about 10 µg/m³ with those data available at the moment. In addition, from 1st January 2015 onwards, the AEI is not permitted to exceed a value of 20 µg/m³. This value has not been exceeded in Germany since the start of the measurements in 2008.

Exposure
The contact of an organism with chemical, biological or physical influences is known as "exposure". A person is "exposed" to particulate matter, for example.

How is the Average Exposure Indicator (AEI) calculated?
The average exposure indicator is determined as an average value over a period of 3 years from the individual annual mean $PM_{2.5}$ values of selected air monitoring stations with an urban background. This results in a value which is expressed in µg/m³ for each 3-year period.

The experimental monitoring station Langen is located in the urban background of the Rhine Main area. Here, the German Environment Agency (UBA) operates a monitoring station that is part of GUAN (German Ultrafine Aerosol Network) in order to measure ultrafine particles.

III Nitrogen dioxide: Decreasing trend continues

1 NO_2-Annual mean values

Presumably two of the air monitoring stations in urban traffic locations exceeded the limit value for the NO_2 annual mean. Figure 9 shows the significant decrease of the share of traffic stations in exceedance. Since 2015 no exceedances have occured at stations in the urban background, in the years before only few exceedances were recorded.

EU limit value

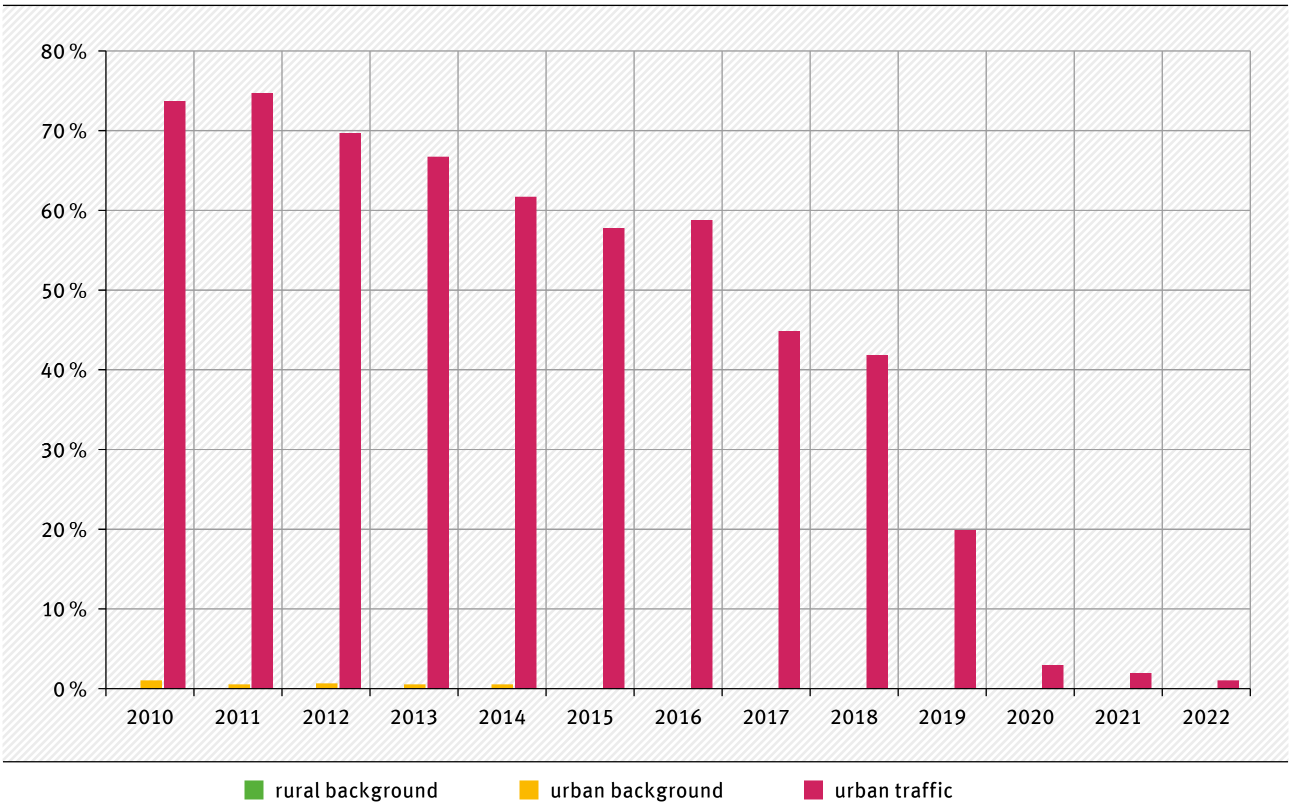
The annual mean NO_2 value must not exceed 40 µg/m³

WHO AQG level 2021

The annual mean NO_2 value should not exceed 10 µg/m³.

Figure 9

Percentage share of air monitoring stations exceeding the NO_2 limit value for the annual mean in the corresponding pollution regime, time frame 2010–2022

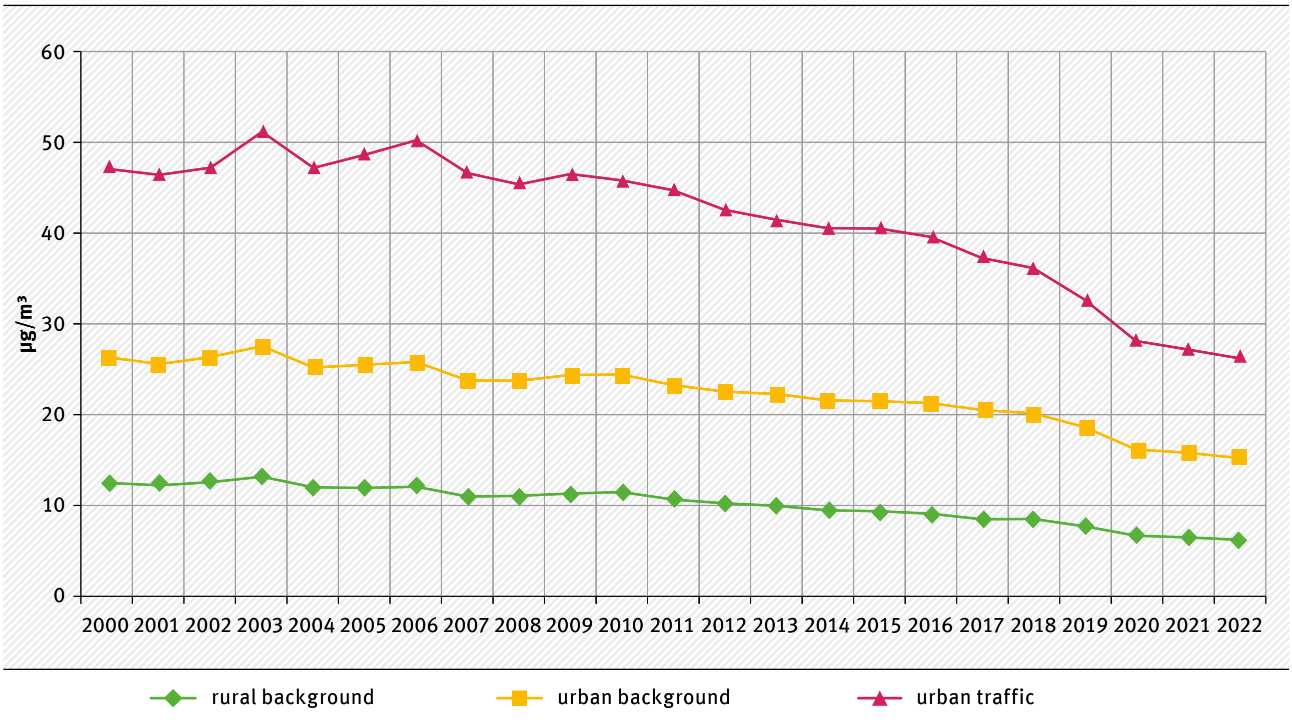


Source: German Environment Agency (UBA) 2023

Figure 10

Development of the annual mean NO_2 values

via selected air monitoring stations in the corresponding pollution regime, time frame 2000–2022



