BACKGROUND // JANUARY 2019

Air Quality 2018
Preliminary Evaluation

German Environment Agency

Umwelt Bundesamt

Imprint

Publisher:
Umweltbundesamt [German Environment Agency]
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Section II 4.2 “Air Quality Assessment”

Design:
Atelier Hauer + Dörfler GmbH, Berlin

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

Photo credits:
Cover photo: hykoe/Fotolia.com
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State Office for Nature, Environment and Consumer
Affairs of North-Rhine Westphalia
Photo of air quality measuring station Schildhornstraße,
Berlin, p. 24: Mario Winkler/MotivWunsch

As at: January 2019

ISSN 2363-829X

The information presented in this brochure refelcts the level of research at the time of publication. The definitive data is presented on the UBA website from the middle of the year onwards.

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I Air Quality in 2018: 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 650 air monitoring stations throughout Germany. For the Germany-wide assessment of the air quality, the data gathered by the federal states is collected and evaluated at the UBA.

Monitoring station Schmücke, Thuringian Forest.

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 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]. The results are also compared with the considerably stricter recommendations of the World Health Organization (WHO).

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)

2 Provisional nature of the information

This evaluation of air quality in Germany in the year 2018 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 18th January 2019. Due to the comprehensive quality assurance within the monitoring networks, the final data will only be available in mid-2019.

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 limit and target values for the protection of human health are still exceeded for such substances.

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 positive 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.

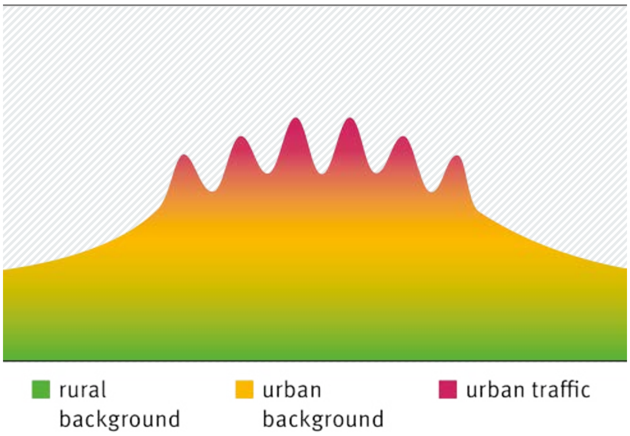
4 Influence of environmental conditions

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 1 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 1

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: Less exceedance days, but increased annual mean values

1 PM_{10} – 24-hour values

The limit value for the 24-hour PM_{10} value, which needs to be complied with since 2005, was only exceeded at one industrial station in North Rhine-Westphalia, with 36 daily values of over 50 µg/m³. Therefore in 2018, like in the three previous years, only few days with exceedances of the PM_{10} limits were recorded. In the past, the exceeding of the limits occurred almost exclusively at urban traffic air monitoring stations. Since 2012 measurements at all background stations are below the limit value, as shown in Figure 2 (red bars). The recommendations of the World Health Organization (WHO[2]) were not complied with at 78 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.

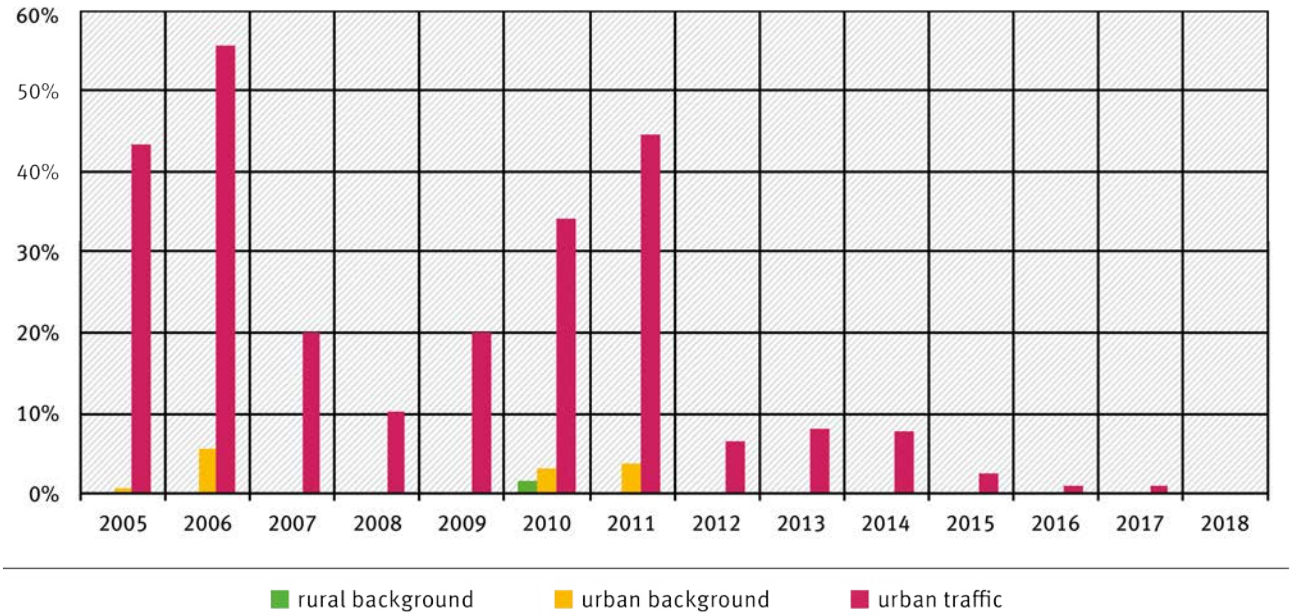
WHO recommendation

The 24-hour PM_{10} value should not exceed 50 µg/m³ more than 3 times per year.

Figure 2

Percentage share of air monitoring stations exceeding the PM_{10} limit value

for the 24-hour values in the corresponding pollution regime, time frame 2005–2018



Source: German Environment Agency (UBA) 2019

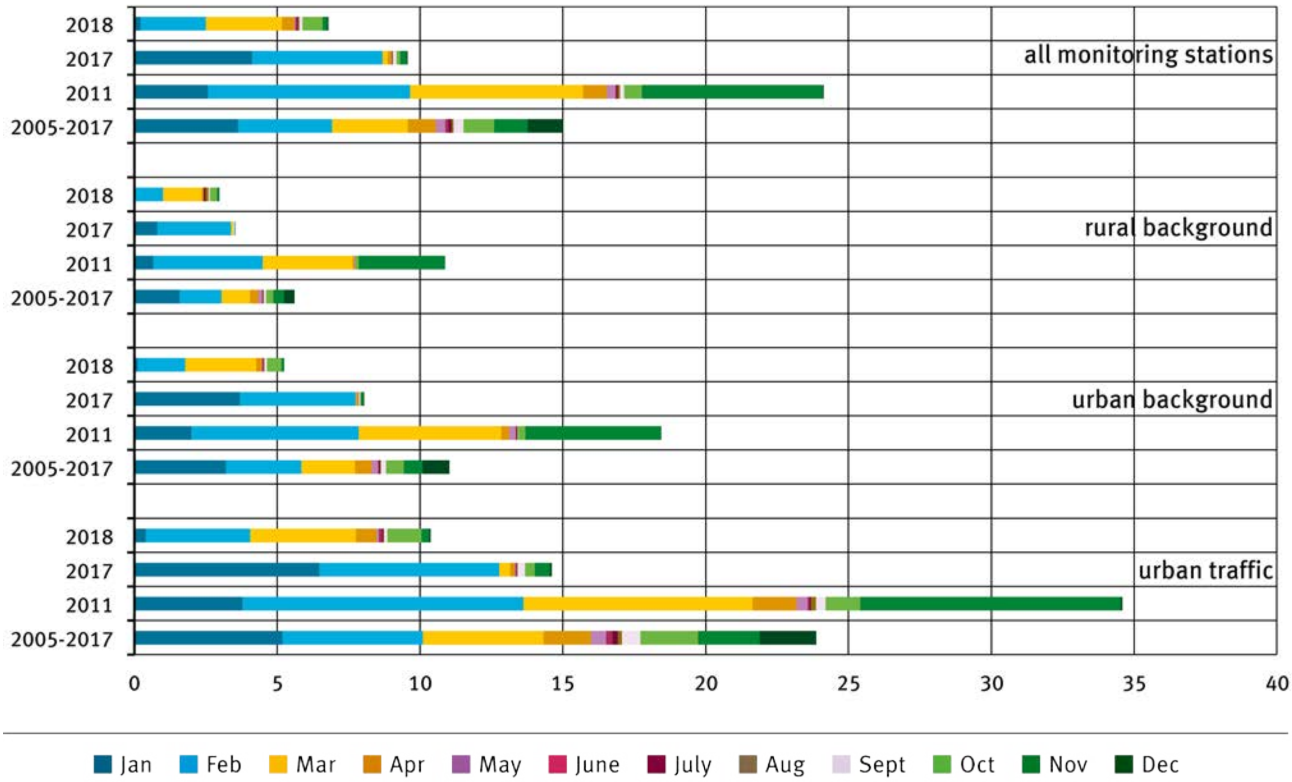
2 WHO – World Health Organization, Air Quality Guidelines for Europe, 2nd Edition 2000, WHO Regional Publications, European Series, No. 91: http://www.euro.who.int/document/e71922.pdf

WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005: http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/air-quality/publications/pre2009/air-quality-guidelines.-global-update-2005.-particulate-matter,-ozone,-nitrogen-dioxide-and-sulfur-dioxide

Figure 3

Average number of days on which the PM_{10} limit was exceeded (24-hour values > 50µg/m³)

per month in the corresponding pollution regime. Shown for the years 2018, 2017, 2011 and the period 2005–2017



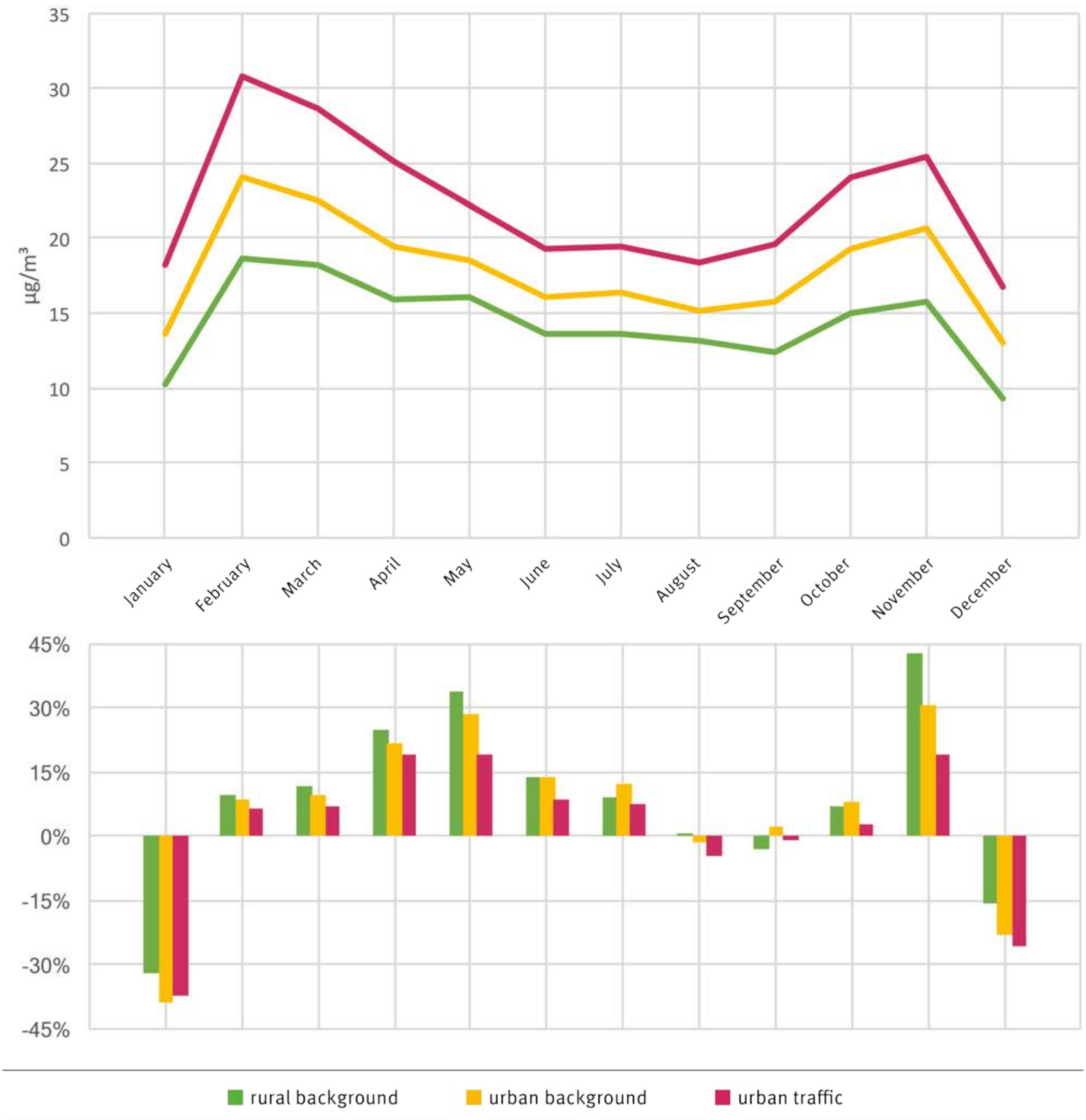
Source: German Environment Agency (UBA) 2019

Figure 3 shows how many days were recorded on which the limits were exceeded, on average, per month. In this case, 2018 is compared with 2011, in which the levels of pollution were high due to the frequent occurrence of cold, stable high-pressure weather conditions, with the previous year (2017) and an extended reference period (2005–2017). It can be seen that most of the days on which the limits were exceeded were recorded in January and February. This goes along with the arrival of cold air masses in the two months[3]. In the rest of the year there were only few days on which the limits were exceeded, i. e. between March and December the 24-hour values were below 50 µg/m³ on most of the days. The year 2018 was an exceptional meteorological year, with several records and it is classified as the warmest and sunniest year since the beginning of the systematic weather observation. These special weather conditions had an effect on the PM_{10} concentrations: During the exceptionally long, ten-month dry period lasting from February to November, increased PM_{10} concentrations were continuously measured. But they were still below the limit value.

3 Press release of the German weather service DWD: https://www.dwd.de/DE/presse/pressemitteilungen/DE/2018/20181228_deutschlandwetter_jahr2018.html?nn=636156

Figure 4

PM_{10} monthly mean values 2018 and its percentage deviation from the average of the period 2015–2017



Source: German Environment Agency (UBA) 2019

Figure 4 shows the monthly averaged PM_{10} concentration in 2018 and its deviation from the average of the last three years. During eight out of the ten dry month the measured values are exceptionally high, but in the months January and December, which were characterised by high precipitation, the values were well below average.

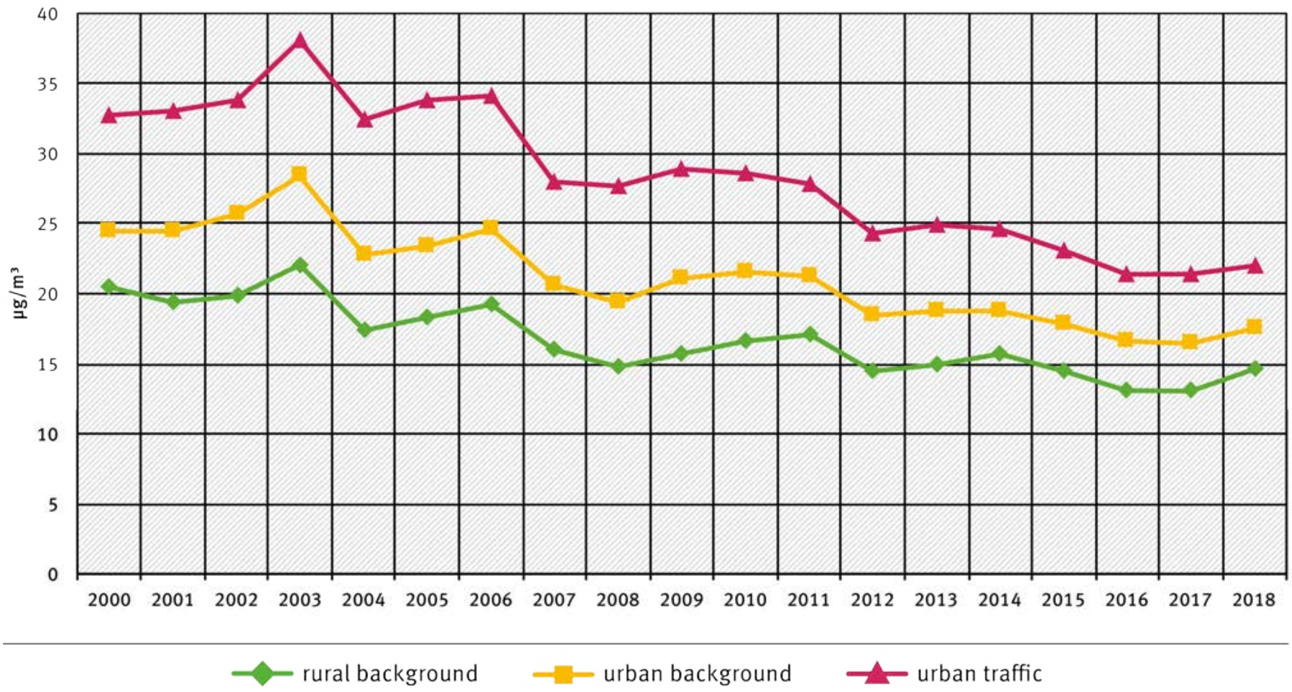
2 PM_{10} – Annual mean values

The permanently increased PM_{10} concentrations during the year also resulted in increased annual mean values compared to the two previous years. Nevertheless, the PM_{10} limit of 40 µg/m³ as the annual mean value was complied with throughout Germany. 32 percent of the air monitoring stations recorded values that infringed the air quality guidelines

