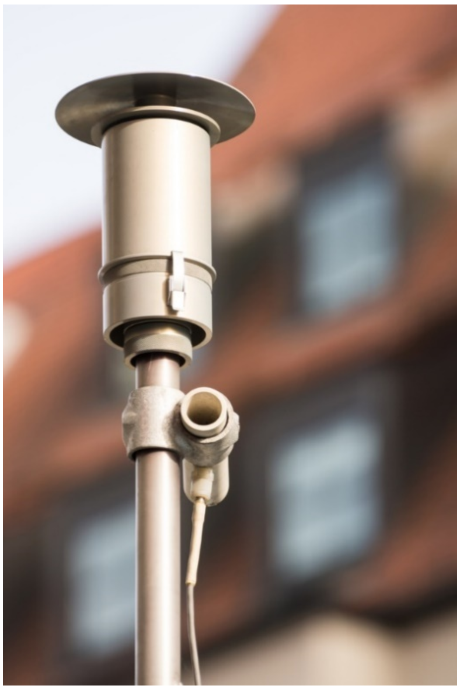
STUDY

Requested by the ENVI committee

Sampling points for air quality

Representativeness and comparability of measurement in accordance with Directive 2008/50/EC on ambient air quality and cleaner air for Europe



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Abstract

Air quality monitoring at fixed sites is a major instrument provided for in the Ambient Air Quality Directive to check compliance with limit or target values, which have been set for the protection of human health. This study analyses the criteria for the location of monitoring sites in five Member States to identify ambiguous provisions that might lead to different assessments of air pollution exposure.

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CONTENTS

LIST OF ABBREVIATIONS

AAQD	Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe
AG	Agglomeration zone
AGRI	Agriculture and Rural Development Committee
ARPALAZIO	Agenzia Regionale Protezione Ambientale del Lazio
AUBE	Axes Ultra Basse Émission (ultra low emission axes)
BR	Ballungsraum (agglomeration)
CDR	Central Data Repository
DWD	Deutscher Wetterdienst (Germany's National Meteorological Service)
EEA	European Environment Agency
FAIRMODE	Forum for air quality modelling in Europe
LEZ	Low Emission Zone
LANUV	State Agency for Nature, Environment and Consumer Protection of North Rhine-Westphalia
CEN	European Committee for Standardization
ENVI	Committeeon the Environment, Public Health and Food Safety of the European Parliament
MS	Member State(s)
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NONAG	Non-agglomeration zone
O_3	Ozone
OGD	Open Government Data
PM	Particulate Matter (addresses both PM_{10} and $PM_{2.5}$)

PM_{10}	Particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 10 µm aerodynamic diameter
$PM_{2.5}$	Particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 2.5 µm aerodynamic diameter
PPA	Plan de Protection de l'Atmosphère
PRIA	Piano Regionale degli Interventi per la qualità dell'aria
PUMS	Piano Urbano Mobilità Sostenibile
RB	Rural Background
RIU	Rhenish Institute for Environmental Research
SB	Suburban Background
TC	Technical Committee
UB	Urban Background
UT	Urban Traffic
ZCR	Zone à Circulation Restreinte (traffic restricted zone)

LIST OF BOXES

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Background

Directive 2008/50/EC on ambient air quality and cleaner air for Europe (AAQD) lays down limit and target values for certain air pollutants. Compliance with these thresholds is checked by air quality monitoring sites, which have to be installed by Member States at specific locations. There are two main types of monitoring site locations, those measuring the highest concentration with risk of general population exposure during a certain period, and locations measuring a more general exposure. To ensure comparability across Europe, the AAQD defines criteria for the location and number of monitoring sites. In addition, these criteria should ensure a certain representativity of sites, as their number is limited, also due to financial restrictions.

Aim

This study aims at supporting the Committee on the Environment, Public Health and Food Safety of the European Parliament (ENVI) in their efforts to assess the adequacy of the criteria for air quality monitoring for a harmonised and consistent implementation of the provisions of the AAQD. To that end, a representative selection of monitoring stations in zones in Austria, Germany, France, Italy, and Poland was examined. Furthermore, this study investigates differences in exposure and exposure trends in the selected Member States. It also provides an overview of measures implemented to improve air quality and of information provided to the public.

Criteria for the number of monitoring sites

The AAQD requires a minimum number of monitoring sites per zone, depending on its air pollution levels and population density.

In most of the analysed zones, the legal provisions for the minimum number of monitoring sites are fulfilled. However, in some zones $PM_{2.5}$ monitoring sites were missing.

Siting criteria for monitoring sites

Provisions of the AAQD for macroscale and microscale siting criteria for air quality monitoring sites should ensure representative and consistent monitoring strategies for air pollutants for all zones in Europe.

Most of the analysed monitoring stations comply with the siting criteria. In several cases however, nearby trees could obstruct a free air flow.

However and with the exception of Germany, no documentation is available showing if the traffic-orientated monitoring stations cover the areas with the highest concentration per zone. Furthermore, none of the analysed Member States have prepared documentation showing if monitoring sites reflect the general population exposure.

Different implementation and ambiguities

The broad siting specifications and criteria of the Directive can be interpreted differently by Member States. Therefore, this study assesses how Member States transposed the AAQD into national legislation. Furthermore, it analyses the ambiguities in its provisions and guidance documents, as well as their possible impact on the assessment of the general population exposure.

In most of the analysed Member States, the AAQD was directly transposed into national law, without amendments regarding the number and criteria for monitoring stations. The following main ambiguities in the provisions were identified:

- According to the AAQD, microscale criteria apply only "in so far as practicable", and the macroscale criteria only "where feasible". This leaves room for interpretation and requires the network operator to only document cases related to deviations from the microscale criteria;
- There is no definition for the general population exposure;
- There is a number of unspecific provisions, such as those regarding the distance to buildings, the air flow to the inlet sampling and the vicinity of sources;
- There are some ambiguities concerning the distribution of monitoring stations between an "urban background" and "traffic".

Exposure to air pollutants and measures to reduce exposure

Of all analysed zones at urban background sites, which are the most relevant station type regarding general exposure, the highest NO_2 levels occur in Italy. PM_{10} and $PM_{2.5}$ levels are highest in the Po Valley (Lombardy) and Poland, while ozone levels are highest in the Po Valley. In general, air pollutant levels have declined in recent years. An exception is ozone, which shows a more stagnant tendency.

In case of exceedances of an air quality limit or target value, the AAQD requires the Member States to develop and implement an air quality plan. The plan has to ensure compliance with the limit value in the shortest time possible. Such a plan has been implemented in all analysed zones and agglomerations. Most of these plans include a number of traffic-related measures and general traffic strategies, e.g. to improve public transport and reduce private car use. Krakow and Warsaw aim to reduce solid fuel use for domestic heating, which is the major source of air pollution in these cities.

An estimation of the measure's and the plan's impact on the exposure to air pollutants is available only for a few zones and agglomerations.

Conclusions

Based on the analysis of monitoring sites, air quality data and air quality plans, the following conclusions can be drawn.

The Member States directly transposed the provisions of the AAQD. Therefore, the ambiguities of the provision are also reflected in the national legislation.

Most of the requirements of the AAQD were fulfilled in all analysed Member States. Especially the number of monitoring stations is clearly sufficient in every case. Nevertheless, it is not clear from the available documentation if the location with the highest concentration is covered by a fixed monitoring site in all Member States. In addition, air flow at some monitoring sites might be obstructed by trees.

The analysis revealed a number of ambiguities in the current provisions, which should be clarified when revising the AAQD. This refers in particular to the methods for the identification of the highest concentration and the general population exposure, to a number of imprecise or ambiguous provisions in the siting criteria, and to certain definitions in the current guidance document. These ambiguities could lead to differing assessments of maximum concentrations and general population exposures, thereby potentially compromising the protection of human health against the negative impact of air pollution. In addition, documentation of site selection is not readily available for most zones. This documentation would allow to fully assess if a monitoring site fulfils the criteria and whether the highest concentrations are covered by the monitoring network.

Recommendations

The following main recommendations provided below are based on the findings of this study and could be addressed during the review process of the AAQD:

- Development of provisions for the identification of highest concentrations, including regular updates, modelling and / or passive sampling campaigns;
- Clarification of the ambiguities in the provisions regarding the microscale and macroscale siting criteria, as well as the number and distribution of monitoring stations;
- Provisions for the delivery of documentation (and regular update) of monitoring site selection, comprising requirements for a complete, thorough assessment, including modelling;
- Development of definitions for imprecise but crucial concepts, such as the "general population exposure" and provisions for the representativeness of monitoring sites;
- The impact of suggested changes to the provisions regarding monitoring locations should be substantiated by modelling or monitoring exercises;
- The number of $PM_{2.5}$ sites is considerably lower compared to PM_{10}, which does not reflect $PM_{2.5}$'s potential impact on human health. Their required minimum number should therefore be increased.
- Regarding air quality plans, requirements for diesel vehicles could be tightened in some zones, and a general reduction of the overall amount of traffic could be considered.

1. GENERAL INFORMATION

KEY FINDINGS

Air pollution is the main environmental risk factor for human health.

Air quality monitoring stations at fixed locations are the main tool to measure the concentration of air pollutants.

The criteria laid down in the Ambient Air Quality Directive are to be used to determine how many air quality monitoring stations Member States have to establish and where to put them.

Altogether around 50 air quality stations in five Member States are analysed in this study for the purpose of determining whether these criteria are fulfilled and whether the provisions allow for a harmonised implementation.

1.1. Background

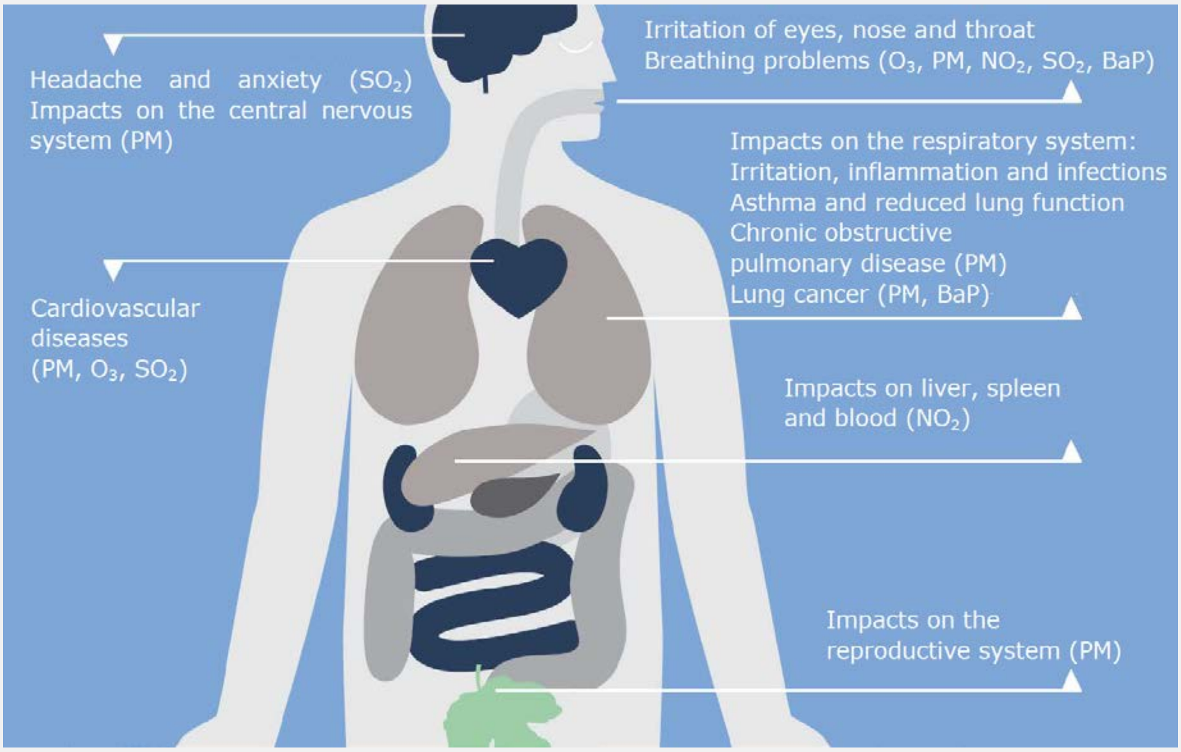
The aim of this study is to provide the Committee on the Environment, Public Health and Food Safety of the European Parliament (ENVI) with information on whether the criteria for the monitoring and assessment of air quality laid down in the AAQD allow for a harmonised and consistent implementation of the AAQD throughout the EU. For this purpose, a representative selection of PM_{10}, $PM_{2.5}$, NO_2, and O_3 monitoring stations in selected zones in Austria, Germany, France, Italy, and Poland is examined. Using these stations as examples, the study aims at identifying those provisions in the AAQD (and other relevant legislation such as Decision 2011/850/EU and the relevant Guidance) which allow for a different interpretation and thus implementation. The study also analyses the implications of differences in implementation for air quality assessment.

Furthermore, the study investigates differences of exposure in these selected Member States and relevant trends and provides an overview of measures implemented in order to improve air quality and of the information provided to the public.

Box 1: Health impacts of air pollutants

Health impacts of air pollution

Air pollutants can have severe impacts on human health (WHO 2013a, 2013b, 2015). $PM_{2.5}$, PM_{10}, O_3 and NO_2 are pollutants of major health concern in general. The illustration below provides a schematic overview of health impacts.



There is widespread evidence throughout the world on adverse health effects associated with exposure to ambient $PM_{2.5}$ and PM_{10} (WHO 2013a, 2013b). These health impacts include effects on the respiratory and cardiovascular system for large groups of the general population, leading to an increased risk of premature mortality and thus a reduced life expectancy.

Ozone affects respiratory and cardiorespiratory mortality. Adverse effects of ozone on asthma incidence and lung function growth have also been reported. Short-term exposure (as analysed for 1-hour and 8-hour mean ozone concentrations) has been shown to have adverse effects on all-cause, cardiovascular and respiratory mortality.

There are many new studies showing associations between short-term and long-term exposure to NO_2 and mortality and morbidity. These effects were found in areas where concentrations were at or below the current standard values.

These health impacts are associated with substantial costs for society; thus, the benefits of stringent air quality policies are usually much higher than the costs (European Commission 2013a, US EPA 2011)

Source: EEA 2013, Nagl et al. (2016).

1.2. Aim and structure of the study

The study explains the main issues and problems regarding the monitoring of air quality in the EU, summarises the measures taken by selected Member States to reduce exposure to air pollutants and draws policy-relevant conclusions.

The structure of the document is as follows:

Chapter 2 provides an overview of the legal background relevant for air quality monitoring and management.

In Chapters 3 and 4 we analyse the number of monitoring sites and their location and compare our findings to the requirements of the AAQD. In addition, we analyse whether Member States have gone beyond these requirements (Chapter 5.2).

Chapter 6 shortly summarises the main measures that Member States and regional authorities have implemented to reduce exposure to air pollutants. In addition, we summarise information provided to the public on air quality and the impact of air pollutants on human health.

Based on the findings of Chapters 3 to 6, we draw conclusions and provide recommendations, which can be found in Chapter 7.

Annex A provides detailed descriptions of the monitoring sites.

Annex B provides more detailed exposure data.

Annex C shows examples of microscale modelling results.

Annex D lists limit values, target values and assessment thresholds for air pollutants.

1.3. Selection of Member States, zones, and monitoring sites

The evaluation of whether the siting criteria for air quality monitoring sites have been applied according to Annexes III, V, VIII and IX of the AAQD is based on selected representative monitoring sites in the following Member States, according to the specifications for this study:

- Austria,
- France,
- Germany,
- Italy and
- Poland.

As the larger Member States are divided into a large number of zones and agglomerations, we have focused on a selected number of zones and agglomerations. This selection of zones within Member States (which are listed in Table 1) is based on the following criteria:

- agglomeration with the highest population number;
- agglomeration with the highest NO_2 and/or PM_{10} pollution levels;
- non-agglomeration zone surrounding one of the above mentioned agglomerations[1].

[1] In Germany, two highly polluted large agglomerations (Munich and Stuttgart) have been selected (rather than the biggest agglomeration Berlin with comparably low pollution levels); and in addition, in the province North Rhine-Westphalia – which covers the most densely populated part of Germany, but with a population that is distributed over a multitude of medium-sized agglomerations

Table 1: List of zones analysed in this study (ag: agglomeration; nonag: non-agglomeration).

Name	Zone code	Zone type	Zone name	Population
Styria (without Graz)	AT_06	nonag	Steiermark ohne BR Graz	930,000
Vienna	AT_09	ag	Wien	1,889,000
Graz	AT_60	ag	BR Graz	310,000
Stuttgart	DEZCXX0007A	ag	Stuttgart	1,146,000
Munich	DEZDXX0001A	ag	München	1,500,000
Düsseldorf	DEZJXX0009A	ag	Düsseldorf	996,000
Urban and rural areas in North Rhine-Westphalia	DEZJXX0016S	nonag	Urbane Bereiche und ländlicher Raum im Land Nordrhein-Westfalen	8,056,000
Duisburg	DEZJXX0017A	ag	Duisburg	1,054,000
Paris	FR11ZAG01	ag	Paris	10,755,000
Ile-de-France	FR11ZRE01	nonag	Ile de France	1,272,000
Marseille - Aix - en - Provence	FR93ZAG01	ag	Marseille - Aix - en - Provence	1,817,000
Milan	IT0306	ag	Milano	3,540,000
Urbanised surroundings of Milan	IT0309	nonag	Zona A - Pianura ad elevata urbanizzazione	2,886,000
Rome	IT1215	ag	Roma	3,286,000
Krakow	PL1201	ag	Kraków	767,000
Lesser Poland	PL1203	nonag	Strefa Małopolska	2,510,000
Warsaw	PL1401	ag	Warszawa	1,758,000

Source: Umweltbundesamt, EEA Central Data Repository.

and towns – two medium-sized agglomerations (Düsseldorf and Duisburg) and a large zone that covers all rural and medium-sized towns areas in North Rhine-Westphalia have been selected.

In these zones and agglomerations, 10 to 12 monitoring sites per Member State have been selected for in-depth analysis according to the following criteria and specifications for this study:

- fairly equal distribution across all zones in the Member State (i.e. 3 or 4 sites per zone in AT, FR, IT, and PL, 2 to 3 sites per zone in DE);
- urban traffic[2] site(s) with the highest NO_2 and PM_{10} levels;
- urban background site with the highest NO_2; and PM_{10}[3] levels (if no urban background site exists, a suburban site is selected[4])
- additional highly polluted urban traffic sites[5] or urban industrial sites[6] (if the selection based on the above criteria results in less than 10 sites per Member State);
- site with the highest O_3 levels that is most relevant for the exposure of the population;
- relevance for similar situations in other Member States and identification of possible ambiguities of the criteria and provisions for the sampling sites.

The selected stations are listed in Table 10 in Annex A.

The analysis is based on the monitoring sites operated in the year 2017 and officially reported via dataflow D to the Central Data Repository (CDR) operated by the European Environment Agency (EEA)[7].

2. LEGAL BACKGROUND

KEY FINDINGS

The Ambient Air Quality Directive (AAQD) sets limit and target values for the concentration of air pollutants, and specifies the monitoring and reporting requirements.

Annexes V and IX of the AAQD specify minimum numbers of monitoring stations per zone, corresponding to population number and pollution level.

Annexes III and VIII of the AAQD specify criteria for the location of monitoring stations.

2.1. The Air Quality Directive in general

Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (AAQD) entered into force on 11 June 2008, merging previously existing legislation into one directive:

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2 Corresponding to "Classification or area" (urban/suburban/rural) and "Station classification in relation to prominent emission sources" (traffic/industrial/background) according to "IPR Guidance" (DG ENV 2018).

3 In zone IT0309, station IT1104 is the urban traffic site with the highest NO_2 levels which has also been selected because of its maximum urban traffic PM_{10} pollution levels (annual mean 2017: 41.2 µg/m³, which is slightly lower than at the urban traffic site with the highest PM_{10} levels, i.e. IT1286: 41.3 µg/m³). In zone IT1215, station IT0956 has been selected as an urban background PM_{10} site (28.5 µg/m³), despite having a lower PM_{10} level than IT1176 (30.5 µg/m³), because IT0956 is the monitoring site with the highest ozone levels; the "low" ozone level (26 days with 8-hour mean values above 120 µg/m³) at this site is an issue that deserves further investigation.

4 This is the case in the zones DEZJXX0016S and FR11ZRE01 (PM_{10}; no urban or suburban NO_2 site).

5 FR04012 in zone FR11ZAG01.

6 DENW338 in zone DEZJXX0017A, PL0039 in zone PL1201.

7 See references to Table 10 in Annex A.

- Council Directive 96/62/EC of 27 September 1996 on ambient air quality assessment and management (Air Quality Framework Directive);
- Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air (1st Daughter Directive);
- Directive 2000/69/EC of the European Parliament and of the Council of 16 November 2000 relating to limit values for benzene and carbon monoxide in ambient air (2nd Daughter Directive);
- Directive 2002/3/EC of the European Parliament and of the Council of 12 February 2002 relating to ozone in ambient air (3rd Daughter Directive);
- Council Decision 97/101/EC of 27 January 1997 establishing a reciprocal exchange of information and data from networks and individual stations measuring ambient air pollution within the Member States.

The Ambient Air Quality Directive (AAQD) regulates ambient air concentrations of air pollutants to protect human health and the environment and covers the following pollutants: sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and other nitrogen oxides (NO_x), particulate matter PM_{10} and $PM_{2.5}$, lead (Pb) in PM_{10}, carbon monoxide (CO), benzene (C_6H_6) and ozone (O_3).

