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Air Quality 2021

Preliminary Evaluation

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I Air Quality in 2021: Data basis and evaluation methodology

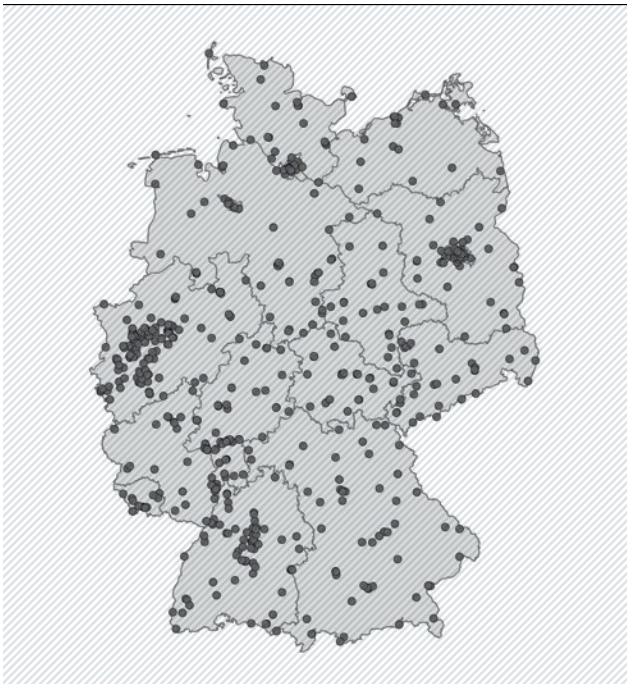
1 Air quality and air pollutants

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].

Figure 1

Overview of the monitoring stations in Germany



Source: German Environment Agency (UBA) 2022

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).

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. Basis of these AQG levels are up-to-date research results of 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. More detailed information and analysis are presented in chapter V "The new air quality guideline levels of the World Health Organization".

2 Provisional nature of the information

This evaluation of air quality in Germany in the year 2021 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 2022. Due to the comprehensive quality assurance within the monitoring networks, the final data will only be available in mid-2022.

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.

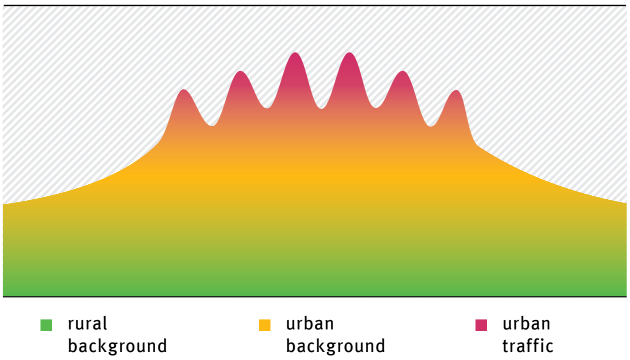
4 Influence of environmental conditions

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) p. 23–33

II Particulate Matter: No exceedances of the EU limite values, but considerable exceedances of the updated WHO AQG levels

1 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 3, yellow bars).

The AQG level of the World Health Organisation (WHO[2]) was not complied with at 33 percent of all air monitoring stations.

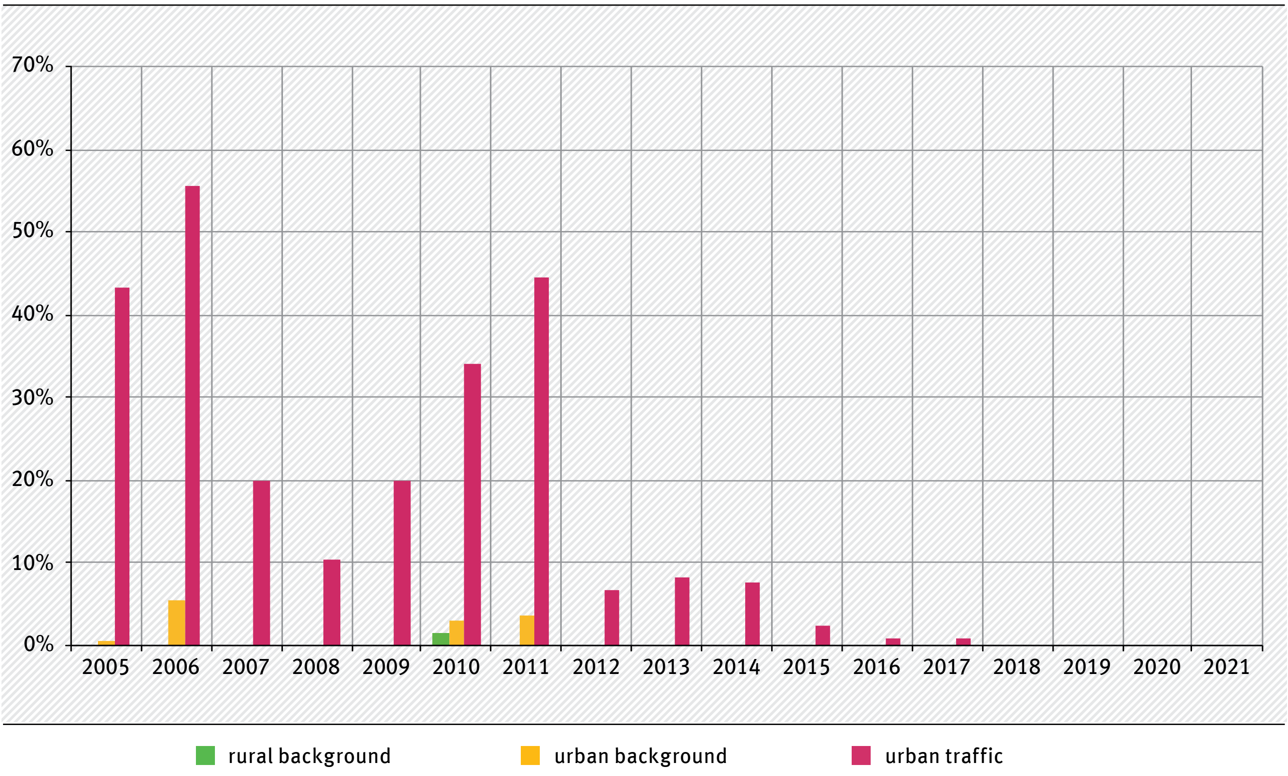
EU limit value
The 24-hour PM_{10} value must not exceed 50 µg/m³ more than 35 times per year.

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.

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

Figure 3

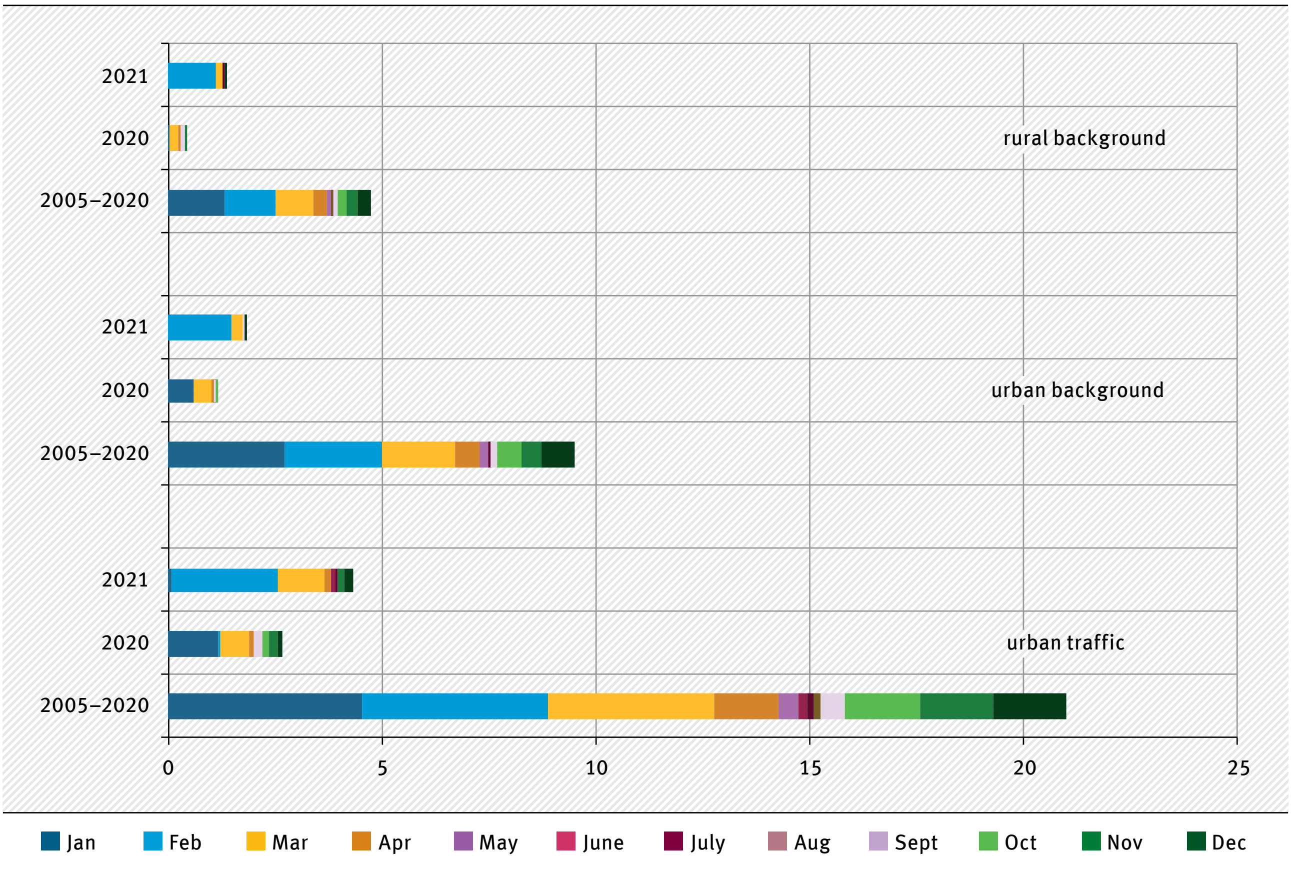
Percentage share of air monitoring stations exceeding the PM_{10} limit value
for the 24-hour values in the corresponding pollution regime, time frame 2005–2021



Source: German Environment Agency (UBA) 2022

Figure 4

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 2021, 2020 and the period 2005–2020



Source: German Environment Agency (UBA) 2022

Figure 4 shows how many days were recorded on which the limits were exceeded, on average, per month. In this case, 2021 is compared with the previous year (2020) and an extended reference period (2005–2020). It can be seen that, compared to the reference period, in 2021 there were only very few days on which the limits were exceeded. But, in contrast to the low polluted previous year 2020, in 2021 many more exceedances occured, especially in February. This month was characterised by heavy snowfall and nights with clear sky and frost[3].

