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Air Quality 2020

Preliminary Evaluation

German Environment Agency

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The information presented in this brochure reflects 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 2020: 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.

Figure 1

Overview of the monitoring stations in Germany

Source: German Environment Agency (UBA) 2021

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).

2 Provisional Nature of the Information

This evaluation of air quality in Germany in the year 2020 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 1st February 2021. Due to the comprehensive quality assurance within the monitoring networks, the final data will only be available in mid-2021.

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 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.

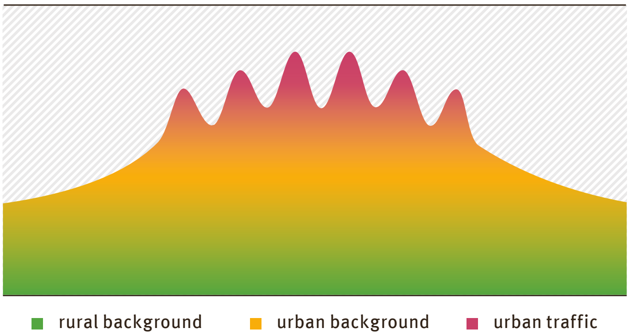
4 Influence of Environmental Conditions

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 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

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).

II Particulate Matter: Further Reduction of Pollution

1 PM_{10} – 24-hour Values

Like in the year before, none of the 380 stations measured PM10 24-hour values over 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 (up to more than half of those stations in 2006). Since 2012 the shares of traffic stations with exceedances has been below 10 percent, and no exceedances at background stations have occured anymore (see figure 3).

The recommendations of the World Health Organization (WHO[2]) were not complied with at 12 percent of all air monitoring stations, and therefore much less than in the year before (37%).

Figure 4 shows how many days were recorded on which the limits were exceeded, on average, per month. In this case, 2020 is compared with the previous year (2019) and an extended reference period (2005–2019). It can be seen that in 2020

EU limit value

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

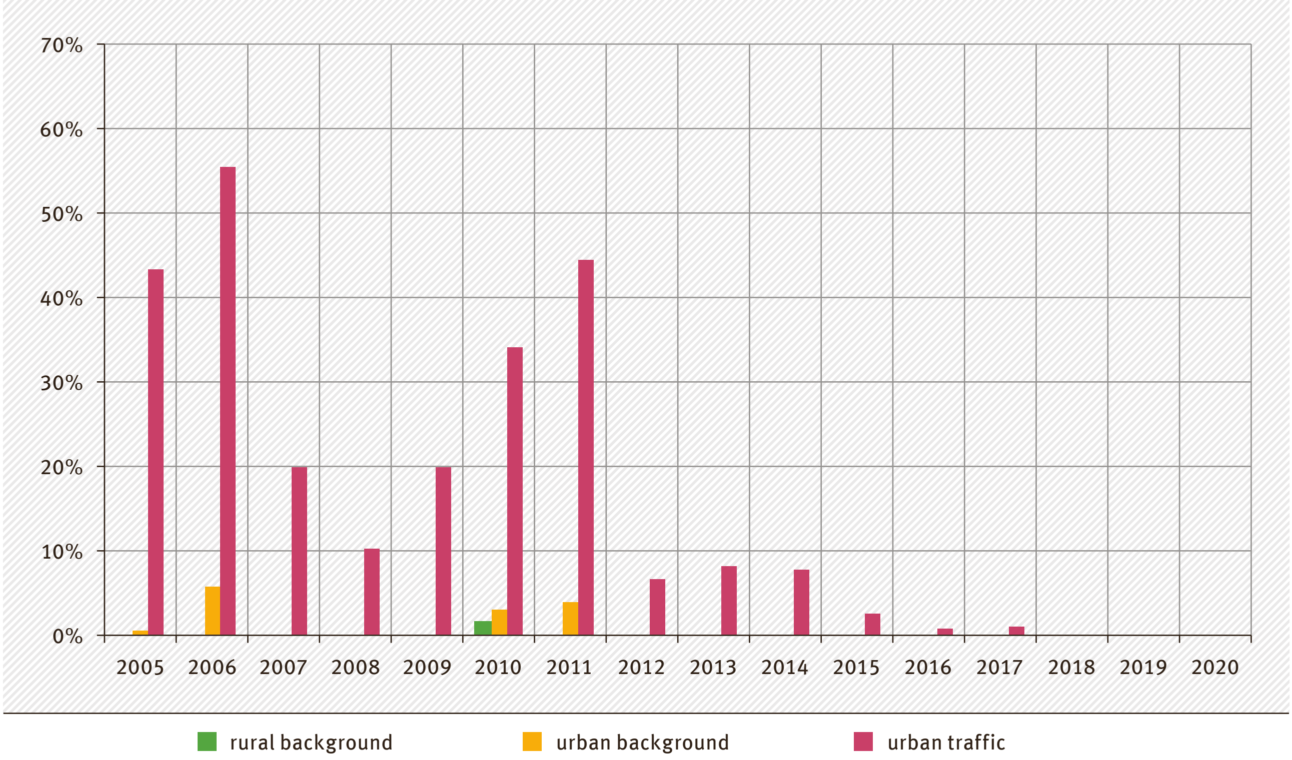
WHO recommendation

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

2 WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide, Global update 2005: http://www.euro.who.int/en/health-topics/environment-and-health/Housing-and-health/publications/pre-2009/air-qualityguidelines.-global-update-2005.-particulate-matter,-ozone,-nitrogen-dioxide-and-sulfur-dioxide

Figure 3

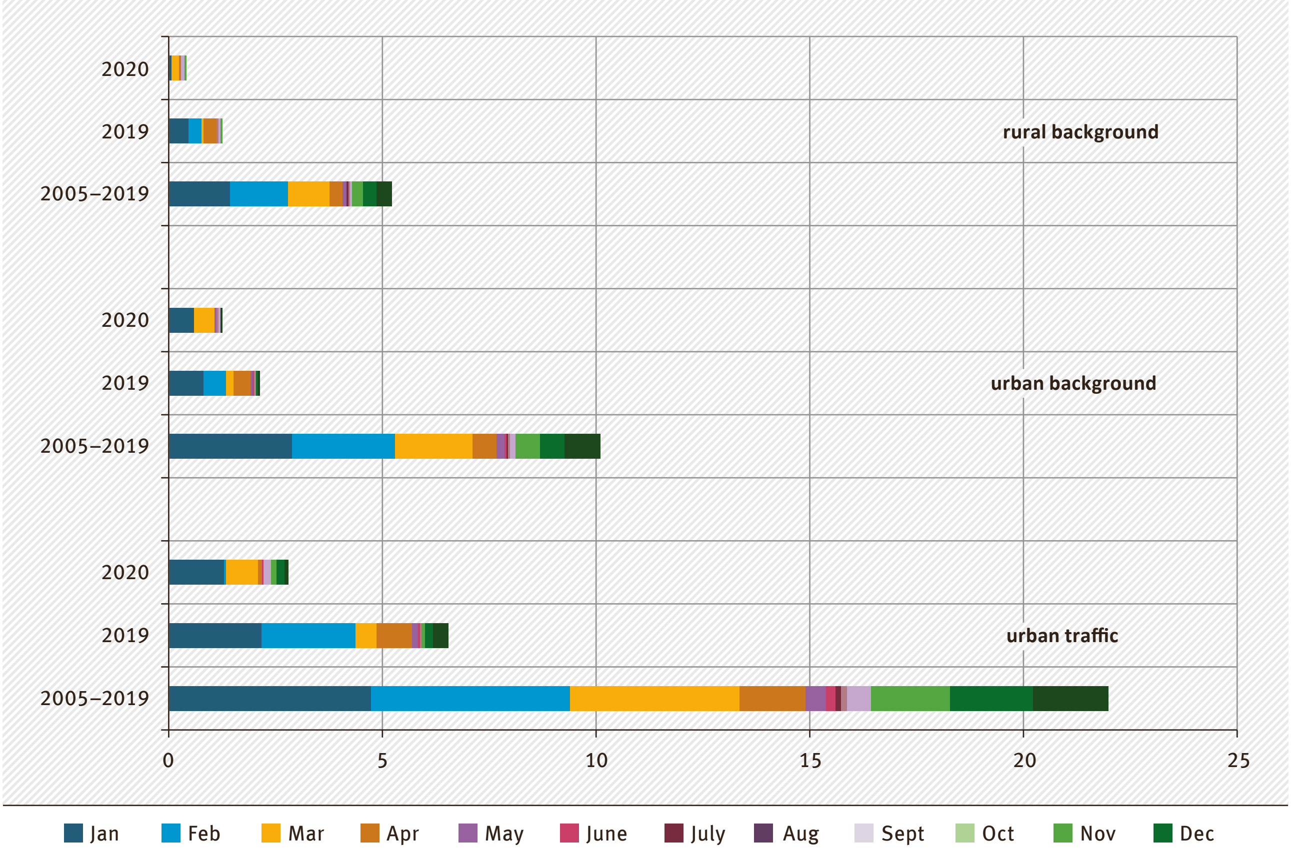
Percentage share of air monitoring stations exceeding the PM_{10} limit value
for the 24-hour values in the corresponding pollution regime, time frame 2005–2020



Source: German Environment Agency (UBA) 2021

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 2020, 2019 and the period 2005–2019.



Source: German Environment Agency (UBA) 2021

there were only very few days on which the limits were exceeded, most of them occurred in January and March. This extraordinarily low number of exceedance days goes along with a very mild and wet winter: Both January and February showed, besides April and August, highest positive temperature differences[3]. Since the beginning of recording, this winter has been the second warmth[4]. Even though in 2020 no episodes with high particulate matter concentrations were observed, with weather conditions like low temperatures and stable high-pressure area exceedances of PM10 limit values for the 24-hour values cannot be excluded in the future.

2 PM_{10} – Annual Mean Values

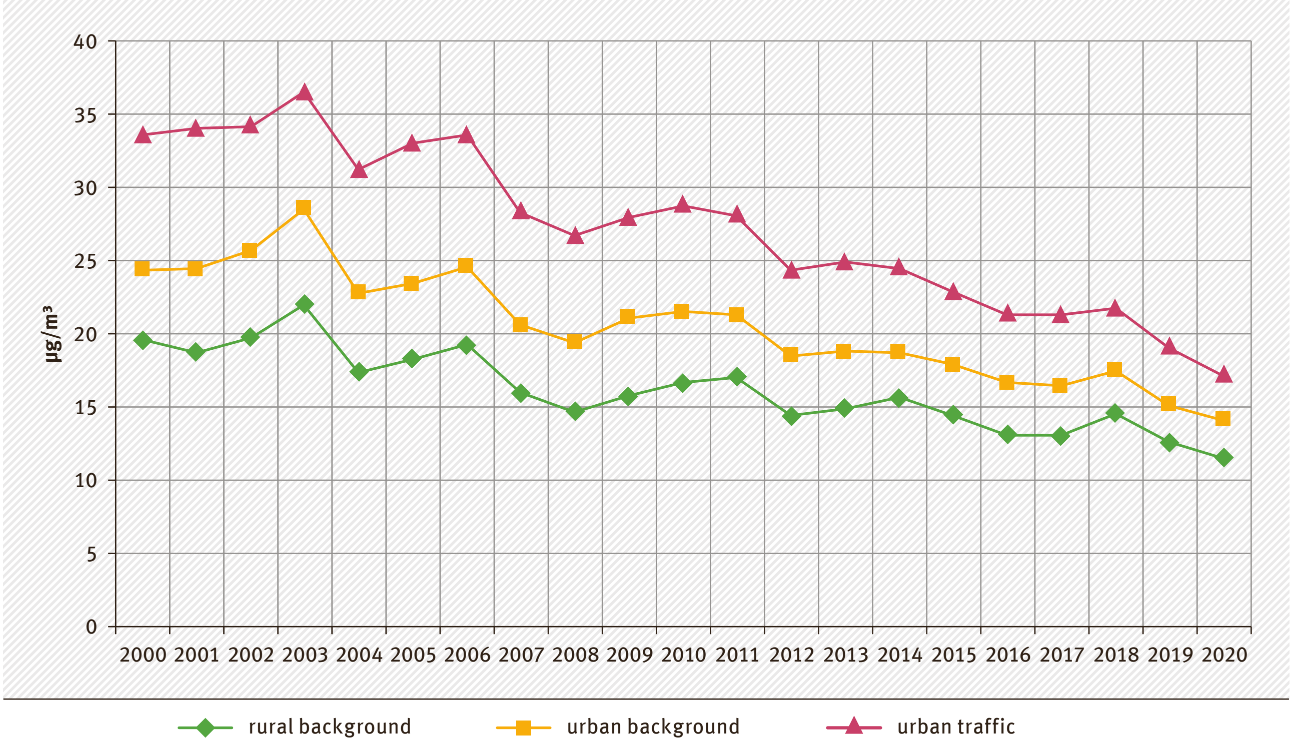
In 2020 the decreasing trend of the mean PM_{10} pollution continued. 2020 was the year with the lowest level of pollution compared to the considered period since 2000 (Figure 5). Accompanied by the regional falls in the PM_{10} emissions, the annual mean PM_{10} values also show a clear fall in all pollution regimes throughout the entire period of observation. 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. Only 5 percent of the air monitoring stations recorded values that infringed the air quality guidelines proposed by the WHO. All of these air monitoring stations were in urban traffic locations.

