Capacity building programme on air quality standards for GCC Countries

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PREFACE

Air pollution affects the health and well-being of people and the environment and is considered to be the world's single largest environmental health risk. As in other parts of the world, the countries of the Gulf Cooperation Council (GCC) are also facing the challenge of air pollution. In response, GCC countries have established air quality monitoring systems and networks with varying geographical coverage, pollutants scope and purpose, and developed air quality guidelines and control measures. The level of analysis and the use of monitoring data vary from one country to another. Discrepancies in data collection and reporting affect national actions to control and prevent air pollution, which is a transboundary issue. Dust storms originating within or beyond the region also have major impacts on the quality of air, yet there is no system in place to apportion the contribution of dust to overall air quality status in the GCC countries.

In 2021, the United Nations Environment Programme (UNEP) West Asia Office with the support of the GCC Secretariat and in collaboration with the World Health Organization (WHO) and Environment Agency Austria (EAA) organized a capacity-building programme on air quality standards. This guidance document compiles the presentations made at the training programme. This manual is divided into six chapters.

Chapter 1 introduces the importance of air quality for both human health and the environment, including the role of air pollution in climate change

Chapter 2 describes the general purpose of air quality standards, procedures and considerations for establishing such standards, as well as different types of standards and thresholds.

Chapter 3 provides an overview of air quality standards in the European Union (EU), including compliance checking, in the United States of America (USA) and selected further countries.

Chapter 4 gives an overview of current air quality standards in GCC countries and compares them to EU and US standards as well as WHO guidelines.

Chapter 5 summarizes the WHO air quality guidelines and interim targets.

Chapter 6 describes methods for source apportionment in general and techniques to account for the contribution of desert dust in particular.

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ACRONYMS

AAQD	Ambient Air Quality Directive
AQ	Air quality
BC	Black carbon
CO_2	Carbon dioxide
CO	Carbon monoxide
CH_4	Methane
EAA	Environment Agency Austria
EEA	European Environment Agency
EC	Elemental carbon
EU	European Union
GHG	Greenhouse Gas
GCC	Gulf Cooperation Council
H_2S	Hydrogen sulfide
JRC	Joint Research Centre
NAAQS	National Ambient Air Quality Standards
NH_3	Ammonia
NMHC	Non-methane hydrocarbon
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O_3	Ozone
Pb	Lead
PM	Particulate matter
QA/QC	Quality assessment/quality control
SO_2	Sulfur dioxide
UFP	Ultrafine particles
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency
USA	United States of America
WHO	World Health Organization
WHO AQG	World Health Organization Air Quality Guideline
WMO	World Meteorological Organization

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1. INTRODUCTION

1.1 Impact of air quality on human health and ecosystems

Air pollution affects the health and well-being of people as well as the environment. According to the World Health Organization (WHO), air pollution is hazardous to human health and causes around 7 million deaths **(Figure 1)** worldwide per year (WHO 2016). Air pollution also affects the environment and the climate **(Figure 2)**. Therefore, it has indirect but tangible adverse effects on economies and societies more generally (Karamfilova 2021).

Figure 1. *Health impacts of air pollution (source: WHO).*

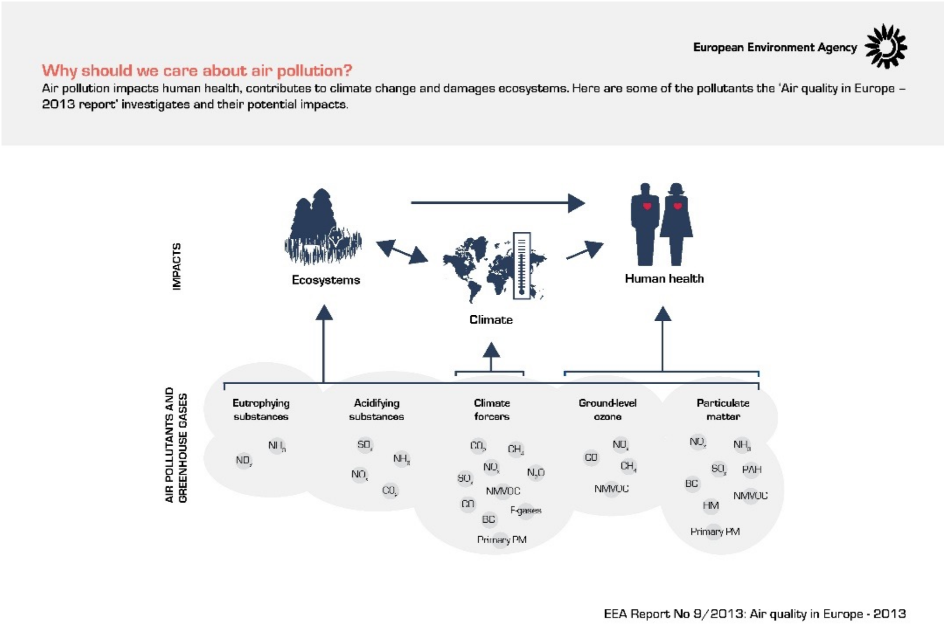


Figure 2: *General impacts of air pollutants on human health and the environment (source: EEA).*

Generally, the most critical pollutants for human health are particulate matter (PM), nitrogen dioxide (NO_2) and ground-level ozone (O_3). Heart disease and stroke are the most common factors for premature deaths attributable to poor air quality, together with lung disease including lung cancer. Groups with lower socioeconomic status are often more exposed to air pollution, while vulnerable groups such as older people, children and those with pre-existing health conditions tend to be more susceptible to the negative effects of air pollution (Karamfilova 2021).

Vegetation and ecosystems are also impacted by air pollution. High concentrations of sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and ozone directly affect vegetation and fauna, the quality of water and soil and the ecosystem services they support.

Ozone is damaging for crops, forests and other vegetation, impairs their growth and affects biodiversity. Reactive nitrogen compounds such as nitrogen oxide (NO) and nitrogen dioxide (NO_2) (grouped together as NO_x) and NH_3 lead to the eutrophication of freshwater and thereby a change in biodiversity. NO_x, NH_3 and SO_2 also lead to acidification, thereby changing the pH level of water and soil, which harms terrestrial and aquatic animals and plants (Bourguignon 2018).

1.2 Impact on climate

Air pollutants are also powerful climate forcers. Some air pollutants, such as sulfates and nitrates, have a cooling effect. Others, such as black carbon (BC), have a warming effect on the surface-atmosphere system. Black carbon is considered a major agent of regional and global warming (UNEP 2008). Pollutants including black carbon, methane (CH_4) and tropospheric ozone are now referred to as short-lived climate forcers (SLCFs) because they have relatively short lifetimes in the atmosphere. However, per unit of mass, black carbon and methane have a much stronger warming effect than carbon dioxide (CO_2). A UNEP study indicates that reducing emissions of SLCFs offers a realistic opportunity to significantly reduce the rate of global warming over the next two to four decades (UNEP 2011).

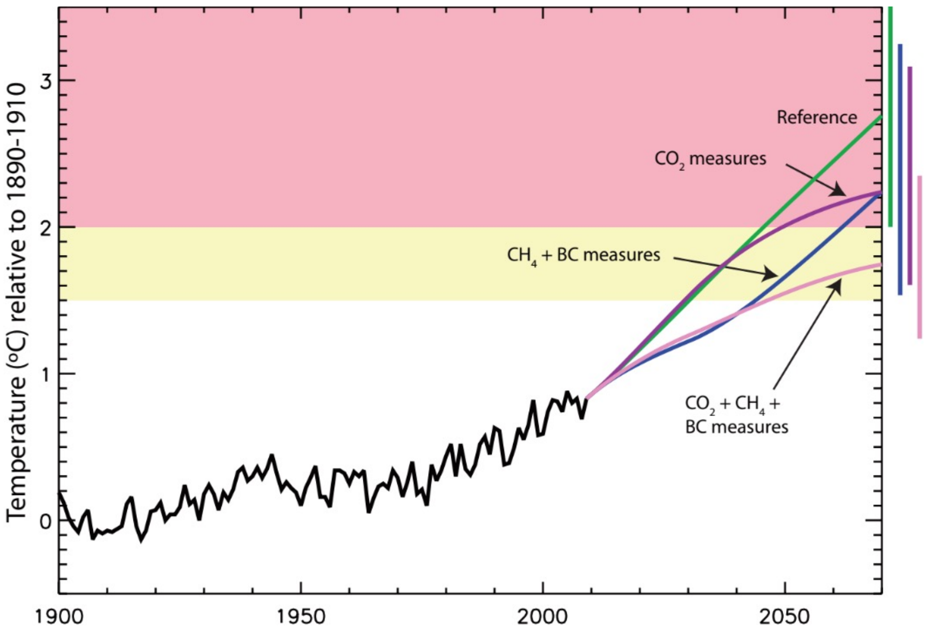


***Figure 3** Observed deviation of temperature to 2009 and projections under various scenarios (source: (UNEP and WMO 2011).*

Air pollution and climate change are considered as two sides of the same coin. Given that greenhouse gases (GHGs) and air pollutants often have the same main emission sources, limiting the emissions of one or the other could bring benefits for both (Karamfilova 2021).

As mentioned, air pollution also has indirect adverse effects on economies and societies. These effects result from the combined direct effects of air pollution on health, environment and climate. More specifically, as regards the economy, air pollution results in market and non-market costs. Market costs include reduced labour productivity, increased health expenditure, losses of crop and forest yield and impacts on the tourism sector.

Non-market costs include those resulting from increased mortality and morbidity, degradation of air and water quality and consequently the health of ecosystems, and climate change. Furthermore, air pollution (as combined with other aspects of the social and physical environment) can also increase inequalities across societies, especially as regards a disproportionate disease burden for more vulnerable groups (Karamfilova 2021).

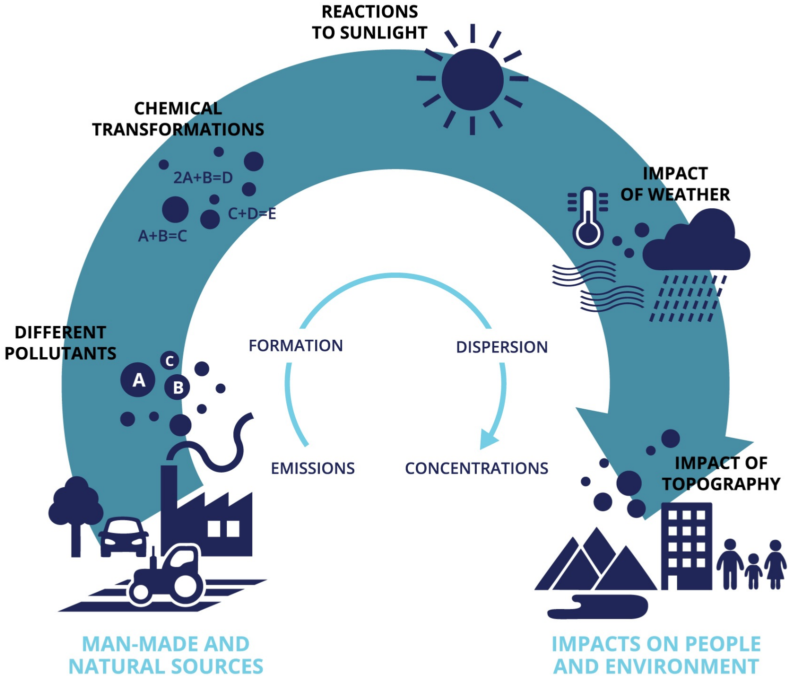
2. AIR QUALITY STANDARDS

Setting air quality standards is a major air pollution control measure implemented by countries around the world. By one definition, air quality standards are “the acceptable levels of air pollution, in terms of potential impacts on public health and the environment, that are adopted by a regulatory authority as enforceable” (WHO Regional Office for Europe 2006).
Air pollutants are emitted from various anthropogenic and natural sources **(Figure 4)** and may undergo transformation in the atmosphere **(Figure 5)**.

Figure 4: *Sources of air pollutants (source: EEA).*

Air pollution: from emissions to exposure

Poor air quality is a serious health and environmental problem. Certain harmful air pollutants are emitted directly from vehicles, such as 'primary' particulate matter (PM) and nitrogen oxides (NO_X). Others, such as ozone and 'secondary' PM, form in the atmosphere after emissions of precursor pollutants, including NO_X and volatile organic compounds. Different sources of pollution, including transport and non-transport sources, emit different types and ratios of pollutants. The extent to which the population and environment are exposed to harmful levels of air pollution is a complex issue, dependent on how pollutants travel in the atmosphere, their mixing and how they react under different meteorological conditions. Road transport emissions are, relatively, more harmful than those from other sources, as most emissions tend to occur in areas where people live and work, such as cities and towns.



Road transport contributes about 20 % of the EU's total emissions of carbon dioxide.

More than 30 % of NO_X emissions in the EU come from road transport.

Around 12 % of the EU's primary $PM_{2.5}$ emissions come from road transport.

Data: EEA 2015 indicators 'Total greenhouse gas (GHG) emission trends and projections' and 'Emissions of air pollutants from transport'.
Read more: EEA, 2015, Air quality in Europe — 2015 report.

Figure 5: *Air pollution: from emission to exposure (source: EEA).*

2.1 Purpose of air quality standards in general

Scientific evidence on the health effects of various air pollutants resulted in the setting of air quality standards in the US in 1970 (Clean Air Act)[1] and for Europe in 1987 (WHO Regional Office for Europe 1987). **Figure 6** summarizes the health impacts of different air pollutants.

