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Air quality in Europe — 2019 report

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Executive summary

This report presents an updated overview and analysis of air quality in Europe from 2000 to 2017. It reviews the progress made towards meeting the air quality standards established in the two EU Ambient Air Quality Directives and towards the World Health Organization (WHO) air quality guidelines (AQGs). It also presents the latest findings and estimates of population and ecosystem exposure to the air pollutants with the greatest impacts. The evaluation of the status of air quality is based mainly on reported ambient air measurements, in conjunction with modelling data and data on anthropogenic emissions and the trends they exhibit over time.

The *Air quality in Europe* report is only possible thanks to countries' official reporting of data. We would like to recognise and acknowledge the support from the air quality experts in the reporting countries.

Europe's air quality

Particulate matter

Concentrations of particulate matter (PM) continued to exceed the EU limit values and the WHO AQGs in large parts of Europe in 2017. For PM with a diameter of 10 µm or less (PM_{10}), concentrations above the EU daily limit value were registered at 22 % of the reporting stations (646 out of 2 886) in 17 of the 28 EU Member States (EU-28) and in six other reporting countries. For $PM_{2.5}$, concentrations above the annual limit value were registered at 7 % of the reporting stations (98 out of 1 396) in seven Member States and three other reporting countries.

The long-term WHO AQG for PM_{10} was exceeded at 51 % of the stations (1 497 out of 2 927) and in all of the reporting countries, except Estonia, Finland and Ireland. The long-term WHO AQG for $PM_{2.5}$ was exceeded at 69 % of the stations (958) located in all of the reporting countries, except Estonia, Finland and Norway.

A total of 17 % of the EU-28 urban population was exposed to PM_{10} levels above the daily limit value and 44 % was exposed to concentrations exceeding the stricter WHO AQG value for PM_{10} in 2017. Regarding $PM_{2.5}$, about 8 % of the urban population in the EU-28 was exposed to levels above the EU annual limit value, and approximately 77 % was exposed to concentrations exceeding the WHO AQG value for $PM_{2.5}$ in 2017 (Table ES.1).

In spite of the decreasing values in exposure to $PM_{2.5}$ observed since 2006, four Member States have yet to meet the exposure concentration obligation, set under the Ambient Air Quality Directive and due to be attained in 2015.

Ozone

In 2017, 20 % of stations (378 out of 1 903) registered concentrations above the EU ozone (O_3) target value for the protection of human health. These stations were located in 17 of the EU-28 and six other European reporting countries. The long-term objective was met in only 18 % of the stations (337) in 2017. The WHO AQG value for O_3 was exceeded in 95 % of all the reporting stations (1 806).

About 14 % of the EU-28 urban population was exposed to O_3 concentrations above the EU target value threshold. The percentage of the EU-28 urban population exposed to O_3 levels exceeding the WHO AQG value was 96 % in 2017, scarcely showing any fluctuation since 2000 (Table ES.1).

Nitrogen dioxide

Concentrations above the annual limit value for nitrogen dioxide (NO_2) are still widely registered across Europe, even if concentrations and exposures continue to decrease. In 2017, around 10 % of all the reporting stations (329 out of 3 260) recorded concentrations above this standard, which is the same as the WHO AQG. These stations were located in 16 of the EU-28 and four other reporting countries. In total, 86 % of concentrations above this limit value were observed at traffic stations.

Around 7 % of the EU-28 urban population was exposed to concentrations above the annual EU limit value (which is equal to the WHO AQG) for NO_2 in 2017 (Table ES.1); this represents the lowest value since 2000.

Box ES.1 New in the *Air quality in Europe — 2019 report*

The *Air quality in Europe* report series from the EEA presents regular assessments of Europe's air pollutant emissions and concentrations and of their associated impacts on health and the environment.

Based on the latest official data available from countries, this updated 2019 report presents new information, including:

- updated 2017 data on air pollutant emissions and concentrations;
- updated information on the status of reporting of $PM_{2.5}$ (particulate matter with a diameter of 2.5 µm or less) speciation, ozone precursors, total deposition of heavy metals and polycyclic aromatic hydrocarbons (both concentrations and total deposition);
- estimates of the exposure of urban (2017) and total (2016) populations and the exposure of ecosystems (2016) to air pollution;
- updated assessments of air quality impacts on health (for 2016);
- a health benefit analysis of the $PM_{2.5}$ WHO air quality guideline value applying everywhere in Europe;
- a special focus on heavy metals, with a more detailed analysis of the health and environmental risks associated with exposure to arsenic, cadmium, lead, mercury and nickel, an overview of the legislation implemented for their control, and more thorough analyses of the available information on the status and the development of their emissions, atmospheric concentrations and deposition in Europe.

Table ES.1 Percentage of the urban population in the EU-28 exposed to air pollutant concentrations above certain EU and WHO reference concentrations (minimum and maximum observed between 2015 and 2017)

Pollutant	EU reference value ([a])	Urban population exposure (%)	WHO AQG ([a])	Exposure estimate (%)
PM_{10}	Day (50)	13-19	Year (20)	42-52
$PM_{2.5}$	Year (25)	6-8	Year (10)	74-81
O_3	8-hour (120)	12-29	8-hour (100)	95-98
NO_2	Year (40)	7-8	Year (40)	7-8
BaP	Year (1)	17-20	Year (0.12) RL	83-90
SO_2	Day (125)	< 1	Day (20)	21-31

Key				
Key	< 5 %	5-50 %	50-75 %	> 75 %

Notes: The reference concentrations include EU limit or target values, WHO AQGs and an estimated reference level (RL).

For some pollutants, EU legislation allows a limited number of exceedances. This aspect is considered in the compilation of exposure in relation to EU air quality limit and target values.

The comparison is made for the most stringent EU limit value set for the protection of human health. For PM_{10}, the most stringent limit value is for the 24-hour mean concentration, and for NO_2 it is the annual mean limit value.

The estimated exposure range refers to the maximum and minimum values observed in a recent 3-year period (2015-2017) and includes variations attributable to meteorology (as dispersion and atmospheric conditions differ from year to year) and to the number of available data series (monitoring stations and/or selected cities) that will influence the total number of the monitored population. The estimate for 2017 is presented in the main text of this report.

As WHO has not set AQGs for BaP, the RL in the table was estimated, assuming WHO unit risk for lung cancer for polycyclic aromatic hydrocarbon mixtures and an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000.

([a]) In µg/m³, except BaP, which is in ng/m³.

Source: EEA, 2019a.

Benzo[a]pyrene, an indicator for polycyclic aromatic hydrocarbons

Thirty-one per cent of the reported benzo[*a*]pyrene (BaP) measurement stations (218 out of 712) registered concentrations above 1.0 ng/m^3 in 2017. They belonged to 13 Member States (out of 24 EU-28 and two other countries reporting data) and were located mostly in urban areas.

Seventeen per cent of the EU-28 urban population was exposed to BaP annual mean concentrations above the EU target value in 2017, which is — together with the figure recorded in 2009 — the lowest value since 2008. Overall, 83 % were exposed to concentrations above the estimated reference level (Table ES.1).

Other pollutants: sulphur dioxide, carbon monoxide, benzene

Only 21 stations (representing less than 2 % of a total of more than 1 400 stations) in two of the EU-28 and four other reporting countries reported values for sulphur dioxide (SO_2) above the EU daily limit value in 2017. However, 43 % of all SO_2 stations, located in 28 reporting countries, measured SO_2 concentrations above the WHO AQG, which is more stringent than the EU daily limit value. This signified that 31 % of the EU-28 urban population in 2017 was exposed to SO_2 levels exceeding the WHO AQG.

Exposure of the European population to carbon monoxide concentrations above the EU limit value and WHO AQG was very localised and infrequent. Only four stations (of which three were outside the EU-28) registered concentrations above the EU limit value in 2017.

Likewise, concentrations above the limit value for benzene were observed at only three European stations (all of them located in the EU-28) in 2017.

Focus on toxic metals

European emissions of arsenic, cadmium, nickel, lead and mercury have been declining since 2000. This has led, on average, to a decrease in air concentrations and deposition, especially in industrial sites, as energy production and industrial activities were the main anthropogenic sources of these metals during the period 2008-2017.

Despite the considerable decrease in emissions of toxic metals into the air during the period 2000-2017, long-term risks to human health and ecosystems still remain, as a result of the accumulation of metal in soils, sediments and organisms from past anthropogenic emissions. It is therefore necessary to continue efforts to reduce air emissions of toxic metals, focusing on implementing the best available techniques and reducing the use of toxic metals in products.

Impacts of air pollution on health

Air pollution continues to have significant impacts on the health of the European population, particularly in urban areas. Europe's most serious pollutants, in terms of harm to human health, are PM, NO_2 and ground-level O_3. Some population groups are more affected by air pollution than others, because they are more exposed or vulnerable to environmental hazards. Lower socio-economic groups tend to be more exposed to air pollution, while older people, children and those with pre-existing health conditions are more vulnerable. Air pollution also has considerable economic impacts, cutting lives short, increasing medical costs and reducing productivity through working days lost across the economy.

Estimates of the health impacts attributable to exposure to air pollution indicate that $PM_{2.5}$ concentrations in 2016 ([1]) were responsible for about 412 000 premature deaths originating from long-term exposure in Europe (over 41 countries; see Table 10.1), of which around 374 000 were in the EU-28. The estimated impacts of exposure to NO_2 and O_3 concentrations on the population in these 41 European countries in 2016 were around 71 000 and 15 100 premature deaths per year, respectively, and in the EU-28 around 68 000 and 14 000 premature deaths per year, respectively.

Exposure and impacts on European ecosystems

Air pollution also damages vegetation and ecosystems. It leads to several important environmental impacts, which affect vegetation and fauna directly, as well as the quality of water and soil and the ecosystem services they support. The most harmful air pollutants in terms of damage to ecosystems are O_3, ammonia and nitrogen oxides (NO_X).

([1]) The methodology uses maps of interpolated air pollutant concentrations, with information on the spatial distribution of concentrations from the European Monitoring and Evaluation Programme (EMEP) model. At the time of drafting this report, the most up-to-date data from the EMEP model were used (2016).

The latest estimates of vegetation exposure to O_3 indicate that the EU target value for protection of vegetation from O_3 was exceeded in 2016 ([1]) in about 15 % of the agricultural land area of the EU-28, and in 19 % of all the European countries considered. The long-term objective for the protection of vegetation from O_3 was exceeded in 73 % of the EU-28 (77 % of all European) agricultural area. The United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) critical level for the protection of forests from O_3 was exceeded in 62 % of the EU-28 (63 % of all European) forest area in 2016.

It is estimated that about 62 % of the European ecosystem area and 73 % of the EU-28 ecosystem area remained exposed to levels of NO_X, leading to exceedances of critical loads for eutrophication in 2016.

Finally, exceedances of the critical loads for acidification (driven by atmospheric nitrogen and sulphur compounds) occurred over 5 % of the European ecosystem area and 7 % of the EU-28 ecosystem area.

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1 Introduction

1.1 Background

Air pollution is a global threat leading to large impacts on human health and ecosystems. Emissions and concentrations have increased in many areas worldwide. When it comes to Europe, air quality remains poor in many areas, despite reductions in emissions and ambient concentrations.

Air pollution is currently the most important environmental risk to human health, and it is perceived as the second biggest environmental concern for Europeans, after climate change (European Commission, 2017a). As a result, there is growing political, media and public interest in air quality issues and increased public support for action. Growing public engagement around air pollution challenges, including ongoing citizen science initiatives engaged in supporting air quality monitoring (EEA, 2019b) and initiatives targeting public awareness and behavioural changes, have led to growing support and demand for measures to improve air quality. The European Commission supports the Member States in taking appropriate action and has implemented various initiatives to increase its cooperation with them (European Commission, 2018a). The European Commission has also launched infringement procedures against several Member States in breach of air quality standards, while both national and local governments face an increasing number of lawsuits filed by non-governmental organisations (NGOs) and citizen groups.

Effective action to reduce air pollution and its impacts requires a good understanding of its causes, how pollutants are transported and transformed in the atmosphere, how the chemical composition of the atmosphere changes over time and how pollutants affect humans, ecosystems, the climate and subsequently society and the economy. To curb air pollution, collaboration and coordinated action at international, national and local levels must be maintained, in coordination with other environmental, climate and sectoral policies. Holistic solutions involving technological developments, structural changes and behavioural changes are also needed, together with an integrated multidisciplinary approach. Efforts to achieve most of the Sustainable Development Goals (SDGs) ([2]) are linked directly or indirectly to mitigating air emissions and changes in atmospheric composition (UN Environment, 2019a).

Although air pollution affects the whole population, certain groups are more vulnerable to its effects on health, such as children, elderly people, pregnant women and those with pre-existing health problems. People living on low incomes are, in large parts of Europe, more likely to live next to busy roads or industrial areas and so face higher exposure to air pollution. Energy poverty, which is more prevalent in southern and central eastern Europe, is a key driver of the combustion of low-quality solid fuels, such as coal and wood, in low efficiency ovens for domestic heating (Maxim et al., 2017; InventAir, 2018). This leads to high exposure of the low-income population to particulate matter (PM) and polycyclic aromatic hydrocarbons (PAHs), both indoors and outdoors. Furthermore, the most deprived people in society often have poorer health and less access to high-quality medical care, increasing their vulnerability to air pollution (EEA, 2018a; WHO, 2019a).

([2]) These goals were set in the United Nations' (UN) 2030 Agenda for Sustainable Development (UN, 2015a), covering the social, environmental and economic development dimensions at a global level (UN, 2015b).

1.2 Objectives and coverage

This report presents an updated overview and analysis of ambient (outdoor) air quality in Europe ([3]) and is focused on the state of air quality in 2017. The evaluation of the status of air quality is based on officially reported ambient air measurements (Box 1.1), in conjunction with officially reported data on anthropogenic emissions and the trends they exhibit over time. Parts of the assessment also rely on air quality modelling.

In addition, the report includes an overview of the latest findings and estimates of ecosystems' exposure to air pollution and of the effects of air pollution on health. It also offers an assessment of the potential health benefits that could materialise if the World Health Organization (WHO) air quality guideline (AQG)

Box 1.1 Ambient air measurements

The analysis of concentrations in relation to the defined EU and WHO standards is based on measurements at fixed sampling points. Only measurement data received by 22 January 2019 were included in the analysis and, therefore, the maps, figures and tables reflect these data. Data officially reported after that date are regularly updated and are available through the EEA's download service for air quality data (EEA, 2019c).

Fixed sampling points in Europe are situated at different types of stations (EU, 2004, 2008, 2011). Depending on the predominant emission sources, stations are classified as follows:

- traffic stations — located in close proximity to a single major road;
- industrial stations — located in close proximity to an industrial area or an industrial source;
- background stations — pollution levels are representative of the average exposure of the general population or vegetation.

Depending on the distribution/density of buildings, the area surrounding the station is classified as follows:

- urban — continuously built-up urban area;
- suburban — largely built-up urban area;
- rural — all other areas.

For most of the pollutants (sulphur dioxide, SO_2, nitrogen dioxide, NO_2, ozone, O_3, particulate matter, PM, and carbon monoxide, CO), monitoring stations have to fulfil the criterion of reporting more than 75 % of valid data out of all the possible data in a year to be included in this assessment. The Ambient Air Quality Directive (EU, 2008) sets, for compliance purposes, the objective of a minimum data capture of 90 % for monitoring stations, but, for assessment purposes, a coverage of 75 % allows more stations to be taken into account without a significant increase in monitoring uncertainties (ETC/ACM, 2012).

For benzene (C_6H_6), the required amount of valid data for the analysis is 50 %. For toxic metals (arsenic, cadmium, nickel and lead) and benzo[*a*]pyrene (BaP), it is 14 % (according to the air quality objectives for indicative measurements; EU, 2004, 2008).

The assessment in this report does not take into account the fact that Member States may use supplementary assessment modelling. Furthermore, in the cases of PM and SO_2, it also does not account for the fact that the Ambient Air Quality Directive (EU, 2008) provides Member States with the possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting under specific circumstances.

([3]) The report focuses as much as possible on the EEA-39 countries, that is:
- the 28 Member States of the EU, or EU-28 — Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom;
- plus the five other member countries of the EEA — Iceland, Liechtenstein, Norway, Switzerland and Turkey — that, together with the EU-28, form the EEA-33;
- plus the six cooperating countries of the EEA — Albania, Bosnia and Herzegovina, Kosovo under United Nations Security Council Resolution 1244/99, Montenegro, North Macedonia and Serbia — that, together with the EEA-33, form the EEA-39 countries.

Finally, most information also covers Andorra as a voluntary reporting country, and some information also covers other smaller European countries, such as Monaco and San Marino.

on particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) were to be met everywhere in Europe.

The report reviews progress towards meeting the air quality standards (Tables 1.1 and 1.2) established in the two Ambient Air Quality Directives presently in force (EU, 2004, 2008). It also assesses progress towards the long-term objectives of achieving levels of air pollution that do not lead to unacceptable harm to human health and the environment, as presented in the latest two European environment action programmes (EU, 2002, 2013), moving closer to the WHO AQGs (WHO, 2000, 2006a) (Table 1.3).

This year's report looks in more detail at heavy metals. A dedicated chapter provides information on the impact on human health and ecosystems of arsenic (As), cadmium (Cd), mercury (Hg), nickel (Ni) and lead (Pb) and on legislation addressing their emissions, concentrations and depositions. Furthermore, the trends in the concentrations and depositions of these metals are presented using data from various monitoring initiatives.

Table 1.1 Air quality standards for the protection of health, as given in the EU Ambient Air Quality Directives

Pollutant	Averaging period	Legal nature and concentration	Comments
PM_{10}	1 day	Limit value: 50 µg/m^3	Not to be exceeded on more than 35 days per year
	Calendar year	Limit value: 40 µg/m^3	
$PM_{2.5}$	Calendar year	Limit value: 25 µg/m^3	
		Exposure concentration obligation: 20 µg/m^3	Average exposure indicator (AEI) ([a]) in 2015 (2013-2015 average)
		National exposure reduction target: 0-20 % reduction in exposure	AEI ([a]) in 2020, the percentage reduction depends on the initial AEI
O_3	Maximum daily 8-hour mean	Target value: 120 µg/m^3	Not to be exceeded on more than 25 days/year, averaged over 3 years ([b])
		Long-term objective: 120 µg/m^3	
	1 hour	Information threshold: 180 µg/m^3	
		Alert threshold: 240 µg/m^3	
NO_2	1 hour	Limit value: 200 µg/m^3	Not to be exceeded on more than 18 hours per year
		Alert threshold: 400 µg/m^3	To be measured over 3 consecutive hours over 100 km^2 or an entire zone
	Calendar year	Limit value: 40 µg/m^3	
BaP	Calendar year	Target value: 1 ng/m^3	Measured as content in PM_{10}
SO_2	1 hour	Limit value: 350 µg/m^3	Not to be exceeded on more than 24 hours per year
		Alert threshold: 500 µg/m^3	To be measured over 3 consecutive hours over 100 km^2 or an entire zone
	1 day	Limit value: 125 µg/m^3	Not to be exceeded on more than 3 days per year
CO	Maximum daily 8-hour mean	Limit value: 10 mg/m^3	
C_6H_6	Calendar year	Limit value: 5 µg/m^3	
Pb	Calendar year	Limit value: 0.5 µg/m^3	Measured as content in PM_{10}
As	Calendar year	Target value: 6 ng/m^3	Measured as content in PM_{10}
Cd	Calendar year	Target value: 5 ng/m^3	Measured as content in PM_{10}
Ni	Calendar year	Target value: 20 ng/m^3	Measured as content in PM_{10}

Notes: ([a]) AEI: based upon measurements in urban background locations established for this purpose by the Member States, assessed as a 3-year running annual mean.

([b]) In the context of this report, only the maximum daily 8-hour means in 2017 are considered, so no average over the period 2015-2017 is presented.

Sources: EU, 2004, 2008.