3 Press release of the German weather service DWD, 2019: https://www.dwd.de/DE/presse/pressemitteilungen/DE/2019/20191230_deutschlandwetter_jahr2019_news.html?nn=16210

4 Press release of the German weather service DWD: https://www.dwd.de/DE/presse/pressemitteilungen/DE/2020/20200228_deutschlandwetter_winter2019_2020.html?nn=714786

Figure 5

Development of the annual mean PM_{10} values
via selected air monitoring stations in the corresponding pollution regime, time frame 2000–2020



Source: German Environment Agency (UBA) 2021

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 2020, 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 6). This figure shows concentrations at urban background and traffic stations, which are usually higher polluted, at the same level than rural background stations some years ago. However, the stricter recommendations of the WHO (10 µg/m³ as the annual mean value) were not complied with at 13 per cent of about 160 measuring stations, which were less exceedances than in 2019 (56%). Furthermore, the WHO recommendation is that the 24-hour $PM_{2.5}$ value should not exceed 25 µg/m³ more than 3 times a year. This recommendation was not complied with at most air monitoring stations (86%). The EU Air Quality

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

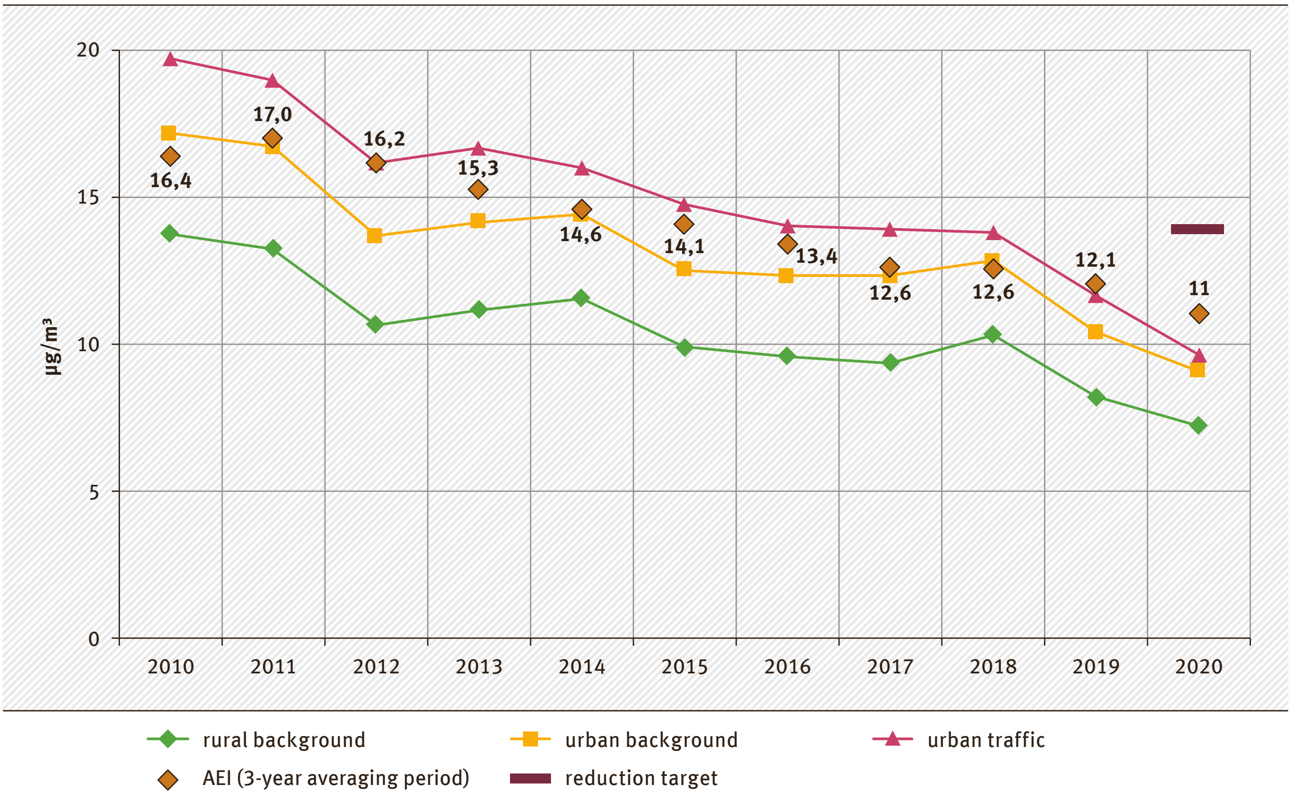
the annual mean $PM_{2.5}$ value must not exceed 25 µg/m³.

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 2010–2020



Source: German Environment Agency (UBA) 2021

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. Even with not all of the necessary data available it is clear: Germany will meet the reduction target of 15 percent in 2020. The AEI for 2020 (average value of the years 2018, 2019 and 2020) is 11 µg/m³ with those data available at the moment, and therefore well below the required 13,9 µg/m³.

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: Hardly any Exceendances

1 NO_2 – Annual Mean Values

Nitrogen dioxide is measured at about 400 automatic monitoring stations across Germany. In addition, about 140 passive collectors measure nitrogen dioxide. Most of the data of the passive collectors is not yet available and thus not included in this preliminary evaluation. Taking into account all measurement data, available for UBA at 1st February 2021, 2 percent of the air monitoring stations in urban traffic locations exceeded the limit. 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 and thus the identical WHO recommendation in 2020 to be approx. 3 to 4 percent (Figure 7, red bars).

EU limit values

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

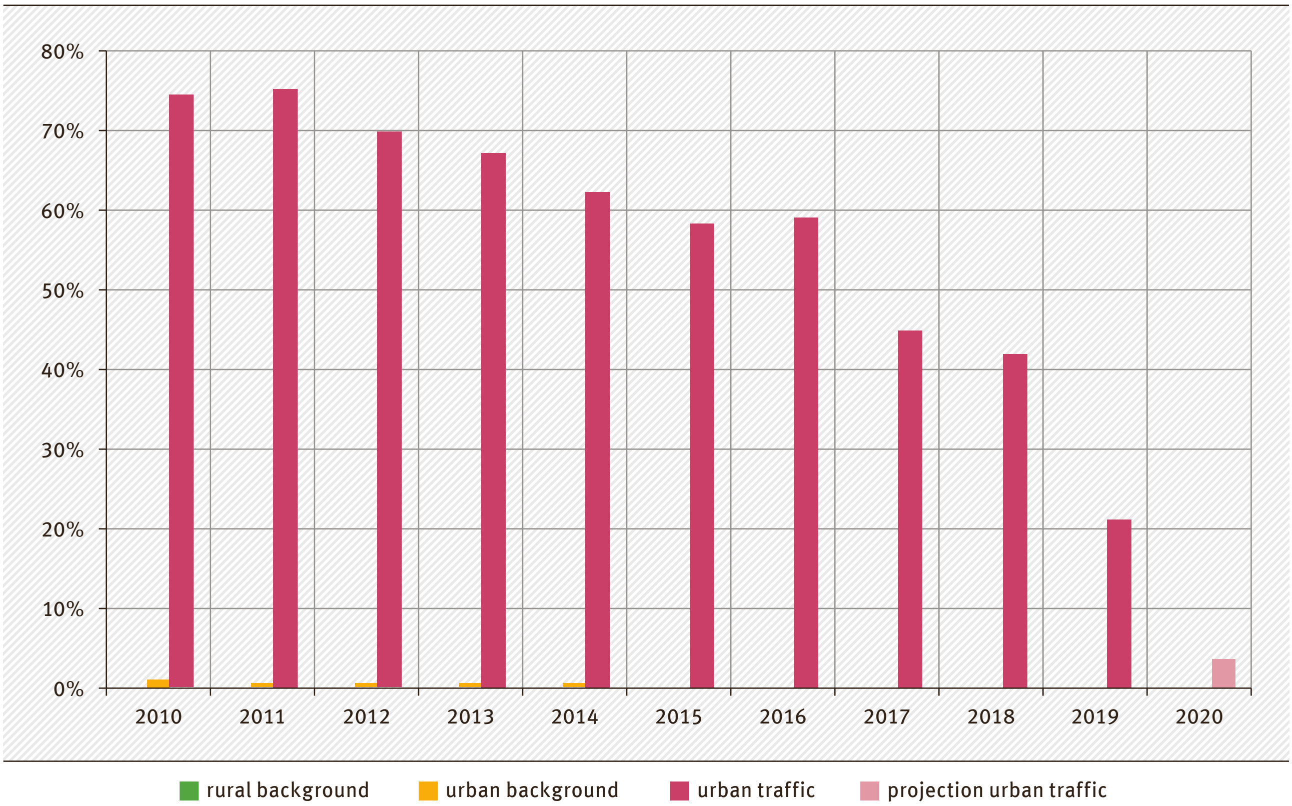
WHO recommendation

The WHO recommendation is equivalent to the EU limit value.

The nitrogen dioxide pollution shows a clear decrease in the last decade, particularly pronounced in the last few 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 due to weather.

Figure 7

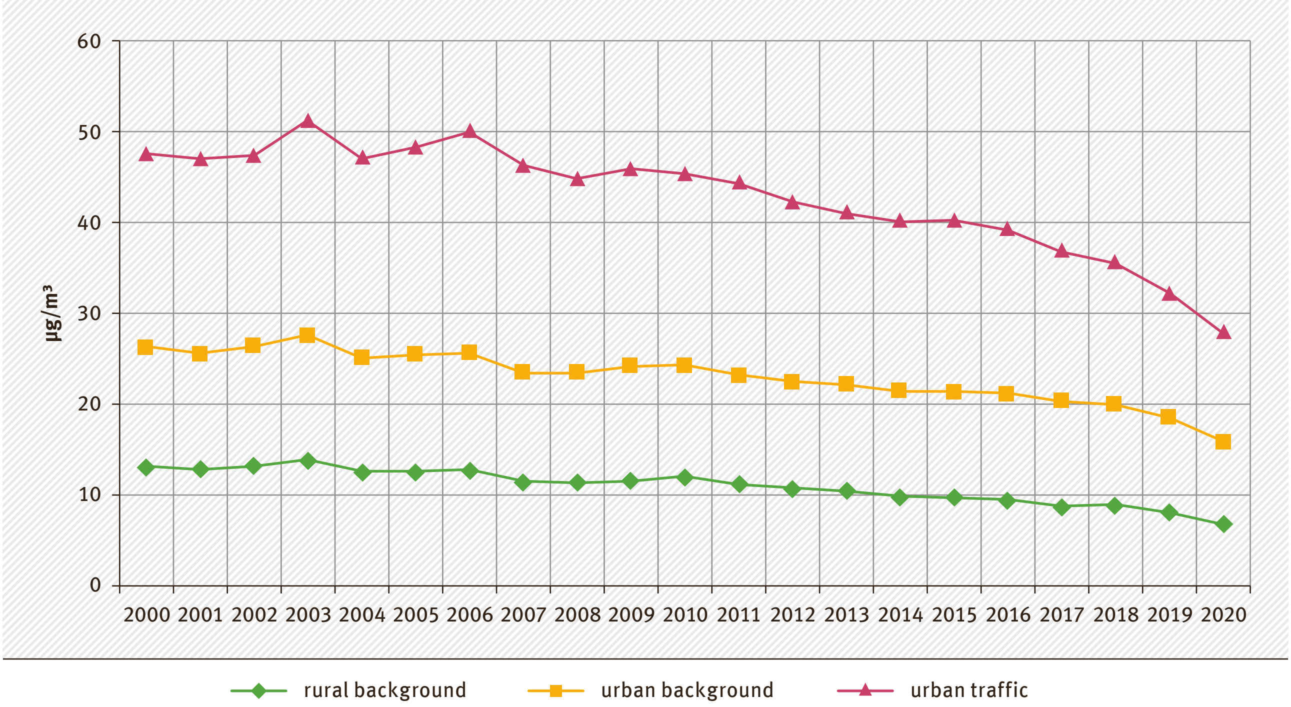
Percentage share of air monitoring stations exceeding the NO_2 limit value for the annual mean in the corresponding pollution regime, time frame 2010–2020



Source: German Environment Agency (UBA) 2021

Figure 8

Development of the annual mean NO_2 values
via selected air monitoring stations in the corresponding pollution regime, time frame 2000–2020



Source: German Environment Agency (UBA) 2021

In rural areas, which are typically a long way from the major sources of NO_2, from 2000–2020, 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 with a slight decline over the last 20 years (Figure 8, yellow curve), as it is also seen at rural background stations. In 2020, like in the previous year, the average NO_2 concentration at urban traffic air monitoring stations was well below 40 µg/m³. Thus, the trend in reduction over the last ten years continues.

