Trends in Air Quality in Germany

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Introduction

Air pollution has markedly decreased in the last 20 years. Through the introduction of filter and flue-gas denitrification systems in power plants and industrial installations; and the use of modern catalysts and fuels, considerably fewer pollutants are today released into the atmosphere. EU-wide air quality limit values for sulphur dioxide, carbon monoxide, benzene and lead are no longer exceeded in Germany.

Air quality is monitored at approx. 650 German measuring stations several times a day. In addition to particulate matter (PM_{10}), nitrogen dioxide (NO_2) and ozone (O_3), further pollutants such as organic compounds and heavy metals in PM_{10} are measured.

On their way from the emission source (for example, flue or exhaust) to receptor (humans, flora and fauna), pollutant emissions are subject to atmospheric transport and mixing processes as well as chemical reaction. Pollutant concentration in the atmosphere (given, for example, in micrograms per cubic metre of air) can therefore not be directly deduced from the emitted pollutant quantity (given, for example, in tonnes per year). In principle, however, markedly reduced pollutant emissions give cause to expect that pollutant concentration in the atmosphere will also decrease. We observe, however, that since the beginning of this decade air pollution in Germany through particulates, nitrogen oxide and ozone, despite steadily reduced emissions, no longer shows a clear trend, but is subject rather to mainly interannual fluctuations.

The limit values for particulates, which were laid down already in 1999 and are obligatory since 2005, are exceeded in many places in Germany. The same applies for limit values for nitrogen dioxide, which come into force in Germany on 1 January 2010. In urban areas – and, above all, in places affected by heavy traffic – air pollution with particulates and nitrogen dioxide is particularly high. Other than in the case of particulates and nitrogen dioxide, ozone pollution is highest in rural areas. For some years, a trend towards higher ozone concentrations has been noticeable in urban areas.

In this booklet we describe trends in air pollution with particulates, nitrogen dioxide and ozone, and explain their connection to changes in air pollutant emissions.

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Pollution regimes

In order to be able to understand spatially differentiated trends in air pollution, it is necessary to combine concentration values obtained at individual air quality measuring stations in such a way that they characterize pollution regimes. The rural background regime (green area in the diagram) represents areas in which air quality is largely uninfluenced by local emissions. Stations in this regime thus represent pollution at a regional level, also termed regional background. The urban background regime (yellow area in the diagram) is characteristic for areas in which measured pollutant concentrations can be regarded as typical for air quality in cities. The urban background regime characterizes the pollution that arises from urban emissions (road traffic, domestic fuel etc.) and the regional background. Urban traffic regime stations (red peaks in the diagram) are typically found on roads with heavy traffic. The result is a cumulative contribution to urban background pollution that arises from direct emissions of road traffic.

The time series curves of air quality shown in this booklet reflect the trend over time of average concentrations in the respective pollution regime. Time series curves are therefore not suitable for assessment of compliance or non-compliance with limit values of individual measuring stations.

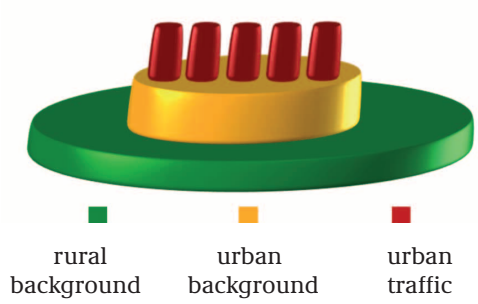
Nitrogen oxides

NO_x is a collective chemical term for nitrogen oxides, and comprises nitrogen monoxide (NO) and nitrogen dioxide (NO_2) as summation parameter. Nitrogen oxides are mainly emitted as nitrogen monoxide. Nitrogen oxide is emitted directly, but also formed indirectly through chemical reactions in the atmosphere. Internal-combustion engines and combustion processes in industry and energy production plants are the main sources of nitrogen oxides.

Based on the year 1995, NO_x emissions of all source categories decreased by 15% by the year 2000. Up to 2007 they sank by a further

Of the nitrogen compounds, gaseous nitrogen dioxide in ambient air has the greatest significance for human health. As a strong oxidizing agent it leads to inflammation of the respiratory tract and aggravates the irritation effect of other air pollutants.

Schematic representation of pollution regimes:



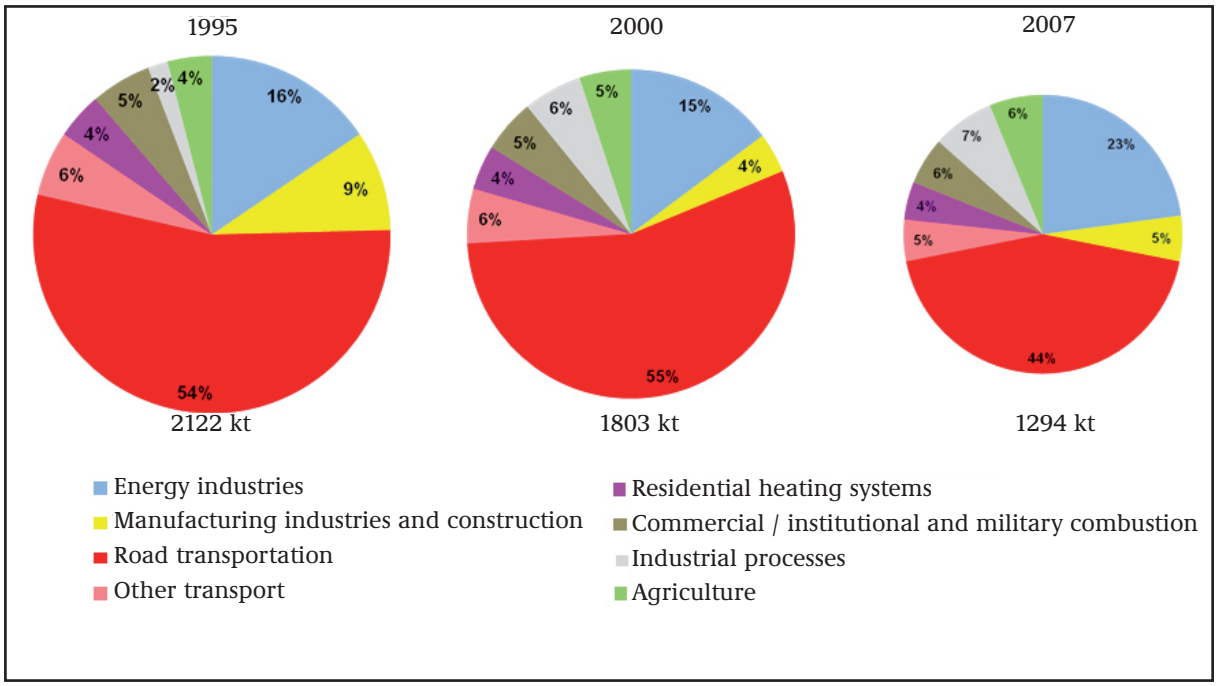


Figure 1: Percentage share of NO_x emissions of source categories in the years 1995, 2000 and 2007.

24 percentage points. If one merely considers emissions from road transportation, it has to be observed that here the largest reduction, namely 50%, was achieved. Nevertheless, road transportation still accounts for the largest share (44%) of total nitrogen oxide emissions.

The effect of a reduction in NO_x emissions can be clearly seen in the trend in annual average NO_x concentrations: In the period from 1995 to 2007 they declined in the urban, traffic-affected pollution regime (Figure 2, red curve) and in the urban background (Figure 2, orange curve).