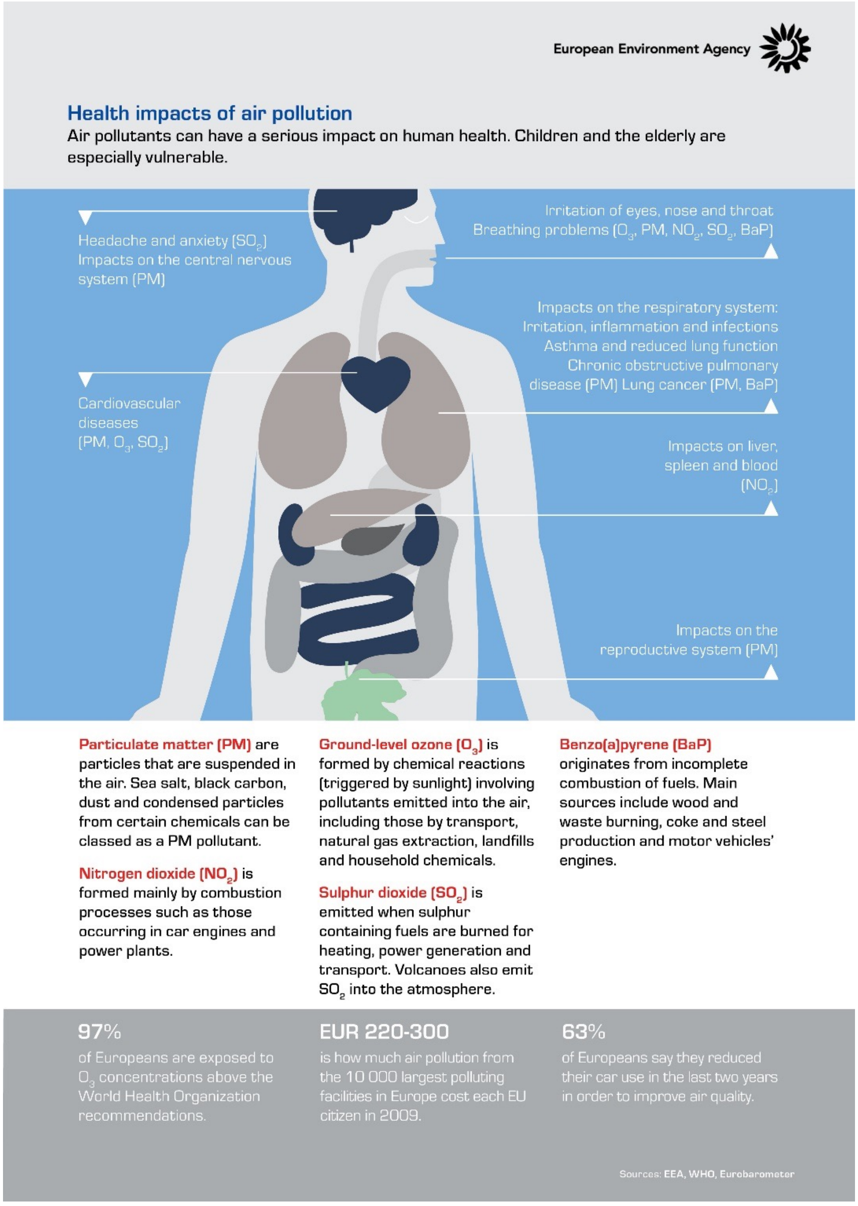


Figure 6: *Health impacts of air pollution (source: EEA).*

[1] https://www.epa.gov/clean-air-act-overview/clean-air-act-requirements-and-history

The levels and thereby the health and/or environmental impacts of air pollutants can be reduced by addressing emissions of the main polluting sectors and products. **Figure 7** shows the policy framework applied in the European Union (EU) to achieve an overall improvement of air quality. However, there may still be areas where high emission densities and/or adverse atmospheric dispersal conditions can result in severe health and/or environmental impacts.

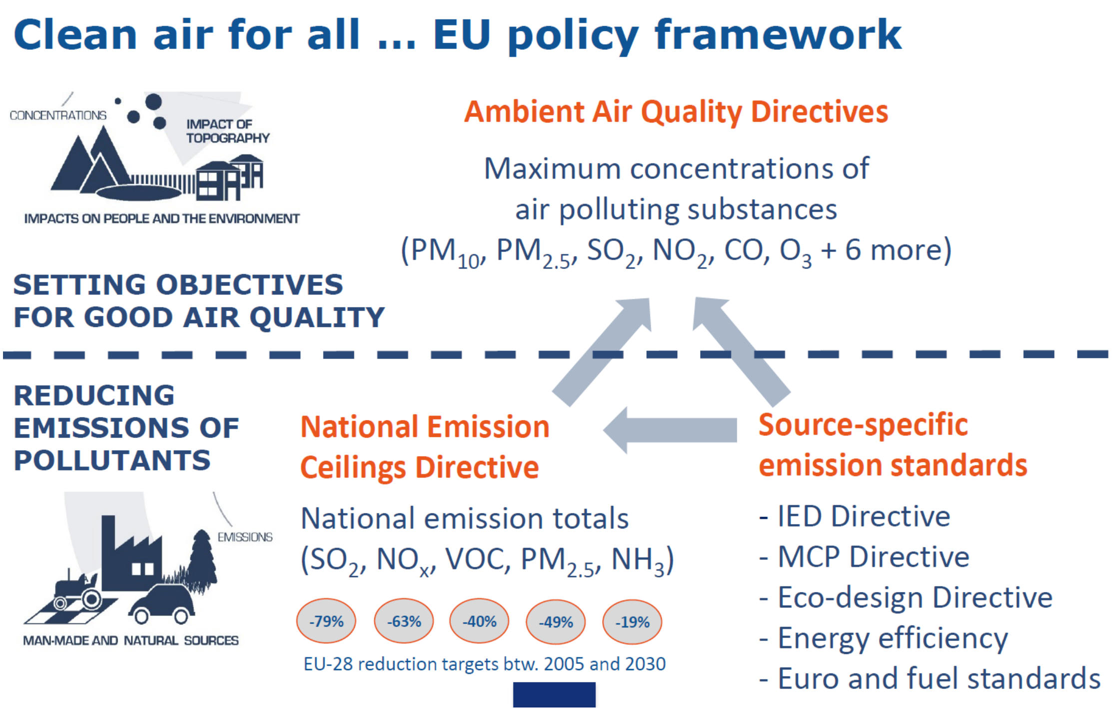


Figure 7: *Clean air policy framework in the EU, which sets objectives for good air quality, reduces emissions and sets source-specific emission standards (source: European Commission).*

Within a policy framework, air quality standards can be introduced, which trigger an action to be taken in case certain concentrations of pollutants are exceeded during a specific time period. Usually, such an action will be detailed in an air quality programme (called "State Implementation Plan" in the USA). Typically, air quality standards are set for common and widespread pollutants such as CO, NO_2, O_3, SO_2, PM, and lead (Pb) (these six pollutants are called criteria pollutants in the USA).

Air quality standards are usually based on scientific, economic, technical, political, and social considerations.

2.2 Procedures and considerations for establishing air quality standards

There are numerous considerations when setting air quality standards based on WHO air quality guidelines (section 5 describes the WHO guidelines in detail).

The WHO describes the main considerations as follows (WHO Regional Office for Europe 1998):

“Different countries usually have different political, regulatory and administrative approaches to controlling air pollution, and legislative and executive activities can be carried out at various levels, e.g. national, regional and local. For fully effective air quality management, a framework is required to guarantee a consistent derivation of air quality standards and provide a transparent basis for decisions with regard to risk reducing measures and abatement strategies. In establishing such a framework, several issues such as legal aspects, protection of specific populations at risk, the role of stakeholders in the process, cost benefit analysis, and control and enforcement measures should be considered".

Legal aspects

A legislative framework usually provides the basis for the evaluation and decision-making process in setting air quality standards at the national or supranational level. The setting of standards strongly depends on the type of risk management strategy adopted. Such a strategy is influenced by country specific sociopolitical considerations and/or supranational agreements.

Legislation as well as the format of air quality standards vary from country to country, but in general the following issues should be considered:

- *identification and selection of pollutants to which the legislative instrument will apply;*
- *the numerical value of the standards for the various pollutants or the process for making decisions about the appropriate standards, applicable detection methods and monitoring methodology;*
- *actions to be taken to implement the standard, such as the definition of the time frame needed/allowed for achievement of compliance with the standard, considering emission control measures and necessary abatement strategies;*
- *identification of responsible enforcement authorities.*

Depending on their position within a legislative framework, standards may or may not be legally binding. In some countries the constitution contains provisions regarding the protection of public health and the environment. The development of a legal framework on the basis of constitutional provisions generally comprises two regulatory actions. The first is the enactment of a formal legal instrument, such as an act, a law, an ordinance or a decree. The second is the development of regulations, by laws, rules and orders.

Air quality standards may be based solely on scientific and technical data on public health and environmental effects, but other aspects such as cost–benefit or cost–effectiveness may be also taken into consideration in deriving these standards. In practice, there are generally several opportunities within a legal framework to address the economic aspects as well as other issues, such as technical feasibility, structural measures and sociopolitical considerations.

They can be taken into account during the standard setting procedure itself or during the design of appropriate measures to control emissions. These considerations might result in several standards being set, for instance an effect oriented standard as a long term goal and less stringent interim standards to be achieved within shorter time periods.

Standards also depend on political choices: which receptors in the environment should be protected and to what extent. Some countries have separate standards for the protection of public health and the protection of the environment. Moreover, the stringency of a standard can be influenced by provisions designed to take higher sensitivities of specific receptor groups (young children, sick and elderly people or pregnant women) into account. It might also be important to specify whether effects are considered for individual pollutants or for the combined exposure to several pollutants.

Air quality standards should be regularly reviewed and revised as new scientific evidence on the effects on public health and the environment emerges. Standards often strongly influence the implementation of an air pollution control policy. In many countries, the exceeding of standards is linked to an obligation to develop action plans at the local, regional or national level to reduce air pollution levels. Such plans often address several pollution sources. Standards also play a role in environmental impact assessment procedures and in the provision of public information on the state of the environment. Provisions for such activities can be found in many national legal instruments.

The role of stakeholders (e.g. science, regulators, public interest groups, industry) in standard setting also needs to be considered within national or supranational legislative procedures (see below under Cost–benefit analysis).

Items to be considered in setting standards

Within established legal frameworks and using air quality guidelines as a starting point, the development of standards involves consideration of several issues, in part determined by characteristics of populations or physical properties of the environment.

- *Adverse effects on health*
- *Special populations at risk*
- *Exposure–response relationships*
- *Exposure characterization*
- *Risk assessment*
- *Acceptability of risk*

Stakeholder input in reviewing standard-setting, public awareness

The development of standards should encompass a process involving stakeholders that assures – as far as possible – social equity or fairness to all the parties involved. It should also provide sufficient information to guarantee understanding by stakeholders of the scientific and economic consequences. A stakeholders' review of the standard setting process, initiated at an early stage, is helpful. Transparency in moving from air quality guidelines to standards helps to increase public acceptance of necessary measures.

Implementation

The main objectives of the implementation of air quality standards are (1) to define the measures needed to achieve the standards, and (2) to establish a suitable regulatory strategy and legislative instrument to achieve this goal. Long as well as medium term goals are likely to be needed.

The implementation process should ensure a mechanism for regular assessment of air quality, set up the abatement strategies and establish the enforcement regulations.

The impact of control actions should also be assessed, both for public health and the effects on the environment through the use of, for example, epidemiological studies and integrated ecosystems monitoring.

Assessment of air quality

Air quality assessment has an important role within the air quality management strategy. The goals of air quality assessment are to provide the air quality management process with relevant data through a proper characterization of the air pollution situation using monitoring and/or modelling programmes and projection of future air quality associated with alternative strategies. Dispersion models can be used very effectively in the design of the definitive monitoring network.

Considerations for air quality assessment

- *Monitoring methods, Quality assessment/quality control (QA/QC) procedures*
- *Monitoring network design (e.g. fixed, mobile stations)*
- *Air quality modelling*

Abatement strategies

Abatement strategies are the set of measures to be taken in order to reduce pollutant emissions and, therefore, to improve air quality. Authorities should consider the measures necessary in order to meet the standards.

Enforcement

The government of each country lays down the responsibilities for implementing the standards. Responsibilities for overseeing different aspects of compliance can be distributed among national, regional and local governments, depending at which level it is necessary to take action."

2.2.1 Process in the United States of America

The first National Ambient Air Quality Standards (NAAQS) set in 1970 by the Clean Air Act in the USA were said to be:

"based on investigations conducted at the outer limits of our capability to measure connections between levels of pollution and effects on man. In the case of carbon monoxide, one of the most important automobile pollutants, we have set a standard to protect against effects reported by investigations which prompt arguments even among our own scientists.

In the case of photochemical oxidants, also largely contributed to by automobiles, our standards approach levels that occur fairly commonly in nature."[2]

[2] https://archive.epa.gov/epa/aboutepa/epa-sets-national-air-quality-standards.html

The Clean Air Act requires a regular review of the NAAQS. This review, carried out by the Environmental Protection Agency (US EPA), follows a certain cycle (**Figure 8**).