The AAQD stipulates limit values[8] and for some pollutants target values[9] (see Annex D of this study). The limit values have to be complied with throughout the territory (with some exceptions as specified in Annex III A of the AAQD)[10] by a given year. As regards the target values, all appropriate measures (as long as they do not entail disproportionate costs) have to be implemented to reach compliance.

The AAQD furthermore includes requirements for the assessment of ambient air quality in the Member States, applying fixed monitoring stations and modelling. These requirements include macro- and microscale siting criteria for different types of air quality monitoring stations as well as requirements for quality assurance and quality control.

In addition to the AAQD, further pollutants (heavy metals, polycyclic aromatic hydrocarbons) are regulated in Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air, the so-called 4th Daughter Directive. However, the scope of this study does not cover this Directive.

It is worth noting that the Advocate General of the Court of Justice of the European Union stated on 28 February 2019 in his opinion[11] on monitoring stations in the Brussels-Capital Region that national courts must examine whether sampling points were sited in accordance with the criteria of the AAQD in case an affected individual applied for an examination. He also stated that compliance with limit values had to be assessed at individual sites, without obtaining an average from several sampling points.

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8 For SO_2, NO_2, NO_x, PM_{10}, $PM_{2.5}$, Pb in PM_{10}, CO, C_6H_6.

9 For O_3, $PM_{2.5}$; 4th Daughter Directive: arsenic, cadmium, nickel and polycyclic aromatic hydrocarbons.

10 Annex III A 2 states that air quality shall not be assessed at any location where members of the public do not have access and there is no fixed habitation, on factory premises, on the carriageway of roads and on the central reservations of roads except where there is normally pedestrian access to the central reservation.

11 https://curia.europa.eu/jcms/upload/docs/application/pdf/2019-02/cp190021en.pdf.

2.2. General requirements for air quality assessment

The territorial basis for air quality (AQ) assessment are zones and agglomerations (Article 4 of the AAQD), which are established by the competent authorities of the Member States. Article 6 and 7 of the AAQD provide requirements for AQ assessment, detailed specifications are laid down in Annexes V and IX (number of monitoring sites), and III and VIII (siting criteria). Fixed monitoring is required if the pollution levels exceed the upper assessment threshold (which are laid down in Annex II of the AAQD and have been summarized in Annex D of this study), and may be supplemented or replaced by indicative measurements, modelling or objective estimations.

Box 2: Different types of monitoring stations

There are three main types of air quality stations:

- Urban traffic sites

- Urban background sites

- Regional background sites

Urban traffic sites are usually located in densely built-up areas and heavily trafficked roads. They should therefore cover the pollution hotspot within a city. However, certain criteria apply to the location to ensure a certain representativeness of the measurement results.

Urban background stations should monitor the general exposure of the urban population to air pollutants.

Regional background sites should monitor the general exposure of the rural population and should be representative of large rural areas.

Source: Umweltbundesamt, Amt der Oberösterreichischen Landesregierung.

The requirements for AQ assessment comprise the following regulations:

- Minimum number of monitoring stations per zone, depending on the population number of the zone and the pollution level in relation to the assessment thresholds: Annex V for all pollutants except ozone, Annex IX (both revised by Directive 2015/1480/EU) for ozone;
- Siting criteria: Annex III (revised by Directive 2015/1480/EU) for all pollutants except ozone, Annex VIII for ozone;
- Reference methods for measurement and criteria for equivalent methods: Annex VI (revised by Dir. 2015/1480/EC);
- Data quality objectives and requirements for quality assurance including requirements for measurement uncertainty: Annex I (revised by Directive 2015/1480/EU);
- Criteria for data aggregation: Annex XI for all pollutants except ozone and Annex VII for ozone.

The minimum number of monitoring stations and the criteria are described in more detail in Chapter 3 and 4.

The reference methods and data quality objectives are described in more detail in Section 2.4 below.

2.3. Implementing Decision 2011/850/EU

The Implementing Decision 2011/850/EU lays down rules and structures for a Europe-wide exchange of air quality data, i.e. for reporting by Member States to the Central Data Repository operated by the EEA, as well as the timetable for data transmission.

The (so-called) "IPR[12] Guidance" (DG ENV 2018) provides guidance on the implementation of the AAQD and Decision 2011/850/EU, e.g. the classification of stations in relation to emissions (traffic/industrial/background), area classification (urban/suburban/rural), criteria for data aggregation, rounding rules (related to the calculation of exceedances of limit/target values), calculating data coverage and data capture.

The structure of the data to be reported to EEA is laid down in Annex II of the decision and covers:

- information about zones;
- assessment regimes (i.e. combination of zones, environmental objective[13], and assessment method[14], for a specific year);
- meta-information about the assessment method. For measurements, this includes detailed information about the monitoring network operator, the location of the monitoring station, its characterisation with respect to the predominant emissions (specific to each pollutant measured), population and dispersion conditions, and about the measurement, sampling and analytical methods applied;
- measurement data. These are to be reported in near-real time (i.e. preliminary), together with validated data sets for the previous year;
- information about the attainment of environmental objectives;

[12] Abbreviation for „Implementing Provisions for Reporting".

[13] I.e. limit values, target values etc. as laid down in Dir. 2008/50/EC and 2004/107/EC.

[14] According to Art. 6 of the AAQD this can be a fixed measurement, an indicative measurement, modelling, an objective estimation, or a combination of these.

- information about air quality management: air quality plans, source apportionment, scenarios, and measures.

2.4. Reference methods, equivalent methods, measurement uncertainty

Reference methods for measurements are laid down in Annex VI of the AAQD, whereas data quality objectives and requirements for quality assurance are laid down in Annex I. For all pollutants regulated in the AAQD standardised methods - European Standards (ENs) - are listed in Annex VI. These ENs for ambient air quality monitoring are prepared by working groups within the Technical Committee (TC) 264 for Air Quality of the European Committee for Standardization (CEN).

Non-reference methods may be used by Member States if the results are equivalent to any of those obtained with the reference methods. A guidance document was published by the European Commission in 2010 for the demonstration of the equivalence of non-reference methods (EC 2010).

For PM_{10} and $PM_{2.5}$ measurements, the reference method given in the AAQD provides 24-h average values only. To provide direct information to the public, monitoring networks usually use automated continuous measurement systems that can provide 1-h average values as an equivalent method.

The measurement uncertainty for measurements made at fixed sites ("fixed measurements") shall not exceed 15 % for NO_2, NO_x, SO_2, CO, O_3 or 25 % for benzene and particulate matter PM_{10} and $PM_{2.5}$ (AAQD Annex I). The calculation of the uncertainty is described in the European standard for the respective pollutant. The main components for the determination of uncertainty are the results of type-approval tests (in the laboratory and in the field) carried out by the analyser, site-specific conditions and own data on uncertainty sources (e.g. calibration gases, converter efficiencies) within the monitoring network.

3. CRITERIA FOR THE NUMBER OF MONITORING SITES

KEY FINDINGS

The AAQD requires a minimum number of monitoring sites, depending on air pollution levels and population density.

Specific provisions require a fairly even distribution of urban traffic and urban background monitoring stations.

The minimum number of NO_2 and PM (PM_{10} + $PM_{2.5}$) monitoring sites has been ensured in all selected zones.

In several zones, there are no dedicated traffic-related monitoring sites.

3.1. Legal provisions

Annex V A.1 of the AAQD[15] determines the minimum number of fixed monitoring stations for air pollutants[16] (for the protection of human health) per zone with respect to diffuse (i.e. non-industrial) sources. The minimum number of monitoring stations per zone depends on the pollution level in relation to the assessment thresholds (specified in Annex II) and the population of the zone. The higher the pollution level and population are, the higher the number of monitoring sites required per zone. According to Article 7(3) of the AAQD, the number of monitoring sites may be reduced if air quality assessment is supplemented by modelling or indicative measurements. Where pollution is below the lower assessment threshold, no monitoring sites are required, and the assessment may be based on modelling or objective estimation alone.

Specific requirements call for a fairly equal distribution of traffic-orientated and urban background monitoring sites, i.e. between 0.5 and 2 respectively. These requirements are laid down in footnote 1 to the table in Annex V A 1 of the AAQD.

Further specific requirements provide for a fairly even distribution of PM_{10} and $PM_{2.5}$ monitoring sites, i.e. between 0.5 and 2 respectively. These are laid down in footnote 2 to the table in Annex V A 1.

Annex IX sets out the minimum numbers for ozone monitoring sites per zone.

3.2. Checking the number of monitoring sites per zone

This subsection reviews compliance with the requirements of Annex V A. 1 of the AAQD, including:

- the minimum number of monitoring sites per zone indicated in the table of Annex V A 1, depending on pollution level (as compared to the assessment thresholds) and the population of the zone;
- an urban background/traffic site ratio (footnote 1 of the table in Annex V A. 1) of between 0.5 and 2;
- a PM_{10} monitoring site/$PM_{2.5}$ monitoring site ratio (footnote 2 of the table in Annex V A. 1) of between 0.5 and 2.

Note: The minimum number of PM monitoring stations required is ambiguous if the classification of PM_{10} and for $PM_{2.5}$ in relation to the assessment thresholds is not identical[17] (as is the case for zones AT_06, AT_09, DEZDXX0001A, and FR11ZRE01). In this case, the – stricter – number requirements related to concentrations above the upper assessment threshold were applied in the assessment.

In addition, the provisions for ozone monitoring stations (AAQD, Annex IX) were reviewed.

Compliance with the provisions of Annex V and IX was verified at zone level.

The monitoring sites that were operated in 2017 and officially reported in dataflow D on CDR were taken into account.

[15] Annex V A. 2 provides criteria for industrial monitoring sites; Annex V B. sets out monitoring requirements for the $PM_{2.5}$ exposure reduction target; Annex V C. sets out criteria for monitoring sites targeting natural ecosystem and vegetation protection. These three types of monitoring stations are not covered in this study.

[16] SO_2, NO_2, NO_x, particulate matter (PM_{10} and $PM_{2.5}$), Pb in PM_{10}, CO, and benzene.

[17] E.g. zone AT_06: PM_{10} levels are above the upper assessment threshold, which would require 4 PM monitoring sites (i.e. PM_{10} & $PM_{2.5}$); $PM_{2.5}$ levels are between the lower and the upper assessment threshold, which would require 2 PM monitoring sites.

The minimum numbers of monitoring stations as required by Annex V A 1 and Annex IX of the AAQD (and, if different, by national legislation) and the actual number of monitoring sites operated in 2017 are given in Table 9 in Annex A.

3.3. Findings

The required minimum number of NO_2 and PM (PM_{10} + $PM_{2.5}$) monitoring sites has been ensured in all zones.

The required minimum number of ozone monitoring stations (Annex IX) has been ensured in all inspected zones except for PL1201 (Kraków).

The zones that are not in compliance with some of the criteria set forth in Annex V A 1 (ratio of traffic to urban background, ratio of PM_{10} to $PM_{2.5}$ sites) are given in Table 2. The results show that

- dedicated traffic-related monitoring sites are missing in several zones[18];
- the ratio of NO_2 urban background to urban traffic sites is outside the prescribed range[19]. However, there is an ambiguity in the provision whether "urban" in footnote 1 corresponds to the area classification of "urban" (see section 5.3); if footnote 1 is understood to include "suburban" stations as well, these criteria have been met in most zones;
- in several zones, the ratio[20] of the number of PM_{10} sites to the number of $PM_{2.5}$ sites is above 2.

The assessment reveals some ambiguity with respect to the interpretation of Annex V A. 1, footnote 1.

The lack, and in some zones the complete absence, of monitoring stations to measure "traffic" PM_{10} or $PM_{2.5}$ may cause maximum concentrations in the various zones to be underestimated. Compared with "suburban" monitoring stations, the lack of "urban" background monitoring stations in a number of zones likely causes the exposure of the general population to be underestimated.

Actually, many more PM_{10} monitoring stations are being operated in most zones than $PM_{2,5}$ monitoring stations. This is due to the following:

- The current limit value for PM_{10} (daily mean value) is more stringent than that for $PM_{2.5}$, as can be seen in the number of monitoring stations where the limit values are exceeded. As a result, there are more zones where the upper assessment threshold is exceeded by PM_{10} levels than by $PM_{2.5}$ levels. Therefore (according to Annex V A. 1), more PM_{10} than $PM_{2.5}$ sites need to be operated (irrespective of the provisions set forth in footnote 2).
- Furthermore, since PM_{10} monitoring started long before $PM_{2.5}$ monitoring, there are actually many more PM_{10} monitoring sites operating in most zones than $PM_{2.5}$ monitoring sites. This ensures compliance with the prescribed $PM_{10}/PM_{2.5}$ site ratio[20] of between 0.5 and 2.0.

[18] Poland plans to put additional traffic-orientated stations into operation in 2019.

[19] Annex V A. 1, footnote 1.

[20] Annex V A. 1, footnote 2.

Table 2: Non-compliance with Annex V A. 1 provisions in the selected zones

Provision	Non-compliant zones	Comment
Ratio of PM_{10} to $PM_{2.5}$ monitoring sites: between 0.5 and 2	DEZJXX0017A Duisburg FR93ZAG01 Marseille – Aix-en-Provence	Insufficient number of $PM_{2.5}$ monitoring stations
Ratio of urban background to traffic NO_2 monitoring sites: between 0.5 and 2	DEZCXX0007A Stuttgart DEZJXX0016S Urban and rural areas in North Rhine-Westphalia FR11ZRE01 Ile-de-France	*
Ratio of urban background to traffic PM_{10} monitoring sites: between 0.5 and 2	DEZJXX0016S Urban and rural areas in North Rhine-Westphalia	No traffic and no urban background PM_{10} monitoring stations
	FR11ZRE01 Ile-de-France	*
	PL1203 Strefa Małopolska	No traffic PM_{10} monitoring stations
Ratio of urban background to traffic $PM_{2.5}$ monitoring sites: between 0.5 and 2	AT_60 Graz FR11ZAG01 Paris FR93ZAG01 Marseille – Aix-en-Provence	*
	PL1203 Strefa Małopolska DEZJXX0017A Duisburg	Footnote 1 to the Table in Annex V A 1. requires "at least one urban background monitoring station and one traffic-orientated monitoring station" for particulate matter. It is not clear if this provision refers to the sum of PM_{10} and $PM_{2.5}$ monitoring sites or to the PM_{10} and $PM_{2.5}$ monitoring sites respectively. In the latter case, there is an insufficient number of traffic $PM_{2.5}$ monitoring stations in these zones.
	PL1401 Warsaw	

Source: Umweltbundesamt.

* Note: Footnote 1 to the Table in Annex V A 1. requires "at least one urban background monitoring station". It is not clear if "urban" in this case corresponds to the area classification of "urban" in 2011/850/EC Annex II (D) (ii) (28) and Guidance DG ENV (2018) or whether it includes stations classified as "suburban". In the latter case, the requirements regarding the ratio of urban background to traffic stations have been met.

4. SITING CRITERIA FOR MONITORING STATIONS

KEY FINDINGS

Macroscale and microscale siting criteria for air quality monitoring sites should ensure representative and consistent monitoring strategies for air pollutants in all zones.

Most of the analysed monitoring stations comply with the local siting criteria. In several cases, nearby trees may obstruct free air flow to the air inlet.

Documentation on the methods implemented to identify the areas with the highest concentrations in the zone is available only for Germany.

There is no documentation available on the representativeness for exposure of the general population in any zone.

Annex III (revised by Directive 2015/1480/EU) of the AAQD provides criteria for siting monitoring stations for all pollutants except ozone[16], whereas Annex VIII describes the siting criteria for ozone.

Siting criteria are given on two different scales:

- Macroscale siting criteria define the general position of monitoring stations within a zone.
- Microscale siting criteria address the immediate vicinity of the monitoring station. These criteria provide basic requirements to ensure that a monitoring station is representative for the area addressed by the macroscale siting criteria.

Generally, measurement data should be representative for large areas: some 100 meters for hot-spots, several kilometres for urban areas in case of background stations and up to one hundred kilometres for remote rural areas. Therefore, care should be taken that a monitoring station does not measure conditions representative only of the station's close vicinity.

4.1. Macroscale siting criteria

4.1.1. Legal provisions

The macroscale siting criteria in Annex III B. aim to ensure that measurements are representative for the average exposure of human population, natural ecosystems and vegetation. As the purpose is to protect human health (AAQD Annex III B I (a) as revised by Directive 2015/1480/EU), the measurements must specifically be made

a) in areas where the highest concentrations in the zone occur to which the population is likely to be directly or indirectly exposed for a period which is significant in relation to the averaging period of the limit value(s);

b) in areas which are representative for the exposure of the general population.

Annex III B 1 (b) specifies that the area where the highest concentrations in the zone occur should cover a street segment of at least 100 m length or an area of at least 250 m x 250 m (in the case of industrial sites).

4.1.2. Assessing the location of monitoring sites

The assessment of the macroscale siting criteria is based on the assumption that the area where the highest concentrations in the zone occur is a "traffic" site for NO_2 and in some specific cases an "industrial site".

Depending on the predominance of PM emissions from road traffic, industry, or domestic heating, respectively, the highest concentrations for PM_{10} and $PM_{2.5}$ may occur at any type of site.

The siting criteria for the location of the "highest concentration" in a zone include a reference to the averaging period of the limit value(s). The shortest averaging period for NO_2 is one hour, whereas it is one day for PM_{10} and one calendar year for $PM_{2.5}$. Therefore, a monitoring site that meets the criteria[21] should be representative of areas (a street segment of at least 100 m length) where people are exposed over these time periods or longer.

When it comes to the criterion addressing the "general population", it must be noted that neither EU legislation nor the IPR Guidance (DG ENV 2018) provide any definition for "exposure of the general population". Therefore, only a qualitative assessment can be made to establish whether a monitoring station is likely representative for large urban or suburban residential areas. In any case, the assumption is that urban background monitoring sites are suitable for tracking the "exposure of the general population" as these sites are representative for a major proportion of the population.

The siting criteria for ozone monitoring stations are described in Annex VIII of the AAQD in a rather qualitative manner. The assumption is that the highest O_3 concentrations are measured at suburban or rural sites. Meta-information and photographs of the monitoring sites are used for a qualitative assessment of compliance with these criteria.

Annex III D (as revised by 2015/1480/EU) requires documentation of the site-selection procedures and information as a means to support network design and choice of location for all monitoring sites. Such documentation was requested by the monitoring network operators. Provided it has been made available, it represents a key input for the assessment of compliance with the macroscale siting criteria.

The assessment of compliance with the macroscale siting criteria is based on the following data:

- documentation provided by the monitoring network operators;
- meta-information (dataflow D) provided on CDR (for 2017);
- photographs and satellite images.

4.1.3. Documentation of site selection

Documentation of the site selection procedure, which aims to ensure measurement[22] of the maximum concentration per zone, is provided (only) for the zones DEZCXX0007A Stuttgart (LUBW 2017; UMEG 2003), DEZDXX0001A Munich (Bayerisches Landesamt für Umwelt 2015).

General documentation of the site selection procedure is available for IT0306 Milano and IT0309 Zona A - Pianura ad elevata urbanizzazione (Arpa Lombardia 2016, 2018), AT_06 Styria, excluding Graz, AT_09 Vienna and AT_60 Graz (Umweltbundesamt 2019).

21 Annex III B I (a), first indent.

22 Including modelling and passive sampling campaigns.

For the zones, DEZJXX0009A (Düsseldorf), DEZJXX0016S (Urban and rural areas in North Rhine-Westphalia), and DEZJXX0017A (Duisburg) (i.e. all other zones examined in Germany), the monitoring network operator will perform an evaluation and documentation study in 2019, which will summarise the site selection procedure based on emission inventories, modelling, and passive sampling[23].

So far, no site selection documentation has been made available for the other zones[24].

No documentation is available on the representativeness for the exposure of the general population in any zone. However, the AAQD does not require such documentation.

4.1.4. Identification of the highest concentration

As explained in section 4.1.1., the AAQD requires measurements to be made at the location with the highest concentrations in keeping with a number of specifications[25].

However, identifying any such area is no easy task for a number of reasons, including the following:

- the minimum averaging periods referred to in the first indent of Annex III B. 1 (a) vary for the different pollutants;
- the location of highest concentrations[25] may change over time as a result of changing emission patterns;
- in the vicinity of streets, the spatial variability of concentrations of reactive pollutants such as NO_2 is very high (Bayerisches Landesamt für Umwelt 2015);
- it may be difficult to find a suitable location for long-term operation of a monitoring site in the densely built-up area of a city;
- some of the provisions are ambiguous (see section 5.3).

Modelling (with appropriately high spatial resolution) and passive sampling campaigns are used by "state-of-the-art" strategies to identify areas with the highest concentrations.

In addition, modelling is all but indispensable when it comes to identifying the total area of exceedance in any given zone.

A UK study has shown that if air quality is assessed through monitoring only, a large number of sites are required to identify all the air quality limit value exceedances within a zone (King's College London & Ricardo-AEA 2013). On that account, the study recommends a combination of monitoring and modelling.

Once modelling is complete, it is crucial that the results are validated. In addition, especially for NO_2, it is crucial that traffic emissions calculations are up to date and adequately cover different traffic situations such as stop-go traffic. Furthermore, it is imperative that buildings are included properly in the model simulations (ETC/ACM 2011).

[23] Large-scale maps of modelling results are available for North Rhine-Westphalia that show PM_{10} and NO_2 levels alongside major roads, see https://www.duesseldorf.de/fileadmin/Amt19/umweltamt/luft/pdf/IMMIS_2017_NO2.pdf; https://www.duesseldorf.de/fileadmin/Amt19/umweltamt/luft/pdf/IMMIS_2017_PM10.pdf; http://www.brd.nrw.de/umweltschutz/umweltzone_luftreinhaltung/pdf/Luftreinhalteplan-Ruhrgebiet-2011-i_d_F_-15_06_2015.pdf.