In terms of weather conditions the remaining month of the year were rather average – despite the July with constant and heavy rain events[4].

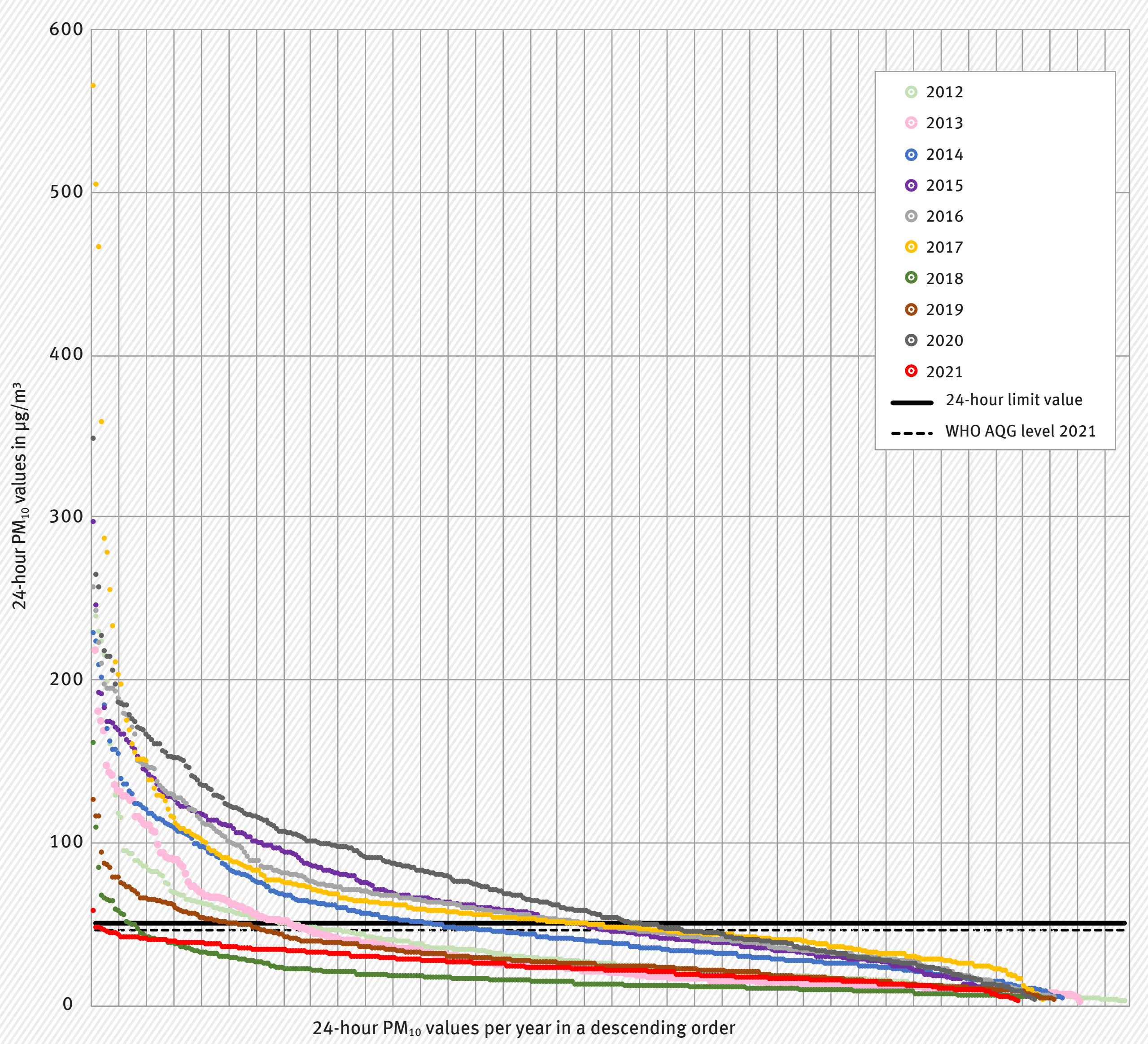
The New Year's Day represents a special case for the PM_{10} 24-hour values. As a result of the emission due to fireworks the PM_{10} pollution during the first hours of the day is exceptionally high. These high 1-hour values have an impact on the PM_{10} 24-hour values.

3 Press release of the German weather service DWD, 2021: https://www.dwd.de/DE/presse/pressemitteilungen/DE/2021/20210226_deutschlandwetter_februar2021.html?nn=731256

4 Press release of the German weather service DWD, 2021: 2021, https://www.dwd.de/DE/presse/pressemitteilungen/DE/2021/20211230_deutschlandwetter_jahr2021.html?nn=731256

Figure 5

24-hour PM_{10} values of all air monitoring stations at the New Year's Days 2012-2021



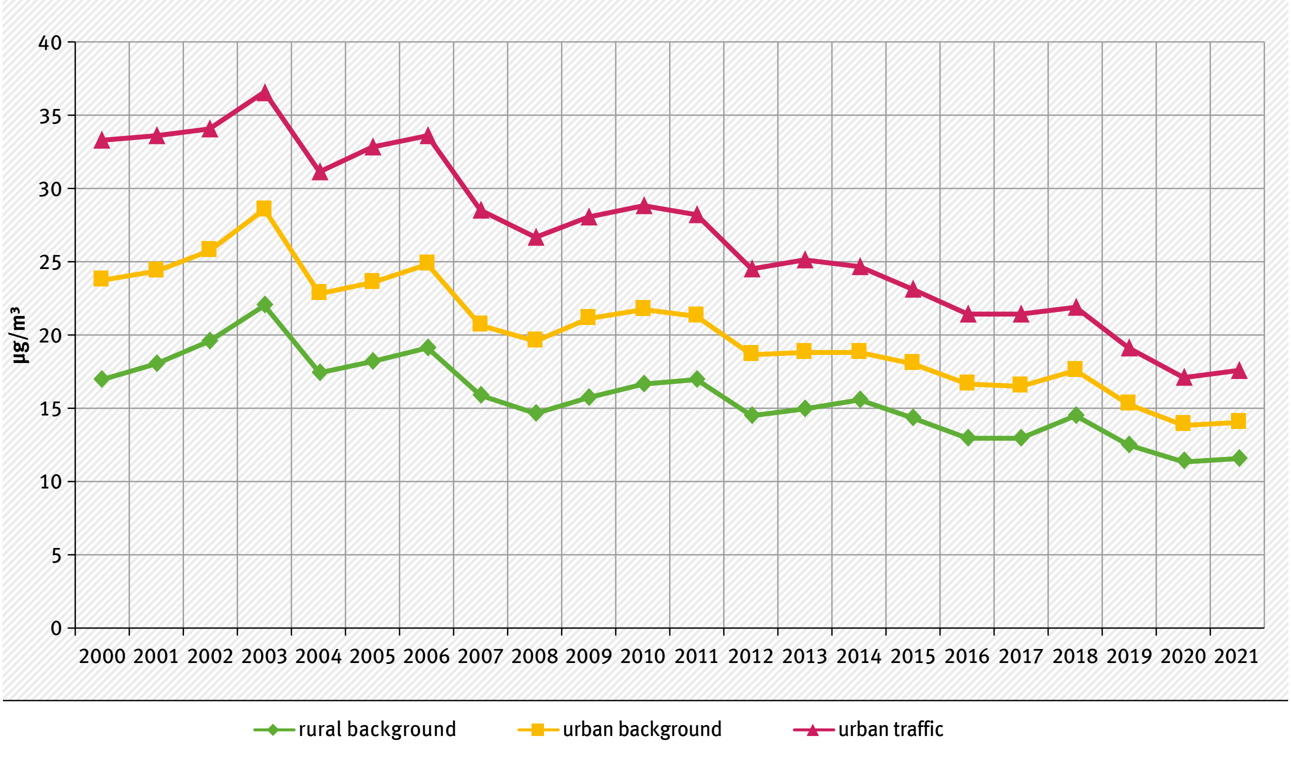
Source: German Environment Agency (UBA) 2022

The 24-hour PM_{10} values of all monitoring stations at the New Year's Days plotted in descending order (Figure 5) show that the pollution in the last 10 years varies with the meteorological situation and many of the monitoring stations (20 to 60 %) are above the limit value. This is different in 2021, here the peak concentrations are missing. This is due to the exceptional small amount of emitted PM_{10} mass as a result of the measures to contain the Corona pandemic. Only at one monitoring station (0.3 %) the limit value of 50 µg/m³ is exceeded.

In 2021 there were no numerous episodes with typical winter conditions and high concentrations of paritculate matter. But in future with a corresponding weather situation (low temperature and stable high pressure system) it is still possible that the PM_{10} limit value is exceeded (i.e. more than 35 exceedance days).

Figure 6

Development of the annual mean PM_{10} values
via selected air monitoring stations in the corresponding pollution regime, time frame 2000–2021