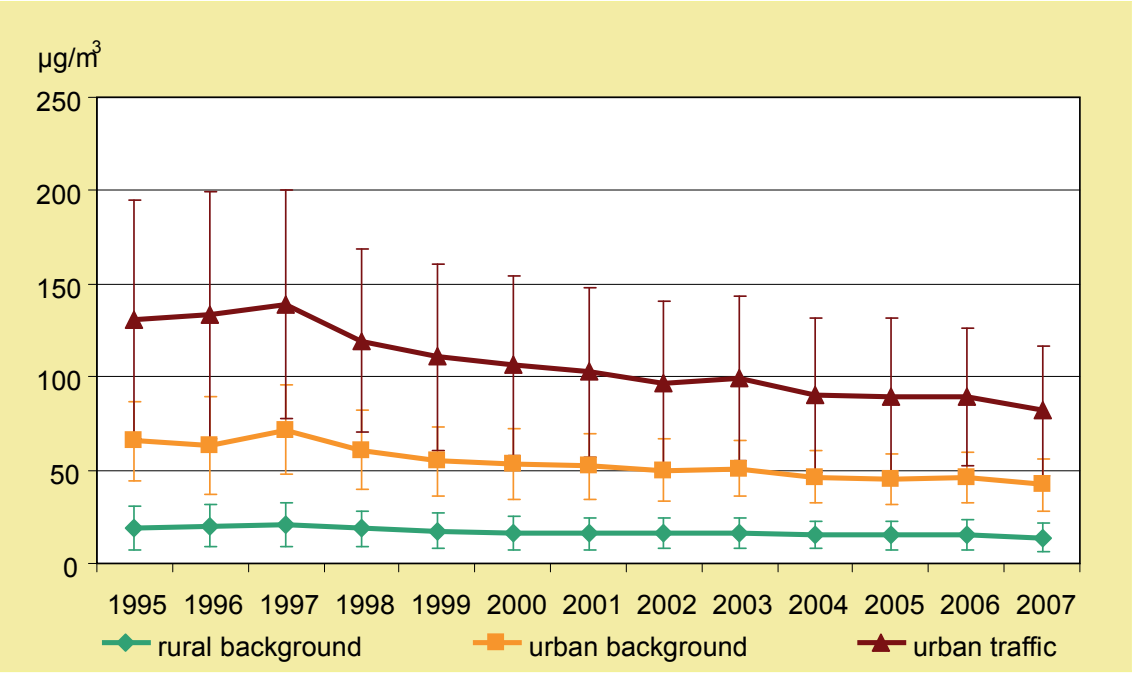


Figure 2: Trend in annual mean NO_x concentration based on the average of measuring stations in the pollution regimes "rural background", "urban background" and "urban traffic" in the period from 1995 to 2007 (with standard deviation).

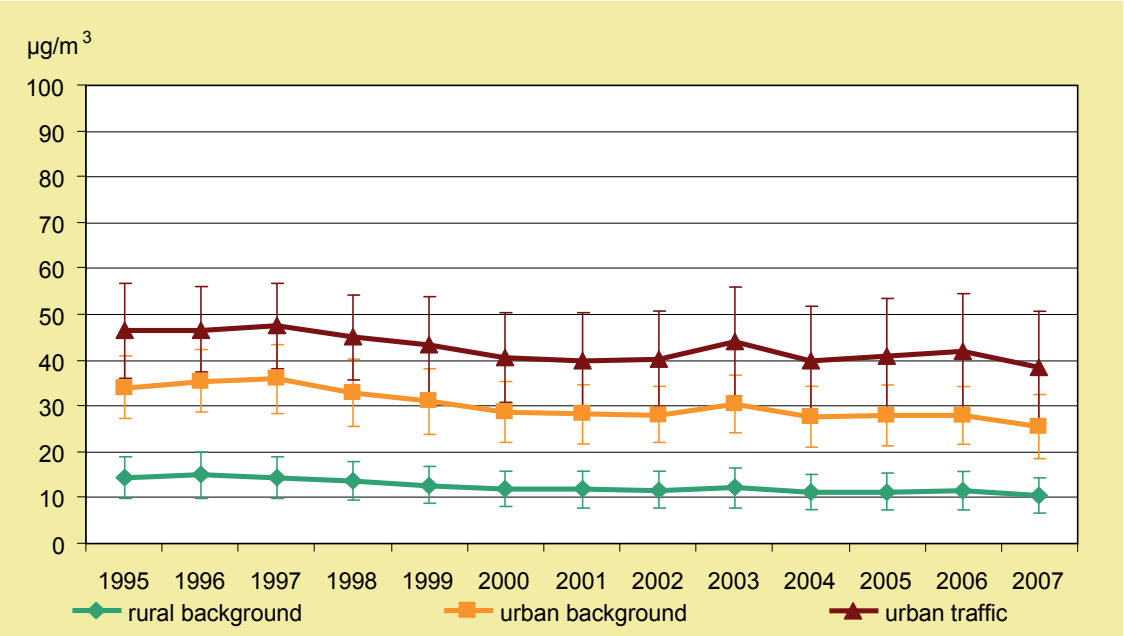


Figure 3: Trend in annual mean NO_2 concentration based on the average of measuring stations in the pollution regimes "rural background" , "urban background" and "urban traffic" in the period from 1995 to 2007 (with standard deviation).

The trend in NO_2 concentrations in the same period shows, however, that the marked reduction in NO_x emissions since 1995 is not reflected in the state of NO_2 pollution (Figure 3). Since the year 2000, annual mean NO_2 concentrations have hardly changed in urban areas affected by traffic (Figure 3, red curve) and in the urban background (Figure 3, orange curve). Recognizable inter-annual fluctuations are attributable; above all, to weather-related influences.

The range of annual mean values of individual measuring stations can be estimated on the basis of the stated standard deviation. At the same time, it becomes clear that in the urban traffic pollution regime, annual mean concentrations occur that lie considerably above the limit value of 40 µg/m³, which will be obligatory from 2010.

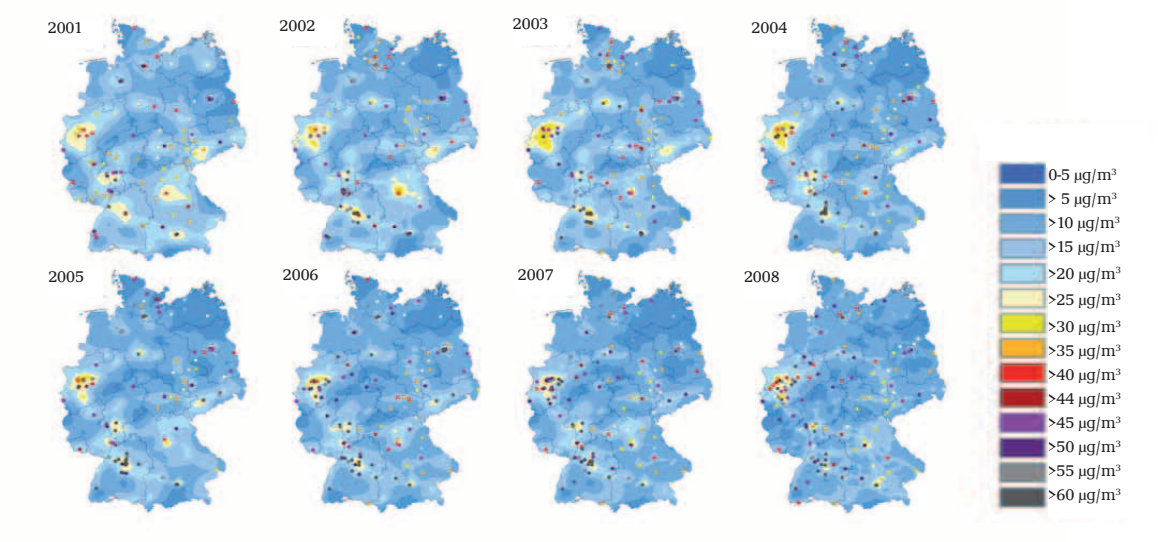


Figure 4: Average NO_2 pollution in Germany in the years 2001 to 2008 with "spots".