Table 1.2 Air quality standards, for the protection of vegetation, as given in the EU Ambient Air Quality Directive and the Convention on Long-range Transboundary Air Pollution (CLRTAP)

Pollutant	Averaging period	Legal nature and concentration	Comments
O_3	AOT40 ([a]) accumulated over May to July	Target value, 18 000 μg/m³·hours	Averaged over 5 years ([b])
		Long-term objective, 6 000 μg/m³·hours	
	AOT40 ([a]) accumulated over April to September	Critical level for the protection of forests: 10 000 μg/m³·hours	Defined by the CLRTAP
NO_X	Calendar year	Vegetation critical level: 30 μg/m³	
SO_2	Winter	Vegetation critical level: 20 μg/m³	1 October to 31 March
	Calendar year	Vegetation critical level: 20 μg/m³	

Notes: ([a]) AOT40 is an indication of accumulated O_3 exposure, expressed in μg/m³·hours, over a threshold of 40 parts per billion (ppb). It is the sum of the differences between hourly concentrations > 80 μg/m³ (40 ppb) and 80 μg/m³ accumulated over all hourly values measured between 08.00 and 20.00 (Central European Time).

([b]) In the context of this report, only yearly AOT40 concentrations are considered, so no average over 5 years is presented.

Sources: EU, 2008; UNECE 2011.

Table 1.3 World Health Organization (WHO) air quality guidelines (AQGs) and estimated reference levels (RLs) ([a])

Pollutant	Averaging period	AQG	RL	Comments
PM_{10}	1 day	50 μg/m³		99th percentile (3 days per year)
	Calendar year	20 μg/m³		
$PM_{2.5}$	1 day	25 μg/m³		99th percentile (3 days per year)
	Calendar year	10 μg/m³		
O_3	Maximum daily 8-hour mean	100 μg/m³		
NO_2	1 hour	200 μg/m³		
	Calendar year	40 μg/m³		
BaP	Calendar year		0.12 ng/m³	
SO_2	10 minutes	500 μg/m³		
	1 day	20 μg/m³		
CO	1 hour	30 mg/m³		
	Maximum daily 8-hour mean	10 mg/m³		
C_6H_6	Calendar year		1.7 μg/m³	
Pb	Calendar year	0.5 μg/m³		
As	Calendar year		6.6 ng/m³	
Cd	Calendar year	5 ng/m³ ([b])		
Ni	Calendar year		25 ng/m³	

Notes: ([a]) As WHO has not set an AQG for BaP, C_6H_6, As and Ni, the RL was estimated assuming an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000.

([b]) AQG set to prevent any further increase of Cd in agricultural soil, likely to increase the dietary intake of future generations.

Sources: WHO, 2000, 2006a.

1.3 Effects of air pollution

1.3.1 Human health

Air pollution is a major cause of premature death and disease and is the single largest environmental health risk in Europe (WHO, 2014, 2016a; GBD 2016 Risk Factors Collaborators, 2017; HEI, 2018), causing around 400 000 premature deaths per year in the EEA-39 (excluding Turkey). Heart disease and stroke are the most common reasons for premature death attributable to air pollution, followed by lung diseases and lung cancer (WHO, 2018a). The International Agency for Research on Cancer has classified air pollution in general, as well as PM as a separate component of air pollution mixtures, as carcinogenic

(IARC, 2013). In 2018, household (indoor) and ambient air pollution were recognised as one of the risk factors for non-communicable diseases, together with unhealthy diets, tobacco smoking, harmful use of alcohol and physical inactivity (UN, 2018).

Both short- and long-term exposure of children and adults to air pollution can lead to reduced lung function, respiratory infections and aggravated asthma. Maternal exposure to ambient air pollution is associated with adverse impacts on fertility, pregnancy, newborns and children (WHO, 2005, 2013a). There is also emerging evidence that exposure to air pollution is associated with new-onset type 2 diabetes in adults, and it may be linked to obesity, systemic inflammation, ageing, Alzheimer's disease and dementia (RCP, 2016, and references therein; WHO, 2016b).

The effects of air pollution on health depend not only on exposure, but also on the vulnerability of people. Vulnerability to the impacts of air pollution can increase as a result of age, pre-existing health conditions or particular behaviours. A large body of evidence suggests that people of lower socio-economic status tend to live in environments with worse air quality (EEA, 2018a).

While this report focuses only on ambient air quality, household air pollution also poses considerable risks to health, especially in homes that use open fires for heating and cooking (WHO, 2019b).

1.3.2 Ecosystems

Air pollution has several important environmental impacts and may directly affect natural ecosystems and biodiversity. For example, nitrogen oxides (NO_X, the sum of nitrogen monoxide (NO) and NO_2) and ammonia (NH_3) emissions disrupt terrestrial and aquatic ecosystems by introducing excessive amounts of nitrogen nutrient. This leads to eutrophication, which is an oversupply of nutrients that can lead to changes in species diversity and to invasions of new species. NO_X, together with SO_2, also contribute to the acidification of soil, lakes and rivers, causing loss of biodiversity. Finally, ground-level O_3 damages agricultural crops, forests and plants by reducing their growth rates and has negative impacts on biodiversity and ecosystem services.

1.3.3 Climate change

Air pollution and climate change are intertwined. Several air pollutants are also climate forcers, which have a potential impact on climate and global warming in the short term. Tropospheric O_3 and black carbon (BC), a constituent of PM, are examples of air pollutants that are short-lived climate forcers and that contribute directly to global warming. Other PM components, such as organic carbon, ammonium (NH_4^+), sulphate (SO_4^{2-}) and nitrate (NO_3^-), have a cooling effect (IPCC, 2013). In addition, methane (CH_4), a powerful greenhouse gas, is also a contributor to the formation of ground level O_3. Changes in weather patterns due to climate change may alter the transport, dispersion, deposition and formation of air pollutants in the atmosphere, and higher temperatures will lead to increased O_3 formation.

As greenhouse gases and air pollutants share the same emission sources, benefits can arise from limiting emissions of one or the other. Policies aimed at reducing air pollutants might help to keep the global mean temperature increase below two degrees. Moreover, climate policies aimed at reducing CH_4 emissions and indirectly also those aimed at reducing CO_2 emissions usually can reduce the damage to human health and the environment. Implementing integrated policies would also mitigate negative impacts of climate policies on air quality. Examples are the negative impacts on air quality arising from subsidising diesel cars (which, generally, for a typical vehicle, have lower carbon dioxide (CO_2) emissions per kilometre but higher PM and NO_X emissions per kilometre than the equivalent petrol vehicle), and the potential increase in PM emissions and emissions of other carcinogenic air pollutants, which an increase in wood burning for residential heating may cause (EEA, 2015a).

1.3.4 The built environment and cultural heritage

Air pollution can damage materials, properties, buildings and artworks, including Europe's culturally most significant buildings. The impact of air pollution on cultural heritage materials is a serious concern, because it can lead to the loss of parts of European history and culture. Damage includes corrosion (caused by acidifying compounds), biodegradation and soiling (caused by particles), and weathering and fading of colours (caused by O_3).

A recent assessment of the risk of corrosion and soiling for 21 unique United Nations Educational, Scientific and Cultural Organization (Unesco) world heritage sites showed that PM_{10}, for instance, is a risk factor for corrosion and soiling of limestone, and soiling of glass, together with NO_2 and SO_2. Furthermore, SO_2 and O_3 present a combined risk factor for corrosion of copper. In a more positive outcome, acid rain currently seems to have only a small impact on the degradation of materials (ICP Materials, 2018).

1.3.5 Economic impacts

The effects of air pollution on health, crop and forest yields, ecosystems, the climate and the built environment also entail considerable market and non-market costs. The market costs of air pollution include reduced labour productivity, additional health expenditure, and crop and forest yield losses. Non-market costs are those associated with increased mortality and morbidity (illnesses causing pain and suffering, for example), degradation of air and water quality and consequently the health of ecosystems, and climate change.

The Organisation for Economic Co-operation and Development (OECD) (2016) estimated that the total costs of ambient air pollution for the OECD region amounted to USD 1 280 (around EUR 1 100) per capita for 2015, corresponding to about 5 % of income in 2015. The non-market costs of ambient air pollution amounted to 94 % of the total costs in 2015.

CE Delft (2018) estimated that the total cost (both market and non-market costs) of road traffic air pollution was EUR 67-80 billion in the EU-28 in 2016, 75-83 % of which was due to emissions from diesel vehicles. NO_X emissions represented the largest share of the total costs of air pollutants (65 %), followed by $PM_{2.5}$ (32 %). These costs are estimated to be reduced in a business-as-usual emissions reduction scenario to EUR 19.5-25.6 billion in 2030, EUR 8.3-23.4 billion of which is expected to be related to health.

1.4 International policy

Increased recognition of the effects and costs of air pollution has led international organisations, national and local authorities, industry and NGOs to take action.

At an international level, the United Nations Economic Commission for Europe (UNECE), WHO and the United Nations Environment Programme, among others, have continued to decide on global actions to address the long-term challenges of air pollution.

The UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) (UNECE, 1979) addresses emissions of air pollutants through its various protocols, among which the 2012 amended Gothenburg Protocol is key in reducing emissions of selected pollutants across the pan-European region. The long-term strategy for 2020-2030 (UNECE, 2018), adopted in 2018 by the CLRTAP's Executive Body, recognises not only the significant reduction in the impacts of air pollution on health and ecosystems brought about by the abatement measures implemented under the CLRTAP but also that substantial problems remain. It urges authorities to address the remaining challenges — based on a multi-pollutant, multi-effect approach — which are identified as follows: O_3 and its precursors; PM and its precursors; nitrogen and sulphur; persistent organic pollutants and heavy metals; the links among the different scales of air pollution (from hemispheric to local); and the links between air pollution, health, ecosystems, materials and climate change.

The First WHO Global Conference on Air Pollution and Health took place at the WHO headquarters in Geneva, Switzerland, from 30 October to 1 November 2018. The conference participants emphasised the urgent need to act against air pollution, both ambient and household, as it is responsible for about 7 million deaths globally each year. It was emphasised that effective interventions are feasible and compatible with economic growth. There is a need to green fuels and technologies, in both transport and energy production, to reduce the use of fertilisers in agriculture and to stop uncontrolled burning of solid and agricultural waste. It was recognised that a reduction in exposure to air pollution is especially important to protect children's health and that actions to mitigate both air pollution and climate change can achieve combined benefits (WHO, 2018b).

At the Conference, the Geneva Action Agenda to Combat Air Pollution (WHO, 2018b) was launched, which included the following elements:

- implementing solutions to reduce burning in any form;
- strengthening action to protect the most vulnerable populations, especially children;
- supporting cities to improve urban air quality;
- enhance joint action between the financial, health and environmental sectors to generate specific actions to improve air quality and mitigate climate change;
- continuing the joint effort for harmonised air pollution monitoring.

The United Nations Environment Assembly (UNEA) of the United Nations Environment Programme held its fourth session in March 2019. In line with previous Resolution 1/7 on Air Quality (UNEP, 2014), and Resolution 3/8 (UNEP, 2017), the ministerial declaration (UNEP, 2019) commits to improving national environmental air monitoring systems and technologies, and to encouraging the development of national environmental data management capacities.

Air quality is closely linked to the SDGs (UN Environment, 2019a), and reducing air pollution through actions tackling climate change would also contribute to reaching the targets set in some of the SDGs. For instance, SDG 3 (Good health and well-being) targets substantially reducing the number of deaths and illnesses caused by air pollution by 2030; SDG 11 (Sustainable cities and communities) targets reducing the adverse per capita environmental impact of cities by 2030 by paying particular attention to air quality; and SDG 13 (Take urgent action to combat climate change and its impacts) targets integrating climate change measures into national policies, strategies and planning.

1.5 European Union legislation

The EU has been working for decades to improve air quality by controlling emissions of harmful substances into the atmosphere, improving fuel quality, and integrating environmental protection requirements into the transport, industrial and energy sectors. The EU's clean air policy is based on three main pillars (European Commission, 2018a):

1. Ambient air quality standards set out in the Ambient Air Quality Directives (EU, 2004, 2008) (Tables 1.1 and 1.2) to protect human health and the environment. The directives also require Member States to assess air quality in all their territories and to adopt and implement air quality plans to improve air quality where standards are not met and to maintain it where the air quality is good.

2. National emission reduction commitments established in the National Emission Ceilings (NEC) Directive (EU, 2016), which requires Member States to develop national air pollution control programmes, to comply with their emission reduction commitments.

3. Emission and energy efficiency standards for key sources of air pollution, from vehicle emissions to products and industry. These standards are set out in EU legislation targeting industrial emissions, emissions from power plants, vehicles and transport fuels, as well as the energy performance of products and non-road mobile machinery ([4]).

The Seventh Environment Action Programme, 'Living well, within the limits of our planet' (EU, 2013) recognises the long-term goal within the EU to achieve 'levels of air quality that do not give rise to significant negative impacts on, and risks to, human health and the environment'. In addition, the Clean Air Programme for Europe, published by the European Commission in late 2013 (European Commission, 2013), aims to ensure full compliance with existing legislation by 2020 at the latest and to further improve Europe's air quality so that, by 2030, the number of premature deaths is reduced by half compared with 2005.

Furthermore, the EU is supporting and facilitating Member States to take the measures necessary to meet their targets and the enforcement action to help ensure that the common objective of clean air for all Europeans is achieved across the EU. This includes the clean air dialogues, the EU Urban Agenda and Urban Innovative Actions, which facilitate cooperation with and among city stakeholders to address air pollution in urban areas across the EU (European Commission, 2018a). The European Commission will hold the Second EU Clean Air Forum in November 2019, with a focus on three themes: (1) air quality and energy; (2) air quality and agriculture; and (3) clean air funding mechanisms. It will bring together decision-makers, stakeholders and experts to reflect on the development and implementation of effective European, national and local air policies, projects and programmes.

By the end of 2019, the ongoing fitness check of the EU Ambient Air Quality Directives (European Commission, 2017b) will be completed. The process aims to examine the performance of the Ambient Air Quality Directives. It will assess whether or not all the directives' provisions are fit for purpose, looking in particular at the monitoring and assessment methods, the air quality standards, the provisions on public information, and the extent to which the directives have facilitated action to prevent or reduce adverse impacts ([5]).

In 2018, the European Court of Auditors issued a special report following its audit of the EU air quality policy, in which the effectiveness of EU actions to protect human health from air pollution was assessed (ECA, 2018). Some recommendations were made to the European Commission to improve air quality. Among other things, the report highlighted the importance of good air quality and, therefore, the importance of achieving not only the EU's air quality standards but also the WHO AQGs. It also stressed the need for better result-oriented air quality plans. When it comes to measurement data, the European Court of Auditors

([4]) For more information on specific legislation, please check: http://ec.europa.eu/environment/air/quality/existing_leg.htm

([5]) More information on the European Commission's activities related to air pollution can be found at: http://ec.europa.eu/environment/air called for more comparable data to be reported earlier to the EEA and better communicated to the public. Finally, the report called for prioritising and mainstreaming air quality policy in other EU policies.

In addition to the specific legislation on air, in 2018, the European Commission adopted the fourth regulation on real driving emissions testing (EU, 2018a), ensuring transparent and independent control of emissions of vehicles during their lifetimes. This reinforces the European Commission's commitment to a clean, safe and connected mobility system. Furthermore, the European Commission has also prioritised a strong Energy Union and the Paris Agreement on decarbonisation. The Regulation on the Governance of the Energy Union and Climate Action, approved in 2018 (EU, 2018b), provides clear guidelines on the integrated national energy and climate plans to be developed by Member States. These plans must set out national objectives for each of the five dimensions of the Energy Union, and the corresponding policies and measures to meet those objectives, paying particular attention to their impact on air quality and emissions of air pollutants.

1.6 National and local measures to improve air quality in Europe

Air quality plans and measures to reduce air pollutant emissions and improve air quality have been implemented throughout Europe and form a core element in air quality management. The Ambient Air Quality Directives (EU, 2004, 2008) set the obligation of developing and implementing air quality plans and measures for zones and agglomerations where concentrations of pollutants exceed the EU standards (and of maintaining quality where it is good; Section 1.5). These plans and measures should be consistent and integrated with those under the NEC Directive (EU, 2016). The integrated national energy and climate plans under the Regulation on the Governance of the Energy Union and Climate Action (EU, 2018b) should also be considered in terms of their capacity to reduce emissions of air pollutants.

Information on the plans and measures reported by national authorities under the Ambient Air Quality Directives can be found in the air quality management section of the EEA's website ([6]).

In 2018, the EEA undertook a follow-up activity to the 2013 Air implementation pilot (EEA, 2013). Five years after the original assessment, the EEA, together with the European Commission, arranged for the local authorities to meet again to better understand policy implementation challenges. In total, 10 out of the 12 original cities took part in the follow-up project, namely Antwerp (Belgium), Berlin (Germany), Dublin (Ireland), Madrid (Spain), Malmö (Sweden), Milan (Italy), Paris (France), Plovdiv (Bulgaria), Prague (Czechia) and Vienna (Austria). The findings of the project are presented in a report (EEA, 2019d) that highlights ongoing challenges for improving air quality at the local level.

The cities involved in the project have all improved their air quality, mainly because of the implementation of EU policies. They have also improved their air quality management, particularly their use of tools and methods to quantify the effects of proposed and implemented measures. In general, there is also an increased understanding of the sources of local air pollution and that health is becoming an important driver of air pollution policies.

While most abatement measures still address emissions from road traffic — mainly NO_X and PM emissions — other sources of pollutant are also considered, such as fuel combustion in residential stoves, inland shipping, and construction and demolition activities, including emissions from non-road mobile machinery. Local measures include expanding district heating, using cleaner fuels for heating, introducing low-emission transport zones, switching to cleaner buses or trams, promoting cycling, lowering speed limits and issuing congestion charges. Because of the variety of these measures and the different types of cities, there is not one specific solution that fits all cities.

Cities report that a number of important challenges remain, including communicating and engaging with the public on air quality issues and making the case for new air quality measures, such as highlighting the co-benefits for health, noise reduction, and climate change mitigation and adaptation. Achieving policy coherence across administrative and governance levels, as well as generating political and public support for improving air quality beyond the minimum EU standards, is challenging. Cities have highlighted the importance of a regular exchange of knowledge and experience concerning, for example, good practice and capacity building, similar to the one offered in the implementation pilots.

([6]) https://www.eea.europa.eu/themes/air/explore-air-pollution-data#tab-air-quality-management

2 Sources and emissions of air pollutants

Air pollutants may be categorised as primary or secondary. Primary pollutants are directly emitted to the atmosphere, whereas secondary pollutants are formed in the atmosphere from precursor pollutants through chemical reactions and microphysical processes. Air pollutants may have a natural, anthropogenic or mixed origin, depending on their sources or the sources of their precursors.

Key primary air pollutants include particulate matter (PM), black carbon (BC), sulphur oxides (SO_X), nitrogen oxides (NO_X) (which includes both nitrogen monoxide, NO, and nitrogen dioxide, NO_2), ammonia (NH_3), carbon monoxide (CO), methane (CH_4), non-methane volatile organic compounds (NMVOCs), including benzene (C_6H_6) ([7]), certain metals and polycyclic aromatic hydrocarbons (PAHs) including benzo[*a*]pyrene (BaP).

Key secondary air pollutants are PM (formed in the atmosphere), ozone (O_3), NO_2 and several oxidised volatile organic compounds (VOCs). Key precursor gases for secondary PM are sulphur dioxide (SO_2), NO_X, NH_3, and VOCs. Gases SO_2, NO_X and NH_3 react in the atmosphere to form particulate sulphate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) compounds. These compounds form new particles in the air or condense onto pre-existing ones to form secondary inorganic PM. Certain NMVOCs are oxidised to form less volatile compounds, which form secondary organic aerosols. Ground-level (tropospheric) O_3 is not directly emitted into the atmosphere. Instead, it is formed from chemical reactions in the presence of sunlight, following emissions of precursor gases, mainly NO_X, NMVOCs, CO and CH_4. These precursors can be of both natural (biogenic) and anthropogenic origin. NO_X in high-emission areas also depletes tropospheric O_3 as a result of the titration reaction with the emitted NO to form NO_2 and oxygen.