Source: German Environment Agency (UBA) 2022

2 PM_{10}-Annual mean values

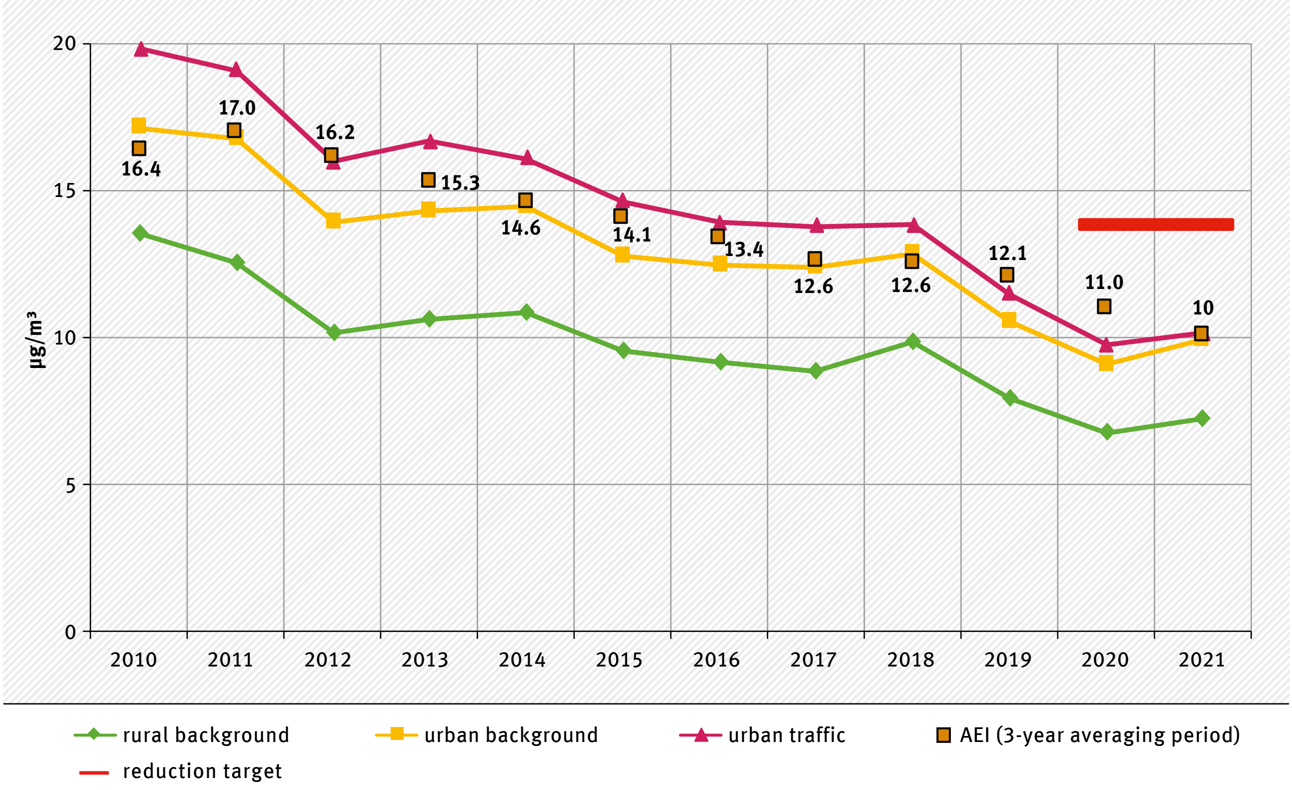
In 2021 the annual mean PM_{10} values were on a similar level as in the year before. That means that the years 2020 and 2021 were the years with the lowest level of pollution compared to the considered period since 2000 (Figure 6). Accompanied by the regional decrease of the PM_{10} emissions, the annual 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. 40 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 shoud not exceed 15 µg/m³.

Figure 7

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 2010–2021



Source: German Environment Agency (UBA) 2022

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 2021, 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 7). 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 %) 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.

The WHO AQG level for the short term pollution were also exceeded at all stations. The EU Air Quality Directive also requires the average exposure of the population to $PM_{2.5}$ to be reduced until the year 2020. 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 results in a national reduction goal of 15 percent until 2020. Accordingly, the AEI calculated for 2020 (average value of the years 2018, 2019 and 2020) may not exceed the value of 13.9 µg/m³. Germany met the reduction target with 11.0 µg/m³ in 2020. The AEI for 2021 (average value of the years 2019, 2020 and 2021) 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.

One of several measuring fields of the Environmental Research Station Schneefernerhaus. The monitoring station is situated on 2650 m above sea level, slighlty below the peak of the Zugspitze and thus the highest envionmental research station in Germany. Here the GAW-global station Zugspitze/Hohenpeißenberg is run by the UBA.

III Nitrogen dioxide: Only few exceedances of the limit value

1 NO_2 – Annual mean values

Only 1-2 percent of the air monitoring stations in urban traffic locations exceeded the limit value for the NO_2 annual mean - 10 years ago this value was around 75 percent (Figure 8, red bars). Since 2015 no exceedances have occured at stations in the urban background, in the years before only few exceedances were recorded.

EU limit value

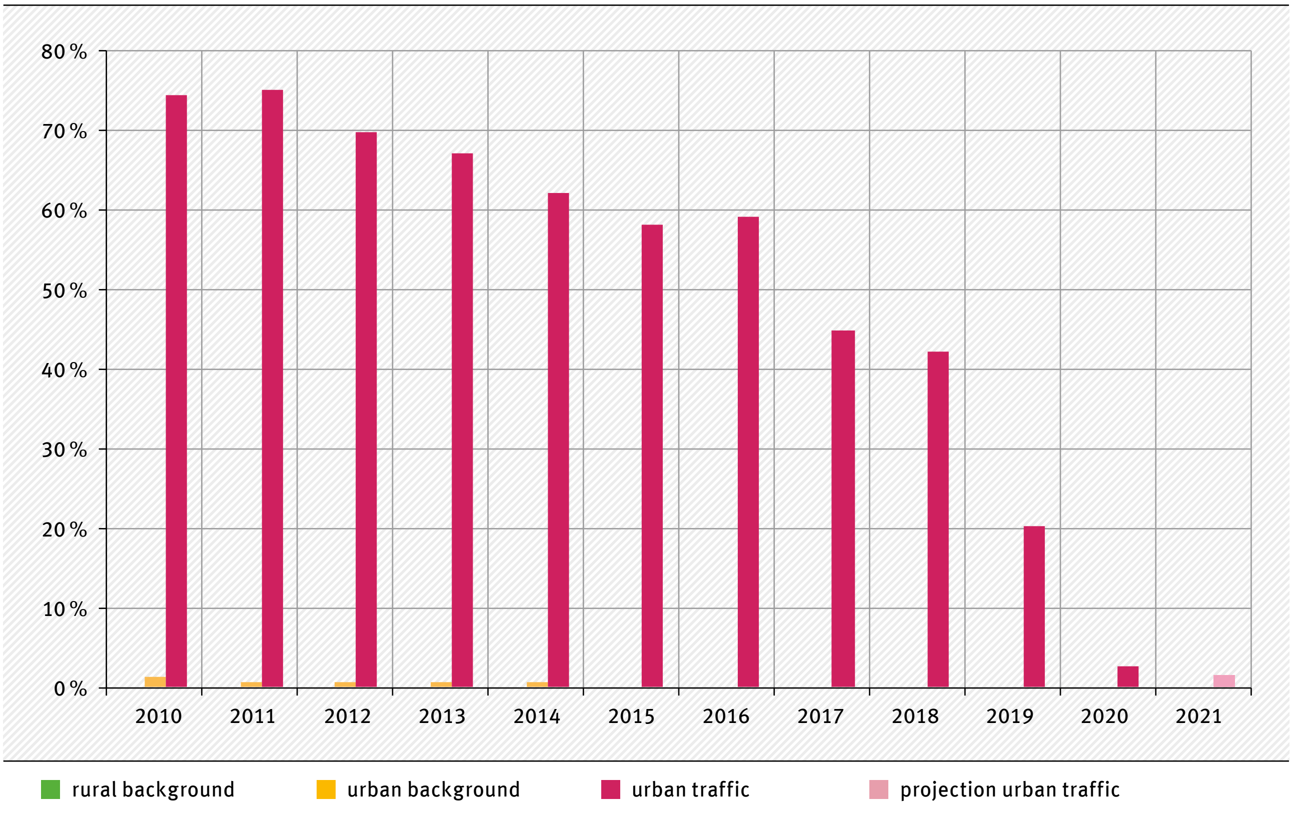
The annual mean NO_2 value must not exceed 40 µg/m³

WHO AQG level 2021

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

Figure 8

Percentage share of air monitoring stations exceeding the NO_2 limit value for the annual mean in the corresponding pollution regime, time frame 2010–2021

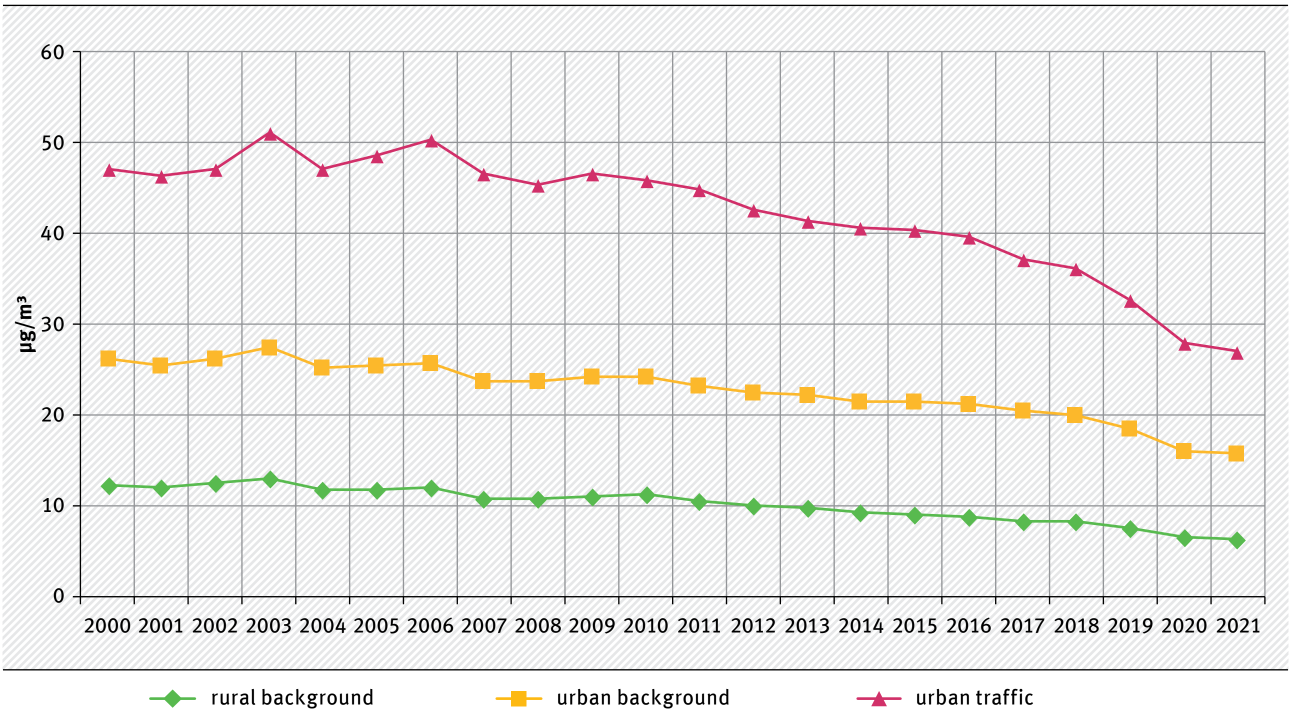


Source: German Environment Agency (UBA) 2022

Figure 9

Development of the annual mean NO_2 values

via selected air monitoring stations in the corresponding pollution regime, time frame 2000–2021