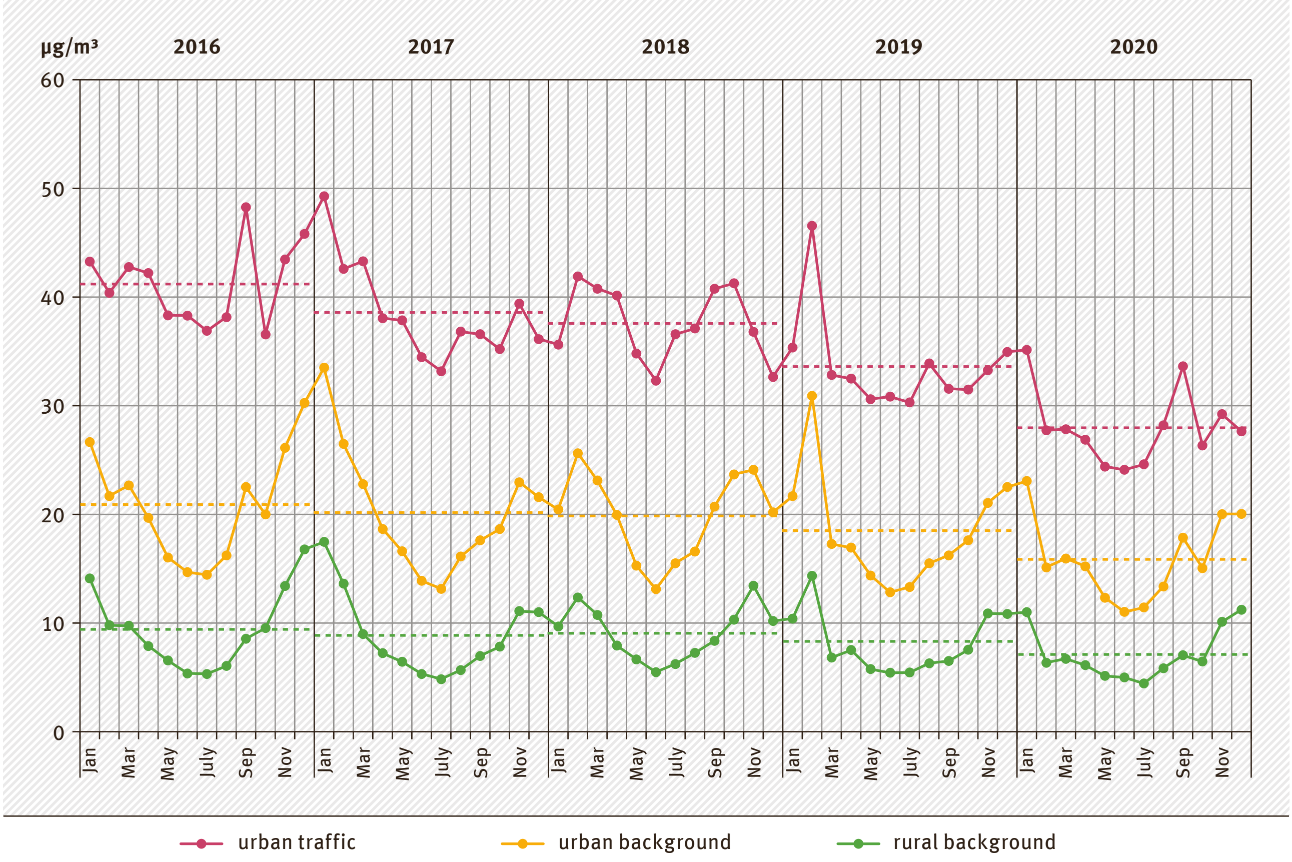
Figure 9 shows the annual variation of NO_2 in the three pollution regimes within the last five years (only stations with data in all five years). A clear decline of concentrations can be seen. Except for variations due to weather conditions, which often lead to higher concentrations in winter and lower concentrations in summer especially in the urban 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). Why the Lockdown of March and April is not reflected directly in figure 9 is explained in the special chapter starting on page 20.

In the last years, the concentrations were above 40 µg/m³ and therefore above the limit value at a large part of the stations close to traffic. This has changed now: there are only few stations with concentrations above 40 µg/m³. Figure 10 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 2021. Their position in the descending order is deduced from the data of the previous year. The pink curve shows the annual mean values of the previous year, in descending order as well. It is apparent that the values decreased not only in highly-polluted areas but also at traffic stations with median or low concentrations.

Figure 9

Medium NO_2 monthly mean values of the period 2016–2020



Source: German Environment Agency (UBA) 2021

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 2020, 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 one of about 200 air monitoring stations in urban traffic locations failed to comply with the WHO recommendation in 2020.

EU limit value

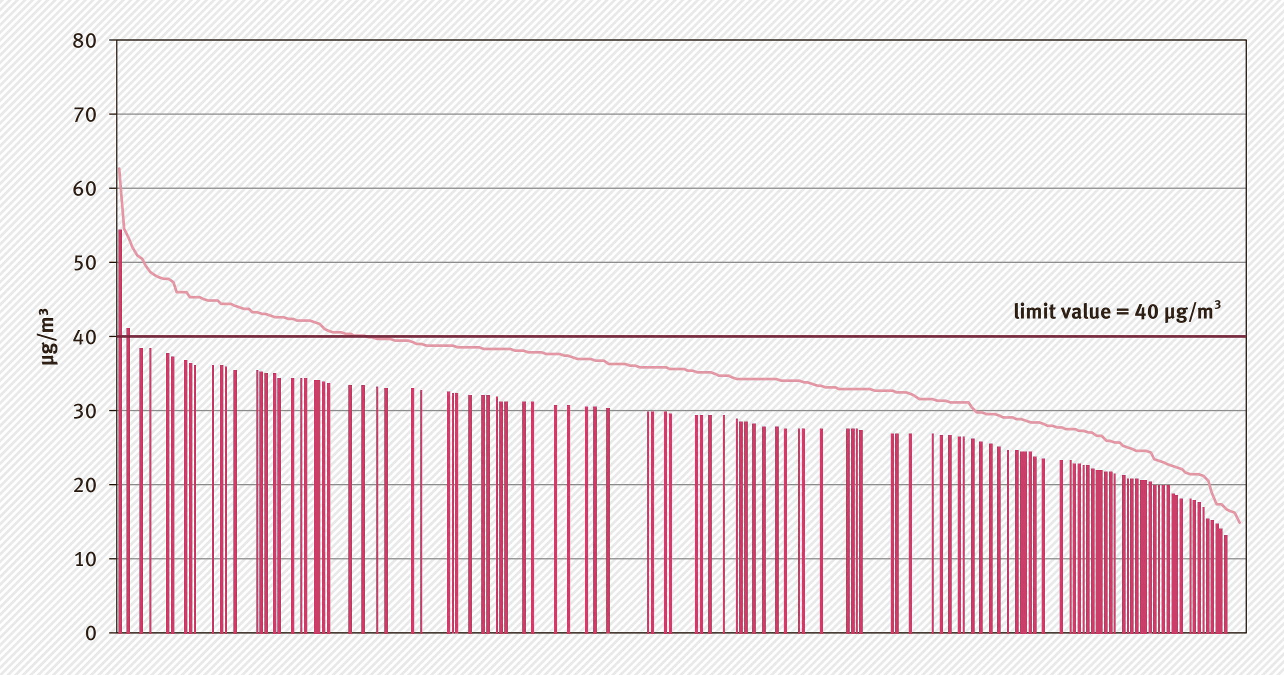
The one hour NO_2 values must not exceed 200 µg/m³ more than 18 times per year.

WHO recommendation

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

Figure 10

NO_2 annual mean values 2020
of all urban traffic monitoring stations



Bars: NO_2 annual mean values 2020 in descending order; gaps: missing data of passive collectors
Line as a comparison to the previous year: NO_2 annual mean values 2019 in descending order

Source: German Environment Agency (UBA) 2021

IV Ground-level Ozone: Less Pollution than in both Previous Years

1 O_3 – Information and Alert Threshold

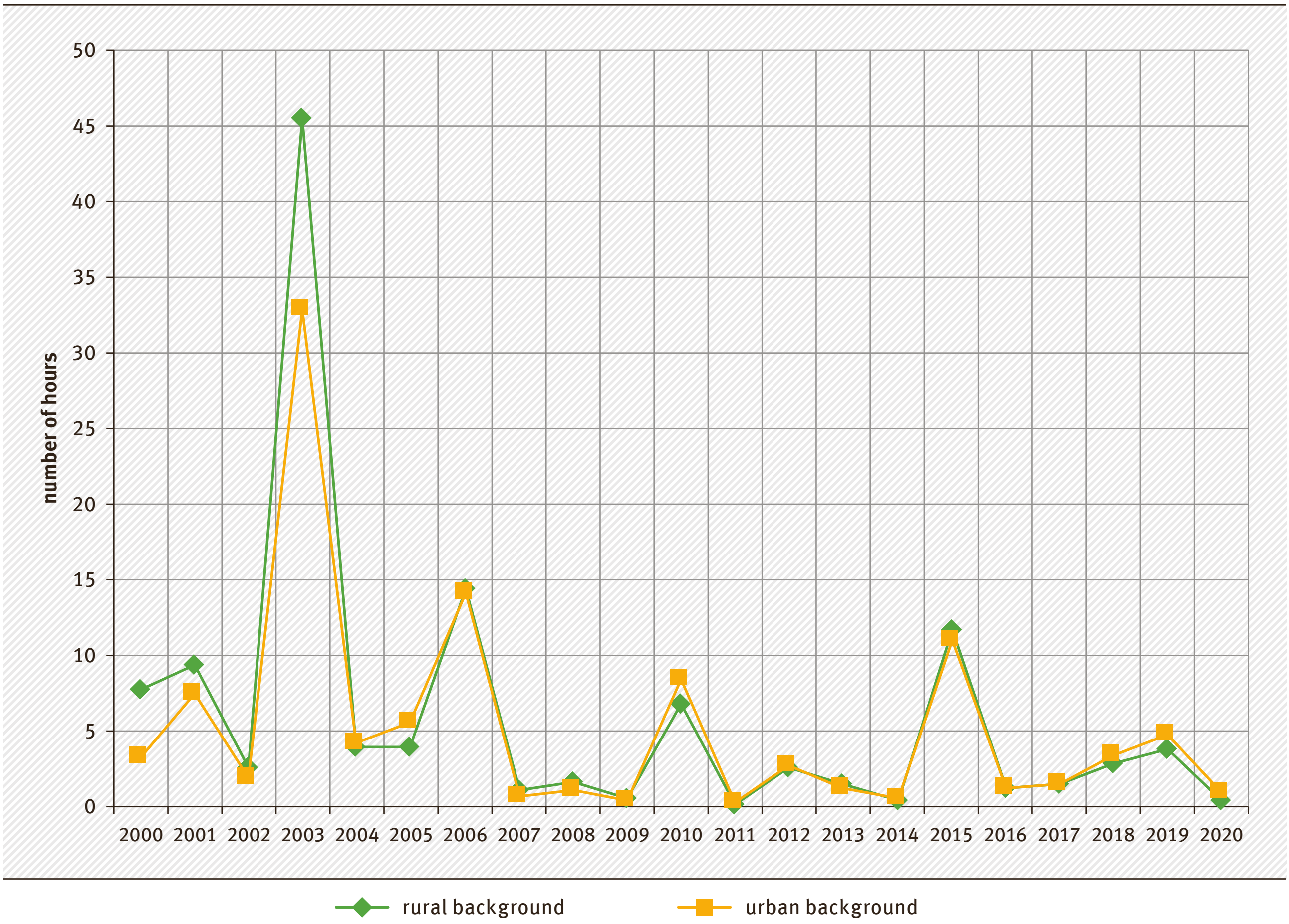
Ozone is measured at about 260 monitoring stations throughout Germany. In 2020, the highest 1-hour average value amounted to 235 µg/m³. This value is considerably lower than the previous year value (314 µg/m³). In 2020 the alert threshold of 240 µg/m³ was not exceeded. The information threshold of 180 µg/m³ was exceeded on 13 days. 2020 was a less affected year with regards to exceedances of the threshold values, compared to the last 20 years, see figure 11. 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. After the first

Figure 11

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

Average over selected monitoring stations, time frame 2000–2020



Source: German Environment Agency (UBA) 2021

summer days in April, both June and July were quite unstable. Only in August a long-lasting heat wave with temperature maxima around 35 °C occurred. Overall, the summer was too warm and too dry, and 2020 was the second warmth year since the beginning of records in 1881[5].