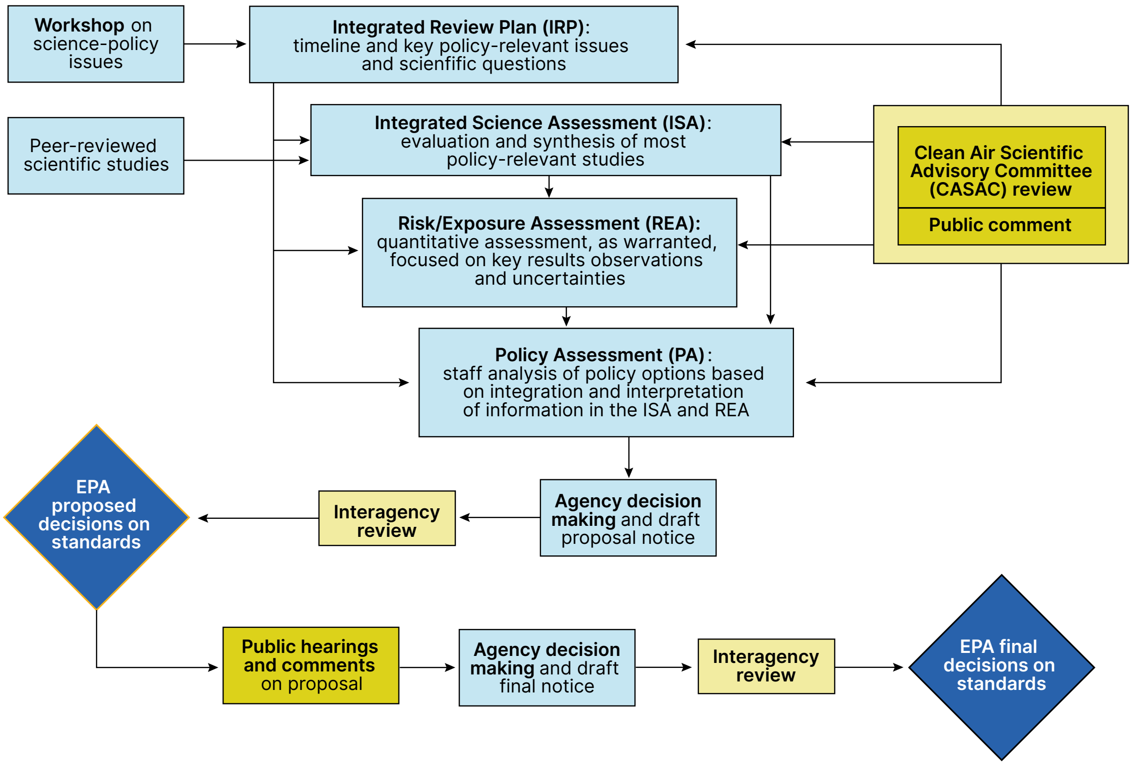


Figure 8: *Schematic overview of the NAAQS review process (source: US EPA).*

The US EPA describes the review process as follows:[3]

"The CAA requires periodic review of the science upon which the standards are based and the standards themselves. Reviewing the NAAQS is a lengthy undertaking and includes the following major phases:

Planning: *The planning phase of the NAAQS review process begins with a science policy workshop, which is intended to gather input from the scientific community and the public regarding policy-relevant issues and questions that will frame the review. Drawing from the workshop discussions, EPA prepares an Integrated Review Plan (IRP) that presents the schedule for the entire review, the process for conducting the review, and the key policy-relevant science issues that will guide the review.*

Integrated Science Assessment (ISA): *This assessment is a comprehensive review, synthesis, and evaluation of the most policy relevant science, including key science judgments that are important to inform the development of the risk and exposure assessments, as well as other aspects of the NAAQS review.*

[3] https://www.epa.gov/criteria-air-pollutants/process-reviewing-national-ambient-air-quality-standards, https://www.epa.gov/naaqs/historical-information-naaqs-review-process

Risk/Exposure Assessment (REA): *This assessment draws upon information and conclusions presented in the ISA to develop quantitative characterizations of exposures and associated risks to human health or the environment associated with recent air quality conditions and with air quality estimated to just meet the current or alternative standard(s) under consideration. This assessment includes a characterization of the uncertainties associated with such estimates.*

Policy Assessment (PA): *This assessment provides a transparent staff analysis of the scientific basis for alternative policy options for consideration by senior EPA management prior to rulemaking. Such an evaluation of policy implications is intended to help "bridge the gap" between the Agency's scientific assessments, presented in the ISA and REA(s), and the judgments required of the EPA Administrator in determining whether it is appropriate to retain or revise the NAAQS. In so doing, the PA is also intended to facilitate the* ***Clean Air Scientific Advisory Committee's (CASAC's)*** *advice to the Agency and recommendations to the Administrator, as provided for in the CAA, on the adequacy of the existing standards or revisions that may be appropriate to consider. The PA focuses on the information that is most pertinent to evaluating the basic elements of the NAAQS: indicator, averaging time, form, and level.*

Scientific review during the development of these documents is thorough and extensive. Drafts of all documents are reviewed by CASAC and the public has an opportunity to comment on them.

Rulemaking: *Taking into consideration the information in the ISA, REA(s), and PA and the advice of CASAC, EPA develops and publishes a notice of proposed rulemaking that communicates the Administrator's proposed decisions regarding the review of the NAAQS. A public comment period, during which public hearings are generally held, follows publication of the notice of proposed rulemaking. Taking into account comments received on the proposed rule, EPA issues a final rule."*

The overall process of setting and implementing NAAQS is broken down as follows:

- ***Standards*** - *setting, reviewing, and revising the standards*
- **Designations** - *determining whether areas meet the standards*
- **Implementation** - *attaining and maintaining the standards*

2.2.2 Process in the European Union

As in the USA, the drive[4] to improve air quality in the EU started in the 1970s with emphasis on controlling emissions, improving fuel quality, and integrating environmental protection requirements into the transport and energy sector. The first limit values and so-called guide values for SO_2 and PM in ambient air[5] were introduced in 1980, followed by limit values for Pb in 1982,[6] air quality standards for NO_2 in 1985,[7] and for O_3 in 1992.[8]

From 1992 to 1996 the EU negotiated the Air Quality Framework Directive[9] with the help of international expert groups, including WHO. In the following years, four daughter Directives were implemented, laying down more details on monitoring as well as standards for various air pollutants. The daughter Directives were based on so-called position papers for NO_2, Pb, SO_2, PM, CO, benzene, O_3, arsenic (As), cadmium (Cd), nickel (Ni), polycyclic aromatic hydrocarbons (PAHs) and mercury. The position papers describe the sources of the pollutant, current levels, a risk assessment, a monitoring and assessment strategy, legislative concepts, costs and possible abatement strategies.

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[4] https://ec.europa.eu/environment/air/index_en.htm
[5] http://data.europa.eu/eli/dir/1980/779/oj
[6] http://data.europa.eu/eli/dir/1982/884/oj
[7] http://data.europa.eu/eli/dir/1985/203/oj
[8] http://data.europa.eu/eli/dir/1992/72/oj
[9] http://data.europa.eu/eli/dir/1996/62/oj

were based on so-called position papers[10] for NO_2, Pb, SO_2, PM, CO, benzene, O_3, arsenic (As), cadmium (Cd), nickel (Ni), polycyclic aromatic hydrocarbons (PAHs) and mercury. The position papers describe the sources of the pollutant, current levels, a risk assessment, a monitoring and assessment strategy, legislative concepts, costs and possible abatement strategies.

Limit and target values for $PM_{2.5}$ were introduced with the Ambient Air Quality Directive[11] 2008/50/EC in 2008. This Directive merged the Air Quality Framework Directive and three of the four daughter Directives.[12] It remains in force, along with the fourth daughter Directive 2004/107/EC, which addresses heavy metals and polycyclic aromatic hydrocarbons. These two Directives are commonly referred to together as the Ambient Air Quality Directives (AAQDs).

The AAQDs were reviewed from 2011 to 2013 under the framework of an air quality policy review.[13] Further review of EU air quality policy began in 2020 and should be finalized in the second half of 2022 **(Figure 9)**.

__Figure 9:__ Clean Air Milestones 2020 to 2023, including the revision of the European air quality policy (source: European Commission).

[10] https://ec.europa.eu/environment/air/quality/assessment.htm
[11] http://data.europa.eu/eli/dir/2008/50/oj
[12] http://data.europa.eu/eli/dir/2004/107/oj
[13] https://ec.europa.eu/environment/air/clean_air/review.htm

As a first step, the shortcomings of current policies were analysed **(Figure 10)**.

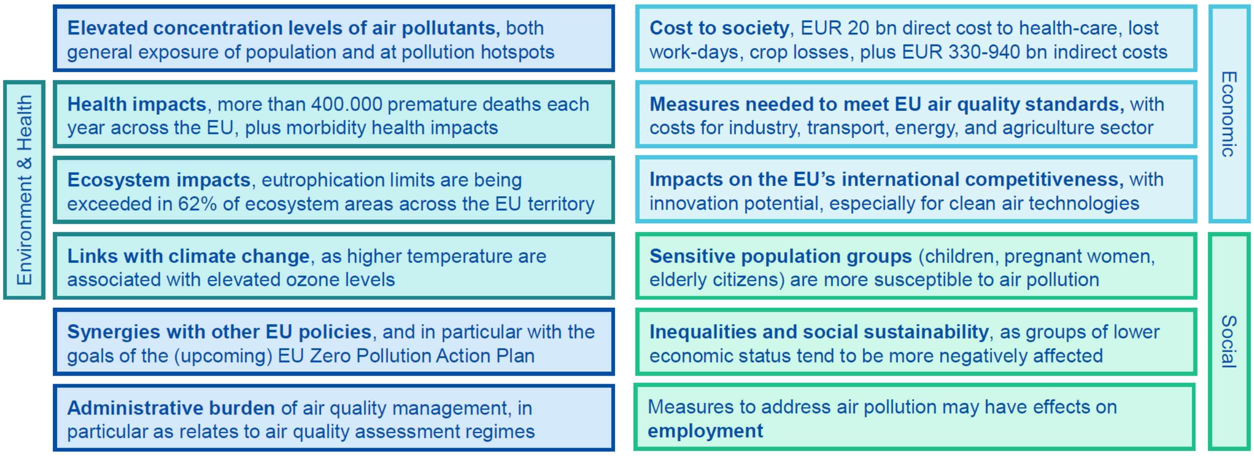


Figure 10: *Consequences of the shortcomings of current EU policies related to air quality (source: European Commission).*

The following figure shows the policy options and ambition levels that will be considered in the review.

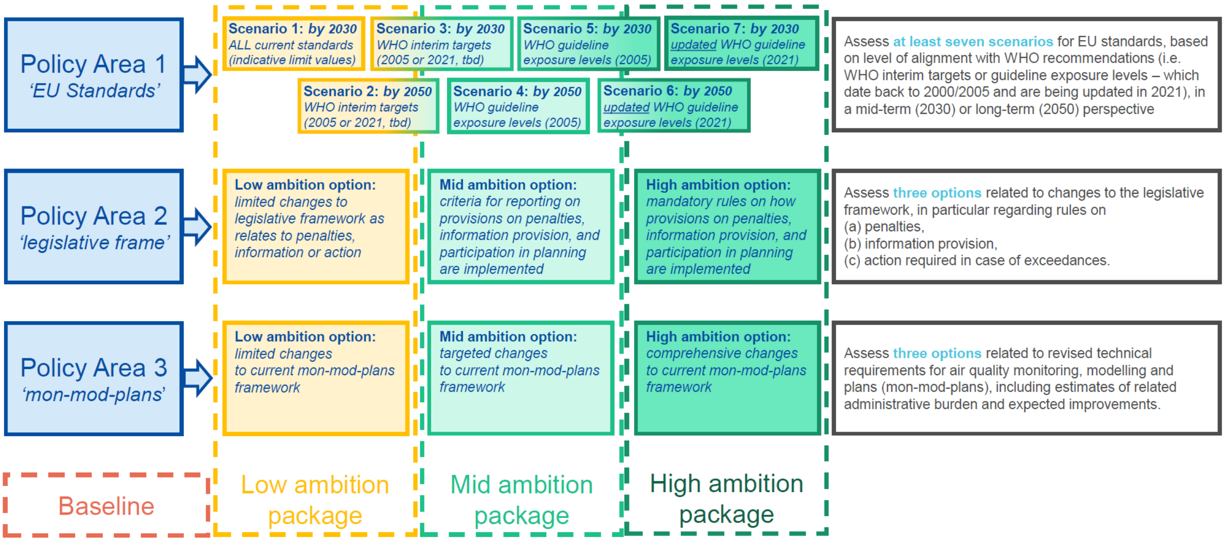


Figure 11: *Policy options to inform the level of ambition (source: European Commission).*

The policy options are divided in three policy areas:

- **Policy area 1:** closer alignment of the EU air quality standards with scientific knowledge including the updated WHO Air Quality Guidelines
- **Policy area 2:** Improving the air quality legislative framework, including provisions on penalties and public information
- **Policy area 3:** strengthening of air quality monitoring, modelling and plans

These policy areas are developed into more detailed policy options and scenarios; different levels of ambition are considered for each policy option. The impacts on human health and ecosystems on the one hand, and the economy, inequalities, social sustainability, administrative burden on the other hand, will be laid out in an impact assessment. This assessment will be the basis for the political negotiation of future air quality policy.

In the EU, the process of reviewing ambient air quality standards is less formalized than in the USA and is not carried out at regular intervals. In addition, the review documentation is less extensive. Nevertheless, EU air quality standards and any revisions are also based on scientific evidence and include stakeholder involvement.

2.3 Types of air quality standards and guidelines

A recent study for the European Parliament describes different types of standards used in the EU (Bourguignon 2018):

*"**limit values** are binding standards, defined as the concentration of a pollutant over an averaging period; limit values are set up for particulate matter, sulphur dioxide, nitrogen dioxide, lead, carbon monoxide and benzene;*

***target values** are standards that must be attained where possible, defined as the concentration of a pollutant over an averaging period; target values are set up for ozone, arsenic, cadmium, nickel and benzo(a)pyrene;*

*the **information threshold** is a pollutant concentration level beyond which brief exposure is deemed to pose health risks for specific segments of the population; if such a threshold has been reached, authorities are required to inform the public; there is an information threshold set for ozone;*

*the **alert threshold** is a pollutant concentration level beyond which brief exposure is deemed to pose health risks for the population as a whole; if such a threshold has been reached, authorities are required to inform the public and draw up short-term action plans; alert thresholds are set for sulphur dioxide, nitrogen dioxide and ozone;*

*the **exposure concentration** obligation is a binding standard reflecting human exposure to fine particulate matter at national level (in contrast, limit and target values apply at the level of air quality zones)."*

In addition, WHO guideline levels and interim targets can be defined as follows (see WHO Regional Office for Europe 2006):

WHO guideline levels	Recommendation or guidance for protecting public health from adverse effects of air pollution, based on scientific results, background information and guidance to governments in making risk management decisions
WHO interim targets	Incremental steps in a progressive reduction of air pollution, intended for use in areas where pollution is high. Targets aim to promote a shift from high air pollutant concentrations, with acute and serious health consequences, to lower concentrations.

03

3. AIR QUALITY STANDARDS WORLDWIDE

3.1 Air quality standards in the European Union

3.1.1 Background

The Ambient Air Quality Directives (AAQDs) 2008/50/EC and 2004/107/EC lay down objectives and standards for ambient air quality and methods and criteria for its assessment in the EU Member States.