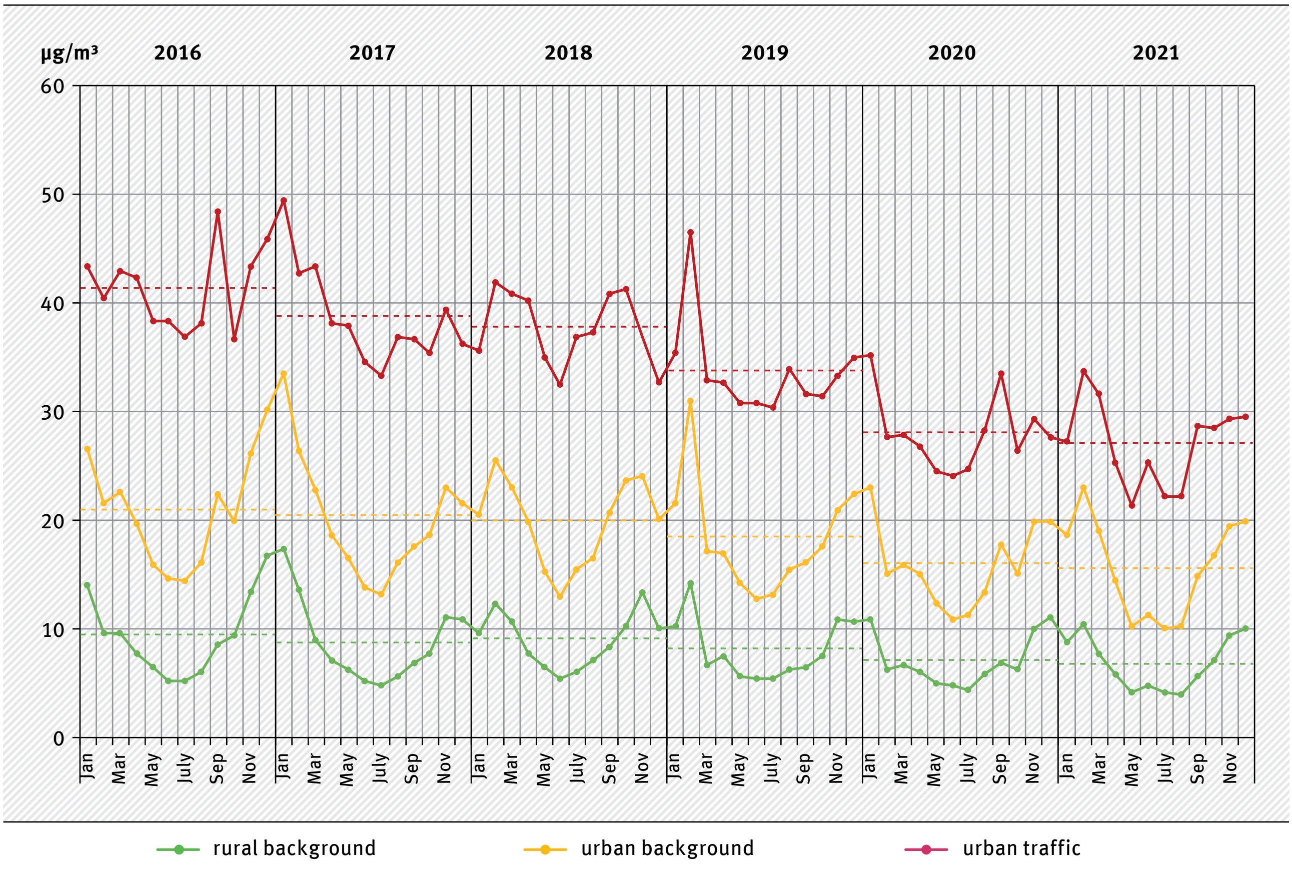
Source: German Environment Agency (UBA) 2022

The much stricter WHO AQG level for the NO_2 annual mean were not complied with at 78 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 9). 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 2000–2021, the average annual concentration for all air monitoring stations amounted to 10 µg/m³ (Figure 9, 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 9, yellow curve), as it is also seen at rural background stations. In 2021 the average NO_2 concentration at urban traffic stations was slightly below 30 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 deacrease started.

Figure 10

NO_2 monthly mean values of the period 2016–2021
annual means as dashed lines



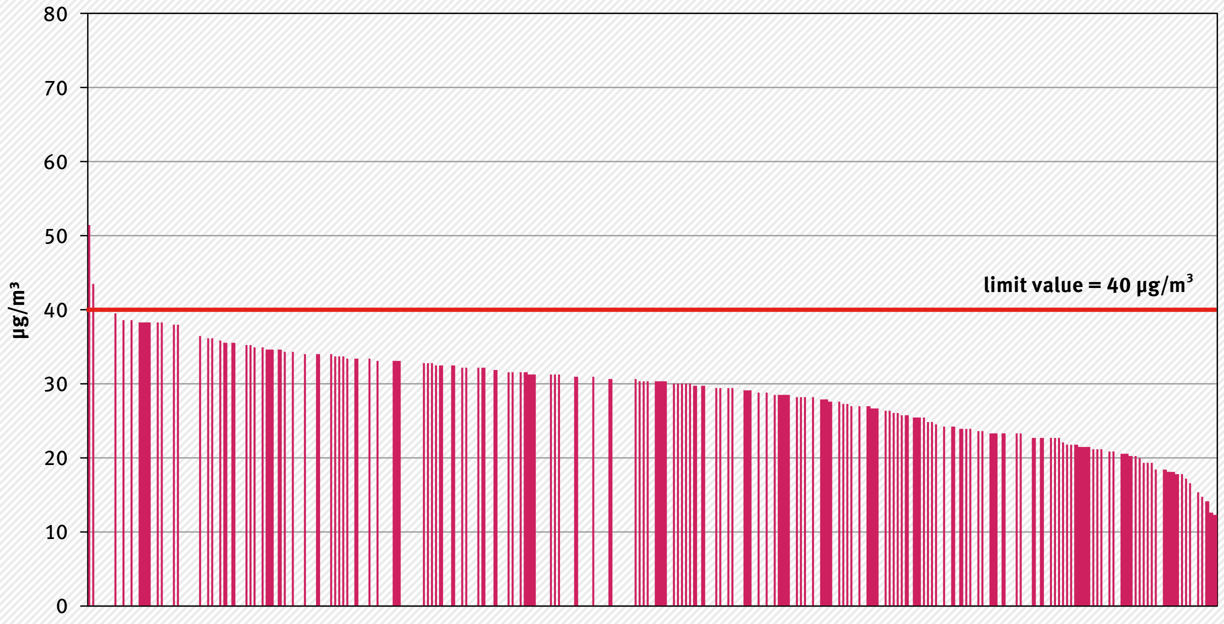
Source: German Environment Agency (UBA) 2022

Figure 10 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 2021 the vlaues are only slightly below the values of the previous year.

In the years 2010 to 2018, at a large part of the stations close to traffic the annual mean concentrations were above 40 µg/m³ and therefore above the limit value. This has changed now: according to the latest data, there are 2 stations with concentrations above 40 µg/m³. Because there are not all station data for the year 2021 availyable yet, it is possible that few stations with exceedances might be added. Figure 11 shows the NO_2 annual mean values of all air monitoring stations in urban traffic locations as bars in descending order. The gaps result from the missing data of the passive collectors, which are only available in the course of 2022.

Figure 11

NO_2 annual mean values 2021
of all urban traffic monitoring stations



Bars: NO_2 annual mean values 2021 in descending order; gaps: missing data of passiv collectors

Source: German Environment Agency (UBA) 2022

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.

2 NO_2-One hour values

Since 2010, one hour NO_2 values exceeding 200 µg/m³ are only permitted a maximum of 18 times per year. In 2021, like in the previous years, this value was not exceeded. The last time that few exceedances at urban traffic station were recorded was in 2016.

Only five of about 400 air monitoring stations failed to comply with the WHO AQG level for the short-term concentration. 80 percent of the air monitoring stations failed to comply with the new WHO AQG level for the 24-hour NO_2 value.

IV Ground-level ozone: Low pollution but still exceedances of the target values

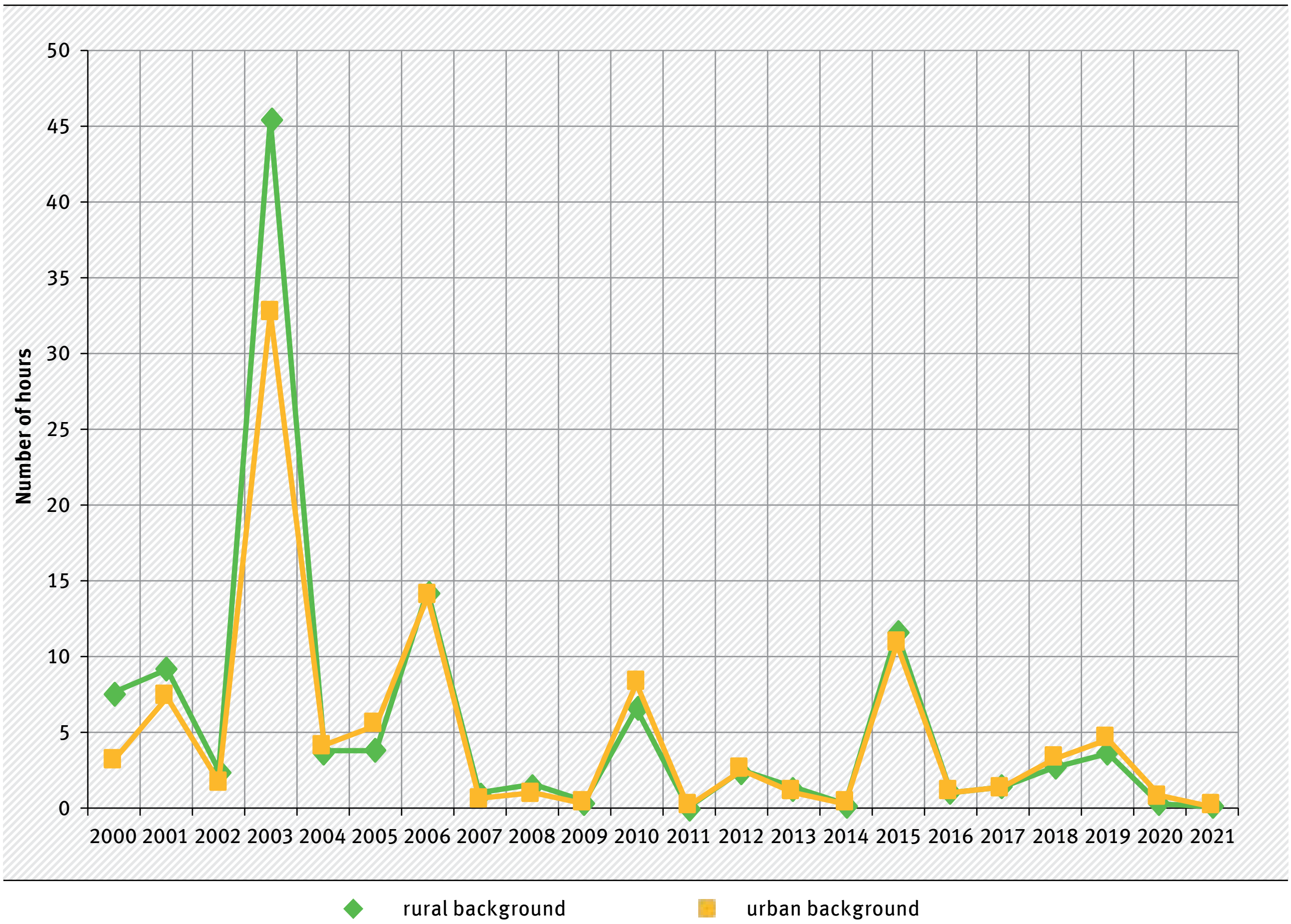
1 O_3-Information and alert threshold

Ozone is measured at about 260 monitoring stations throughout Germany. In 2021, the highest 1-hour average value amounted to 226 µg/m³. This value is at a slimilar level as the previous year value (235 µg/m³). In 2021 the alert threshold of 240 µg/m³ was not exceeded. The information threshold of 180 µg/m³ was exceeded on 6 days (previous year: 13 days). 2021 was a less affected year with regards to exceedances of the threshold values, compared to the last 20 years, see Figure 12. It 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 characterised 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. Summer 2021