Figure 5

Development of the annual PM_{10} values

via selected air monitoring stations in the corresponding pollution regime, time frame 2000–2018



Source: German Environment Agency (UBA) 2019

proposed by the WHO, however. The vast majority of these air monitoring stations were in urban traffic locations. Accompanied by the regional falls in the PM_{10} emissions, the annual mean PM_{10} values also show a clear fall in all pollution regimes throughout the entire period of observation from 2000 to 2018. This is shown by Figure 5, for which only air monitoring stations were selected that conducted measurements over an extended period. The progression is also characterised by strong inter-year variations, however, particularly due to the different weather conditions. The concentrations in 2018 are slightly higher than in the previous year, but still on a very low level compared to the considered period since 2000.

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, in 2018, as in the two previous years, this value was not exceeded at any air monitoring station even though the exceptional weather conditions resulted in increased annual mean $PM_{2.5}$ concentrations (Figure 6). The stricter recommendations of the WHO (10 µg/m³ as the annual mean value) were not complied with at almost all measuring stations (93 %). Furthermore, the WHO recommendation is that the 24-hour $PM_{2.5}$ value should

EU limit value

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

WHO recommendation

The annual mean PM_{10} value should not exceed 20 µg/m³.

EU limit value

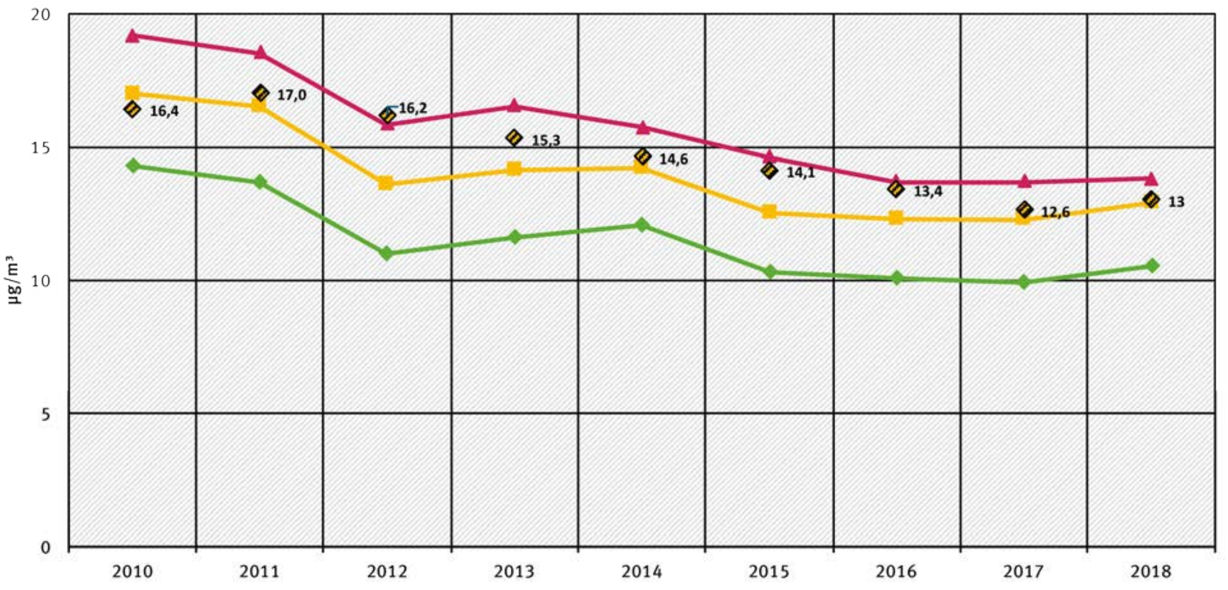
the annual mean $PM_{2.5}$ value must not exceed 25 µg/m³.

WHO recommendation

The annual mean $PM_{2.5}$ value should not exceed 10 µg/m³. The 24-hour $PM_{2.5}$ value must not exceed 25 µg/m³ more than 3 times per year.

Figure 6

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 2010–2018



Source: German Environment Agency (UBA) 2019

not exceed 25 µg/m³ more than 3 times a year. This recommendations was not complied with at any air monitoring 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 as the average value of the years 2008 to 2010. According to the requirements of the EU Directive, 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. In 2018 (average value of the years 2016, 2017 and 2018), the AEI is totalled 13 µg/m³ (estimation, because not for all measuring stations data are already available) and therefore was complied with for the third time, together with the 2016's and 2017's AEI. Even if the future compliance seems to be ensured right now, calculations made clear, that for the 3 year average two lowly polluted years like we had in the last years are not enough to compensate one highly polluted year like 2011.

Therefore it is not definitely sure that the national reduction goal for 2020 can be reached. 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.

III Nitrogen dioxide: Further reduction of pollution

1 NO_2 – Annual mean values

According to the current data, 37 percent of the air monitoring stations in urban traffic locations exceeded the statutory limit and/or the WHO air quality guidelines. But only values of stations with automatic measurements are included. The NO_2 concentrations measured by passive collectors (see photo), primarily at highly polluted urban traffic locations, are not yet available for this preliminary evaluation. On the basis of a projection derived from the previous years' data, we estimate the proportion of all air monitoring stations in urban traffic locations that exceeded the limit in 2018 to be approx. 39 percent (Figure 7, red bars).

EU limit values

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

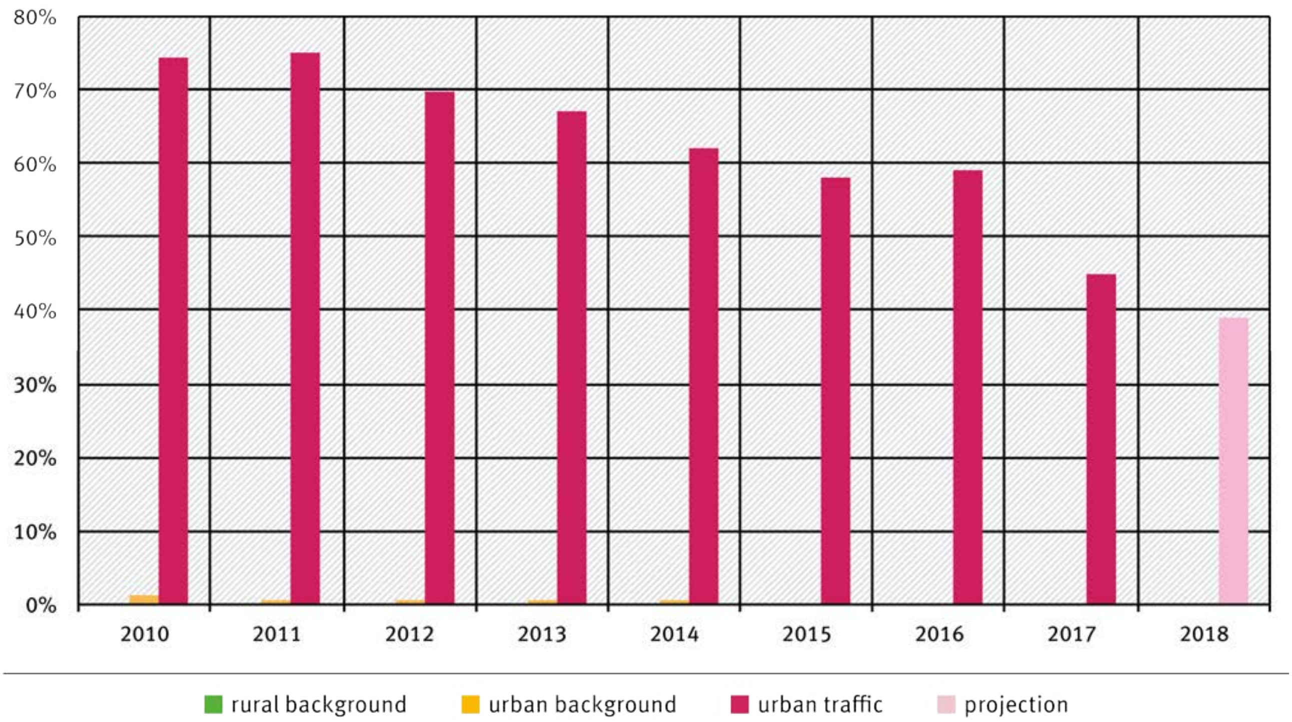
WHO recommendation

The WHO recommendation is equivalent to the EU limit value.