Source: German Environment Agency (UBA) 2023

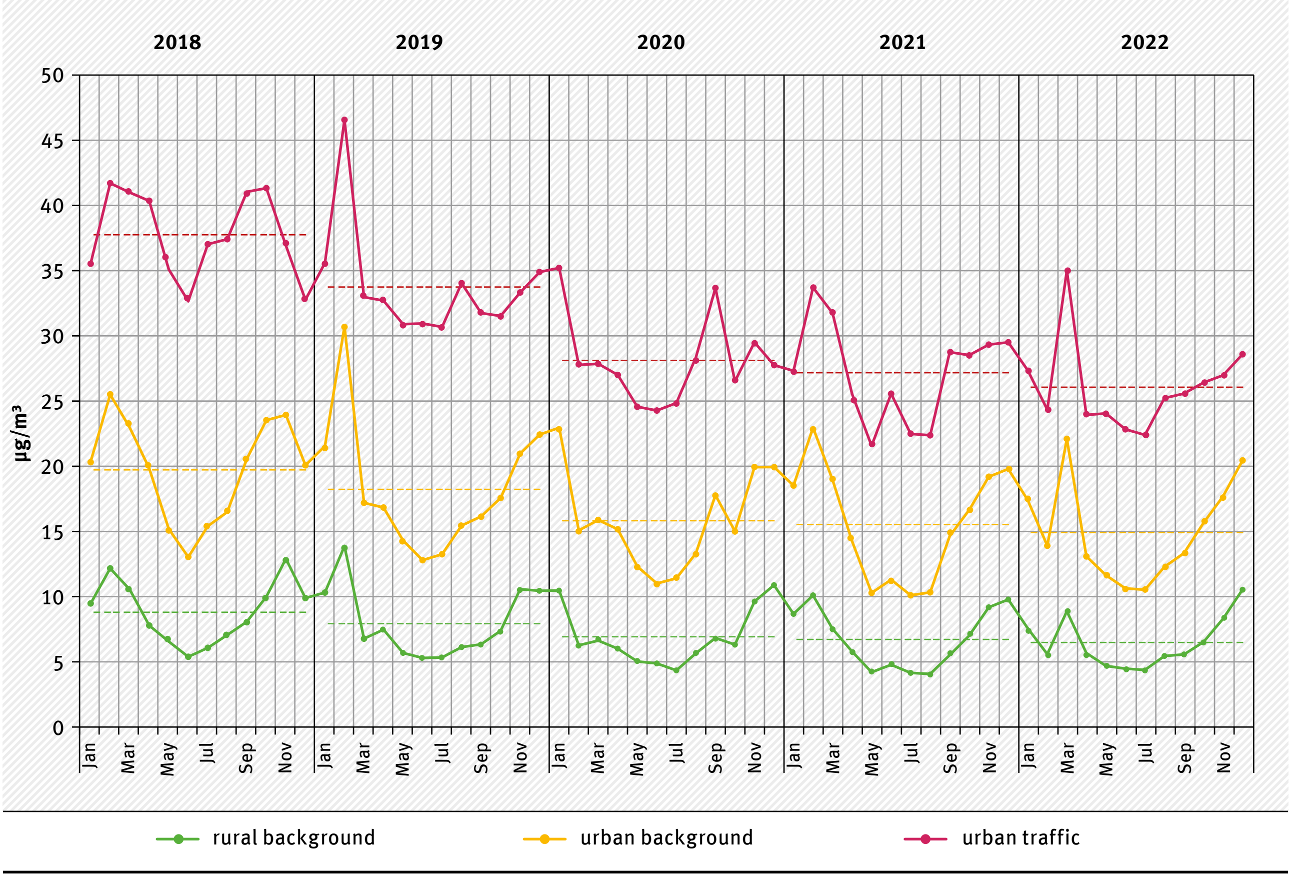
The much stricter WHO AQG level for the NO_2 annual mean were not complied with at 80 percent of all air monitoring stations. The nitrogen dioxide pollution shows a clear decrease in the last decade, particularly pronounced in the last few years (Figure 10). In order to minimize the impact of the closure or opening of stations on the development of the average NO_2 values only air monitoring stations were selected for this figure that conducted measurements over an extended period. The levels of pollution are primarily determined by local emission sources – particularly the traffic in urban conurbations – and only show limited inter-year variations due to weather.

In rural areas, which are typically a long way from the major sources of NO_2, from 2000–2022, the average annual concentration for all air monitoring stations amounted to 10 µg/m³ (Figure 10, green curve). At the air monitoring stations with an urban background, the values were well below the limit of 40 µg/m³ with a slight decline over the last 20 years (Figure 10, yellow curve), as it is also seen at rural background stations. In 2022 the average NO_2 concentration at urban traffic stations was approx. 25 µg/m³ (red curve). The mean values in traffic locations in the period 2000 to 2010 stagnated in the range of 45 to 50 µg/m³, around the year 2010 a year to year continuing decrease started.

Figure 11

NO_2 monthly mean values of the period 2018–2022

annual means as dashed lines



Source: German Environment Agency (UBA) 2023

Figure 11 shows the annual variation of NO_2 in the three pollution regimes within the last six years (only stations with data in all six years). A clear decline of concentrations can be seen. Except for variations due to weather conditions, which often lead to higher concentrations in winter and lower concentrations in summer especially in the background regime, most of the monthly mean values are lower as in the year before. Therefore, a steady decline of annual means is seen in every pollution regime (dashed lines). In 2022 the values are only slightly below the values of the previous year. Due to meteorological conditions, considerable variations in the concentrations may occur. For the year 2022 this can be illustrated by the high NO_2 concentrations in March.

2 NO_2-One hour values

Since 2010, one hour NO_2 values exceeding 200 µg/m³ are only permitted at a maximum of 18 times per year. In 2022, like in the previous years, this limit value was not exceeded. The last time that few exceedances at urban traffic station were recorded was in 2016. Only two of about 400 air monitoring stations failed to comply with the WHO AQG level for the short-term concentration. 82 percent of the air monitoring stations failed to comply with the new WHO AQG level for the 24-hour NO_2 value.

EU limit value

The one hour NO_2 values must not exceed 200 µg/m³ more than 18 times per year.

WHO AQG level 2021

For the short-term concentration the 99th percentile of the 24-hour NO_2 value should not exceed 25 µg/m³. The one hour NO_2 values should not exceed 200 µg/m³.

IV Ground-level ozone: Typical pollution but higher than in the previous year

1 O_3-Information and alert threshold

Ozone is measured at about 260 monitoring stations throughout Germany. In 2022, the highest 1-hour average value amounted to 228 µg/m³. This value is at a similar level as the previous year value (226 µg/m³). Like in 2021, the alert threshold of 240 µg/m³ was again not exceeded in 2022. The information threshold of 180 µg/m³ was exceeded on 15 days which is considerably more than in the previous year (5 days). 2022 was a less affected year with regards to exceedances of the threshold values, compared to the last 20 years, see Figure 12. However, there were slightly more exceedances than in the previous year. Figure 12 also shows that the exceedances of the information threshold vary in a wide range between the years, the record-breaking summer of 2003 sticks out clearly. But also the year 2015, with exceptional hot and dry periods in July and August, was characterized by a rather high ozone pollution.

The reason for the variation of the peak concentration between the years is the high dependency on the weather conditions. In contrast to particulate matter and nitrogen dioxide, ozone is not emitted directly but formed from specific precursors (nitrogen oxides and volatile organic compounds) and with intensive solar radiation. When there are several days of summery high-pressure weather conditions, ozone can be accumulated in the lower atmospheric layers which leads to high concentrations. The summer of 2022 was sunniest and together with 2019 the third warmest summer since the start of recording [5]. With a precipitation deficit of 40 percent it was the sixth driest summer since 1881[6]. While June and July where characterized by several intensive heat waves, the August was considerably too warm (second warmth).