2 O_3 – Target Value for the Protection of Human Health

At almost all monitoring stations (=100%) 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 2020, an ozone value of 120 µg/m³, as the highest daily 8-hour average value, was exceeded on an average of 17 days per station. Compared to the time period since 2000, this value is slightly above average. In the previous year, 24 exceedance days were recorded as an average over all air monitoring stations.

Figure 12 shows the spatial distribution of the number of exceedance days in 2020 in comparison to the last five years. This figure highlights the differences between the years. In 2020 especially the south-west and west of Germany was affected by exceedances of the long-term objective, but overall Germany was less polluted than in the year before. Ozone concentration is generally lower in Northern Germany, particularly so in 2015.

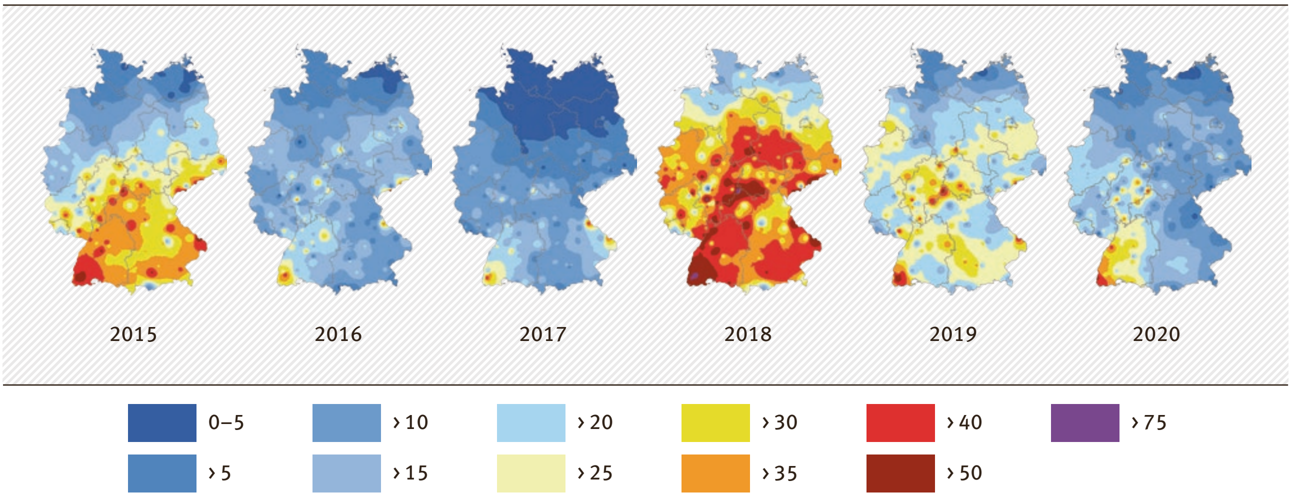
The WHO recommendation that the 8-hour average values should not exceed 100 µg/m³ was missed again at almost all stations.

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 2018 to 2020, however, 48 percent of the air monitoring stations exceeded this value on more than 25 days. This is slightly more than in the previous averaging period (42 percent). Figure 13 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.

5 https://www.dwd.de/DE/presse/pressemitteilungen/DE/2020/20200831_deutschlandwetter_sommer2020.html?nn=714786

Figure 12

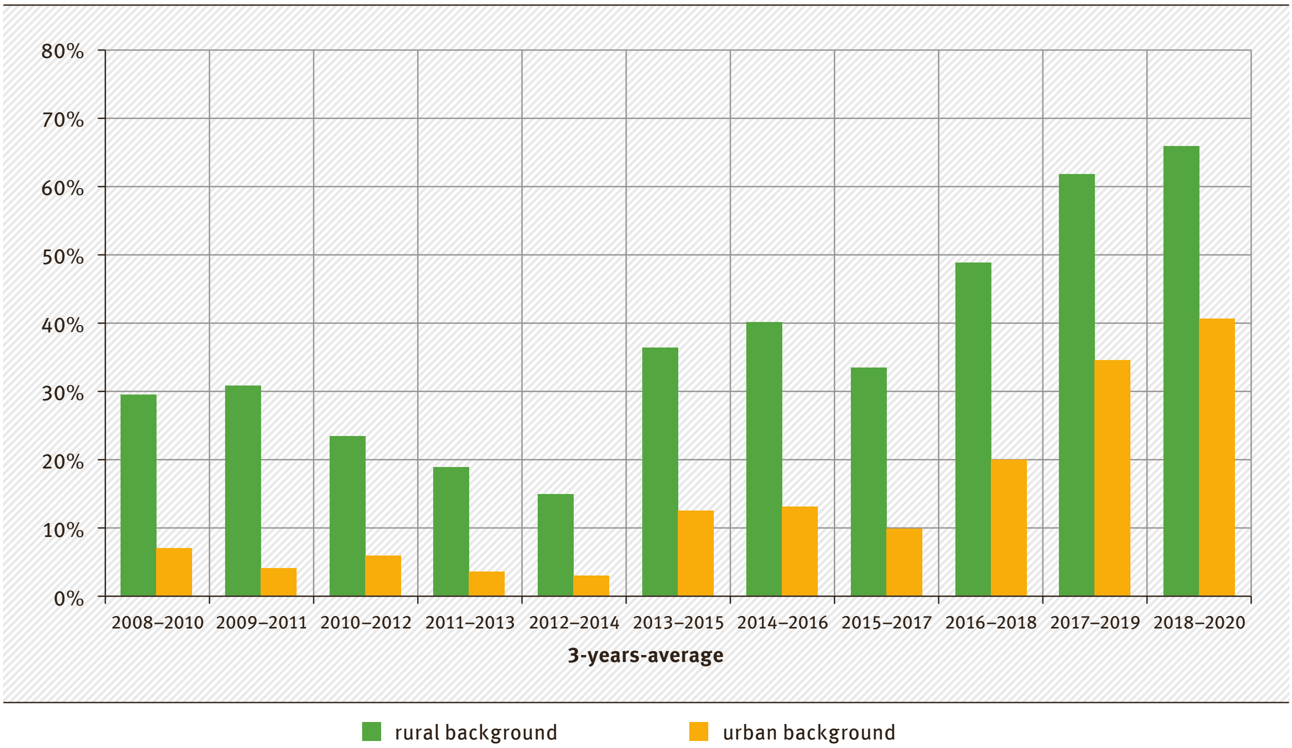
Spatial distribution of the number of days on which the long-term objective for the protection of human health was exceeded (number of days with 8-hour average values › 120 µg/m³)
time frame 2015–2020, based on station measurements and a geostatistical interpolation method



Source: German Environment Agency (UBA) 2021

Figure 13

Percentage share of air monitoring stations recording an exceedance of the target value
for the protection of human health, time frame 2010–2020 (in each case, 1-year moving average over 3 years)



Source: German Environment Agency (UBA) 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 2016 to 2020 was exceeded at 32 out of 161 air monitoring stations (= 20%, previous year: 31%).

In 2020, the long-term objective for the protection of the vegetation (6,000 µg/m³ h) was complied with at 23 monitoring stations, that is 15 percent of all stations. In both 2018 and 2019, the target value was exceeded at every station. Averaged over all rural background stations the AOT40-value in 2020 is very low in comparison to other years since 2000, and well below the value of 2018 and 2019.

New methods of 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.

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 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.

The measuring field of the UBA monitoring station Schauinsland in January 2021. Located 1.200 meters above sea level, this means a lot of additional work for the staff due to snow and ice in such winterly conditions.

V Air Quality During the Spring Lockdown

1 Introduction

Less traffic, less production, fewer pollutants: environmental pressures are decreasing as a result of the Corona crisis. In relation to the medium air, this becomes particularly visible on the basis of satellite measurements. Satellite data from the spring of 2020 show that pollution levels within the atmosphere decreased in many countries around the world.

Fig. 14 illustrates that large parts of Europe, especially hotspots such as the Po Valley, Madrid, Paris, Milan and Rome, showed a decrease in tropospheric nitrogen dioxide (NO_2) during the months of lockdown compared to the previous year. This amounted to more than 40 percent in many places (DLR2020). It is however worth noting that the satellite captures the total amount of pollutant between the ground and the measuring instrument. The concentration of pollutants varies greatly in this "column", however, and usually decreases with increasing altitude. Conclusions about air quality on the ground, i. e. where people are breathing the air, can therefore not readily be drawn.

Federal and state-wide measures to contain the Corona pandemic came into effect in Germany in March 2020. Kindergartens and schools were closed, and people began to work from home more. Beginning on the 23 March 2020, far-reaching contact bans, under which people were only allowed to leave the house if they had a valid reason to do so, were in effect nationwide. The following constraints on public life have resulted in a significant decrease in mobility/road travel during this time:

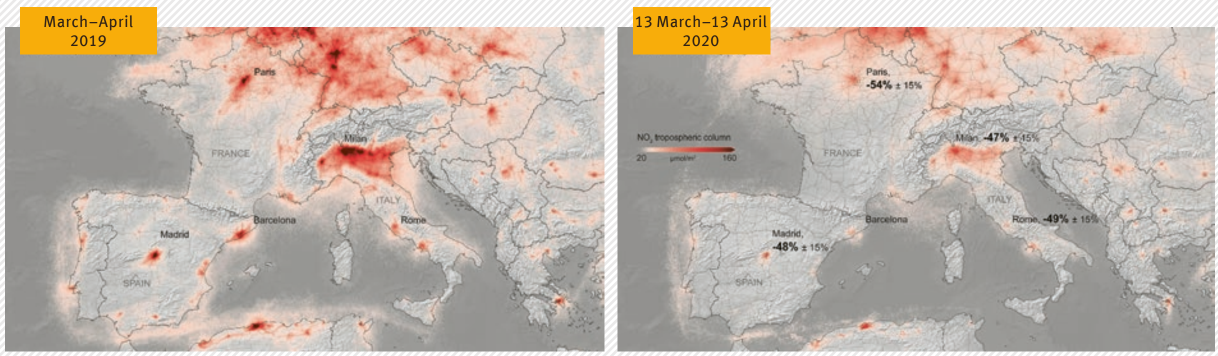
Which effects have an influence on the air quality at ground level?

The concentration of an air pollutant results from the interaction of various processes. Important factors influencing the concentration of air pollutants at a location include

- Local emissions: the release of air pollutants and precursors into the atmosphere
- Transmission: horizontal transport and vertical mixing of air pollutants in the atmosphere
- Chemical processes: chemical production, conversion and degradation of air pollutants
- Deposition: processes that remove air pollutants from the atmosphere by deposition on the ground
- Background concentration: underlying pollution at a location not in the immediate vicinity of emission sources (including from cross-border transport)
- Prevailing weather conditions
- Measuring station location on a small and large scale

Figure 14

Comparison of NO_2 levels in the total air column in Europe between March/April 2019 and 2020



Source: https://www.dlr.de/content/de/bilder/2020/02/earth-day-stickstoff-konzentration.html

- Spending time in public spaces was only permitted when alone, with one other person not residing in the same household, or with members of one's own household;
- Catering establishments, cultural and leisure facilities and personal care services were forced to close;
- Retail stores which were not necessary for daily needs were closed;
- Events, meetings, religious services, etc. were prohibited.

The following averaging periods for air quality data are examined in the following evaluations with consideration of the duration of the above-mentioned restrictions (see Tab. 1):

Table 1

Averaging periods by calendar weeks and corresponding periods with date

Averaging period	corresponds to the time period
CW1–CW4	30.12.2019–26.01.2020
CW5–CW8	27.01.2020–23.02.2020
CW9–CW12	24.02.2020–22.03.2020
*CW13–CW16	23.03.2020–19.04.2020
CW17–CW20	20.04.2020–17.05.2020
CW21–CW24	18.05.2020–14.06.2020
CW25–CW28	15.06.2020–12.07.2020
CW29–CW32	13.07.2020–09.08.2020
CW33–CW36	10.08.2020–06.09.2020
CW37–CW40	07.09.2020–04.10.2020
CW41–CW44	05.10.2020–01.11.2020
CW45–CW48	02.11.2020–29.11.2020
CW49–CW52	30.11.2020–27.12.2020

The period most affected by the lockdown measures occurred in calendar weeks 13 to 16 (March 23 to April 19).

Changes in road traffic during the lockdown period

State evaluations can be used to quantify the reduction in road traffic during the lockdown as follows:

In Berlin, the number of vehicles identified as cars and small trucks fell by 20–30 percent, while the number of medium and large trucks remained about the same. A rough estimate suggests that nitrogen oxide emissions decreased by about 15–20 percent (BE2020) on account of the observed decrease in traffic for passenger cars and small trucks. Traffic volume measurements at three locations in Hesse showed that, on average, traffic volumes decreased by approximately 30 to 40 percent, with the percentage of traffic reduction being greater on weekends than during the week (HE2020). Daily traffic volumes on the Heiligengeistwall in Oldenburg, Lower Saxony, showed a significant decrease in total traffic volume (40–50 percent), most notably for passenger cars, though the number of vans, trucks, and buses also decreased (NI2020). According to estimates from North Rhine-Westphalia, road traffic decreased by as much as 30 to 50 percent (NW2020). The counting station at Mommsenstraße/Bergstraße in Dresden recorded a 42 percent decrease in total traffic, a 44 percent decrease in car traffic, and a 25 percent decrease in delivery traffic (SN2020).