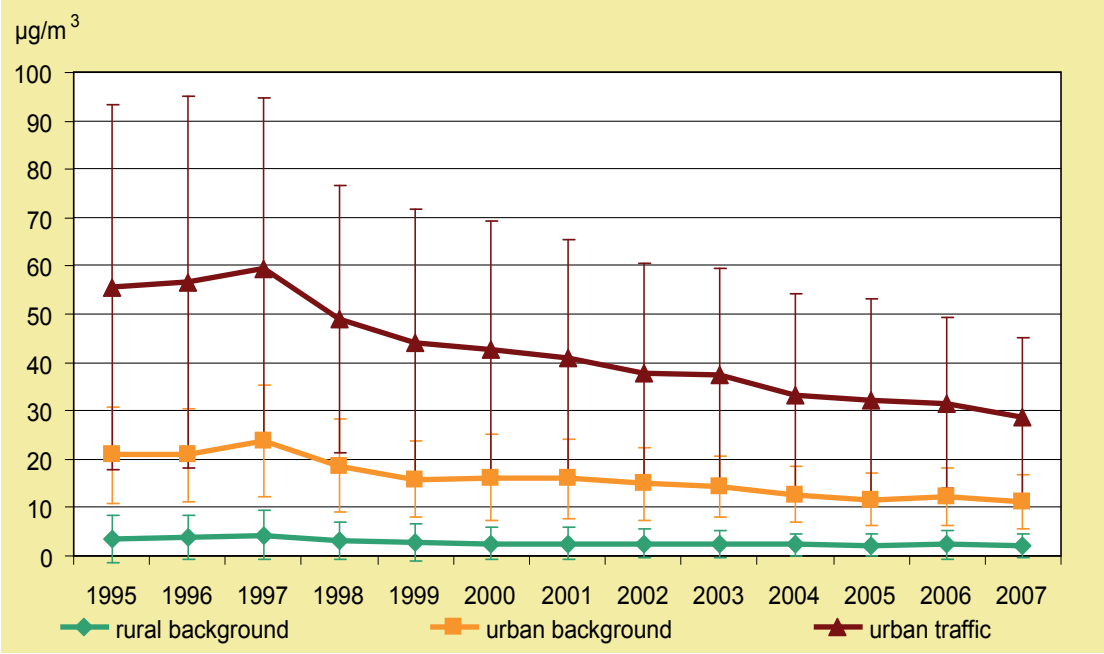


Figure 5: Trend in annual mean NO concentration based on the average of measuring stations in the pollution regimes "rural background", "urban background" and "urban traffic" in the period 1995 to 2007 (with standard deviation).

Average NO_2 pollution in Germany demonstrates a strongly defined slope from urban conurbations to rural areas (cf. Figure 4). The share of background pollution amounts to around 20% in places with high NO_2 pollution.

Measurement results obtained in areas influenced by roads with heavy traffic are plotted as spots, since they characterize local, small-scale pollution and are therefore inappropriate for regional interpolation.

Since NO_2 concentration in the period under consideration has shown no reduction since 1995, the decline in NO_x concentration must be attributable to declining NO concentration. A declining trend in NO annual mean values since 1995 is easily discernible in the urban background (Figure 5, orange curve) and even more so in places affected by heavy traffic (Figure 5, red curve).

Limit values for NO_2 and NO_x

Designation	Average period	Limit value	Point in time, by which the limit value has to be achieved
Hourly limit value for the protection of human health	1 hour	200 µg/m³ NO_2 may not be exceeded more often than 18 times per calendar year	1. January 2010*
Annual limit value for the protection of human health	Calendar year	40 µg/m³ NO_2	1. January 2010*
Annual limit value for the protection of vegetation	Calendar year	30 µg/m³ NO_x	19. July 2001*

*** Possible extension of deadline pursuant to EU Directive 2008/50/EC (cf. page 8)**

Measurements in urban areas affected by heavy traffic show high NO_x concentrations with a high share of NO (Figure 5, red curve), since the transport time from tail pipe to the measuring point is short, compared with the reaction time for conversion of NO to NO_2. With increasing transport time NO is largely converted to NO_2. This also explains the low NO pollution level in rural areas (Figure 5, green curve), which has remained more or less constant over the entire period under observation.

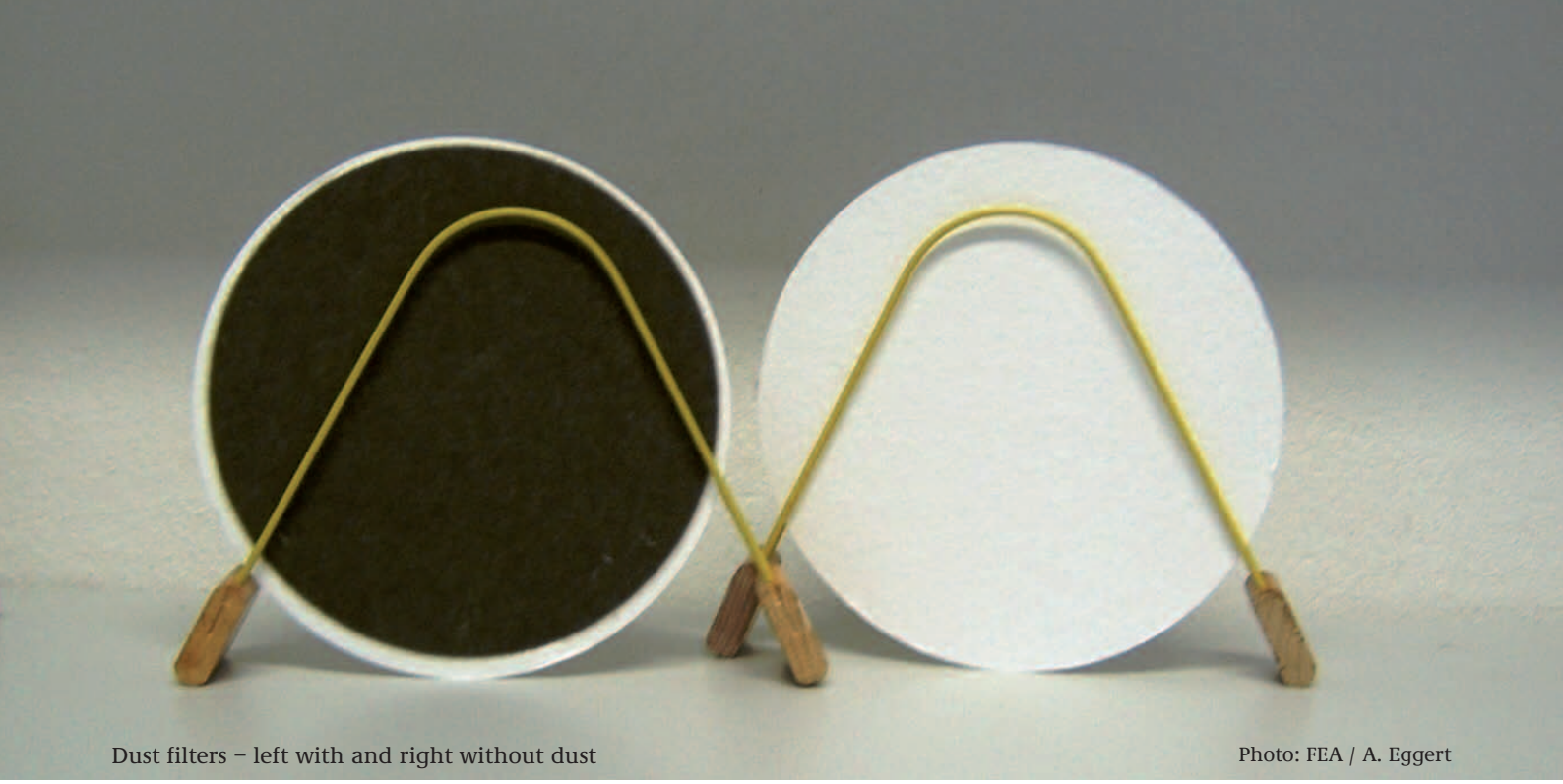
On "postponement of the attainment deadline" pursuant to Articles 22 and 23 of Directive 2008/50/EC:

A particular feature of the new Directive 2008/50/EC is the possibility to postpone laid down deadlines for attainment of air quality limit values by notification to the Commission. This conceded flexibility is accompanied by stringent measures on implementation of the Directive. Flexibleness is a deliberately rigid instrument. Certain conditions for postponement have to be met, regarding which the Member States has to submit documentary evidence. For PM_{10}, postponement is possible for three years from the date of promulgation of the Directive; that is, until 11 June 2011. For NO_2, the maximum possible postponement of the attainment deadline ends in 2015.