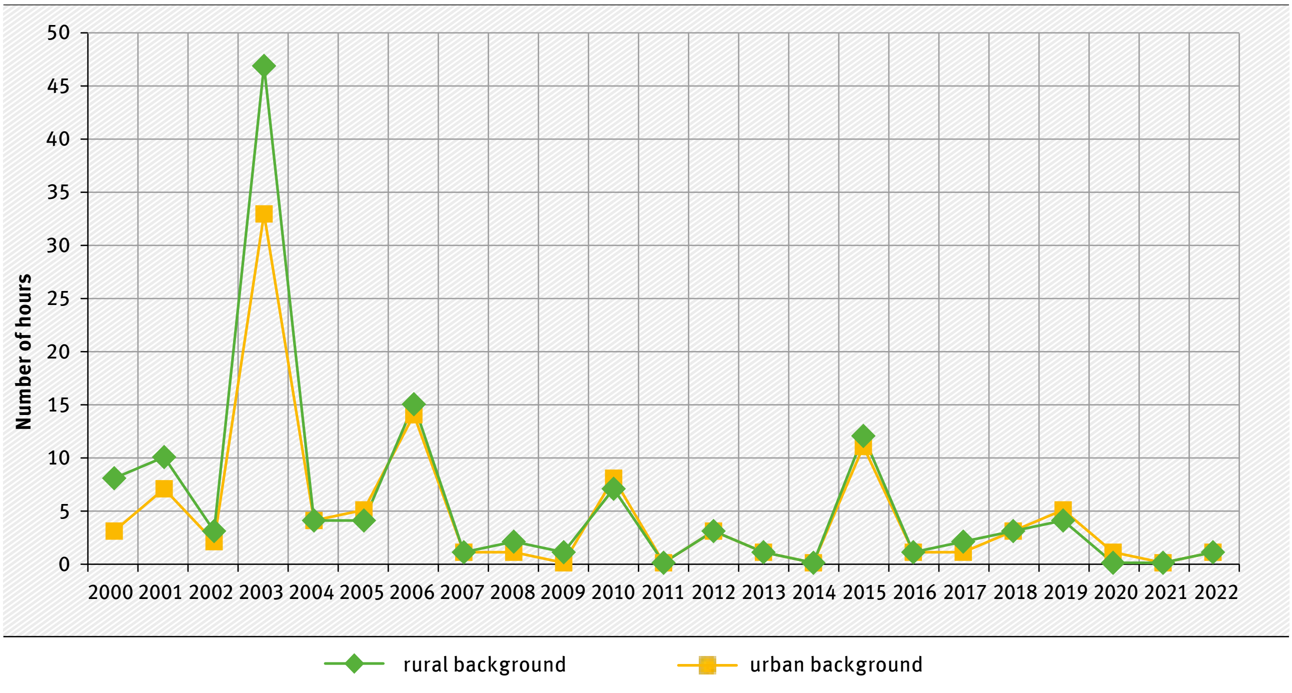
5 Klimatologischer Rückblick Sommer 2022, DWD, https://www.dwd.de/DE/leistungen/besondereereignisse/temperatur/20220921_bericht_sommer2022.html

6 Deutschlandwetter im Sommer 2022, Pressemitteilung des DWD, https://www.dwd.de/DE/presse/pressemitteilungen/DE/2022/20220830_deutschlandwetter_sommer2022.html?nn=762256

Figure 12

Hours during which the information threshold (180 µg/m³) for ozone was exceeded

Average over selected monitoring stations, time frame 2000–2022



Source: German Environment Agency (UBA) 2023

2 O_3-Target value and long-term objective for the protection of human health

Only one monitoring station did not exceed the daily maximum 8-hour value of 120 µg/m³. So that, like in the previous year, this the long-term objective is not complied with at almost every station.

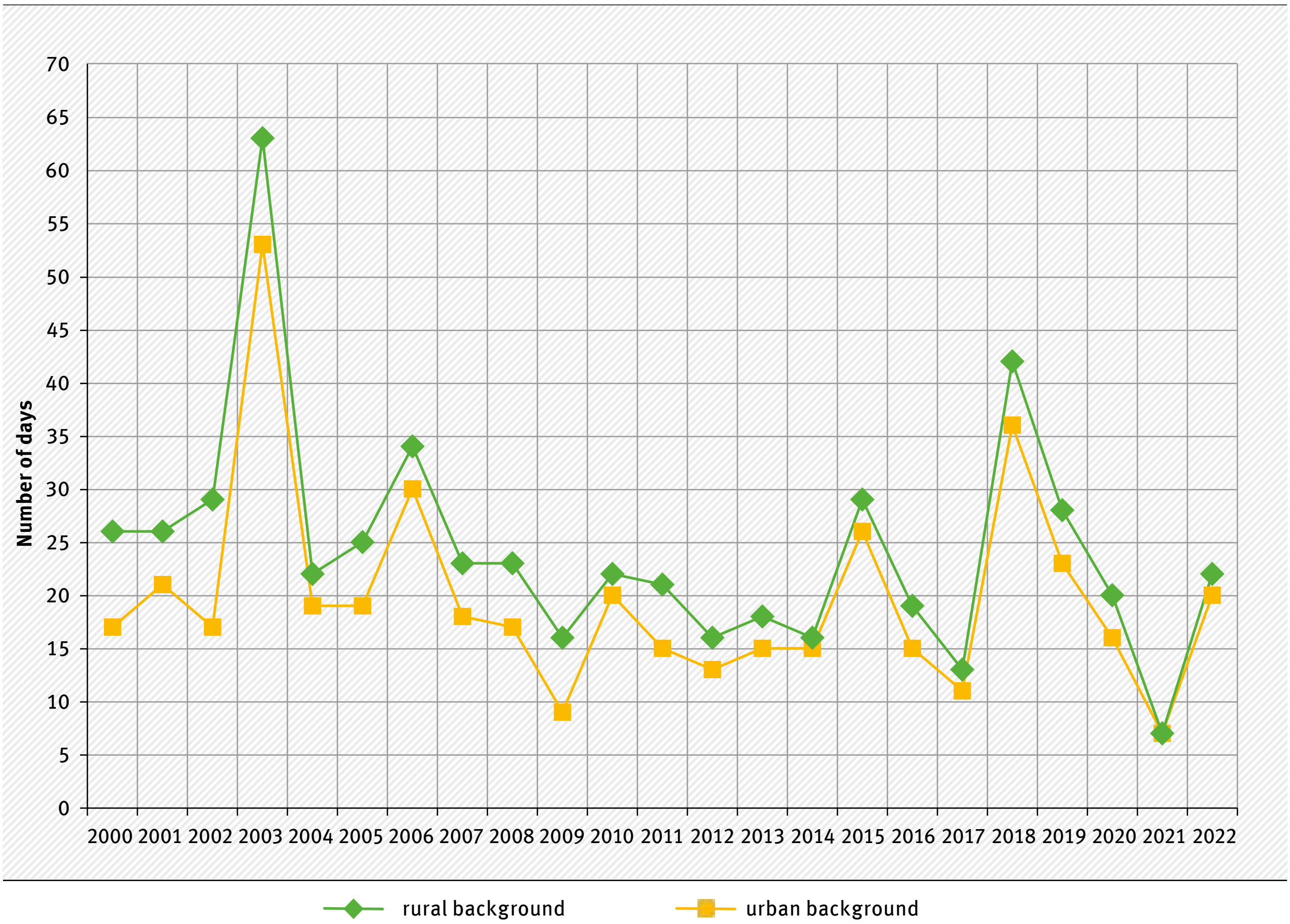
In 2022, an ozone value of 120 µg/m³, as the highest daily 8-hour average value, was exceeded on an average of 20 days per station. This is considerably more than in the year before (7). The exceedances occurred on 108 calendar days.

Figure 13 illustrates the development of the mean exceedance days from 2000 until 2022: the significant inter-year variations are caused by different meteorological conditions. In contrast to the exceedances of information and alert thresholds, there is no such clear decline of the number of days in exceedance. In general, the Northern part of Germany shows a lower number of exceedance days (Figure 14).