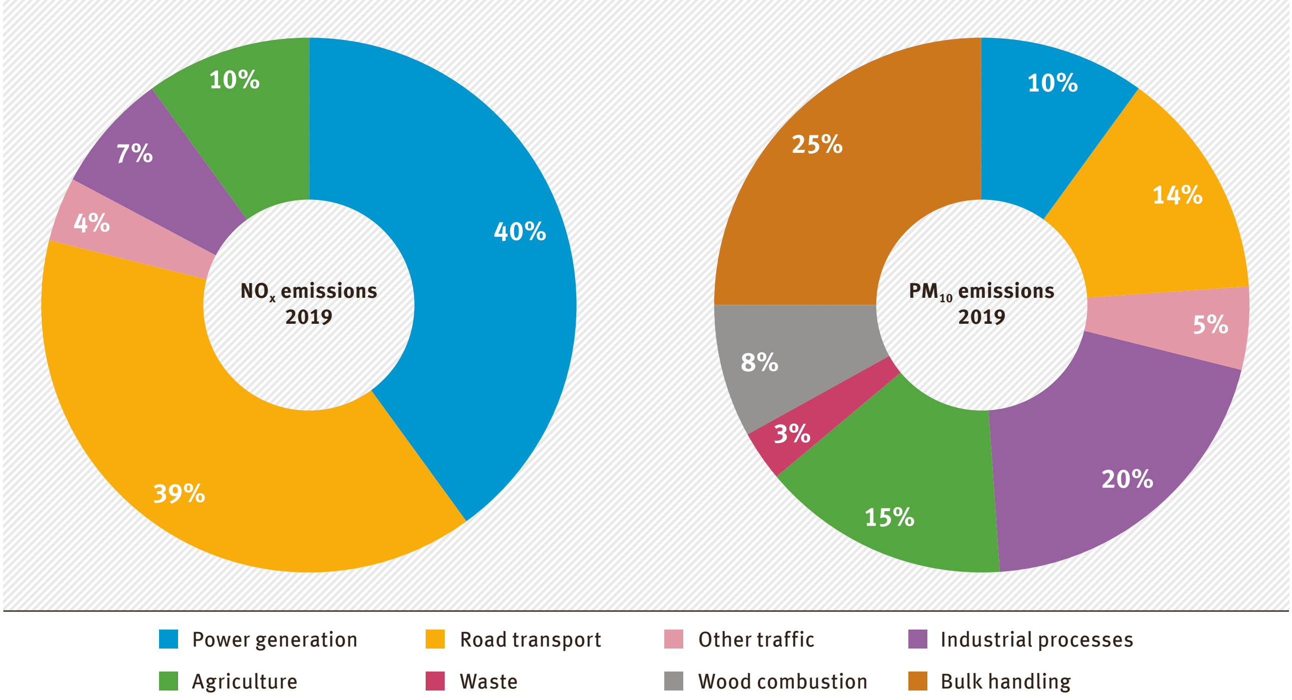
This exemplary data shows that the lockdown significantly reduced traffic, but it was not brought to a complete standstill. Buses in the public transport system and private cars were still on the road in the cities. It must even be assumed that there was an increased volume of delivery traffic at times. It can also be assumed that public transport was avoided in many cases due to the risk of infection and that the use of cars increased. Furthermore, other emission effects are also conceivable, e. g. resulting from the increased number of people working from home.

Focus on pollutants

Road traffic and power generation are the main sources of nitrogen dioxide pollution (see Fig. 15, left). Consequently, the highest NO_2 concentrations in metropolitan areas and cities are typically measured on busy roads. It was therefore to be expected that reduced traffic counts during the spring Corona lockdown would have had an impact on nitrogen dioxide levels.

Figure 15

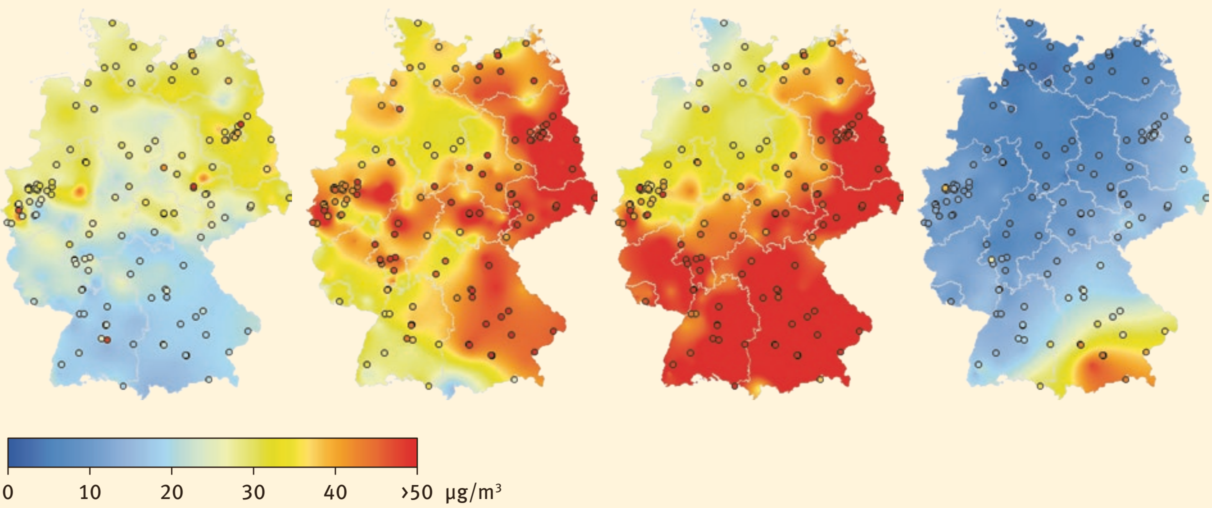
Composition of German NO_x and PM_{10} emissions for the year 2019



Source: German Environment Agency (UBA) 2021

Excursus on particulate matter (PM_{10})

Although everyday particulate matter pollution is mostly determined by local and regional sources of particulate matter, atmospheric transport processes over sometimes long distances also play an important role in this regard. This is not the case with NO_2. One such transport process occurred at the end of March 2020, when Saharan dust from North Africa reached Germany: The DWD (German Meteorological Service) shows days with a high Saharan Dust Index[6] during that time period. The areal PM_{10} maps also illustrate that this type of long-distance transport led to increased PM_{10} levels here in Germany, despite being in the middle of the lockdown period. This example demonstrates how possible lockdown-induced PM_{10} decreases can be outweighed by atmospheric influences to a greater extent than for NO_2.



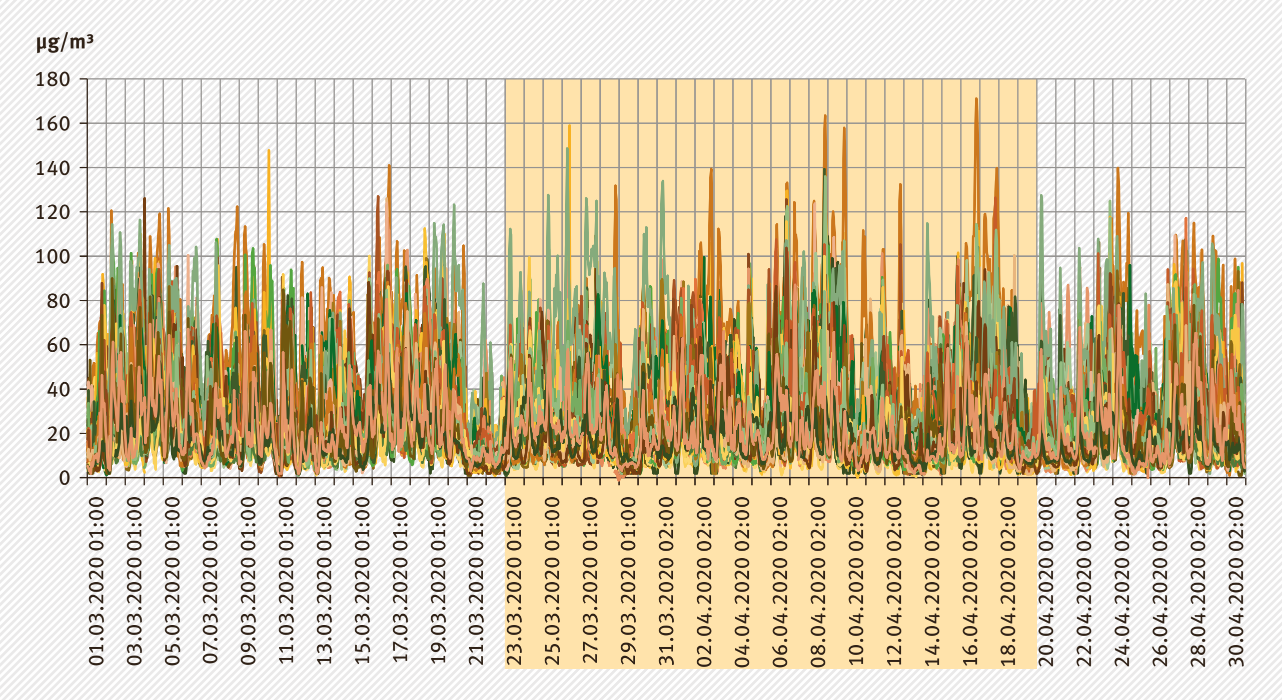
Daily mean values of particulate matter (PM_{10}) from 26–29 March 2020

Source: German Environment Agency (UBA) 2021

6 Saharastaub-Index des DWD, Quelle: https://www.dwd.de/DE/forschung/atmosphaerenbeob/zusammensetzung_atmosphaere/aerosol/inh_nav/saharastaubindex_node.html

Figure 16

Hourly NO_2 levels in March and April 2020 for all stations close to traffic. Lockdown period marked



Source: German Environment Agency (UBA) 2021

By contrast, road traffic accounts for a much smaller share of total emissions of particulate matter in Germany (see Fig. 15, right). Agriculture is another significant source of emissions, especially in the spring: When fertilising the fields, particulate matter is formed from gaseous precursors, which is then also transported into the cities by the wind. Furthermore, particulate matter can also be of natural origin – for example Saharan dust or as a result of soil erosion, forest fires and bush fires – and can be transported to Germany over long distances. Short-term reductions in only a few sources of particulate matter, for example through the lockdown, can therefore not be expected to lead to a significant reduction in concentrations. Other sources of particulate matter may even contribute to such an extent that increased concentrations of particulate matter may occur despite reduced traffic volumes (see box “Excursus on particulate matter”). In the following evaluations of the concentration data, particulate matter is therefore not considered further, the focus is instead placed on NO_2.

2 NO_2 Situation During the Spring Lockdown

Concentration developing (01.03. to 30.04.2020)

Fig. 16 shows the hourly course of NO_2 concentrations at all monitoring stations close to traffic for the months of March and April 2020. At first glance, no decrease in concentrations during the marked lockdown period is discernible – contrary to expectations based on the reduced traffic figures.

Average diurnal variation

On closer inspection, however, two particular features can be seen in the average diurnal variations (see Fig. 17 above) across all stations close to traffic throughout Germany:

- During the lockdown in spring, average concentrations in the early morning hours were above average.
- The average load in the afternoon hours (13–18 hrs) was lower than throughout the rest of the year.

These effects vary regionally and locally, as is seen from the average traffic-related diurnal variations per federal state (Fig. 17 below). The afternoon load during the lockdown was significantly below the average for 2020, especially in Berlin, Bavaria, Lower Saxony and Saxony. Conceivable causes for this heterogeneous picture include different decreases in traffic figures (see chapter “Changes in road traffic during the lockdown period”) and differing meteorological conditions in Germany throughout the year.

The assessment of the afternoon pollution on weekdays for all German stations close to traffic (i.e. average for 13–18 hrs, weekdays) reveals a clear picture: at 42 percent of all stations close to traffic, the average afternoon load during the lockdown period (CW13–CW16; 23.03.2020–19.04.2020) was the lowest observed for the entire year (see Fig. 18). Almost 20 per cent of the stations registered their lowest afternoon load in the calendar weeks immediately following the lockdown (CW17-CW20; 20.04.–17.05), which still saw school/childcare closures.

Meteorological conditions during the lockdown period

It is not possible to quantify the effects of the Corona measures on NO_2 concentrations directly based on the measurement data, as meteorological conditions have a major influence on the concentration of pollutants in addition to emissions.