Figure 7

Percentage share of air monitoring stations exceeding the NO_2 limit value for the annual mean

in the corresponding pollution regime, time frame 2010–2018

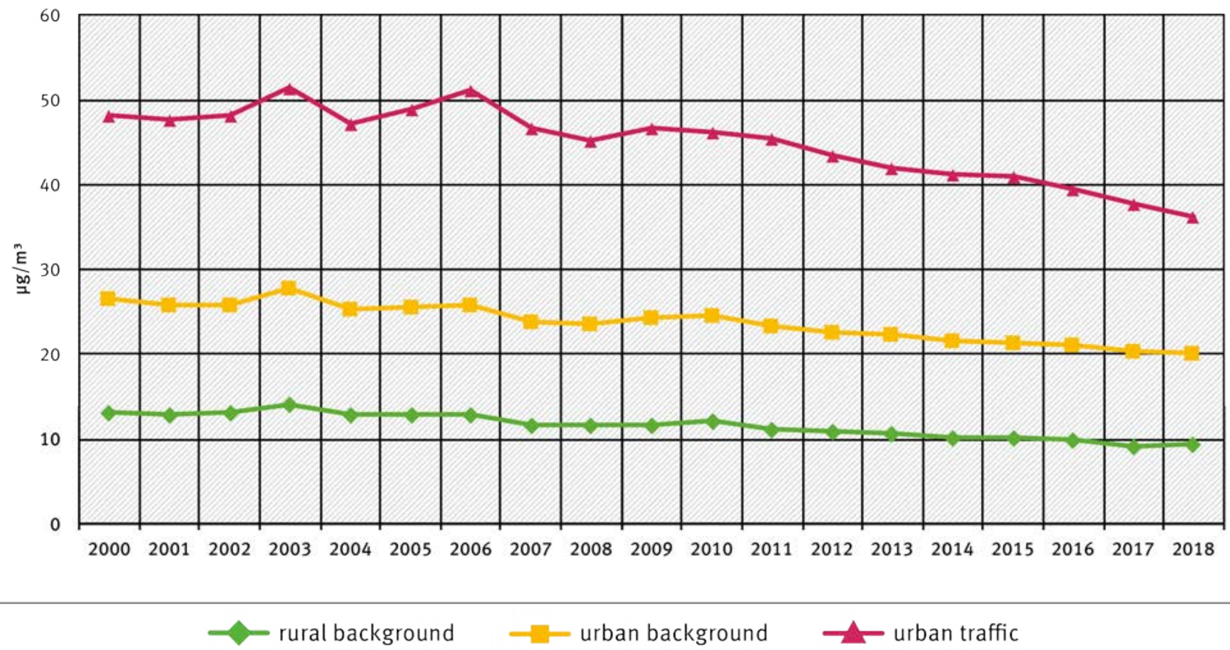


Source: German Environment Agency (UBA) 2019

Figure 8

Development of the annual mean NO_2 values

via selected air monitoring stations in the corresponding pollution regime, time frame 2000–2018



Source: German Environment Agency (UBA) 2019

The nitrogen dioxide pollution shows a fall in the last ten years (Figure 8). In order to minimize the influence 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.

In rural areas, which are typically a long way from the major sources of NO_2, from 2000–2018, the average annual concentration for all the air monitoring stations amounted to 10 µg/m³ (Figure 8, green curve). At the air monitoring stations with an urban background, the values were well below the limit of 40 µg/m³ (Figure 8, yellow curve). In 2018, like in the previous year, the average NO_2 concentration at urban traffic air monitoring stations fell below 40 µg/m³. In comparison, the average NO_2 value at urban traffic locations between 2000–2011 (Figure 8, red curve) clearly exceeded the limit with which compliance has been required since 2010.

Passive collector: A passive collector is a small monitoring device which operates without electrical power and in which several detection tubes absorb the pollutants from the air. The detection tubes are regularly removed and their contents evaluated in the laboratory.

Figure 9

NO_2 annual mean values 2018
of all urban traffic monitoring stations

Source: German Environment Agency (UBA) 2019

Even though the concentrations at urban traffic stations are generally decreasing, annual mean values of over 40 µg/m³ were still measured at many air monitoring stations and cases in which the limits were exceeded were therefore recorded. Figure 9 shows the NO_2 annual values of all air monitoring stations in urban traffic locations in descending order. The gaps result from the missing data of the passive collectors, which are only available in the course of 2019. Their position in the descending order is deduced from the data of the previous year. It becomes clear that there are big differences between the monitoring stations: Some stations exceed the limit value of 40 µg/m³ slightly, whereas other stations exceed the limit value clearly.

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 2018, like in the year before, this value was not exceeded. In the previous years there used to be a few exceedances at urban traffic stations.

7 percent of all air monitoring stations in urban traffic locations failed to comply with the WHO recommendation in 2018.

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

WHO recommendation
The one hour NO_2 values should never exceed 200 µg/m³.

IV Ground-level ozone: Frequently exceedances of the target value for the protection of human health

1 O_3 – Information and alert threshold

The highest 1-hour average value amounted to 258 µg/m³ and is therefore slightly higher than the previous year value (238 µg/m³). In 2018 the alert threshold of 240 µg/m³ was exceeded at one single station one time. In the previous year the measured concentration were always below this value. The information threshold of 180 µg/m³ was exceeded on 30 days. In the last 20 years, 2018 was one of the many years in which no or only few exceedances of the alert threshold were recorded.

Figure 10 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 higher ozone pollution than 2018. As a result of the long-lasting summer weather with temperatures often above 30 °C more exceedances of the information threshold may have been expected. This is because the contribution of volatile organic compounds (so called biogenic hydrocarbons), which are emitted by plants, to the ozone formation increases at temperatures above 30 °C. A possible explanation for the absence of the expected ozone increase, is the drought stress in the vegetation which results in the absence or decrease of the emission of biogenic hydrocarbons. This thesis still needs to be explored in more detail.

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 NO_2, 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.

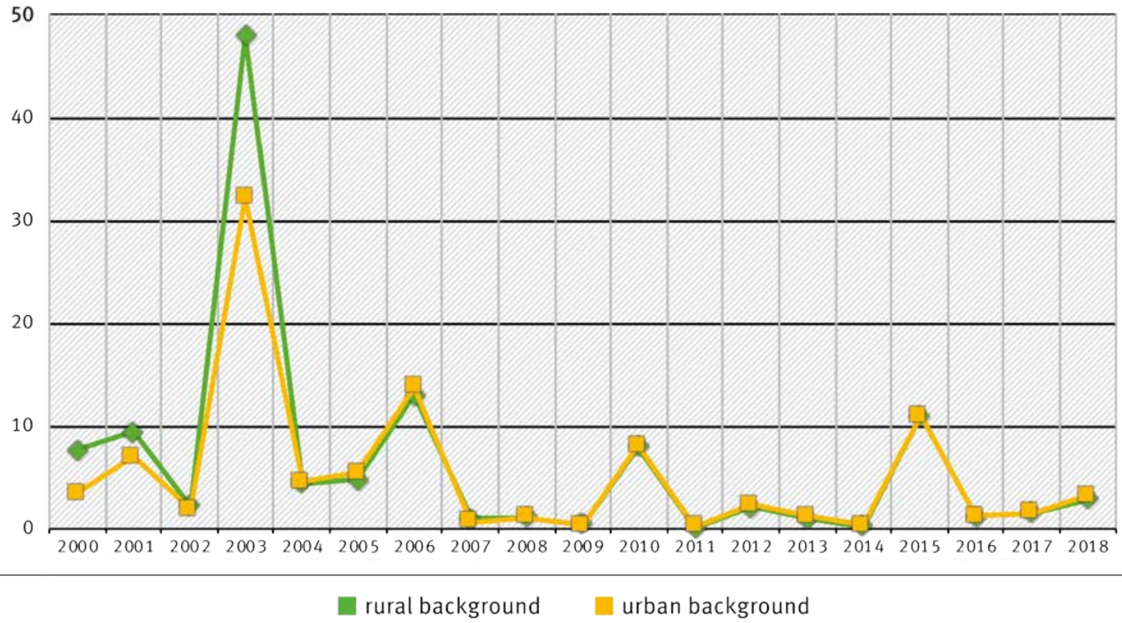
2 O_3 – Target value for the protection of human health

According to the German Weather Service, the summer 2018 was the warmest summer in the north and east of Germany since the beginning of the systematic weather observation. Higher temperatures were only measured in 2003 throughout Germany. As a result of the

Figure 10

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

Average over selected monitoring stations



Source: German Environment Agency (UBA) 2019

large-scale circulation pattern over Europe, high pressure systems were situated over north Europe which caused a flow of warm and dry air to Germany. In middle Germany the largest precipitation anomaly ever measured in summer was recorded in 2018. Particularly remarkable: The dry, summery conditions already started in April and lasted until the end of August, furthermore a heatwave started in the last third of July.[4]

The large-scale and sustained high pressure weather conditions with an above-average number of summer days and a record in sunshine duration, favoured the formation of ozone. This is also indicated by the long-term objective for the protection of human health: 8-hour average values of over 120 µg/m³ were measured at all monitoring stations (= 100 %), that is the long-term objective is not complied with throughout Germany. In the previous year 2017, at least 14 stations (= 6 %) met the long-term goal.