Directive 2008/50/EC addresses SO_2, NO_2, NO_x, PM_{10}, $PM_{2.5}$, O_3, Pb, and CO. Directive 2004/107/EC lays down target values for As, Cd, Ni and benzo[a]pyrene (BaP) as a marker for PAHs (European Parliament and the Council of the European Union 2004). In 2015, several annexes to the AAQDs were amended by Directive 2015/1480.[14] This Directive lays down rules concerning reference methods, data validation and the location of sampling points for the assessment of ambient air quality.

3.1.2 Limit values for the protection of human health

Table 1 describes the limit values for specific air pollutants as laid down in Annex XI of the AAQDs. These limit values were to be complied with from 2005 onwards (SO_2, CO, Pb, PM_{10}) or from 2010 onwards (NO_2, benzene). Under Article 22 of the AAQD, postponing the deadline (until 2015 for NO_2 and benzene, and until June 2011 for PM_{10}) has been possible under specific circumstances. The Commission objected to a considerable number of applications for time extension[15] from the Member States.

The limit values must be complied with throughout a territory with some exceptions depending on the assessment regime.

[14] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1449504754993&uri=CELEX:32015L1480
[15] https://ec.europa.eu/environment/air/quality/time_extensions.htm

Table 1: Limit values of the AAQD
(European Parliament and the Council of the European Union 2008).

Pollutant	Averaging period	Limit value	Remark
SO_2	One hour	350 µg/m³	not to be exceeded more than 24 times a calendar year
SO_2	One day	125 µg/m³	not to be exceeded more than 3 times a calendar year
NO_2	One hour	200 µg/m³	not to be exceeded more than 18 times a calendar year
NO_2	Calendar year	40 µg/m³	
Benzene	Calendar year	5 µg/m³	
CO	Maximum daily eight hour mean	10 mg/m³	
Lead	Calendar year	0.5 µg/m³	
PM_{10}	One day	50 µg/m³	not to be exceeded more than 35 times a calendar year
PM_{10}	Calendar year	40 µg/m³	

3.1.3 Targets, obligations and limit value for $PM_{2.5}$

Annex XIV of the AAQD introduced several provisions for $PM_{2.5}$ that are summarized in **Table 2** and **Table 3**. The limit value, which was a target value until 2015, was set to provide an overall limit throughout a territory, hence also at local hotspots. From a public health perspective, much larger health benefits can accrue if the overall $PM_{2.5}$ levels are reduced.

This is due to the fact that health effects have been found even at fairly low concentrations and that there is a fairly linear dose-response relationship (WHO Regional Office for Europe 2013a, 2013b). To account for these facts the AAQD introduced the so-called Exposure Concentration Obligation (ECO; 20 µg/m³ for 2013-2015 at urban background sites, see **Table 2**) and the National Exposure Reduction Target (NERT, percentage reduction between 2009-2011 and 2018-2020, see **Table 3**). Compliance with the ECO and reaching the NERT will reduce $PM_{2.5}$ urban background concentrations for a large share of the population. The ECO and NERT are determined via the Average Exposure Indicator (AEI).

The AEI is assessed at a specific number of urban background stations throughout a territory. It is calculated as a three-calendar-year running annual mean over all sampling points.

This means that one AEI value is provided for a whole Member State. The reference year 2010 is the mean concentration for the period 2008-2010 or 2009-2011. The ECO for 2015 is calculated on the basis of the annual means for 2013-2015 and the NERT on the basis of the annual means for 2018-2020.

While the ECO and NERT are assessed at urban background sites only, compliance with their target and limit values has to be achieved throughout the territory (with certain exceptions regarding the assessment regime).

Table 2: *Provisions for $PM_{2.5}$ of the AAQD*
(European Parliament and the Council of the European Union 2008).

Provision	Value	Year	Remark
ECO	20 µg/m³	2015	AEI
Target value	25 µg/m³	2010	Applicable throughout the territory
Limit value stage 1	25 µg/m³	2015	Applicable throughout the territory
Limit value stage 2	20 µg/m³	2020	Indicative limit value, no changes in 2013 review

Table 3: *NERT compared to the reference year for $PM_{2.5}$*
(European Parliament and the Council of the European Union 2008)

Initial concentration in µg/m³	Reduction target in percent
< 8.5 = 8.5	0 %
> 8.5 — < 13	10 %
= 13 — < 18	15 %
= 18 — < 22	20 %
≥ 22	All appropriate measures to achieve 18 µg/m³

3.1.4 Ozone target values and long-term objectives

3.1.4.1 Target values

Table 4 shows the target values for ozone for the protection of human health and vegetation.

Table 4: *Target values for ozone*
(European Parliament and the Council of the European Union 2008)

Objective	Averaging period	Target value
Protection of human health	Maximum daily eight-hour mean	120 µg/m³ not to be exceeded on more than 25 days per calendar year averaged over three years
Protection of vegetation	May to July	AOT40(1) of 18,000 µg/m³.h averaged over five years

(1) *AOT40 is the sum of hourly concentrations of ozone greater than 80 µg/m³ (= 40 parts per billion) measured between 8.00 and 20.00 Central European Time (CET) each day over a given period.*

3.1.4.2 Long-term objectives for ozone

Table 5 shows the long-term objectives for ozone (the date by which the objectives should be met is not defined in the AAQD).

Table 5: *Long-term objectives for ozone*
(European Parliament and the Council of the European Union 2008).

Objective	Averaging period	Target value
Protection of human health	Maximum daily eight-hour mean within a calendar year	120 µg/m³
Protection of vegetation	May to July	AOT40 (calculated from 1h values) 6000 µg/m³.h averaged over five years

3.1.5 Information and alert thresholds

3.1.5.1 Alert thresholds for SO_2 and NO_2

The alert thresholds are exceeded when pollutant concentrations are measured above the threshold level for three consecutive hours at locations representative of air quality over at least 100 km^2 or an entire zone or agglomeration, whichever is the smaller.

Table 6: *Alert thresholds for SO_2 and NO_2*
(European Parliament and the Council of the European Union 2008)

SO_2	500 $\mu g/m^3$
NO_2	400 $\mu g/m^3$

3.1.5.2 Information and alert thresholds for ozone

Table 7 shows the information and alert thresholds for ozone.

Table 7: *Information and alert thresholds for ozone*
(European Parliament and the Council of the European Union 2008).

Purpose	Averaging period	Thresholds
Information	1 hour	180 $\mu g/m^3$
Alert	1 hour	240 $\mu g/m^3$

3.1.6 Critical levels for the protection of vegetation

Sampling points for monitoring the critical levels for the protection of vegetation **(Table 8)** shall be representative for an area of at least 1,000 km^2 and shall be sited at a certain distance from agglomerations, industry and major roads.

Table 8: *Critical levels of SO_2 and NO_x for the protection of vegetation (European Parliament and the Council of the European Union 2008).*

Pollutant	Averaging period	Critical level
SO_2	Calendar year and winter (1 October to 31 March)	20 µg/m^3
NOx	Calendar year	30 µg/m^3

3.1.7 Target value of the 4th daughter Directive

The target values of the 4th daughter Directive **(Table 9)** are monitored as the total content in PM_{10} averaged over a calendar year.

Table 9: *Target values for heavy metals and benzo(a)pyren (European Parliament and the Council of the European Union 2004).*

Pollutant	Target value
As	6 ng/m^3
Cd	5 ng/m^3
Ni	20 ng/m^3
BaP	1 ng/m^3

3.1.8 Monitoring and assessment of air pollution and compliance with air quality standards

Compliance with thresholds listed above is checked in the European Union with data gathered at air quality monitoring sites, which have to be installed by Member States at specific locations.[16] Monitoring can be supported by modelling, also for compliance checking.

The territorial basis for air quality assessment are zones and agglomerations (Article 4 of the AAQD), which are established by the competent authorities of the Member States. Articles 6 and 7 of the AAQD provide requirements for air quality assessment, while detailed specifications are laid down in Annexes V and IX (number of monitoring sites), and Annexes III and VIII (siting criteria). Monitoring at continuously operated sites is required if the level of a pollutant exceeds an upper assessment threshold (as laid down in Annex II of the AAQD), and may be supplemented or replaced by indicative measurements, modelling or objective estimations.

There are three main types of monitoring site locations: those measuring the highest concentrations of pollutants with risk of general population exposure during a certain period; locations measuring a more general exposure; and rural background sites. 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 may be limited, also due to financial constraints.

High pollutant concentrations are usually monitored at urban traffic or industrial sites. General exposure is monitored at urban background sites. Regional background sites are located in a certain distance from major emission sources.

Urban traffic sites are usually located in densely built-up areas and heavily trafficked roads. They therefore cover many of the pollution hotspots within a city. However, certain criteria apply to their 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.

The EU legislation lays down reference methods for monitoring the pollutants listed in the AAQD and the 4th daughter Directive. The reference methods are described in European standards. According to AAQD Annex VI, any other method can be used which gives results equivalent to this method. The European Commission has developed a guidance document [17] on demonstrating equivalence.

[16] https://www.europarl.europa.eu/thinktank/de/document.html?reference=IPOL_ATA%282019%29631058
[17] https://ec.europa.eu/environment/air/quality/legislation/pdf/equivalence.pdf,
https://ec.europa.eu/environment/air/quality/legislation/pdf/Equivalence%20Tool%20v10.xlsm

The EU legislation also specifies how to establish the correct number of monitoring sites, depending on pollutant concentration levels. The higher the concentration in a certain area, the more stations are needed and stricter data quality objectives apply.

The AAQD also describes provisions for informing the public about pollutant levels and air quality plans.

3.2 Air quality standards in the United States of America

Standards in the USA are available at the website of the US EPA (Table 10)[18]. The website states:

"**The Clean Air Act**, *which was last amended in 1990, requires EPA to set National Ambient Air Quality Standards (40 CFR part 50) for pollutants considered harmful to public health and the environment. The Clean Air Act identifies two types of national ambient air quality standards. Primary standards provide public health protection, including protecting the health of 'sensitive' populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.*

The EPA has set National Ambient Air Quality Standards for six principal pollutants, which are called **'criteria' air pollutants**. *Periodically, the standards are reviewed and may be revised. The current standards are listed below. Units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air (µg/m³).*"

[18] https://www.epa.gov/criteria-air-pollutants/naaqs-table

Table 10: *National Ambient Air Quality Standards for six critical air pollutants (source: https://www.epa.gov/criteria-air-pollutants/naaqs-table).*

Pollutant		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)		primary	8 hours	9 ppm (10 µg/m³)	Not to be exceeded more than once per year
			1 hour	35 ppm (41 µg/m³)	
Lead (Pb)		primary and secondary	Rolling 3 month average	0.15 µg/m³ (1)	Not to be exceeded
Nitrogen Dioxide (NO_2)		primary	1 hour	100 ppb (191 µg/m³)	98th percentile of - 1hour daily maximum concentrations, averaged over 3 years
		primary and secondary	1 year	53 ppb (2) (101 µg/m³)	Annual Mean
Ozone (O_3)		primary and secondary	8 hours	0.070 ppm (3) (140 µg/m³)	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 µg/m³	annual mean, averaged over 3 years
		secondary	1 year	15.0 µg/m³	annual mean, averaged over 3 years
		primary and secondary	24 hours	35 µg/m³	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	150 µg/m³	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb (4) (200 µg/m³)	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3 hours	0.5 ppm (1332 µg/m³)	Not to be exceeded more than once per year

(1) In areas designated nonattainment for the Pb standards prior to the promulgation of the current (2008) standards, and for which implementation plans to attain or maintain the current (2008) standards have not been submitted and approved, the previous standards (1.5 µg/m³ as a calendar quarter average) also remain in effect.

(2) The level of the annual NO_2 standard is 0.053 ppm. It is shown here in terms of ppb for the purposes of clearer comparison to the 1-hour standard level.

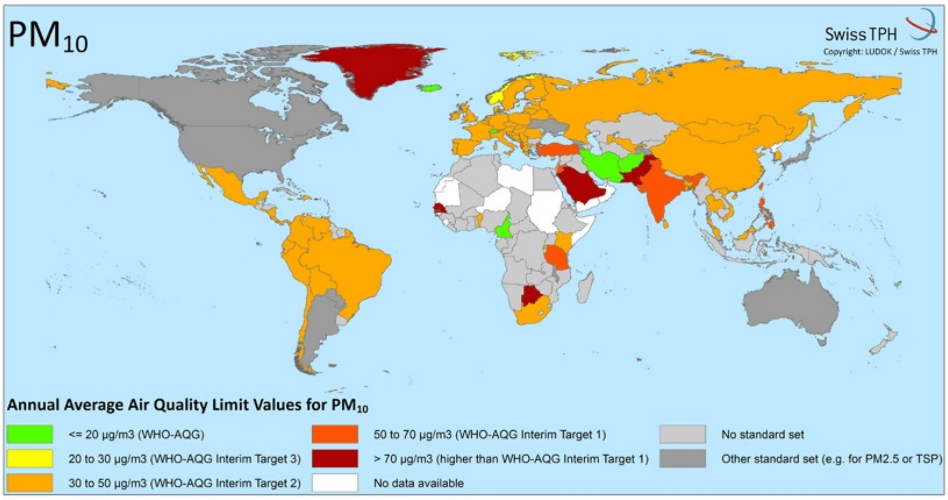
(3) Final rule signed October 1, 2015, and effective December 28, 2015. The previous (2008) O_3 standards additionally remain in effect in some areas. Revocation of the previous (2008) O_3 standards and transitioning to the current (2015) standards will be addressed in the implementation rule for the current standards.

(4) The previous SO_2 standards (0.14 ppm 24-hour and 0.03 ppm annual) will additionally remain in effect in certain areas: (1) any area for which it is not yet 1 year since the effective date of designation under the current (2010) standards, and (2) any area for which an implementation plan providing for attainment of the current (2010) standard has not been submitted and approved and which is designated nonattainment under the previous SO_2 standards or is not meeting the requirements of a SIP call under the previous SO_2 standards (40 CFR 50.4(3)). A SIP call is an EPA action requiring a state to resubmit all or part of its State Implementation Plan to demonstrate attainment of the required NAAQS.