Figure 12

Hours during which the information threshold (180 µg/m³) for ozone was exceeded
Average over selected monitoring stations, time frame 2000–2021



Source: German Environment Agency (UBA) 2022

was the summer with the most rain since 10 years[5], June 2021 was the third warmth June since the beginning of records[6] and the September was sunny, very dry with partly warm temperatures[7].

2 O_3-Target value for the protection of human health

At almost all monitoring stations (=98 %) 8-hour average values of over 120 µg/m³ were measured, so that, like in the previous year, the long-term objective is not complied with.

In 2021, an ozone value of 120 µg/m³, as the highest daily 8-hour average value, was exceeded on an average of 7 days per station. This is less than in the year before (17).

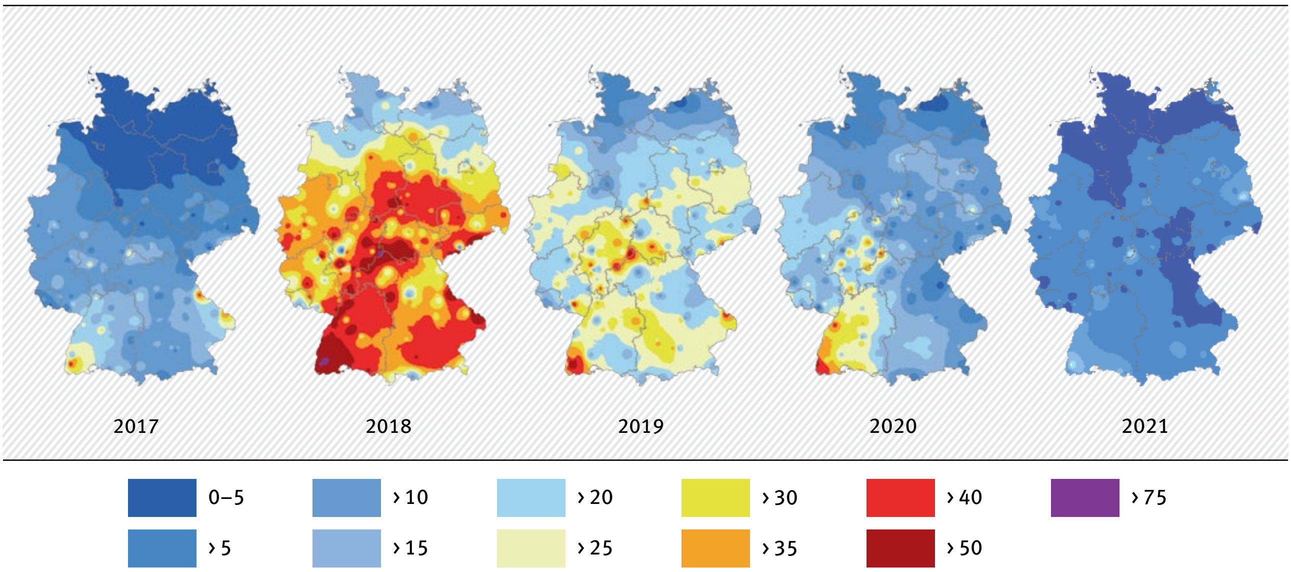
5 https://www.dwd.de/DE/presse/pressemitteilungen/DE/2021/20210929_deutschlandwetter_september2021.html?nn=731256
6 https://www.dwd.de/DE/presse/pressemitteilungen/DE/2021/20211230_deutschlandwetter_jahr2021.html?nn=731256
7 https://www.dwd.de/DE/presse/pressemitteilungen/DE/2021/20210929_deutschlandwetter_september2021.html?nn=731256

Figure 13 shows the spatial distribution of the number of exceedance days in 2021 in comparison to the last four years. This figure highlights the differences between the years. In 2021, simliar to 2017, there were considerably less exceedances of the long-term target recorded compared to for example the year 2018. Ozone concentrations is generally lower in Northern Germany.

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 2019 to 2021, however, 23 of the air monitoring stations (9 %) exceeded this value on more than 25 days. This is considerably less than in the previous averaging period (48 %). Figure 14 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

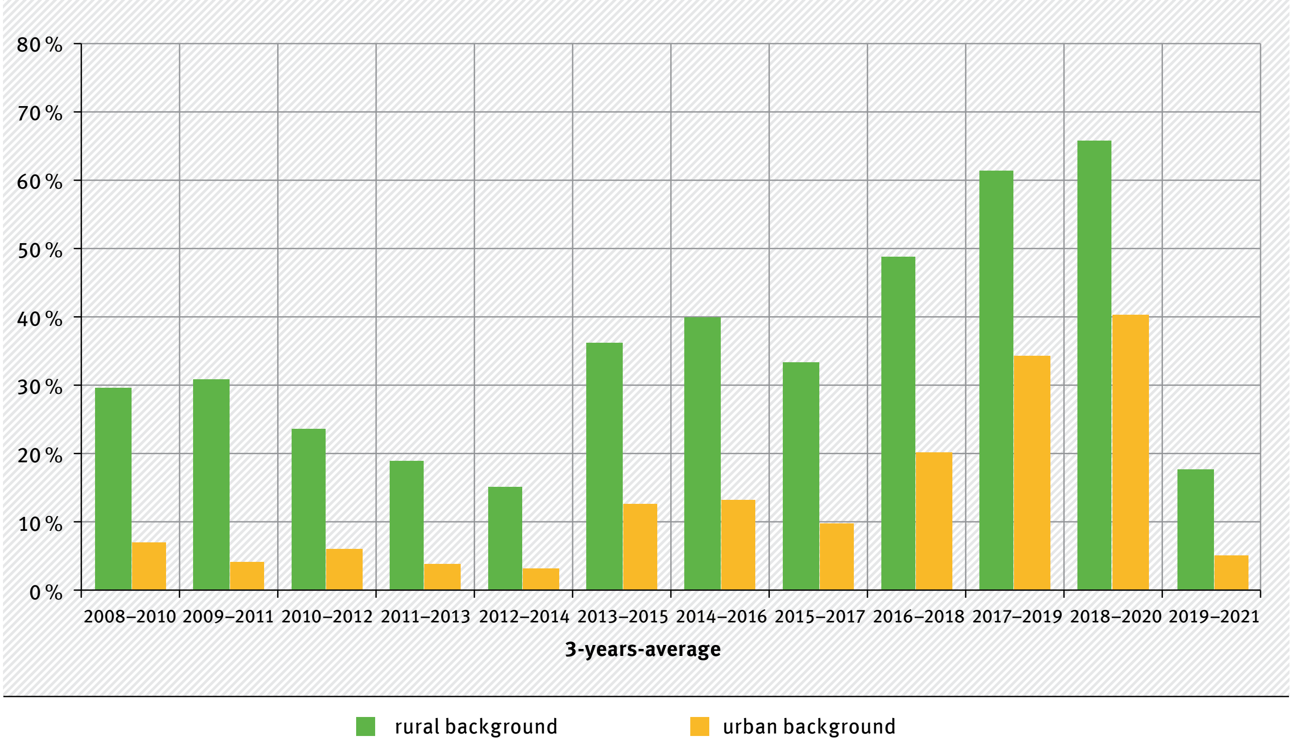
Spatial distribution of the number of days on which the long-term objective for the protection of human health was exceeded (number of days with 8-hour average values › 120 µg/m³)
time frame 2017–2021, based on station measurements and a geostatistical interpolation method



Source: German Environment Agency (UBA) 2022

Figure 14

Percentage share of air monitoring stations recording an exceedance of the target value
for the protection of human health, time frame 2010–2021 (in each case, 1-year moving average over 3 years)



Source: German Environment Agency (UBA) 2022

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 (99th percentile of the daily maximum 8-hour mean concentration of one year), which was exceeded at alomst all stations in 2021.

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 2017 to 2021 was exceeded at 21 out of 160 air monitoring stations (= 13 %, previous year: 19 %).

In 2021, the long-term objective for the protection of the vegetation (6,000 µg/m³ h) was complied with at 10 monitoring stations, that is 6 % of all stations (previous year: 23 stations, 15 %). Averaged over all rural background stations the AOT40-value in 2021 is very low in comparison to other years since 2000, and well below the value of 2018 and 2019.

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 assesment it is assumend 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

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

Alert threshold

With ozone values of over 240 µg/m³ (1-hour average value), the general public is warned by the media of the 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 99th percentil 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 the total sum of the differences between the 1-hour average 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 long term, 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 The new air quality guideline levels of the World Health Organization – background and situation in Germany in 2020

Background

The limit and target values specified in European air quality directives are based on the WHO air quality guideline (AQG) levels for the protection of human health.

What are guideline levels?
A central task of the World Health Organization (WHO) is the derivation and publication of air quality guideline levels for the protection of human health: Guideline levels are numerical values expressed as the concentration of a pollutant in a given medium (e.g. air, water) with a mean calculation time (=time period for which the guide value is valid). No or minimal adverse health effects are thought to occur below this concentration. Guideline levels are not legally binding. Rather, these represent recommendations for the protection of human health.