In 2018, an ozone value of 120 µg/m³, as the highest daily 8-hour average value, was exceeded on an average of 37 days per station. This is exceptionally often. In the previous year, which was characterised by low ozone pollution, only 9 exceedance days were recorded as an average over all air monitoring stations. Going back to the year 2000, the 2018 value was the second highest value following the record-breaking summer of 2003.

Figure 11 shows the spatial distribution of the number of exceedance days in 2018 in comparison to the last three years. It can be seen that throughout Germany, except in the north, a high number of exceedance days were recorded. In 2018, compared to the previous years, considerably more exceedances were recorded and distributed over a larger area. Furthermore, the WHO recommendation that the 8-hour average values should not exceed 100 µg/m³ was missed.

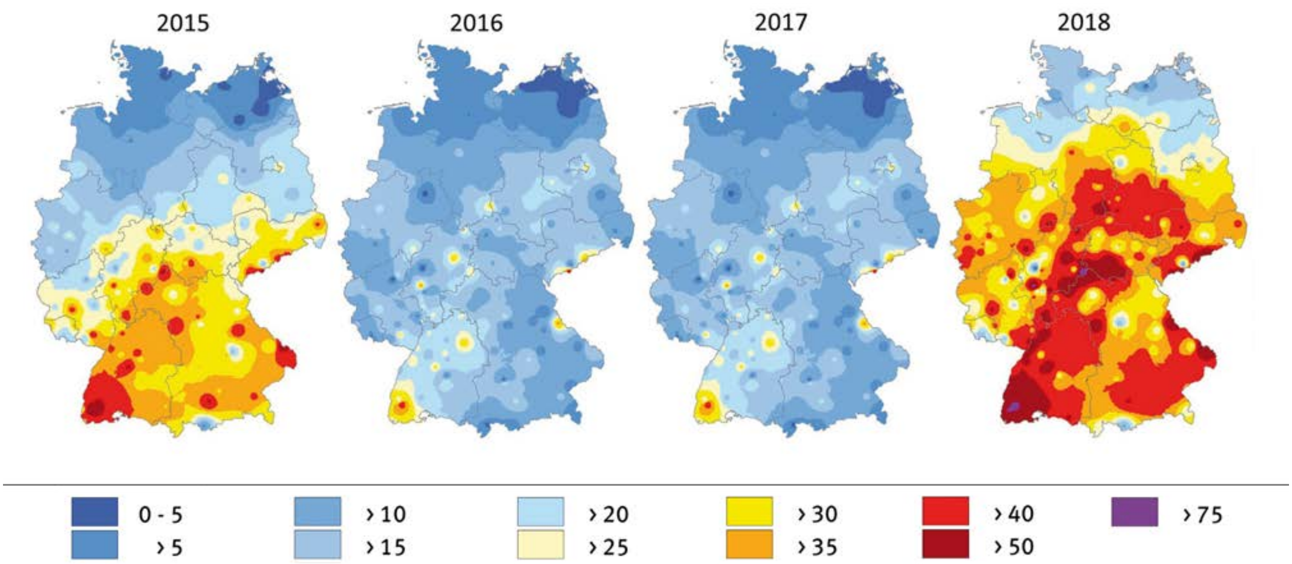
A 3-year period is monitored for the target value for the protection of human health: on average, an 8-hour average value of 120 µg/m³ may only be exceeded on 25 days. In the most recent averaging period of 2016 to 2018, however, 29 percent of the air monitoring stations exceeded this value on more than 25 days. Figure 12 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.

4 www.dwd.de/DE/leistungen/besondereereignisse/temperatur/20180906_waermstersommer_nordenosten2018.pdf?__blob=publicationFile&v=7

Figure 11

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 2015–2018, based on station measurements and a geostatistical interpolation method

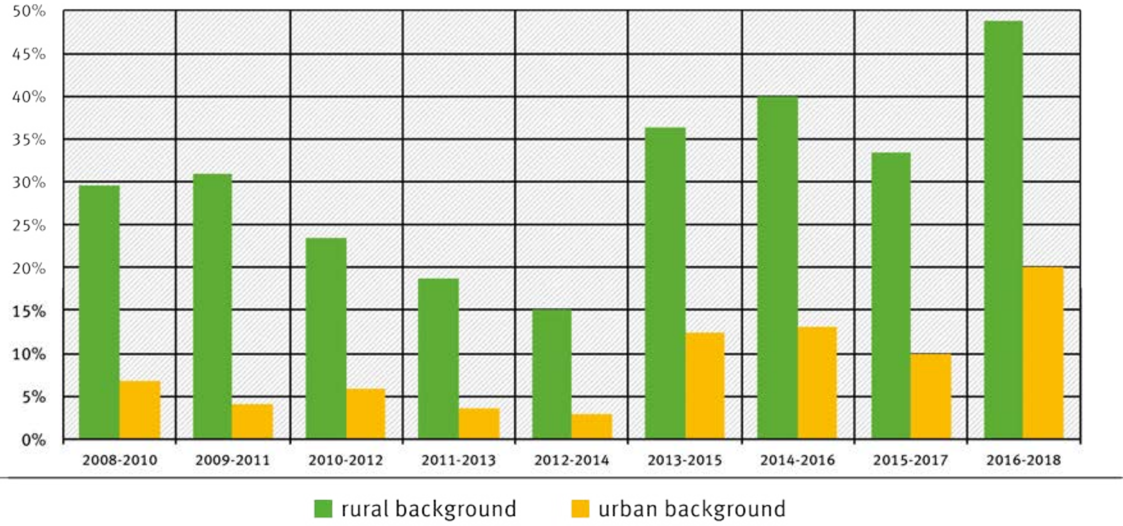


Source: German Environment Agency (UBA) 2019

Figure 12

Percentage share of air monitoring stations recording an exceedance of the target value

for the protection of human health, time frame 2010–2018 (in each case, 1-year moving average over 3 years)



Source: German Environment Agency (UBA) 2019

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 2014 to 2018 was exceeded at 39 out of 160 air monitoring stations (= 24 %, previous year: 20 air monitoring stations = 12 %).

In 2018, the long-term objective for the protection of the vegetation (6,000 µg/m³h) was exceeded at every air monitoring stations. In the previous year, the target value was compiled with at, at least, 20 stations.

In comparison with the last 10 years the ATO40-values at rural background stations were clearly higher but still below the values of the years 2003 and 2006. The methods of the impact evaluation of ozone are currently undergoing development in Europe. 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.

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 recommendation
The 8-hour average values should never exceed 100 µg/m³.

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 – 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 in one year – i. e. 3,000 ppb h and/or 3 ppm h.

V The European Air Quality Directive

Background

On 2nd May 2008, the European Parliament and the European Council passed Directive 2008/50/EC on ambient air quality and cleaner air for Europe which had previously been proposed by the EU Commission. This Directive was required to be transposed into national law by all the EU Member States within two years. In Germany, this took place on the basis of the 39th Ordinance for the Implementation of the German Federal Imission Control Act (39th BImSchV[5]). This contains the requirements of the Directive without any amendments. In 2015, amendments were made to individual annexes of the Directive of 2008, which were published with Directive 2015/1480/EC. The requirements of this Directive were also adopted 1:1 in the 39th BlmSchV.

According to these legal principles, the authorities in the federal states operate the air monitoring networks in Germany. Additional measurements are carried out by the air monitoring network of the Federal Environment Agency.

Historical development and objectives of the Directive

As long ago as 1992, in the fifth “Environment Action Programme”, the European Council recommended making changes to the legal regulations on air quality in the interests of better protecting the environment and human health. The European Council defined the necessary framework in 1996, with the Directive on ambient air quality assessment and management (96/62/EC). This framework was followed by further Directives in 1999, 2000, 2002 and 2004, determining limit and target values for numerous air pollutants.

“Clean Air for Europe” was the name of the strategy for fighting air pollution which was adopted by the European Commission in 2002. The objective of this strategy was to reduce air pollution to a level so that it would no longer have any unacceptable effects on people or the environment by the year 2020. The strategy also specified the importance of improving the monitoring and assessment of the air quality and the necessity to inform the general public.