Notification of postponement of the attainment deadline has to include extensive documentation of the reasons why, despite measures of air pollution control plans and action plans, the limit values could not be complied with, as well as how and with which additional measures the Member State intends to comply with limit values by the new deadline. The Commission has nine months following receipt of the notification to examine the documentation. Should the Commission raise no objections within this nine-month period, the relevant conditions for postponement of the attainment deadline are deemed to be satisfied.

Summary:

The trend in NO_x concentrations reflects the reduction in NO_x emissions. As to NO_2, air quality has not improved to the extent that the trend in NO_x emissions led to expect. NO_2 concentrations have remained virtually unchanged since 2000, and show merely inter-annual fluctuations in all three pollution regimes. In urban conurbations, and here in particular in traffic-affected pollution regimes, NO_2 annual mean concentrations occur that lie above the limit value of 40 µg/m³, which is obligatory from 2010.



Dust filters – left with and right without dust

Photo: FEA / A. Eggert

Particulate matter

Particulate matter are airborne particles that do not immediately sink to the ground, but rather linger for a particular period of time in the atmosphere. Depending on particle size, particulates are divided into so-called fractions. All dust particles, whose aerodynamic diameter is less than 10 micrometres, are designated PM_{10}. A subset of the PM_{10} fraction is the still finer $PM_{2.5}$ particles, whose aerodynamic diameter is less than 2.5 micrometres. PM_{10} are considered below.

Particulate concentrations in the air stem partially from PM_{10} emissions (for example, traffic and industrial installations), but also arise from secondary PM_{10}. The latter arises through chemical reaction of the inorganic and organic precursor substances ammonia (NH_3), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and non-methane volatile organic compounds (NMVOC) during transport over substantial distances. Total particulate pollution results from the sum of both components (primary and secondary). Important anthropogenic sources of particulates are vehicles, power and district heat plants, furnaces and heating systems in residential buildings, handling of dry bulk materials as well as certain industrial processes. In urban conurbations, road traffic is a particularly important source of particulates. At the same time, particulates enter the atmosphere not only from engines – primarily from diesel engines – but also from brake and tyre abrasion, as well as through the raising of dust from road surfaces. Agriculture is another important source: Emissions of gaseous precursors – in particular ammonia – from livestock husbandry contribute to secondary aerosol formation. Natural contributions towards particulate pollution arise, for example, through sea salt, Sahara dust and forest fires.

Breathed in particulates have harmful effects on human health. Possible illnesses range from inflammation of the respiratory tract to cardiac and circulatory problems. The smaller the dust particle and the deeper it penetrates into the respiratory tract the greater the risk of illness. The World Health Organization (WHO) has established in epidemiological investigations that no concenration threshold for particulate matter in ambient air exists, below which a harmful effect is not to be expected. Not only briefly-increased concentrations lead to adverse health effects; lower concentrations over longer periods also make a marked contribution towards the total effect.

Based on the year 1995, primary PM_{10} emissions decreased by 7% by the year 2000 (cf. Figure 6); by 2007 they had decreased by a further 10 percentage points. The greatest reductions in absolute terms were recorded in the areas of industrial processes and road transportation. With the exception of

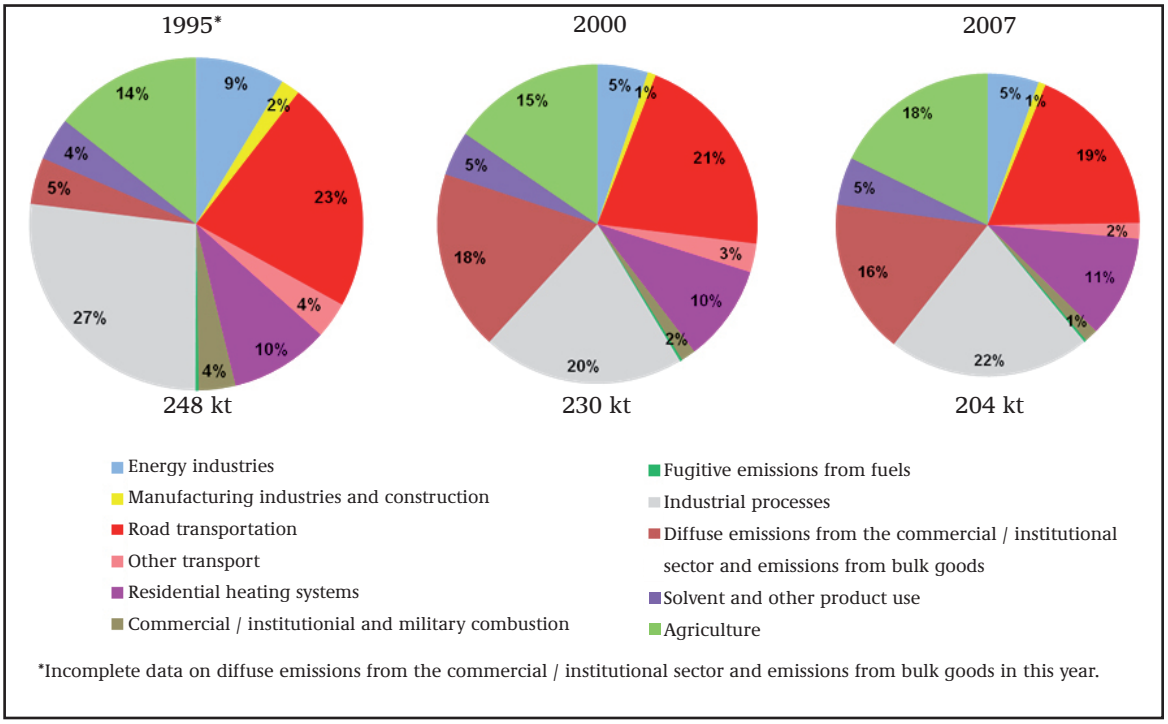


Figure 6: Percentage share in PM_{10} emissions of source categories in the years 1995, 2000 and 2007.

agriculture, shares in emissions of individual polluters in the total period have hardly changed.

Sulphur dioxide and non-methane volatile organic compounds contribute towards the formation of secondary particulates. Emissions of these PM_{10} precursors have been considerably reduced since 1995. By contrast, emissions of ammonia, 95% of which come from agriculture (Figure 7), have barely decreased since 1995.

Accompanying the strong reduction in SO_2 emissions and the decline in primary PM_{10} emissions in the period from 1995 to 2000, PM_{10} concentrations in all pollution regimes also decreased in the same period (cf. Figure 8). Since then, a clearly-declining trend in emission concentration is no longer to be observed.