Since their first edition (Air Quality Guidelines for Europe 1987[8]), the WHO air quality guidelines have been a fundamental part of the process to improve air quality in Europe. In total, WHO has assessed 35 air pollutants in several editions and most recently revised the AQG levels for particulate matter (PM_{10} and $PM_{2.5}$), ozone, nitrogen dioxide, and sulphur dioxide in 2005[9]. The current new edition (Global AQG 2021[10]) now reassesses the aforementioned pollutants as well as carbon monoxide. For all other pollutants, the previous assessments, recommendations and AQG levels continue to apply. In all editions of its air quality guidelines, WHO indicates that they are designed to maximize health protection for all populations. In addition, WHO emphasizes that the air quality guidelines have focused on both outdoor air and indoor air from the outset.

The new WHO air quality guidelines, published in September 2021, are based on a systematic review of the available scientific evidence on the health effects of air pollution. For this purpose, WHO has used environmental epidemiological studies (=large population studies in which the effect of risks from the environment on groups of people is investigated), meta-analyses (=summary of results of several studies on the same question) and reviews (=overview of individual studies). The results show that air pollutants have adverse health effects even below the previously recommended AQG levels. As a result, the WHO now recommends partly much stricter AQG levels. Due to the ambitious high level of the new AQG levels, the WHO has set several interim targets in some cases. In addition to redefining AQG levels, the WHO classifies the effects of ultra-fine particulate matter, particles from sand and dust storms, and soot, and makes qualitative recommendations to protect health.

The new WHO AQG levels form an essential basis for the upcoming revision of the European Air Quality Directive (2008/50/EC) and the EU-wide limit and target values it contains. In contrast to the WHO AQG levels, these limit and target values are defined by law and, in the case of limit values, are mandatory from a certain point in time. In addition to the state of scientific knowledge, considerations of the fundamental feasibility, together with the costs and benefits of abatement measures, are taken into account when setting limit values. In the following chapters, air pollution in 2020 is assessed according to the currently valid limit and target values, the "old" and the "new" WHO AQG levels, in order to show the situation in Germany.

According to the European Environment Agency, air pollution continues to be considered a significant health burden in the 27 EU member states, leading to many premature deaths and illnesses. Particulate matter poses the greatest threat: For example, 307,000 premature deaths were attributed to chronic exposure to particulate matter in 2019 (Source: https://www.eea.europa.eu/publications/air-quality-in-europe-2021/health-impacts-of-air-pollution).

8 https://apps.who.int/iris/handle/10665/107364
9 https://www.who.int/publications/i/item/WHO-SDE-PHE-OEH-06.02
10 https://apps.who.int/iris/handle/10665/345329

Achieving improvements in air quality requires the adoption of ambitious measures and programs to reduce air pollutant emissions.

Overview of the valid WHO AQG levels 2021

Table 1 lists all WHO AQG levels valid from 2021, with interim targets where applicable. The new WHO air quality guidelines contain AQG levels for the pollutants particulate matter (PM_{10} and $PM_{2.5}$), ozone, nitrogen dioxide, sulphur dioxide, and carbon monoxide. For other air pollutants regulated in EU air quality directives that have not been reassessed and for individual mean calculation periods, the AQG levels from previously valid WHO guidelines continue to apply (in italics in the table).

Table 1

WHO AQG levels and interim targets valid in 2021

(italics: WHO AQG levels from previous guidelines still valid)

Pollutant, unit	Averaging time	Interim target				WHO AQG levels
		1	2	3	4	
$PM_{2.5}$, µg/m³	Annual	35	25	15	10	5
	24-hour[a]	75	50	37.5	25	15
PM_{10}, µg/m³	Annual	70	50	30	20	15
	24-hour[a]	150	100	75	50	45
Ozone, µg/m³	Peak Season[b]	100	70	-	-	60
	Maximum daily 8-hour[a]	160	120	-	-	100
NO_2, µg/m³	Annual	40	30	20	-	10
	24-hour[a]	120	50	-	-	25
	1-hour	-	-	-	-	*200*
SO_2, µg/m³	24-hour[a]	125	50	-	-	40
CO, mg/m³	24-hour[a]	7	-	-	-	4
	Maximum daily 8-hour	-	-	-	-	*10*
	1-hour	-	-	-	-	*30*
Pb in PM_{10}, µg/m³	*Annual*	-	-	-	-	*0.5*
Cd in PM_{10}, ng/m³	*Annual*	-	-	-	-	*5*

[a] 99th percentile of the daily mean
[b] Mean value of the daily maximum 8-hour ozone mean values within the six consecutive months with the highest ozone concentrations (here: April-September)

For carcinogenic substances, the WHO does not give AQG levels, since no safe health level of exposure can be recommended. For guidance purposes, WHO2000 gives the additional lifetime risk of developing cancer for concentration levels derived from occupational health studies. In Table 2, the concentration corresponding to the risk of 1:100,000 is given in each case (i.e., one additional cancer case related to 100,000 exposed inhabitants).

Table 2

WHO2000 concentration values valid in 2021 for additional lifetime risk of developing cancer of 1:100,000

Pollutant, unit	Averaging time	Concentration value
Benzene, µg/m³	Annual	1.7
B(a)P in PM_{10}, ng/m³	Annual	0.12
As in PM_{10}, ng/m³	Annual	6.6
Ni in PM_{10}, ng/m³	Annual	25

Exceedance situation based on 2021 WHO AQG levels

Table 3 lists the proportion of all monitoring stations with exceedances of the 2021 WHO AQG levels/interim targets. The reference year for the measurement data is 2020. This is the most recent year for which the German Environment Agency has complete data on all pollutants from all monitoring networks at this time. Compared to previous years and with respect to the applicable limit and target values, 2020 was on the mean a very lightly polluted year for particulate matter and nitrogen dioxide, and with respect to ozone the pollution was moderate[11]. However, when compared with the new WHO AQG levels, it is clear that the concentrations of the pollutants $PM_{2.5}$ and ozone were too high at all stations, almost without exception. Also, with regard to the NO_2 AQG levels for the annual and daily mean, a majority of all stations register values that are too high (83 % and 76 % exceedance share, respectively). In addition, exceedances of the AQG level for the PM_{10} annual mean occurred at a good third (36 %) of all stations. The exposure to B(a)P in PM_{10} continues to be problematic.

11 https://www.umweltbundesamt.de/publikationen/air-quality-2020

Table 3

Proportion of monitoring stations with exceedance of WHO AQG levels valid in 2021
(reference year of data: 2020, *italics: WHO AQG levels from predecessor guidelines still valid)*

Pollutant, unit	Averaging time	Interim Target				WHO AQG level
		1	**2**	**3**	**4**	**AQG level**
$PM_{2.5}$, µg/m³	Annual	0 %	0 %	0 %	14%	**99 %**
$PM_{2.5}$, µg/m³	24-hour[a]	0 %	0 %	2 %	78%	**99.5 %**
PM_{10}, µg/m³	Annual	0 %	0 %	0 %	5%	**36 %**
PM_{10}, µg/m³	24-hour[a]	0 %	0 %	0 %	7%	**16 %**
Ozone, µg/m³	Peak Season[b]	3 %	100 %	-	-	**100 %**
Ozone, µg/m³	Maximum daily 8-hour[a]	0.4 %	95 %	-	-	**99.6 %**
NO_2, µg/m³	Annual	1 %	22 %	51 %	-	**83 %**
NO_2, µg/m³	24-hour[a]	0 %	21 %	-	-	**76 %**
NO_2, µg/m³	*1-hour*	-	-	-	-	**0.3 %**
SO_2, µg/m³	24-hour[a]	0 %	2 %	-	-	**2 %**
CO, mg/m³	24-hour[a]	0 %	-	-	-	**0 %**
CO, mg/m³	*Maximum daily 8-hour[a]*	-	-	-	-	**0 %**
CO, mg/m³	*1-hour*	-	-	-	-	**0 %**
Pb in PM_{10}, µg/m³	*Annual*	-	-	-	-	**0 %**
Cd in PM_{10}, ng/m³	*Annual*	-	-	-	-	**0 %**
						Concentration value for increase of cancer lifetime risk by 1:100,000
Benzene, µg/m³	*Annual*	-	-	-	-	**5 %**
B(a)P in PM_{10}, ng/m³	*Annual*	-	-	-	-	**80 %**
As in PM_{10}, ng/m³	*Annual*	-	-	-	-	**0 %**
Ni in PM_{10}, ng/m³	*Annual*	-	-	-	-	**0 %**

Comparison with the exceedance situation based on previous guideline/limit/target values

Table 4 compares the exceedance situation of all EU-wide regulated air pollutants based on the new WHO AQG levels with the exceedance situation of previously valid WHO AQG levels and applicable target and limit values. The exceedance percentages are also listed separately according to the four pollution regimes: rural background, urban background, urban traffic (see Chapter I of this brochure) and industry. This allows the determination of whether the exceedance is a local problem (e.g. on a busy road, near an industrial plant or a power station) or an area-wide problem (in urban residential areas or rural areas).

Table 4

Proportion of monitoring stations with exceedance of WHO AQG levels valid in 2021, of previous valid WHO AQG levels and of applicable EU target and limit values, reference year of data: 2020

Basis of the exceedance	All stations	Rural background	Urban background	Urban traffic	Industry
$PM_{2.5}$-annual mean					
2008/50/EG (25 µg/m³)	0 %	0 %	0 %	0 %	0 %
WHO2005 (10 µg/m³)	14 %	0 %	8 %	26 %	20 %
WHO2021 (5 µg/m³)	99 %	94 %	100 %	100 %	100 %
$PM_{2.5}$- daily mean					
EU: no limit value	-	-	-	-	-
WHO2005 (25 µg/m³, 3 times)	84 %	47 %	84 %	97 %	100 %
WHO2021 (15 µg/m³, 99th perc.)	99.5 %	97 %	100 %	100 %	100 %
PM_{10}-annual mean					
2008/50/EG (40 µg/m³)	0 %	0 %	0 %	0 %	0 %
WHO2005 (20 µg/m³)	5 %	0 %	0 %	13 %	16 %
WHO2021 (15 µg/m³)	36 %	3 %	17 %	73 %	63 %
PM_{10}-daily mean					
2008/50/EC (50 µg/m³, 35 times)	0 %	0 %	0 %	0 %	0 %
WHO2005 (50 µg/m³, 3 times)	11 %	0 %	3 %	22 %	28 %
WHO2021 (45 µg/m³, 99th perc.)	16 %	3 %	5 %	32 %	34 %
O_3-Peak Season					
EU: no target value	-	-	-	-	-
WHO2005: no guideline value	-	-	-	-	-
WHO2021 (60 µg/m³)	100 %	100 %	100 %	100 %	100 %
O_3-8h mean					
2008/50/EC (120 µg/m³)	99.6 %	100 %	100 %	83 %	100 %
WHO2005 (100 µg/m³)	99.6 %	100 %	100 %	83 %	100 %
WHO2021 (100 µg/m³, 99th perc.)	99.6 %	100 %	100 %	83 %	100 %
NO_2-annual mean					
2008/50/EC (40 µg/m³)	1 %	0 %	0 %	3 %	0 %
WHO2005 (40 µg/m³)	1 %	0 %	0 %	3 %	0 %
WHO2021 (10 µg/m³)	83 %	9 %	88 %	100 %	88 %
NO_2-daily mean					
EU: no limit value	-	-	-	-	-
WHO2005: no guideline value	-	-	-	-	-
WHO2021 (25 µg/m³, 99th perc.)	76 %	19 %	84 %	99 %	79 %