In 2008, the framework Directive of 1996 was merged with the Directives from 1999, 2000 and 2002 to create Directive 2008/50/EC. This confirmed the limit values for nitrogen dioxide and nitrogen oxides, particulate matter (PM_{10}), sulphur dioxide and lead which had been in force since 1999 and the limit values for benzene and carbon monoxide which had been in force since 2000. On the basis of scientific evidence, the Directive also established further air quality standards for the even smaller $PM_{2.5}$ particulate matter.

In the interests of protecting human health and the environment as a whole, a clearly defined objective of the Directive is to combat the emission of pollutants at the source and to apply the most effective emission control measures at the local, national and community level. In locations where air quality is already good, this should be maintained or further improved. If the air quality objectives set out in the Directive are not achieved, it is incumbent on the Member States to adopt measures to ensure compliance with the limit values.

What does the Directive regulate?

The Directive determines the limit values for nitrogen dioxide and nitrogen oxides, particulate matter (PM_{10}, $PM_{2.5}$), sulphur dioxide, benzene, carbon monoxide, lead and the target values for ozone. The Directive also determines a uniform approach as well as criteria for the assessment of the air quality. These include the following:

- The division of the territory of the state into air quality zones and agglomerations which correlate with the population density
- Methods of assessment such as measurements and model simulations
- Number and location of the measuring stations
- Standardised measurement techniques
- Data quality objectives and quality assurance
- Air quality assessment
- Establishing air quality plans for maintaining clean air when limit values are exceeded
- Notification of the general public
- Reporting obligations to the EU Commission

5 https://www.gesetze-im-internet.de/bimschv_39/index.html#BJNR106510010BJNE003201116

How were the limit values for ambient air determined?

Limit values for air pollutants aim to protect **all** groups in the population as a whole, at all places, **24 hours a day, 365 days a year and throughout their lives** against adverse health effects. These groups also include people with a particular degree of sensitivity, such as people with asthma as well as infants and older people, including people who have a damaged respiratory tract. The limit values of the Directive are based on the recommendations of the World Health Organization (WHO), but take the cost-effectiveness of the reduction measures into account at the same time (see Table 1). The WHO updated its Air Quality Guidelines (AQG[6]) to protect human health against atmospheric pollutants most recently in the year 2005. The derivation of the air quality guideline values is based on the results and findings of environmental epidemiological studies.

As the level of scientific knowledge on health effects has improved significantly since 2008, in the year 2012, the EU Commission commissioned the WHO to arrange for the latest scientific findings concerning the links between air pollution and health to be assessed by recognised scientists. In its initial report on the "**R**eview of **EVI**dence on **H**ealth **A**spects of **A**ir **P**ollution (REVIHAP[7])", the WHO concluded that on the basis of the current findings, a further tightening of the EU limit values is advisable so as to best protect human health.

6 http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/air-quality/publications/pre2009/air-quality-guidelines.-global-update-2005.-particulate-matter,-ozone,-nitrogen-dioxide-and-sulfur-dioxide

7 http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report

Table 1

Comparison of the limit/target values applicable in Europe and the recommendations of the World Health Organization (WHO) regarding the protection of human health

	EU limit/target values[a]	WHO recommendations[b, c]
	Limit values	Reference values
Particulate matter PM_{10} annual average	40 µg/m³	20 µg/m³
Particulate matter PM_{10} daily average	50 µg/m³, 35 exceedances permitted	50 µg/m³, 3 exceedances permitted
Particulate matter $PM_{2.5}$ annual average	25 µg/m³ [d]	10 µg/m³
Particulate matter $PM_{2.5}$ daily average	–	25 µg/m³, 3 exceedances permitted
Nitrogen dioxide NO_2 annual average	40 µg/m³	40 µg/m³
Nitrogen dioxide NO_2 hourly average	200 µg/m³, 18 exceedances permitted	200 µg/m³
Sulphur dioxide SO_2 daily average	125 µg/m³, 3 exceedances permitted	20 µg/m³
Sulphur dioxide SO_2 hourly average	350 µg/m³, 24 exceedances permitted	
Carbon monoxide CO 8-hourly average	10 mg/m³	10 mg/m³

	EU limit/target values[a]	WHO recommendations[b, c]
Lead Pb annual average	0.5 µg/m³	0.5 µg/m³
	Target values	**Reference values**
Ozone O_3 8-hourly average	120 µg/m³	100 µg/m³
Cadmium Cd annual average	5 ng/m³	5 ng/m³
	EU limit/target values for carcinogenic substances[a]	**WHO: excess lifetime risk of developing cancer[e]**
	Limit values	
Benzene Annual average	5 µg/m³	1.7 µg/m³ (risk 1:100,000)
	Target values	
Arsenic Annual average	6 ng/m³	6.6 ng/m³ (risk 1:100,000)
Nickel Annual average	20 ng/m³	25 ng/m³ (risk 1:100,000)
Benzo[a]pyrene Annual average	1 ng/m³	0.12 ng/m³ (risk 1:100,000)

[a] Limit/target values for the protection of human health according to the EU directives 2008/50/EG and 2004/107/EG
[b] Recommendations of WHO for the protection of human health from the Air Quality Guidelines for Europe, 2nd edition 2000
[c] WHO Regional Publications, European Series, No. 91 and WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulphur dioxide, Global update 2005 – the updated WHO recommendations from the year 2000 regarding PM_{10}, $PM_{2.5}$, NO_2, SO_2, ozone
[d] Target value to be achieved by 1.1.2010, threshold value to be complied with from 1.1.2015
[e] The WHO does not provide any reference values for carcinogenic substances, as no safe level of exposure can be recommended. For the purposes of orientation, the WHO states the additional lifetime risk of developing cancer for concentration values that are derived from occupational health studies. The table contains the respective concentration in accordance with the risk of 1:100,000 (that means one additional case of cancer relating to 100,000 exposed inhabitants).

Compilation German Environment Agency (UBA), As at: 08.01.2019

Why do different limit values apply at the workplace to those that apply to ambient air?

Limit values at the workplace (occupational exposure limit values) only apply to industrial workplaces and skilled trades where an increased toxic load is to be expected during the working hours of eight hours a day, five days a week due to the use or production of certain agents.

Nitrogen dioxide, for example, is produced – and/or used – during work processes such as welding, the manufacturing of dynamite and nitrocellulose, or the use of diesel engines in the fields of agriculture or road building. Workers, who are required to be healthy, can only be exposed to the occupational values for a maximum of 40 hours per week. They also receive occupational health care and are therefore subject to a stricter level of medical observation than the population as a whole.

In contrast, all people are exposed to pollutants in the ambient air every day and throughout their lifetime. The limit values for ambient air therefore apply 365 days a year, 24 hours a day. It is also necessary to protect sensitive people such as children, pregnant women, the elderly or people with pre-existing conditions like asthma, some of whom react much more sensitively to environmental influences.

The occupational limit values do not apply to office workplaces or private spaces. In this respect, the reference values of the Committee on Indoor Reference Values (AIR[8]) apply. As a general rule, indoor air quality is to be assessed differently from ambient air quality. In contrast to the NO_2 concentration in ambient air, the levels of NO_2 in indoor air depend on additional sources in the indoor space as well as the ventilation conditions. Such sources typically include combustion processes such as gas stoves, candles or the consumption of cigarettes.

Accordingly, compared with the requirements for ambient air, the assessment of the indoor air quality essentially targets short-term increases in the specific and temporary concentrations compared with ambient air. The AIR has defined two reference values for indoor air. Short-term reference value I, also known as the precautionary value, is 80 µg/m³ (Table 2). Short-term reference value I is the concentration of a substance up to which no negative impact on health may be expected, also in the case of sensitive people. Short-term reference value II, also known as the danger value, is 250 µg/m³. This indicates the concentration above which a negative impact on the health of sensitive people cannot be ruled out, and measures to reduce the toxic load are necessary. Both values are derived for a reference period of one hour and are therefore referred to as short-term reference values. The AIR has not determined a long-term reference value. If necessary, however, it alternatively recommends the application of the reference value for indoor air derived from WHO of 40 µg/m³, which refers to a period of one year.

8 https://www.umweltbundesamt.de/en/topics/health/commissions-working-groups/german-committee-on-indoor-guide-values

Where do the limit values for ambient air apply?

The limit values of the Air Quality Directive apply throughout the whole territory. The only exceptions to this requirement are areas to which the general public has no access and where there is no fixed residential accommodation (such as road tunnels, airport runways), industrial facilities and road carriageways.

What are target values?