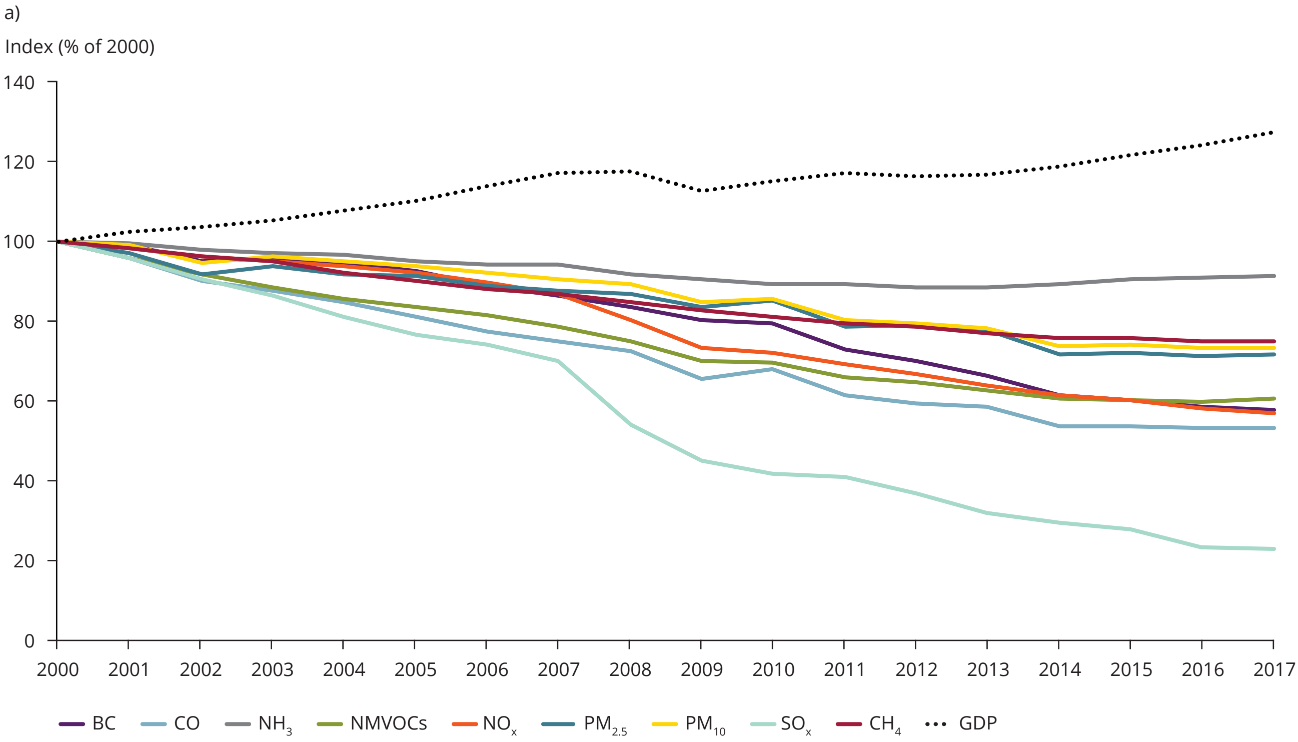
2.1 Total emissions of air pollutants

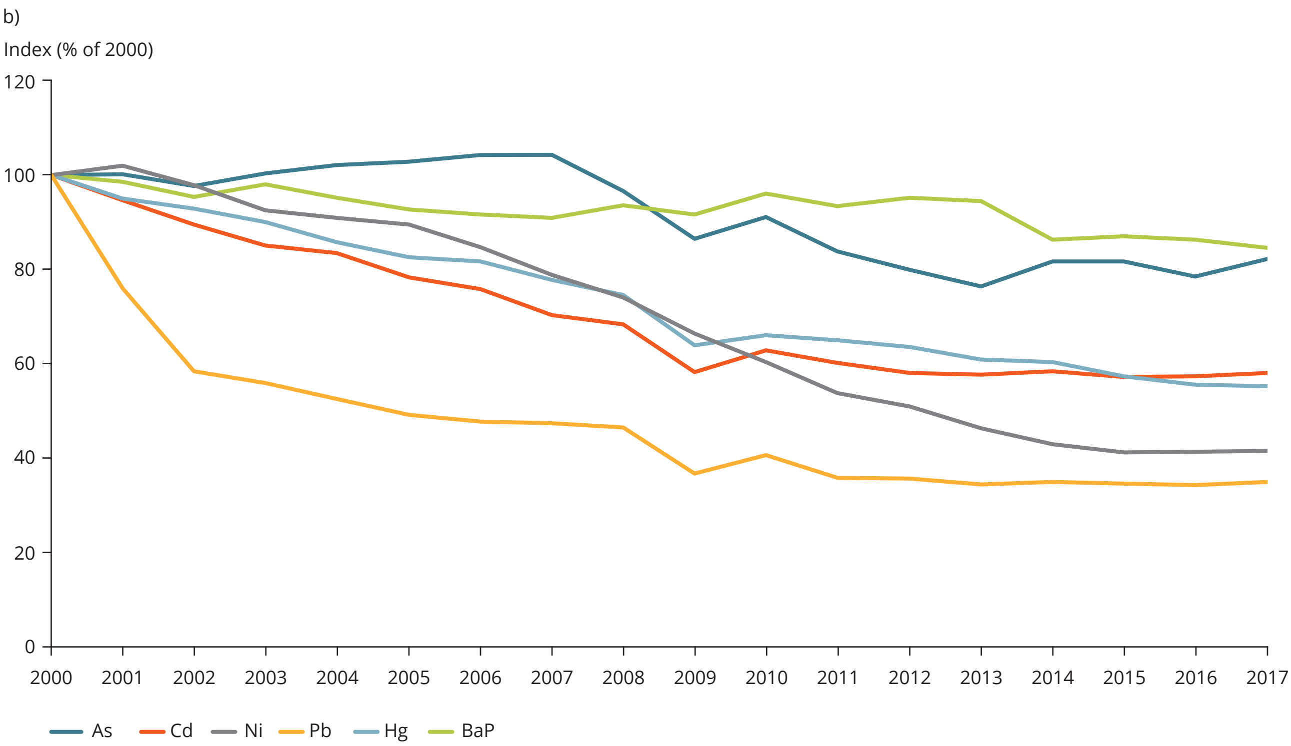
Figure 2.1 shows the total emissions of pollutants in the EU-28, indexed as a percentage of their value in the reference year 2000. Emissions for all primary and precursor pollutants contributing to ambient air concentrations of PM, O_3 and NO_2, as well as arsenic (As), cadmium (Cd), nickel (Ni), lead (Pb), mercury (Hg) and BaP ([8]), decreased between 2000 and 2017 in the EU-28 (Figure 2.1) and the EEA-33 ([9]). SO_X emissions show the largest reductions (77 % in the EU-28 and 62 % in the EEA-33) since 2000 and NH_3 emissions the smallest (9 % in the EU-28 and 4 % in the EEA-33). However, NH_3 emissions have been increasing since 2013, mainly driven by the agriculture sector. In general, reductions in emissions in the EU-28 and in the EEA-33 were similar. There were larger reductions in the EU-28 than in the EEA-33 for CO, NH_3, NMVOCs, NO_X, primary PM with a diameter of 10 µm or less (PM_{10}) and SO_X. Apart from the differences shown above for SO_X and NH_3, the differences for primary PM_{10} were also noticeable (27 % reduction in EU-28 versus 20 % in EEA-33).

During the period 2000-2017, emissions showed a significant absolute decoupling ([10]) from economic activity, which is desirable for both environmental and productivity gains. This is indicated by the contrast between a reduction in EU-28 air pollutant emissions and an increase in EU-28 gross domestic product (GDP) ([11]) (Eurostat, 2019a), which effectively means that there are now fewer emissions for each unit of GDP produced per year. The greatest decoupling has

([7]) There is no separate emission inventory for C_6H_6, but it is included as a component of NMVOCs.
([8]) The emissions reported from Portugal (2000-2017) and from Bulgaria (2000-2006) for the activity 'asphalt blowing in refineries' were not taken into account to ensure consistency between the nationally reported data (they were not reported by any other country).
([9]) The analysis of the trends in emissions in Europe is based on emissions reported by the countries (EEA, 2019d, 2019e). The nominal increase or decrease in reported emissions is analysed, not statistical trends.
([10]) 'Absolute decoupling' is when a variable is stable or decreasing when the growth rate of the economic driving force is growing, while 'relative decoupling' is when the growth rate of the variable is positive but less than the growth rate of the economic variable (OECD, 2002).
([11]) Based on chain-linked volumes (2010), in euros, to obtain a time-series adjusted for price changes (inflation/deflation).

Figure 2.1 Trends in EU-28 emissions, 2000-2017 (% of 2000 levels): (a) SO_X, NO_X, NH_3, PM_{10}, $PM_{2.5}$, NMVOCs, CO, CH_4 and BC. Also shown for comparison is EU-28 gross domestic product (GDP, expressed in chain-linked volumes (2010), % of 2000 level); (b) As, Cd, Ni, Pb, Hg and BaP





Note: CH_4 emissions are total emissions (integrated pollution prevention and control sectors 1-7) excluding sector 5: land use, land use change and forestry. The present emission inventories include only anthropogenic VOC emissions.

Sources: EEA, 2019e, 2019f; Eurostat 2019a.

been for SO_X, CO, NO_X, BC and certain metals (Ni, Pb, Cd, Hg) and organic species (BaP), for which emissions per unit of GDP were reduced by over 40 % between the years 2000 and 2017. A decoupling of emissions from economic activity may be due to a combination of factors, such as increased regulation and policy implementation, fuel switching, technological improvements and improvements in energy or process efficiencies (see Sections 1.5 and 1.6), and the increase in the consumption of goods produced in industries outside the EU (ETC/ATNI, 2019).

2.2 Sources of regulated pollutants by emissions sector

The main sectors contributing to emissions of air pollutants in Europe are (1) transport — split into road and non-road (which includes, for example, air, rail, sea and inland water transport); (2) commercial, institutional and households; (3) energy production and distribution; (4) industry — split into energy use in industry, and industrial processes and product use; (5) agriculture; and (6) waste, which includes landfill, waste incineration with heat recovery and open burning of waste.

Figure 2.2 shows the trends in SO_X, NO_X, NH_3, primary PM_{10}, primary $PM_{2.5}$, NMVOCs, CO, BC and CH_4 emissions from the main sectors in the EU-28 between the years 2000 and 2017. Similarly, Figure 2.3 shows the trends in As, Cd, Ni, Pb, Hg and BaP emissions. For clarity, these figures show only pollutants for which the sector contributed more than 5 % of the total EU-28 emissions in 2017. In general, most sectors show significant reductions in emissions. The commercial, institutional and households, waste and agriculture sectors show the smallest reductions. With regard to the commercial, institutional and households sector, for most of the pollutants, emissions have shown a small increase since 2014. Changes in emissions by sector and pollutant were generally similar in the EU-28 and the EEA-33. To indicate the degrees of emission decoupling from sectoral activities within the EU-28 between 2000 and 2017, Figure 2.2 also shows the change in sectoral activity (Box 2.1) for comparison with the change in emissions over time; the emissions data are expressed as an index (% relative to the year 2000) on the figure.

Box 2.1 Choice of sectoral activity data

The change in emissions over time was compared with the changes in sectoral activity data that would best represent the sector to be analysed. The indicators are briefly described here; for more detail, please refer to the previous *Air quality in Europe* report (EEA, 2018c).

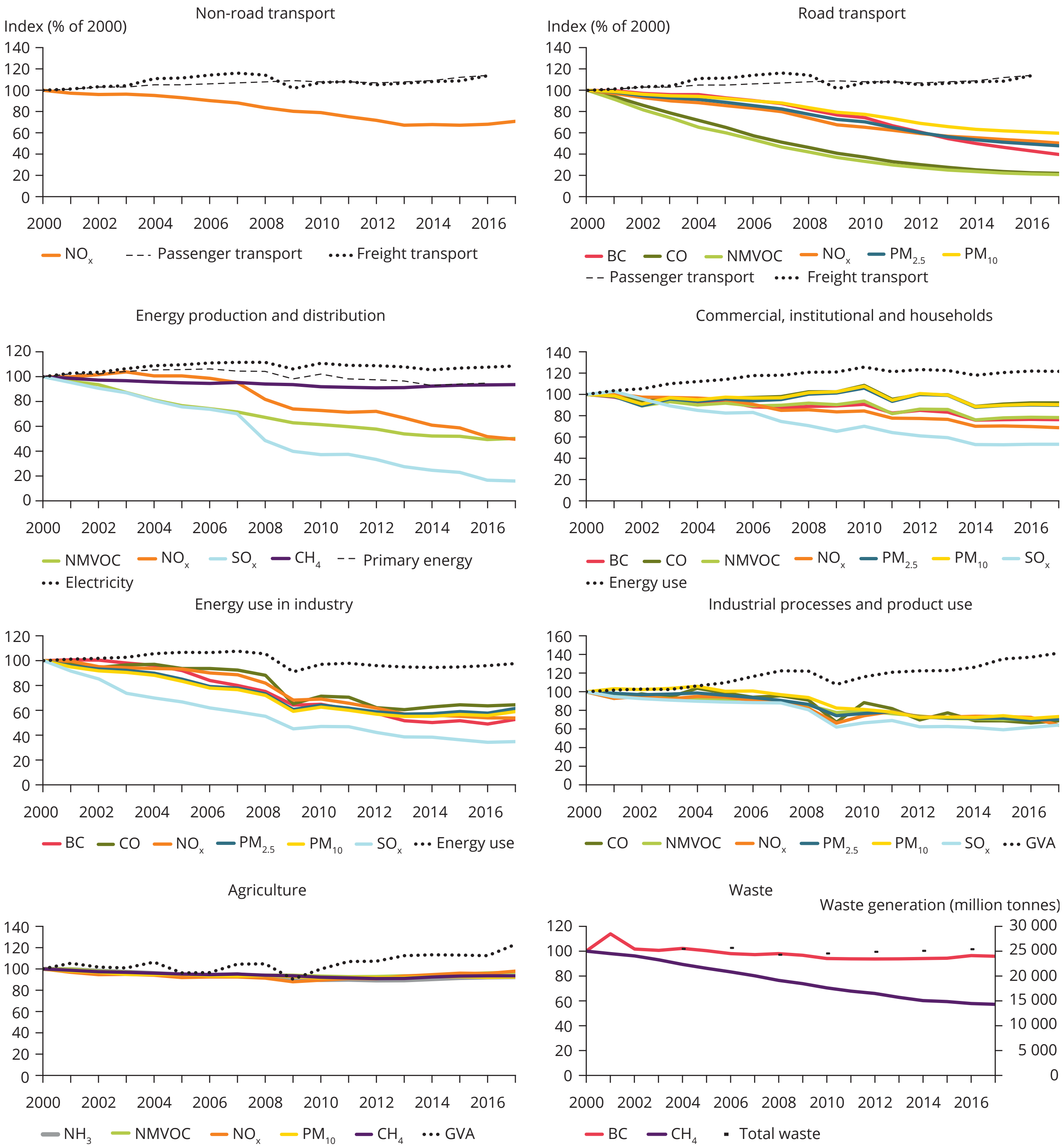
For road and non-road transport sectors, the sectoral activity is expressed in terms of passenger (billion passenger-kilometres (pkm)) and freight transport (billion tonne-kilometres (tkm)) demand, representing the transport of one passenger or tonne of goods, respectively, over 1 km in a year (European Commission, 2018b). Road transport includes cars, motorbikes, buses and coaches, and non-road transport includes railway, tram, metro, air and sea travel.

Sectoral activity for the commercial, institutional and households and the energy use in industry sectors is expressed in terms of the final energy consumption (described in units of tonnes of oil equivalent (TOE)) by the end users, excluding energy used by the energy sector itself (Eurostat, 2019b).

For the energy production and distribution sector, the sectoral activity is expressed in terms of total primary energy production (Eurostat, 2019b) and total gross electricity production (Eurostat, 2019c), both described in TOE. The production of primary energy is the extraction of energy products, in any useable form, from natural sources, and the total gross electricity generation covers gross electricity generation in all types of power plants. The sectoral activity for the agriculture sector and the industrial processes and product use sector is expressed in terms of gross value added (GVA) in euros. GVA is a measure of the value of goods and services produced by the sector (Eurostat, 2019d).

For the waste sector, the sectoral activity is expressed by the total mass of waste generated (Eurostat, 2018) and described in the original units of tonnes. This includes both hazardous and non-hazardous waste from all classified economic activities plus households.

Figure 2.2 **Trends in EU-28 emissions from the main source sectors of NO_X, PM_{10}, $PM_{2.5}$, SO_X, CH_4, NH_3, NMVOCs, BC and CO, 2000-2017 (% of 2000 levels). Also shown for comparison are key EU-28 sectoral activity statistics (% of 2000 levels) ([a])**

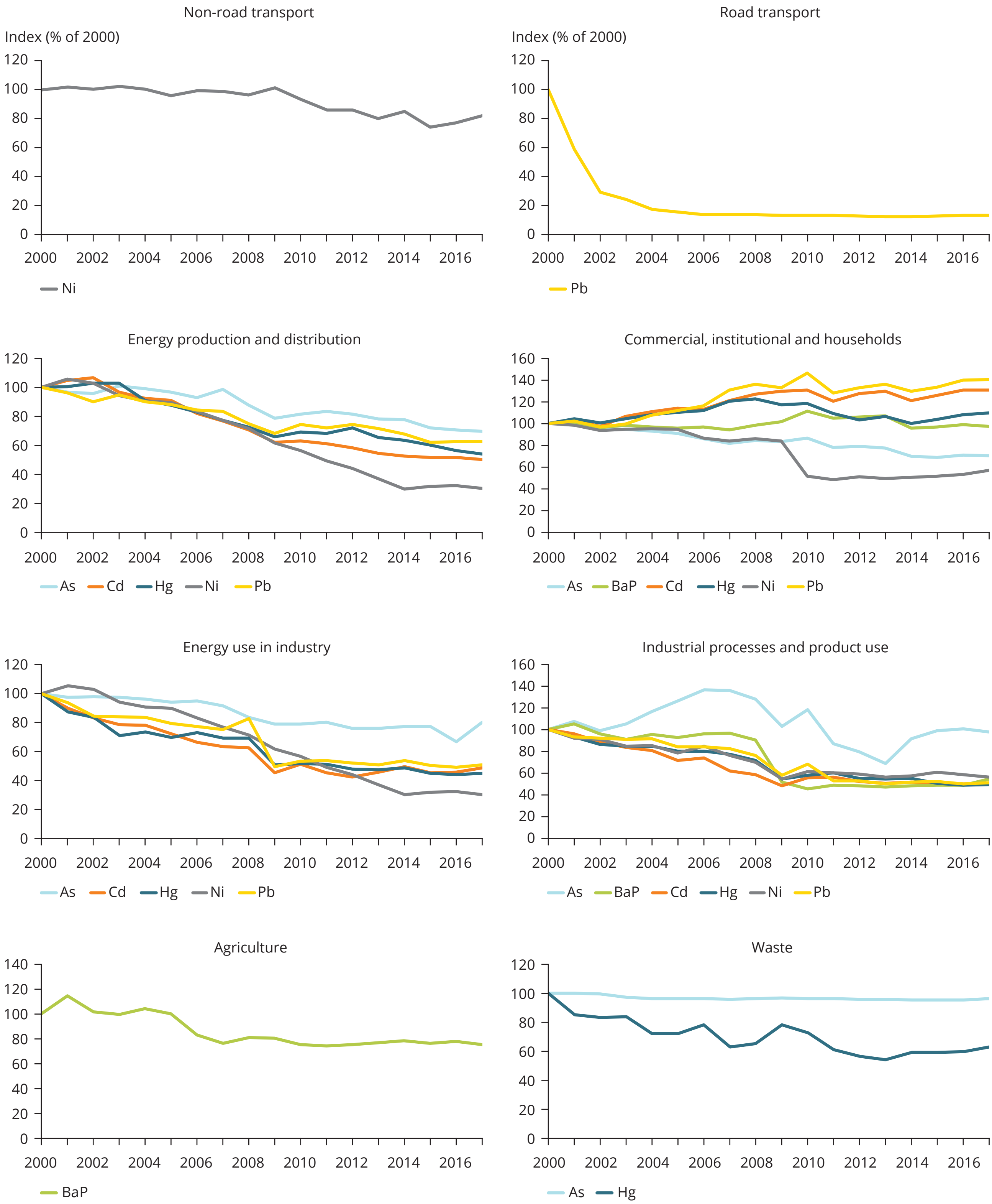


Notes: Only pollutants for which the sector contributes more than 5 % to the total pollutant emissions for 2017 are shown in the figures. For comparison, key data indicative of sectoral activity is displayed. These include passenger and freight transport volume (only until 2016, latest available data at the time of drafting) with original units of billion passenger-kilometres and billion tonne-kilometres (road transport sector and non-road transport sector), final sectoral energy consumption with original units of, for example, TOE (commercial, institutional and households sector and energy use in industry sector), total primary energy production (only until 2016, latest available data at the time of drafting) and total gross electricity production with original units of, for example, TOE (energy production and distribution sector), sectoral gross value added, expressed in euros in chain linked-volumes (reference year 2010) (agriculture sector and industrial processes and product use sector) and total waste generated (only until 2016, latest available data at the time of drafting) with original units of tonnes (waste sector).