[24] Poland is due to start an assessment to determine any changes needed in the air quality monitoring regime in 2019.

[25] Macro- and microscale criteria must be applied, and population exposure must be over a period which is significant in relation to the averaging period of the limit value(s).

Passive sampling exercises such as the CurieuzeNeuzen[26] project in Belgium have clearly shown that NO_2 concentrations can be higher than indicated by fixed monitoring sites and modelling (Bossche & Meysman 2016).

A determination of whether the location of highest concentrations[25] has actually been identified in all zones is beyond the scope of this study. This is also due to the fact that detailed documentation is available only for several cities in Germany.

However, the above-mentioned studies and projects indicate that the highest concentration may not have been identified in all zones. Therefore, this is an issue that should be addressed when reviewing the AAQD (see section 7.2).

4.1.5. Representativeness of the "exposure of the general population"

No information about the representativeness of the "exposure of the general population" is available for any zone covered by this study.

It is assumed that a monitoring station representative of the "exposure of the general population" should cover "urban[27] background" rather than "suburban background" as population density is usually higher in the former.

A qualitative check of the area classification was performed using satellite images. The satellite images of some stations[28] classified as "urban" show mostly detached buildings with large green areas, which would suggest a "suburban" area classification.

4.1.6. Ozone

The criteria laid down in Annex VIII of the AAQD have been met in all zones.

4.2. Microscale siting criteria

4.2.1. Legal provisions

The microscale siting criteria (AAQD Annex III C, as revised by 2015/1480/EU) that apply "in so far as practicable" are:

- the flow around the inlet sampling probe shall be unrestricted (generally, free in an arc of at least 270° or 180° in the case of sampling points at the building line),
- the inlet sampling height shall be between 1.5 m and 4 m above the ground,
- the inlet probe shall not be positioned in the immediate vicinity of sources,
- the sampler's exhaust outlet shall be positioned so that recirculation of exhaust air to the sampler inlet is avoided,
- for all pollutants, traffic-orientated sampling probes shall be at least 25 m from the edge of major junctions and no more than 10 m from the kerbside.

Any non-compliance with these provisions must be documented according to Annex III C (last paragraph) and III D. On request, the authorities responsible for air quality assessment are obliged to

26 https://curieuzeneuzen.be/in-english/.

27 See area classification at http://dd.eionet.europa.eu/vocabulary/aq/areaclassification/.

28 DENW038 (Mühlheim Styrum) in zone DEZJXX0017A, and IT2232 (Cormano Via Edison) in zone IT0306.

provide the European Commission with documentation of the site-selection procedures and recorded information to support network design and choice of location for all monitoring sites.

Microscale siting criteria help to avoid:

- the impact of very local sources (Annex III C., third indent: "not to be positioned in the immediate vicinity of sources in order to avoid direct intake of emissions unmixed with ambient air");
- recirculation of the sampler's outlet (fourth indent);
- nearby obstacles (buildings or part of buildings, trees). Such obstacles may impair the exchange of ambient air around the sampler inlet. Free air flow around the air inlet is a prerequisite for any representative measurement.

The impact of obstacles is difficult to quantify. The provisions in Annex III C., first indent, as well as the "Guidance on assessment" (DG ENV 2010) provide only qualitative criteria ("some metres").

Annex III C., fifth indent, sets forth specific requirements for traffic-orientated monitoring stations. A maximum distance of 10 m from the kerbside ensures that the highest concentrations in the zone are measured. A minimum distance from major junctions helps to avoid the specific influence of stop-go traffic situations.

Monitoring stations should cover the "breathing zone" of people on the ground, i.e. they should be positioned at a height of some 1.5 to 2 m. However, the air inlet of monitoring stations is usually positioned on the roof of a shelter and therefore located at 3 to 4 m above the ground. This complies with Annex III C., second indent, which requires the air inlet to be positioned at a height of between 1.5 and 4 m. Monitoring results provided by the City of Vienna have shown that there is no significant difference between NO_2 levels measured at 2.5 m, 3.5 m and at 4 m[29].

Nevertheless, higher positioning is allowed "if the station is representative for a large area". If the station is to be representative for the exposure of multi-storey buildings, a justification must be provided.

Air pollution caused by low-level sources such as traffic usually decreases with elevation. Therefore, the height of the air inlet is of relevance, especially in traffic-orientated stations. However, concentrations will only become lower at heights well above 4 m. Other factors are the height of surrounding buildings, building density and prevailing wind direction.

4.2.2. Assessment for monitoring sites classified as "traffic"

Compliance with the microscale siting criteria is verified using the following information:

- most recent station metadata (reporting year 2017) officially submitted by the Member States to the EEA (CDR);
- additional information about station metadata submitted by the monitoring network operators at the contractor's request (note: if the information available at the EEA and the information provided directly by the monitoring network operator are inconsistent[30], the latter is used);

[29] Personal information provided by H. Tizek, head of air quality monitoring department of the City of Vienna.

[30] E.g. if meta-information updates have not been transmitted from the regional monitoring network operator to the national data manager.

- photographs of the monitoring stations (photographs are provided by the monitoring network operator or taken from Google Street View);
- satellite images of the area around the monitoring stations;
- for the monitoring stations in North Rhine-Westphalia, a detailed assessment of compliance with the microscale siting criteria has been commissioned by the monitoring network operator (TÜV 2018).

For each monitoring station, information relating to the distance from the kerbside, inlet height, distance from buildings and distance from junctions is summarised in Table 11 in Annex A of this study.

Annex III C, fifth indent, addresses "traffic-orientated sampling probes". However, according to 2011/850/EU, "traffic-orientated" is not an attribute of monitoring stations or sampling points that needs to be reported as meta-information (dataflow D). Therefore, the present assessment verifies compliance with the criteria laid down in Annex III C, fifth indent, for monitoring stations classified as "traffic" according to the IPR Guidance (DG ENV 2018).

4.2.3. Unrestricted air flow

An assessment of possible obstructions affecting the free air flow around the sampler inlet yielded the following results:

- The air flow around the air inlet appears to be obstructed by trees at the stations DEBY115 (München Landshuter Allee)[31], DEBY037 (München Stachus), and FR03006 (Marseille Rabatau).
- For DEBW118 (Stuttgart Am Neckartor), which is located near the corner of a building, microscale representativeness has been demonstrated by modelling and measurements using passive samplers[32] (LUBW 2017, UMEG 2003).

At all other "traffic" stations, the air flow around the air inlet is unrestricted[33].

On the one hand, trees can reduce air pollution through increased deposition. On the other hand, trees can reduce wind speed and thus increase pollution levels (see, e.g., Janhäll 2015). However, the impact of nearby single trees on concentrations measured in specific situations is difficult to quantify.

4.2.4. Air inlet

The assessment provided the following results:

At all stations, the air inlet is positioned at a height of over 1.5 m above the ground.

The air inlet is positioned at a height of over 4 m (4.5 m for PM) at the stations DEBY115 (München Landshuter Allee) and DEBY037 (München Stachus)[34]. No documentation (as required by Annex III C. and D.) has been provided for this non-compliance with the provisions.

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[31] The tree near the station München Landshuter Allee is part of a row of trees along the building facades of the sampled road section. The influence of these trees on air flow is thus similar over the entire road section. However, it may be necessary to cut some branches protruding over the shelter to improve air flow to the inlet.

[32] Small tubes filled with adsorbing materials. Passive sampling is a cheap method to monitor gaseous pollutants for an averaging period of usually two weeks to one month.

[33] Air flow around the air inlet is severely obstructed by trees near the urban background stations DEBY039 München Lothstraße, FR03014 Marseille St. Louis, and IT0950 Roma Cinecitta.

[34] At München Landshuter Allee and München Stachus, the air inlet for gaseous pollutants is positioned at a height of 3.5 m, for particles at 4.5 m above ground.

Positioning an inlet at a height of 4.5 m is not considered critical. Identifying a vertical concentration gradient on a scale of 0.5 m by modelling lies within the modelling uncertainty.

Monitoring "the highest [occurring] concentrations…to which the population is likely to be directly or indirectly exposed for a period which is significant in relation to the averaging period of the limit value(s)" addresses resident populations in multi-storey buildings. Therefore, not only near-ground concentrations are of interest.

The criterion relating to the sampler's exhaust outlet has been met by all surveyed stations.

No monitoring site is positioned in the immediate vicinity of air pollutant sources.

4.2.5. Distance to junctions

The table below lists the monitoring stations classified as "traffic" and positioned less than 25 m from the edge of major junctions. It shows that:

- The stations München Stachus (DEBY037) and Milano Viale Marche (IT0477) are less than 10 m from the edge of a major junction. Paris Place Victor Basch (FR0412) and Graz Don Bosco (AT60164) are around 10 m away from a major junction. Two further stations in Italy are located at a distance of approximately 20 m from a major junction.
- No documentation (as required by Annex III C. and D.) was provided for such non-compliance with the provisions.

Microscale model calculations indicate that positioning an air quality station closer than 25 m to the edge of a major junction (see Annex C) has no significant effect. In some situations, better ventilation at junctions causes comparably lower concentrations at the junction itself. However, no such effect can be seen at junctions surrounded by detached buildings (see Annex C).

Table 3: "Traffic" monitoring stations with a distance of less than 25 m from the edge of major junction

Station code	Station name	Distance from junction (m)
AT60164	Graz Don Bosco	10
DEBY037	München Stachus	5
FR04012	Paris Place Victor Basch	approx. 10*
IT0477	Milano Viale Marche	7
IT1016	Milano Senato	18
IT1104	Pavia Piazza Minerva	20

Source: Umweltbundesamt.

* Not provided in the CDR, estimates based on photographs.

4.2.6. "Traffic" sites located in the street

In addition to quantitative information such as "distance from the kerbside" and "distance from a building", several other characteristics of a traffic monitoring station significantly influence the concentration level measured and its representativeness for the whole road network of a given zone. Specifically, they may also have an impact the objective of measuring the highest concentrations in the zone.

Such characteristics are:

- traffic volume or traffic emissions (see section 4.1.4),
- width and the type of street,
- the structure of buildings around the monitoring site, and the actual position of the monitoring station in the street.

Although there are no legal provisions for these criteria, they have a relevant impact on the pollutant levels measured. Therefore, this study includes an assessment of the differences in the selected Member States.

This assessment is of importance particularly with respect to NO_2. NO_2 measurements exhibit high spatial variability due the compound's short atmospheric lifetime as well as the major impact of low-level sources (road vehicle traffic) confined to street canyons. Detailed analyses using passive sampling and/or modelling reveal considerable differences in concentration within a few metres (see e.g. Bayerisches Landesamt für Umwelt 2015). Thus, the location with the "highest concentrations in the zone" may not be found.

Table 11 in Annex A breaks down this characterisation of monitoring sites. In addition to the distance from the kerbside and from buildings, the summary in Table 4 also includes street type with reference to the classification "local dispersion situation"[35] according to the "IPR[36] Guidance" (DG ENV 2018)[37].

The assessment of the 22 traffic sites surveyed in this study produced the following results:

- 8 traffic sites are located in "wide" street canyons,
- 7 stations are located in areas with detached buildings,
- 5 stations in streets with compact buildings on one side,
- only 3 stations are located in street canyons.
- 11 traffic sites are located 2 m from the kerbside or closer, the other 50% are located at a distance of 4 to 8 m.
- 6 stations are located in the median strip of large roads, which in most cases is a green area.

Model calculations for NO_2 cannot be used to determine whether concentrations on the median strip of a street are representative for the concentrations on the pavement or at the building line, or they underestimate or overestimate these concentrations. Calculations for München Landshuter Allee[38], a street with 8 lanes separated by two green median strips, show no variation in NO_2 concentrations in the street (Bayerisches Landesamt für Umwelt 2015). Other model calculations show that concentrations on a median strip can be higher or lower than those on the pavements at the sides of the streets (AVISO 2017). In any case, it should be the monitoring network operator's task to prove that measurements on the median strip are representative for exposure on the pavements and near the building line.

When it comes to unfavourable dispersion conditions, higher traffic-related concentrations are to be expected in street canyons – given the similar emissions – compared to wide streets or streets in open terrain. Anyhow, less than one third of the traffic stations are located in street canyons. This may reflect the fact that it is easier to find a place for a shelter in wide streets or streets with detached buildings. However, several Member States and/or network operators resolved this issue by positioning monitoring sites in the parking lane, including[39] Germany, Luxembourg, Sweden, and the United Kingdom. Nevertheless, the representativeness of these sites for exposure of resident population should be documented.

All but two monitoring stations are located at least 4 m from the building line, likely due to the dimensions of the shelter. Only AT90MBA is positioned in the façade (air inlet protruding by 0.75 m). DENW158 is a passive sampler[32] on a street lighting post.

Table 4: Classification of "traffic" monitoring stations according to street type, position of the station in the street, distance from the kerbside and distance from the building line.

Street type	Distance from the kerbside	Distance from building line	Position of the monitoring station	Monitoring stations
Street canyon	≤ 2 m	≥ 4 m	Parking lane	DENW082, DENW188*
Street canyon	≥ 4 m	≥ 4 m	Pavement	AT90TAB
"Wide" street canyon	≤ 2 m	≤ 2 m	Passive sampler[32] on street lighting pole	DENW158
"Wide" street canyon	≤ 2 m	≥ 4 m	Parking lane or pavement	DEBY115, IT1016, IT1837, PL0140
"Wide" street canyon	≤ 2 m	≥ 4 m	Medial strip	FR04012, PL0641
"Wide" street canyon	≥ 4 m	≥ 4 m	Medial strip	DEBY037, IT1104, PL0012
One-sided compact buildings	≥ 4 m	≥ 4 m	Pavement, corner of large building	DEBW118

35 http://dd.eionet.europa.eu/vocabulary/aq/dispersionlocal/.
According to the IPR Guidance, the criteria for "street canyon" are: "Continuous/compact buildings along both sides of the street over more than 100 m. Average ratio of height of buildings to width of street > 0.5.

36 Abbreviation for „Implementing Provisions for Reporting".

37 The criteria for the "Local dispersion situation" (IPR Guidance DG ENV 2018; http://dd.eionet.europa.eu/vocabulary/aq/dispersionlocal/) do not cover a situation with continuous multi-storey buildings on both sides of the street with a low height/width ratio. The present study refers to this situation as a "wide street canyon" (see also chapter 5.3).

38 This station is located on the pavement.

39 E.g. station Düsseldorf Corneliusstraße (DENW082), station Esch-sur-Alzette Gare (LU0110A), and station Stockholm Hornsgatan (SE0003A9; station Glasgow Kerbside (GB0657A).

Street type	Distance from the kerbside	Distance from building line	Position of the monitoring station	Monitoring stations
One-sided compact buildings	≤ 4 m	≤ 2 m	Façade of large building	AT90MBA
Detached buildings	≤ 2 m		Parking lane or pavement	FR04058, FR04173, FR03006, IT0477, IT1834
Detached buildings	≥ 4 m		Park	AT60197, AT60164

Source: Umweltbundesamt.

* Not clear if criterion for "street canyon" has been met.

5. ASSESSMENT OF VARYING IMPLEMENTATIONS AND AMBIGUITIES

KEY FINDINGS

The provisions of the AAQD were uniformly transposed into national law in nearly all Member States.

In nearly all zones, more monitoring sites are in operation than required.

There are a number of ambiguities in the AAQD's local siting criteria and in the criteria given in the Commission's guidance document for network operators.

This section provides an outline of the procedure employed by Member States in selecting specific monitoring site locations (section 5.1). In addition, we analyse whether any Member States strengthened the provisions of the AAQD (section 5.2). Based on these assessments and the results of chapters 3 and 4, we then proceed to examine the main ambiguities (section 5.3). As these ambiguities, and actual AAQD implementation itself, may affect the levels of exposure to air pollutants, section 5.4 discusses the exposure levels for NO_2, PM_{10}, $PM_{2.5}$, and O_3.

5.1. Selection of monitoring sites locations

One of the study's goals is to answer the following general questions:

- How did the network operators select the specific sites?
- Which general strategy was followed?
- Who was responsible for the process?
- What part did *population exposure monitoring* play and what part did *hotspot monitoring* play?

An analysis of the readily available information for the selected zones did not provide answers to all these questions (see chapter 3 and 4). Therefore, network operators had to be addressed a second time. The information obtained was for the most part heterogeneous; Table 5 provides an overview.

Table 5: Overview of air quality monitoring site selections by authorities in selected zones

Name	Zone code	Selection of sites	Responsible authority	Role of hotspots / exposure	Documentation
Styria (without Graz)	AT_06	Implemented in the 1980s under a different legislative framework, later progressively modified	Amt der Steiermärkischen Landesregierung	Focus on exposure; hotspots not covered by monitoring, but by modelling. Some modelling data are available in studies analysing exceedances (status reports[1]).	Umweltbundesamt 2019
Vienna	AT_09	Implemented in the 1980s under a different legislative framework	Amt der Wiener Landesregierung, MA 22	Focus on exposure; modelling data not public. Passive sampling not available, thus no evaluation of hotspots possible.	Umweltbundesamt 2019
Graz	AT_60	Implemented in the 1980s under a different legislative framework, later modified	Amt der Steiermärkischen Landesregierung	Focus on exposure; hotspots may have been left out; modelling data not publicly available.	Umweltbundesamt 2019
Stuttgart	DEZCXX0007A	Evaluation and adaptation based on emission inventories, passive sampling, modelling	LUBW	In accordance with the standard operating procedure ("Verfahrensanweisung")	LUBW 2017; UMEG 2003
Munich	DEZDXX0001A	Evaluation and adaptation based on emission inventories, modelling, and passive sampling	LfU Bayern	Equally covers hotspots and urban background	Bayerisches Landesamt für Umwelt 2015

Name	Zone code	Selection of sites	Responsible authority	Role of hotspots / exposure	Documentation
Düsseldorf	DEZJXX0009A	Evaluation and adaptation based on emission inventories, modelling, and passive sampling	LANUV NRW	Equally covers hotspots and urban background	LANUV NRW 2019
Urban and rural areas in North Rhine-Westphalia	DEZJXX0016S	Evaluation and adaptation based on emission inventories, modelling, and passive sampling	LANUV NRW	Equally covers hotspots and urban background	LANUV NRW 2019
Duisburg	DEZJXX0017A	Evaluation and adaptation based on emission inventories, modelling, and passive sampling	LANUV NRW	Equally covers hotspots and urban background	LANUV NRW 2019
Paris	FR11ZAG01	No information provided	Airparif	No information provided	No information provided
Ile-de-France	FR11ZRE01	No information provided	No information provided	No information provided	No information provided
Marseille – Aix-en-Provence	FR93ZAG01	Implemented in the 1980s, progressively adapted to current regulation	AtmoSud	According to the AAQD: parity between background sites (for exposure) and traffic-influenced sites (for hotspots). The monitoring data are supplemented by microscale modelling and monitoring	Metadata spreadsheets are available for each monitoring site. For all metadata (format and accessibility), compliance with the INSPIRE Directive is planned in the next two years.

Name	Zone code	Selection of sites	Responsible authority	Role of hotspots / exposure	Documentation
				campaigns. All data are publicly available (open data).	
Milan	IT0306	Implemented in the 1970s, later modified in accordance with EU air quality directives	ARPA Lombardia	Focus on exposure; hotspots covered; modelling data available to public.	ARPA Lombardia 2016, 2018
Urbanised surroundings of Milan	IT0309	Implemented in the 1970s, later modified in accordance with EU air quality directives	ARPA Lombardia	Focus on exposure; hotspots covered; modelling data available to public.	ARPA Lombardia 2016, 2018
Rome	IT1215	No information provided	No information provided	No information provided	No information provided
Krakow	PL1201	Implementation of EU law; based on emission inventories, modelling, expert analyses,	Chief Inspectorate for Environmental Protection	Focus on exposure; hotspots covered by monitoring and modelling; modelling data publicly available[2].	Documentation in air quality national database JPOAT2.0 of Chief Inspectorate for Environmental Protection
Lesser Poland	PL1203	Implementation of EU law; based on emission inventories, modelling, expert analyses	Chief Inspectorate for Environmental Protection	Focus on exposure; some hotspots covered by monitoring and also by modelling; modelling data publicly available[2].	Documentation in air quality national database JPOAT2.0 of Chief Inspectorate for Environmental Protection

Name	Zone code	Selection of sites	Responsible authority	Role of hotspots / exposure	Documentation
Warsaw	PL1401	Implementation of EU law; based on emission inventories, modelling, expert analyses	Chief Inspectorate for Environmental Protection	Focus on exposure and hotspots (two additional stations from January 2019 onwards); hotspots covered by monitoring and modelling; modelling data publicly available.	Documentation in air quality national database JPOAT2.0 of Chief Inspectorate for Environmental Protection

Source: Umweltbundesamt, EEA Central Data Repository.

[1] available at: http://powietrze.gios.gov.pl/pjp/maps/modeling.

5.2. Strengthening of the Directive

In accordance with the specifications of this study, the purpose of the analysis is to find ways to strengthen the provisions relating to the number of monitoring sites and the siting criteria in the national legislation of selected Member States.

An analysis of national legislation delivered the following results:

- In all the Member States examined, AAQD[40] requirements regarding the minimum number of monitoring stations have been uniformly transposed into national law. The only exception is Austria, where the law requires a larger number of monitoring sites per zone[41] on account of the complex Alpine topography (Umweltbundesamt 2018a).
- In all the Member States examined, the actual number of monitoring stations is higher than required by national law.
- In all the Member States examined, monitoring stations are operated in all zones, even if pollution levels are below the lower assessment threshold that would allow an assessment based solely on modelling and objective estimation.
- In all the Member States examined, the provisions for macroscale and microscale siting criteria laid down in Annex III have been uniformly transposed into national law.
- In all the Member States examined, the provisions for macroscale and microscale siting criteria laid down in Annex VIII have been directly transposed into or referenced in national law.
- In all of the Member States examined, the data quality objectives match those laid down in Annex I.