In contrast to limit values, with which compliance is mandatory at a given point in time, target values are “softer” thresholds which have been determined with the objective of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole. Compliance with these target values is required in a specific time frame which is considered over the long term. The Directive also includes a target value of this kind for ozone, which is known as a secondary air pollutant, and is formed by precursor substances in the atmosphere, and whose

Table 2

Comparison of the ambient air and occupational exposure limit values and indoor reference values for NO_2

	EU ambient air limit values	Occupational exposure limit values	Indoor reference values
Long-term values	40 µg/m³ Annual average	–	40 µg/m³ Annual average[a]
Short-term values	200 µg/m³ Hourly average[c] 400 µg/m³ Alert threshold/ 3 hourly average[b]	–	80 µg/m³ Precautionary value/ one-hour measurement 250 µg/m³ Danger value/ one-hour measurement
Work shift	–	950 µg/m³ 8 hours on 5 days	–
Protects	**Population as a whole**	**Workers at specific workplaces**	**Population as a whole**

[a] The long-term reference value is based on the threshold value of the World Health Organization, which is the same for ambient and indoor air.
[b] Measurements over the course of three successive hours.
[c] Should not be exceeded more than 18 times per year.

concentration can therefore only be influenced by local measures to a limited extent. Compliance with the target values for ozone should be achieved on the basis of a sustainable, large-scale reduction of the ozone precursor substances.

Where is the air quality assessed?

The air quality assessment takes place for the whole of Germany. In this respect, the whole of Germany is divided up into agglomerations and other air quality zones, both summarized in the term "air quality zones" hereafter. By definition, an "agglomeration" is an urban area with a population of more than 250,000 inhabitants or, if 250,000 inhabitants or fewer live in the area, with a population density per square kilometre which is to be determined by each Member State.

With which methods is the air quality to be assessed?

The way in which air quality is to be assessed depends on the load of air pollution with individual pollutants in the air quality zones. If the load of air pollution for a pollutant exceeds the upper assessment thresholds which have been determined in the Directive, the furthest-reaching measurement obligation exists, with several measuring stations and a high degree of temporal coverage. The number of measuring stations to be operated also depends on the population in the air quality zone. In the case of concentrations below this assessment threshold the measurement obligation is reduced, and supplementary model calculations and orientating measurements with a lower temporal coverage can be applied. If the concentrations are below the lower assessment threshold, which is a long way below the limit value, the measurements can be abandoned, with the use of model calculations, derived values from emission inventories or estimation methods only being necessary. In certain federal states, the concentration of sulphur dioxide and carbon monoxide is already only assessed with the results from model simulations. For this purpose, chemistry transport models (CTM) are usually used. These models combine three key components: emissions of air pollutants and their precursor substances, the transport processes of air pollutants (meteorology) and chemical processes that take place between the transported air pollutants. In this way, the air pollutant concentration is calculated on the basis of emissions and meteorology data with CTMs.

The upper assessment threshold for NO_2 amounts to 80 % of the annual limit value, i. e. 32 µg/m³. In the agglomeration of Berlin, this assessment threshold is exceeded. With a population of approximately 3.6 million, the operation of at least seven measuring stations is therefore necessary, which measure the NO_2 concentration 24 hours a day, 365 days a year. If the load of air pollution in Berlin falls below the threshold of 32 µg/m³, the number of measuring stations can be reduced to just three. In Munich, which has a population of just under 1.5 million, the minimum number is four and/or two NO_2 measuring stations.

The minimum requirements do not prevent the use of further measuring stations. The use of more measuring stations results in an improved data basis, which cannot be a disadvantage in terms of the protection of human health. In this context, Berlin has 16 NO_2 measuring stations rather than the minimum of seven actually required, six of which are traffic-orientated.

Location of the measuring stations

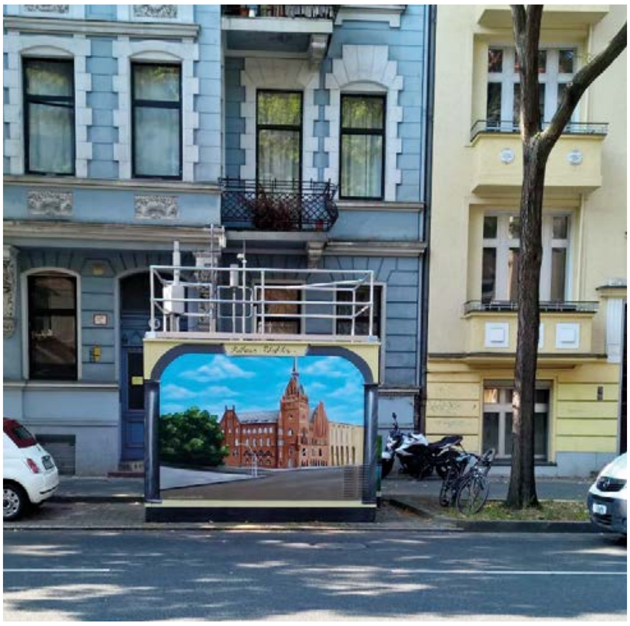
Since the basic principle of the Air Quality Directive is to safely comply with the limit values for the protection of human health everywhere, the measuring stations must be located in the interests of detecting the highest concentrations to which the population is exposed either directly (time spent in the vicinity of roads, for example) or indirectly (through home ventilation, for example). For pollutants such as nitrogen dioxide which primarily come from road traffic, that means: measuring stations at busy roads (traffic-oriented measuring stations). The measurement data from these stations should therefore be representative for a road section of at least 100 metres. Since June 2010, as far as possible, with the positioning of traffic-oriented measuring stations, the distance from the edge of the carriageway should not be more than 10 metres, and the distance to the nearest junction should be at least 25 metres. In addition to this, disruptive factors (such as trees and balconies), safety, accessibility, power supply and telephone lines, the visibility of the measuring stations in the vicinity, the safety of the general public and of the operating personnel must also be taken into account when deciding the location. To prevent the direct intake of exhaust emissions that are not mixed with ambient air, the measuring inlet at which the air to be tested is taken in should not be installed in close proximity to exhaust pipes. The air sampling should therefore take place at a height of 1.5 to 4 metres.

In addition to the requirement to measure at the place of highest exposure, it is also necessary to collect data which is characteristic for the load of air pollution on the population as a whole. This takes place at measuring stations in typical residential urban areas which are known as background urban measuring stations. The air quality is also monitored in rural areas, a long distance from the sources of pollution.

Why do discretionary powers apply to the location of traffic-oriented measuring stations?

To find the location with the highest degree of air pollution in a conurbation or a town, the authorities in the federal states complete what are known as screening procedures. For this purpose, model simulations of the pollution levels, sample-based measurements or ongoing measurement programmes are used. Long-term experiences in the monitoring of air quality and discussions with the affected local authorities also help to find the location with the highest load of air pollution. Once the location with the highest load of air pollution has been found, it is necessary to plan the installation of a measuring station to house the measuring equipment. Depending on the scope of the measurement, such measuring stations have different dimensions (width of 1–2 metres, length of 2–3 metres and height of approx. 2.40 metres).

In agreement with the local authority, it is necessary to find a location where safety and accessibility of the measuring stations is ensured for the maintenance personnel, but also one at which the safety on the road, footpath or cycle path is not put at risk. Power and telephone lines must also be available, and the above criteria should be fulfilled as far as possible. In practice, the final location of a traffic-oriented measuring station is frequently a compromise between an ideal location and one which is achievable. This compromise does not place the utility of the measuring station for the assessment of the air quality in question. It usually finds reflection in a fluctuation range of the concentration values in a low single-digit µg/m³ range. Particularly, on narrow roads with high buildings – also known as “road canyons” – it is not always possible to access the location with the highest load of air pollution with the use of measuring stations. In such cases, a passive measuring process is used for nitrogen dioxide. The small tubes of the passive collectors do not require any electricity and can be attached to existing street light masts, for instance.



Schildhornstraße air quality measuring station in Berlin-Steglitz

The bottom line: the discretionary powers are conceived to take the locations with the highest load of air pollution into account, rather than to exclude them.

An initial inspection of the measuring locations in North Rhine Westphalia by TÜV Rhineland[9] demonstrated compliance with the statutory requirements.

It also makes sense to continue operating older measuring stations that no longer meet with the location criteria for the current directive. Only in this way is it possible to achieve series of measurements that extend over many years. With these series of measurements it is possible to document the development of the air quality, and in some cases, all the way back to the 1970s.

Standardised measurement techniques

The Directive also determines the measuring processes which have to be used in order to verify the compliance with the limit values. The so-called reference methods are set out in DIN EN standards. The concentration of nitrogen dioxide for example, must be determined with the reference method according to DIN EN 14211:2012 issued in November 2012, “Ambient air – Standard method for the measurement of the

9 https://www.lanuv.nrw.de/umwelt/luft/messstellenueberpruefung/

concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence". With this procedure, hourly NO_2 values are determined throughout the year, enabling verification of compliance with both the hourly limit value and the annual limit value. If other methods are used, it is necessary to demonstrate and document to the EU Commission that equivalent results can be achieved with these methods. The passive collectors that are used in order to measure nitrogen dioxide do not correspond to the reference method; their degree of equivalence to the reference method is continuously verified and demonstrated by the operator of the measuring network, however. In this context, it is necessary for the annual average result to be equivalent to the reference method. In practice, both measuring processes are used simultaneously at several air measuring stations. Passive collectors deliver fortnightly or monthly values with which it is only possible to monitor the compliance with the limit threshold value.