([a]) Sectoral statistics are plotted as an index (% of 2000 levels), except for the waste sector, where total waste generated was available only from 2004. These data are therefore plotted on a secondary (right-hand) axis.

Sources: EEA, 2019e, 2019f; European Commission, 2018b; Eurostat, 2018, 2019b, 2019c, 2019d.

Figure 2.3 **Trends in EU-28 emissions from the main source sectors of As, Cd, Ni, Pb, Hg and BaP, 2000-2017 (% of 2000 levels)**



Note: Only pollutants for which the sector contributes more than 5 % to the total pollutant emissions are shown in the figures. The emissions reported from Portugal (2000-2017) and from Bulgaria (2000-2006) for the activity 'asphalt blowing in refineries' (under the industrial processes and product use sector) were not taken into account to ensure consistency between nationally reported data (they were not reported by any other country).

Source: EEA, 2019e.

For both road and non-road transport sectors, emissions of key pollutants (e.g. NO_X) have decreased significantly, although transported passenger and freight volumes have been gradually increasing. Policy actions at EU level have been taken to address transport-related air pollution while allowing sectoral growth. Regulating emissions by setting emission standards (e.g. Euro 1-6) or by establishing requirements for fuel quality are good examples of such actions at EU level.

Emissions from aviation and international shipping activities (for which aviation cruise and international maritime navigation activities are not considered in the total emissions shown above because of the reporting regulation ([12])) are still an important issue in Europe. Aviation activities emit air pollutants not only during taxiing, take-off and landing, and cruising at altitude but also from the numerous ground support services, such as airport heating, and transport to and from airports. For its part, the estimated contribution of international maritime navigation in 2017 would add 20 % to the total EU-28 NO_X emissions, 5 % to PM_{10} emissions, 7.5 % to $PM_{2.5}$ emissions and 22 % to SO_X emissions (EEA, 2019g). This contribution is projected to increase until 2050 under current emission control regulations (IIASA, 2018). The International Institute for Applied Systems Analysis (IIASA, 2018) estimated that enhanced emission controls, despite the expected growth in shipping, could reduce emissions of SO_2, $PM_{2.5}$ and NO_X by 87 %, 92 % and 56 %, respectively, by 2050, compared with 2015. This would improve air quality for a large share of the European population living in coastal areas, especially along the coast of Mediterranean countries. Here the concentrations of $PM_{2.5}$ could decrease by up to 1.2 µg/m^3 by 2030 and up to 1.5 µg/m^3 by 2050, which would lead to considerable health benefits that would largely outweigh the costs of further emission controls for international shipping (IIASA, 2018).

Emissions of pollutants from industry (the industrial processes and product use sector and the energy use in industry sector), and energy production and distribution have significantly decreased since 2000, with the largest decoupling between emissions and key indicators seen for the energy production and distribution sector and the industrial processes and product use sector. Energy use in industry is the only sector in which the indicator for the sector activity — electricity consumption — has almost flattened since 2008, but the decoupling is still very prominent. The decrease in emissions reflects the EU legislation targeting stationary emission sources in the industry and energy sectors (EEA, 2017a, 2018b), setting emission limits for medium-sized combustion plants (EU, 2015) and adopting sectoral implementing decisions on the best available techniques (under Directive 2010/75/EU on industrial emissions (EU, 2010)).

Commercial, institutional and households sector emissions have slowly decreased since 2000, even when the energy consumption (key indicator) steadily increased during the same period. Nevertheless, there has been an increase in emissions of Cd, Hg, and Pb in this sector.

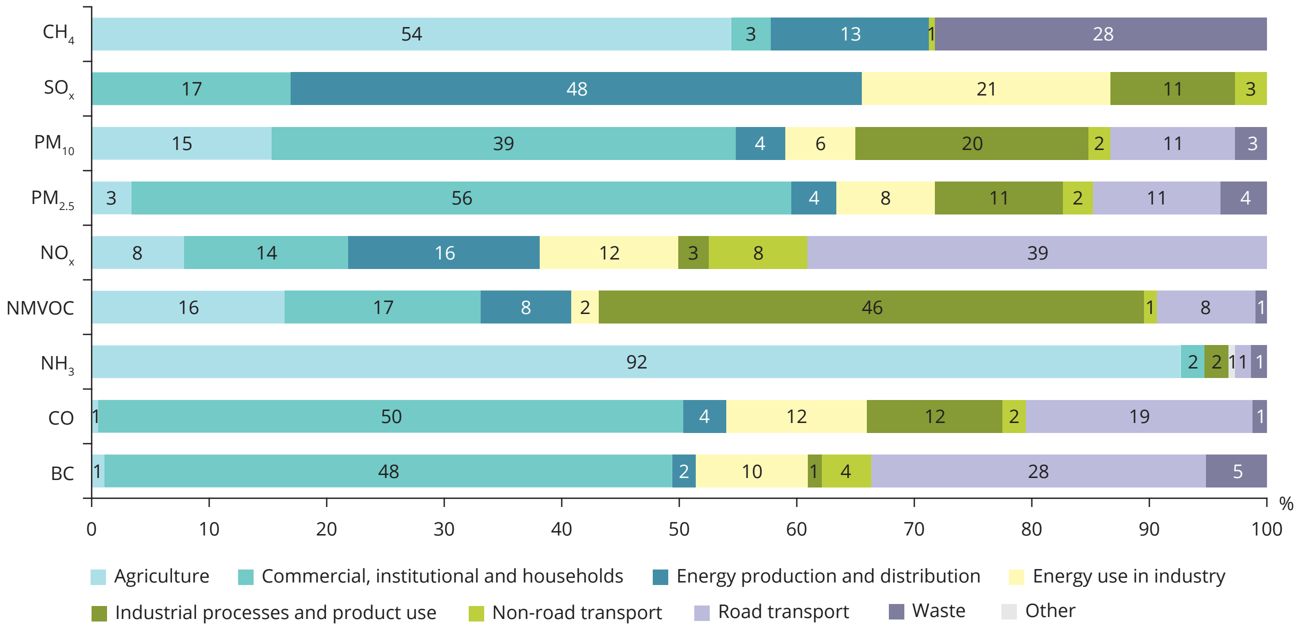
Agriculture and waste are the other sectors in which the reduction in emissions has been the lowest since 2000 — less than 10 % — showing a limited decoupling with the key indicators. However, there are exceptions, and some pollutant emissions have decreased, such as those of BaP in agriculture, and those of CH_4 and Hg in waste.

Figures 2.4 and 2.5 give an overview of each sector's contribution to total emissions for all chosen pollutants in the EU-28, for 2017. The road transport sector was the most significant contributor to total NO_X emissions and the second largest contributor to BC, CO, primary $PM_{2.5}$ and Pb emissions. The energy production and distribution sector was the largest contributor to SO_X, Hg, and Ni, as well as a significant contributor to NO_X, As, and CH_4 emissions. The industrial processes and product use sector ([13]) contributed the majority of NMVOC, Cd, and Pb emissions, and the second largest emissions of primary PM, As, and Hg. The energy use in industry sector contributed the majority of As emissions, the second largest amount of SO_X and Cd, and significant amounts of Pb, Hg, Ni, CO and BC emissions. The commercial, institutional and households sector was the largest contributor to BaP, primary PM, CO and BC, and it also contributed to NMVOC, Cd, SO_X, Ni, and NO_X emissions. The agriculture sector contributed the majority of NH_3 and CH_4 emissions, as well as a significant amount of BaP, NMVOC and primary PM_{10} emissions. The waste sector is the second largest contributor to CH_4 emissions.

([12]) According to the reporting regulation, emissions from these activities are not taken into account for assessing the national total emissions, even if they are estimated and reported under what is called 'Memo Items' (https://www.ceip.at/ms/ceip_home1/ceip_home/reporting_instructions).

([13]) See footnote ([8]).

Figure 2.4 **Contribution to EU-28 emissions from the main source sectors in 2017 of SO_x, NO_x, primary PM_{10}, primary $PM_{2.5}$, NH_3, NMVOCs, CO, BC and CH_4**

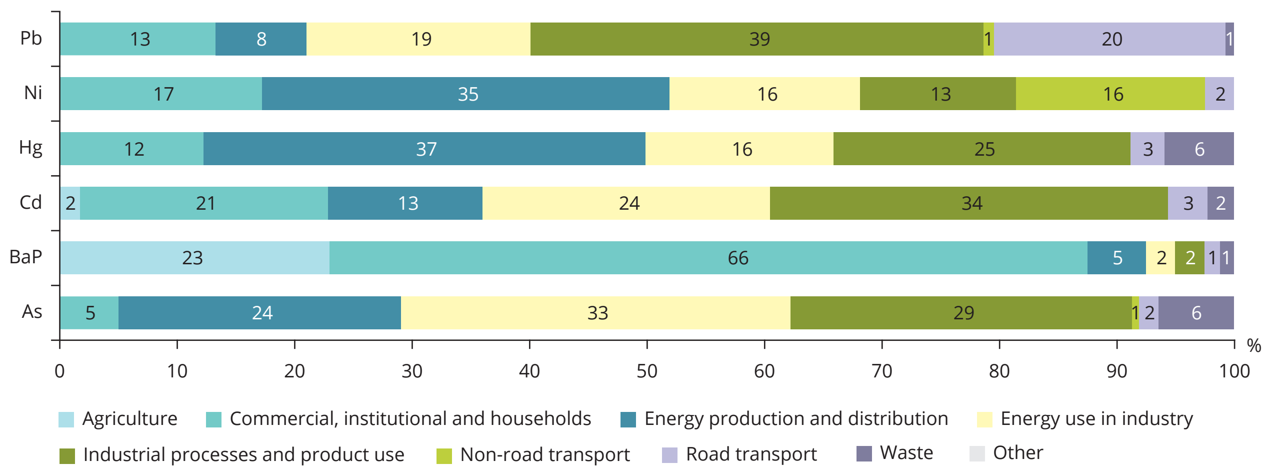


Notes: Only sectors contributing more than 0.5 % of the total emissions of each pollutant were considered.

When the sum of all contributions is either 99 or 101, it is due to rounding of the numbers.

Sources: EEA, 2019e, 2019f.

Figure 2.5 **Contribution to EU-28 emissions from the main source sectors in 2017 of As, Cd, Ni, Pb, Hg and BaP**



Notes: The emissions reported from Portugal (2000-2017) and from Bulgaria (2000-2006) for the activity 'asphalt blowing in refineries' (under the industrial processes and product use sector) were not taken into account to ensure consistency between the nationally reported data (they were not reported by any other country).

Only sectors contributing more than 0.5 % of the total emissions of each pollutant were considered.

When the sum of all contributions is either 99 or 101, it is due to rounding of the numbers.

Source: EEA, 2019e.

Sector contributions to total emissions for the EEA-33 countries are similar to those of the EU-28 described above. Some of the largest distribution differences are seen for primary PM_{10}, SO_X, and CH_4 emissions. The largest difference between the EU-28 and EEA-33 was the primary PM_{10} emissions from the industrial processes and product use sector, which accounted for 33 % of the total PM_{10} in 2017 in the EEA-33 but only 20 % of the total PM_{10} in the EU-28. This is because Turkey contributed to more than half of the PM_{10} emissions from that sector.

As a final point, note that the contributions from the different emission source sectors to ambient air pollutant concentrations and air pollution impacts depend not only on the amount of pollutant emitted but also on the proximity to the source, emission/dispersion conditions and other factors, such as topography. Emission sectors with low emission heights, such as traffic and household emissions, generally make larger contributions to surface concentrations and health impacts in urban areas than emissions from high stacks.

2.3 Emissions of toxic metals

Figure 2.1 shows the toxic metal emissions in Europe for the period 2000-2017. An overall downward trend can be seen, although the reductions vary depending on the specific metal.

Hg emissions in Europe over the last two decades have been reduced (see Figures 2.1 and 2.3), thanks to regulations limiting or banning the use of Hg and imposing emission limits (see Section 8.2). In 2017, Hg emissions were 45 % lower than in 2000 for both the EU-28 and the EEA-33, but the reduction was lower during the period 2008-2017 — a 26 % reduction. However, global emissions increased from 2010 to 2015, because of activities such as gold mining, fossil fuel burning and industry (e.g. vinyl chloride production), thus offsetting European emission reductions (UN Environment, 2019b).

About 50 % of the anthropogenic Hg deposited annually in Europe is emitted by sources outside Europe (EEA, 2018d; UN Environment, 2019b). The largest foreign contributors are East Asia (18 %), Africa (8 %), the former Soviet Union countries (6 %) and South Asia (5 %) (EMEP, 2018a; UN Environment, 2019b). Furthermore, previously released Hg — mostly from anthropogenic sources — that has built up over decades and centuries in surface soils and oceans is 're-emitted' into the air, before being re-deposited onto land or in water (through what is known as the 'global mercury cycle'). These 're-emissions' form a considerable part of the total emissions in Europe (about 60 %) (UN Environment, 2019b), as Europe's use and emissions of Hg were high in the past. Thus, present-day anthropogenic emissions of Hg contribute to both current and future emissions to the air.

At present the energy production distribution sector and the industrial processes and product use sector are the main sectors responsible for direct anthropogenic emissions of Hg in Europe (Figure 2.5), mostly as a result of coal combustion for energy production and industrial activities, such as iron and steel production, non-ferrous metal production, cement/minerals and the chemical industry. Currently, the use of Hg in the manufacturing of chlorine products is limited to one plant in Slovakia (producing vinyl chloride monomer) and two plants in Germany (producing speciality alcoholates); these plants must cease their use by 2022 and 2028, respectively. The use of Hg in the industrial manufacture of chlorine was banned as of December 2017. In addition, the use of coal in commercial, institutional and households heating was responsible for 12 % of Hg emissions in 2017, which occurred predominantly in central and eastern Europe. In total, coal combustion accounts for over 50 % of total anthropogenic Hg emissions in Europe (UN Environment, 2019b).

Anthropogenic emissions of As, Cd, Ni and Pb were reduced by 18 %, 42 %, 58 % and 65 %, respectively, from 2000 to 2017, in both the EU-28 and the EEA-33 (Figure 2.1 and Section 8.3). The industrial processes and product use sector was the main emitter of Pb (38 %) and Cd (34 %), and the second largest emitter of As (29 %) in the EU-28 in 2017 (Figure 2.5). The energy use in industry sector was the main emitter of As (33 %) and second largest emitter of Cd (25 %), while the main emitter of Ni (35 %) and Hg (38 %) was the energy production and distribution sector (Figure 2.5).

3 Particulate matter

3.1 European air quality standards and World Health Organization guideline values for particulate matter

The legal standards set by the Ambient Air Quality Directive (EU, 2008) for both particulate matter with a diameter of 10 µm or less (PM_{10}) and particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) can be found in Table 1.1, and the air quality guidelines (AQGs) set by the World Health Organization (WHO) can be found in Table 1.3. For convenience, they are summarised in Table 3.1.

3.2 Status of concentrations

The EEA received PM_{10} data for 2017, with sufficient valid measurements (a minimum coverage of 75 %) from around 3 000 stations (2 927 stations were analysed in relation to the annual limit value and 2 886 in relation to the daily limit value). The stations were located in all the EEA-39 countries (except Albania, Greece, Kosovo ([14]) and Liechtenstein) and Andorra. For additional information on the type of area and station, see Annex 1.

Seventeen Member States and six other reporting countries (Map 3.1 and Figure 3.1) reported PM_{10} concentrations above the EU daily limit value in 2017. This was the case for 22 % of reporting stations. In total, 95 % of those stations were either urban (83 %) or suburban (12 %).

Concentrations above the PM_{10} annual limit value (40 µg/m^3) in 2017 were monitored at 7 % (207 stations) of all the reporting stations, located in 13 countries. Most of them were located in Turkey (121), Poland (31), Italy (14), North Macedonia (14) and Bulgaria (13). There was also at least one station with values above the PM_{10} annual limit value in the Member States of Croatia, France, Hungary, Romania and Spain (one station in each), and in the cooperating countries of Bosnia and Herzegovina (five), Montenegro (one) and Serbia (three) (Map 3.2). The stricter value of the WHO AQG for PM_{10} annual mean (20 µg/m^3) was exceeded at 51 % of the stations and in all the reporting countries, except Estonia, Finland and Ireland (Map 3.2 and Figure 3.2).

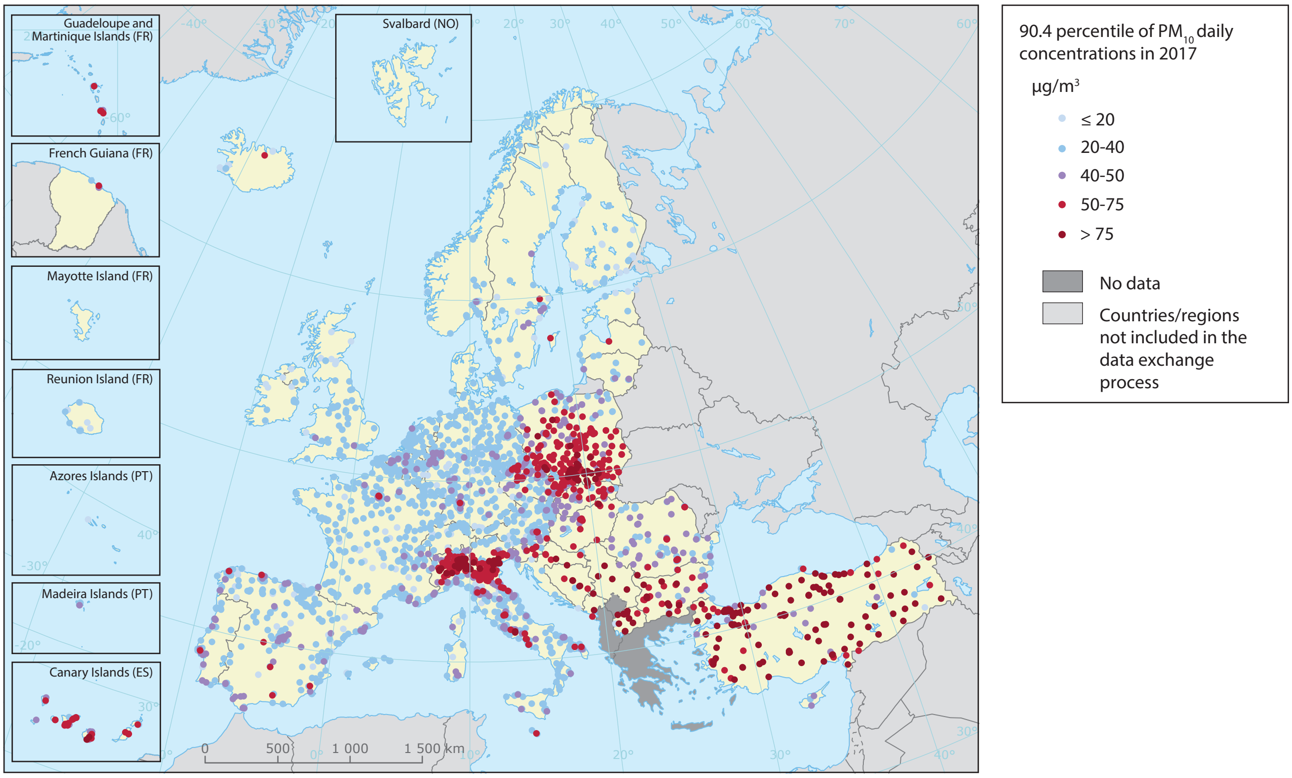
Table 3.1 Air quality standards for protecting human health from PM

Pollutant	Averaging period	Standard type and concentration	Comments
PM_{10}	1 day	EU limit value: 50 µg/m^3	Not to be exceeded on more than 35 days per year
		WHO AQG: 50 µg/m^3	99th percentile (3 days per year)
	Calendar year	Limit value: 40 µg/m^3	
		WHO AQG: 20 µg/m^3	
$PM_{2.5}$	1 day	WHO AQG: 25 µg/m^3	99th percentile (3 days per year)
	Calendar year	EU limit value: 25 µg/m^3	
		EU exposure concentration obligation: 20 µg/m^3	Average exposure indicator (AEI) ([a]) in 2015 (2013-2015 average)
		EU national exposure reduction target: 0-20 % reduction in exposure	AEI ([a]) in 2020, the percentage reduction depends on the initial AEI
		WHO AQG: 10 µg/m^3	

Note: ([a]) AEI: based upon measurements in urban background locations established for this purpose by the Member States, assessed as a 3-year running annual mean.