A 3-year period is monitored for the target value for the protection of human health: on average, an 8-hour average value of 120 µg/m³ may only be exceeded on 25 days. In the most recent averaging period of 2020 to 2022, however, 23 of the air monitoring stations (9 %) exceeded this value on more than 25 days. As in the previous averaging period this corresponds to 9 percent of all monitoring stations. Figure 15 shows that most cases in which the target values were exceeded occurred in rural areas – in contrast to pollutants such as particulate matter and nitrogen dioxide, which have the highest concentrations in the vicinity of roads, the ozone values in the vicinity of roads are a lot lower. Therefore, ozone is rarely measured at air monitoring stations in urban traffic locations.

Figure 13

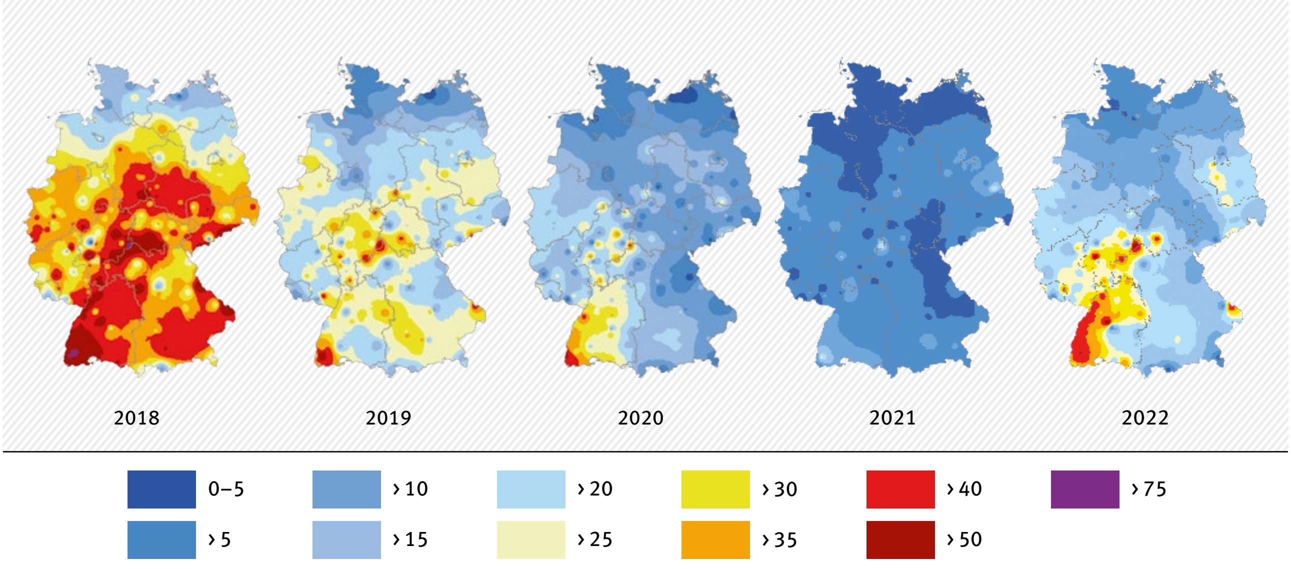
Days in exceedanceof the O_3 long-term objective (120 µg/m³)
Average over selected monitoring stations, time frame 2000–2022



Source: German Environment Agency (UBA) 2023

Figure 14

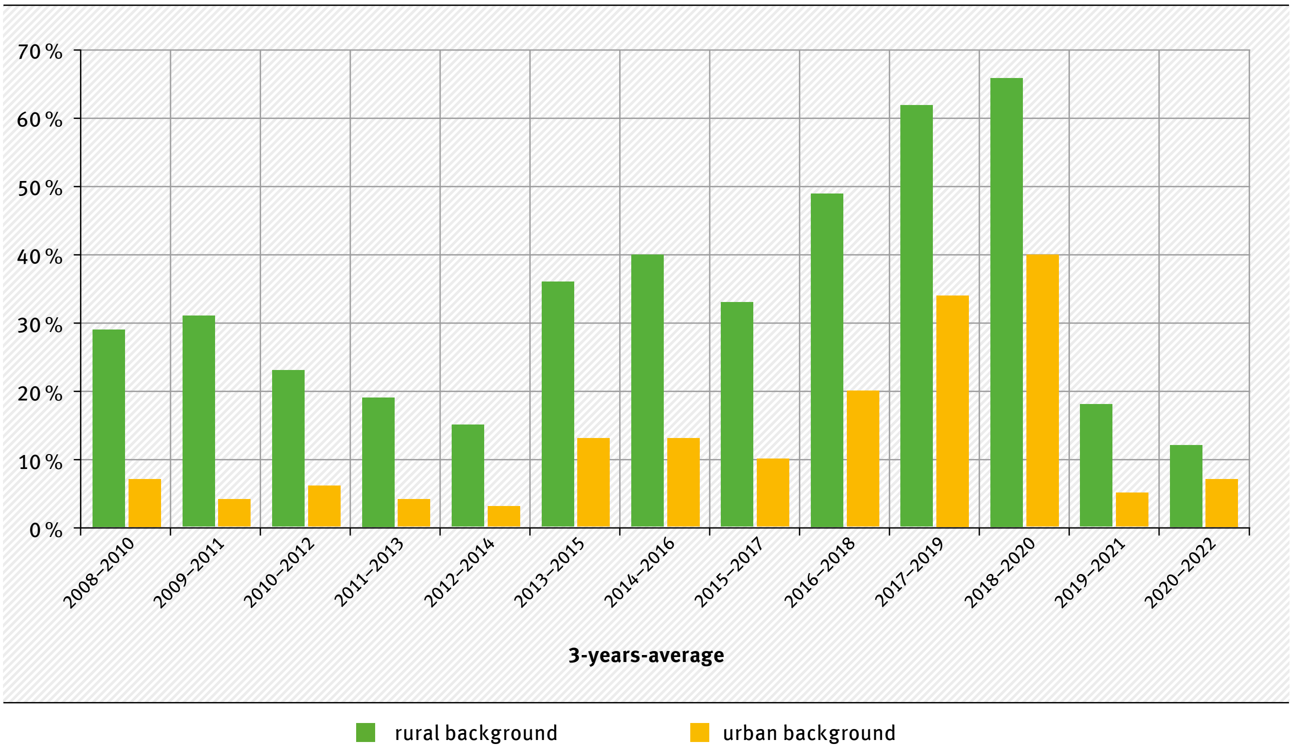
Spatial distribution of the number of days on which the long-term objective for the protection of human health was exceeded (number of days with 8-hour average values › 120 µg/m³)
time frame 2018–2022, based on station measurements and a geostatistical interpolation method



Source: German Environment Agency (UBA) 2023

Figure 15

Percentage share of air monitoring stations recording an exceedance of the target value
for the protection of human health, time frame 2010–2022
(in each case, average over 3 years)



Source: German Environment Agency (UBA) 2023

The WHO AQG level in relation to the long-term pollution (peak season) was not complied with at all stations. This is similar for the WHO AQG level in relation to the short-term pollution (99^{th} percentile of the daily maximum 8-hour mean concentration of one year), which was exceeded at all stations.

3 O_3-Protection of the vegetation

According to the EU Air Quality Directive, to determine the target values for the protection of the vegetation (AOT40), only the data from the around 160 air monitoring stations in non-urban locations is considered. For the target value (which has been mandatory since 2010), an averaging over a five-year period is required. The target value (18,000 µg/m³ h obtained from May to July) for the most recent averaging period of 2018 to 2022 was exceeded at 29 out of 131 air monitoring stations (= 18 percent, previous year: 14 percent).

In 2022, the long-term objective for the protection of the vegetation (6,000 µg/m³ h) was complied with at none of the monitoring stations (previous year: 10 stations, 6 percent). Averaged over all rural background stations the AOT40-value in 2022 is slightly higher than in the other years since 2000, and well above the low values of 2020 and 2021.