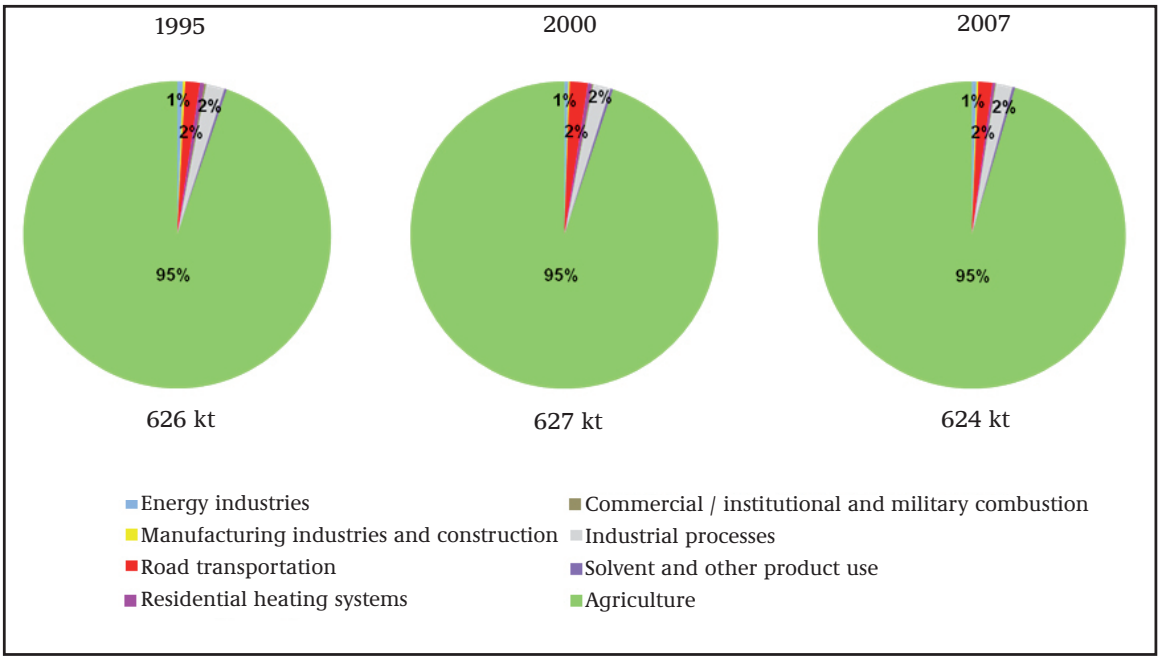


Figure 7: Percentage share in NH_3 emissions of source categories in the years 1995, 2000 and 2007.

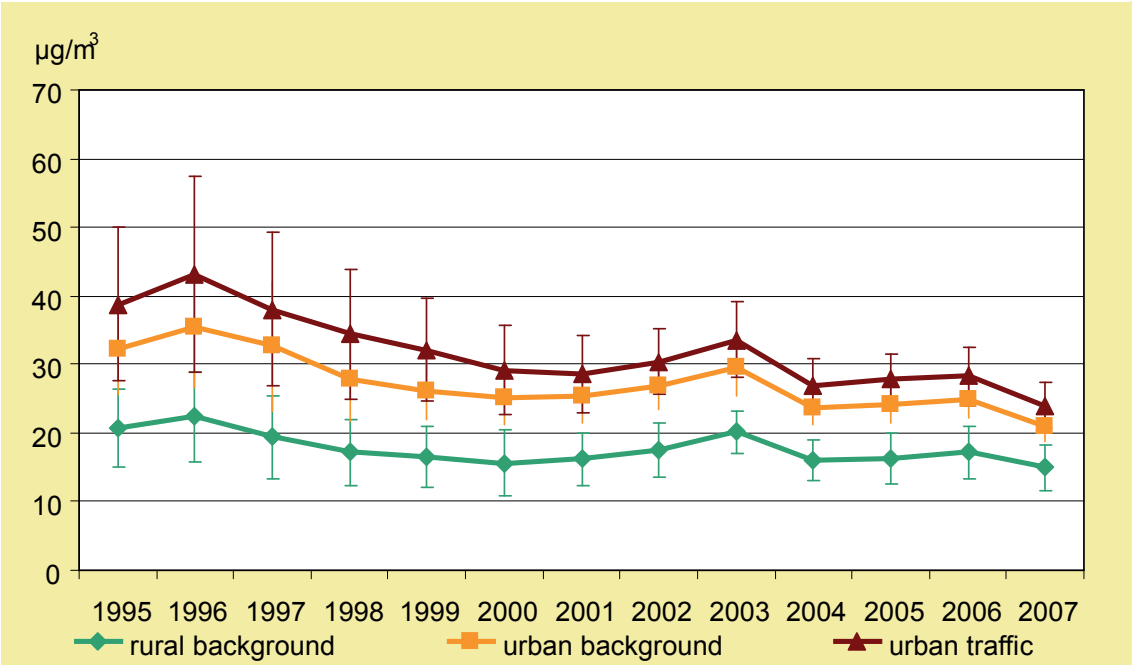


Figure 8: Trend in annual mean PM_{10} concentration based on the average of measuring stations in the pollution regimes "rural background", "urban background" and "urban traffic" in the period from 1995 to 2007 (with standard deviation).

The fact that the level of PM_{10} concentration in urban conurbations has remained static since the year 2000, not only in the urban background but also in the urban traffic pollution regime, is primarily attributable to a low reduction in traffic-related PM_{10} emissions and a slight decrease in emissions in residential heating. PM_{10} pollution in the rural background, far-removed from emitters, which has remained at a more or less constant level since the year 2000, indicates that the secondary PM_{10} share in total PM_{10} pollution has not decreased. While emissions of the PM_{10} precursor NMVOC and NO_x each dropped markedly by about 40%, NH_3 emissions barely decreased. NH_3 emissions are a limiting factor in the formation of secondary particles in rural areas. Since agriculture, with a share of over 90%, is the main source of NH_3 emissions, and these have hardly decreased in the period since 1995, this source categories has made no contribution towards the reduction in particulate pollution.

The trend in PM_{10} concentrations over time is overlaid by inter-annual, weather-related fluctuations, which is easily recognizable, for example, in the "peaks" in all three curves in the year 2003.

Limit values for PM_{10}

Designation	Average period	Limit value	Point in time, by which the limit value has to be achieved
Limit value for the protection of human health	24 hours	50 µg/m³ PM_{10} may not be exceeded more often than 35 times per year	1. January 2005*
Limit value for the protection of human health	Calendar year	40 µg/m³ PM_{10}	1. January 2005*