([14]) Under United Nations Security Council Resolution 1244/99.

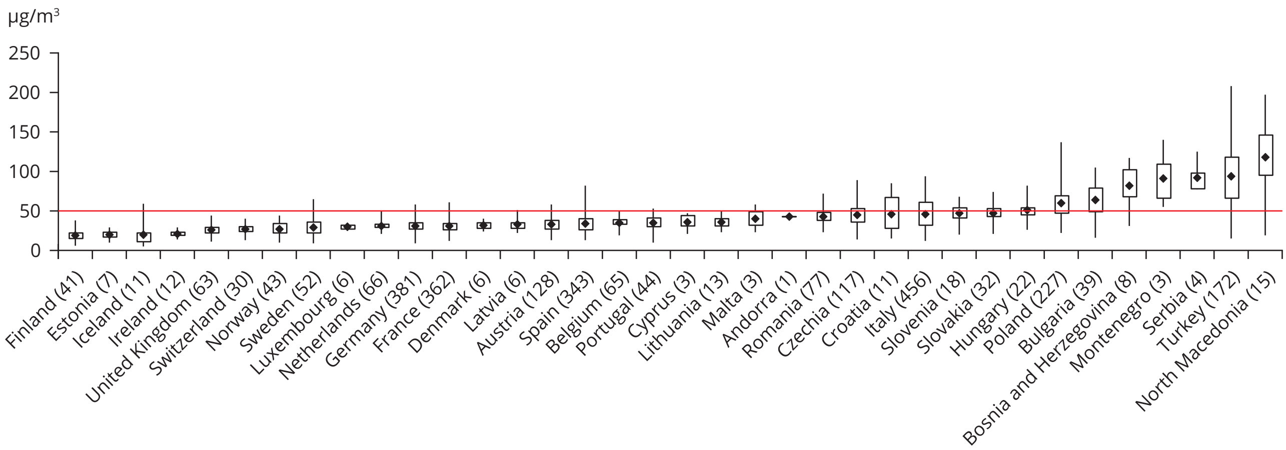
Map 3.1 **Concentrations of PM_{10}, 2017 — daily limit value**



Note: Observed concentrations of PM_{10} in 2017. The possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting has not been considered. The map shows the 90.4 percentile of the PM_{10} daily mean concentrations, representing the 36th highest value in a complete series. It is related to the PM_{10} daily limit value, allowing 35 exceedances of the 50 µg/m³ threshold over 1 year. Dots in the last two colour categories indicate stations with concentrations above this daily limit value. Only stations with more than 75 % of valid data have been included in the map.

Source: EEA, 2019c.

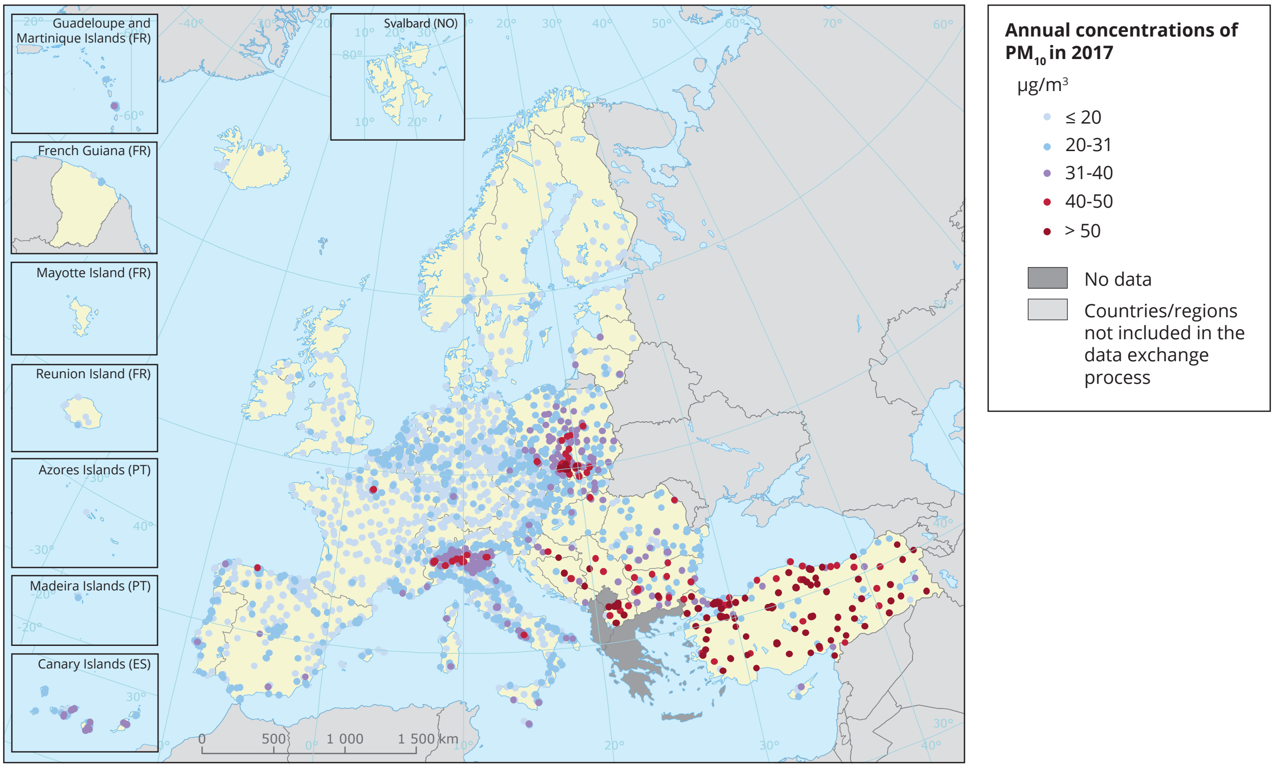
Figure 3.1 **PM_{10} concentrations in relation to the daily limit value in 2017 and number of stations considered for each country**



Note: The graph is based, for each country, on the 90.4 percentile of daily mean concentration values corresponding to the 36th highest daily mean. For each country, the number of stations considered (in brackets) and the lowest, highest and average 90.4 percentile values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The daily limit value set by EU legislation is marked by the horizontal line. The graph should be read in relation to Map 3.1, as a country's situation depends on the number of stations considered.

Source: EEA, 2019c.

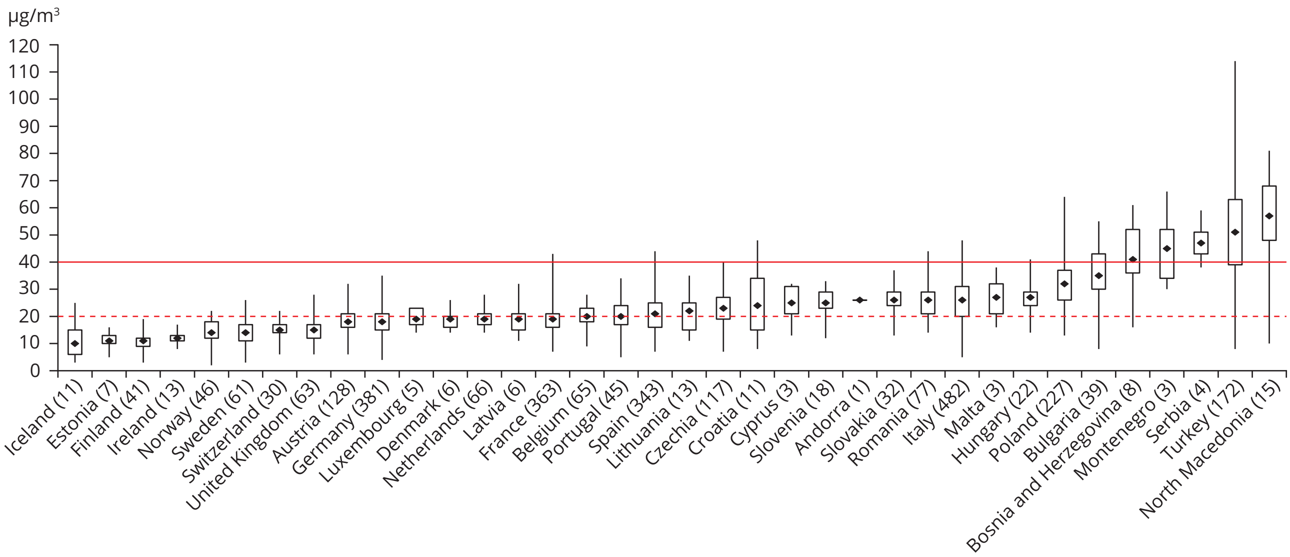
Map 3.2 Concentrations of PM_{10}, 2017 — annual limit value



Note: Observed concentrations of PM_{10} in 2017. The possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting has not been considered. Dots in the last two colour categories indicate stations reporting concentrations above the EU annual limit value (40 µg/m³). Dots in the first colour category indicate stations reporting values below the WHO AQG for PM_{10} (20 µg/m³). Only stations with more than 75 % of valid data have been included in the map.

Source: EEA, 2019c.

Figure 3.2 PM_{10} concentrations in relation to the annual limit value in 2017 and number of stations considered for each country



Note: The graph is based on annual mean concentration values. For each country, the number of stations considered (in brackets) and the lowest, highest and average values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The annual limit value set by EU legislation is marked by the upper continuous horizontal line. The WHO AQG is marked by the lower dashed horizontal line. The graph should be read in relation to Map 3.2, as a country's situation depends on the number of stations considered.

Source: EEA, 2019c.

Regarding $PM_{2.5}$, data with a minimum coverage of 75 % of valid data were received from 1 396 stations located in all the EEA-39 countries, except Albania, Greece, Kosovo, Liechtenstein, Montenegro and Serbia. For additional information on the type of area and station, see Annex 1.

In 2017, the $PM_{2.5}$ concentrations were higher than the annual limit value in seven Member States and three other reporting countries (Map 3.3 and Figure 3.3). These values above the limit value were registered at 7 % of all the reporting stations and also occurred primarily (94 % of cases) in urban (83 %) or suburban (11 %) areas.

The stricter value of the WHO AQG for $PM_{2.5}$ annual mean (10 µg/m^3) was exceeded at 69 % of the stations, located in 30 of the 33 countries reporting $PM_{2.5}$ data (Map 3.3 and Figure 3.3). Estonia, Finland and Norway did not report any concentrations above the WHO AQG for $PM_{2.5}$.

Annex 2 offers information on PM background concentrations in the most polluted, the least polluted and the most populated cities for each reporting country.

The rural background concentration levels of PM vary across Europe. In 2017, concentrations above the PM_{10} daily limit value occurred in 27 rural background stations across Italy (16), Czechia (six), Turkey (three), Slovenia (one) and Spain (one). There were also two rural background stations in Turkey, whose 2017 annual mean concentrations were above the PM_{10} annual limit value. With regard to $PM_{2.5}$, Italy (four stations), Czechia (one) and Turkey (one) registered concentrations above the annual limit value in rural background stations.

The Copernicus Atmosphere Monitoring Service (CAMS, 2018) identified fewer PM events during the spring of 2017 than in previous years; this was partially explained by the fact that there were higher levels of precipitation and fewer cold and stable meteorological periods during that time than in previous springs. The main high PM pollution episodes occurred during the winter and autumn of 2017 (CAMS, 2018). Two large European-wide winter episodes of high background PM occurred from 20-30 January and from 9-17 February 2017. Both events were associated with considerable long-range transport of PM. In addition, episodes of high background $PM_{2.5}$ occurred from 7-9 November and from 18-22 December. The year 2017 was also characterised by major wildfires, especially in the Iberian Peninsula, which led to high PM concentrations occurring close to the fires and being transported over large distances, as further discussed in Box 3.1.

The Ambient Air Quality Directive (EU, 2008) also requires Member States to make additional measurements on the chemical speciation concentrations of fine particulate matter ($PM_{2.5}$) at least at one rural background station. The chemical species that have to be measured are sulphate (SO_4^{2-}), nitrate (NO_3^-), sodium (Na^+), potassium (K^+), ammonium (NH_4^+), chloride (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), elemental carbon (EC) and organic carbon.

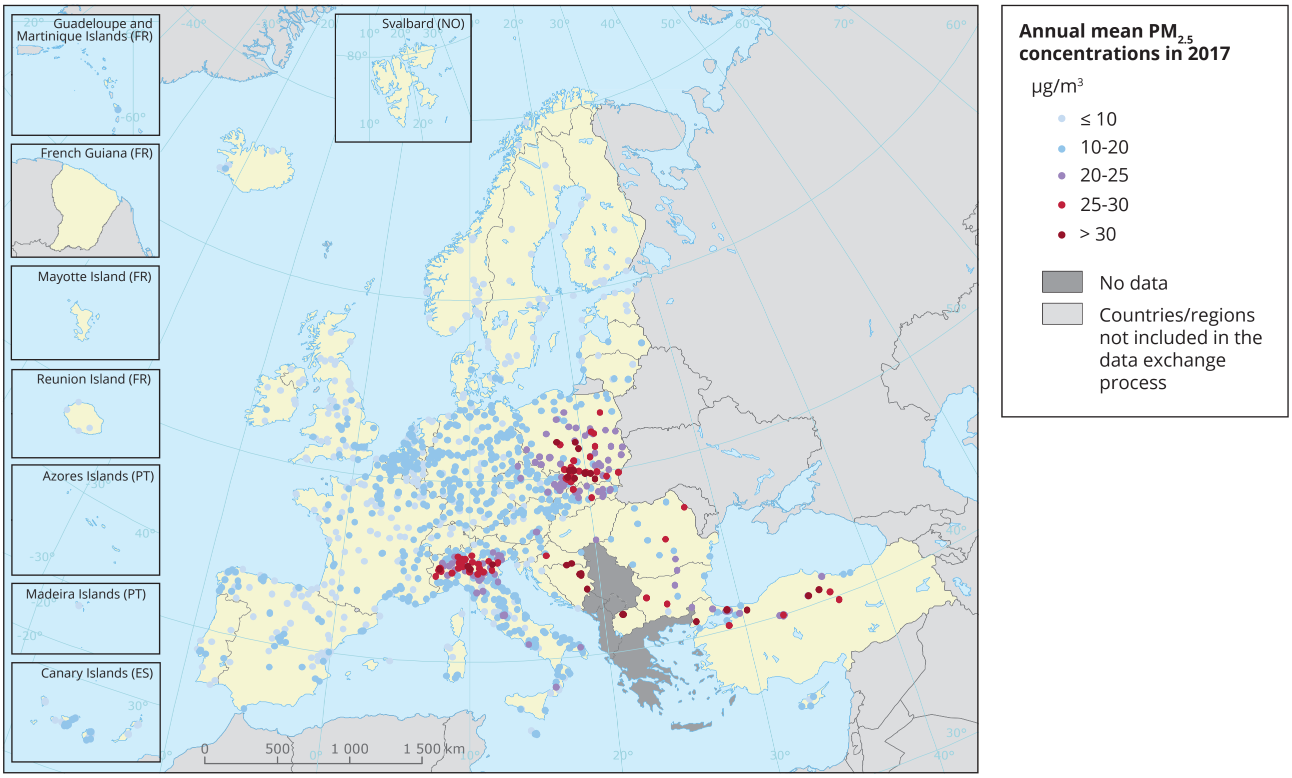
In 2017, the countries that reported these species as measured in $PM_{2.5}$ ([15]) were Austria, Croatia, Cyprus, Denmark, Finland (except EC), Germany, Ireland, Latvia (except EC and organic carbon), Lithuania, Malta, the Netherlands, Poland, Slovenia, Spain and the United Kingdom. Values can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2019h).

3.3 $PM_{2.5}$ average exposure indicator

The Ambient Air Quality Directive (EU, 2008) also sets two additional targets for $PM_{2.5}$, the exposure concentration obligation (ECO) and the national exposure reduction target (NERT) (Tables 1.1 and 3.1). Both targets are based on the average exposure indicator (AEI), calculated at national level. The AEI is an average of concentration levels (over a 3-year period) measured at urban background stations (representative of general urban population exposure) selected for this purpose by every national authority. The reference year for the AEI is 2010 (average 2008-2010), but the Ambient Air Quality Directive offered two additional alternatives where data are not available for 2008: (1) an alternative AEI 2010, with a 2-year average (2009 and 2010) instead of the 3-year average; or (2) the AEI 2011 (average 2009-2011). For comparability purposes, the data presented here are analysed with reference to the AEI 2011, independently of the reference year chosen by each Member State. The exception is Croatia for which 2015 is the AEI reference year (average 2013-2015).

([15]) Sweden reported Na^+, K^+, Cl^- and Mg^{2+} as aerosols, without any specification of the PM fraction.

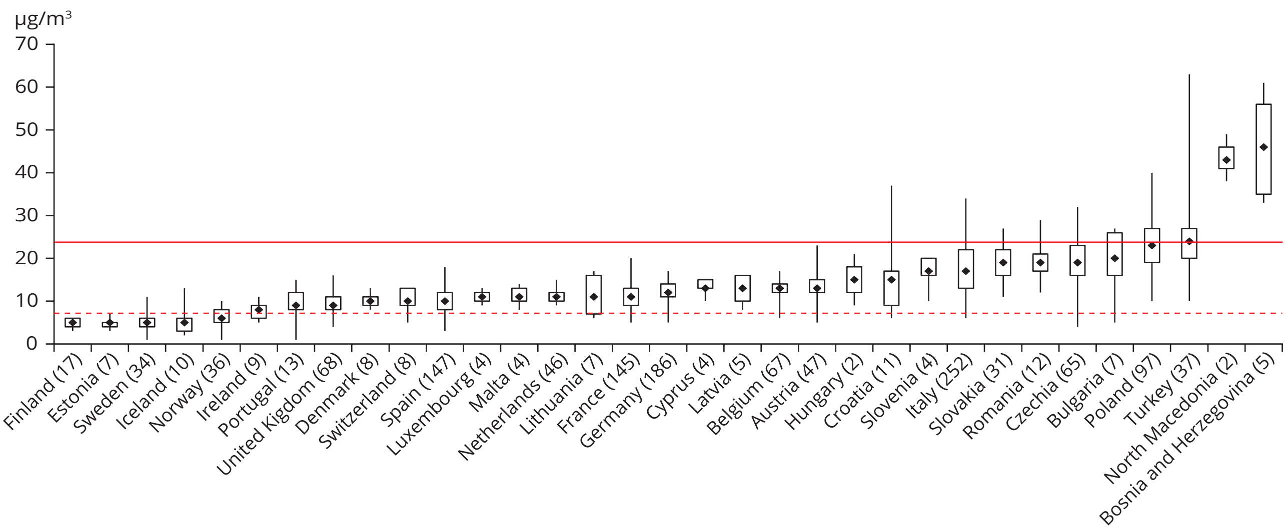
Map 3.3 **Concentrations of $PM_{2.5}$, 2017 — annual limit value**



Note: Observed concentrations of $PM_{2.5}$ in 2017. The possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting has not been considered. Dots in the last two colour categories indicate stations reporting concentrations above the EU annual limit value (25 µg/m³). Dots in the first colour category indicate stations reporting values below the WHO AQG for $PM_{2.5}$ (10 µg/m³). Only stations with more than 75 % of valid data have been included in the map.