3.3 Air quality standards worldwide

Figure 12 gives an overview of annual average air quality limit values for PM_{10} and NO_2 (Kutlar Joss et al. 2017). In the sections below, standards for the main pollutants for selected countries are provided.

a



b

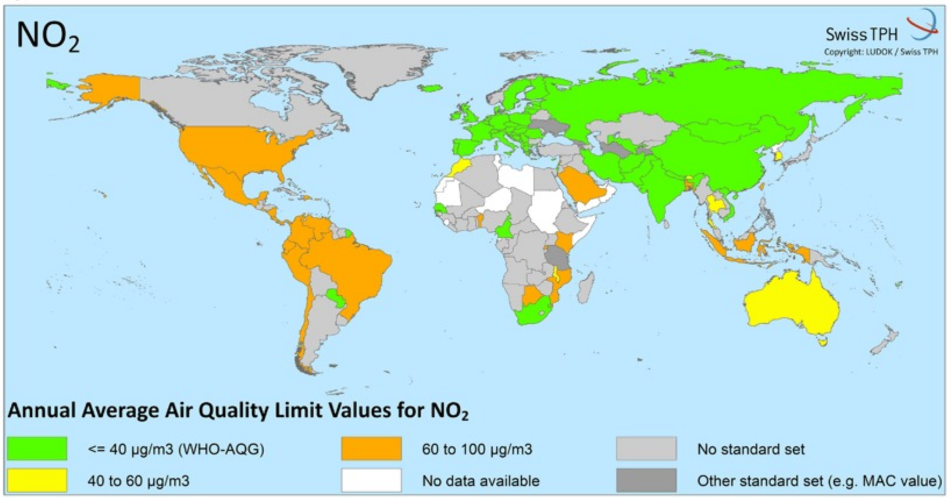


Figure 12: *Annual average air quality limit values for PM_{10} and NO_2 (Kutlar Joss et al. 2017)*

3.3.1 Annual mean $PM_{2.5}$ standards

Table 11 shows annual mean $PM_{2.5}$ standards in the EU, USA, Japan, India as well as the WHO guideline level for $PM_{2.5}$.

Table 11: *Annual mean $PM_{2.5}$ standards in different countries and regions, WHO guideline level.*

	EU[1]	USA[2]	Japan[3]	India[4]	WHO[5]
µg/m³	25	12 (primary) 15 (secondary)	15	40	10

[1] EU: ec.europa.eu/environment/air/quality/standards.htm

[2] USA: https://www.epa.gov/criteria-air-pollutants/naaqs-table
primary: health-based. Secondary: public welfare (e.g. visibility, damage to property, transportation hazards, economic values, personal comfort and well-being). Averaged over three years

[3] Japan: https://www.env.go.jp/en/air/aq/aq.html

[4] India: https://cpcb.nic.in/air-quality-standard/

[5] WHO: https://www.who.int/airpollution/publications/aqg2005/en/

Table 12 shows different air quality management levels for $PM_{2.5}$ in Canada.

Table 12: *$PM_{2.5}$ management levels in Canada (source: https://www.ccme.ca/en/resources/air/pm_ozone.html).*

Management Level	$PM_{2.5}$ 24-hour		$PM_{2.5}$ annual	
	2015	2020	2015	2020
Red (CAAQS)	> 28	> 27	> 10.0	> 8.8
Orange	20 to 28	20 to 27	6.5 to 10.0	6.5 to 8.8
Yellow	11 to 19	11 to 19	4.1 to 6.4	4.1 to 6.4
Green	≤ 10	≤ 10	≤ 4.0	≤ 4.0

To reduce pollutant levels below the CAAQS through advanced air management actions (AQ plan needed)

To improve air quality through active air management and prevent exceedance of the CAAQS (AQ plan needed)

To improve air quality using early and ongoing actions for continuous improvement

To maintain good air quality through proactive air management measures to keep clean areas clean

3.3.2 Daily mean $PM_{2.5}$ standards

Table 13 shows daily mean $PM_{2.5}$ standards in the EU, USA, Japan, India as well as the WHO guideline level for $PM_{2.5}$.

Table 13: *$PM_{2.5}$ daily mean standards in different countries and regions, WHO guideline level (source: see links below **Table 11**).*

	EU	USA[2]	Japan[3]	India[4]	WHO[5]
µg/m³	-	35	35	60	25

[2] USA: primary and secondary. 98th percentile, averaged over three years

[3] Japan: 98th percentile

[4] India: 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time, they may exceed the limits but not on two consecutive days of monitoring

[5] WHO: 99th percentile

3.3.3 Annual mean PM_{10} standards

Table 14 shows annual mean PM_{10} standards in the EU, USA, Japan, India as well as the WHO guideline level for PM_{10}.

Table 14: *PM_{10} annual mean standards in different countries and regions, WHO guideline level (source: see links below **Table 11**).*

	EU	USA	Japan	Canada	India	WHO
µg/m³	40	-	-	-	60	20

Table 15 shows daily mean PM_{10} standards in the EU, USA, Japan, India as well as the WHO guideline level for PM_{10}.

Table 15: *PM_{10} daily mean standards in different countries and regions, WHO guideline level (source: see links below **Table 11**).*

	EU[1]	USA[2]	Japan[3]	Canada	India[4]	WHO[5]
µg/m³	50	150	-	-	100	50

[1] EU: not to be exceeded more than 35 times per calendar year

[2] USA: primary and secondary. Not to be exceeded more than once per year on average over 3 years

[4] India: 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98 % of the time, they may exceed the limits but not on two consecutive days of monitoring

[5] WHO: 99th percentile

3.3.4 Annual mean NO_2 standards

Table 16 shows annual mean NO_2 standards in the EU, USA, Japan, India as well as the WHO guideline level for NO_2.

Table 16: *NO_2 annual mean standards in different countries and regions, WHO guideline level (source: see links below **Table 11**).*

	EU	USA[2]	Japan	India[4]	WHO
µg/m³	40	100	-	30/40	40

[2] *USA: primary and secondary (53 ppb)*

[4] *India: 30 µg/m³ in ecologically sensitive areas*

Table 17 shows different air quality management levels for NO_2 in Canada.

Table 17: *NO_2 management levels in Canada (source: https://www ccme.ca/en/resources/air/pm_ozone.html).*

Management level	NO_2 1-hour (µg/m³)		
	2020	2025	
Red (CAAQS)	> 32.5	> 22.9	To reduce pollutant levels below the CAAQS through advanced air management actions (AQ plan needed)
Orange	13.6 to 32.5	13.6 to 22.9	To improve air quality through active air management and prevent exceedance of the CAAQS (AQ plan needed)
Yellow	4.0 to 13.4	4.0 to 13.4	To improve air quality using early and ongoing actions for continuous improvement
Green	≤ 38	≤ 38	To maintain good air quality through proactive air management measures to keep clean areas clean

3.3.5 Hourly mean NO_2 standards

Table 18 shows annual mean NO_2 standards in the EU, USA, Japan, India as well as the WHO guideline level for NO_2.

Table 18: *NO_2 hourly mean standards in different countries and regions, WHO guideline level (source: see links below **Table 11**).*

	EU[1]	USA	Japan	India[4]	WHO
µg/m³	200	100	-	80	200

[1] EU: not to be exceeded more than 18 times a calendar year

[4] India: 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98 % of the time, they may exceed the limits but not on two consecutive days of monitoring

Table 19 shows different air quality management levels for the hourly mean of NO_2 in Canada.

Table 19: *NO_2 management levels in Canada (source: https://www.ccme.ca/en/resources/air/pm_ozone.html).*

Management level	NO_2 1-hour (µg/m³)		
	2020	2025	
Red (CAAQS)	> 115	> 80	To reduce pollutant levels below the CAAQS through advanced air management actions (AQ plan needed)
Orange	61 to 115	61 to 80	To improve air quality through active air management and prevent exceedance of the CAAQS (AQ plan needed)
Yellow	40 to 59	40 to 59	To improve air quality using early and ongoing actions for continuous improvement
Green	≤ 38	≤ 38	To maintain good air quality through proactive air management measures to keep clean areas clean

3.3.6 8-hour mean O_3 standards

Table 20 shows 8-hour mean O_3 standards in the EU, USA, Japan, India as well as the WHO guideline level for O_3.

Table 20: *8-hour mean O_3 standards in different countries and regions, WHO guideline level (source: see links below **Table 11**).*

	EU[1]	USA[2]	Japan	India	WHO[5]
µg/m³	120	140	-	100	100

[1] EU: target value, maximum daily 8-hour mean, not to be exceeded on more than 25 days per calendar year averaged over three years

[2] USA: primary and secondary, annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years

[5] WHO: daily maximum

3.3.7 1-hour mean O_3 standards

Table 21 shows 1-hour mean O_3 standards in the EU, USA, Japan, India as well as the WHO guideline level for O_3.

Table 21: *O_3 1-hour mean standards in different countries and regions, WHO guideline level (source: see links below **Table 11**).*

	EU[1]	USA	Japan[3]	India[4]	WHO
µg/m³	180/240	-	(120)	180	-

[1] EU: 180 µg/m³: information threshold, 240 µg/m³: alert threshold

[3] Japan: Hourly values of photochemical oxidants shall not exceed 0.06 ppm

[4] India: 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time, they may exceed the limits but not on two consecutive days of monitoring

Table 22 shows different air quality management levels for the 8-hour mean of O_3 in Canada.

Table 22: *O_3 management levels in Canada (source: https://www.ccme.ca/en/resources/air/pm_ozone.html).*

Management level	**O_3 (µg/m³) (the 3-year average of the annual 4th highest daily maximum 8-hour average concentrations)**			
	2020	2025	2025	
Red (CAAQS)	> 126	> 124	> 120	To reduce pollutant levels below the CAAQS through advanced air management actions (AQ plan needed)
Orange	114 to 126	114 to 124	114 to 120	To improve air quality through active air management and prevent exceedance of the CAAQS (AQ plan needed)
Yellow	102 to 112	102 to 112	102 to 112	To improve air quality using early and ongoing actions for cont nuous improvement
Green	≤ 100	≤ 100	≤ 100	To maintain good air quality through proactive air management measures to keep clean areas clean

3.3.8 SO_2 standards

Table 23 shows hourly and daily SO_2 standards in the EU, USA, Japan, India as well as the WHO guideline level for NO_2.

Table 23: *SO_2 standards in different countries and regions, WHO guideline level (in µg/m³. source: see links below **Table 11**).*

EU[1]		USA[2]		Japan[3]		India[4]		WHO	
1 h	350	1 h	200	1 h	107	1 d	80	10 min	500
1 d	125	3 h	1332	1 d	266	1 y	20 / 50	24 h	20

[1] EU: 1 h value not to be exceeded more than 24 times per calendar year; 1d value not to be exceeded more than 3 times per calendar year

[2] USA: 1 h primary (99th percentile of 1-hour daily maximum concentrations, averaged over 3 years); 3h secondary (not to be exceeded more than once per year)

[3] Japan: The daily average for hourly values shall not exceed 0.04 ppm, and hourly values shall not exceed 0.1 ppm

[4] India: 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time, they may exceed the limits but not on two consecutive days of monitoring; 1y value of 20 µg/m³ applies in ecologically sensitive areas

4. AIR QUALITY STANDARDS IN THE GCC COUNTRIES

This chapter provides an overview of air quality standards in individual GCC countries before comparing standards in the region to those in the USA and EU and to WHO guidelines.

4.1 Bahrain

The following table shows the air quality standards in Bahrain; a comparison with other standards and guidelines is shown in **section 4.7.**

Table 24: *Air quality standards in Bahrain (source: sce.gov.bh)*

Pollutant	Limit		Avg. period
	ppb	µg/m³	
SO_2	115	300	1 h
	48	125	24 h
	19	50	Annual
NO_2	106	200	1 h
	80	150	24 h
	21	40	Annual
PM_{10}	-	340	24 h
		80	Annual
$PM_{2.5}$	-	50	24 h
		25	Annual
CO	17 ppm	20,000	1 h
	9 ppm	10,000	8 h
Benzene	4	13	24 h
	1.56	5	Annual
Toluene	300	1,130	24 h
	106	400	Annual
Xylene	100	434	24 h
	23	100	Annual
Total non-methane hydrocarbons (NMHC)	0.240 ppm	160	3 h
Hydrogen sulfide (H_2S)	30	42	1 h
	11	15	24 h
NH_3	604	420	1 h
	144	100	24 h

The general standards for the protection of the environment and environmental standards for air and water quality are stipulated by the Ministerial Edict No **(10)**[19] for the year 1999 on environmental standards (air and water), amended by ministerial edicts No **(2)** and **(3)** for the **year 2001**. Recently, the standards have been updated; the table above includes the updated levels.

4.2 Kuwait

The following table shows the air quality standards in Kuwait; a comparison with other standards and guidelines is shown in **section 4.7**.

Table 25: *Air quality standards in Kuwait*
(source: https://enterprise.emisk.org/eMISKAirQuality/#/KAQI).

Parameter	Limit	Avg. period
SO_2	200 µg/m³ (75 ppb)	1h
	51 µg/m³ (19 ppb)	24h
NO_2	191 µg/m³ (100 ppb)	1h
	40 µg/m³ (21 ppb)	Annual
CO	41 mg/m³ (35 ppm)	1h
O_3	140 µg/m³ (70 ppb)	8h
PM_{10}	350 µg/m³	24h
$PM_{2.5}$	75 µg/m³	24h

The air quality standards are laid down in the Appendices of Decision No 8/2017 of the Executive Orders of Law No. 42 of 2014 Promulgating The Environment Protection Law.[20]

4.3 Oman

The following table shows the air quality standards in Oman; a comparison with other standards and guidelines is shown in **section 4.7**.