5.3. Assessment of ambiguities

The assessments in chapters 3 and 4 show that Member States interpret various provisions in different ways. They further reveal that, in a number of cases, compliance with the provisions in Annex III and VIII cannot be positively verified, because the criteria laid down in these annexes and in the IPR Guidance (DG ENV 2018) are open to different interpretations due to their ambiguous language or insufficiently precise wording.

Table 6 provides these findings in an overview. Section 7.2 offers recommendations on how to reduce these ambiguities in a possible revision of the AAQD.

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40 AT: IG-L Messkonzeptverordnung 2012; Ozon-Messkonzeptverordnung 2012; DE: 39 BImschV; FR: Code de l'Environnement et l'arrêté; IT: G. U. n. 216 del 15 settembre 2010; PL: Dz.U. 2016 poz. 672.

41 At least for the zones selected for this study.

Table 6: Main ambiguities in the provisions for air quality monitoring

Reference	Legal provisions	Ambiguity to be addressed
Annex III B 1 (a), first indent-	"highest concentrations occur to which the population is likely to be directly or indirectly exposed for a period which is significant in relation to the averaging period of the limit value(s)"	Specification of the "period which is significant in relation to the averaging period of the limit value(s)"
Annex III B 1 (a), second indent	"exposure of the general population"	No definition
Annex III B 1 (b)	Representative for "a street segment no less than 100 m length" and "…at least 250 m × 250 m at industrial sites, where feasible"	Unclear: what is regarded as feasible and which variations are not covered by this exception?
Annex III C	"In so far as practicable"	Unclear: what is regarded as "practicable" and which variations are not covered by this exception?
Annex III C, first indent	"normally some metres away from buildings, balconies, trees and other obstacles"	• "some metres" is not defined • The (acceptable) size of buildings, trees and other obstacles is not specified.
Annex III C, first indent	"— the flow around the inlet sampling probe shall be unrestricted (in general free in an arc of at least 270° or 180°"	Unclear: within which surroundings do these angles have to be measured? (corresponds to the comment above)
Annex III C, first indent	"at least 0,5 m from the nearest building in the case of sampling points representing air quality at the building line"	• Does the distance "at least 0,5 m" refer to the building line (façade) itself (or, alternatively, to protruding corners or other buildings or obstacles)? • Which maximum distance from the façade corresponds to measurements taken "at the building line"?
Annex III C, first indent	"— the flow around the inlet sampling probe shall be unrestricted (in general free in an arc of at least 270° or 180° for sampling points at the building line)"	It is reasonable to assume that unrestricted air flow in an arc of "180°" refers to sampling points at the building line. However, the structure of the sentence is not entirely clear.
Annex III C, third indent	"in the immediate vicinity of sources"	"Immediate" is not specified.

Reference	Legal provisions	Ambiguity to be addressed
Annex III C, fifth indent	"traffic-orientated"	"Traffic-orientated" does not necessarily correspond to the classification "traffic" under DG ENV (2018). There is no obligation to report if a monitoring station is "traffic-orientated".
Annex V A 1	Identification of pollution level in relation to the assessment thresholds	If there is no highly polluted (traffic) site in the zone, the pollution level measured is below the lower assessment threshold, which results in an assessment regime that does not require monitoring at all (and therefore does not require any measurement at highly polluted traffic sites).
Annex V A 1, footnote 1	For "…particulate matter…at least one urban background monitoring station and one traffic-orientated monitoring station"	It is unclear whether this provision refers to the sum total of PM10 and PM2.5 monitoring sites, or to PM10 and PM2.5 respectively.
Annex V A 1, footnote 1	"at least one urban background monitoring station"	It is unclear whether "urban" corresponds to the classification "urban" under DG ENV (2018).
Annex V A 1	Minimum number of PM stations, depending on pollution level	Ambiguity arises if the classification relating to the assessment thresholds varies for PM10 and PM2.5.
Annex V A 2.	"For the assessment of pollution in the vicinity of point sources, the number of sampling points for fixed measurement shall be calculated taking into account emission densities, the likely distribution patterns of ambient-air pollution and the potential exposure of the population."	No quantitative, clear provisions
Annex VIII	"Criteria for classifying and locating sampling points for assessments of ozone concentrations"	No quantitative, clear provisions (passage originally from Directive 2003/2/EC)
Annex VIII A, "rural background"	"avoid…summits of higher mountains"	There is no reason to assume that the summits of higher mountains may be unsuitable for large-scale representative ozone monitoring.

Reference	Legal provisions	Ambiguity to be addressed
Annex IX A	Headline "Other zones (suburban and rural)"	Non-agglomeration zones may include urban (and not only suburban) areas as well.
Annex V C, Annex IX	Specification "1 station per…km^2"	It is unclear whether to round off or to round up.
DG ENV (2018)	Classification in relation to prominent emission sources	Criteria that are insufficiently quantitative in nature may cause implementation to vary.
DG ENV (2018)	Classification of area	Criteria that are insufficiently quantitative in nature may cause implementation to vary.
DG ENV (2018)	Recommendations for assessing the local dispersion situation: "Street canyon: Continuous/compact buildings along both sides of the street over more than 100 m. Average ratio of height of buildings to width of street > 0,5."	These provisions do not cover streets with "continuous/compact buildings along both sides of the street over more than 100 m" with a height/width ratio of under 0.5

Source: Umweltbundesamt.

So far, we have been unable to identify the source for the criteria laid down in Annex III C. It is worth noting that the criteria provided by the US EPA[42] are stricter and less ambiguous. It is also worth noting that the distance from trees required for rural stations in France is four times the height of the trees (LCSCQA 2017).

5.4. Differences in (long-term) citizens exposure of

"Exposure" is the average long-term concentration a population is exposed to and is calculated using the concentration data from representative (urban) background monitoring stations. On a national scale, information about the spatial distribution both of concentrations and population[43] is definitely required to calculate exposure.

This section will discuss the urban background levels of NO_2, PM_{10} and $PM_{2.5}$ in the selected zones and Member States as well as possible reasons for their variation. It should be noted that the levels measured are a general reflection of the different monitoring strategies chosen and therefore the monitoring site locations are discussed in this study.

[42] See Code of Federal Regulations Title 40, Chapter I, Subchapter C, Part 58, Appendix E, which requires a distance of 10 m from the dripline if the tree(s) is an obstruction. The distance from obstacles such as buildings must be at least twice the distance the obstacle juts out over the inlet. A discussion regarding this criterion was published in Federal Register Vol. 51, No. 53, March 19, 1996 on page 9585. However, supporting documents or studies analysing the difference between various criteria could not be found (https://www.loc.gov/item/fr051053/).

[43] The ideal way to calculate the exposure on a national scale is to use model data. If these are unavailable, estimates of the representative area of monitoring sites can be used to combine concentration and population data.

Table 7 lists the annual mean NO_2, PM_{10} and $PM_{2.5}$ levels averaged over all urban background monitoring sites per zone for 2017. Pollutant trends and more detailed data are summarised in Annex B below.

NO_2

By far the highest urban background NO_2 levels in the selected zones occur in Italy. They even exceed the annual limit value (40 µg/m^3)[44]. These stations – insofar as they can be identified on the satellite images used to check the classification "background" with respect to nearby major streets or industrial plants – represent "urban background", i.e. they are not affected by nearby traffic or industrial sources. The high urban background NO_2 levels in Lombardy and Rome can be attributed to adverse dispersion conditions and high urban emission densities (Regione Lombardia 2018).

Agglomerations and large cities in the other countries have urban background NO_2 concentrations of around 30 µg/m^3[45].

The lowest urban background concentration of around 20 µg/m^3 was measured in the non-agglomeration zones AT_06 and PL1203, which comprises only small towns[46].

Hence, concentration levels and exposure are clearly related to the size of the agglomeration, but also to emission densities, which are likewise affected by the diesel vehicle share.

PM_{10} and $PM_{2.5}$

The urban background PM_{10} and $PM_{2.5}$ concentrations measured in the Po Valley and in southern Poland were decidedly the highest (an annual mean PM_{10} concentration of 40 to 45 µg/m^3). This is attibutable to both the adverse dispersion conditions and the high emission densities of both primary PM and precursors of secondary inorganic particles on the urban and regional scale. In the Po Valley, these emissions are generated by domestic heating (biomass burning), traffic, industrial sources and agriculture, whereas, in Poland, domestic heating, traffic and energy production are the predominant sources (see section 6.2).

Medium PM levels (PM_{10} 25 to 30 µg/m^3) were measured in the zones AT_60 (Styria without Graz), FR93ZAG01 (Marseille – Aix-en-Provence), PL1401 (Warsaw), and IT1215 (Roma), all of which are affected by moderately adverse dispersion conditions.

Paris and German agglomerations had urban background PM_{10} levels of between 15 and 20 µg/m^3.

Ozone

The highest ozone levels were measured in Lombardy (zones IT0306 and IT0309), where the 8-hour mean value of 120 µg/m^3 was exceeded on around 70 days (2017). These exceedances result from the high emission densities of ozone precursors, on the one hand, and the climatic conditions that are amenable to ozone formation, on the other.

In terms of urban background ozone levels, Austria and Germany had an average of around 15 exceedance days, whereas Poland and Paris had around or under 10 exceedance days.

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[44] Urban background stations exceeding the annual mean of 40 µg/m^3 are located in Zone IT0306 (aggl. Milano): IT2232 Cormano Via Edison, IT1743 Monza Via Macchiavelli, IT0592 Rho, IT1692 Milano Via Pascal; in Zone AT0309 (Urbanised surroundings of Milan): IT1739 Cremona Via Fatebenefratelli; in Zone IT1215 (aggl. Roma): IT1836 Roma Cipro, IT1906 Roma Arenula, 1176 Roma Largo Perestrello, IT0956 Roma Cinecittà.

[45] The annual mean NO_2 levels (2017) in other agglomerations in these Member States: Frankfurt (DE) up to 38 µg/m^3; Berlin, Hamburg (DE), Lyon (FR), Katowice (PL) 25 – 30 µg/m^3, Cologne (DE), Napoli (IT), Wroclaw (PL) approx. 25 µg/m^3; Łodz, Gdansk (PL) approx. 20 µg/m^3.

[46] Biggest town in the zone AT_06: Leoben with 25,000 inh., in PL1203: Nowy Sącz with 84,000 inh.

Urban background concentrations in Rome (zone IT1215) have been surprisingly low in recent years, despite the climatic conditions and regional emission densities. As the trends show (see Annex B), the zone experienced a steep decrease[47] in ozone levels in 2004. No such decline in ozone levels has been observed anywhere else in Italy. Recent model calculations have confirmed the low ozone levels in Rome, although they indicate higher levels east of Rome (ARPALAZIO 2018).

Table 7: Average, minimum and maximum urban background[1] NO_2, PM_{10} and $PM_{2.5}$ concentrations (annual mean for 2017) per zone (µg/m³); O_3: number of days with maximum daily 8-hour concentrations exceeding 120 µg/m³

Name	Zone code	NO_2	PM_{10}	$PM_{2.5}$	O_3 (no. of days)
Styria (without Graz)	AT_06 (AT_O3_2)	19.0	21.9	14.0 (12.3 – 15.9)*	6
Vienna	AT_09	24.9 (23.0 – 28.1)	19.5 (18.3 – 20.3)	14.3 (14.0 – 14.5)	16
Graz	AT_60	29.4 (23.7 – 33.3)	24.3 (17.8 – 28.3)	18.4 (16.0 – 20.7)	16 (15 – 19)
Stuttgart	DEZCXX0007A	29.7	17.3	11.9	17
Munich	DEZDXX0001A	31.8	18.2	13.0	14
Düsseldorf	DEZJXX0009A	25.0	16.2	12.1	15
Urban and rural areas in North Rhine-Westphalia	DEZJXX0016S	20.5*	16.4*	14.5*	14*
Duisburg	DEZJXX0017A	25.9	18.3	12.7	14
Paris	FR11ZAG01	32.0 (24.4 – 38.5)	19.7 (17.2 – 20.8)	14.2	7 (5 – 11)
Ile-de-France	FR11ZRE01	8.3[#]	-	7.9*	12*
Marseille - Aix - en - Provence[+]	FR93ZAG01[+]	11- 33	18 - 22	12	31 – 68

[47] The decrease is most significant at the station IT0952, where the number of exceedance days dropped from 96 in 2003 to 8 in 2004 (strong decreases were likewise observed at station IT0957 in 2002, and at station IT0953 in 2006).

Name	Zone code	NO_2	PM_{10}	$PM_{2.5}$	O_3 (no. of days)
Milan	IT0306	44.3 (38.6 – 48.4)	38.3 (34.6 – 40.4)	27.6 (23.4 – 30.0)	68 (50 – 82)
Urbanised surroundings of Milan	IT0309	28.1 (19.1 – 44.1)	33.2 (20.4 – 42.0)	25.8 (17.2 – 31.1)	76 (66 – 91)
Rome	IT1215	41.9 (36.6 – 46.9)	26.4 (23.5 – 30.5)	14.8 (13.3 – 17.3)	11 (1 – 26)
Krakow	PL1201	32.5	41.8 (38.1 – 45.0)	31.4 (31.0 – 31.9)	5
Lesser Poland	PL1203	21.2 (20.4 – 25.5)	38.9 (27.3 – 48.9)	29.9 (24.7 – 34.1)	10 (3 – 16)
Warsaw	PL1401	24.4 (22.9 – 26.0)	32.2 (31.2 – 33.6)	21.1 (20.9 – 21.4)	0

Source: Umweltbundesamt, EEA.

[1] If a zone has no urban background sites, the levels measured at suburban background sites are given. If a zone has neither urban nor suburban background sites, the levels measured at rural sites are given. All the data originate from EEA (CDR) and refer to 2017, except zone FR93ZAG01, for which 2018 values provided by Air PACA are given.

* Suburban background sites

Rural background site

[+] Range of levels in 2018 (source: Air PACA)

Average $PM_{2.5}$ exposure

A subset of urban background monitoring stations have been designated "Average Exposure Indicator (AEI) sites" in accordance with Article 15(4) of the AAQD. These AEI sites should be representative for the urban population in large towns (> 250,000 inh.) and should be used to assess $PM_{2.5}$ exposure in the whole Member State (but could also be used for other pollutants).

Table 8 shows the AEI for the whole Member State. In Germany, France, Italy, and Poland, the AEI average was nearly identical with the average for all urban background sites in the country. In Austria, the AEI average was 1.1 µg/m^3 (8%) lower. This is due to the large number of "non-AEI" urban background sites measuring higher $PM_{2.5}$ levels on account of the large west-to-east gradient in Austria's PM concentrations.

Table 8: Average $PM_{2.5}$ concentrations per Member State for AEI sites and for all urban background sites, 2017 ($\mu g/m^3$).

Member State	AEI sites	All urban background sites
AT	13.2	14.3
DE	12.3	12.1
FR	10.9	10.8
IT	20.1	20.0
PL	22.3	22.9

Source: Umweltbundesamt, EEA.

6. MEASURES TO REDUCE EXPOSURE

KEY FINDINGS

When an air quality limit or target value is exceeded, Member States have to develop an air quality plan.

Air quality plans have been implemented in all zones and agglomerations that are analysed in this study.

The main focus of most of these plans lies on traffic; in Krakow and Warsaw it is on solid fuel burning for domestic heating.

The impact of these measures and the plans on exposure levels has been ascertained only for a few cities and regions.

Information on ambient air quality data and exceedances of limit or target values is made available to the public in all zones and agglomerations that are analysed in this study. The information is mainly provided on the internet.

Daily air quality forecasts are available for all analysed Member States at least at national level. Health messages are not linked to predicted pollution levels.

In case of pollution episodes, a warning system for pollutants except ozone is available only for cities and regions in France and in Stuttgart.

6.1. Background

According to Article 23 of the AAQD, Member States are required to draw up air quality plans and programmes in case of an exceedance of the limit or target values.

The information to be reported in these plans is laid down in Annex XV of the AAQD. Member States have to report specific elements of their programmes to the European Commission. This is done with the help of the e-reporting system established under the Implementing Decision 2011/850/EU. The plans also have to be made available to the public.

Article 19 of the AAQD states that the public has to be informed in case an information or alert threshold is exceeded by means of radio, television, newspapers or the Internet.

Article 26 of the AAQD requires that information about air quality is provided to the public. The content of that required information regarding ambient air quality is specified in more detail in Annex XVI. The necessary information includes:

- Ambient air quality data;
- Postponement decisions and exemptions
- Air quality plans
- Annual reports on air quality
- Competent authority

Article 7 (3) of the AAQD requires that the public is informed in case modelling and/or indicative measurements are used and the number of sampling points is therefore reduced.

In addition to these specific information requirements, many Member States provide further information to the public such as on the sources and impacts of air pollution, forecasts etc. Moreover, warning systems are in place, e.g. to provide specific information to sensitive population groups.

National air pollution control programmes are required under the revised Directive on the reduction of national emissions as of 1 April 2019, and hence have not been available for this study (NEC Directive, Dir. 2016/2284/EU).

6.2. Main measures implemented in Member States and cities

In the following the main measures are described which have already been implemented in the selected zones, or are planned to be implemented. The focus lies on those measures that are deemed to be most relevant for improving the exposure of the population living in these areas. Some of the cities and regions[48] have also been analysed in a recent study for the European Parliament's Committee on Petitions (Nagl et al. 2018).

[48] Lombardy and Milan, Marseille, Paris.

6.2.1. Austria – Graz and Styria

The most recent air quality programme for Styria and Graz does not quantify the impact of implemented and planned measures; however, the impacts of some measures are described in the evaluation report (Steiermark 2018a, Steiermark 2018c). It is estimated that the following measures are the most relevant ones:

- ban on old trucks (above 3.5 t);
- public transport: renewal of bus fleet;
- restrictions and bans on Easter and Solstice bonfires;
- extension of district heating network;
- subsidies for the renewal of old heating systems; and
- improved manure management approaches to reduce ammonia emissions (precursor for secondary particles).

These and further measures contributed to reducing PM_{10} levels from more than 50 µg/m^3 in early 2000 to around 30 µg/m^3 in 2018. The number of exceedances of the daily mean limit value went down from more than 130 to around 40 (Steiermark 2002, Steiermark 2018b).

6.2.2. Austria – Vienna

The City of Vienna has adopted an integrated approach and developed and implemented a number of strategies and plans which have helped to improve air quality, including climate protection programmes, mobility strategies, energy efficiency programmes, and a Smart City Framework strategy.

As far as specific air quality plans are concerned, a plan for NO_2 was implemented in 2008 and evaluated in 2011, 2014 and 2017 (Stadt Wien 2008; Rosinak & Partner 2011; Umweltbundesamt 2015, 2018b). In addition to the NO_2 plan, three programmes for PM_{10} were published in the years 2005 and 2011, specifying measures to reduce PM_{10} emissions (Stadt Wien 2005a, b, 2011).

The main measures are:

- constant improvement in public transport, pedestrian and bicycle traffic;
- constant improvement in the building sector to reduce emissions from domestic heating (e.g. extension of the district heating network; restrictions on solid fuel burning; requirements for new buildings; thermal insulation of old buildings);
- restrictions for construction sites to reduce traffic and dust emissions;
- ban on old trucks.

An estimate of the exposure reduction achieved through these measures is not available; however, PM and NO_2 levels have shown constant improvement for several years.

6.2.3. France – Paris

The city of Paris published a climate plan in 2018, which also addresses air quality (Mairie de Paris 2018). Annual activity reports are provided under the title “Bleu Climat”. For the whole region Île-de-France a specific air quality plan (Plan de Protection de l’Atmosphère, PPA) was published at the beginning of 2018 (DRIEE 2018a). The PPA includes the relative impact of some measures, overall objectives and a multi-criteria analysis for ranking the measures in an Annex. The Annex also includes a model simulation of expected future air quality levels. The main measures in Paris and Île-de-France are:

- a low emission zone (Zone à Circulation Restreinte, ZCR), which imposes restrictions on the use of old vehicles. The restrictions are progressively strengthened and the plan sets the ambition[49] to phase out diesel engines by 2024. In addition, Paris is planning limited traffic zones and so-called Axes Ultra-Basses Émissions (AUBE, ultra-low emission axes) in several districts. AUBE will introduce restrictive policies and allow only clean vehicles within certain zones. The PPA provides for a widening of the ZCR to zones outside the city of Paris.
- foster the use of active modes of mobility (cycling, walking), also by improving bicycle and pedestrian infrastructures and by redistributing public space.
- promote the renewal of old individual wood heating equipment. This is done with the help of information campaigns and financial support.

The PPA also includes scenario calculations for exposure reduction in case the PPA is fully implemented. The number of people exposed to NO_2 levels above the limit value for the annual mean should be reduced from 870 000 in 2014 to 200 000 in 2020, and the number of people exposed to PM_{10} levels above the daily mean limit value should be reduced from 540 000 to 300 000.

6.2.4. France – Marseille

For Marseille, which is part of the region Bouches-du-Rhône, a first air quality plan was published in 2006 (not available), a revised plan was approved in 2013, and a progress report for 2016 was published in 2017 (Préfet des Bouches-du-Rhône 2013, 2017). The main measures for Marseille are:

- encourage a modal shift, the development of public transport and active modes. This is done by a variety of measures such as improving public transport infrastructure, travel plans for businesses, government agencies and schools, promoting fleet renewal, introduction of pedestrian areas.
- electrification of ships at berth in the Grand Port Maritime de Marseille[50].
- clarification and reaffirmation of the ban on agricultural waste burning.