Source: EEA, 2019c.

Figure 3.3 **$PM_{2.5}$ concentrations in relation to the annual limit value in 2017 and number of stations considered for each country**



Note: The graph is based on annual mean concentration values. For each country, the number of stations considered (in brackets) and the lowest, highest and average values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The limit value set by EU legislation is marked by the upper continuous horizontal line. The WHO AQG is marked by the lower dashed horizontal line. The graph should be read in relation to Map 3.3, as a country's situation depends on the number of stations considered.

Source: EEA, 2019c.

Box 3.1 PM pollution episodes in 2017 due to wildfires in the Iberian Peninsula

The year 2017 was one of the most devastating for wildfires in Europe, with over 1.2 million hectares of natural land burnt across the EU and 127 deaths. The European Forest Fire Information System estimated that these fires caused losses of around EUR 10 billion (JRC, 2018). In addition to the danger they pose to lives and their destruction of natural and built environments, smoke from these fires pose a substantial risk to human health (Knorr et al., 2017), as wildfires emit large amounts of pollutants, such as particulate matter (PM), nitrogen oxides (NO_X), carbon monoxide (CO), volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs). The impact on PM concentration is analysed below.

Following an intense heatwave in Portugal and extremely dry conditions, fires erupted in the mountainous areas situated to the north/north-east of Lisbon. The worst single incident took place from 17-22 June in central Portugal, near Pedrogão Grande ([16]), and led to the death of 64 people, the largest number of deaths due to wildfires in Portugal's recent history. Measured PM_{10} daily mean concentrations averaged over a region covering the Iberian Peninsula, France, Benelux and the south of Great Britain were 17 µg/m^3 before and after the episode, while the average daily mean during the episode was 26 µg/m^3. This wildfire event led to elevated concentrations of $PM_{2.5}$ in Portugal over the WHO daily air quality guideline on 18 June. The smoke plume also led to elevated $PM_{2.5}$ levels in Galicia and Asturias in northern Spain from 20-22 June (CAMS, 2018). During the wildfire episode, when hundreds of smaller fires also occurred in Portugal and Spain, the $PM_{2.5}$ daily mean concentrations, averaged over the region increased from 8 µg/m^3 to 14 µg/m^3. The fire plume contributed to the high $PM_{2.5}$ concentrations observed at French and British sites from 20-21 June (when $PM_{2.5}$ increased, on average, from 5 to 15 µg/m^3), and to the high $PM_{2.5}$ concentrations observed across central Europe and at Balkan monitoring sites on 21 and 22 June (when $PM_{2.5}$ increased, on average, from 5 to 20 µg/m^3).

The other major incident took place in Portugal and north-western Spain from 13 to 17 October, when major outbreaks of wildfires, exacerbated by strong winds that were enhanced by Hurricane Ophelia and the associated dust storm, led to a further 49 deaths (WMO, 2018). The area that was burned in Portugal in 2017 was more than six times the average for 2007-2016 (JRC, 2018). The effects of this event, which combined the ash from the wildfires with the dust from North Africa brought about by the remnants of Hurricane Ophelia, could be seen in the United Kingdom and Ireland, as well as in northern Europe ([17]) (CAMS, 2018). Observations across a region covering all of the EEA-39 show similar PM concentrations before and after the two wildfire episodes in June and October 2017. However, during the wildfire and dust episode in October, daily mean levels, on average, over the EEA-39 were higher than those during the June episode, namely 17 µg/m^3 and 34 µg/m^3 for $PM_{2.5}$ and PM_{10}, respectively. Daily mean levels started to increase on 13 October and returned to usual levels on 20 October. The plume from the fire and dust from North Africa affected more sites across Europe; an increase in levels of daily mean concentrations in central and eastern Europe was observed from 14 October and from 16 October for sites in Norway and Sweden.

Figure 3.4 shows the AEI for every EU-28 Member State calculated for 2017 (average 2015-2017) and the situation in relation to the ECO. The bars show the AEI 2017 using the stations designated for this purpose by the Member States ([18]), while the dots show instead the 3-year (2015-2017) average concentrations from measurements at all urban and suburban background stations with 75 % data coverage. This calculation, covering the urban and suburban background stations, has been used in previous *Air quality in Europe* reports as an approximation of the AEI and is presented here for comparison with the information presented in those reports. The calculation using reported urban and suburban background stations is also made for the rest of the non-EU countries.

For the 27 countries where the AEI 2017 could be calculated using the designated stations, the AEI continued to be above the exposure concentration obligation in Slovakia (22 µg/m^3 ([19])), Poland (22 µg/m^3) and Bulgaria (24 µg/m^3).

Furthermore, based on the average of $PM_{2.5}$ concentrations measured at urban and suburban background stations, Hungary was also above the exposure concentration obligation with an estimated AEI 2017 of 21 µg/m^3 ([20]). Other countries with an estimated AEI 2017 above 20 µg/m^3 are Turkey (21 µg/m^3, with data for 2016-2017), Bosnia and Herzegovina (33 µg/m^3, 2016-2017), and North Macedonia (51 µg/m^3). In addition, and based on the estimated AEI 2016, as they did not report 2017 data, Serbia (23 µg/m^3, only data for 2016), Albania (25 µg/m^3, 2015-2016) and Kosovo (27 µg/m^3, 2015-2016) also had values above the ECO.

([16]) The spread of the wildfire was observed by the MODIS instrument, as can be seen in https://earthobservatory.nasa.gov/images/90427/wildfires-light-up-portugal

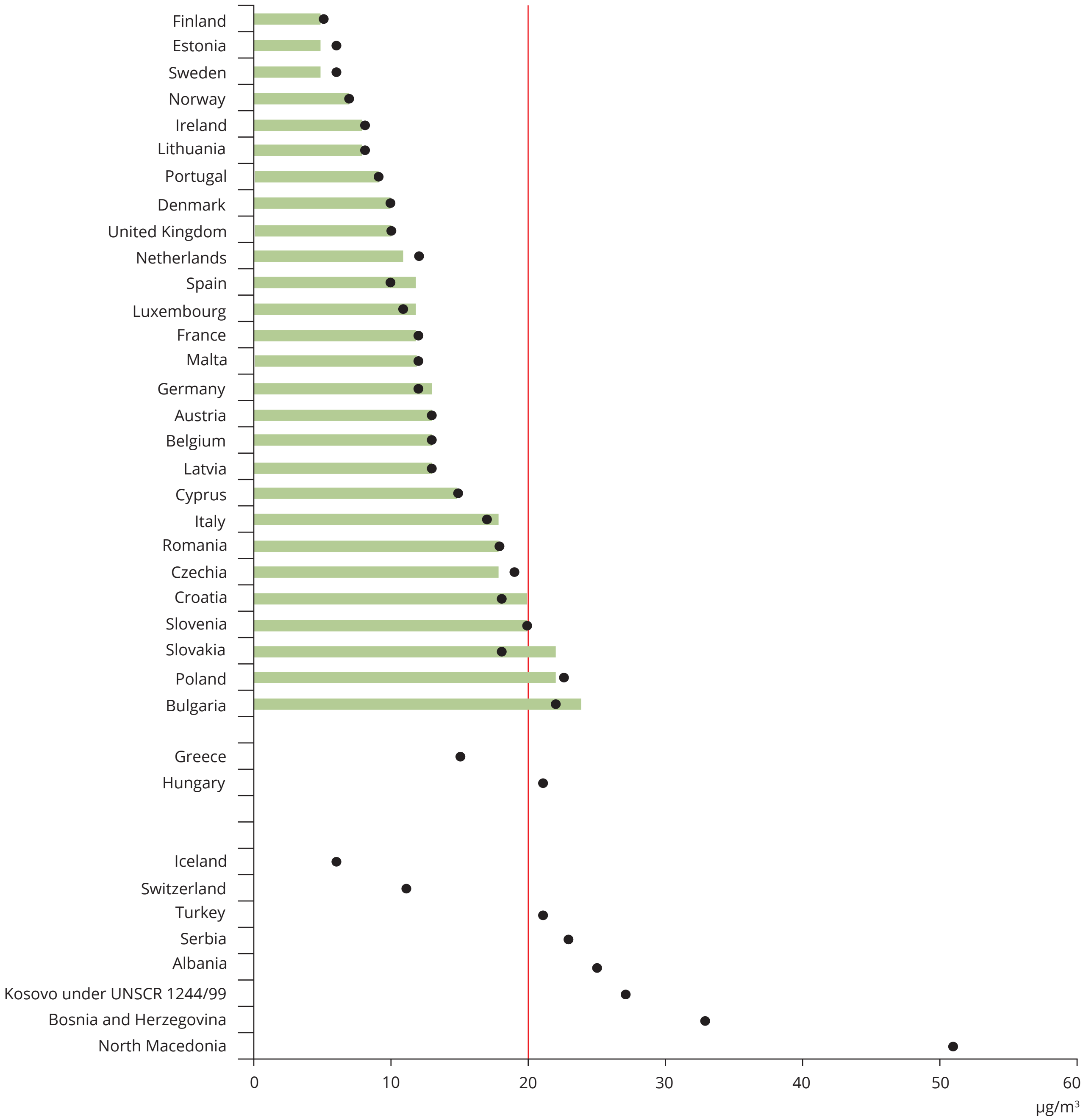
([17]) The smoke and flames from these extensive wildfires could be clearly seen on satellite imagery. This satellite imagery can be found at https://www.eumetsat.int/website/home/Images/ImageLibrary/DAT_3688467.html

([18]) No AEI stations designated by Greece in 2017. The four stations designated by Hungary did not fulfil the requirement of a minimum data coverage of 75 % to be included in this analysis. The non-EU country of Norway has also designated AEI stations. The rest of the countries covered by this report in which the EU directives do not apply are not obliged to designate AEI stations.

([19]) However, taking into account all the urban and suburban stations results in a value of 18 µg/m^3 for 2017.

([20]) AEI 2017 calculated using only 2017 data, since Hungary did not report $PM_{2.5}$ data from urban or suburban background stations with enough data coverage in 2015 or 2016.

Figure 3.4 Average exposure indicator in 2017 and exposure concentration obligation



Notes: The bars show the average exposure indicator (AEI) calculated in 2017 (averages 2015-2017) using the stations designated for this purpose by the Member States (except for Greece and Hungary — see the main text) and Norway.

The dots show all urban and suburban background $PM_{2.5}$ concentrations (for stations with at least 75 % of data coverage) in all reporting countries presented as 3-year (2015-2017) averages, as an approximation of the AEI in 2017 and to facilitate comparison with information provided in previous Air quality in Europe reports.

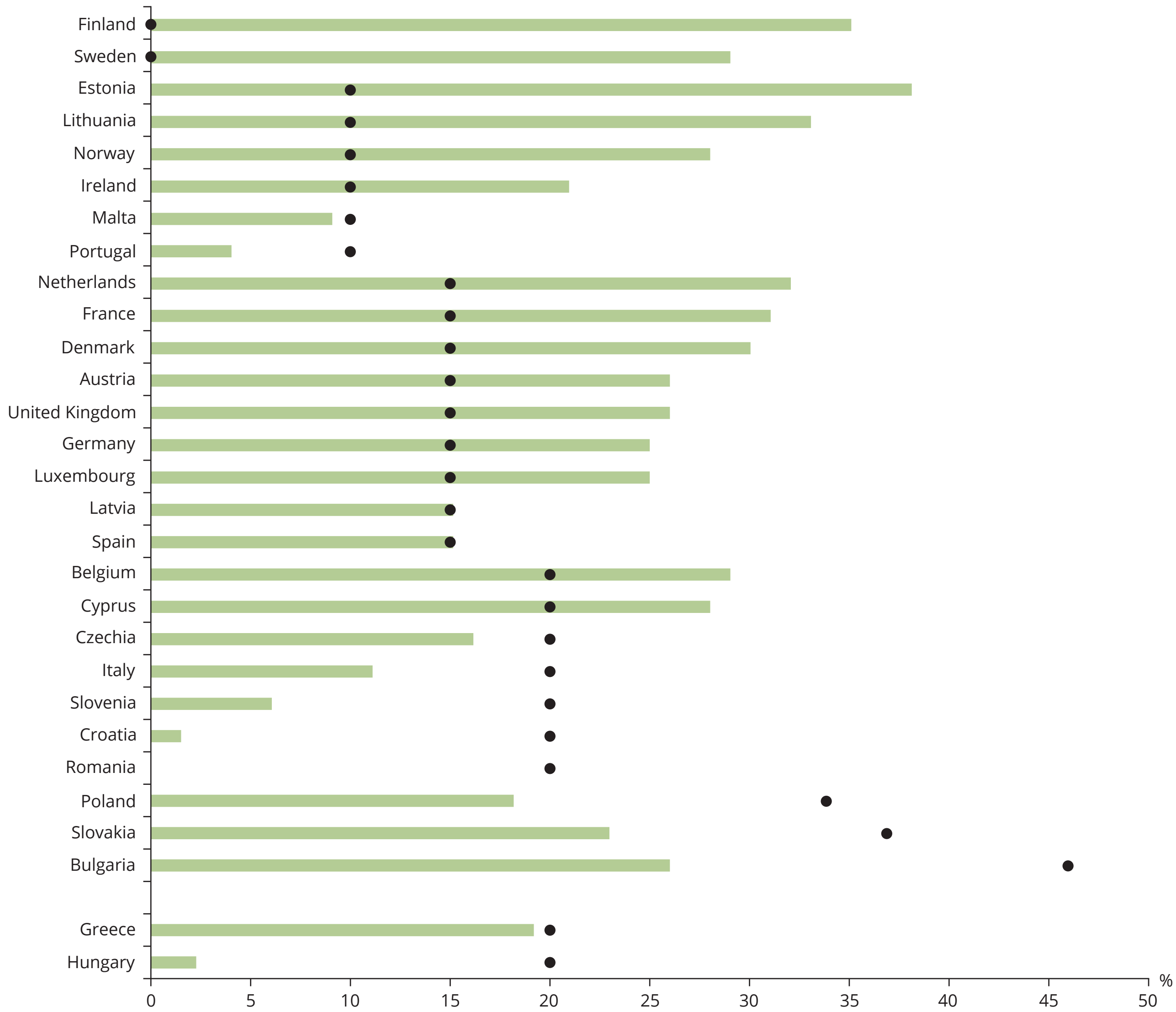
The vertical line represents the exposure concentration obligation for the EU-28, set at 20 μg/m³, to be achieved by 2015.

For Hungary, whose designated AEI stations for 2017 and reported $PM_{2.5}$ data from urban or suburban background stations in 2015 or 2016 did not fulfil the minimum data coverage criteria, the estimation using urban background stations is presented for 2017 (no average). For Bosnia and Herzegovina and Turkey, the estimation using urban background stations considered only the years 2016 and 2017. For Greece, Albania, Kosovo, and Serbia, which did not report 2017 data, only the years 2015 and 2016 were considered.

Source: EEA, 2019c.

Figure 3.5 shows the situation of the EU Member States and Norway in relation to the NERT. This reduction target is expressed as a percentage of the initial AEI 2010 (here, as stated above, AEI 2011 has been used for comparison). The dots indicate the percentage reduction to be attained in AEI 2020 (average 2018-2020) and the bars indicate the reduction in the AEI 2017 (AEI 2016 for Greece) as a percentage of the AEI 2011 (AEI 2015 for Croatia). Figure 3.5 indicates that 17 out of the 29 countries considered ([21]) have already attained their corresponding NERT values, and that those countries that are further from reaching their NERTs are generally those that are required to achieve a larger reduction.

Figure 3.5 Percentage of reduction in AEI 2017 in relation to AEI 2011 and distance to the national exposure reduction target



Notes: Bars indicate the reduction in the AEI 2017 as a percentage of the AEI 2011 (AEI 2015 in the case of Croatia — see the main text). Dots indicate the reduction to be obtained in the AEI 2020 as a percentage of the AEI 2011 (AEI 2015 in the case of Croatia). If the end of the bar is to the right of the dot or in the same spot, the NERT was already achieved in 2017.

For Greece (no 2017 data) and Hungary (where the stations designated for the AEI calculation do not reach the minimum data coverage), all urban and suburban background stations have been used instead.

For Hungary, which did not report $PM_{2.5}$ data from urban background stations with enough data coverage in 2015 or 2016, the reduction for 2017 (no average) is presented. For Greece, which did not report 2017 data, the reduction in the AEI 2016 (average 2015-2016) is presented.

Source: EEA, 2019c.

([21]) Austria, Belgium, Cyprus, Denmark, Estonia, Finland, France, Germany, Ireland, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Spain, Sweden and the United Kingdom.

3.4 Contribution of primary PM and precursor emissions, meteorological variability and natural sources to ambient PM concentrations

Trends in PM are influenced by the relative trends in concentrations of all aerosol compounds that, together, constitute PM_{10} or $PM_{2.5}$. A good understanding of the chemical composition of PM is therefore needed. This need is also shared by the European monitoring and evaluation programme monitoring strategy (currently under revision) (EMEP, 2019), to which the 2008 Ambient Air Quality Directive recommends that authorities refer regarding good practices for PM composition, emphasising the mutual benefit of coordinating different air quality monitoring programmes.

With the exception of ammonia (NH_3), the reductions in emissions of the secondary PM precursors (NO_X, SO_X and non-methane volatile organic compounds, NMVOCs) were much larger than the reductions in primary PM emissions from 2000 to 2017 in the EU-28 (see Figure 2.1). The EuroDelta-Trends modelling experiment (ETC/ACM, 2017a) estimated that the impact of the reduction of European emissions of PM precursors and of primary PM was the most important factor in explaining the reduction in PM_{10} concentrations between 1990 and 2010 in Europe. From 2000 to 2010, PM_{10} trends in Europe generally decreased; in southern and central parts of Europe, meteorological conditions helped to counteract this reduction in PM_{10} levels, while in the north they enhanced the reduction (ETC/ACM, 2018a).

Natural sources, which are not targeted by mitigation measures, contribute to both background PM concentrations and episodes with high PM levels, such as those that occur as a result of the transport of desert dust and wildfires. Measures to abate local emissions and to alert the most susceptible populations could be effective during dust outbreaks. Wildfires are a significant cause of air pollutants; sometimes they can affect air quality far from their source (Box 3.1). The occurrence and severity of wildfires seem to have increased in recent decades, and this increase is predicted to continue as a result of climate change (Knorr et al., 2017). Developing and implementing effective methods for wildfire management and prevention will therefore become increasingly important.

Chapter 2 showed that road transport contributed to 11 % of total PM_{10} and $PM_{2.5}$ primary emissions in the EU-28 in 2017. Road transport emissions include exhaust emissions, resulting from combustion, as well as non-exhaust emissions. The latter includes brake, tyre and road wear and road dust resuspension. On a global scale, non-exhaust PM_{10} emissions are at least as important as exhaust emissions; non-exhaust $PM_{2.5}$ emissions would represent one third of total $PM_{2.5}$ road emissions (Amato et al., 2018). Road dust makes the most significant contribution to PM_{10} road transport emissions (about 22 %), followed by exhaust emissions (21 %), break wear (7 %) and tyre wear (4 %). For road transport emissions of $PM_{2.5}$, exhaust emissions are the principal source (24 %), with road dust contributing 11 %, break wear 9 % and tyre wear 2 %.