*** Possible extension of deadline pursuant to EU Directive 2008/50/EC (cf. page 8)**

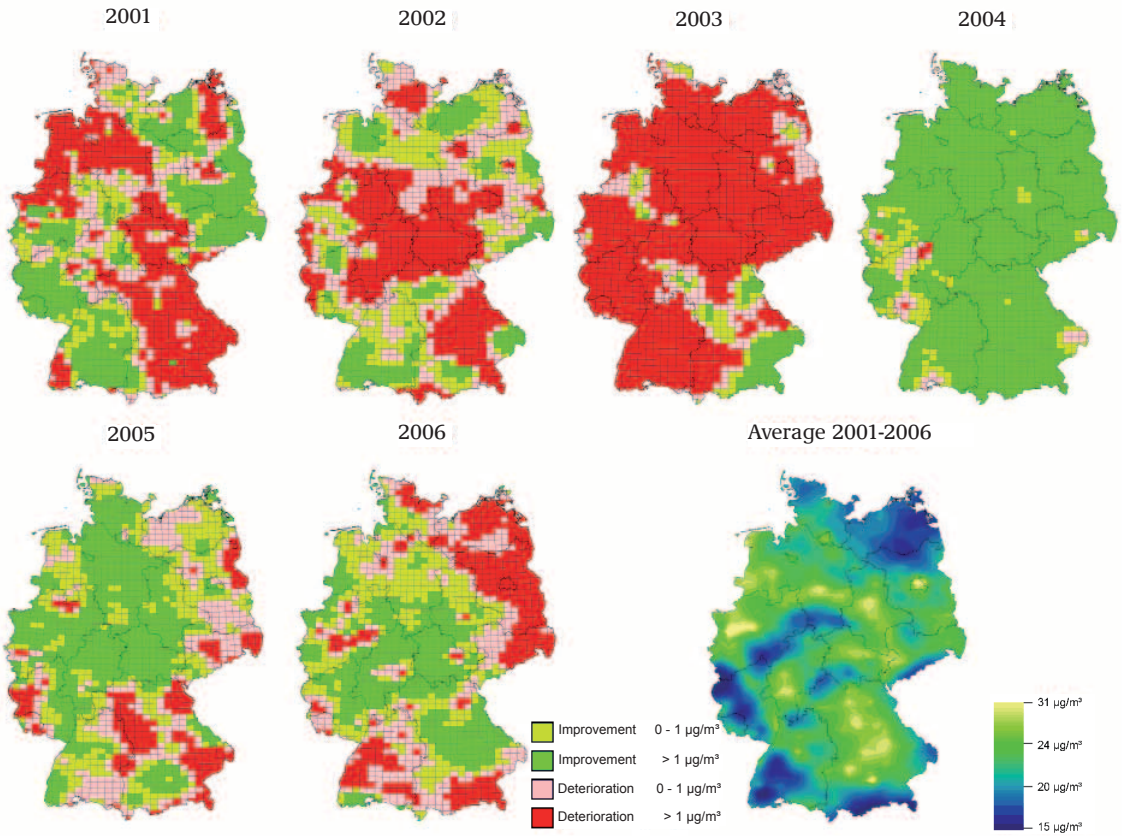


Figure 9: Average inter-annual deviation in PM_{10} annual mean values in the period from 2001 to 2006, compared to the PM_{10} mean value of the period 2001 to 2006.

Figure 9 shows the average deviation of PM_{10} annual mean values for the years 2001 to 2006, compared to the PM_{10} mean value over the 6-year period from 2001 to 2006. Areas that had higher PM_{10} annual mean values in the year under consideration, compared to the 6-year average, are coloured red. Green-coloured regions are those that, compared to the six-year average, are characterized by lower PM_{10} annual mean values. Here, too, the year 2003 is conspicuous on account of the much higher PM_{10} pollution compared to the multi-year average.

Inter-annual fluctuations are also clearly discernible in the spatial representation of the number of days with PM_{10} daily mean values in excess of 50 µg/m³ in the individual years 2001 to 2008 (Figure 10). There is a clear PM_{10} pollution slope from urban conurbations to rural areas, which, however, is less pronounced than in the case of NO_2.

Influence of weather conditions on pollution:

Air pollution is caused by emissions from widely-differing sources. The transport and distribution of pollutants in the atmosphere depends on meteorological conditions. Wintry high-pressure meteorological conditions with low wind speeds, in which vertical air exchange is limited to just a few hundred metres, lead to accumulation of pollutants in low atmospheric layers. On the other hand, weather conditions with good mixing contribute towards dispersion and thus attenuation of pollutants in the atmosphere. Furthermore, precipitation processes also play a role. This way, meteorological conditions that vary from year to year clearly characterize inter-annual fluctuations in air pollution.

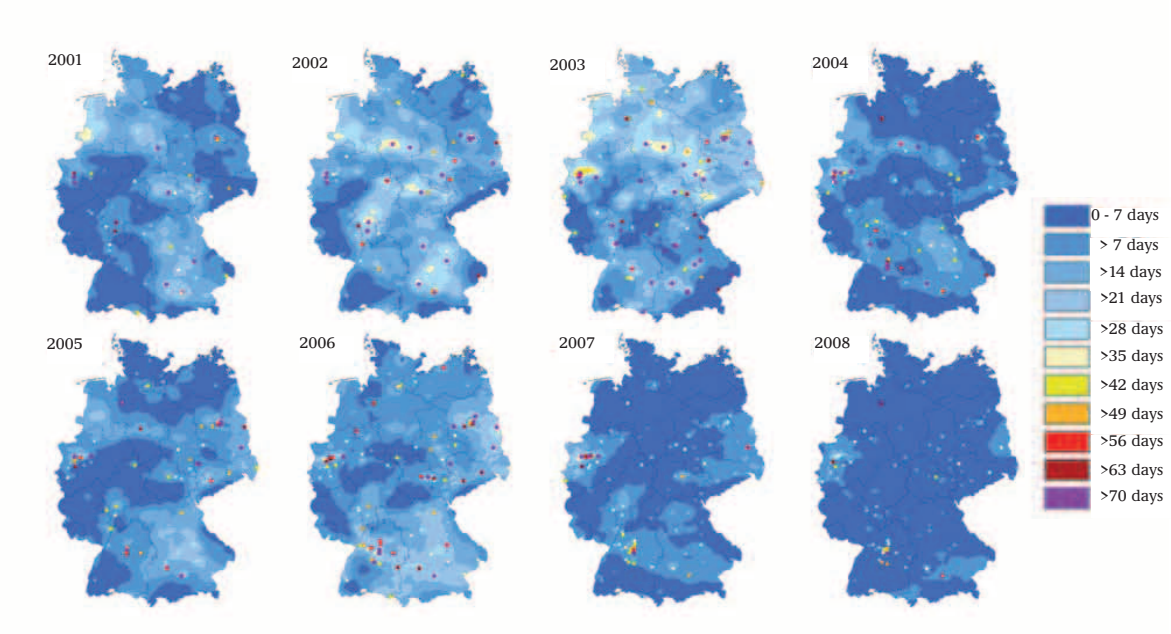


Figure 10: PM_{10} pollution – number of days with PM_{10} daily mean values in excess of 50 µg/m³ - in Germany 2001 to 2008 with "spots".

Summary:

Reductions in primary PM_{10} emissions and precursors are not reflected in the trend in PM_{10} concentrations over time. From the year 2000, PM_{10} concentrations in all three pollution regimes have been characterized merely by inter-annual fluctuations. Particulate limit values, which have been obligatory since 2005, have been exceeded even in years with comparatively low particulate pollution in the urban traffic area.


Photo: www.imageafter.com

Ozone and its precursors

Ground level ozone – three-atom oxygen, O_3 – is not directly released, but rather develops secondarily with intensive solar radiation from precursors – predominantly nitrogen oxides and non-methane volatile organic compounds (NMVOC) – through complex photochemical processes. High air temperatures and strong solar radiation favour the development of ground-level ozone in the atmosphere. This is characteristic for high-pressure meteorological conditions during the summer.

Ozone precursors have both natural and anthropogenic sources. 44% of nitrogen oxides stem from the traffic area, in particular from road traffic (see the chapter on nitrogen oxides). More than half (56%) of volatile organic compounds are released during the use of solvents. Solvents are found in many products, such as paint and varnish, adhesives and detergents. Compared with the year 1995, NMVOC and NO_x emissions in Germany declined in the period to 2007 by 39%. The largest NMVOC reductions in absolute terms occurred in the traffic area, the application of solvents and in fugitive emissions from fuels.

Although emissions of ozone precursors declined substantially, ozone annual mean concentrations have shown a clear upward trend since 1990. The increase of 0.80 µg/m³ and year in the urban background regime (Figure 12, orange curve) is the most pronounced. The difference between concentrations in urban stations (Figure 12, red and orange stations) and those in the rural background (Figure 12, green curve) steadily decreased from 1990 to 2007.