New methods for the impact evaluation of ozone have been developed meanwhile. They are recommended for monitoring air pollution impacts according to annex V in the NEC-directive (Directive 2016/2284 on the reduction of national emissions of certain atmospheric pollutants). In this respect, it isn't just the concentration of ozone, but the meteorological conditions, the opening characteristics of the stomata of the plants and therefore the ozone flux into the plants, which are taken into account. In 2019, Germany reported results for monitoring air pollution impacts to the European Environmental Agency for the first time. In 2017, at 21 air monitoring stations sufficient measurement data were available to be used in the new valuation model based on ozone flux. At every station the critical level was exceeded.

This means that the vegetation types (forest, field or grassland) in the surroundings of the stations are risked to be exposed by ozone. For the assessment it is assumed that sufficient soil moisture was available and thus the stomata of the plants were open at all times (worst case), which is a realistic assumption for the quite wet year 2017.

Information threshold

When ozone values of over 180 µg/m³ (1-hour average value) occur, the general public is notified by the media about the total the presence of a health risk for particularly sensitive average sections of the population.

Alert threshold

When ozone values of over 240 µg/m³ (1-hour average value) occur, the general public is warned by the media about the long term, presence of a general risk to human health.

Target values for the protection of human health

Ozone values of over 120 µg/m³ (highest daily 8-hour average value) are only permitted to occur on a maximum of 25 days per calendar year, averaged over 3 years. Over the long-term, the 8-hour average values should never exceed 120 µg/m³ (long-term objective.

WHO AQG levels 2021

For the short-term pollution the 99^{th} percentile of the highest daily 8-hour average value per year should not exceed a value of 100 µg/m³. For the long-term pollution the average of daily maximum 8-hour mean concentration in the six consecutive months with the highest six-month running-average concentration (peak season) should not exceed a value of 60 µg/m³. In Germany this corresponds typically to the month April to September.

Target values for the protection of vegetation (AOT40)

The term AOT40 (Accumulated Ozone exposure over a Threshold of 40 parts per billion) designates sum of the differences between the 1-hour values exceeding 80 µg/m³ (= 40 ppb) and the value 80 µg/m³ between 8 am and 8 pm in the months of May to July. Since 2010, as 5-year average, the AOT40 target value should not exceed a value of 18,000 µg/m³ h – i. e. 9,000 ppb h and/or 9 ppm h. Over the value should not exceed a maximum value of 6,000 µg/m³ h in one year – i. e. 3,000 ppb h and/or 3 ppm h.

V Challenges in air quality control – unregulated air pollutants

1 Background

Air pollutants are released by a wide variety of processes and activities and affect people and the environment. Probably the best-known examples are the smog episodes in London in the 1950s and in the Ruhr area in the 1960s. Finally, in the mid-1970s, high sulphur dioxide emissions throughout Central Europe led to "acid rain" with severe harm to humans and the environment. Since then, measures have been continuously taken in Germany and Europe to reduce air pollutants and improve air quality accordingly. Since the 1990s, European directives have set limits and target values for air pollutants. As a result, concentrations of particulate matter (PM_{10}, $PM_{2.5}$), nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2), carbon monoxide (CO) and lead (Pb) in particular have been reduced, leading to a significant improvement in air quality.

Limit values are set by the EU on the scientific basis of the health and/or ecosystem effects of the respective air pollutants. The revision of the WHO Guidelines published in 2021 shows that the currently applicable provisions are still not providing sufficient protection in terms of human health. Ecosystems continue to be threatened primarily by ozone and high ammonia concentrations. These findings prompted the EU Commission to call for stricter limit values for 2030 and also to propose a revised concept for air quality monitoring. In addition to monitoring for compliance with limit and target values, the EU Commission's proposal for a new directive on air quality[7] provides for further objectives for the monitoring of air pollutants: Pollutants not regulated by limit or target values where so far too little information is available should also be taken into account. In addition, the precursor substances that contribute to the formation of ozone and particulate matter, for example, also need to be recorded in order to be in a position to identify suitable measures for their reduction. For this purpose, the EU Commission calls for the establishment of so-called supersites in its proposal, which primarily serve to gain knowledge and are not aimed at monitoring compliance with limit values.

Initially, however, it is important to ensure that the air quality limits set by law are generally complied with everywhere. It is of course not possible to measure air quality across the board. Concentrations are therefore monitored at a fixed number of measuring points, which are ideally placed at the locations of highest exposure. In recent years, model calculations have increasingly been used as a supplementary method for determining air quality. This also makes it possible to classify polluters and assess the impact of measures. High demands on the quality of measurements need to be imposed in order to ensure compliance with legally defined limit values. The use of common reference methods, which are defined internationally in CEN standards, and the performance of measurements exclusively by accredited laboratories are prerequisites. Furthermore, substance-specific data quality objectives also need to be taken into account. It is essential that the measurement has a high accuracy, especially in the range of the limit values. In addition to the model calculation, the measurement of other substances (for which no limit/target values are defined) also serves to optimise measures. For example, the constituents of dust allow conclusions to be drawn as to whether agriculture or combustion processes are the main causes of high concentrations of particulate matter. The identification of precursors is essential for the targeted mitigation of a secondary air pollutant such as ozone. Standardised procedures also often already exist for precursor substances. Nevertheless, only few surveys are conducted. It is important in this regard to raise awareness that knowledge of only the substances regulated by limit/target values is not sufficient for successful air pollution control planning.

In addition to the objectives already outlined, the recording of "new" air pollutants is also the subject of a monitoring programme. Initial indications of the harmful effects of ultrafine particles, for example, only allow their substantiation if comparable data are collected at a sufficient number of measuring points for further studies. This is the only way to correlate

7 EU COM (2022): Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on ambient air quality and cleaner air for Europe. Brussels, 26.10.2022; 542 final 2022/0347 (COD)

impact and concentration and to classify the relevance of polluters. Standardised reference methods are often not yet available for “new” air pollutants. Existing survey methods are not sufficiently well established and are therefore time-consuming and costly. These circumstances suggest that orientational measurements should first be undertaken at a few locations, which should be as representative as possible, and that the observations then optimised on the basis of the data evaluation.

2 Ultrafine particles

Ultrafine particles (UFP) are produced in almost all natural and technical combustion processes and are emitted directly as particles or represent the precursor substances from which UFP are finally formed. Sources of UFP include transport in general and airports in particular, as well as combustion plants, industry and agriculture. In short, UFP occur from domestic chimneys to waste incinerators and are highly variable in the extent to which they occur, depending on whether the source is currently emitting or not.

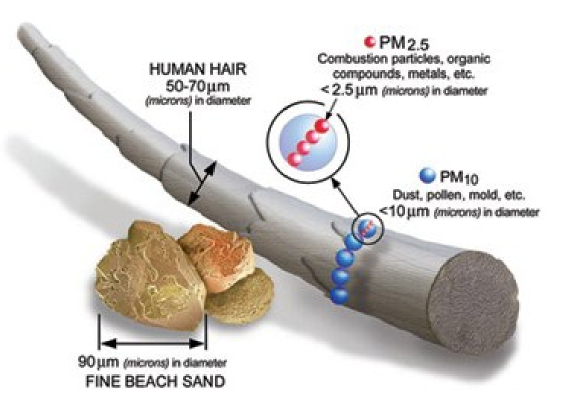
Furthermore, medical studies indicate that UFP in ambient air pose a health risk. This risk, however, is not yet clearly quantifiable, so that there are still largely no restrictive regulations for UFP. It is only on the emissions side, e.g. directly at the exhaust of motor vehicles, that regulations on the permissible number of emitable particles already exist. Not yet regulated, however, is what actually reaches people and the environment (immission). This means that the main emitters have been identified in principle, but only partially quantified. In addition, there are too few health studies so far available on the effects of UFP that might have led to a limit value. Although the recording of UFP is standardised in principle, further detailed coordination and standardisation efforts are still required. Improvements in the classification of polluters also require the further development of model calculations and forecasting models: This concerns, among other aspects, the description of particle formation in the model, the inclusion of non-volatile and volatile components, and the compilation of emission inventories of UFP and their precursors. No clear health perspective has yet emerged, although there is a tendency towards a view of possible harmful effects of UFP on humans. It is necessary to conduct further epidemiological studies on the different short-term and especially long-term effects of UFP in order to clarify this further. Here, the high spatial and temporal variability of UFP needs to be taken into account in particular, and consideration given to the comparability of measurements and medical examinations.