The Ministry of Environment and Climate Affairs has developed and issued the ambient air quality standards for sultanate of Oman through MD 41/2017.[21]

[19] https://www.sce.gov.bh/en/AirQuality?cms=iQRpheuphYtJ6pyXUGiNqiQQw2RhEtKe
[20] http://extwprlegs1.fao.org/docs/pdf/kuw142030E.pdf,
https://www.ilo.org/dyn/natlex/natlex4.detail?p_lang=en&p_isn=99818, https://epa.org.kw/en-us/AirQuality
[21] https://www.duqm.gov.om/upload/files/air-quality-protection.pdf

Table 26: *Air quality standards in Oman (source: https://www.duqm.gov.om/upload/files/air-quality-protection.pdf).*

Pollutant	Limit		Avg. period (h)
	ppb	**µg/m³**	
SO_2	131	350	1
	56	150	24
H_2S	20	30	1
NO_2	131	250	1
	68	130	24
O_3	60	120	8
NH_3		200	24
CO	25,773	30 mg/m³	1
	8,591	10 mg/m³	8
PM_{10}	-	150	24
$PM_{2.5}$	-	65	24
NMHC	0.24	160	3
Pb		1.5	3 months

4.4 Qatar

The following table shows the air quality standards in Qatar; a comparison with other standards and guidelines is shown in **section 4.7**.

Table 27: *Air quality standards in Qatar*
(State of Qatar - Ministry of Development Planning and Statistics 2014).

Parameter	Limit	Avg. period
SO_2	365 µg/m³ (137 ppb)	24 h
	80 µg/m³ (30 ppb)	Annual
NO_2	400 µg/m³ (209 ppb)	1 h
	150 µg/m³ (78 ppb)	24 h
	100 g/m³ (52 ppb)	Annual
O_3	235 µg/m³ (118 ppb)	1 h
	120 µg/m³ (60 ppb)	8 h
CO	40 mg/m³ (34 ppm)	1 h
	10 mg/m³ (9 ppm)	8 h
PM_{10}	150 µg/m³	24 h
	50 µg/m³	Annual
$PM_{2.5}$	-	24 h
	-	Annual

The national standards for ambient air quality are laid down in the Executive By-Law for The Environment Protection Law 30/2002 (State of Qatar - Ministry of Development Planning and Statistics 2014).

4.5 Saudi Arabia

The following table shows the air quality standards in Saudi Arabia; a comparison with other standards and guidelines is shown in **section 4.7**.

The air quality standards were introduced in 2012 by the Kingdom of Saudi Arabia's Presidency of Meteorology and Environment; recently, the standards have been updated.[22]

[22] https://www.mewa.gov.sa/ar/InformationCenter/DocsCenter/RulesLibrary/Pages/default.aspx

Table 28: *Air quality standards in Saudi Arabia*
(source: https://www.mewa.gov.sa/ar/InformationCenter/DocsCenter/RulesLibrary/Pages/default.aspx).

Parameter	Limit	Avg. period	Number of exceedances
CO	10 mg/m³ (9 ppm)	8 h	2 times per month
	40 mg/m³ (34 ppm)	1 h	1 time per year
Pb	0.15 µg/m³	3 months	none
NO_2	200 µg/m³ (105 ppb)	1 h	24 times per year
	100 µg/m³ (52 ppb)	Annual	N/A
SO_2	441 µg/m³ (165 ppb)	1 h	24 times per year
	217 µg/m³ (81 ppb)	24 h	3 times per year
	65 µg/m³ (24 ppb)	Annual	N/A
Benzene	5 µg/m³ (1.5 ppb)	Annual	N/A
PM_{10}	340 µg/m³	24 h	12 times per year
	50 µg/m³	Annual	N/A
$PM_{2.5}$	35 µg/m³	24 h	12 times per year
	15 µg/m³	Annual	N/A
O_3	157 µg/m³ (79 ppb)	8 h	25 times a year (average over 3 years)
H_2S	150 µg/m³ (100 ppb)	24 h	10 times per year
	40 µg/m³ (30 ppb)	Annual	N/A

4.6 United Arab Emirates

The following table shows the air quality standards in the United Arab Emirates; a comparison with other standards and guidelines is shown in **section 4.7**.

Table 29: *Air quality standards in the United Arab Emirates (source: https://www.adairquality.ae/).*

Parameter	Limit	Avg. period*
SO_2	350 µg/m³ (131 ppb)	1 h
	150 µg/m³ (56 ppb))	24 h
	60 µg/m³ (23 ppb)	Annual
NO_2	400 µg/m³ (209 ppb)	1 h
	150 µg/m³ (78 ppb)	24 h
CO	30 mg/m³ (26 ppm)	1 h
	10 mg/m³ (9 ppm)	8 h
O_3	200 µg/m³ (100 ppb)	1 h
	120 µg/m³ (60 ppb)	8 h
PM_{10}	150 µg/m³	24 h
TSP	230 µg/m³	24 h
	90 µg/m³	Annual
Lead	1 µg/m³	Annual

** no exceedances allowed*

The law where the air quality standards are laid down is not mentioned on the Environment Agency's air quality monitoring system website.[23]

[23] https://www.adairquality.ae/

4.7 Comparison of GCC and other standards

The following figures show a comparison of the air quality standards in the GCC countries with WHO guideline levels as well as standards in the EU and USA.

4.7.1 Carbon monoxide

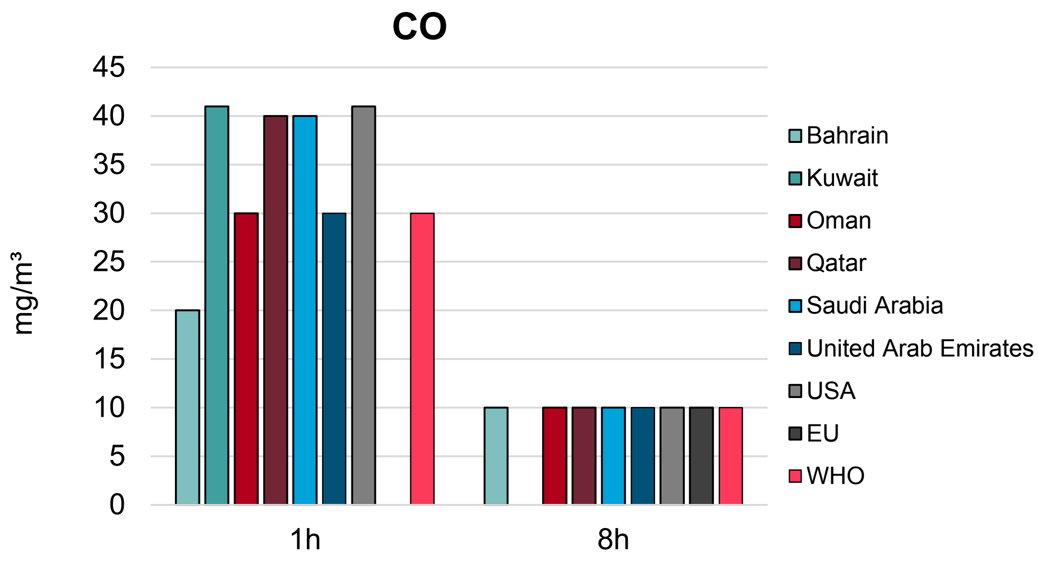


Figure 13: *Comparison of air quality standards and guideline levels for CO.*

4.7.2 NO_2

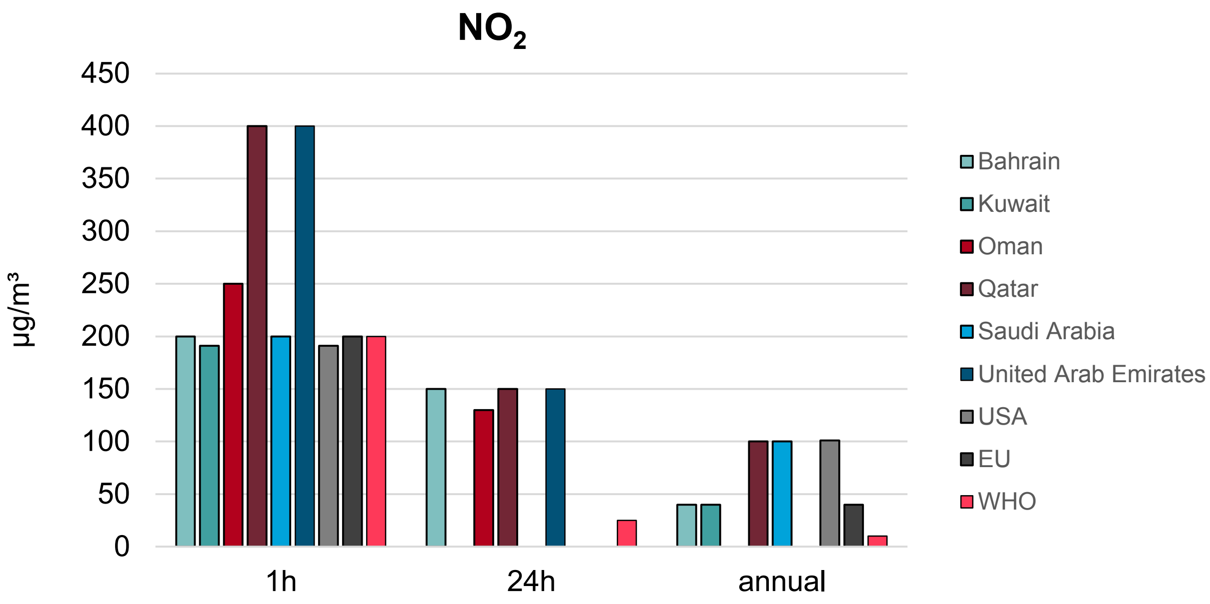


Figure 14: *Comparison of air quality standards and guideline levels for NO_2.*

4.7.3 Ozone

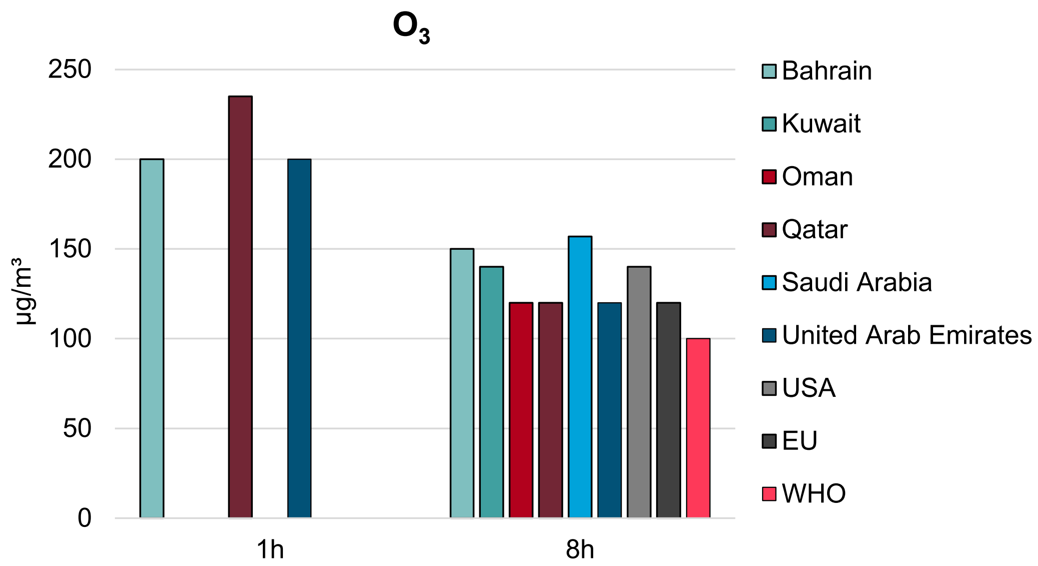


Figure 15: *Comparison of air quality standards and guideline levels for O_3.*

4.7.4 PM_{10}, $PM_{2.5}$

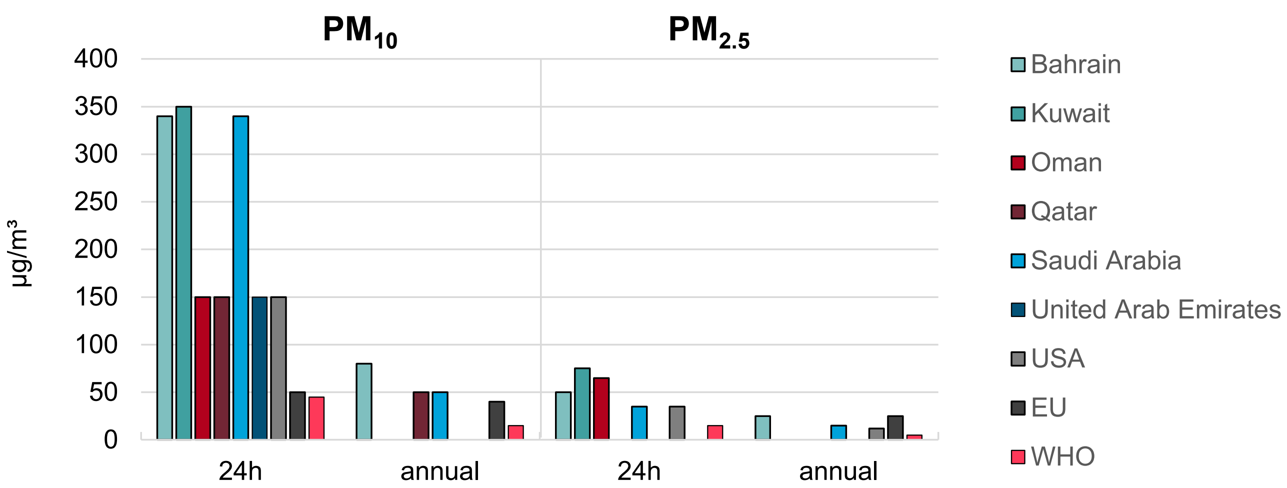


Figure 16: *Comparison of air quality standards and guideline levels for PM_{10} and $PM_{2.5}$.*