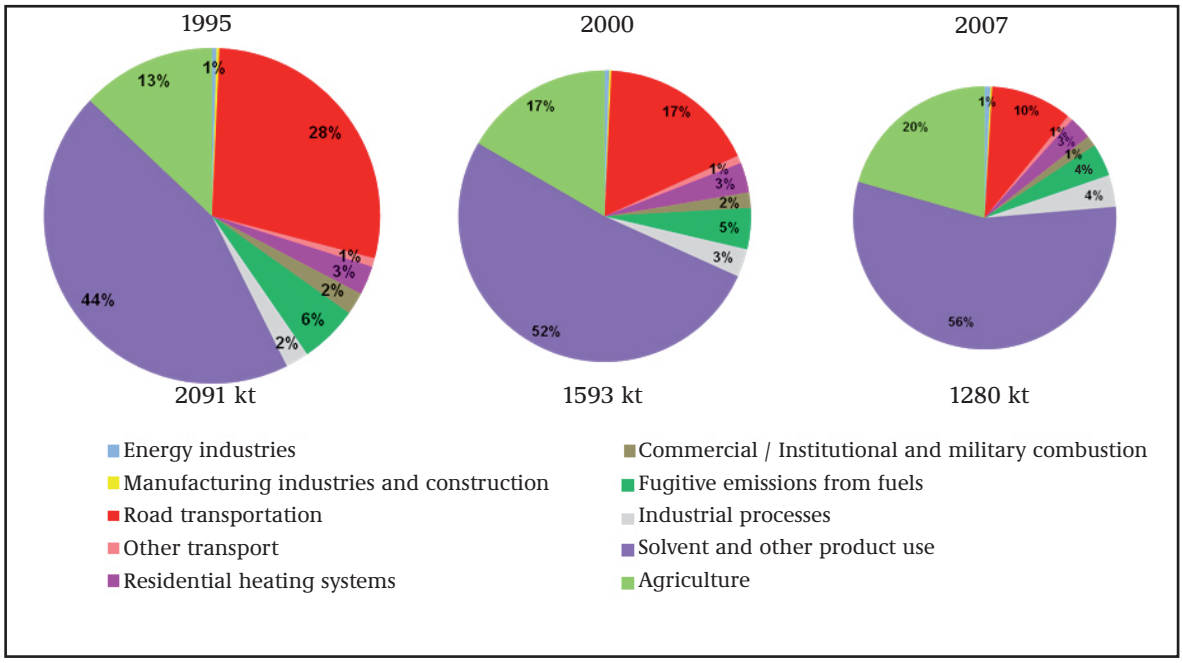


Figure 11: Percentage share in NMVOC emissions of source categories in the years 1995, 2000 and 2007.

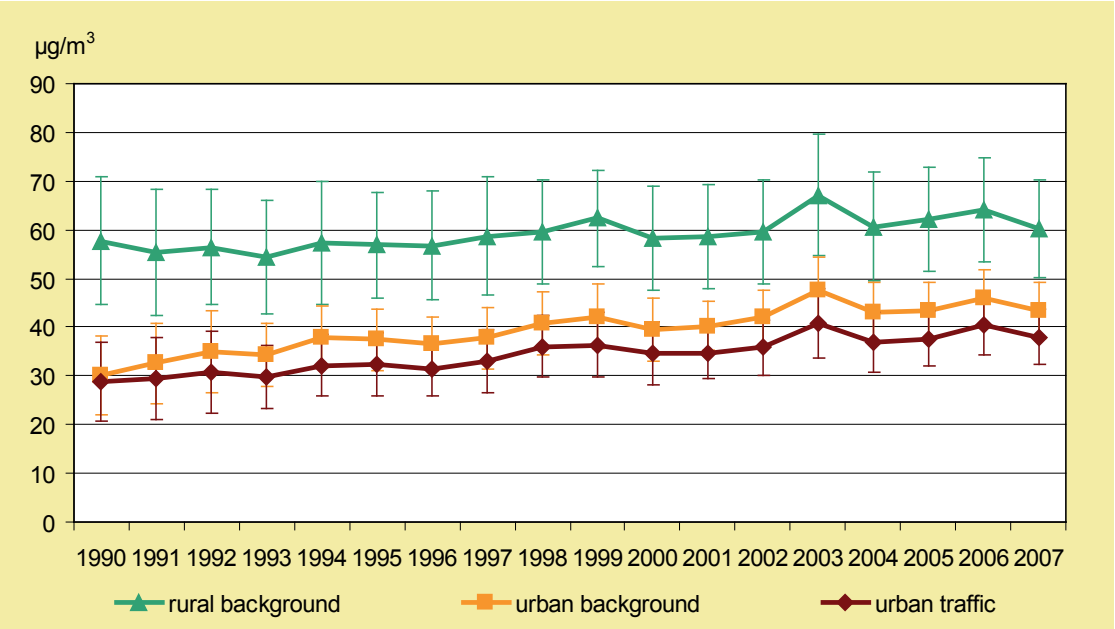


Figure 12: Trend in ozone annual mean values based on the average of measuring stations in the pollution regimes "rural background", "urban background" and "urban traffic" in the period from 1990 to 2007 (with standard deviation).

This trend can be further highlighted by means of the frequency distribution of mean hourly ozone concentrations in the urban background pollution regime (cf. Figure 13). For this purpose, mean ozone values in concentration classes of 20 µg/m³ are plotted for the period from 1990 (bar extreme left in the respective class) to 2006 (bar extreme right in the respective class).
The number of low ozone concentrations up to 20 µg/m³ greatly declined between 1990

Ozone is a highly reactive gas. Due to its oxidizing effect, increased ozone concentrations can cause, in humans, irritation of the respiratory tracts, coughing, headaches and breathing difficulties as well as restriction of lung function. The extent of ill-effects is partly determined by the duration of exposure to ozone-polluted air. Disorders, such as the occurrence of irritation of the eyes and mucous membranes are caused, above all, by ozone-accompanying compounds.

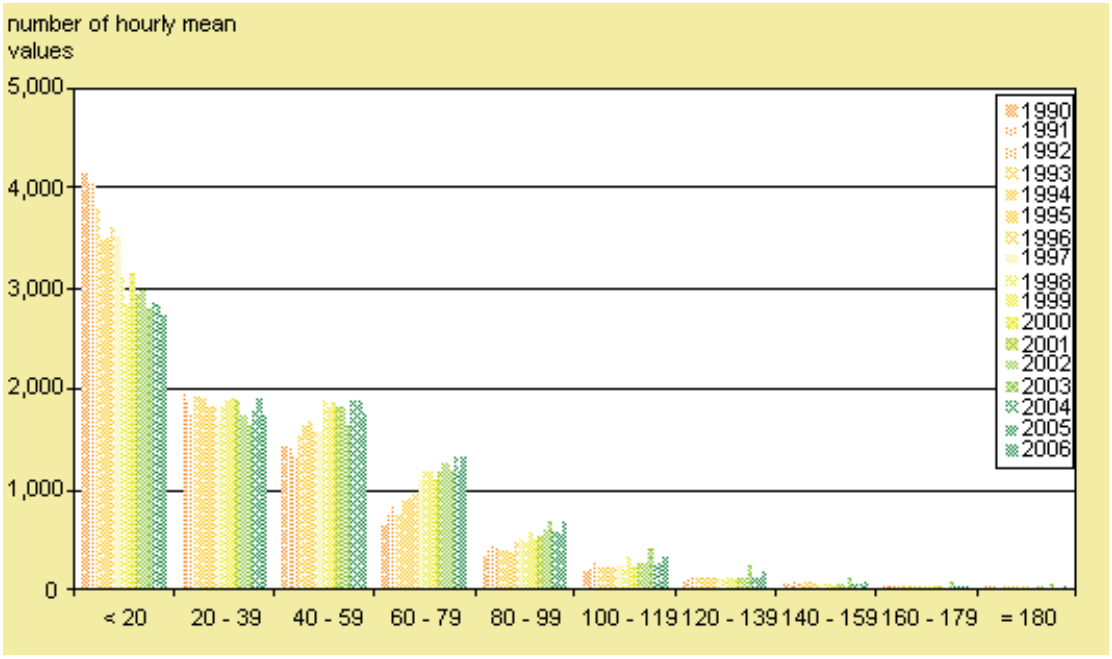


Figure 13: Trend in hourly mean values of ozone concentration by concentration class in the years 1990 to 2006 for the measuring station class "urban background".