A low-pressure weather pattern favouring the spread of air pollutants with mainly westerly currents, a lot of wind and high precipitation characterised February and the first weeks of March 2020. At almost the same time as the lockdown, the weather situation changed from mid-March onwards: For the most part, unfavourable circulation conditions prevailed due to high-pressure weather conditions with little wind and low levels of vertical air exchange. This led to a situation in many places during the lockdown period where the decrease in emissions resulting from a reduction in road traffic was compensated for by meteorological influences, with the effect varying in time and location. It is only possible to draw direct conclusions about emission reductions and concentration reductions after a “weather adjustment”. “Weather-adjusted” means that the meteorological effects are removed from the concentration changes. The following approaches, among others, are used for that purpose:

- Calculation of differences between data from background stations in close proximity to traffic and urban stations with largely identical weather conditions,
- Comparison of temporally offset station data measured under similar meteorological conditions,
- Use of the statistical correlation between weather and concentration,
- Modelling concentration data with chemistry transport models.

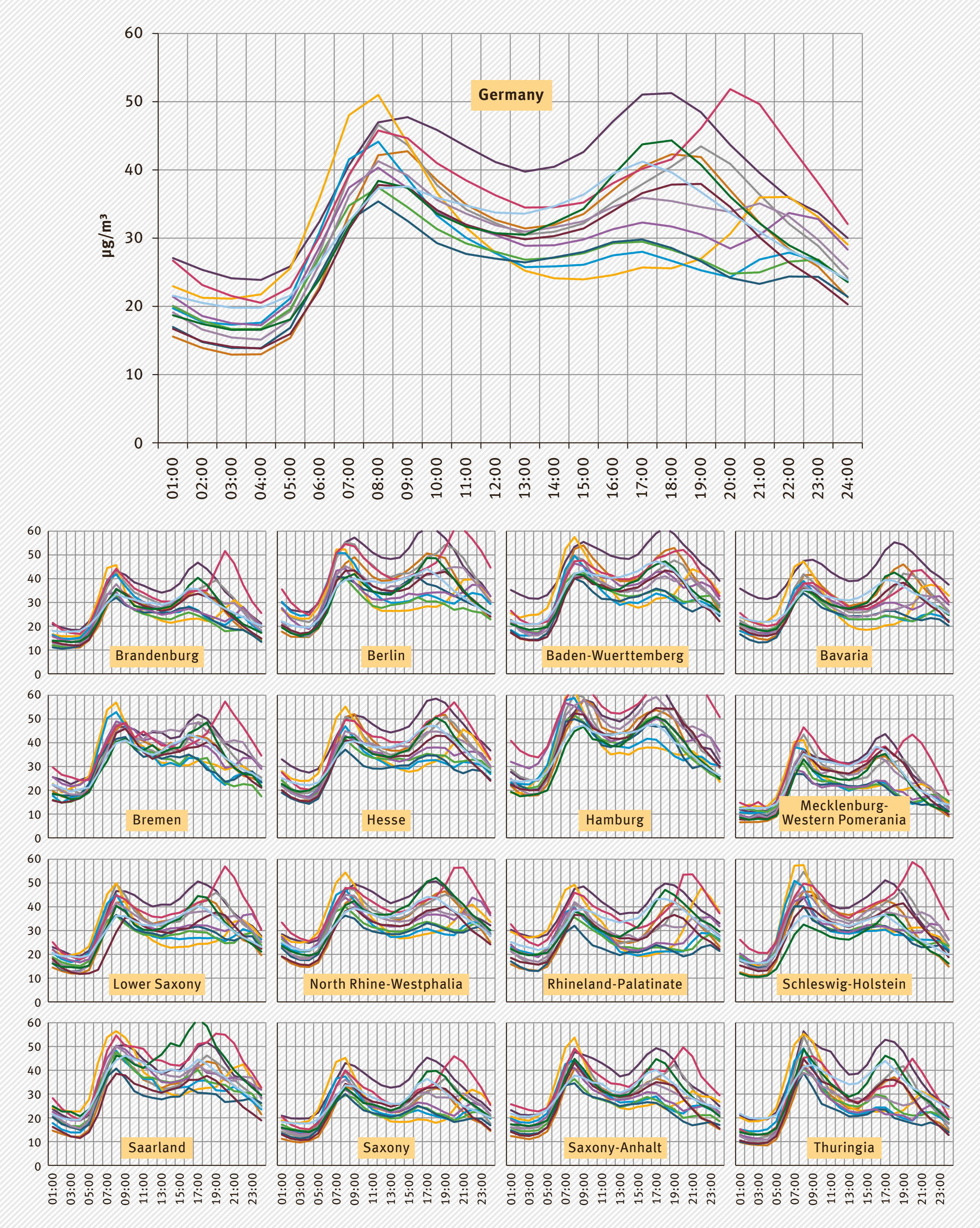
Evaluations of the federal states

In Germany, responsibility for monitoring air quality to protect human health is located at state level, which means that 99 percent of German measuring stations are operated by the state environmental administrations. They have detailed knowledge of the conditions on site and can assess and interpret concentration trends of individual stations. A number of different approaches were used in the state evaluations.

- Using the differences between neighbouring stations, Berlin calculated that the local NO_2 content originating from traffic decreased by approx. 15 percent (BE2020).
- Evaluations in Hesse looked for days with the same or similar wind currents as those during the lockdown for the previous six months. The results suggested that NO_2 concentrations decreased significantly from the lockdown onwards. The average decrease across all monitoring sites in close proximity to traffic was about 35 percent (HE2020).
- Mecklenburg-Western Pomerania compared the NO_2 values during lockdown with those from the identical period in 2019. On average, the values for March and April 2020 were below those of the previous year (MV2020).
- A similar approach was taken in North Rhine-Westphalia, using identical time periods from 2015–2019, the result being that weekday NO_2 concentration values were significantly lower than in 2015–2019 (NW2020).
- The evaluations of the measuring stations in Rhineland-Palatinate show that, with a few exceptions, there was a reduction in NO_2 concentrations in 2020 for the March/April compared to the same

Figure 17

Average daily NO_2 concentrations in close proximity to traffic for Germany and all federal states in 2020, lockdown period in yellow

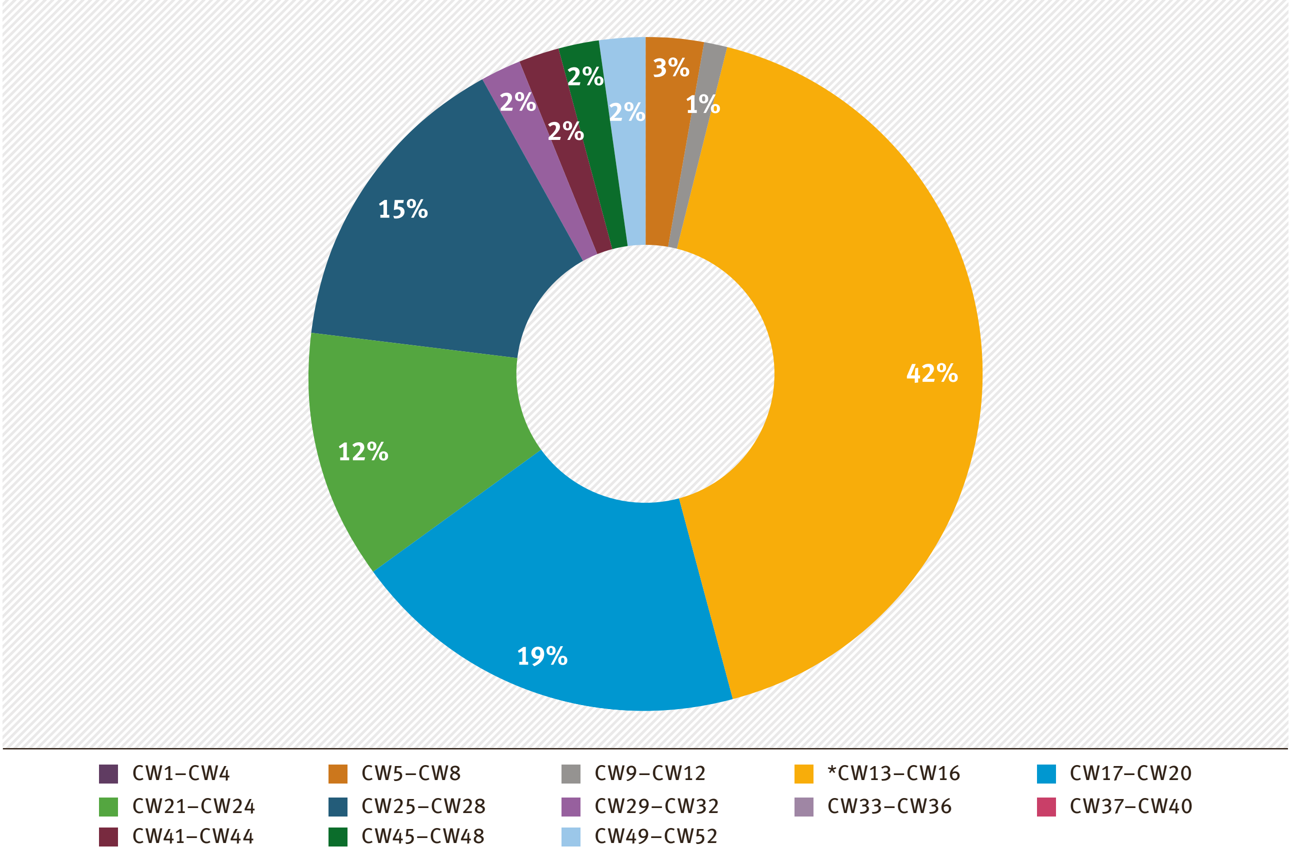


CW1–CW4 | CW5–CW8 | CW9–CW12 | *CW13–CW16 | CW17–CW20 | CW21–CW24 | CW25–CW28 | CW29–CW32 | CW33–CW36 | CW37–CW40 | CW41–CW44 | CW45–CW48 | CW49–CW52

Source: German Environment Agency (UBA) 2021

Figure 18

Distribution of the lowest afternoon NO_2 pollution levels (Mon–Fri, 13–18 hrs) at all traffic-related measuring stations in Germany 2020



Source: German Environment Agency (UBA) 2021

period in 2019, ranging between 1–7 µg/m³ and greater at traffic measuring stations than at the urban and rural background stations (RP2020).

- Lower Saxony investigations revealed significantly lower temperature decreases with altitude during the lockdown period during nighttime hours, which is an indication of greater atmospheric stability. The result is poor dilution of pollutants during the night hours. That is reflected in above-average NO_2 levels during the early morning hours (see Fig. 17).

When comparing with identical periods of the previous year, it should be noted that long-term measures to reduce emissions (e. g. fleet modernisation) may also have led to a decrease in concentration values. The observed improvement in air quality in March and April 2020 is therefore also – but not only – due to the influence of the effects of Corona.

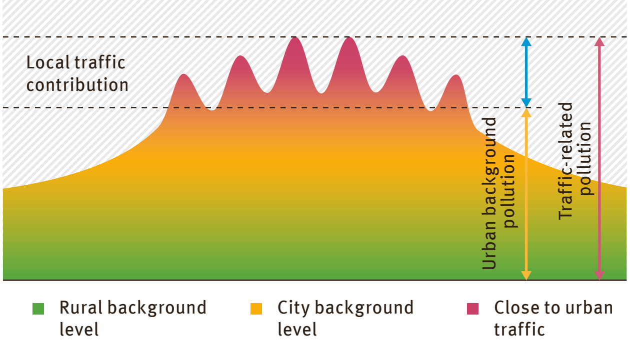
Evaluations by the German Environment Agency

To quantify the impact of the Corona effect on springtime NO_2 pollution, the relationship was used that the total traffic-related pollution is composed of the pollution in the urban background (i. e. in typical urban residential areas) plus the local traffic contribution directly at the road (see Fig. 19).

Stations in close proximity to traffic and background stations within the same city are subject to the same large-scale weather conditions, i. e. favourable or unfavourable propagation conditions affect all locations equally. A study of the local traffic contribution together with the traffic-related pollution therefore provides an indication of whether a change in the traffic-related pollution is emission-related or weather-related. Fig. 20 illustrates that with an example: in this case, the NO_2 concentrations in a city show a peak value in the morning and evening hours, in keeping with rush-hour traffic. Traffic-related pollution is higher in the evening than in the morning, but that is obviously not due to an increase in traffic,

Figure 19

Breakdown of urban NO_2 pollution



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

as the local traffic contribution actually decreases. The evening peak values are therefore caused by less favourable dispersion conditions and not by an increase in traffic.

It may therefore be possible to use a time series of the local traffic contribution to reveal changes in emissions that under certain circumstances are masked by meteorological variations, by proceeding as follows:

1. Determination of the local traffic contribution within all German municipalities where at least one measurement in close proximity to traffic and at least one measurement in the urban background was available. Where several stations were located in a municipality, the mean pollution levels in close proximity to traffic and at the background stations were determined and the local traffic contribution calculated by taking the difference between the two.