4.7.5 SO_2

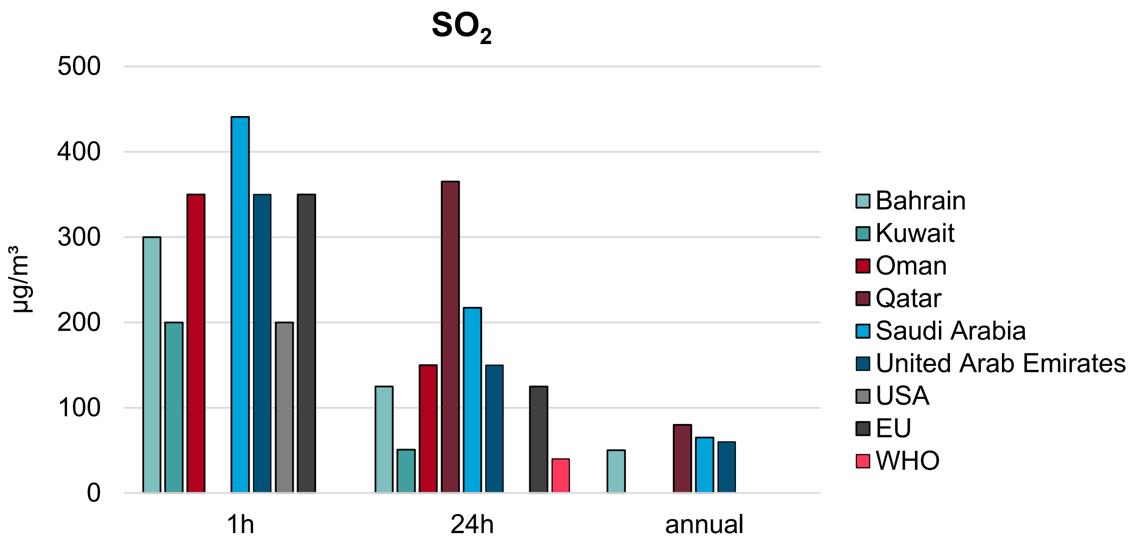


Figure 17: *Comparison of air quality standards and guideline levels for SO_2.*

5. WHO AIR QUALITY GUIDELINES AND INTERIM TARGETS

The WHO Air Quality Guidelines (WHO AQGs) aim to provide a basis for protecting human health from the adverse effects of air pollution (WHO Regional Office for Europe 1987, 2000, 2006; WHO 2021). The WHO AQGs offer quantitative health-based recommendations for air quality management, expressed as long or short-term concentrations. In September 2021, WHO published an update of the AQGs with levels and interim targets for $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2 and CO (WHO (2021); see **Section 5.2**). In addition, WHO published so-called good practice statements (see **Section 5.3**).

5.1 Air quality guidelines – how they differ from standards

The WHO AQGs aim at providing a basis for protecting humans from adverse effects of air pollution (WHO Regional Office for Europe 2000, 2006; WHO 2021). They are usually specified by a concentration level and an averaging period (Schneider et al. 2014).

Although WHO AQGs are based on health considerations, exposure even below the guideline values may constitute health risks. This is especially true for pollutants such as PM for which it has been found that there is no threshold level below which adverse effects can be excluded. Also, mixtures of pollutants might have additive effects; highly sensitive groups might also be affected when exposed to levels at or below the WHO AQGs.

The WHO AQGs are not air quality standards in themselves but are intended to provide background information and guidance to policy makers. Guidelines are based only on health considerations whereas for regulatory standards further aspects have to be taken into account. For instance, WHO AQGs do not consider the technical feasibility or the economic, political and social aspects of efforts to achieve these levels. The WHO AQGs can thus be considered as recommendations.

In contrast, limit values as laid down in EU Directives have to be attained within a given period of time and are not to be exceeded once they have been attained. Non-compliance with the limit values stipulated in the AAQD can have legal consequences such as the start of infringement proceedings or lawsuits by citizens against the relevant agencies or administrations.
Thus the economic, technical, political and social aspects of attaining limit values are usually taken into account when setting the relevant regulatory standards. In addition, the technical details of compliance (e.g. where do the standards have to be met: at urban background sites or at hot spots like street canyons?) have to be specified.

Developing and revising guidelines

As described in the study "EU Air Quality Policy and WHO Guideline Values for Health" (Schneider et al. 2014), the development of WHO AQGs is evidence-based and relies on the most recent scientific knowledge from various disciplines, including epidemiology, toxicology, occupational and environmental medicine. More than 100 experts contributed to the preparation of the background documents or participated in the scientific discussions that led to the derivation of guideline values for a great number of air pollutants.

The pollutants for which guidelines were to be established and revisions to be carried out were selected by working groups on the basis of various criteria, including whether significant health effects might occur and where considerable exposure could be expected. The working groups prepared indepth reviews of the scientific background documents for each pollutant. Based on these documents, guidelines were discussed and drafted. The draft report was reviewed by a consultancy group.

In addition to the guideline values, a special working group provided guidance for policy makers for setting air quality regulatory standards based on these values.

To account for the attainability of the guideline values in different parts of the world, WHO provided interim targets for PM, O_3 and SO_2 in its global updates in 2005 and 2021 (WHO Regional Office for Europe 2006; WHO 2021).

5.2 Recommendations on principal air pollutants

The updated AQGs provide short- and long-term levels and interim targets for $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2 and CO that are shown in **Table 30**.

Table 30: *WHO AQG levels and interim targets (WHO 2021).*

Pollutant	Averaging time	Interim target				AQG level
		1	2	3	4	
$PM_{2.5}$, µg/m³	Annual	35	25	15	10	5
	24-hour[a]	75	50	37.5	25	15
PM_{10}, µg/m³	Annual	70	50	30	20	15
	24-hour[a]	150	100	75	50	45
O_3, µg/m³	Peak season[b]	100	70	-	-	60
	8-hour[a]	160	120	-	-	100
NO_2, µg/m³	Annual	40	30	20	-	10
	24-hour[a]	120	50	-	-	25
SO_2, µg/m³	24-hour[a]	125	50	-	-	40
CO, mg/m³	24-hour[a]	7	-	-	-	4

[a] *99th percentile (i.e. 3–4 exceedance days per year).*

[b] *Average of daily maximum 8-hour mean O_3 concentration in six consecutive months with the highest six-month running-average O_3 concentration.*

How the AQG levels compare to those set in 2005 is shown in **Figures 18** and **19** below.

Figure 18: *2021 long-term WHO AQGs in comparison with those set in 2005 (source WHO).*

Figure 19: *2021 short-term AQG levels compared to those set in 2005 (source: WHO).*

AQG levels for shorter averaging times that were not re-evaluated and remain valid are provided in **Table 31** .

Table 31: *AQGs for nitrogen dioxide, sulfur dioxide and carbon monoxide with short averaging times (WHO Regional Office for Europe 2006).*

Pollutant	Averaging time	AQG that remain valid
NO_2, µg/m³	1-hour	200
SO_2, µg/m³	10-minute	500
CO, mg/m³	8-hour	10
	1-hour	35
	15-minute	100

5.3 Good practice statements

The potential health effects of black carbon, ultrafine particles and particles from sand and dust storms have been under discussion for several years (WHO Regional Office for Europe 2012, 2013b). Data is still insufficient to provide recommendations for AQG levels and interim targets for these specific types of PM.

Nevertheless, action to reduce emissions and concentration levels as well as further research on risks and approaches to mitigation are warranted, as reflected in the *"good practice statements"* in the updated AQGs (WHO 2021).

5.3.1 Black carbon/elemental carbon

Black carbon (BC) is airborne, soot-like carbon that is measured with optical methods. It is closely related to the mass concentration of elemental carbon (EC, i.e. carbon in various crystalline forms) which is monitored by thermo-optical methods. BC/EC is typically formed through the incomplete combustion of fossil fuels, biofuel and biomass, and is emitted from both anthropogenic and natural sources. BC can include known carcinogens and other toxic species. Black carbon is a powerful climate-warming agent that acts by absorbing heat in the atmosphere and by reducing albedo (the ability to reflect sunlight) when deposited on snow and ice (IPCC 2021).

The updated AQGs provide the following good practice statements for BC/EC (WHO 2021):

1. Make systematic measurements [24] of BC and/or EC. Such measurements should not replace or reduce the existing monitoring of pollutants for which guidelines currently exist.

2. Undertake the production of emission inventories, exposure assessments and source apportionment for BC/EC.

3. Take measures to reduce BC/EC emissions from within relevant jurisdiction and, where considered appropriate, develop standards (or targets) for ambient BC/EC concentrations

5.3.2 Ultrafine particles

Ultrafine particles (UFP) are generally considered as particulates with a diameter less than or equal to 0.1 μm (i.e. 100 nm). The most significant process generating UFP is fuel combustion and the main sources of UFP include transport, industrial and power plants, and residential heating.

The updated AQGs provide the following good practice statements for UFP (WHO 2021):

1. Quantify ambient UFP in terms of particle number concentration (PNC) for a size range with a lower limit of ≤ 10 nm and no restriction on the upper limit.

[24] In Europe, there is currently no standard method for measuring BC. For EC (and organic carbon, OC), a European Standard was developed: EN 16909:2017: Ambient air - Measurement of elemental carbon (EC) and organic carbon (OC) collected on filters.

2. Expand the common air quality monitoring strategy by integration of UFP monitoring [25] into existing air quality monitoring. Include size-segregated real-time PNC measurements at selected air monitoring stations in addition to, and simultaneously with, other airborne pollutants and characteristics of PM.

3. Distinguish between low and high PNC to guide decisions on the priorities of UFP source emission control. Low PNC can be considered < 1,000 particles/cm³ (24-hour mean). High PNC can be considered > 10,000 particles/cm³ (24-hour mean) or 20,000 particles/cm³ (1-hour).

4. Utilize emerging science and technology to advance approaches to the assessment of exposure to UFP for application in epidemiological studies and UFP management.

5.3.3 Particles originating from sand and dust storms

Dealing with sand and dust storm (SDS) particles has become a growing priority within the global community. SDS events can have widespread impacts owing to the proven long-range transport of dust across countries and even continents. There is no precise distinction between sand storms and dust storms, since there is a continuum of particle sizes in any storm. Desert dust events have coincided with substantial increases in measured concentrations of both PM_{10} and $PM_{2.5}$. Research from southern Europe suggests an increased accumulation of anthropogenic pollutant concentrations during events of transported dust, likely owing to a number of related meteorological phenomena (Querol et al. 2019).

The updated AQGs provide the following good practice statements for SDS particles (WHO 2021):

1. Maintain suitable air quality management and dust forecasting programmes. These should include early warning systems and short-term air pollution action plans to alert the population to stay indoors and take personal measures to minimize exposure, and subsequent short-term health effects, during SDS incidents with high levels of PM.

2. Maintain suitable air quality monitoring programmes and reporting procedures, including source apportionment activities to quantify and characterize the PM composition and the percentage contribution of SDS to the overall ambient concentration of PM. This will enable local authorities to target local emissions of PM from anthropogenic and natural sources for reduction.

3. Conduct epidemiological studies, including those addressing long-term effects of SDS, and research activities aimed at better understanding the toxicity of the different types of PM. Such studies are especially recommended for areas where there is a lack of sufficient knowledge and information about the health risk due to frequent exposure to SDS.

4. Implement wind erosion control through the carefully planned expansion of green spaces that considers and is adjusted to the contextual ecosystem conditions. This calls for regional collaboration among countries in the regions affected by SDS to combat desertification and carefully manage green areas.

[25] *A technical standard for monitoring UFP was developed in Europe: CEN/TS 16976:2016: Ambient air - Determination of the particle number concentration of atmospheric aerosol.*

5. Clean the streets in those urban areas characterized by a relatively high population density and low rainfall to prevent resuspension by road traffic as a short-term measure after intense SDS episodes with high dust deposition rates. Cleaning can be done by washing and/or sweeping. For the former, non-drinking, underground water from the subway drainage system or treated urban waters should be used (Querol et al. 2019). This intervention is not feasible in many countries where water is scarce. In such cases, minimizing some of the local urban sources of dust such as construction and demolition activities can be a better alternative intervention.

Before planning street cleaning, local authorities should:

- assess the magnitude of the problem;
- evaluate rainfall statistics;
- select the streets that are most critically affected by the dust load situation;
- ascertain the accumulation rate of sediments; and
- determine the most effective cleaning method (e.g. frequency, timing and cleaning machine characteristics).

06

6. SOURCE APPORTIONMENT TO ACCOUNT FOR CONTRIBUTIONS FROM DESERT DUST

6.1 Overview of general source apportionment techniques

A recent report by the European Commission's Joint Research Centre (JRC) reviews the most widely used source apportionment methods for air quality management and provides a theoretical background (European Commission – Joint Research Centre 2020).
The report gives the following definition:

"Source apportionment is a technique used to relate emissions from various pollution sources to air pollution concentrations at a given location and for a given time period"

Three general types of results for source apportionment are described in the guidance:

- potential impacts (changes in concentrations due to changes in emissions)
- contributions (of individual sources to concentration levels at a certain point)
- increments

These methods can be combined. For example, for AQ plans, urban and regional components can be identified by increments, with potential impacts computed in a second step to identify and quantify the sectoral origins of the pollution.

6.1.1 Potential impacts

The JRC reports describes impacts as concentration changes resulting from emission changes.

***"Potential impacts** correspond to the pollutant mass obtained by differencing two air quality model (AQM) simulations performed with the full emission source and a reduced emission source, scaled by the emissions reduction factor (ranging from 0 to 1)."*

Impacts are best calculated with models, which can be of different types: Gaussian, Lagrangian, Eulerian or simplified source-receptor models based on any of these.

Figure 20 shows a simplified example of such a calculation. Potential impacts correspond to the change of mass (projected to 100%) that results from the reduction or elimination of the emission source, i.e. the difference between the downwind concentrations, with and without the source emissions, scaled by the percentage reduction (four black squares in the example).
With this representation, pollutant concentrations can be computed by summing up the symbols with a given volume of air at a given receptor location (e.g. the dashed lines rectangle).