In its latest air quality report of 2021, the World Health Organization considers UFP to be a pollutant of special concern, although the data situation is not yet conducive to the recommendation of limit values.

Ultrafine particles

Ultrafine particles (UFP) are tiny airborne particles with a diameter of less than 100 nm (0.1 µm), roughly 500–700 times smaller than the diameter of a human hair.

Particle sizes (diameter) compared to a human hair



Source: https://www.epa.gov/pmcourse/what-particle-pollution

The WHO advises that standardised measurement methods be further developed and used on a permanent basis, allowing for a meaningful comparison between the results of different studies.

The EU Commission has complied with a measurement obligation for UFP in the context of supersites in its proposal for a new directive on air quality.

In summary:

- UFP measurements conducted so far are sufficiently comparable to identify different exposure areas. Elevated UFP number concentrations occur in urban areas, near traffic, indoors and in the vicinity of airports.
- Existing impact studies show that UFP in ambient air may pose a health risk, but this is not yet possible to quantify unambiguously and is not comparable with the health risk caused by particulate matter.

3 Black Carbon

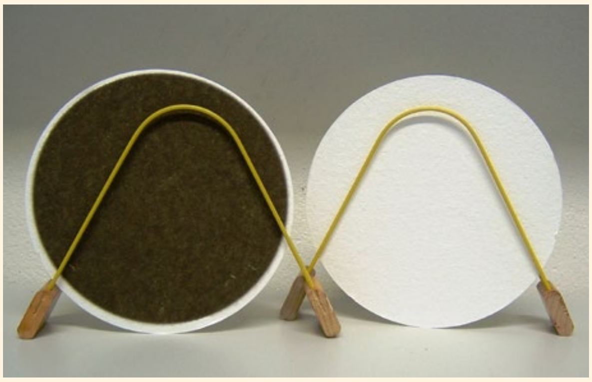
Black Carbon (BC) is not a clearly defined ingredient or measurement parameter, but is currently defined by the measurement method used. Aerosol measurements mostly apply the definitions of the Global Atmospheric Watch (GAW) Scientific Advisory Group. The measurement of BC primarily utilises the optical properties of carbon by recording the change in radiation. The thermal-optical method analyses the mass content of Elemental/Organic Carbon (EC/OC) by heating the material step by step and detecting the change in radiation. This method is already standardised so that these measurements are comparable throughout Europe. The all-optical method is a near real-time recording of the disturbance of the radiation by BC (with no heating).

In recent years, many studies have shown that both methods provide reliable data and are comparable under certain efforts. Accordingly, standardised and normative measurement procedures for both methodologies are expected in the coming years, which in turn are expected to provide the foundation for a possible regulation of BC with a limit/target value.

Health studies prove that a regulatory approach should indeed be adopted. Impact studies show that BC in ambient air poses a risk to human health. In this context, BC, compared to the mass of particulate matter, is particularly suitable for determining and predicting possible health effects caused by primary combustion particles and as such provides additional information on possible health effects of particles. Consequently, in its latest report on air quality, the WHO also considers Black Carbon to be a parameter of special interest, but at the same time states no benchmark value. And even at European and national level, BC is not regulated by limit/target values as from a health perspective, the effects of BC, PM_{10} or $PM_{2.5}$ are not yet clearly and sufficiently distinguishable and quantifiable from each other.

Soot, often referred to as **Black Carbon** (BC), is produced by incomplete combustion of fossil fuels, biomass and biofuel. The main BC sources are from burning materials and fossil fuels outside, households, transport and industry. One of the characteristics of black carbon is the blackness it produces when deposited.

An aerosol is a mixture of solid and/or liquid particles suspended in a gas, in this case in the air.



Comparison of fresh and coated dust filter. The blackness is mainly attributable to Black Carbon.

In summary:

- Measurements conducted so far are not yet sufficiently comparable to identify different exposure areas. Elevated BC concentrations, however, are mainly found in the vicinity of traffic.

- Existing impact studies show that Black Carbon in outdoor air poses a health risk, but that this risk is not yet clearly distinguishable from the health risk caused by particulate matter. Nevertheless, compared to particulate matter, it is probably more suitable for assessing possible health effects – specifically from combustion processes, especially of traffic.

4 Volatile organic compounds (VOC)

Volatile organic compounds (VOCs) are more or less regulated or in need of regulation owing to their different effects. VOCs are potentially hazardous to health, as in benzene or 1,3-butadiene, which are classified as carcinogenic. At the same time, they represent ground-level ozone precursors (together with nitrogen monoxide and nitrogen dioxide), especially in ambient air, which may lead to increased, harmful ozone concentrations. In addition, some VOCs, such as methane or chlorofluorocarbons, have a high impact on the climate, with the consequence of increasing global warming.

VOCs originate from a wide variety of sources and these include natural and human sources. The natural sources (especially emissions through vegetation) cannot and should not be changed or regulated, as this would be an interference with our fragile ecosystem. What we are able to regulate and hence reduce, however, are VOC emissions of human origin, which are emitted into the air, for example, by traffic, industry, the evaporation of fuels and, above all, solvents. VOCs are thus characterised by very different sources and also sites of action. Some sources are at least partially regulated, such as emissions of volatile organic compounds from larger spray facilities. This also includes restrictions on the solvent content in products themselves, e.g. for coatings on building products such as wooden facades, stairs, windows, doors, etc. (EU Directive 1999/13/EC, EU Directive 2004/42/EC). Harmful emissions of VOCs, for example through fumes from varnishes, paints or furniture, are to be avoided, especially if these occur in inside areas. Accordingly, so-called guideline values exist for inside areas, which are recommended by the Committee on Indoor Air Quality Guidelines[8] in order to protect oneself effectively from health hazards caused by VOCs in those areas. Nevertheless, these guideline values are not binding. There is a need for further action in this regard from a health perspective with a view to potentially binding regulation. This, however, is a very big challenge, as legally regulation in private households is not permissible. Similarly, monitoring is almost impossible to implement. This leaves the regulation of products containing VOCs and their processing and use, for example in the workplace, as an important policy tool.

VOCs are an increasingly serious problem, especially in urban areas, due to their role as ozone precursors.

Volatile organic compounds
Volatile organic compounds (VOCs) are a variety of carbon-containing substances that occur in the air mainly in gaseous form, i.e. "volatilised", due to their low boiling point

8 https://www.umweltbundesamt.de/themen/gesundheit/kommissionen-arbeitsgruppen/ausschuss-fuer-innenraumrichtwerte#ausschuss-fur-innenraumrichtwerte-

The increasing frequency of periods of hot weather in Germany in recent years shows no increase in peak ozone concentrations, though the mean ozone concentration in cities is increasing (see Figure 16).