Basis of the exceedance	All stations	Rural background	Urban background	Urban traffic	Industry
NO_2 - hourly mean					
2008/50/EC (200 µg/m³, 18 times)	0 %	0 %	0 %	0 %	0 %
WHO2005 (200 µg/m³)	0.3 %	0 %	0 %	1 %	0 %
WHO2021 (200 µg/m³)	0.3 %	0 %	0 %	1 %	0 %
SO_2-daily mean					
2008/50/EC (125 µg/m³, 3 times)	0 %	0 %	0 %	0 %	0 %
WHO2005 (20 µg/m³)	9 %	7 %	2 %	0 %	43 %
WHO2021 (40 µg/m³, 99th perc.)	2 %	0 %	0 %	0 %	14 %
CO-daily mean					
EU: no limit value	-	-	-	-	-
WHO: no guideline value	-	-	-	-	-
WHO2021 (4 mg/m³, 99th perc.)	0 %	0 %	0 %	0 %	0 %
CO-8h mean					
2008/50/EC (10 mg/m³)	0 %	0 %	0 %	0 %	0 %
WHO2000 (10 µg/m³)	0 %	0 %	0 %	0 %	0 %
WHO2021 (10 µg/m³)	0 %	0 %	0 %	0 %	0 %
CO-hourly mean					
EU: no limit value	-	-	-	-	-
WHO2000 (35 mg/m³)	0 %	0 %	0 %	0 %	0 %
WHO2021 (35 mg/m³)	0 %	0 %	0 %	0 %	0 %
Pb in PM_{10} - annual mean					
2008/50/EC (0.5 µg/m³)	0 %	0 %	0 %	0 %	0 %
WHO2000 (0.5 µg/m³)	0 %	0 %	0 %	0 %	0 %
WHO2021 (0.5 µg/m³)	0 %	0 %	0 %	0 %	0 %
Cd in PM_{10} - annual mean					
2004/107/EG (5 ng/m³)	0 %	0 %	0 %	0 %	0 %
WHO2000 (5 ng/m³)	0 %	0 %	0 %	0 %	0 %
WHO2021 (5 ng/m³)	0 %	0 %	0 %	0 %	0 %
Benzene - annual mean					
2008/50/EG (5 µg/m³)	0 %	0 %	0 %	0 %	0 %
WHO2000[c] (1.7 µg/m³)	5 %	0 %	0 %	0 %	33 %
WHO2021[c] (1.7 µg/m³)	5%	0%	0%	0%	33%
B(a)P in PM_{10} - annual mean					
2008/50/EG (1 ng/m³)	0 %	0 %	0 %	0 %	0 %
WHO2000[c] (0.12 ng/m³)	80 %	29 %	88 %	85 %	64 %
WHO2021[c] (0.12 ng/m³)	80 %	29 %	88 %	85 %	64 %
As in PM_{10} - annual mean					
2004/107/EG (6 ng/m³)	0 %	0 %	0 %	0 %	0 %
WHO2000[c] (6.6 ng/m³)	0 %	0 %	0 %	0 %	0 %
WHO2021[c] (6.6 ng/m³)	0 %	0 %	0 %	0 %	0 %
Ni in PM_{10} - annual mean					
2004/107/EG (20 ng/m³)	0 %	0 %	0 %	0 %	0 %
WHO2000[c] (25 ng/m³)	0 %	0 %	0 %	0 %	0 %
WHO2021[c] (25 ng/m³)	0 %	0 %	0 %	0 %	0 %

[c] Concentration value for increase of cancer lifetime risk to 1:100 000 according to WHO2000

Previously valid WHO guidelines with AQG levels:

- for carbon monoxide, benzene, benzo(a)pyrene, arsenic and the metals in PM_{10}
  - WHO2000: Air Quality Guidelines for Europe, World Health Organization, Regional Office for Europe, Copenhagen, WHO Regional Publications, European Series, No. 91, Second Edition, 2000
- for particulate matter (PM_{10} and $PM_{2.5}$), ozone, nitrogen dioxide and sulphur dioxide:
  - WHO2005: WHO Air quality guidelines, for particulate matter, ozone, nitrogen dioxide and sulphur dioxide, Global update 2005

Applicable EU directives with limit and target values:

- for particulate matter (PM_{10} and $PM_{2.5}$), ozone, nitrogen dioxide, sulphur dioxide, carbon monoxide, benzene, lead in PM_{10}
  - 2008/50/EC: DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe
  - for arsenic, cadmium, nickel and benzo(a) pyrene in PM_{10}: DIRECTIVE 2004/107/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air

The valid EU limit values for particulate matter PM_{10} and $PM_{2.5}$ were complied with throughout Germany in 2020. However, concentrations in relation to long-term exposure (annual mean values) were above the WHO AQG levels of 2005, especially in the vicinity of traffic and industry. Exceedances of the short-term AQG levels are also found in urban residential areas. With the tightening of the WHO AQG levels, both short-term and long-term exposure to $PM_{2.5}$ must be classified as too high almost everywhere in Germany, regardless of the exposure regime.

In Germany, exceedances of the annual mean NO_2 limit value, valid since 2010, occurred primarily at stations close to traffic and have declined sharply over the past 10 years. In 2020, only 1 % of all stations exceeded the limit value and the identical WHO AQG level of 2005. For NO_2, the enormous reduction of the AQG level for the annual mean from 40 µg/m³ to 10 µg/m³ leads to a significantly changed exceedance situation: The percentage of exceedance increases from 3 % to 100 % in the area close to traffic and from 0 % to 88 % in the urban background or close to industry. Even in the rural background, NO_2 levels are too high at 9 % of stations. The load is also problematic with regard to the new assessment basis of the daily mean for NO_2.

For the pollutant ozone, the situation has remained equally bad: The measured values are almost without exception above the old and new evaluation standards.

Contrary to the other tightening of the WHO AQG levels, the SO_2 daily mean is assessed less strictly under the new WHO air quality guidelines. Therefore, the share of industry-related stations with exceedance decreases from 43 % to 14 %. For all other regulated pollutants, the assessment has not changed with the new WHO AQG levels.

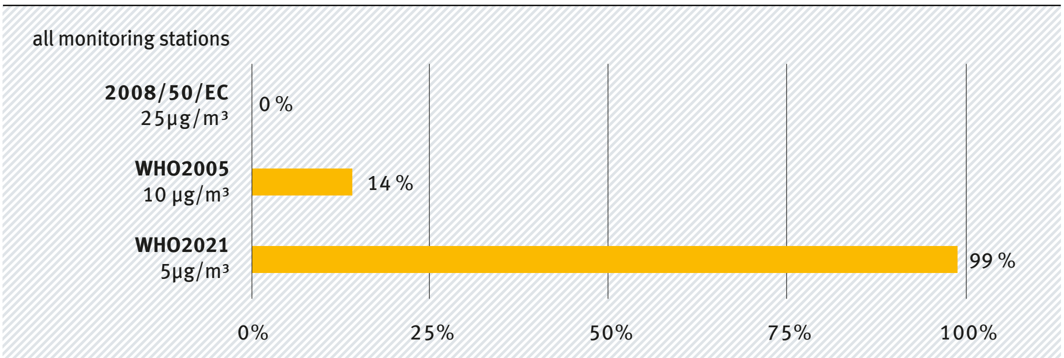
The results show that: To protect health, air pollution from particulate matter, nitrogen dioxide and ozone must be reduced on a large scale in Germany.

Appendix

Figures: Overview of the exceedance situation based on previous guideline/limit/target values for all air pollutants in detail

Figure a

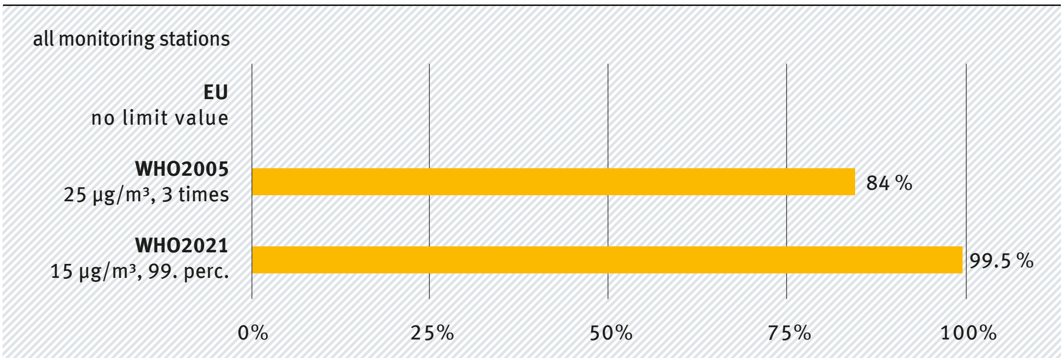
Comparison of the exceedance situation 2020 based on the $PM_{2.5}$ annual mean



Source: German Environment Agency (UBA) 2022

Figure b

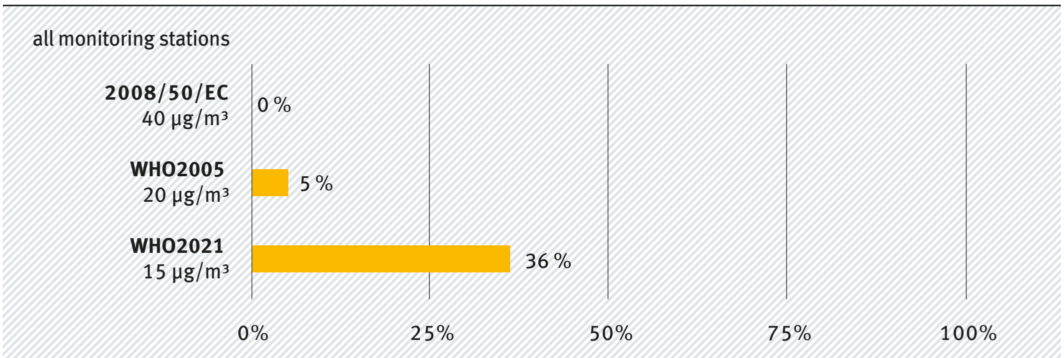
Comparison of the exceedance situation 2020 based on the $PM_{2.5}$ daily mean