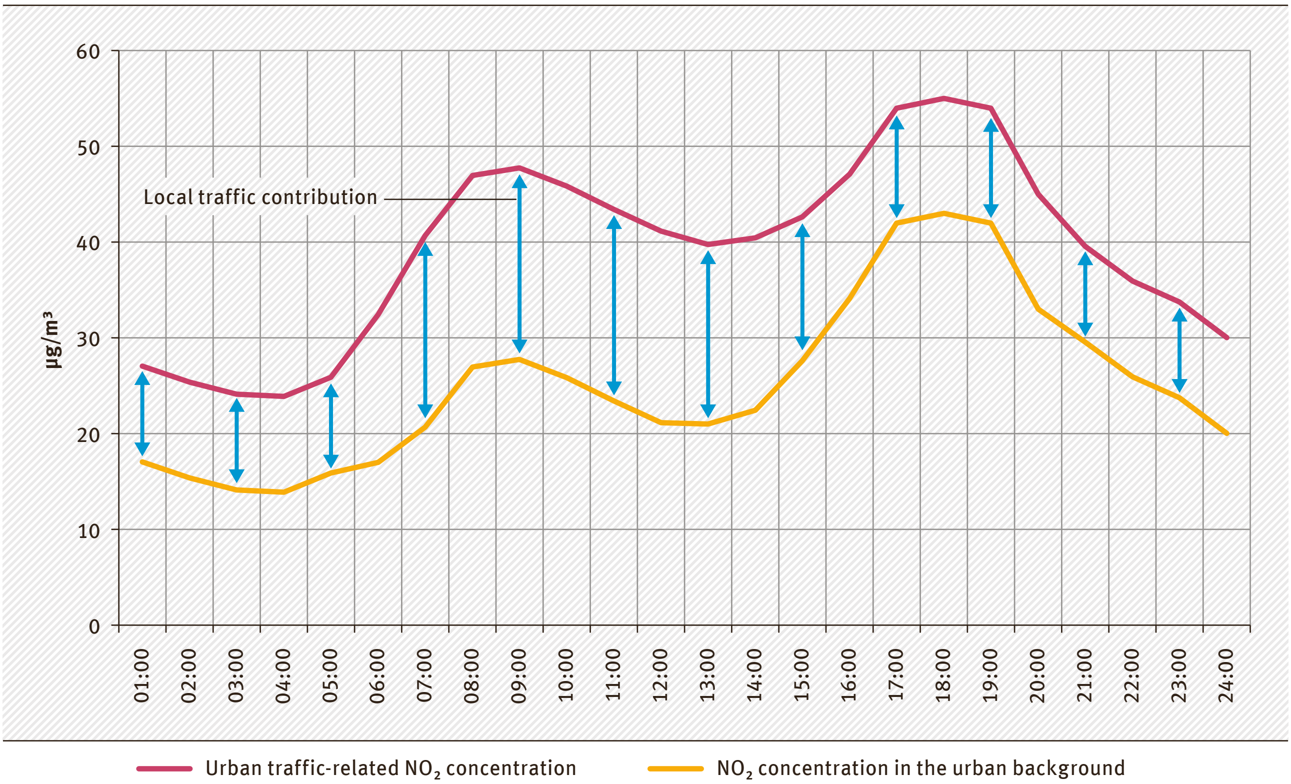
2. All municipalities in which the mean local traffic contribution was almost constant[7] in the weeks before the lockdown were selected.

That produced the following patterns of the average local traffic contribution for 30 municipalities (see Fig. 21). The analysis clearly shows that the local

7 Where the local traffic contribution varied significantly prior to the lockdown, the approach can be regarded as unsuitable for the respective municipality, as it was assumed that emissions had not changed significantly prior to the lockdown.

Figure 20

Example of a measurement in close proximity to traffic and in an urban background with marked local traffic contribution



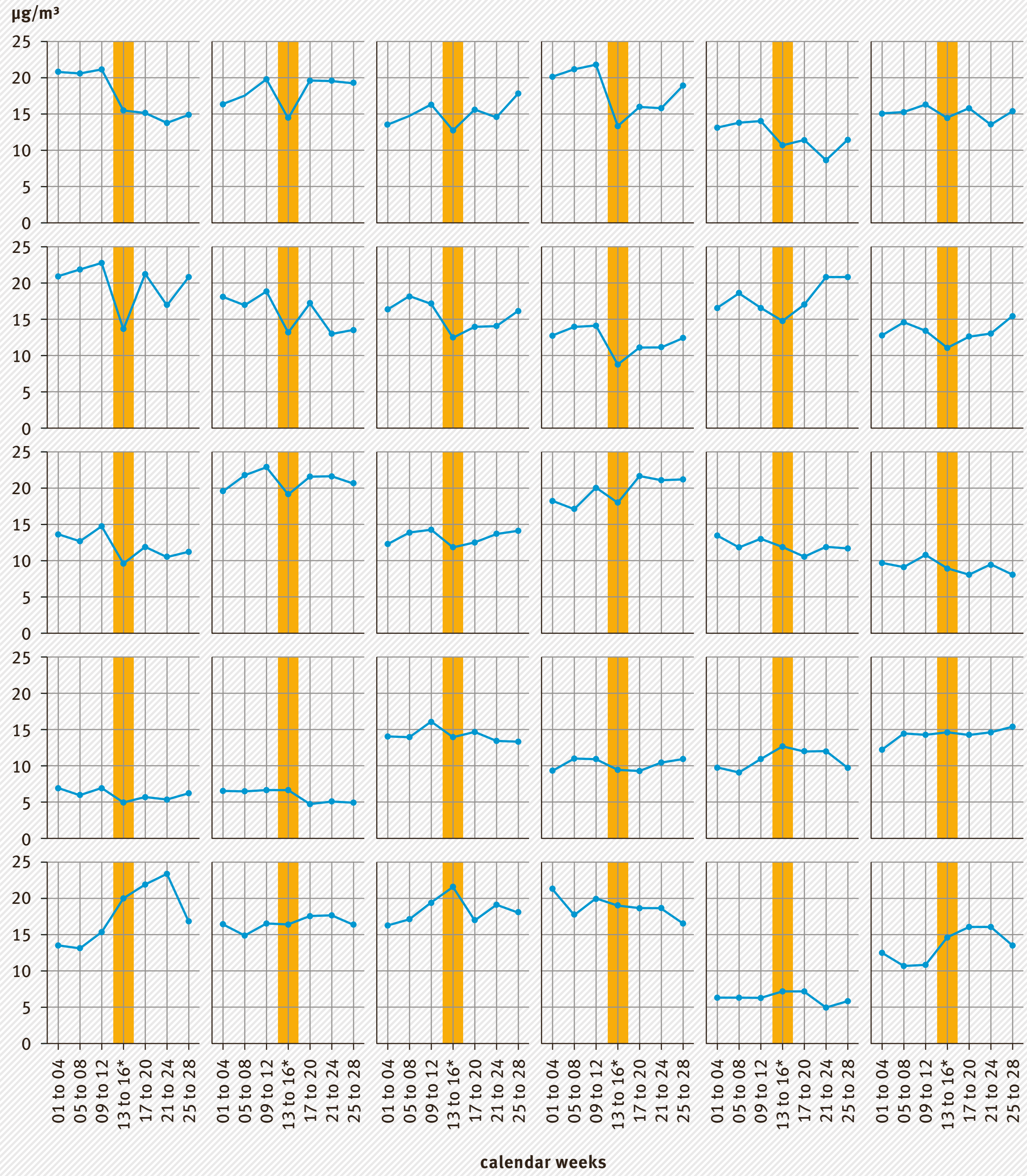
Source: German Environment Agency (UBA) 2021

traffic contribution of a majority of the municipalities (73 percent) decreased during the lockdown period (CW13–CW16, in yellow).

The decrease of the local traffic contribution in relation to the mean total traffic-related pollution indicates that the lockdown-related decreases in traffic-related NO_2 pollution lie in the range of 2 to 24 percent and are not due to weather-related influences.

Figure 21

Average course of the local traffic contribution of the 30 municipalities three months before and after spring lockdown, lockdown period marked in yellow



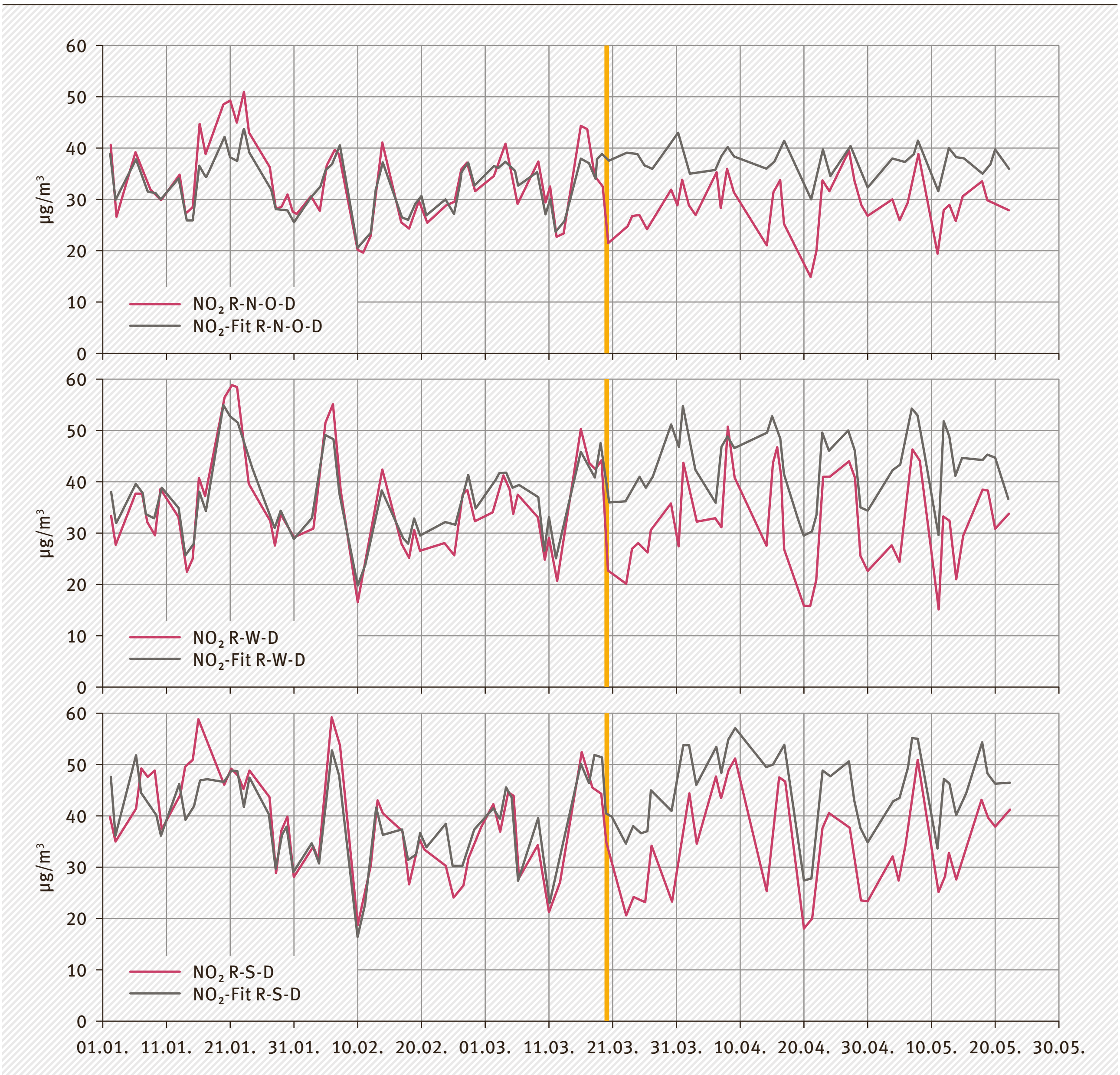
Source: German Environment Agency (UBA) 2021

Evaluations of the German Meteorological Service (DWD)

The DWD uses the statistical correlation between meteorological conditions and the concentration of pollutants, which can be determined from past data. A fit function was developed using the parameters of wind speed, temperature, NO_2 trend and ozone, and was determined for the data from 01.01.2015 to 22.03.2020 (DWD2020). The lockdown effect can then be quantified by comparing the NO_2 concentrations of this fit function (Fig. 22, grey line) with those actually measured (Fig. 22, red line). Due to the large influence of meteorology on concentrations, regions with strongly correlated wind speeds and temperatures were grouped together: North-East Germany, West Germany and South Germany. There were consistent

Figure 22

Mean NO_2 time series in German cities with populations of > 100 000 (red) compared with the time series fitted using meteorological parameters and their forecast for the Corona period (grey). Daily averages on working days from measuring points in close proximity to traffic are shown for the regions of northern and eastern Germany (R-N-O-D), western Germany (R-W-D) and southern Germany (R-S-D); start of Corona lockdown (yellow)



Source: https://www.dwd.de/DE/Home/_functions/aktuelles/2020/20200717_hintergrundbericht_gaw.html and significant reductions between regions of 23±6 per cent in the first four weeks of the lockdown. In the second four-week phase of the lockdown, these weather-adjusted reductions were weaker due to the renewed increase in traffic activity.