4 Ozone

4.1 European air quality standards and World Health Organization guideline values for ozone

The European air quality standards for the protection of health and the air quality guidelines (AQGs) set by the World Health Organization (WHO) for ozone (O_3) are shown in Tables 1.1 and 1.3, respectively. For convenience, they are summarised in Table 4.1.

The Ambient Air Quality Directive (EU, 2008) also sets targets for the protection of vegetation, shown in Table 1.2. In addition, the Convention on Long-range Transboundary Air Pollution (CLRTAP) (UNECE, 1979) defines a critical level (CL) for the protection of forests (Table 1.2). The vegetation exposure to O_3 levels above these standards and the exposure of forests to O_3 levels above the critical level are assessed in Section 11.1.

4.2 Status of concentrations

Data for O_3 in 2017 were reported from 1 903 stations in 35 of the EEA-39 countries (all, except Greece, Iceland, Kosovo and Liechtenstein) and Andorra. For additional information on the type of area and station, see Annex 1.

Seventeen Member States and six other reporting countries (Figure 4.1 and Map 4.1) registered concentrations above the O_3 target value more than 25 times. In total, 20 % of all stations reporting O_3, with the minimum data coverage of 75 %, showed concentrations above the target value for the protection of human health in 2017. In addition, only 18 % (337) of all stations fulfilled the long-term objective. Overall, 87 % of the stations with values above the long-term objective were background stations.

In total, 5 % (97) of all stations and only 9 of the 497 rural background stations reported in 2017 had values below the WHO AQG value for O_3 (8-hour mean of 100 μg/m^3), set for the protection of human health.

Annex 2 presents information on the O_3 background concentrations of the most polluted, the least polluted and the most populated cities for each reporting country.

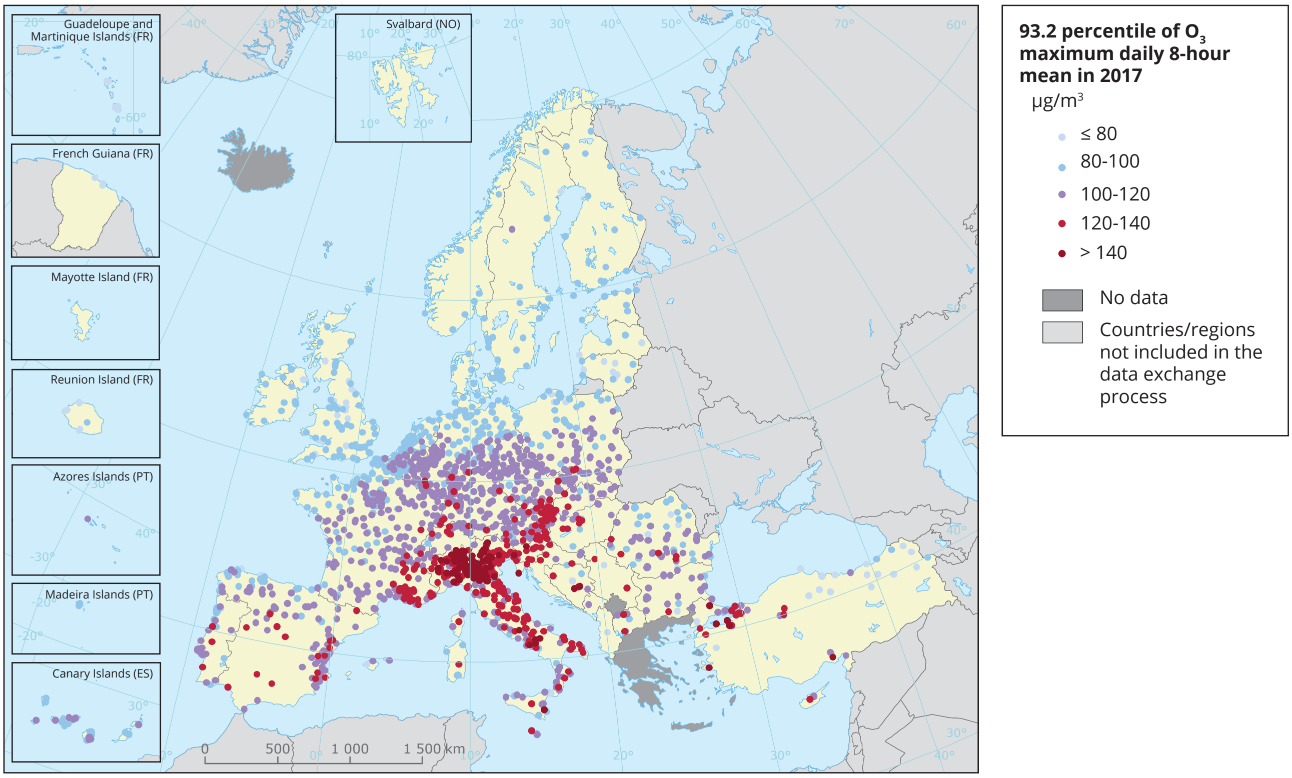
Peak O_3 episodes are strongly linked to weather conditions and favoured by warm, stagnant high-pressure conditions. These episodes, which usually occur during summer, are caused by anthropogenic emissions of precursors (nitrogen oxides, NO_X, and volatile organic compounds, VOCs). The year 2017 was cooler than 2016, the warmest year, but 2017 was one of the three warmest years on record and was the warmest year that was not influenced by an El Niño event (WMO, 2018). On average, across Europe, 2017 was the fifth warmest year up to that point (WMO, 2018).

Table 4.1 Air quality standards for protecting human health from O_3

Pollutant	Averaging period	Standard type and concentration	Comments
O_3	Maximum daily 8-hour mean	EU target value: 120 μg/m^3	Not to be exceeded on more than 25 days/year, averaged over 3 years ([a])
		EU long-term objective: 120 μg/m^3	
		WHO AQG: 100 μg/m^3	
	1 hour	EU information threshold: 180 μg/m^3	
		EU alert threshold: 240 μg/m^3	

Notes: ([a]) In the context of this report, only the maximum daily 8-hour means in 2017 are considered, so no average over the period 2015-2017 is presented.

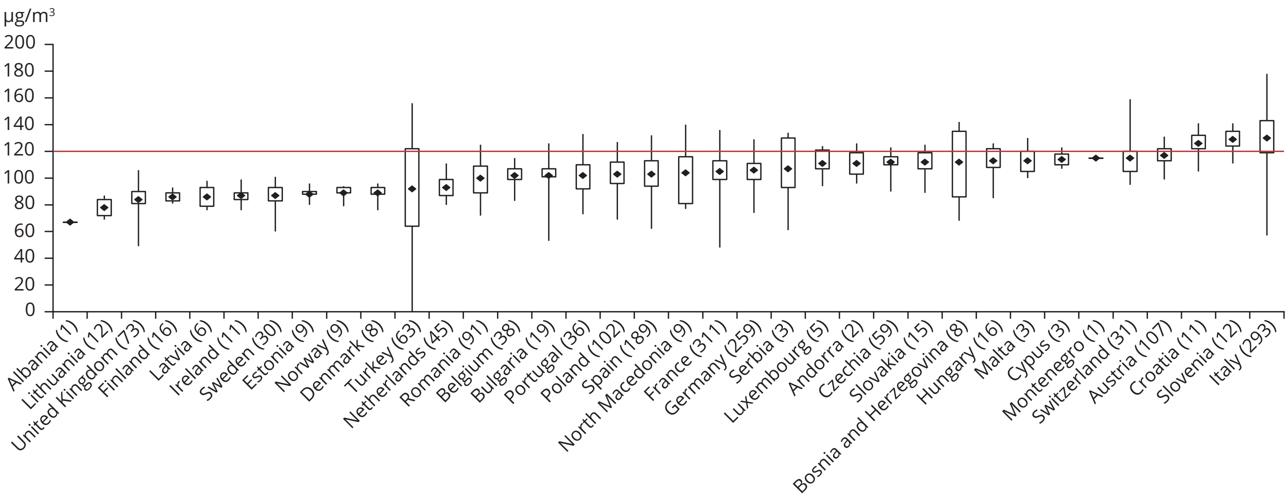
Map 4.1 Concentrations of O_3 in 2017



Note: Observed concentrations of O_3 in 2017. The map shows the 93.2 percentile of the O_3 maximum daily 8-hour mean, representing the 26th highest value in a complete series. It is related to the O_3 target value. At sites marked with dots in the last two colour categories, the 26th highest daily O_3 concentrations were above the 120 μg/m³ threshold, implying an exceedance of the target value threshold. Please note that the legal definition of the target value considers not only 1 year but the average over 3 years. Only stations with more than 75 % of valid data have been included in the map.

Source: EEA, 2019c.

Figure 4.1 O_3 concentrations in relation to the target value in 2017 and number of stations considered for each country



Note: The graph is based, for each country, on the 93.2 percentile of the maximum daily 8-hour mean concentration values, corresponding to the 26th highest daily maximum of the running 8-hour mean. For each country, the number of stations considered (in brackets), and the lowest, highest and average values (in μg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The target value threshold set by the EU legislation is marked by the horizontal line. Please note that the legal definition of the target value considers not only 1 year but the average over 3 years. The graph should be read in relation to Map 4.1, as a country's situation depends on the number of stations considered.

Source: EEA, 2019c.

Since 1990, the occurrence of peak O_3 episodes has shifted to earlier in the year, i.e. spring and early summer, mostly because of a reduction in peak O_3 concentrations in July and August (EMEP, 2016). In 2017, the Copernicus Atmosphere Monitoring Service (CAMS, 2018) estimated that the worst O_3 episodes in 2017 occurred from 19-22 June and from 27-30 May, which is consistent with the meteorological characterisation of 2017, in which maximum temperature anomalies were observed during spring. Traffic and industrial emissions were considered the main contributors to these O_3 episodes (CAMS, 2018).

4.3 Contribution of emissions of ozone precursors, meteorology and hemispheric inflow to ozone concentrations

The EuroDelta-Trends modelling experiment (ETC/ACM, 2017a) estimated that the impact of reducing European anthropogenic emissions of O_3 precursors was the main factor in the reduction in O_3 concentrations between 1990 and 2010 in Europe. Regarding other factors, meteorological conditions contributed to a reduction in peak O_3 episodes (also confirmed by ETC/ACM, 2018b). In addition, hemispheric contributions helped to bring about an increase in the trend in annual means during the period 1990-2000 and a decrease in concentrations during the period 2000-2010. More information on O_3 trends can be found in the *Air quality in Europe — 2018 report* (EEA, 2018c).

4.4 Ozone precursors

With the objective of analysing any trend in O_3 precursors, checking the efficiency of emission reduction strategies, checking the consistency of emission inventories and helping attribute emission sources to observed pollution concentrations, the Ambient Air Quality Directive (EU, 2008) establishes the obligation of installing at least one sampling point per Member State to supply data on concentrations of some volatile organic compounds (VOCs), as they are O_3 precursors.

The recommended VOCs for measurement are presented in Table 4.2. Benzene (C_6H_6) is also recommended but, as a regulated pollutant, it is analysed in Chapter 7. For the rest of the recommended VOCs, 19 countries reported at least one of them; and, for each VOC, measurements were reported for at least two countries in 2017. The most commonly reported compounds are toluene (reported by 19 countries), *m*+*p*-xylene (15 countries), and ethyl benzene and *o*-xylene (14 countries each).

No single country reported all the recommended VOCs in 2017. Poland and Spain reported all except total non-methane hydrocarbons, and the United Kingdom reported all except 2-pentene, formaldehyde and total non-methane hydrocarbons.

The situation for the 30 recommended VOCs, excluding C_6H_6, and the 19 reporting countries is summarised in Table 4.2. The reported concentrations can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2019h).

Table 4.2 Status of reporting of O_3 precursors (VOCs) in 2017

Recommended VOCs	AT	BE	BG	DK	FI	DE	HU	IE	LV	LU	MT	NL	PL	PT	SI	ES	SE	CH	UK
ethane C_2H_6					×	×	×						×			×			×
ethylene $H_2C=CH_2$						×	×						×			×			×
acetylene $HC=CH$					×	×							×			×			×
propane $H_3C-CH_2-CH_3$					×	×	×						×			×			×
propene $CH_2=CH-CH_3$						×	×						×			×			×
n-butane $H_3C-CH_2-CH_2-CH_3$		×			×	×	×						×			×			×
i-butane $H_3C-CH(CH_3)_2$					×	×	×						×			×			×
1-butene $H_2C=CH-CH_2-CH_3$						×	×						×			×			×

Table 4.2 Status of reporting of O_3 precursors (VOCs) in 2017 (cont.)

Recommended VOCs	AT	BE	BG	DK	FI	DE	HU	IE	LV	LU	MT	NL	PL	PT	SI	ES	SE	CH	UK
trans-2-butene *trans*-$H_3C\text{-}CH{=}CH\text{-}CH_3$		×				×							×			×			×
cis-2-butene *cis*-$H_3C\text{-}CH{=}CH\text{-}CH_3$		×				×							×			×			×
1,3-butadiene $CH_2{=}CH\text{-}CH{=}CH_2$		×				×							×			×			×
n-pentane $H_3C\text{-}(CH_2)_3\text{-}CH_3$	×	×		×	×	×							×			×			×
i-pentane $H_3C\text{-}CH_2\text{-}CH(CH_3)_2$	×	×			×	×							×			×			×
1-pentene $H_2C{=}CH\text{-}CH_2\text{-}CH_2\text{-}CH_3$	×	×		×									×			×			×
2-pentene $H_3C\text{-}HC{=}CH\text{-}CH_2\text{-}CH_3$	×			×									×			×			
isoprene $CH_2{=}CH\text{-}C(CH_3){=}CH_2$		×		×		×							×			×			×
n-hexane C_6H_{14}	×	×		×		×							×			×			×
i-hexane $(CH_3)_2\text{-}CH\text{-}CH_2\text{-}CH_2\text{-}CH_3$	×	×		×		×							×			×			×
n-heptane C_7H_{16}	×	×		×		×							×			×			×
n-octane C_8H_{18}	×	×		×									×			×	×		×
i-octane $(CH_3)_3\text{-}C\text{-}CH_2\text{-}CH\text{-}(CH_3)_2$	×	×		×									×			×			×
toluene $C_6H_5\text{-}CH_3$	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
ethyl benzene $C_6H_5\text{-}C_2H_5$	×	×		×	×	×	×	×			×		×	×	×	×	×		×
m+*p*-xylene *m,p*-$C_6H_4(CH_3)_2$	×	×	×	×	×	×	×	×			×		×	×	×	×	×		×
o-xylene *o*-$C_6H_4\text{-}(CH_3)_2$	×	×		×	×	×	×	×			×		×	×	×	×	×		×
1,2,4-trimethylebenzene 1,2,4-$C_6H_3(CH_3)_3$	×	×	×	×									×			×			×
1,2,3-trimethylebenzene 1,2,3-$C_6H_3(CH_3)_3$	×		×	×									×			×			×
1,3,5-trimethylebenzene 1,3,5-$C_6H_3(CH_3)_3$	×	×	×	×	×								×			×			×
formaldehyde HCHO													×			×			
total non-methane hydrocarbons THC (NM)			×															×	

Notes: Information on C_6H_6, which is also a recommended VOC, is presented in Chapter 7.

AT: Austria, BE: Belgium, BG: Bulgaria, DK: Denmark, FI: Finland, DE: Germany, HU: Hungary, IE: Ireland, LV: Latvia, LU: Luxembourg, MT: Malta, NL: Netherlands, PL: Poland, PT: Portugal, SI: Slovenia, ES: Spain, SE: Sweden, CH: Switzerland, UK: United Kingdom.

× indicates that the pollutant was reported by the corresponding country.

5 Nitrogen dioxide

5.1 European air quality standards and World Health Organization guideline values for nitrogen dioxide

The European air quality standards, set by the Ambient Air Quality Directive (EU, 2008) for the protection of human health, and the air quality guidelines (AQGs) set by the World Health Organization (WHO) for nitrogen dioxide (NO_2) are shown in Tables 1.1 and 1.3, respectively. For convenience, they are summarised in Table 5.1.

The Ambient Air Quality Directive (EU, 2008) also sets a critical level for nitrogen oxides (NO_X) for the protection of vegetation, shown in Table 1.2. The vegetation exposure to NO_X concentrations above this standard is assessed in Section 11.4.

5.2 Status of concentrations

All the EEA-39 countries (except Greece, Kosovo and Liechtenstein) and Andorra submitted NO_2 data in 2017 with a minimum coverage of 75 % of valid data from 3 260 stations for the annual limit value and 3 078 stations for the hourly limit value. For additional information on the type of area and station, see Annex 1.

Sixteen of the EU Member States and four other reporting countries (Figure 5.1) recorded concentrations above the annual limit value (and the identical WHO AQG value). Concentrations were above the annual limit value at 10 % of all stations measuring NO_2. Map 5.1 shows that stations with concentrations above the annual limit value continued to be widely distributed across Europe in 2017, as in previous years.

The highest concentrations, as well as 86 % of all values above the annual limit value, were observed at traffic stations, with the exception of a few urban background stations in Turkey. In fact, the only six rural stations with concentrations above the annual limit value were traffic stations. Traffic is a major source of NO_2 and nitrogen monoxide (NO) (which reacts with ozone (O_3) to form NO_2). Furthermore, 98 % of the stations with values above the annual limit value were located in urban or suburban areas. Therefore, measures to reduce NO_2 concentrations and exceedances are often focused on traffic and urban locations, as mentioned in Section 1.6.

Annex 2 offers information on the NO_2 traffic concentrations of the cities with the traffic station reporting the highest and the lowest concentrations for each country.

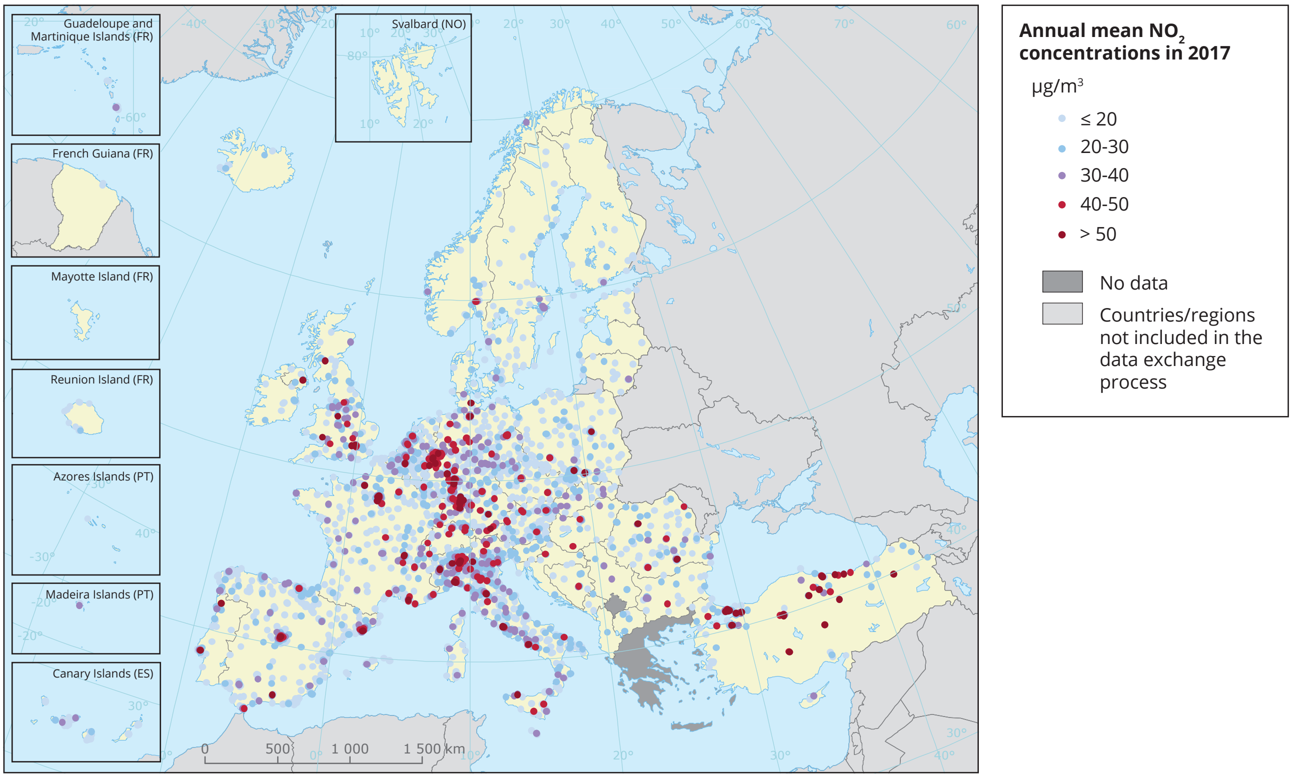
Concentrations above the hourly limit value were observed in 2017 in 1.3 % (39 stations) of all reporting stations, mostly at urban stations, except for one rural background station in Turkey. They were observed in nine countries ([22]).