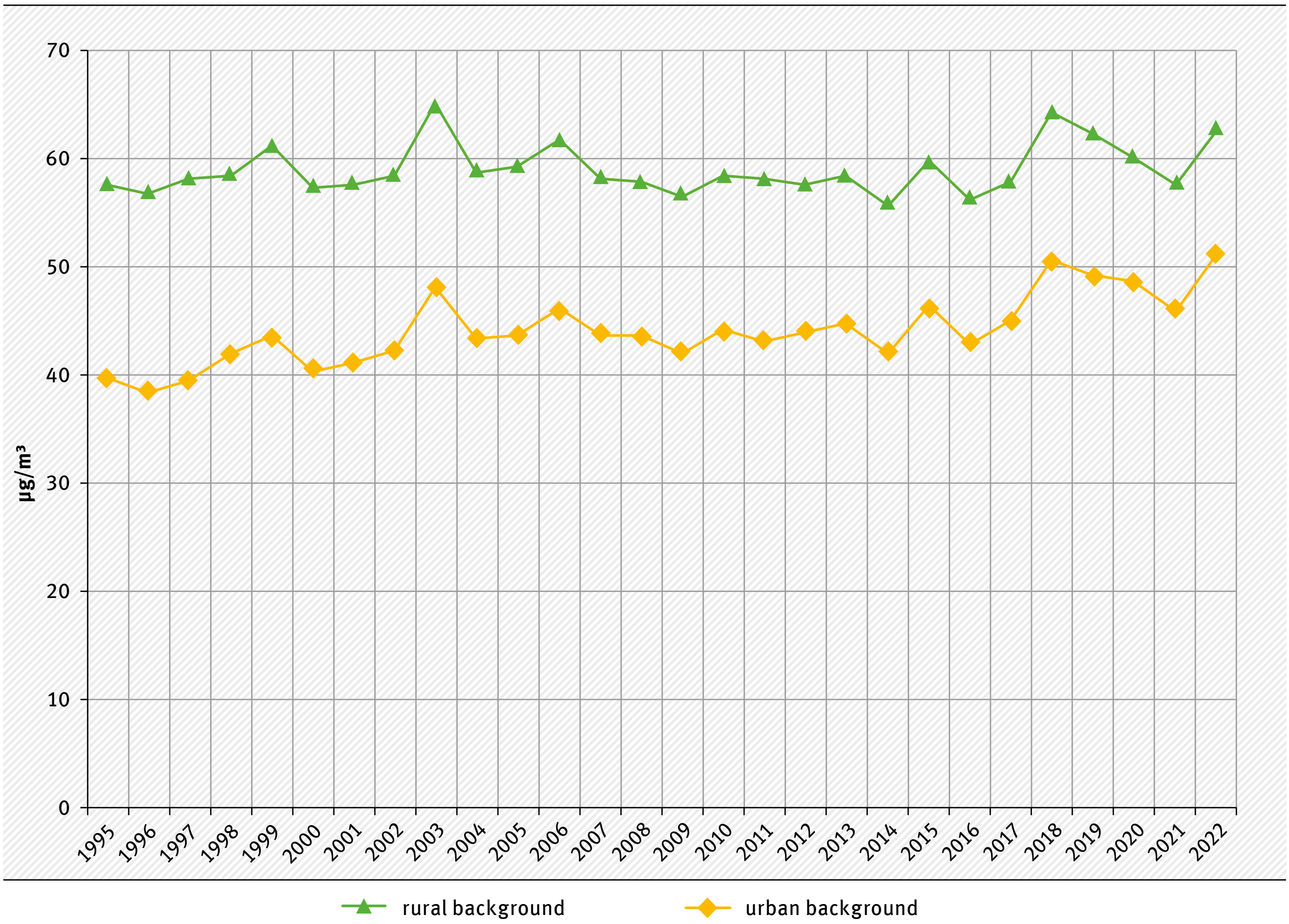
There is only a limited requirement to monitor concentrations in ambient air for VOCs that contribute to the formation of ozone. The current Air Quality Directive (2008/50/EC) and also the proposal for its revision only regulate the mandatory measurement of the ozone precursors nitrogen oxides and benzene. The measurement of additional VOCs is generally required, though no minimum scope of the components to be measured is specified. Only one recommendation of "suitable" VOCs exists. Accordingly, and within the framework of Convention on Long-Range Transboundary Air Pollution, only a part of the recommended VOCs is recorded at rural background stations in Germany. The information obtained there, however, is not sufficient to estimate the contribution of VOCs to ozone formation for urban areas as well.

In summary:

- There is an effective regulation of VOCs, which particularly focuses on the health aspect. More mandatory VOC monitoring for inside areas is, however, desirable.
- Mandatory recording of VOCs in ambient air, especially in urban areas, is necessary to be able to react to the growing problem of ozone concentrations.
- There is an urgent need to further reduce VOC emissions that affect the climate in order to limit global warming.

Figure 16

Development of the annual mean O_3 values



Source: German Environment Agency (UBA) 2023

5 Ammonia

Ammonia pollution and its assessment

So far, there is no legally binding ammonia limit value at European level for the protection of ecosystems. Orientation values for maximum ammonia concentrations, which if exceeded are expected to have negative consequences for vegetation, are provided by the so-called Critical Levels of the Convention on Long-range Transboundary Air Pollution[9] of 1 µg/m³ for sensitive species, such as lichens and mosses, and 3 µg/m³ for higher plants. The model calculation of the annual average ammonia concentration shown in Figure 17 shows that the critical levels for ammonia are exceeded over large areas in many regions of Germany.

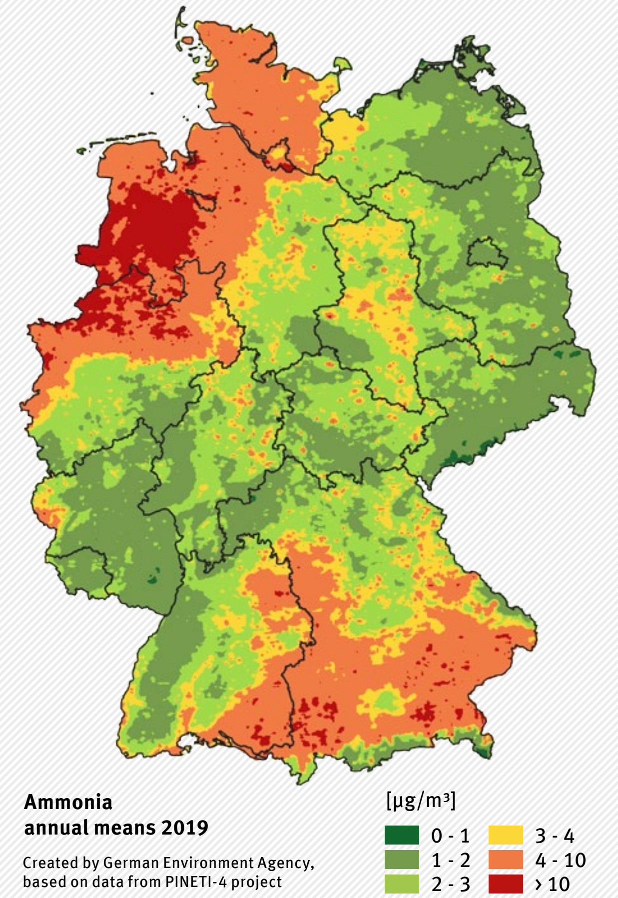
Ammonia

Ammonia is a gaseous compound of nitrogen. It enters the air mainly through emissions from agriculture. Ammonia has the potential to cause various adverse effects on human health as well as on plants and ecosystems:

- It reacts with other air pollutants and forms particulate matter.
- It contributes to the eutrophication and acidification of natural and semi-natural ecosystems such as forests, heaths or dry grasslands.
- It poses a direct toxic hazard to plants and as such affects the health of plants and the stability of ecosystems.

Figure 17

Ammonia concentration from model calculations for the year 2019



Source: German Environment Agency (UBA) 2023

In Germany, about 95 percent of ammonia emissions stem from livestock farming and the use of mineral fertilisers[10]. In contrast to the steadily decreasing emissions of other air pollutants, the level of ammonia emissions has remained almost constant since the 1990s (see Figure 18), and only in the last five years has there been a downward trend.

Various legal regulations in Europe and also in Germany take this as their starting point and specify requirements for the reduction of ammonia emissions. These include the Directive on the reduction of national emissions of certain atmospheric pollutants[11], according to which Germany must reduce ammonia emissions by 29 percent by 2030 compared to 2005, and the Industrial Emissions Directive[12], which regulates, among other things, the licensing and operation of large-scale livestock farming facilities. In Germany, the Federal Immission Control Act[13] supplemented by the Technical Instructions on Air Quality Control[14] incorporates these requirements.