Data quality objectives and quality assurance

In addition to the use of reference methods, the Directive also stipulates the data quality requirements. In this respect, in the case of fixed measurements – i. e. measurements which already are to be completed for a load of air pollution which is slightly below the limit value – at least 90 % of the time in a calendar year has to be covered by valid measurements. For gaseous air pollutants, the uncertainty of the measurements[10] may not exceed 15 %, and for particles, 25 %.

The authorities in the federal states which operate the air measurement networks must also have a quality assurance and quality control system. This must also include the regular servicing of the measuring equipment to ensure their continuous precision. These systems will be inspected at least once every five years by the national reference laboratories. The national reference laboratories are accredited for the reference methods of the EU Directive according to EU-wide processes and partake in EU-wide quality assurance programmes.

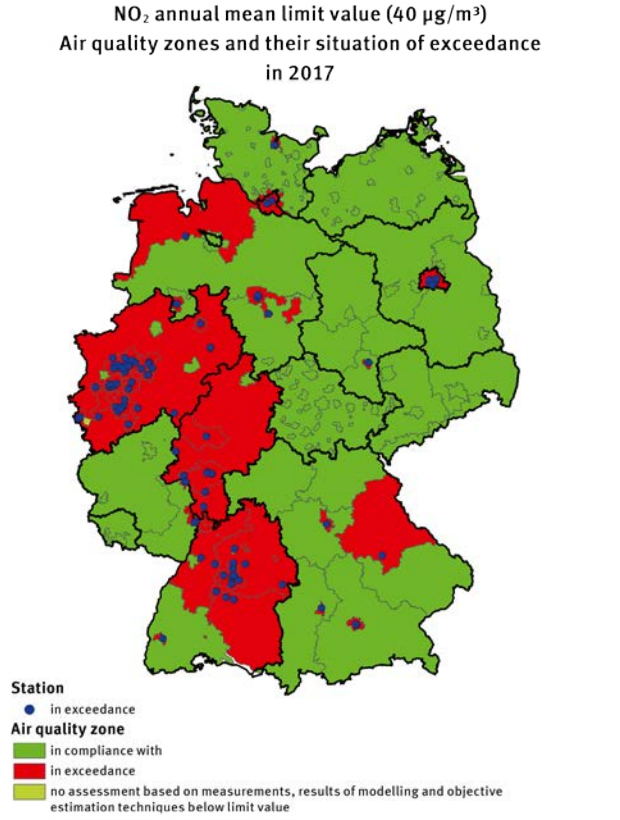
Air quality monitoring

Compliance with the limit values is verified with measurements at each measuring station and possible model simulations. Before this inspection, contributions from natural sources such as Sahara dust or dust from volcanic eruptions can be eliminated. Contributions from grit and salt which is spread in the winter can be subtracted from particulate matter (PM_{10}).

For the final assessment, all the data are aggregated so that they can be compared with the respective limit value. In this respect, the fulfilment of the data quality goals is also verified and measurements which fail to fulfil the required quality are discarded. Annual average values e.g. are calculated from hourly values for the purpose of complying with an annual limit value. In doing so, all the measuring stations[11] in each air quality zone are drawn on and

Figure 13

Map of the air quality zones for nitrogen dioxide and their classification for the year 2017



Source: German Environment Agency (UBA) 2019

10 The measurement uncertainty states the level of certainty for the actual value of the measured value to be achieved. Without the measurement uncertainty, there is no true value.

11 In this respect, "all measuring stations" means all of the measuring stations that have been chosen for assessing air quality as defined in the EU Air Quality Directive.

verified individually. The highest single value in an air quality zone then determines the classification of the air quality zone either as "limit value complied with" or "limit value exceeded". Therefore, if a pollutant is measured at seven measuring stations in an air quality zone and the limit value for this pollutant is only exceeded at one station, the air quality zone is assessed as "limit value exceeded" and reported to the EU Commission.

If a limit value for a pollutant is exceeded in an air quality zone, the responsible authorities in the federal state are required to draw up an air quality plan.

In air quality zones in which the airborne sulphur dioxide, nitrogen dioxide, particulate PM_{10}, particulate $PM_{2.5}$, lead, benzene and carbon monoxide values are lower than the respective limit values, the competent authorities shall endeavour to maintain the best ambient air quality which is consistent with a sustainable development and to take this objective into account in all their planning of relevance to air quality.

If the limit values are exceeded: creating air quality plans is obligatory

Air quality plans aim to ensure that the exceeding of a limit value is kept as brief, and its extent is kept as limited as possible. To this end, it is necessary for the air quality plan to contain appropriate measures to permanently reduce the rates of air pollution and ensure the protection of sensitive sections of the population and the protection of children. If air quality plans have to be drawn up and implemented for several pollutants, the responsible authorities are required to create and implement an integrated air quality plan for all the respective pollutants. Towns and municipalities can also apply urban and regional planning measures in the air quality plan. Many local authorities, for example, have decided to create "low emission zones", to build bypasses or to set up urban logistics centres. Numerous towns and municipalities have laid down the requirements for an environmentally-friendly form of public transport – such as the mandatory procurement of buses with particulate filters – when placing tenders for public transport services.

Before an air quality plan is drawn up, the "exceedance event" is analysed first. The analysis consists of the investigation into the size of an area and/or the length of a section of road over which the exceeding of the limit value extends, how many people are affected by the exceeding of the limit value, and which emission sources have contributed to the exceeding of the limit value and with what contribution. This analysis forms the basis for including and implementing appropriate and effective measures in the air quality plan. All of the air quality plans drawn up in Germany have a time frame of several years. Plans with short-term measures, for cases in which the alert thresholds are exceeded for example, do not exist in Germany, as the alert thresholds for NO_2 and SO_2 are reliably complied with throughout Germany and short-term measures regarding ozone are not effective.

Notification of the general public

The responsible authorities in the federal states inform the general public about the current ambient air quality and the air quality plans. The provision of this information must take place free of charge and via easily accessible media. All the authorities in the federal states provide this information on their websites[12]. If the information or alert threshold for ozone is exceeded, the authorities in the federal states also inform the general public via the media. In addition to the information which is updated daily, the authorities in the federal states also publish annual reports containing a summarised presentation and assessment of cases in which limit values were exceeded as well as the target values, long-term goals and information thresholds. In addition to the information provided by the authorities in the federal states, the Federal Environment Agency publishes air quality data which is updated several times a day, and provides summary of all the air quality plans and low emission zones[13].

12 https://www.umweltbundesamt.de/themen/luft/messenbeobachtenueberwachen/luftmessnetze-der-bundeslaender
13 https://www.umweltbundesamt.de/en/topics/air/particulate-matter-pm10/low-emission-zones-in-germany

Reporting obligations to the EU Commission

All of the data collected in the federal states in accordance with the EU Directive is sent to the Federal Environment Agency (UBA), where it is collated for Germany, before being transferred to the European Environment Agency (EEA). The EEA has been given responsibility for the operation of the data exchange portals by the EU Commission[14].

For the pollutants of NO_2, CO, PM_{10}, SO_2 and ozone, the federal states send the UBA current, unaudited data from the automatic measurements several times a day, which are replaced by data which has been subject to a basic audit each month. On the 31st May of each year, the authorities in the federal states send the final audited data of the previous year for all substances covered by the Directive to the UBA. This includes the measurement data which is subject to a sophisticated laboratory analysis, such as data from passive collectors. On the basis of this data and the information on the air quality zones, assessment methods and site-specific assessment results (limit value complied with or exceeded), the UBA sends reports to the EU Commission and the EEA on air quality in Germany on 30th September of each year.

Infringement proceedings

According to the EU treaties, the EU Commission is able to launch legal action against EU countries which fail to implement EU law in the form of infringement proceedings. The Commission may refer the matter to the European Court of Justice, which may order[15] the payment of fines in certain cases.

In June 2015, the EU Commission launched infringement proceedings against Germany because of its long-term exceedance of the air quality limit values for nitrogen dioxide. On 17.5.2018, the Commission filed a lawsuit with the Court of Justice of the European Union against Germany and other EU Member States due to non-compliance with the limit values for nitrogen dioxide stipulated in the EU Directive and for failing to take any appropriate measures in the past.

14 http://aqportal.discomap.eea.europa.eu/products/data-viewers/

15 https://ec.europa.eu/info/law/law-making-process/applying-eu-law/infringement-procedure_en

Further information on the topic

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

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:
http://www.umweltbundesamt.de/luft/entwicklung.htm

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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