The PPA for Marseille does not include an estimate of an exposure reduction, but provides objectives for PM_{10} and NO_x emission reductions for 2020. The progress report shows that PM_{10} emissions have been stagnating in recent years and are still well above the objective (Préfet des Bouches-du-Rhône 2017). The objective for NO_x emissions was almost reached in 2015, even though NO_2 ambient concentrations are still above the limit value.

6.2.5. Germany – Munich

The first air quality plan for Munich was published in 2004 and has been updated several times since then[51]. A draft for the 7th update was published in 2018 (Regierung von Oberbayern 2017). Due to on-going legal challenges, the 7th update was not yet finalised. In 2018 the city of Munich published a "masterplan" for implementing the measures stipulated in the air quality plan (gevas humberg & partner 2018). However, the masterplan is not legally binding. The draft for the 7th update does not

49 Without prohibition or sanction measures: https://www.paris.fr/actualites/la-ville-de-paris-reagit-a-l-annonce-de-la-fin-des-vehicules-diesel-et-essence-5178.

50 See also: https://www.lemondedelenergie.com/marseille-port-electrification-navires/2018/02/10/.

51 https://www.muenchen.de/rathaus/Stadtverwaltung/Referat-fuer-Gesundheit-und-Umwelt/Luft_und_Strahlung/Luftreinhalteplan.html.

include the impact of the measures. It is estimated that the following measures are the most effective ones:

- fostering a renewal of the passenger car fleet e.g. by improving the charging infrastructure for electric vehicles
- improvements of public transport such as a renewal of the bus fleet, improved and more frequent tram and underground services, new or improved infrastructure
- improvements of bicycle infrastructures such as a network for everyday bicycle traffic, fast lanes for cycling

6.2.6. Germany – Stuttgart

The city of Stuttgart published a draft for a 3rd update of its air quality plan in summer 2018 (Regierungspräsidium Stuttgart 2018).

- low emission zone, which includes a ban on Euro 4/IV diesel vehicles from the beginning of 2019 onwards[52]. This ban might be extended to Euro 5/V diesel vehicles, depending on the pollutant levels in 2019. This is a result of a ruling of the administrative court.
- improvements in public transport, bicycle traffic and pedestrian traffic, including the replacement of pre-Euro VI standard buses for public transport, improvements of the bicycle infrastructure, fast lanes for cycling
- extension of parking management and increasing parking fees.
- reduction of inner-city speed limits on major roads from 50 km/h to 40 km/h.

The aim of all the measures specified in the air quality plan is to comply with the NO_2 and PM_{10} air quality limit values from 2020 onwards.

Box 3: Court rulings in Germany

Court rulings in Germany

On 27 February 2018 the Federal Administrative Court in Germany ruled that it may be necessary to ban certain types of diesel vehicles on specific roads or in specific areas of a city, if this is the only appropriate measure. Such a traffic ban must comply with the principle of proportionality. Exceptions must be allowed to account for special situations.

The Administrative Court of Stuttgart ruled on 19 July 2017 that the air quality plan for Stuttgart had to be updated and that a ban on diesel vehicles older than Euro 6/VI was the most effective measure to ensure compliance with the NO_2 limit value and had to be introduced as soon as possible.

Source: https://www.stuttgart.de/diesel-verkehrsverbot, https://www.bverwg.de/de/270218U7C26.16.0, http://www.vgstuttgart.de/pb/,Lde_DE/4988506/?LISTPAGE=4988256.

[52] https://www.stuttgart.de/diesel-verkehrsverbot.

6.2.7. Germany – North Rhine-Westphalia (Düsseldorf)

An air quality plan for the city of Düsseldorf was published in 2013, and a draft for an update was published in summer 2018. The final version will be published at the beginning of the year 2019[53] (Bezirksregierung Düsseldorf 2013, 2018). Model calculations were performed for three individual possible measures and four combined measures. These modelled measures are:

- complete replacement of public transport buses with Euro VI buses by 2020 (for bus routes passing through Corneliusstraße).
- ban on trucks > 3.5 t in Corneliusstraße.
- strengthening of the existing environmental zone (ban on diesel vehicles including Euro 5).

The largest impact can be achieved by strengthening the environmental zone, in combination with further measures. The most stringent scenario will achieve compliance with the NO_2 limit value in 2021, the less stringent ones by 2022 or 2024. However, it is currently not clear which of these measures will be implemented. The main measures already implemented are:

- environmental zone
- improvements of public transport
- renewal of the municipal fleet

6.2.8. Italy – Lombardy, Milan

For Lombardy an AQ plan (PRIA, Piano Regionale degli Interventi per la qualità dell'aria) was approved in September 2013 and updated in 2018 (Regione Lombardia 2018). The plan includes the Milan agglomeration as well. A low emission zone in Milan is part of the Sustainable Urban Transport Plan for Milan (PUMS, Piano Urbano Mobilità Sostenibile). The updated PRIA includes estimates of emission reductions for individual measures. The most relevant measures for the inner city area are (in addition to the PUMS):

- low emission zones (LEZ), charging scheme, access regulations and low speed areas for Milan[54] and Lombardy[55]. A LEZ is in place in Milan and in further cities in Lombardy. The LEZ in Milan will be extended from 25 February 2019 onwards. The requirements will be strengthened in future years. A charging scheme is applicable in the historical centre (Area C[56]). Access restrictions apply to parts of this Area C.
- renewal of the public transport bus fleet and trains and improvements of public transport in general.

For exposure reductions in the regional and urban background, the following additional measures are the most relevant ones:

- Regulations for biomass burning. Burning in low efficiency stoves and fireplaces has been prohibited between 15 October and 15 April since 2006 in Milan, Bergamo, Brescia, and all regions of Lombardy that are below 300 m above sea level. In addition, a requirement has been in place since August 2014 to have wood-burning appliances installed by certified experts,

53 http://www.brd.nrw.de/umweltschutz/umweltzone_luftreinhaltung/Luftreinhaltung_aktuell.html.

54 https://www.comune.milano.it/wps/portal/ist/it/servizi/ambiente/aria_rumore_inquinamento/Low_emission_zone.

55 http://www.urbanaccessregulations.eu/countries-mainmenu-147/italy-mainmenu-81/milan-area-c-charging-scheme.

56 http://www.comune.milano.it/wps/portal/ist/it/servizi/mobilita/Area_C/AREA_C.

regularly maintained and registered (Regione Lombardia 2014). Burning of coal and high sulphur content fuel oils in small appliances has been prohibited[57] since 2002.

- energy efficiency improvements in private buildings
- improvements for breeding housings to lower NH_3 emissions, improved manure application methods

Overall, the PRIA should result in considerable reductions in PM and NO_x emissions. For PM these will only be achieved if the measures for biomass burning are implemented as planned. The PRIA should result in a reduction of annual PM_{10} and $PM_{2.5}$ concentrations by around 10 µg/m^3 in 2025 compared to 2013-2017 levels. In addition, NO_2 levels should be reduced by 10 to 20 µ/m^3, resulting in compliance with the limit value for the annual mean at almost all stations (Regione Lombardia 2018).

6.2.9. Italy – Rome

For the region Lazio and the Rome agglomeration a short air quality plan was published in 2009 and adopted in 2010 (Regione Lazio 2010). The plan requires annual reporting on the implementation, but these reports do not seem to be made publicly available[58]. The plan does not include information about the impact of measures. The main measures stipulated in the plan are thought to be the following ones:

- low emission zone for Rome[59], which includes three different schemes for the city centre, a specified area within a railway ring and a so-called green zone. In addition, there are access regulations on Sundays and restrictions for coaches[60].
- improvements of public transport;
- regulations for biomass burning;
- strengthening emission regulations for industrial facilities; and
- Facilitating controls over industrial facilities.

An urban traffic plan (Piano Generale del Traffico Urbano, PGTU)[61] was approved in 2015. Data on expected changes in exposure are not available.

6.2.10. Poland – Krakow

The main sources for PM_{10} in the city of Krakow are domestic heating, local industry and traffic (Małopolska 2013a, 2013b, 2017). The national air protection programme published in 2015 related 88 % of PM_{10} exceedances to domestic heating and 9 % to traffic (Ministerstwo Środowiska 2015). Thus, the main focus of the "anti-smog resolution" lies on measures for domestic heating, which include (Małopolska 2013a, 2013b, Resolution No. XXXV/527/17, Resolution No. XVIII/243/16):

- Ban on the use of coal sludge since 1 July 2017 and on the use of solid fuels for domestic heating.
- Total ban on the use of solid fuels from 1 September 2019 onwards.

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57 http://www.misureprqa.sinanet.isprambiente.it/misure_prqa_anonimusview.php?Anno=2011&IDMisura=I03_D1T_04**.

58 Annual air quality reports and assessments are available at: http://www.arpalazio.net/main/aria/doc/pubblicazioni.php.

59 https://www.comune.roma.it/pcr/it/dip_pol_amb_qualita.page.

60 http://www.urbanaccessregulations.eu/countries-mainmenu-147/italy-mainmenu-81/rome, https://www.comune.roma.it/pcr/it/dip_mob_ztl.page.

61 https://romamobilita.it/it/progetti/piano-generale-traffico-urbano-pgtu.

- Replacement of low-efficiency solid fuel appliances (Since July 2017 new coal or wood burning boilers have had to comply with the emission parameters of the Ecodesign regulations[62]. By the end of 2022, all wood and coal burning boilers have to be replaced that do not meet any standard).
- Subsidies for replacing old heating systems.
- Expansion and modernisation of the district heating network.
- Expansion of the gas network.
- Renovation of existing buildings and energy efficient construction of new buildings.
- Increased use of renewable energy sources for domestic heating.
- Ban on (agricultural) waste burning.

The PM_{10} levels show a decline over the recent years, which is considered to be the result of replacing a large number of old solid fuel boilers and stoves[63]. A large reduction of emissions is expected by 2023 according to the latest air protection programme, resulting in compliance with the PM_{10}, $PM_{2.5}$ and NO_2 limit values in that year (Małopolska 2017).

6.2.11. Poland – Warsaw

The government of the Mazowieckie Voivodeship published air quality programmes for PM_{10}, $PM_{2.5}$, NO_2 and benzo(a)pyrene as well as an "antismog resolution" (Mazowieckie 2017a, 2017b). In addition, the Voivodeship prepared short-term action plans for ozone (Mazowieckie 2015a, 2016a). The main focus lies on measures to tackle emissions from domestic heating and traffic. The former have been identified as the major source for PM_{10}, the latter as the most relevant one for NO_2 (Annex 6 to resolution 96/17). For domestic heating the following measures are planned:

- restrictions on the use of specific fuels;
- replacement of low efficiency heating devices;
- improvement of building insulations;
- expansion of the district heating and gas network;
- promoting the use of renewable energy sources for heating and hot water.

Regarding traffic emissions, the following main measures are planned:

- pedestrian zones, speed limits of 30 km/h in the city centre, restricted traffic zones;
- improvements of public transport;
- improvements of the bicycle infrastructure;

In addition, the programme addresses the (illegal) burning of municipal waste and garden waste.

With all these measures, considerable reductions of PM_{10} emissions and thus compliance with both PM_{10} and NO_2 limit values should be achieved by 2024 (Annex 3 to resolution 96/17).

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62 Commission Regulation (EU) 2015/1185, Commission Regulation (EU) 2015/1189.

63 https://powietrze.malopolska.pl/en/air-quality-plan/effects-of-activities/.

6.3. Information of the public

In the following, information provided by Member States based on the legal requirements of the AAQD is summarised. In addition, information relating to health impacts is analysed. Public information and warning systems are analysed in cases where an information or alarm threshold is exceeded.

6.3.1. Austria – Graz and Styria

The Regional Government of Styria is responsible for ambient air quality measurements in Styria and the Graz agglomeration. Current measurement data for all pollutants covered by the AAQD are provided on the website of the Styrian government and, on national level, on the website of the Environment Agency Austria[64]. The data are updated every half hour. Information on exceedances of the limit values and thresholds, as well as daily, monthly and yearly reports are available. Measurement data for all pollutants regulated in the AAQD can be downloaded from the Styrian website.

Air quality forecasts in the form of an air quality index for the current and the following two days are available only at national level[65]. The air quality index is not linked to any health messages.

6.3.2. Austria – Vienna

The Regional Government of Vienna is responsible for ambient air quality measurements in the Vienna agglomeration. Current measurement data for all pollutants covered by the AAQD are provided on the website of the City of Vienna and at national level on the website of the Environment Agency Austria[66]. A colour coded air quality index[67] which is divided into six bands (ranging from "very good" to "very poor") is used for the presentation of the current data. The data are updated every hour. Information on exceedances of limit values and thresholds and daily, monthly and yearly reports are available. In addition, a telephone service is available to inform the public about the latest measured air quality in Vienna[68]. Measurement data are available as OGD datasets[69].

Air quality forecasts in the form of an air quality index for the current and the following two days are available only at national level[70]. The air quality index is not linked to any health messages.

6.3.3. France – Paris

Airparif, a non-profit organisation accredited by the French Ministry of Environment to monitor air quality, is responsible for air quality monitoring and assessment in the Île-de-France region.

Detailed information on air quality for the Paris agglomeration is available on the website of Airparif[71]:

- up-to-date measurement data and real-time pollution maps (updated hourly);
- daily air quality forecasts for Paris for NO_2, O_3 and PM_{10} and air quality index maps;
- information on current and past pollution episodes;

64 http://www.umwelt.steiermark.at/cms/ziel/2060750/DE/, http://www.umweltbundesamt.at/umweltsituation/luft/luftguete_aktuell/.

65 http://www.umweltbundesamt.at/umweltsituation/luft/luftguete_aktuell/luftqualitaetsindex/, in the winter season the city of Graz provides a daily PM_{10} forecast for the next day on their website: http://www.umwelt.graz.at/cms/ziel/4849428/DE/.

66 https://www.wien.gv.at/umwelt/luft/, http://www.umweltbundesamt.at/umweltsituation/luft/luftguete_aktuell/.

67 Vienna air quality index („Wiener Luftgüteindex"): https://www.wien.gv.at/ma22-lgb/luftwl.htm.

68 https://www.wien.gv.at/umwelt/luft/luftqualitaet.html.

69 Open Government Data, https://www.data.gv.at/katalog/dataset/luftmessnetz-aktuelle-messdaten-wien.

70 http://www.umweltbundesamt.at/umweltsituation/luft/luftguete_aktuell/luftqualitaetsindex/.

71 http://www.airparif.asso.fr.

- database with monitoring results for download; and
- extensive additional information on air quality (e.g. legislation and standards, pollutants and their sources, effects on health).

The air quality forecasts are available for the current and the following two days. The French air quality index ATMO and the European Citeair index are used. Both indexes are not linked to any health messages.

For episodes of elevated NO_2, SO_2, O_3 and PM_{10} pollution a warning and management system is in place[72]. Health recommendations, in particular for sensitive population groups, have been developed by the High Council for Public Health (HCSP) and are provided on the Airparif website[73]. The pollution episode management system allows the prefects in the region to trigger emergency measures in the sectors transport and industry (e.g. speed limits).

6.3.4. France – Marseille

AtmoSud is responsible for air quality monitoring and assessment in the Provence-Alpes-Côte d'Azur region. AtmoSud is an independent association approved by the French Ministry of Environment for air quality monitoring.

Detailed information on air quality for the Marseille agglomeration is available on the website of AtmoSud[74]:

- up-to-date measurement data (updated hourly);
- information on current and past pollution episodes;
- information on current and past incident alerts (e.g. industrial incident or fire) with impact on air quality;
- daily high-resolution air quality forecasts for Marseille for NO_2, O_3 and PM_{10};
- measurement data archive; and,
- extensive additional information on air quality (e.g. air and health, pollutants, recommended actions for individuals and communities to improve air quality).

The air quality forecasts are available for the current and the following two days. The French air quality index ATMO is used, which is based on NO_2, O_3 and PM_{10}. The index is updated daily. A ten-band scale is used for the index, ranging from “very good” to “very bad”. The index is not linked to any health messages. Measurement data can be downloaded from the AtmoSud website or accessed via an open data air quality portal[75].

For pollution episodes a warning and management system is in place[76]. Health advice and recommendations for behavioural changes are given by the authorities to the public and to sensitive population groups. The pollution episode management system allows the prefects in the region to trigger emergency measures in the sectors transport, residential, agriculture and industry.

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72 http://www.airparif.asso.fr/reglementation/episodes-pollution.

73 http://www.airparif.asso.fr/_pdf/avis-hcsp20131115_messagesanitairesepisopollution.pdf.

74 https://www.atmosud.org/.

75 https://opendata.atmosud.org/.

76 http://www.paca.developpement-durable.gouv.fr/gestion-des-episodes-de-pollution-de-l-air-r1756.html.

6.3.5. Germany – Munich

The Bavarian Environment Agency provides on their website up-to-date information on the concentration of NO_2, O_3, CO and PM_{10}[77]. The measurement data are updated hourly. A colour coded air quality index with six bands (ranging from "very good" to "very poor") is used for the presentation of current data. In addition, information on exceedances of limit values, long-term trends and yearly reports are available. All measurement data for the years since 1980 can be downloaded from the website.

The website of the Environment Agency publishes documentation for the location of each monitoring station[78]. QR codes are attached to the monitoring stations, allowing a smartphone user to see the current data measured at a particular station. During the summer months (May to September), the Environment Agency publishes an hourly updated ozone report[79] on monitoring data results, a forecast, and concentrations maps[80].

In case of exceedances of the information or alert threshold for ozone, the public is informed on the website of the Environment Agency and via the media. Daily air pollution forecasts for the following 72 hours for NO_2, O_3 and PM_{10} are provided for Bavaria by the German Aerospace Center[81]. However, no information on health impacts is given on the website.

6.3.6. Germany – Stuttgart

The State of Baden-Württemberg and the city of Stuttgart provide up-to-date information on the concentration of NO_2, O_3, PM_{10} and $PM_{2.5}$ on their websites[82].The measurement data are updated hourly, information on exceedances of limit values and yearly reports are available.

In the summer months a daily ozone pollution forecast for the next day is published on the website of the regional environment agency of Baden-Württemberg. In case of exceedances of the information or alert threshold for ozone, the public is informed by the regional environment agency via the website and via the media. Additionally, an ozone information service is available on the telephone. For NO_2, O_3 and PM_{10} air pollution forecasts for Baden-Württemberg are provided for the next two days on a daily basis[83]. For the presentation of the data, Baden-Württemberg uses its own air quality index ("Luftqualitätsindex LuQx"), a colour-coded index which is divided into six bands ranging from "very good" to "very poor". Health advice or information on health impacts is not available on the website.

For the city of Stuttgart "Feinstaubalarm – PM alarm" is triggered in case of high PM_{10} concentrations at the monitoring station Stuttgart am Neckartor and when the German Meteorological Service (DWD) forecasts particular constraints on atmospheric airflows on at least two consecutive days between 15 October and 15 April[84]. In case of PM alarm, the city of Stuttgart and the state of Baden-Württemberg sends an appeal to people to use environmentally friendly means of transport. In addition, the operation of fireplaces in private homes is prohibited under an ordinance issued by the regional government (Landesregierung Baden-Württemberg 2017).

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77 https://www.lfu.bayern.de/luft/index.htm.

78 https://www.lfu.bayern.de/luft/immissionsmessungen/dokumentation/index.htm.

79 https://www.lfu.bayern.de/luft/immissionsmessungen/ozon/bericht/index.htm.

80 https://www.lfu.bayern.de/luft/immissionsmessungen/ozon/karten/index.htm.

81 http://wdc.dlr.de/data_products/projects/promote/BY-forecast/index.php.

82 https://www.lubw.baden-wuerttemberg.de/luft/messwerte-immissionswerte#karte, http://www.stadtklima-stuttgart.de/index.php?luft_messdaten_station_smz.

83 https://www.lubw.baden-wuerttemberg.de/luft/atmobw.

84 https://www.stuttgart.de/feinstaubalarm/.

6.3.7. Germany – North Rhine-Westphalia (Düsseldorf)

The State Agency for Nature, Environment and Consumer Protection of North Rhine-Westphalia (LANUV) and the city of Düsseldorf carry out ambient air quality measurements in Düsseldorf. Current measurement data for NO_2, O_3 and PM_{10} are provided on the website of LANUV and for NO and NO_2 only on the website of the city of Düsseldorf[85]. The data are updated hourly. LANUV uses, like other states in Germany, a colour-coded air quality index divided into six bands (ranging from "very good" to "very poor"). Detailed information on exceedances of limit values and thresholds, short- and long-term trends and yearly reports are available. Measurement data for all pollutants regulated in the AAQD can be downloaded from the LANUV website.

A daily air quality forecasts for North Rhine-Westphalia are provided for O_3, SO_2, NO_2, PM_{10}, CO, formaldehyde for the current and the following two days, and an air quality index is provided on the LANUV website[86]. The forecasts are estimates of the regional background concentrations at a resolution of 5 x 5 km by the Rhenish Institute for Environmental Research (RIU) Cologne. The air quality index is not linked to any health messages.

6.3.8. Italy – Lombardy, Milan

For Lombardy and the Milan agglomeration data on ambient air quality are provided on the website of the regional environmental protection agency of Lombardy (Agenzia Regionale per la Protezione dell'Ambiente (ARPA), Lombardia)[87]. Latest measurement data are only available for the previous day. For the current day and the following two days modelled air quality forecasts for PM_{10}, $PM_{2.5}$, NO_2, O_3 and an air quality index are presented as colour-coded maps for the region of Lombardy. Although the data are displayed using a five-band index ranging from "very good" to "very poor", the air quality index is not linked to any health messages. However, general information on the health impacts of air pollutants is provided[88]. Information on exceedances of limit values and thresholds is available, as well as yearly reports. Non-validated measurement data from the last three to six months can be downloaded from the ARPA website. Validated data from previous years are available from the open data portal of Lombardy[89].