Source: German Environment Agency (UBA) 2022

Figure c

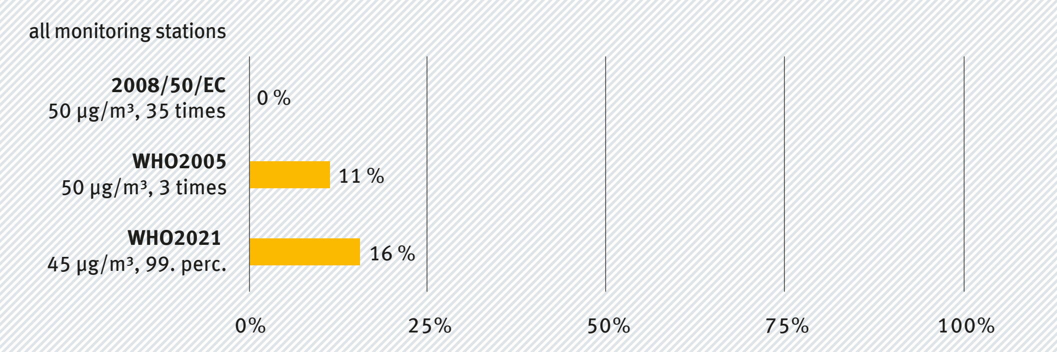
Comparison of the exceedance situation 2020 based on the PM_{10} annual mean



Source: German Environment Agency (UBA) 2022

Figure d

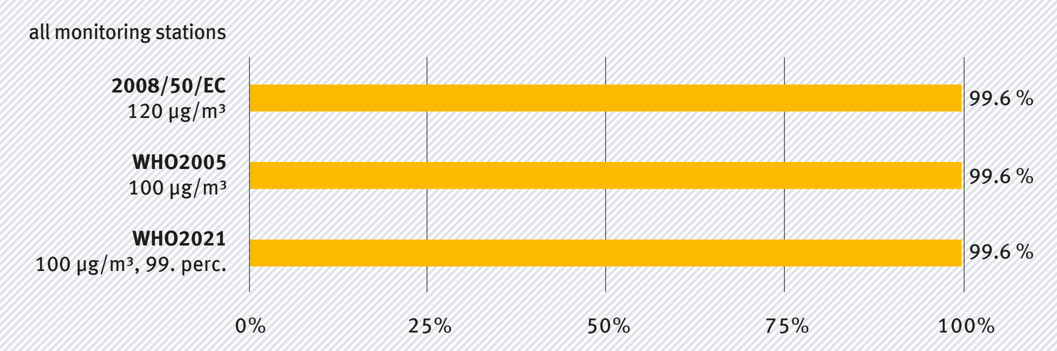
Comparison of the exceedance situation 2020 based on the PM_{10} daily mean



Source: German Environment Agency (UBA) 2022

Figure e

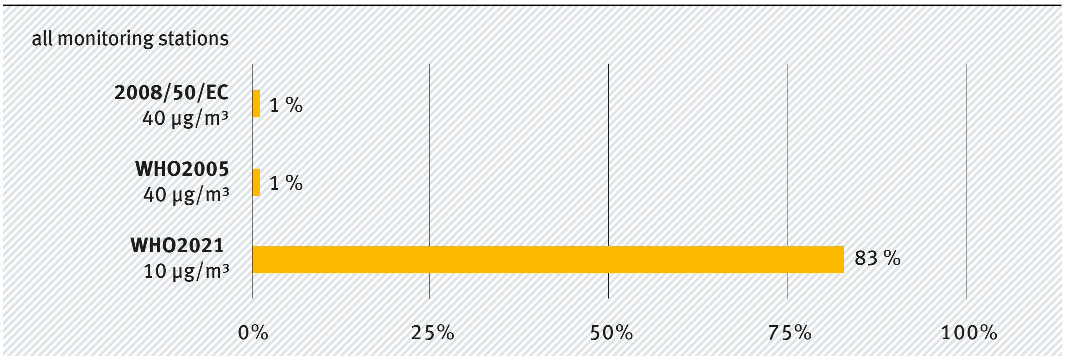
Comparison of the exceedance situation 2020 based on the maximum daily 8-hour average ozone value



Source: German Environment Agency (UBA) 2022

Figure f

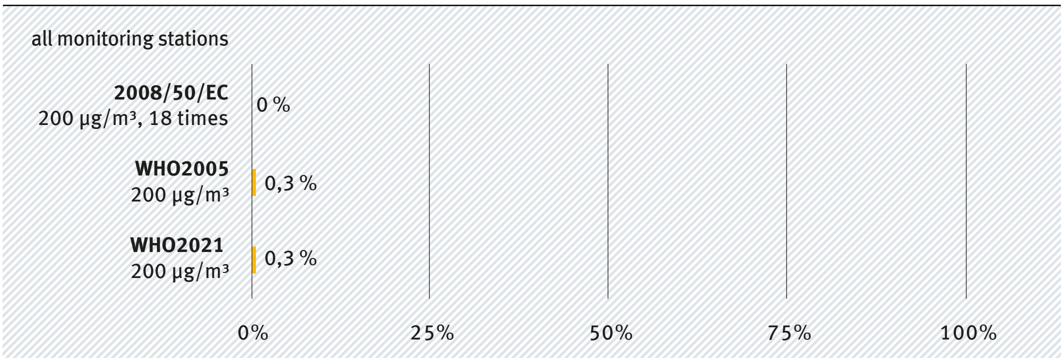
Comparison of the exceedance situation 2020 based on the NO_2 annual mean



Source: German Environment Agency (UBA) 2022

Figure g

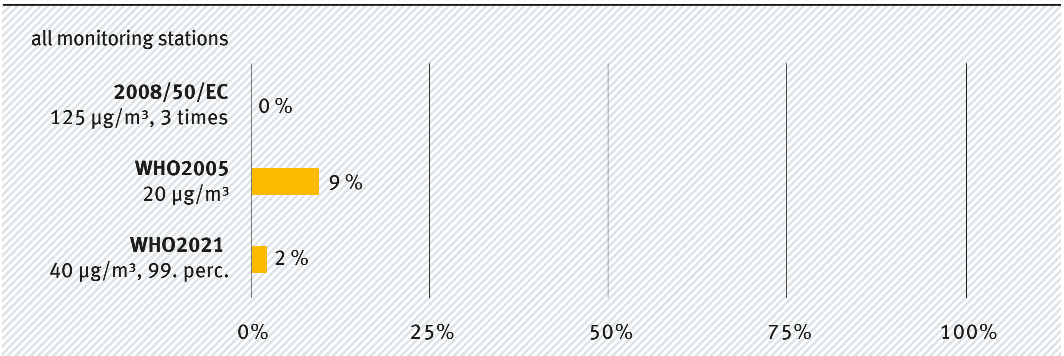
Comparison of the exceedance situation 2020 based on the NO_2 hourly mean



Source: German Environment Agency (UBA) 2022

Figure h

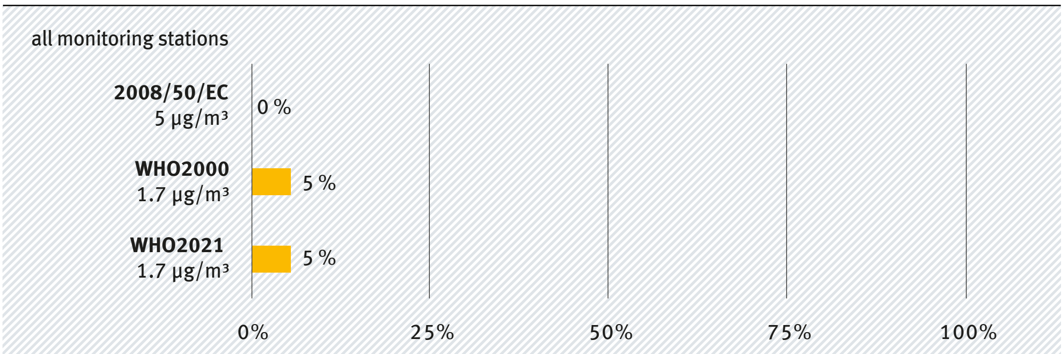
Comparison of the exceedance situation 2020 based on the SO_2 daily mean



Source: German Environment Agency (UBA) 2022

Figure i

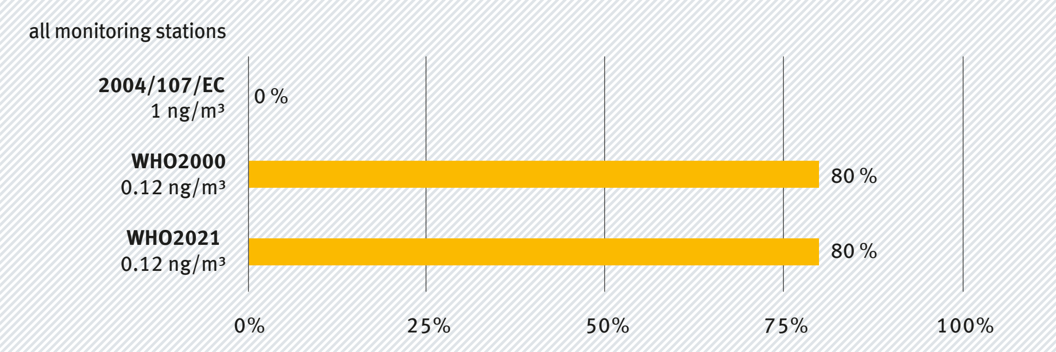
Comparison of the exceedance situation 2020 based on the benzene annual mean



Source: German Environment Agency (UBA) 2022

Figure j

Comparison of the exceedance situation 2020 based on the B(a)P annual mean



Source: German Environment Agency (UBA) 2022

Further information on the topic

Current air quality data:
https://www.umweltbundesamt.de/en/data/current-concentrations-of-air-pollutants-in-germany

Air quality app
https://www.umweltbundesamt.de/en/press/pressinformation/german-environment-agency-enhances-its-air-quality

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

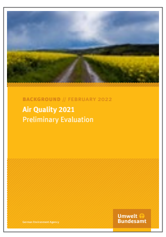
Development of air quality in Germany:
https://www.umweltbundesamt.de/themen/luft/daten-karten/entwicklung-der-luftqualitaet

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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