9 UN ECE Convention on Long-range Transboundary Air Pollution (2007): Report on the Workshop on Atmospheric Ammonia: Detecting Emission Changes and Environmental Impacts

10 https://www.umweltbundesamt.de/daten/luft/luftschadstoff-emissionen-in-deutschland/ammoniak-emissionen#entwicklung-seit-1990 called on 21th December 2022

11 NEC-Richtlinie (2016): Richtlinie (EU)2016/2284 des Europäischen Parlaments und des Rates vom 14. Dezember 2016 über die Reduktion der nationalen Emissionen bestimmter Luftschadstoffe, zur Änderung der Richtlinie 2003/35/EG und zur Aufhebung der Richtlinie 2001/81/EG called on 21th December 2022 here: https://eur-lex.europa.eu/legal-content/DE/ALL/?uri=CELEX%3A32016L2284

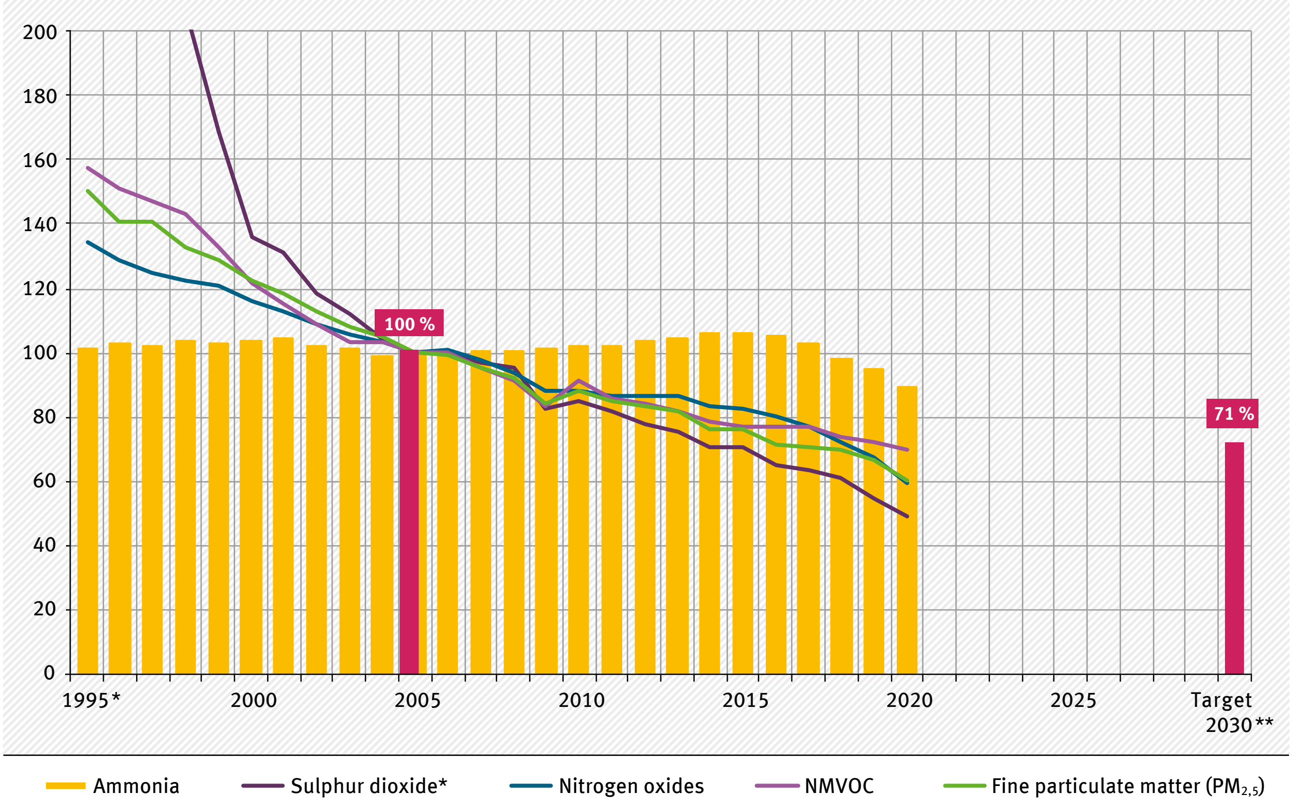
12 IED Richtlinie 2010/75/EU des europäischen Parlaments und des Rates vom 24. November 2010 über Industrieemissionen (integrierte Vermeidung und Verminderung der Umweltverschmutzung) called on 21th December 2022 here: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:de:PDF

13 https://www.gesetze-im-internet.de/bimschg/

14 https://www.verwaltungsvorschriften-im-internet.de/bsvwvbund_18082021_IGI25025005.htm

Figure 18

Trend of ammonia emissions relative to 2005 (in mean percentage)
in comparison to other air pollutants



* Sulphur dioxide value in 1995: 360
** 2030 target based on the future EU 'national emission ceilings directive' and the target of the Federal Governments 'Strategy for Sustainable Development'

German Environment Agency (UBA) 2022, National trend tables for German reporting on atmospheric emissions since 1990, Emissions from 1990 to 2020 (02/2022)

While a number of legal requirements exist to reduce emissions, not only is there a lack of ecologically oriented, legally binding monitoring of ammonia concentrations in the air, until now, no concentration values to be complied with have been included in European or national law.

Need for monitoring of ammonia to protect ecosystems

Knowledge of the ammonia concentration in potentially endangered ecosystems is necessary to assess the direct effects of ammonia on ecosystems and, if necessary, to take targeted measures to mitigate them.

Ammonia is measured at the seven rural background stations of the Federal Environment Agency. In addition, almost all federal states – with the exception of the city states – conduct measurements within their existing air quality measurement networks and at forest environmental monitoring sites. The objectives of the individual federal and state measurement programmes differ. For example, they can be used to monitor background concentrations and their development, or aimed directly at protecting ecosystems. Ammonia measurements are also increasingly being conducted at sites close to traffic, partly to understand the impact of diesel engine exhaust purification treatment, which to some extent releases ammonia, as well as its role on particulate matter formation.

In total, ammonia measurement data are currently collected at more than 120 stations throughout Germany. However, given the heterogeneous distribution of ammonia and the different ecosystems, the number of measurements conducted in Germany is low compared to countries such as the Netherlands or Switzerland.

In summary:

- The measurement of ammonia for air quality monitoring is not yet required by law. There are no limit or target values for the concentration of ammonia in the air.
- The objectives of ammonia monitoring should be sharpened in future through greater coordination between the individual measurement programmes of the federal government and the states.
- Ammonia concentrations are too high in many regions of Germany and measures are required to reduce them, especially in agriculture – and above all in livestock farming.

Measurement of ammonia at the UBA background station Waldhof (in Lower Saxony) using a so-called denuder (centre of picture).

Further information on the topic

Current air quality data:
https://www.umweltbundesamt.de/en/data/air/air-data

Air quality app:
https://www.umweltbundesamt.de/app-luftqualitaet

Air and air pollution control website:
https://www.umweltbundesamt.de/en/topics/air

UBA map service on air pollutants:
http://gis.uba.de/Website/luft/index.html

UBA map service on low emission zones and air quality plans:
http://gis.uba.de/website/umweltzonen/index.html

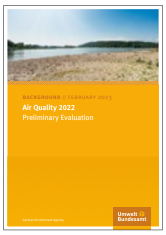
Development of air quality in Germany:
https://www.umweltbundesamt.de/themen/luft/daten-karten/entwicklung-der-luftqualitaet

Information on the air pollutant PM_{10}:
https://www.umweltbundesamt.de/en/topics/air/particulate-matter-pm10

Information on the air pollutant NO_2:
https://www.umweltbundesamt.de/en/topics/air/nitrogen-dioxide

Information on the air pollutant ozone:
https://www.umweltbundesamt.de/en/topics/air/ozone

39th Ordinance for the Implementation of the German Federal Imission Control Act (39th BImSchV):
https://www.gesetze-im-internet.de/bimschv_39/



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