6.3.9. Italy – Rome

For the region of Lazio and the Rome agglomeration, data on ambient air quality are provided on the website of the regional environmental protection agency of Lazio (Agenzia Regionale Protezione Ambientale del Lazio - ARPALAZIO)[90]. Latest measurement data are only available for the previous day. For the current day and the following four days modelled air quality forecasts for PM_{10}, NO_2, CO, SO_2 and O_3 are available for Rome. The forecasts are updated every three hours, health messages are not linked to predicted pollution levels.

Information on exceedances of limit values and thresholds and daily, weekly and yearly reports are available. Measurement data for the years since 1999 can be downloaded from the ARPALAZIO website.

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85 https://www.lanuv.nrw.de/umwelt/luft/immissionen/aktuelle-luftqualitaet/, https://www.duesseldorf.de/umweltamt/umweltthemen-von-a-z/luft/messprogramm.html.

86 https://www.lanuv.nrw.de/umwelt/luft/ausbreitung/aktuelle-immissionsprognose/.

87 http://www.arpalombardia.it/Pages/Aria/Qualita-aria.aspx.

88 http://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/cittadini/salute-e-prevenzione/Sicurezza-negli-ambienti-di-vita-e-di-lavoro/inquinamento-atmosferico/inquinamento-atmosferico/.

89 https://dati.lombardia.it/.

90 http://www.arpalazio.gov.it/ambiente/aria/.

6.3.10. Poland – Krakow, Warsaw

The Chief Inspectorate for Environmental Protection (Główny Inspektorat Ochrony Środowiska GIOŚ) publishes all information on a national air quality portal[91]. The portal offers the following information:

- up-to-date measurement data (all data collected within State Environmental Monitoring system) including warnings in case of exceedances of limit values or information and alert thresholds;
- air quality forecasts (short-term) and long-term projections of PM (to 2020 and 2025);
- measurement data archive (all data collected within State Environmental Monitoring system);
- information about the air quality monitoring system in Poland;
- modelling data used for annual air quality assessments;
- results of annual and five year air quality assessments, and
- additional information on air quality (e.g. legislation, air quality programmes).

The air quality forecasts are available for PM_{10}, NO_2, SO_2 and O_3 (only in the summer months) for the current and the following two days on the national and regional level. A Polish air quality index is used by GIOŚ which is based on NO_2, O_3, CO, SO_2, PM_{10}, $PM_{2.5}$ and benzene. The index is updated hourly and is calculated as 1-hour means. A six-band scale is used for the index, ranging from "very good" to "very poor". The index is linked to simple health messages (advising e.g. reduced outdoor activities in case of poor air quality).

7. CONCLUSIONS AND RECOMMENDATIONS

KEY FINDINGS

Most of the requirements of the AAQD are fulfilled in the air quality zones analysed in this study.

The information available does not allow an analysis of whether the pollution hotspots have been identified in all zones and Member States.

There are a number of ambiguities in the provisions that can lead to different interpretations. These should be addressed when revising the AAQD.

7.1. Conclusions

Based on the results of the analysis in section 3 to 6 the following conclusions can be drawn:

Number of monitoring stations per zone (AAQD Annex V A 1):

- The requirement for the minimum number of NO_2 monitoring sites is fulfilled in all zones.
- The requirement for the minimum number of PM (PM_{10} + $PM_{2.5}$) monitoring sites is fulfilled in all zones.

[91] http://powietrze.gios.gov.pl/pjp/home.

- The provisions for ozone monitoring stations (Annex IX) are fulfilled in all investigated zones except PL1201 (Kraków).
- There is still an insufficient number of $PM_{2.5}$ stations in several zones, especially at traffic sites;
- There might be an insufficient number of $PM_{2.5}$ traffic sites, which however depends on the interpretation of the provisions regarding particulate matter.
- There might be an insufficient number of NO_2, PM_{10} and $PM_{2.5}$ urban background stations in several zones, which however depends on the interpretation of the provisions regarding "urban" and "suburban" stations.
- The criteria for the required minimum number of $PM_{2.5}$ sites should be reconsidered to reflect the health impacts and the widespread exceedance of the WHO guideline values[92] in Europe (EEA 2018).

Macroscale siting criteria:

- Site selection methodologies for traffic stations, which shall cover the location of the highest concentration, are only available for Germany. Thus, it is not clear whether the locations of these stations have been properly selected in all other Member States analysed in this study;
- In some zones traffic sites are missing[93] (see section 3.3);
- No documentation is available in any of the selected Member State describing the representativeness for the exposure of the general population. This might be also due to missing definitions for this provision.

Microscale siting criteria:

- The free air flow around the air inlet might be restricted by nearby trees at several monitoring sites. However, there is no systematic analysis available of a possible impact of nearby trees on monitored pollutant levels.
- The height of the air inlet is in compliance with the requirements at almost all stations;
- There are no immediate sources of air pollutants in the vicinity of the air inlet that might lead to a direct intake of emissions. In addition, there is no risk of recirculation for any of stations;
- Several urban traffic stations are closer than 25 m to major junctions. However, there is no systematic analysis available of a possible impact on monitored pollutant levels. Microscale model calculations indicate that this might be only of minor influence.
- Most of the urban traffic stations are located in wide streets with commercial or residential buildings either freestanding or in a series on both sides. There are, however, only few stations located in street canyons in inner city areas, which might represent the location of highest concentrations according to modelling and / or passive sampling (section 4.2.2). Therefore, the highest levels might be missed.
- There are a number of ambiguities in the provisions that can lead to different interpretations (section 5.3).

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92 The WHO guideline values are currently under review, see http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/update-of-who-global-air-quality-guidelines.

93 DEZJXX0016S, DEZJXX0017A, FR96ZAG01, PL1203, PL1401.

"Strengthening" of the AAQD by national implementation:

- The requirements regarding the number of monitoring sites, the data quality objectives, and the siting criteria have been directly transposed into national legislation by all Member States analysed. The only exception is Austria, where a higher number of monitoring sites is required per zone. This is justified by the complex alpine topography (Umweltbundesamt 2018a).
- The actual numbers of monitoring sites are (much) higher than required by national legislation (and AAQD) in all countries.
- All countries apply fixed monitoring for the pollutants covered in this study in all zones, even if the pollution level is below the lower assessment threshold, which would allow for air quality assessment via modelling or objective-estimation techniques.

Exposure to air pollutants and measures to reduce exposure

- For all analysed zones air quality plans have been implemented, including a number of stringent measures for traffic and domestic heating.
- Nevertheless, additional measures to reduce the impact of diesel vehicle exhaust and the overall amount of traffic could be implemented in some zones (Nagl et al. 2018).
- However, the data on the effect of the plans on the exposure of the affected population is available in very few cases only.

7.2. Recommendations

The analysis of the legal provisions and the siting of monitoring stations in the selected Member States and zones indicated a number of ambiguities and differences that might lead to differences in (exposure) assessment of air quality in the Member States. Therefore, these ambiguities should be clarified when revising the AAQD, the "Guidance on assessment" (DG ENV 2010) and the "IPR Guidance" (DG ENV 2018).

In addition, it would be worthwhile to include further Member States and zones in the analysis to broaden the basis for the possible revision of the provisions.

The following issues are regarded as the most urgent ones:

- Clear provisions for the identification of the highest concentrations in an agglomeration and zone. This includes the obligation for regular updates[94] of such an analysis as the spatial pattern of sources and therefore concentrations can change over time. This also includes provisions for obligatory modelling and/or passive sampling campaigns;
- Development of definitions for the "exposure of the general population" and provisions for the identification of locations for monitoring sites representative[95] of the exposure;
- There is a number of ambiguous provisions regarding the microscale and macroscale siting criteria, as well as the number of monitoring stations;

[94] Present legislation (AAQD Annex III D.) requires updating the documentation of the site-selection procedures, but not of the site selection itself.

[95] FAIRMODE (Forum for air quality modelling in Europe, http://fairmode.jrc.ec.europa.eu/wg1.html) has launched an initiative to discuss concepts for the spatial representativeness of monitoring stations. The results of this exercise are of help for these provisions as well.

- Ambiguous criteria in the "Guidance" e.g. concerning the classification of monitoring sites (DG ENV 2018).
- Any changes to the siting criteria should be substantiated by modelling and / or monitoring exercises.
- The high variability of NO_2 levels is difficult to grasp with fixed monitoring sites. Therefore, NO_2 assessment should be performed obligatory by a combination of fixed monitoring and modelling (with suitable spatial resolution), optionally accompanied by passive sampling.
- The provision regarding the documentation (and regular update) of the monitoring site selection according to Annex III D of the AAQD should comprise requirements for a complete, thorough assessment[96] including modelling.
- In case of a review of the AAQD, which might lead to a more stringent limit value for $PM_{2.5}$ in line with the WHO guidelines, provisions to increase the minimum number of required $PM_{2.5}$ sites should be considered.
- Regarding air quality plans, it is recommended to tighten requirements for diesel vehicles in some zones, as well as aiming for a general reduction of the overall amount of traffic.

96 An "incomplete" preliminary assessment that missed the highest concentrations in a zone can yield an assessment regime below the lower assessment threshold, which poses no obligation on monitoring at all.

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ANNEX A: AIR QUALITY MONITORING SITES

Table 9: Minimum number of air quality monitoring stations per zone (according to Annex V A 1 of the AAQD and to national legislation) and actual number of monitoring stations per zone for NO_2, PM_{10}, $PM_{2.5}$ and O_3

Name	Zone code	Required by AAQD / Actual number		
		NO_2	$PM_{10}+PM_{2.5}$	O_3
Styria (without Graz)	AT_06	0 (10)* / 24	4 (10)* / 24	2 (15)* / 18
Vienna	AT_09	5 (12)* /16	7 (18)* / 19	3 (5)* / 5
Graz	AT_60	5 (5)* / 6	3 (9)* / 10	1 (2)* / 4
Stuttgart	DEZCXX0007A	2 / 12	6 / 11	2 / 3
Munich	DEZDXX0001A	5 / 5	7 / 8	3 / 3
Düsseldorf	DEZJXX0009A	3 / 13	4 / 11	2 / 2
Urban and rural areas in North Rhine-Westphalia	DEZJXX0016S	10 / 31	15 / 24	9 / 10
Duisburg	DEZJXX0017A	4 / 15	6 / 8	3 / 4
Paris	FR11ZAG01	10 / 37	15 / 24	9 / 15
Ile-de-France	FR11ZRE01	0 / 2	6 / 8	3 / 8
Marseille - Aix-en-Provence	FR93ZAG01	5 / 10	7 / 11	3 / 9
Milan	IT0306	7 / 18	10 / 19	5 / 8
Urbanised surroundings of Milan	IT0309	7 / 25	10 / 31	5 / 14
Rome	IT1215	7 / 15	10 / 23	5 / 9
Krakow	PL1201	3 / 3	4 / 14	2 / 1
Lesser Poland	PL1203	0 / 7	8 / 24	4 / 5
Warsaw	PL1401	5 / 5	7 / 18	3 / 4

Source: Umweltbundesamt, EEA Central Data Repository.

* In brackets: Minimum numbers required by Austrian national legislation.

The selected stations are listed in the following table (Area classification: U urban, S suburban, R rural; emission classification: B background, T traffic, I industrial). Note: Emission classification (pollutant-specific according to 2011/850/EU) is identical[97] for NO_2, PM_{10}, $PM_{2.5}$ and O_3.

Table 10: List of the monitoring stations analysed in this study.

Zone code	Station code	Station name	Area classification	Emission classification	Distance from kerb (gases)	Distance from kerb (PM)	Dist. to building	Dist. to junction	Inlet Height gas	Inlet Height PM
AT_06	AT60197	Leibnitz	S	T	4.7	5.6	20.0	35	4.0	4.0
AT_06	AT60143	Leoben Zentrum	S	B			20.0		4.0	4.0
AT_06	AT60185	Klöch	R	B					4.0	4.0
AT_09	AT90MBA	Wien Hietzinger Kai	U	T	3.2		0.8	400	3.0	3.0
AT_09	AT90TAB	Wien Taborstraße	U	T	6.0		11.0	50	4.0	4.0
AT_09	AT90AKC	Wien Kendlerstraße	U	B			18.0		4.0	4.0
AT_09	AT9BELG	Wien Belgradplatz	U	B					4.0	4.0
AT_09	AT900ZA	Wien Hohe Warte	S	B			0.8		6.0	6.0
AT_60	AT60164	Graz Don Bosco	U	T	6.5	6.0	27.0	10	4.0	4.0
AT_60	AT60170	Graz Süd	U	B			14.0		4.0	4.0

97 except FR02008, which is classified as a “background” station for PM_{10} and an “industrial” station for $PM_{2.5}$.

Zone code	Station code	Station name	Area classification	Emission classification	Distance from kerb (gases)	Distance from kerb (PM)	Dist. to building	Dist. to junction	Inlet Height gas	Inlet Height PM
AT_60	AT60172	Graz Mitte	U	B			13.0		4.0	4.0
DEZCXX0007A	DEBW118	Stuttgart Am Neckartor	U	T	4.0	4.0	5.0	160	3.5	3.5
DEZCXX0007A	DEBW013	Stuttgart Bad Canstatt	U	B					3.5	3.5
DEZDXX0001A	DEBY115	München Landshuter Allee	U	T	1.0	1.0	8.0	40	3.9	4.5
DEZDXX0001A	DEBY037	München Stachus	U	T	4.0	4.0	23.0	5.0	3.8	4.5
DEZDXX0001A	DEBY039	München Lothstr.	U	B					3.5	3.5
DEZJXX0009A	DENW082	Düsseldorf, Corneliusstraße	U	T	2.0	2.0	4.0	75	2.3	3.3
DEZJXX0009A	DENW071	Düsseldorf Lörick	U	B					3.5	3.5
DEZJXX0016S	DENW158	Paderborn Friedrichstraße	U	T	1.0		2.0	65.0	2.6	
DEZJXX0016S	DENW030	Wesel Feldmark	S	B					3.5	3.5
DEZJXX0017A	DENW1188	Oberhausen, Mühlheimer Straße 117	U	T	1.0	1.0	4.0	98	2.4	3.1

Zone code	Station code	Station name	Area classification	Emission classification	Distance from kerb (gases)	Distance from kerb (PM)	Dist. to building	Dist. to junction	Inlet Height gas	Inlet Height PM
DEZJXX0017A	DENW338	Duisburg Bruckhausen	U	I					3.5	3.5
DEZJXX0017A	DENW038	Mühlheim Styrum	U	B					3.5	3.5
FR11ZAG01	FR04058	Paris, Auto 1 St. Denis	U	T	1.5*	1.5*	1.0*	>>25*	3.0	3.0
FR11ZAG01	FR04012	Paris Place Victor Basch	U	T	1.0*	1.0*	25.0*	10*	3.0	2.0
FR11ZAG01	FR04004	Paris 18eme	U	B					3.0	3.0
FR11ZAG01	FR04319	Tremblay-en-France	S	B					3.0	3.0
FR11ZRE01	FR04181	Ramboullet	S	B						3.0
FR11ZRE01	FR04158	Zone Rural NO	R	B						3.0
FR11ZRE01	FR04173	RD934 Coulommiers	U	T		1.5*	2.5			3.0
FR93ZAG01	FR03006	Marseille, Rabatau	U	T	1 to 2	1 to 2		158	5.0	5.0
FR93ZAG01	FR03014	Marseille, St. Louis	U	B					5.0	6.0

Zone code	Station code	Station name	Area classification	Emission classification	Distance from kerb (gases)	Distance from kerb (PM)	Dist. to building	Dist. to junction	Inlet Height gas	Inlet Height PM
FR93ZAG01	FR02008	Port de Bouc Leque	U	B						3.0
FR93ZAG01	FR02004	Martigues P. Central / Martigues Notre Dame des Marins	U	B					7.0	
IT0306	IT0477	Milano, Viale Marche	U	T	4.0*	4.0*	5.0	7	3.5	3.5
IT0306	IT1016	Milano, Senato	U	T	2.0*	2.0*	5.0	18	3.5	3.5
IT0306	IT2232	Cormano, Via Edison	U	B					3.5	3.5
IT0306	IT1692	Milano, Via Pascal, Citta Studi	U	B					3.5	3.5
IT0306	IT1648	Cantu, Via Meucci	S	B					3.5	3.5
IT0309	IT1104	Pavia, Piazza Minerva	U	T	8.0*	8.0*	6.0**	20	3.0	3.0
IT0309	IT1739	Cremona, Via Fatebenefratelli	U	B					3.0	3.0

Zone code	Station code	Station name	Area classification	Emission classification	Distance from kerb (gases)	Distance from kerb (PM)	Dist. to building	Dist. to junction	Inlet Height gas	Inlet Height PM
IT0309	IT1873	Ferno	U	B					3.5	3.5
IT1215	IT1837	Roma, Piazza Fermi	U	T	2.0*	2.0*	15.0*	25*	3.0	3.0
IT1215	IT1834	Roma, Via Tiburtina	U	T	4.0*	4.0*	15.0*	150*	3.0	3.0
IT1215	IT1836	Roma, Cipro	U	B					3.0	3.0
IT1215	IT0956	Roma, Cinecittà	U	B					3.0	3.0
PL1201	PL0012	Kraków, Aleja Krasińskiego	U	T	7.0	7.0	18.0	200	3.7	3.5
PL1201	PL0501	Kraków, ul. Bujaka	U	B				350	3.8	3.0
PL1201	PL0641	Kraków, ul. Dietla	U	T	2.0	2.0	10.0	105	2.5	2.5
PL1201	PL0643	Kraków, ul. Złoty Róg	U	B						2.5
PL1201	PL0039	Kraków, ul. Bulwarowa	U	I				100	4.1	4.0
PL1203	PL0550	Nowy Sącz, ul. Nadbrzeżna	U	B				180	4.0	3.0

Zone code	Station code	Station name	Area classification	Emission classification	Distance from kerb (gases)	Distance from kerb (PM)	Dist. to building	Dist. to junction	Inlet Height gas	Inlet Height PM
PL1203	PL0671	Nowy Targ, Plac Słowackiego	U	B						4.0
PL1203	PL0640	Kaszów	S	B					3.7	
PL1401	PL0140	Warszawa-Komunikacyjna	U	T	1.0	1.0	6.0	92	3.5	3.5
PL1401	PL0143	Warszawa-Targówek	U	B				170	3.5	3.5
PL1401	PL0141	Warszawa-Ursynów	U	B				225	3.5	3.5

Source: Umweltbundesamt, EEA

* Estimated using photos.

** According to photos approx. 15 m.

Note: There is no PM_{10} traffic site in zone DEZJXX0016S.

All meta-information about zones and monitoring stations originate from the 2017 data submission on CDR, downloaded on4./8.1.2019: http://cdr.eionet.europa.eu/at/eu/aqd/c/envxc2_6a/, http://cdr.eionet.europa.eu/at/eu/aqd/d/envxa_vla/, http://cdr.eionet.europa.eu/de/eu/aqd/b/colww_e5w/envw3v_ga/, http://cdr.eionet.europa.eu/de/eu/aqd/c/colw3welw/envw5xpq/, http://cdr.eionet.europa.eu/de/eu/aqd/d/colwzonea/envw5tyyq/, http://cdr.eionet.europa.eu/fr/eu/aqd/b/envw5fx1g/, http://cdr.eionet.europa.eu/fr/eu/aqd/c/envw5p4_g/, http://cdr.eionet.europa.eu/fr/eu/aqd/d/envxbecrw/, http://cdr.eionet.europa.eu/it/eu/aqd/b/envw_6eua/, http://cdr.eionet.europa.eu/it/eu/aqd/c/envxapzgq/, http://cdr.eionet.europa.eu/it/eu/aqd/d/envw82f6w/, http://cdr.eionet.europa.eu/pl/eu/aqd/b/envw6ok_w/, http://cdr.eionet.europa.eu/pl/eu/aqd/c/envw6jalw/, http://cdr.eionet.europa.eu/pl/eu/aqd/d/envxbweua/.

Air Quality data downloaded from http://aqportal.discomap.eea.europa.eu/products/aide-family/f-statistics/ (9.1.2019).