Evaluations of the European Environment Agency

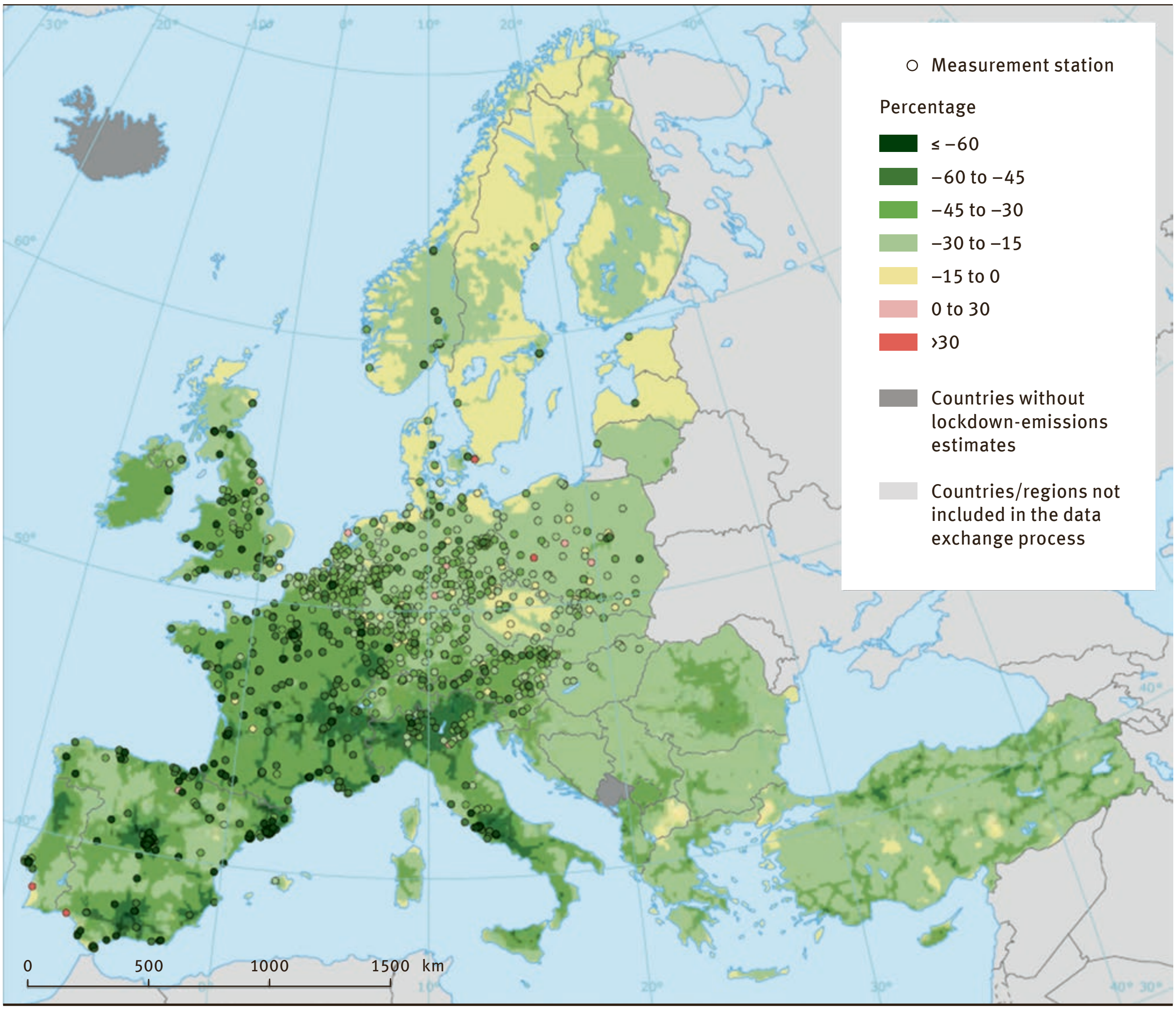
The European Environment Agency uses a model[8] to quantify the effect of lockdown on all European NO_2 monitoring stations. The model uses historical data (2015–2019) to establish a statistical relationship between pollutant concentrations and the weather conditions that occurred at the same time (EEA2020). This relationship is used to model the concentrations that would have occurred without lockdown-related changes in emissions using the meteorological conditions of March/April 2020. If the concentrations modelled in this way are compared with those actually measured, the difference indicates the lockdown effect. The dots on the map in Fig. 23 show the lockdown-related NO_2 decreases at the stations in green/yellow and the increases in shades of red. The areal decreases in concentrations were calculated using an ensemble of 11 chemical shipment models (CAMS[9]) and a recently developed emission inventory.

8 GAM: Generalized additive model

9 CAMS: Copernicus Atmosphere Monitoring Service; https://www.ecmwf.int/en/about/what-we-do/environmental-services/copernicus-atmosphere-monitoring-service

Figure 23

Relative changes in NO_2 concentrations due to lockdown restrictions in April 2020



Source: https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report

As the map clearly shows, almost all (99 per cent) of the European stations evaluated here experienced decreasing concentrations in April 2020 that cannot be attributed to weather-related fluctuations, but can be attributed to the measures taken to contain the Corona pandemic. The greatest decreases are seen in Spain, France, Italy and Portugal, consistent with their comparatively stringent measures. The Czech Republic, Hungary and Poland, on the other hand, show the smallest decreases. Germany is in the middle range with an average NO_2 decrease of about 30 percent.

3 Impact on Compliance with Air Limit Values

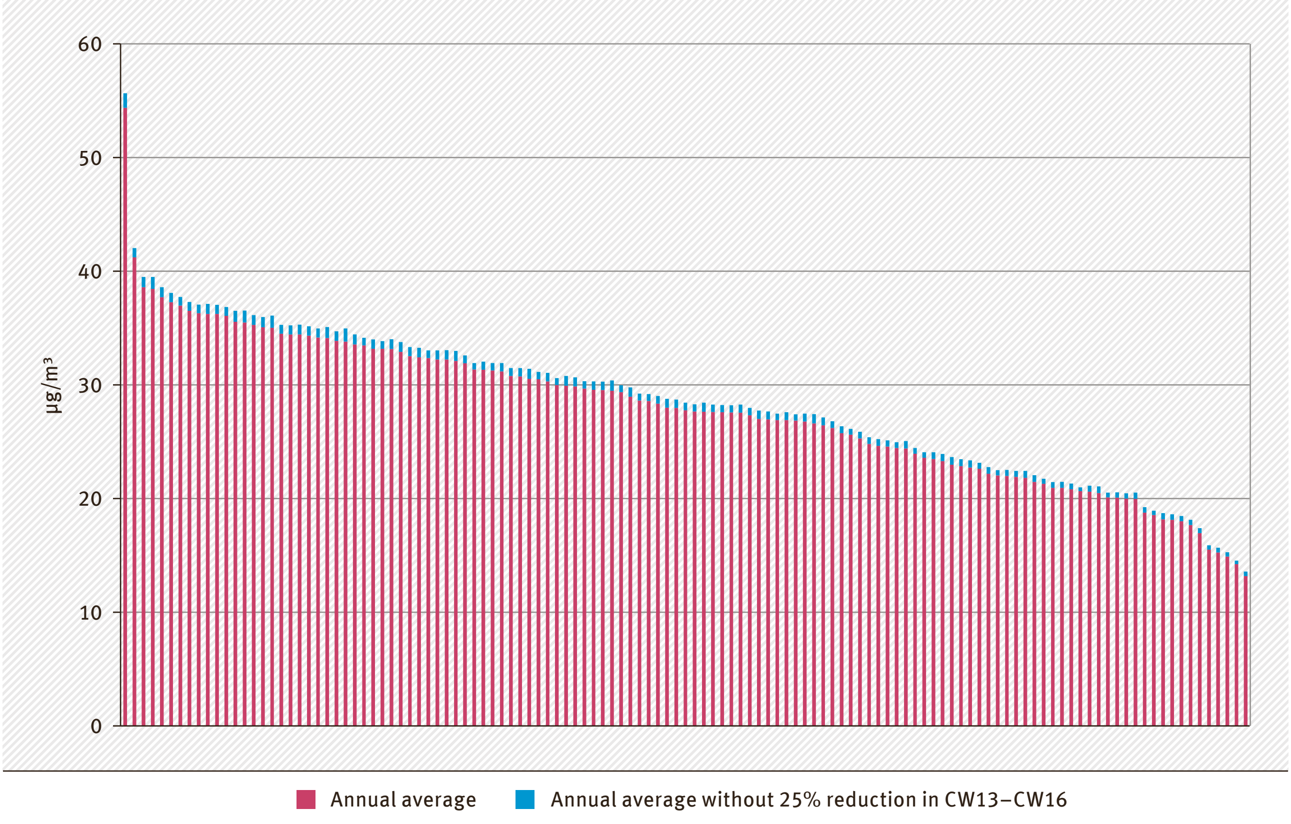
The short-term limit value for NO_2 set for the protection of human health has been complied with everywhere in Germany since 2017, making consideration of the reduction in pollution due to the lockdown irrelevant in this respect. In contrast, the annual mean limit value of 40 µg/m³ is not complied with at all locations. As the previous studies show, the lockdown-related restrictions in Germany in spring 2020 led to temporary reductions in average NO_2 pollution levels of 20 to 30 percent, but only for the comparatively short period of about four weeks. As a means of roughly quantifying the impact of this short period on the year as a whole, all annual mean values of stations in close proximity to traffic in 2020 were compared with synthetic annual mean values in which the concentrations of the lockdown period were not subject to an average reduction of 25 per cent (mean of 20–30 per cent). Figure 24 shows the annual mean values of NO_2 in close proximity to traffic for the year 2020 (red), and what the annual mean values would have looked like without lockdown-related decreases (blue). This simplified assumption makes it clear that the temporarily reduced concentrations in spring have only a minor influence on compliance with the limit value.

4 Conclusion

The measures taken in spring 2020 to contain the Corona pandemic had a largely positive effect on air quality. NO_2 concentrations measured at urban monitoring stations in close proximity to traffic decreased during the lockdown period, but the decrease was slowed by unfavourable dispersion

Figure 24

NO_2 annual mean values 2020 of all hourly measuring stations in close proximity to traffic



Source: German Environment Agency (UBA) 2021

conditions. After adjustment for weather, average decreases were determined to be in the range of 20–30 percent. In some places, the lowest monthly NO_2 levels since measurements began were recorded. Depending on the respective decrease in traffic and the meteorological background conditions, the effects of the lockdown on NO_2 concentrations varied greatly from region to region and from place to place. As the Corona lockdown was only limited to a comparatively short period of about four weeks, the influence on the annual mean values and thus on the long-term exposure to NO_2 is low. Instead, targeted air pollution control measures in cities and the replacement of fleets are the main drivers of the significant decrease in NO_2 concentrations measured in close proximity to traffic that has been observed for several years (see chapter "III Nitrogen Dioxide: Hardly any Exceendances").

5 References

BE2020: https://www.berlin.de/sen/uvk/presse/weitere-meldungen/2020/ist-die-luft-wegen-der-corona-beschraenkungen-besser-geworden-929793.php

DLR2020: https://www.dlr.de/content/de/artikel/news/2020/02/20200505_corona-effekt-auf-luftqualitaet-eindeutig.html

DWD2020: https://www.dwd.de/DE/Home/_functions/aktuelles/2020/20200717_hintergrundbericht_gaw.html

EEA2020: Air quality in Europe – 2020 report; https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report

HE2020: https://www.hlnug.de/dossiers/sauberere-luft-durch-corona

NI2020: https://www.umwelt.niedersachsen.de/startseite/themen/luftqualitat/lufthygienische_uberwachung_niedersachsen/berichte/sonderberichte/stickstoffdioxid-belastung-in-niedersachsen-vor-und-wahrend-der-corona-pandemie-187854.html

NW2020: https://www.lanuv.nrw.de/fileadmin/lanuv/luft/immissionen/ber_trend/Auswirkungen_Covid19_Luftqualit%C3%A4t.pdf

MV2020: http://www.lung.mv-regierung.de/umwelt/luft/lume.htm

RP2020: https://lfu.rlp.de/de/startseite/geringere-schadstoffbelastung-durch-corona/

SN2020: https://www.luft.sachsen.de/download/Fachbeitrag_2020_06_22.pdf

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

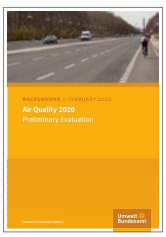
Development of air quality in Germany:
http://www.umweltbundesamt.de/luft/entwicklung.htm

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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