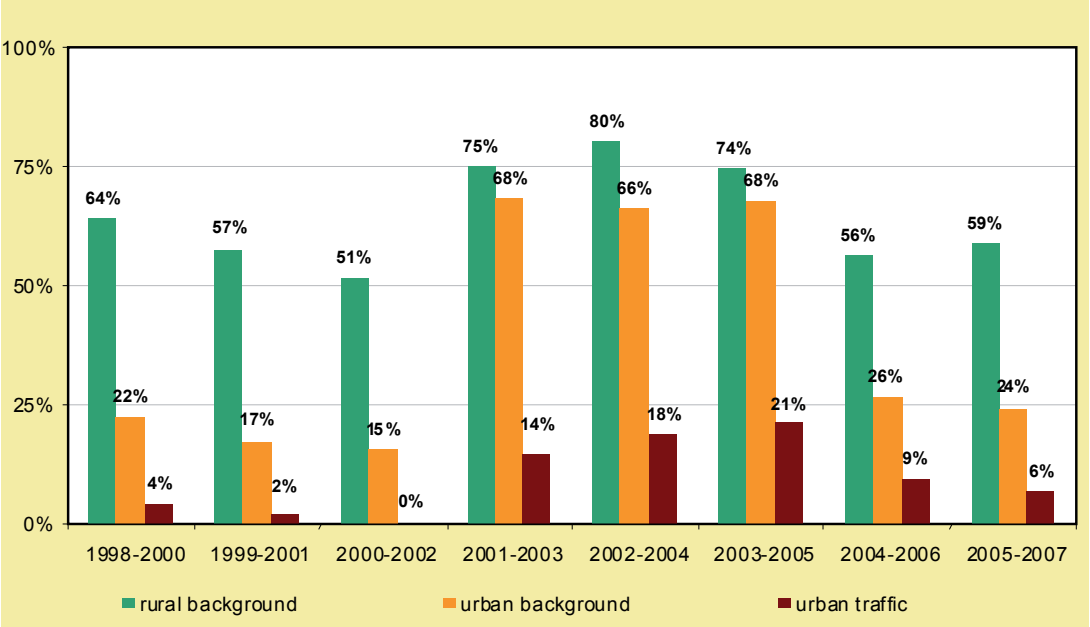


Figure 14: Percentage share of measuring stations with concentration values exceeding the ozone target value in the pollution regimes “rural background“, “urban background“ and “urban traffic” on three-year moving average.

and 2006. In the mid-range of concentrations from 40 to 100 µg/m³, on the other hand, a marked increase can be seen. The increase is greatest in the range from 60 to 80 µg/m³, where the number of concentrations doubled between 1990 and 2006. Concentrations of up to 120 µg/m³ have been observed with increasing frequency since 1990, while above this level no clear trend is discernible. In the period from 1990 to 2006, a shift has taken place from low to medium concentrations. The reason for this is the reduction in nitrogen oxide emissions. Since NO_x is predominantly emitted as NO, the reduction in NO leads to a weakening of the titration effect, by which, on account of a reaction with locally emitted NO, ozone is degraded while NO is oxidized to NO_2. This leads to increased ozone persistence. The diminishing number of low ozone concentrations with a concurrent increase in the number of middle-range ozone concentrations gives rise to an increase in ozone average mean concentrations. The increase in annual mean concentrations in the rural background can be explained with the increase in the share of ozone pollution that arises with northern hemisphere transport. This shift has no recognizable effect on the frequency of exceedance of ozone target values for the protection of human health (cf. Figure 14), since the reduction in the number of low hourly mean concentrations occurs to the advantage of middle-range concentrations, and the range of high concentrations, which is relevant for the target value, is not affected. The year 2003 alone leads in all three pollution regimes, due to the particular meteorological conditions, to an increased number of concentration values in excess of the target value.

Target values and long-term objectives for O_3

Designation	Average period	Target value for 2010	Long-term objective
Protection of human health	Maximum daily 8-hour mean	120 µg/m³ not to be exceeded on more than 25 days per calender year, averaged over three years	120 µg/m³ within a calendar year
Protection of vegetation	AOT40, calculated from 1 h values from May to July	18,000 µg/m³•h, averaged over five years	6,000 µg/m³•h within a calendar year

Summary:

The level of peak ozone concentrations and the frequency of very high ozone values have clearly decreased since 1990. The emission reduction measures that were introduced in the 1990s to combat "summer smog" have proven to be effective. In contrast to the trend in peak values, ozone annual mean concentrations have increased in the same period. This increase is most pronounced in the urban background, and is attributable to the weakening of the titration effect on account of lower nitrogen oxide emissions. The target value for 2010 for the protection of human health will continue to be exceeded.

Conclusions and implications for future measures

The trend in concentrations of the air pollutants NO_2, PM_{10} and O_3 over time clearly shows that for causal analysis there are insufficient grounds to directly infer an improvement in air quality from a reduction in emissions. This must be taken into consideration in future in the deduction of indicators. Beyond that, it is apparent that some pollutant-specific measures had an effect on other pollutants. Through the disproportionately high rise in the share of diesel vehicles in the total vehicle fleet, and through technical reduction of vehicle-related particulate emissions, the NO/NO_2 emission ratio has therefore changed and contributed to an increase in NO_2 pollution. This is a clear argument for expedited introduction of the EURO 5 and, in particular, EURO 6 norm for passenger cars and commercial vehicles. A further example, which has basically to be welcomed, is the decrease in traffic-related NO emissions, which, however, is accompanied by a weakening of the titration effect and results in increased ozone concentrations in urban conurbations. The necessity of greater efforts towards the abatement of emissions of volatile organic compounds therefore remains, particularly in the use of solvents and product use.

Observations also show that with the decline in industrial and traffic-related emissions, the relative importance of other sectors for pollution grows. Reduction measures in the agricultural sector have up to now not been pursued with the required determination, as a result of which the decrease in concentrations of particulates in the rural background, and thus also in urban conurbations, has remained behind the required, cost-effective rate.

Since limits on particulate emissions, despite improved exhaust gas treatment in the traffic area, cannot be complied with in the urban traffic pollution regime, additional non-technical measures remain necessary. The main focus is on traffic avoidance and speed limit, which contribute, at the same time, towards city centres worth living in.

Emissions from as yet secondary sectors, such as single combustion with solid fuels, likewise gain in importance in the context of climate policy. The laying down of ambitious

regulations for small-scale combustion plants and their fuels is a measure with which, inter alia, particulate emissions are effectively limited.

At the same time, efforts in the area of technical emission reduction must be maintained also in the future. Large stationary plants have to be continuously adapted to the latest developments in technology, in order to minimize as far as possible nitrogen oxides as well as ozone and particulate precursors. Apart from road traffic, air traffic and shipping has also to be included in emission reduction concepts. In order to weigh up and compare available measures and to take cost-optimized decisions, the laying down of national emission ceilings through international agreements has proven of value. The limit values laid down for 2010 have to be urgently revised and supplemented with a regulation for particulate emissions.

Although limit and target values for some air pollutants are still exceeded, immission control during the past 30 years in Germany has also recorded a number of successes. With the Federal Immission Control Act (Bundes-Immissionsschutzgesetz) of 1974, for the first time systematic regulation – in particular of state-of-the art emission limitation – was introduced of new installations and existing plants in polluted areas. The 1980s were marked by extensive remediation programmes for all power plants and major industrial plants. In the 1990s, sources of emission in the new federal states (the former GDR) were fundamentally remediated and replaced with modern plants with state-of-the-art emission reduction facilities. Pollutants such as soot and coarse dust, sulphur dioxide and summer smog with the lead compound ozone are therefore nowadays no longer a problem. This applies also to carbon monoxide, benzene and lead.

Protection against harmful influences on human health and the environment, as well as their prevention, remain an important task for German and international air pollution control policy on the way towards cleaner air in Germany.