Table 11: Description of the location of "traffic" monitoring sites

Code	Station name	Distance from kerb	Distance from building line	Position of monitoring site	Description of buildings	Width of street *
AT60197	Leibnitz	4.7 to 5.6 m	No building line, nearest building 20 m	Shelter in park	Detached 1 – 3-storey buildings 5 – 20 m from kerb	Ca. 10 m**
AT90MBA	Wien Hietzinger Kai	4 m	0.75 m	On the facade of a large building	100 m facade of 6-storey-buildings behind the monitoring site. 1 – 2-storey, partly detached buildings on the opposite side of the road at 70 m distance	7 m wide lanes in each direction, separated by river and underground tracks
AT90TAB	Wien Taborstraße	6 m	10 m (eastern side of Glockengasse), 20 m (western side of Taborstra0ße)	Shelter on median strip between Taborstraße and Glockengasse (small lane)	Row of 4 – 6-storey terraced houses along the streets	30 m
AT60164	Graz Don Bosco	6.0 to 6.5 m	No building line, nearest building 27 m	Shelter in park	Detached 2 – 4-storey buildings 2 – 20 m from kerb (around junction)	20 m
DEBW118	Stuttgart Am Neckartor	4 m	5 m	Small shelter near recessed corner of large building	150 m facade of 6-storey buildings behind the monitoring site; large park (no buildings) on the opposite side of the road.	Ca. 20 m**

Code	Station name	Distance from kerb	Distance from building line	Position of monitoring site	Description of buildings	Width of street *
DEBY115	München Landshuter Allee	1 m	8 m	Shelter on parking lane.	90 m facade of 5-storey buildings behind the monitoring site, partly detached 5 – 6-storey buildings on the opposite side of the road	Ca. 50 m**
DEBY037	München Stachus	4 m	23 m	Shelter on median stip between traffic lanes	Row of 5 – 6-storey terraced buildings on both sides	70 m**, lanes separated by 30 m wide median strip with park
DENW082	Düsseldorf Corneliusstraße	2 m	4 m	Small shelter on parking lane	Row of 4 – 5-storey terraced buildings on both sides	Ca. 30 m**
DENW158	Paderborn Friedrichstraße	1 m	2 m	Passive sampler[32] on street lighting pole	Row of 2 – 3-storey terraced buildings on both sides	Ca. 50 m**, covered by Friedrichstraße (15 m), large park and Westernmauer street
DENW188	Oberhausen Mühlheimer Straße 117	1 m	4 m	Small shelter on parking lane	Row of 3 – 5-storey terraced buildings on both sides	Ca. 25 m **
FR04058	Paris Auto 1 St. Denis	Ca. 1.5 **	Ca. 10 m**	Small Shelter on pavement	Detached large buildings of different shapes and sizes	Ca. 30 m**

Code	Station name	Distance from kerb	Distance from building line	Position of monitoring site	Description of buildings	Width of street *
FR04012	Paris Place Victor Basch	Ca. 1 m**	Ca. 25 m**	Small shelter on pavement between traffic lanes near a circular square	5 – 10-storey buildings in 6 sectors around a circular square	Circular square, about 50 m in diameter**
FR04173	RD934 Coulommiers	1.5 m**	2.5 m	Small shelter on parking lane	Detached 1 – 2-storey buildings	15 m**
FR03006	Marseille Rabatau	2 m	2 m	Shelter on parking lane	Detached large buildings of different sizes	Ca. 25 m**
IT0477	Milano, Viale Marche	Ca. 4 m**	5 m	Shelter in garden	Detached large buildings of different sizes	Ca. 25 m**
IT1016	Milano, Senato	2 m**	5 m	Small Shelter on pavement	Row of 4 – 5-storey terraced buildings on 3 sides, large park on 1 side of a square	Square, approx. 60 m
IT1104	Pavia, Piazza Minerva	Ca. 8 m**	15 m**	Small shelter on median strip between traffic lanes	Row of 4 – 7-storey terraced buildings on both sides	Ca. 65 m**
IT1837	Roma, Piaza Fermi	Ca. 2 m**	Ca. 15 m**	Shelter on parking area	Row of 6 – 10-storey terraced buildings on both sides	Wide street or drawn-out square, width ca. 70 m**
IT1834	Roma, Via Tiburtina	Ca. 4 m**	Ca. 20 m	Shelter on parking lane	Detached large buildings of different sizes	Ca. 40 m**

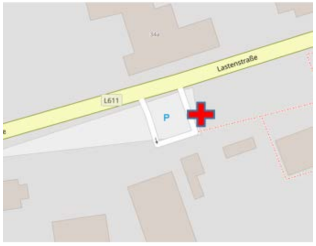
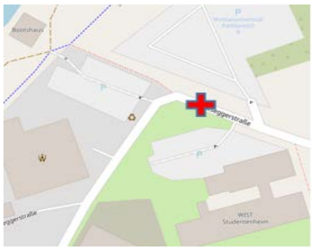
Code	Station name	Distance from kerb	Distance from building line	Position of monitoring site	Description of buildings	Width of street *
PL0012	Kraków, Aleja Krasińskiego	7 m	18 m	Shelter on median strip between traffic lanes	Row of 4 – 7 - storey terraced buildings on both sides	44 m
PL0641	Kraków, ul. Dietla	2 m	10 m	Shelter on median strip between traffic lanes	Row of 3 – 6 - storey terraced buildings on both sides	50 m
PL0140	Warszawa-Komunikacyjna	1 m	6 m	Shelter on green strip beside street	Mostly rows of 5 –10 - storey terraced buildings on both sides	24 m***

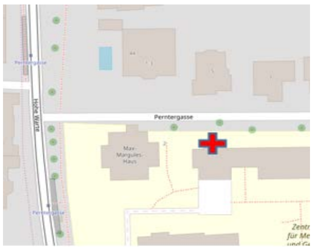
* in case of street canyons distance between opposite façades; in case of detached buildings width of road incl. parking lanes and pavement.

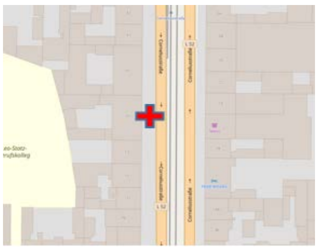
** estimated using photos.

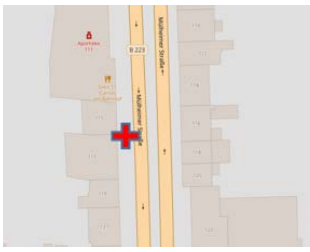
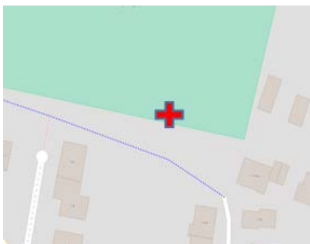
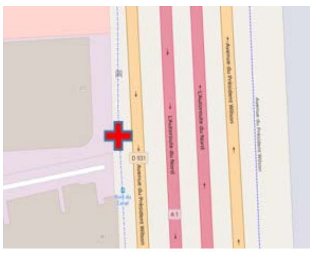
*** 24 m according to dataset D on CDR; ca. 40 m according to photos for Aleja Niepodległości, ca. 55 m immediately around the monitoring station.

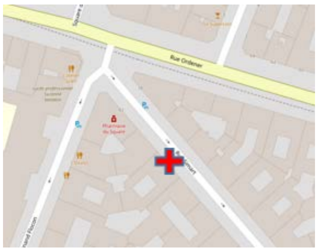
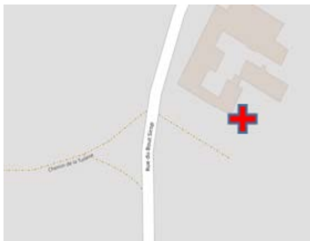
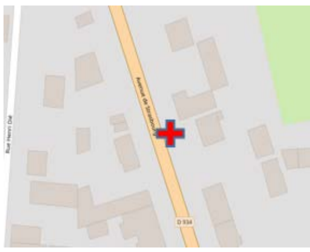
Table 12: List of monitoring stations analysed in this study. (Note: The photos from Italy show the view from the roof of the monitoring site).

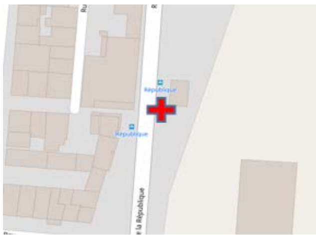
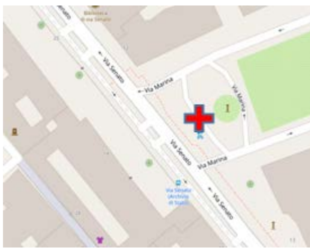
Zone code	Station code	Station name	Map	Photo
AT_06	AT60197	Leibnitz		
AT_06	AT60143	Leoben Zentrum		
AT_06	AT60185	Klöch		
AT_09	AT90MBA	Wien Hietzinger Kai		
AT_09	AT90TAB	Wien Taborstraße		
AT_09	AT9KEND	Wien Kendlerstr.		

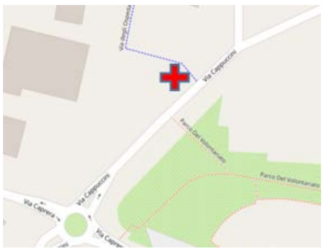
Zone code	Station code	Station name	Map	Photo
AT_09	AT9BELG	Wien Belgradplatz		
AT_09	AT900ZA	Wien Hohe Warte		
AT_60	AT60164	Graz Don Bosco		
AT_60	AT60170	Graz Süd		
AT_60	AT60172	Graz Mitte		
DEZCXX0007A	DEBW118	Stuttgart Am Neckartor		

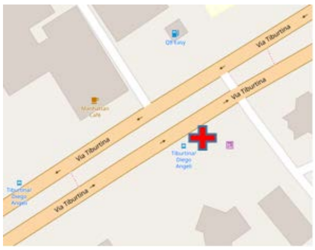
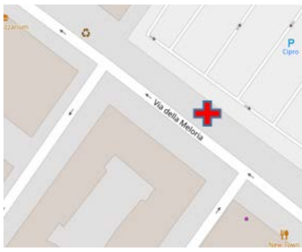
Zone code	Station code	Station name	Map	Photo
DEZCXX0007A	DEBW013	Stuttgart Bad Canstatt		
DEZDXX0001A	DEBY115	München Landshuter Allee		
DEZDXX0001A	DEBY037	München Stachus		
DEZDXX0001A	DEBY039	München Lothstr.		
DEZJXX0009A	DENW082	Düsseldorf Corneliusstr.		
DEZJXX0009A	DENW071	Düsseldorf Lörick		

Zone code	Station code	Station name	Map	Photo
DEZJXX0016S	DENW158	Paderborn Friedrichstr.		
DEZJXX0016S	DENW030	Wesel Feldmark		
DEZJXX0017A	DENW1188	Oberhausen Mühlheimer Straße 117		
DEZJXX0017A	DENW338	Duisburg Bruckhausen		
DEZJXX0017A	DENW038	Mühlheim Styrum		
FR11ZAG01	FR04058	Paris Auto 1 St. Denis		

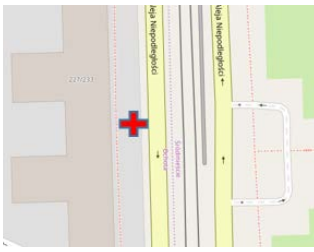
Zone code	Station code	Station name	Map	Photo
FR11ZAG01	FR04012	Paris Place Victor Basch		not available
FR11ZAG01	FR04004	Paris, 18eme		
FR11ZAG01	FR04319	Tremblay - en - France		
FR11ZRE01	FR04181	Ramboullet		
FR11ZRE01	FR04158	Zone Rural NO		
FR11ZRE01	FR04173	RD934 Coulommiers		

Zone code	Station code	Station name	Map	Photo
FR93ZAG01	FR03006	Marseille Rabatau		
FR93ZAG01	FR03014	Marseille St. Louis		
FR93ZAG01	FR02008	Port de Bouc Leque		
FR93ZAG01	FR02004	Martigues Notre Dame des Marins		
IT0306	IT0477	Milano, Viale Marche		
IT0306	IT1016	Milano, Senato		

Zone code	Station code	Station name	Map	Photo
IT0306	IT2232	Cormano, Via Edison		
IT0306	IT1692	Milano, Via Pascal Cittá Studi		
IT0306	IT1648	Cantu, Via Meucci		
IT0309	IT1104	Pavia, Piazza Minerva		
IT0309	IT1739	Cremona, Via Fatebenefratelli		
IT0309	IT1873	Ferno		

Zone code	Station code	Station name	Map	Photo
IT1215	IT1837	Roma, Piazza Fermi		not available
IT1215	IT1834	Roma, Via Tiburtina		not available
IT1215	IT1836	Roma, Cipro		not available
IT1215	IT0956	Roma, Cinecittà		not available
PL1201	PL0012	Kraków, Aleja Krasińskiego		
PL1201	PL0501	Kraków, ul. Bujaka		

Zone code	Station code	Station name	Map	Photo
PL1201	PL0641	Kraków, ul. Dietla		
PL1201	PL0643	Kraków, ul. Złoty Róg		
PL1201	PL0039	Kraków, ul. Bulwarowa		
PL1203	PL0550	Nowy Sącz, ul. Nadbrzeżna		
PL1203	PL0671	Nowy Targ, Plac Słowackiego		
PL1203	PL0640	Kaszów		

Zone code	Station code	Station name	Map	Photo
PL1401	PL0140	Warszawa-Komunikacyjna		
PL1401	PL0143	Warszawa-Targówek		
PL1401	PL0141	Warszawa-Ursynów		

Source: Maps https://www.openstreetmap.org.

Photos: Austria: Amt der Steiermärkischen Landesregierung, MA 22;
Stuttgart: https://www.lubw.baden-wuerttemberg.de/luft/messwerte-immissionswerte#karte;
Munich: https://www.lfu.bayern.de/luft/immissionsmessungen/doc/lueb_dokumentation/aktiv/;
North Rhine-Westphalia: https://www.lanuv.nrw.de/umwelt/luft/immissionen/messorte-und-werte/;
Paris, Ile-de-France: https://www.airparif.asso.fr/en/stations/;
Marseille: Air PACA;
Poland: http://powietrze.gios.gov.pl/pjp/current.

ANNEX B: DETAILED EXPOSURE DATA AND TRENDS

Table 13 compares NO_2 concentrations averaged over different site types – rural background, suburban background, urban background, and traffic (irrespective of area classification) for the selected Member States for the year 2017.

In Germany, there is a comparatively small difference between average urban and suburban background NO_2 concentrations, which may point to ambiguities in the area classification of the monitoring stations.

Urban background NO_2 concentrations – which are likely most relevant for population exposure – are highest in Austria and Italy (about 25 µg/m³) and lowest in France and Poland (about 19 µg/m³).

Table 13: Average NO_2 concentrations per Member State for rural background, suburban background, urban background and traffic sites, 2017 (µg/m³)

Member State	Rural background	Suburban background	Urban background	Traffic
AT	10.8	18.1	25.4	35.7
DE	8.6	18.3	21.4	39.6
FR	6.9	15.8	19.0	37.2
IT	11.2	20.0	25.4	35.8
PL	9.0	13.2	18.4	36.8

Source: Umweltbundesamt, EEA.

In case of PM_{10} (annual mean values per station type in Table 14) there is almost no difference in the average concentrations at urban and suburban background sites.

In Austria, the traffic sites show, on average, PM_{10} concentrations that are similar to those measured at the urban background sites. This is due to the fact that most traffic (motorway) PM_{10} monitoring stations are located in the western, alpine parts of Austria, where the overall PM_{10} levels are lower than the rural background levels in eastern Austria.

Table 14: Average PM_{10} concentrations per Member State for rural background, suburban background, urban background and traffic sites, 2017 (µg/m³)

Member State	Rural background	Suburban background	Urban background	traffic
AT	14.5	17.8	19.3	19.5
DE	12.8	16.1	16.8	21.4
FR	13.5	19.0	17.5	21.7

IT	20.4	25.7	26.6	29.2
PL	21.6	28.6	31.4	40.1

Source: Umweltbundesamt, EEA.

Findings for Ozone (average number of days with 8-hour mean values > 120 µg/m^3 per Member State in Table 15):

- Ozone levels increase with "remoteness", i.e. the distance from emission sources in Austria and (less uniformly) in Italy;
- In Germany and France, suburban and rural background levels are almost identical, but higher than urban background levels.
- In Poland, urban background ozone levels are higher than rural and suburban background levels.

It cannot be determined if these spatial patterns reflect inconsistencies in the area classification of the stations.

Table 15: Ozone: Number of days with 8-hour mean values > 120 µg/m^3 averaged per Member State for rural background, suburban background, urban background and traffic sites, 2017 (µg/m^3)

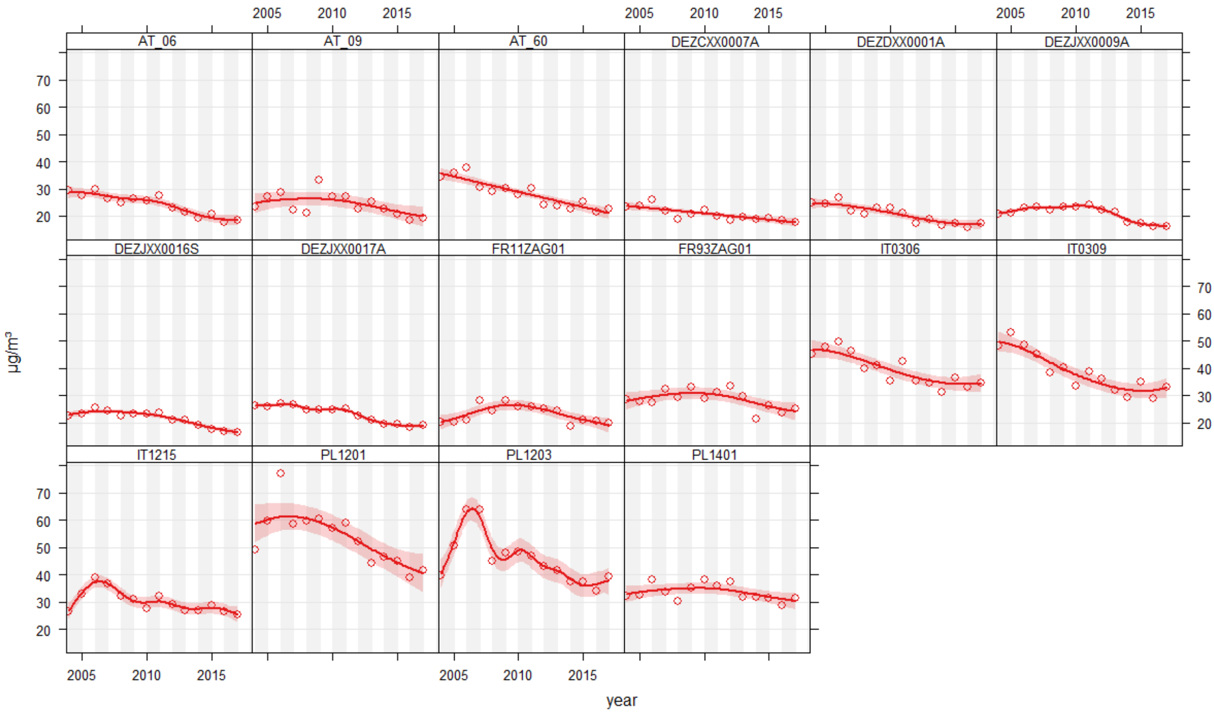
Member State	Rural background	Suburban background	Urban background	Traffic
AT	25.4	18.2	15.0	10.2
DE	12.1	12.1	9.4	4.0
FR	13.3	13.7	9.5	No traffic sites
IT	52.0	42.9	44.8	11.0
PL	5.8	5.2	8.1	No traffic sites

Source: Umweltbundesamt, EEA.

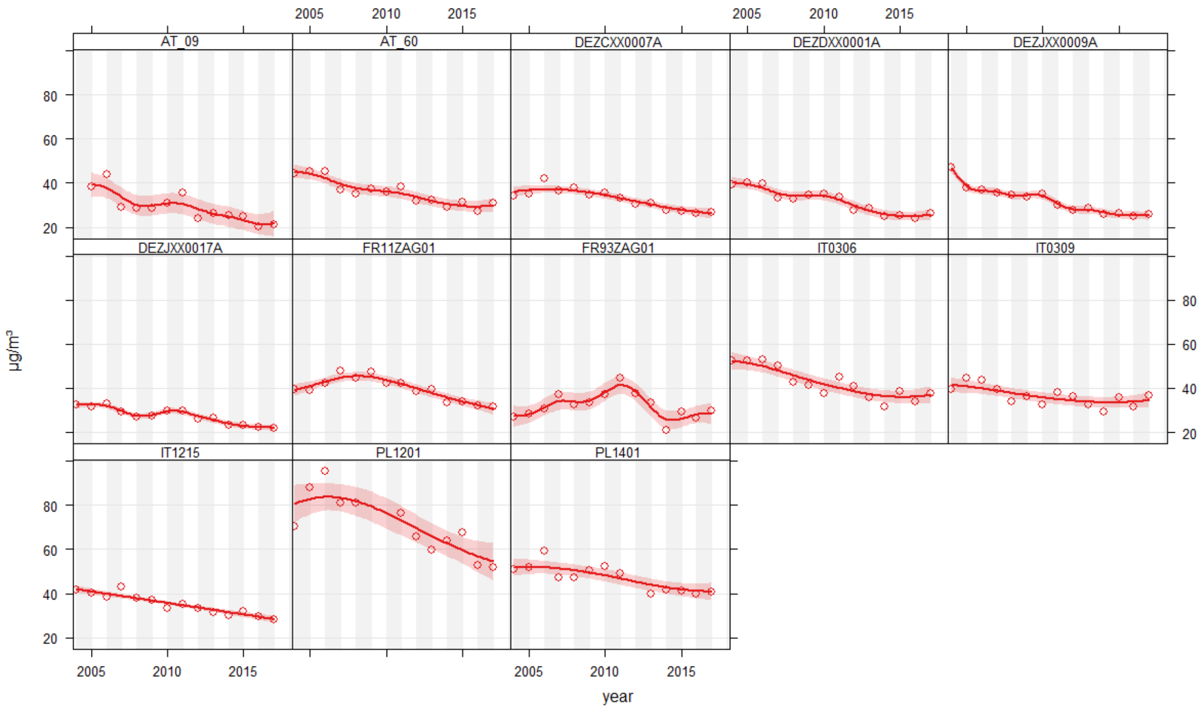
NO_2 levels: trend at suburban and urban background sites in the selected zones