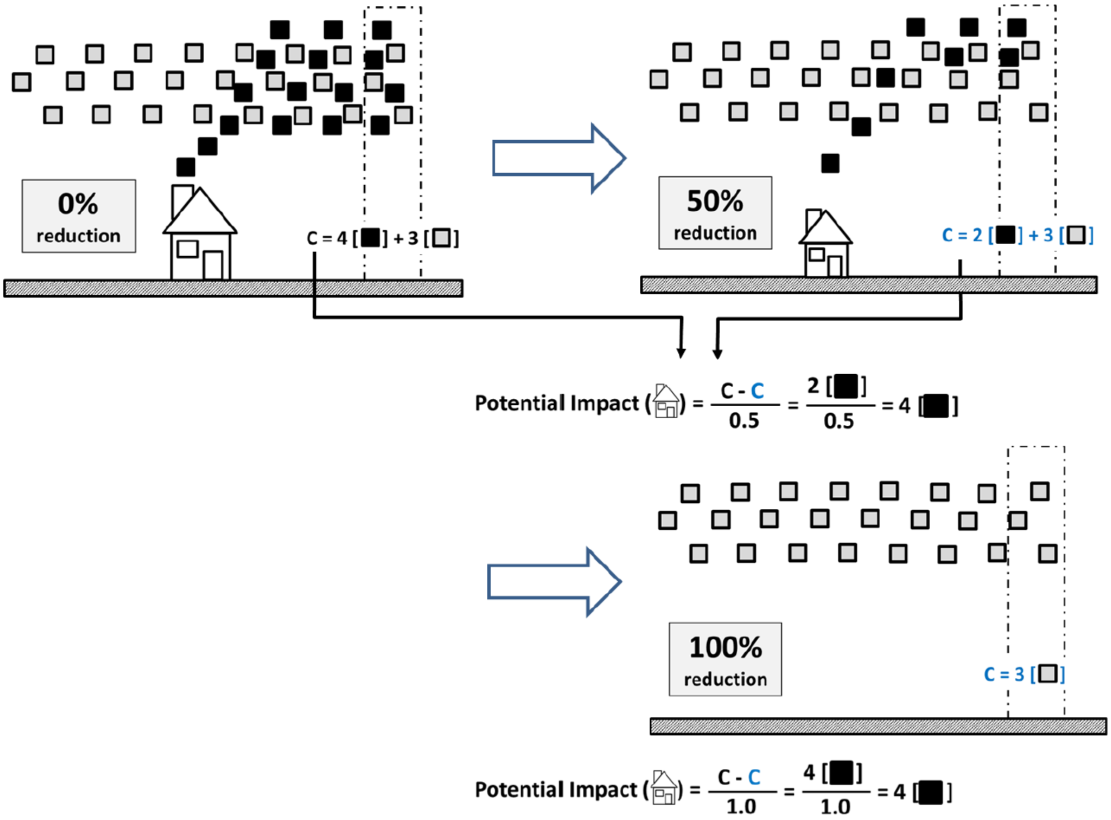


Figure 20: *Residential emissions (black squares) mix with the background pollution (grey squares) and lead to a given concentration downwind of the source (right dashed rectangle). When the source is reduced by 50% (right top), two out of the four black squares remain together with the background while for a full reduction, only the background remain (right bottom). Squares are used to represent model-based output. Note that in this figure, each symbol (circle or square) represents a unit of mass that may come from the background or may be emitted by a source (European Commission – Joint Research Centre 2020).*

6.1.2 Contributions

The JRC report provides the following definition:

"Contributions correspond to the mass of a pollutant transferred from the emission sources to the ambient concentrations."

The assessment of contributions is based on measurements (via receptor-oriented models) or from model results with the help of source-oriented models using a tagging algorithm.

Figure 21 shows an example of contributions obtained by recognizing in the downwind concentration (via pre-established source emission fingerprints) the emitted pollutant from the source (**left panel**) or by tagging the emission precursors (**right panel**). Both options lead to four black symbols in the example.

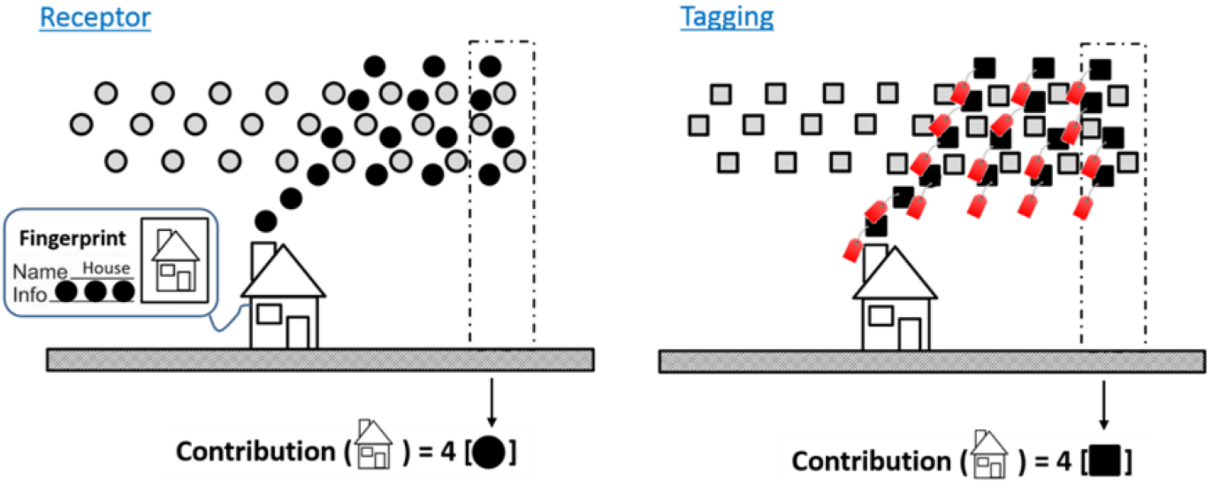


Figure 21: *Residential emissions (black symbols) mix with the background pollution (grey symbols) and lead to a given pollutant concentration downwind of the source (dashed rectangle). Circle and square symbols are used to differentiate measurement- from model-based approaches (European Commission – Joint Research Centre 2020).*

6.1.3 Increments

The JRC report provides the following definition:

"Increments are based on spatial gradients of concentration and are calculated as the difference between concentrations at two specific locations (one influenced by the source, the other not)."

This method is mainly used for source apportionment of PM constituents. It is based on measurements at different locations.

Figure 22 shows an example of how increments are obtained by subtracting the background concentration (CBg, left dashed rectangle) from the concentration C downwind of the source, i.e. four black circles in the example.

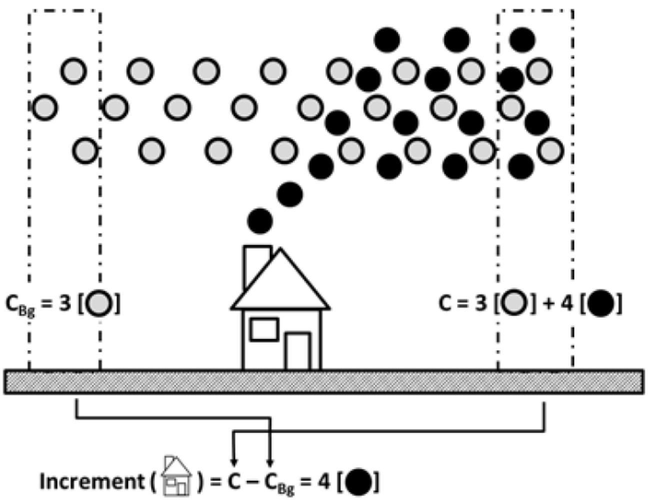


Figure 22: *Residential emissions (black circles) mix with the background pollution (grey circles) and lead to a given pollutant concentration downwind of the source (right dashed rectangle). Circles are used as symbols in this figure because increments are mostly based on measurements (European Commission – Joint Research Centre 2020).*

6.2 Deduction of contributions from natural sources

6.2.1 European Union legislation

Where exceedances are due to natural sources (Article 20 AAQD) and compliance is reached after deducting the contribution of these sources, EU Member States do not have to draw up air quality plans. The European Commission has published guidelines[26] related to these deductions.

According to these guidelines, a number of key principles that have to be fulfilled for the subtraction to be allowed. Of interest when considering desert dust (dust originating from the Sahara can affect air quality particularly across southern parts of the EU) is how the guidelines distinguish wind-blown dust of natural origin from that generated by agricultural activities:

"Member States thus need to be very cautious in identifying the true natural origin when assessing this contribution. Particles directly re-suspended by agricultural activities or that originate from agricultural field (e.g. ploughed field) should be considered as formed by the interaction of natural with anthropogenic activities and shall not be considered eligible for deduction."

6.2.2 Accounting for Saharan dust contributions

The guidelines propose the following procedure for deducting Saharan dust from daily mean PM_{10} concentrations above 50 µg/m³. Member States could also use a different method, if validated and documented.

The procedure is based on a method developed in Spain and Portugal for application in both countries (Escudero et al. 2007; Pey Betrán et al. 2008).

The procedure can be summarized in the following tasks.

Identifying Saharan dust episodes

To identify the occurrence and the duration of Saharan dust episodes the following steps should be taken:

- Interpretation of the daily meteorological situations with the five-day back trajectories of the calculated daily air masses at 12 h, for 750 m, 1,500 m and 2,500 m above sea level such as those obtained with a Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model,[27] including modelled vertical speed. The conclusions drawn from the analysis of back trajectories should be validated by inspecting synoptic meteorological charts, such as those available at ECMWF[28] .

[26] https://ec.europa.eu/environment/air/quality/legislation/pdf/sec_2011_0208.pdf
[27] https://ready.arl.noaa.gov/HYSPLIT.php
[28] https://www.ecmwf.int/

- Consultation of maps showing the aerosol index of Ozone Monitoring Instrument (OMI).[29] It is important to highlight that the OMI does not detect Saharan events produced at surface level and therefore it is advisable also to check daily satellite images where this type of event is clearly visible.

- Consultation of the daily results of aerosol models such as SKIRON,[30] BSC,[31] Copernicus,[32] ZAMG[33] and NAAPs.[34]

- Information on the levels of PM measured in real time at regional background stations, where available, should be consulted. A rapid increase of PM_{10} levels in the network and at particular regional background stations may indicate an occurrence of a dust episode triggering further specific activity for identification and quantification of the event. The data from measuring stations that are not equipped with real-time instruments but PM filter samplers should be used in a final stage together with the real-time corrected measurements to validate the episodes. These steps will result in tables containing a compilation of the levels of PM registered in the regional background stations, with an indication of the days and areas with Saharan dust contributions.

Quantifying Saharan dust outbreak episodes

The method for quantifying Saharan dust contributions was developed for the Iberian Peninsula (Escudero et al. 2007; Pey Betrán et al. 2008). The use of this indicator in other countries has not been validated and no certainty exists on its accuracy.

To quantify the fraction of the PM_{10} regional background levels not attributed to the Saharan dust outbreak for the days with identified Saharan influence, in each time series of the station of corresponding regional background, the monthly moving 40th percentile is determined for each day, excluding days with identified Saharan influence. The value corresponding to this calculated moving 40th percentile is subtracted from the daily average of PM_{10} determined in the station of regional background for every day affected by the Saharan contribution.

In the absence of specific studies that identify a statistical indicator that better reproduces PM_{10} background concentration, the use of a more conservative indicator, like the average PM_{10} concentration registered during 15 days before and 15 days after the analysed dust outbreak episode excluding the days with the identified episode, or the moving 50th percentile of 30 days, should be preferred.

[29] http://www.temis.nl/airpollution/absaai/
[30] https://forecast.uoa.gr/en/forecast-maps/dust/europe
[31] https://sds-was.aemet.es/forecast-products/dust-forecasts/forecast-comparison
[32] https://atmosphere.copernicus.eu/
[33] https://www.zamg.ac.at/cms/de/umwelt/luftqualitaetsvorhersagen/schadstofftransport/?imgtype=0
[34] https://www.nrlmry.navy.mil/aerosol/

With this procedure, by subtracting the 40th percentile or the 30-day average value from the bulk PM_{10} levels recorded during the "Saharan" day at the relevant regional background station, the daily net dust load in PM_{10} is obtained **(Figure 23)**. The daily values of net dust load in PM_{10} registered in regional background stations is added to the tables previously mentioned for the coincident days with episodes of Saharan PM_{10}.

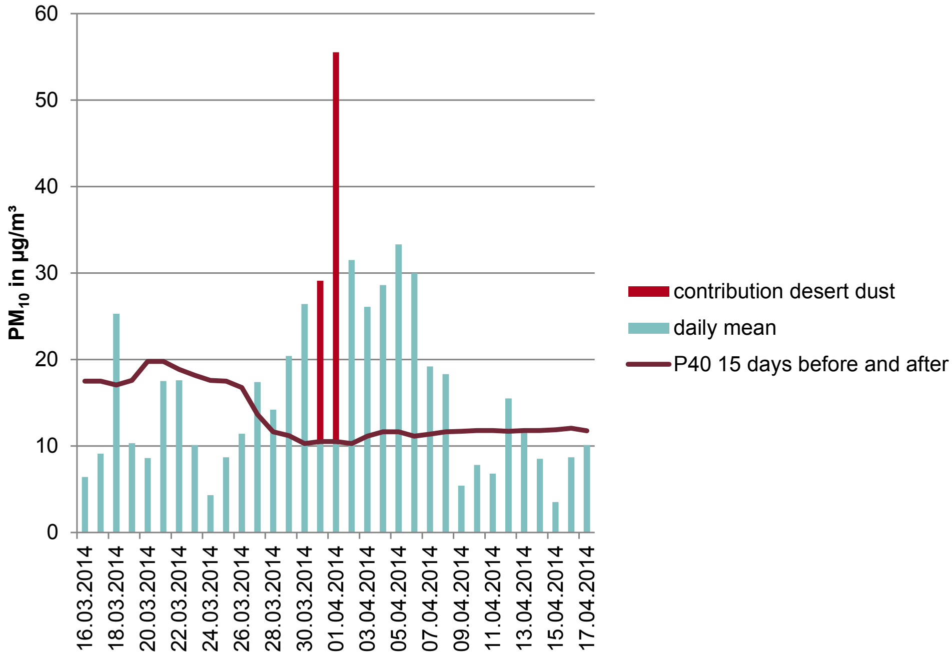


Figure 23: *Example of calculating the contribution of desert dust ("daily net dust load") to PM_{10} daily mean levels (source: Environment Agency Austria/Umweltbundesamt).*

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