NO_2 levels: trend at urban traffic sites in the selected zones

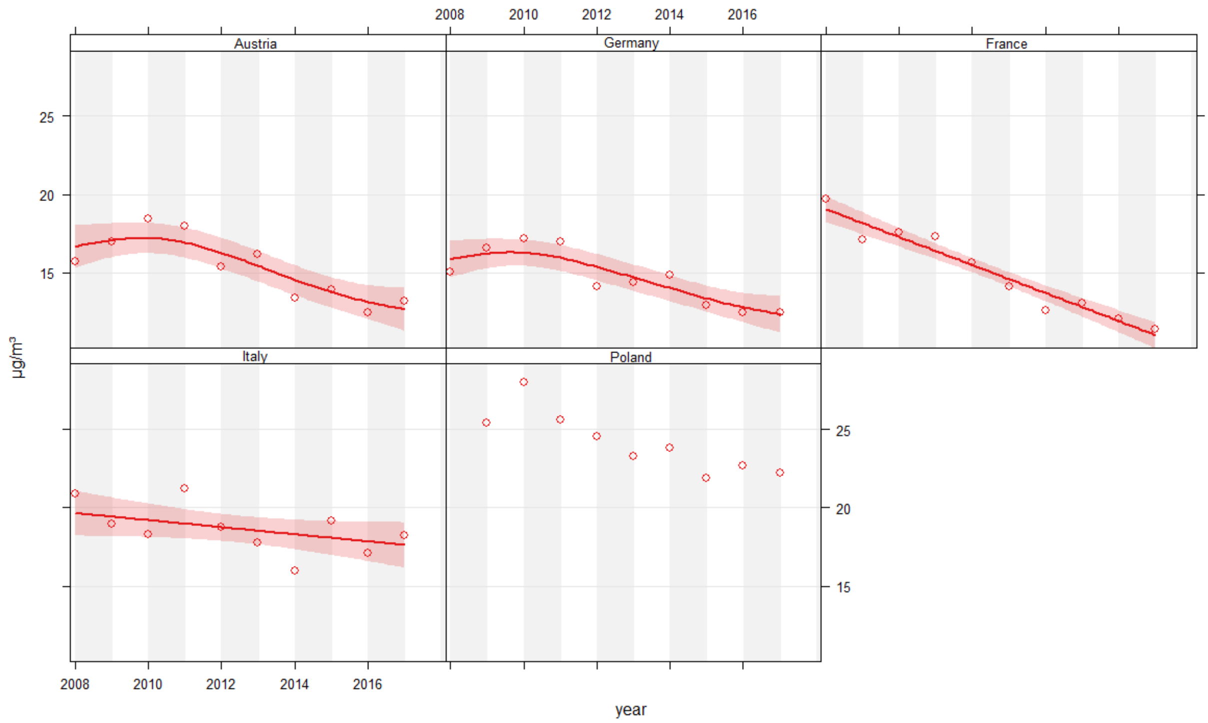
PM_{10} levels: trend at urban and suburban background sites in the selected zones



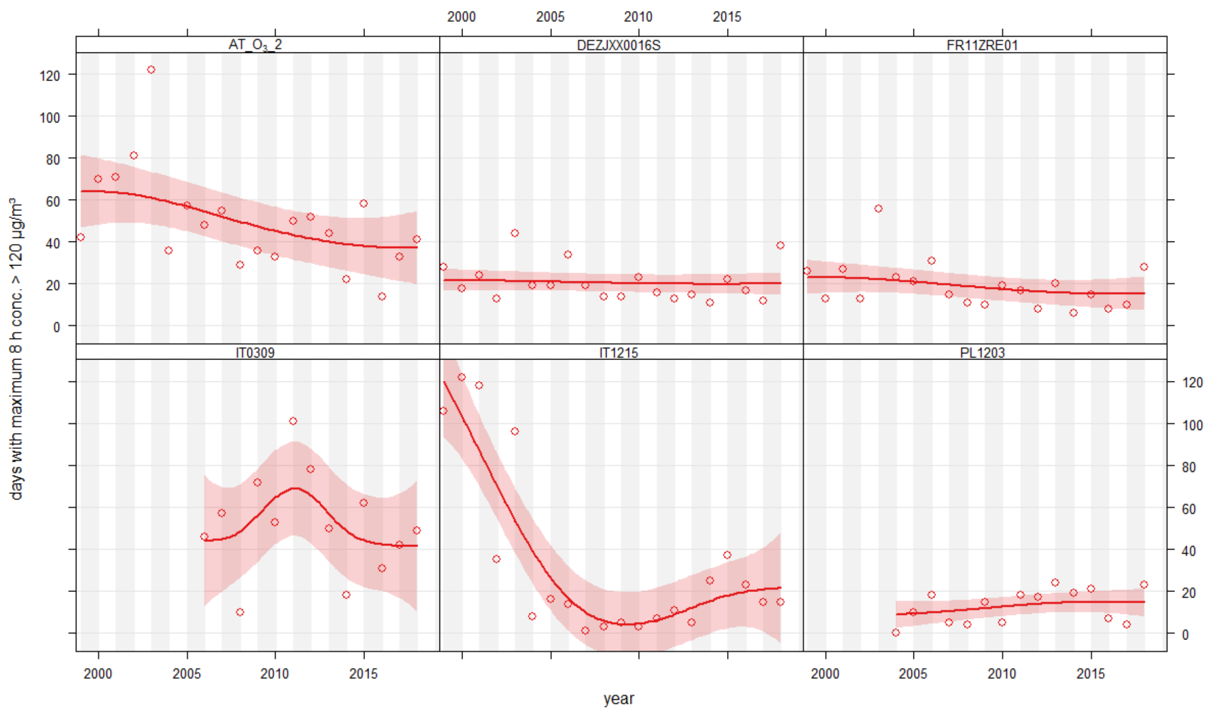
PM_{10} levels: trend at urban traffic sites in the selected zones



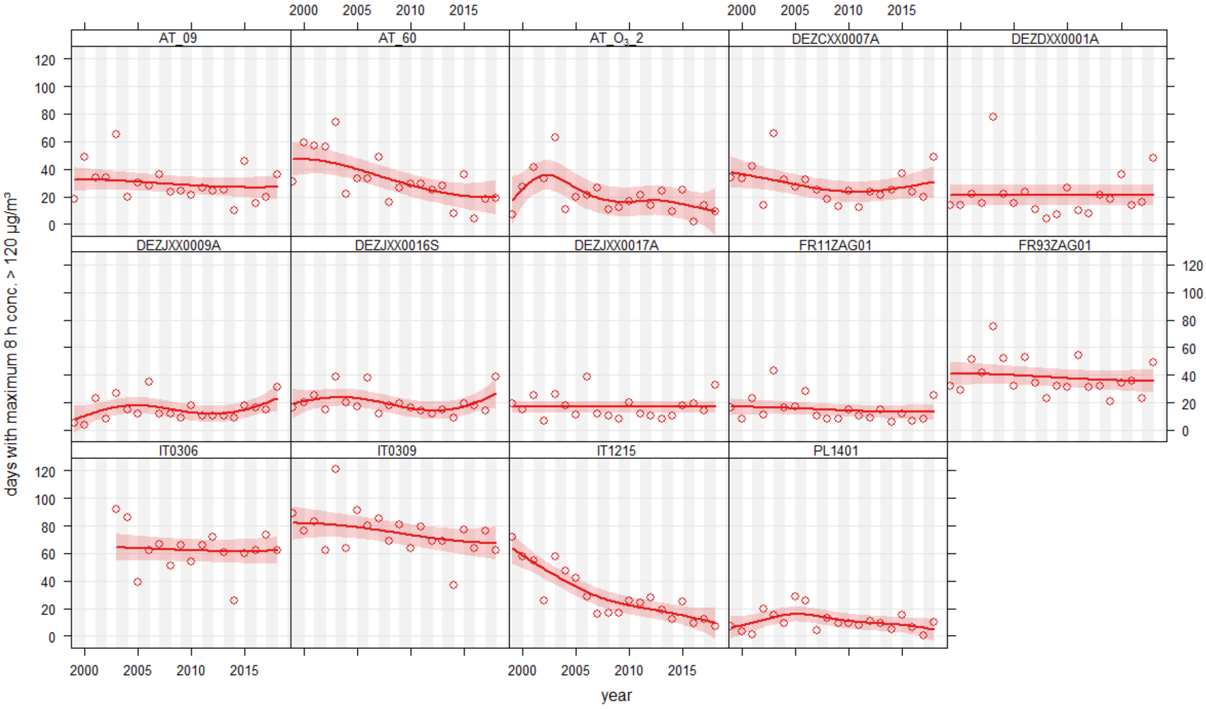
$PM_{2.5}$ levels: trend at AEI sites in the Member States



O_3 levels: trend at rural background sites in the selected zones



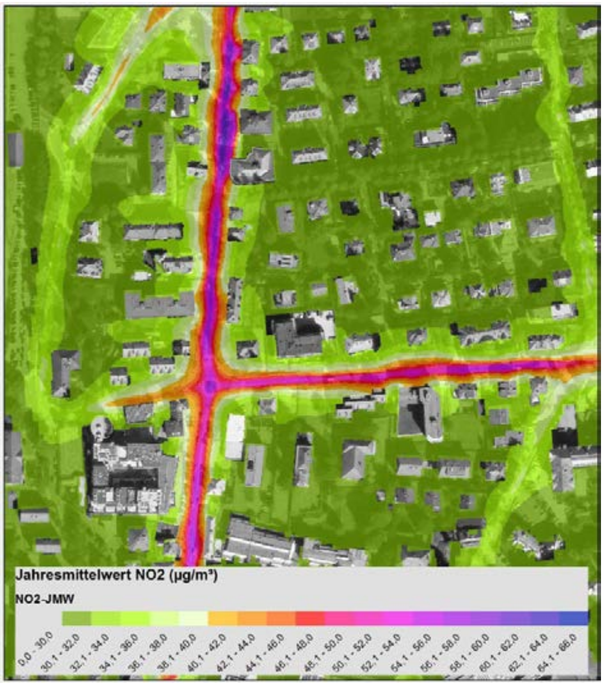
O_3 levels: trend at urban and suburban background sites in the selected zones



ANNEX C: EXAMPLES OF MODEL CALCULATIONS

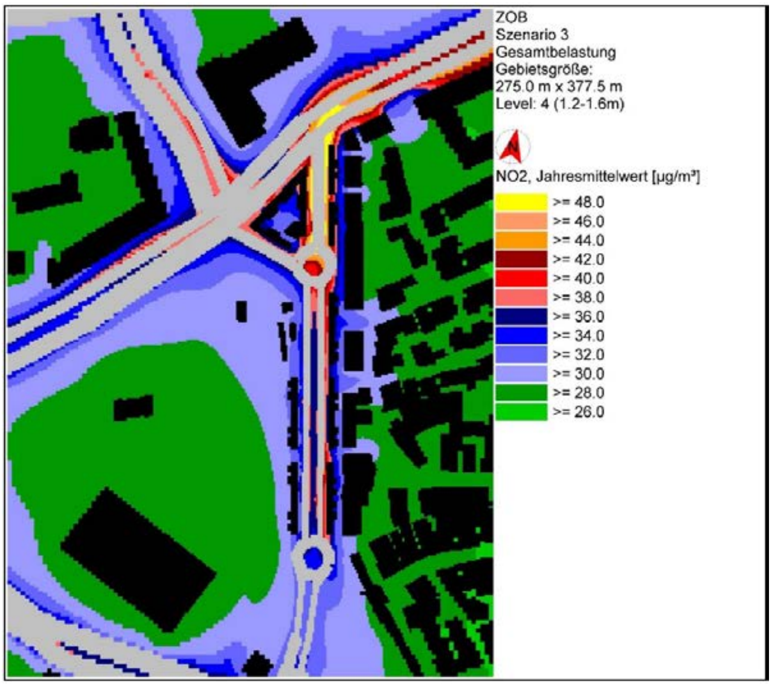
The results of the model calculations presented in Annex C illustrate the influence of the distance between possible monitoring sites and major junctions and the concentration distributions within the streets.

Figure 1: NO_2 Brixen



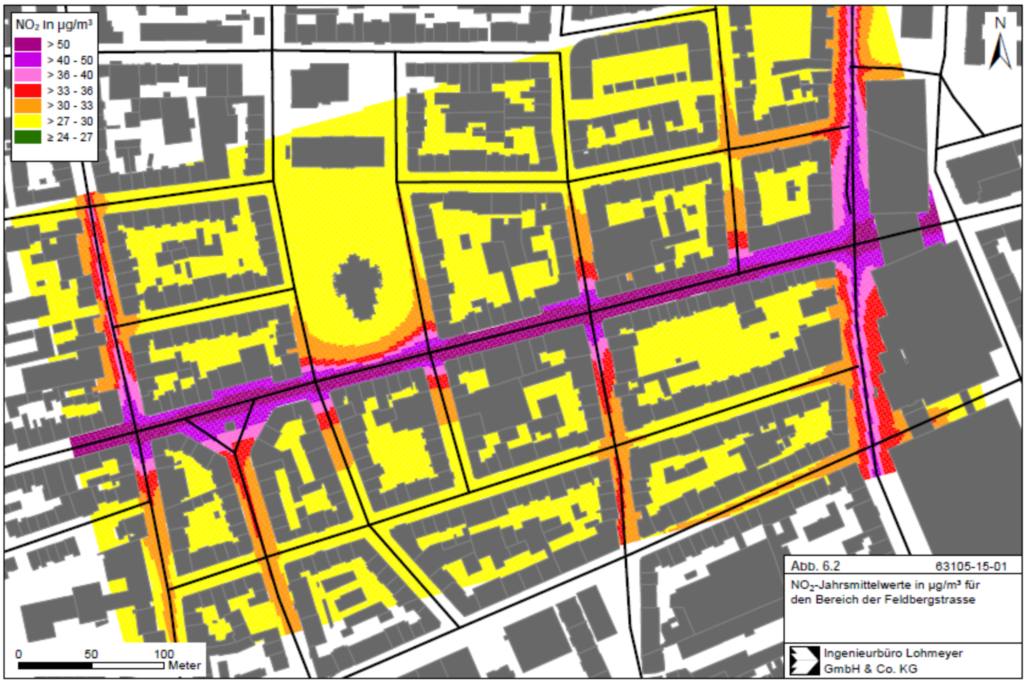
Source: Autonome Provinz Bozen – Südtirol / Provincia Autonoma di Bolzano – Alto Adige (2018).

Figure 2: NO_2 Reutlingen



Source: AVISO (2017)

Figure 3: NO_2 Basel



Source: Lohmeyer (2016)

Figure 4: NO_2 München Landshuter Allee

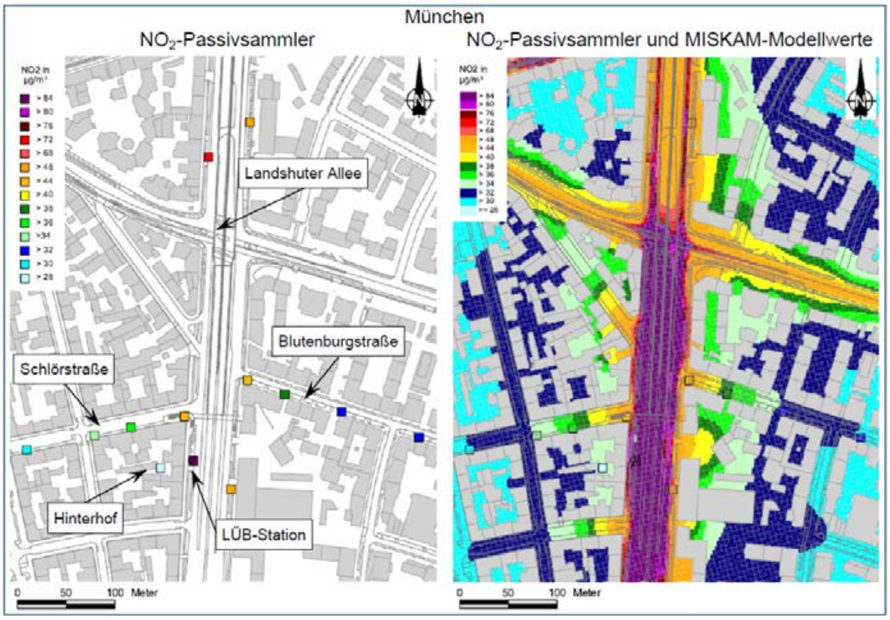
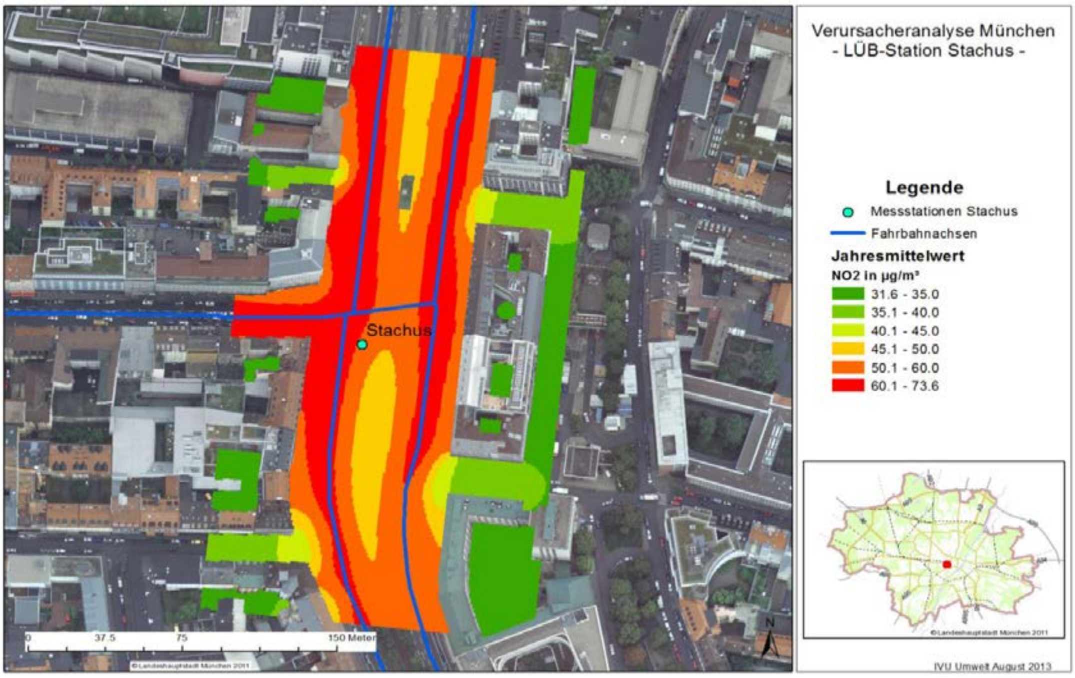


Abb. 25: Vergleich der Jahresmittelwerte für 2011 der NO_2-Passivsammler (Quadrate mit farbiger Skalierung) mit den MISKAM-Modellrechnungen im Umfeld der LÜB-Station in der Landshuter Allee in München.

Source: Bayerisches Landesamt für Umwelt (2015)

Figure 5: NO_2 München Stachus



Source: Bayerisches Landesamt für Umwelt.

ANNEX D: ASSESSMENT THRESHOLDS, LIMIT AND TARGET VALUES OF THE AAQD

The limit and target values for the protection of human health of the AAQD for the pollutants covered in this study can be found in the tables below.

Table 16: Limit values of the AAQD.

Pollutant	Averaging period	Limit value	Remark
NO_2	One hour	200 µg/m^3	Not to be exceeded more than 18 times a calendar year
NO_2	Calendar year	40 µg/m^3	
PM_{10}	One day	50 µg/m^3	not to be exceeded more than 35 times a calendar year
PM_{10}	Calendar year	40 µg/m^3	

Source: AAQD.

Table 17: Provisions for $PM_{2.5}$ of the AAQD.

Provision	Averaging period	Limit value	Remark
Exposure concentration obligation	20 µg/m^3	2015	Average Exposure Indicator
Target value	25 µg/m^3	2010	Applicable throughout the territory
Limit value stage 1	25 µg/m^3	2015	Applicable throughout the territory
Limit value stage 2	20 µg/m^3	2020	Indicative limit value, no changes in 2013 review

Source: AAQD.

Table 18: Ozone target values.

Objective	Averaging period	Target value
Protection of human health	Maximum daily eight hour mean	120 µg/m^3 not to be exceeded on more than 25 days per calendar year averaged over three years
Protection of vegetation	May to July	AOT40 (calculated from 1 h values) 18 000 µg/m^3.h averaged over five years

Source: AAQD.

Table 19: Upper and lower assessment thresholds.

Pollutant	Type of threshold	Threshold	Limit value
NO_2	Upper assessment threshold	70 % of limit value (140 µg/m^3, not to be exceeded more than 18 times in any calendar year)	hourly
NO_2	Upper assessment threshold	80 % of limit value (32 µg/m^3)	annual
NO_2	Lower assessment threshold	50 % of limit value (100 µg/m^3, not to be exceeded more than 18 times in any calendar year)	hourly
NO_2	Lower assessment threshold	65 % of limit value (26 µg/m^3)	annual
PM_{10}	Upper assessment threshold	70 % of limit value (35 µg/m^3, not to be exceeded more than 35 times in any calendar year)	24-hour
PM_{10}	Lower assessment threshold	50 % of limit value (25 µg/m^3, not to be exceeded more than 35 times in any calendar year)	24-hour
PM_{10}	Upper assessment threshold	70 % of limit value (28 µg/m^3)	annual
PM_{10}	Lower assessment threshold	50 % of limit value (20 µg/m^3)	annual

Pollutant	Type of threshold	Threshold	Limit value
$PM_{2.5}$	Upper assessment threshold	70 % of limit value (17 µg/m^3)	annual
$PM_{2.5}$	Lower assessment threshold	50 % of limit value (12 µg/m^3)	annual

Source: AAQD.

Air quality monitoring at fixed sites is a major instrument provided for in the Ambient Air Quality Directive to check compliance with limit or target values, which have been set for the protection of human health. This study analyses the criteria for the location of monitoring sites in five Member States to identify ambiguous provisions that might lead to different assessments of air pollution exposure.

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