Table 5.1 Air quality standards for protecting human health from NO_2

Pollutant	Averaging period	Standard type and concentration	Comments
NO_2	1 hour	EU limit value: 200 μg/m^3	Not to be exceeded on more than 18 hours per year
		WHO AQG: 200 μg/m^3	
		EU alert threshold: 400 μg/m^3	To be measured over 3 consecutive hours over 100 km^2 or an entire zone
	Calendar year	EU limit value and WHO AQG: 40 μg/m^3	

([22]) Turkey (24 stations), Spain (seven), the United Kingdom (two), and Bosnia and Herzegovina, Bulgaria, Italy, Portugal, Romania and Serbia (one each).

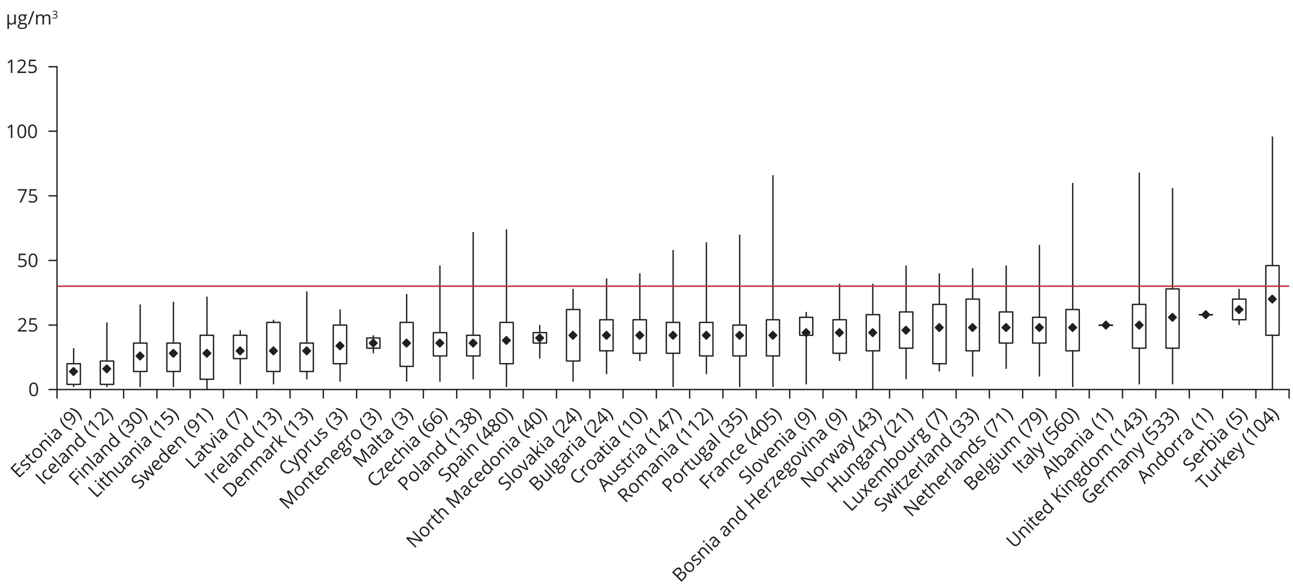
Map 5.1 Concentrations of NO_2, 2017



Note: Observed concentrations of NO_2 in 2017. Dots in the last two colour categories correspond to values above the EU annual limit value and the identical WHO AQG (40 µg/m³). Only stations with more than 75 % of valid data have been included in the map.

Source: EEA, 2019c.

Figure 5.1 NO_2 concentrations in relation to the annual limit value in 2017 and number of stations considered for each country



Note: The graph is based on the annual mean concentration values. For each country, the number of stations considered (in brackets) and the lowest, highest and average values (in µg/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The limit value set by EU legislation (which is equal to that set by the WHO AQG) is marked by the horizontal line. The graph should be read in relation to Map 5.1, as a country's situation depends on the number of stations considered.

Source: EEA, 2019c.

5.3 Contribution of nitrogen oxides emissions and meteorology to ambient nitrogen dioxide concentrations

Contributions from different emission sources and sectors to ambient air concentrations depend not only on the amount of pollutant emitted but also on the emission conditions (e.g. height of emission points), meteorological conditions and the distance to the receptor site. The road transport sector continued to contribute the highest proportion of NO_x emissions (39 % in the EU-28; see Figure 2.4) in 2017, followed by the energy production and distribution sector, and the commercial, institutional and households sector (see Section 2.2). However, the contribution of the road transport sector to population exposure to ambient NO_2 concentrations, especially in urban areas, is considerably higher, because its emissions are close to the ground and are distributed across densely populated areas.

For the period 1990-2000, meteorology caused an increase in measured NO_2 concentrations, which counteracted the effect of reduced NO_x emissions. Conversely, for the period 2000-2010, meteorology led to reduced NO_2 levels in north-western Europe and a slight increase in the south of Europe (ETC/ACM, 2018a).

Photo: © Johann P. Gebhardt, My City/EEA

6 Benzo[*a*]pyrene

6.1 European air quality standard and reference level for benzo[*a*]pyrene

The target value for benzo[*a*]pyrene (BaP) for the protection of human health and the estimated reference level (RL) ([23]) are presented in Tables 1.1 and 1.3. For convenience, they are summarised in Table 6.1.

6.2 Status of concentrations

Twenty-four Member States (all except Greece, Malta, Portugal and Romania) and two other reporting countries (Norway and Switzerland) reported BaP data ([24]), with sufficient data coverage ([25]) for 2017, from a total of 712 stations. For additional information on the type of area and station, see Annex 1.

Thirteen Member States ([26]) measured concentrations above 1.0 ng/m^3 in 2017 (Figure 6.1). As in previous years, values above 1.0 ng/m^3 are predominant in central and eastern Europe. The highest concentrations were recorded at many stations in Poland, mainly, and Czechia.

Similarly to 2015 and 2016, concentrations above 1.0 ng/m^3 were measured at 31 % of the reported BaP measurement stations in 2017 (Map 6.1), mainly at urban (79 % of all stations with values above 1.0 ng/m^3) and suburban (15%) stations.

Regarding the RL, all reporting countries, except Cyprus, the Netherlands and Sweden, have at least one station with concentrations above 0.12 ng/m^3. Only 16 % of the reported stations in 2017 had annual concentrations below the RL.

Ambient air concentrations of BaP are high mostly because of emissions from the domestic combustion of coal and wood (EEA, 2016), although for some specific countries (mostly in southern Europe) the contribution from burning agricultural waste is also relevant (EEA, 2017b).

6.3 Concentrations of other polycyclic aromatic hydrocarbons

To assess the contribution of BaP in ambient air, the Ambient Air Quality Directive (EU, 2004) outlines an obligation for Member States to monitor other relevant polycyclic aromatic hydrocarbons (PAHs) at a limited number of measurement sites. The compounds to be measured must include, at least, benzo[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*j*]fluoranthene, benzo[*k*]fluoranthene, indeno[1,2,3-*cd*]pyrene and dibenz[*a*,*h*]anthracene.

Table 6.1 Air quality standards for protecting human health from BaP

Pollutant	Averaging period	Standard type and concentration	Comments
BaP	Calendar year	EU target value: 1 ng/m^3	Measured as content in PM_{10}
		RL: 0.12 ng/m^3	

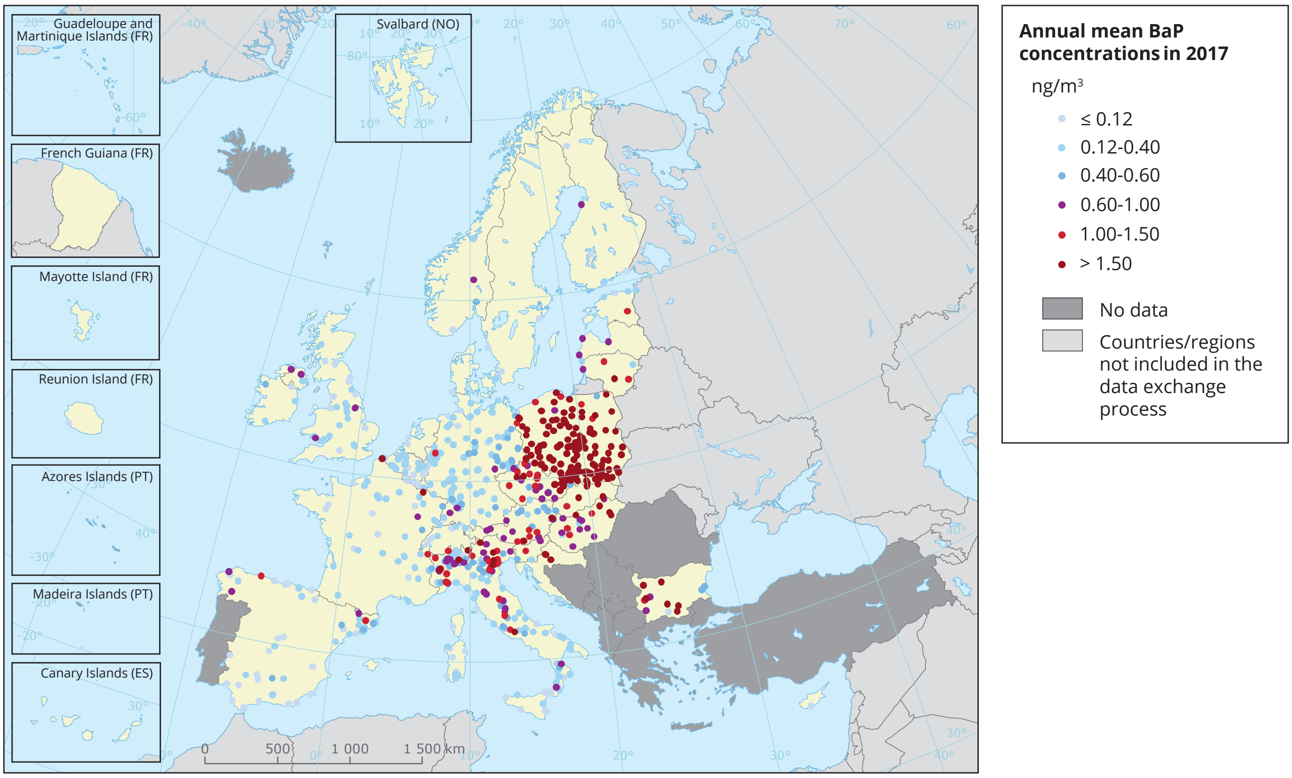
([23]) The estimated RL (0.12 ng/m^3) was estimated assuming WHO unit risk (WHO, 2010) for lung cancer for PAH mixtures and an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000 (ETC/ACM, 2011).

([24]) BaP is a PAH found mainly in fine PM. The Ambient Air Quality Directive (EU, 2004) prescribes that BaP concentration measurements should be made in the PM_{10} fraction. Going beyond this requirement, data available for any PM fraction were used in the current analysis. The justification is that most of the BaP is present in $PM_{2.5}$, not in the coarser fraction of PM_{10}, and the gaseous fraction of the total BaP is quite small. On the one hand, this may introduce some systematic differences in the measured data, but, on the other hand, the inclusion of additional measured data allows a broader analysis of BaP levels across Europe. For more information, see discussion by ETC/ACM (2015).

([25]) A data coverage of 14 %, as required by the Ambient Air Quality Directive (EU, 2004) for indicative measurements, was used as a minimum requirement for the analysis of BaP data.

([26]) Austria, Bulgaria, Croatia, Czechia, Estonia, France, Germany, Hungary, Italy, Lithuania, Poland, Slovakia and Spain.

Map 6.1 Concentrations of BaP, 2017

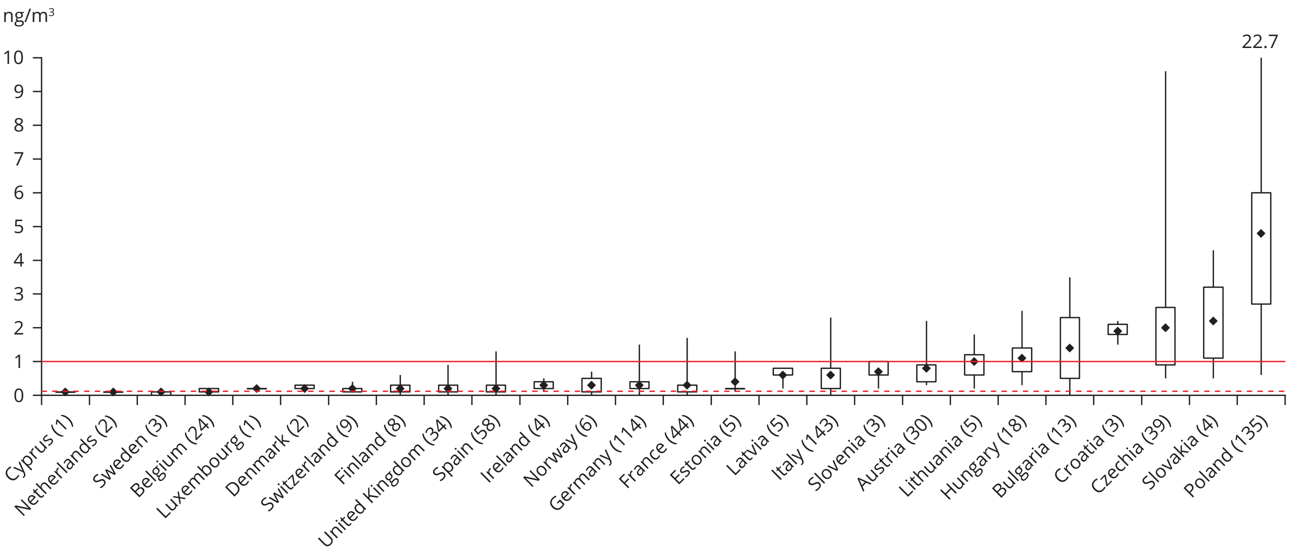


Notes: Observed concentrations of BaP in 2017. Dots in the first colour category correspond to concentrations under the estimated RL (0.12 ng/m³, Table 1.3). Dots in the last colour category correspond to concentrations exceeding the 2004 Ambient Air Quality Directive target value of 1 ng/m³.

Only stations reporting more than 14 % of valid data, as daily, weekly or monthly measurements, have been included in the map.

Source: EEA, 2019c.

Figure 6.1 BaP concentrations in 2017 and number of stations considered for each country



Note: The graph is based on the annual mean concentration values. For each country, the number of stations considered (in brackets), and the lowest, highest and average values (in ng/m³) recorded at its stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The upper horizontal line marks the concentration of 1.0 ng/m³. The lower horizontal line marks the estimated air quality RL. The graph should be read in relation to Map 6.1, as a country's situation depends on the number of stations considered. The highest value for Poland, 22.7 ng/m³, is out of the graph for representation purposes.

Source: EEA, 2019c.

In 2017, at least 16 countries reported measurements of one of the PAHs indicated in the Ambient Air Quality Directive (EU, 2004) (measured as particulate matter with a diameter of 10 µm or less, PM_{10} (aerosol)). Austria, Germany, Malta, Poland, Spain and the United Kingdom reported the six compounds; Croatia, Cyprus, Finland, Latvia and Lithuania reported all except benzo[*j*]fluoranthene; and Denmark reported all except benzo[*b*]fluoranthene and benzo[*j*]fluoranthene. The remaining reporting countries were Hungary, Ireland, the Netherlands and Slovenia, which reported three compounds each.

The reported concentrations can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2019h).

6.4 Deposition of polycyclic aromatic hydrocarbons

The Ambient Air Quality Directive (EU, 2004) also includes the obligation of setting up at least one background station for the indicative measurement of the total deposition of BaP and the other PAHs referred to previously. In 2017, 13 Member States reported at least one of the listed PAHs (reported as precipitation and dry deposition). The situation is summarised in Table 6.2, and the reported concentrations can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2019h).

Table 6.2 Reporting of total deposition of BaP and other PAHs in 2017

	AT	DK	FI	DE	HU	IE	LV	LT	PL	SI	ES	SE	UK
Benzo[*a*]pyrene	×	×	×	×	×	#	×	×	×	×	×	×	×
Benzo[*a*]anthracene	×	×	×	×	×	×			×	×	×	×	×
Benzo[*b*]fluoranthene	×			×		#			×			×	×
Benzo[*j*]fluoranthene	×			×					×				×
Benzo[*k*]fluoranthene	×			×		#			×		×	×	×
Indeno[1,2,3-*cd*]pyrene	×	×	×	×	×	#			×	×	×	×	×
Dibenz[*a*,*h*]anthracene	×	×		×	×	#			×	×	×	×	×

Notes: AT: Austria, DK: Denmark, FI: Finland, DE: Germany, HU: Hungary, IE: Ireland, LV: Latvia, LT: Lithuania, PL: Poland, SI: Slovenia, ES: Spain, SE: Sweden, UK: United Kingdom.

× indicates that the pollutant was reported by the corresponding country for at least one background station.
# indicates that the pollutant was reported by the corresponding country but not from its background stations.

7 Other pollutants: sulphur dioxide, carbon monoxide, benzene and toxic metals

7.1 European air quality standards and World Health Organization guideline values

Table 1.1 presents the European air quality standards for sulphur dioxide (SO_2), carbon monoxide (CO), lead (Pb), benzene (C_6H_6), arsenic (As), cadmium (Cd) and nickel (Ni) for the protection of human health, as established in the Ambient Air Quality Directives (EU, 2004, 2008).

Table 1.3 shows the World Health Organization (WHO) air quality guidelines (AQGs) for SO_2, CO, Cd and Pb and the reference levels (RLs) for As, Ni and C_6H_6 ([27]).

For convenience, all the standards are summarised in Tables 7.1-7.4 under the corresponding sections.

The Ambient Air Quality Directive (EU, 2008) also sets standards for SO_2 for the protection of vegetation, as shown in Table 1.2. The vegetation exposure to SO_2 levels above these standards is assessed in Section 11.4.

7.2 Status in concentrations

7.2.1 Sulphur dioxide

All EEA-39 countries (except Albania, Greece, Kosovo and Liechtenstein) plus Andorra reported measurements of SO_2 with data coverage over 75 % in 2017 from 1 644 stations for the hourly limit value and 1 415 for the daily limit value (Table 7.1).

In general, SO_2 concentrations are generally well below the limit values for the protection of human health, although exceedance of the WHO daily mean guideline persists.

In 2017, 19 stations ([28]) registered concentrations above the hourly limit value, and 21 stations ([29]) registered concentrations above the daily limit value for SO_2.

In contrast, 43 % of all the stations reporting SO_2 levels, located in 28 reporting countries ([30]), measured SO_2 concentrations above the WHO AQG of 20 μg/m^3 (Table 7.1) for daily mean concentrations in 2017.

Additional information on the different 2017 aggregations for SO_2 can be found in the EEA's 'Air quality statistics viewer' (EEA, 2019i).

Table 7.1 Air quality standards for protecting human health from SO_2

Pollutant	Averaging period	Standard type and concentration	Comments
SO_2	10 minutes	WHO AQG: 500 μg/m^3	
	1 hour	EU limit value: 350 μg/m^3	Not to be exceeded on more than 24 hours per year
		EU alert threshold: 500 μg/m^3	To be measured over 3 consecutive hours over 100 km^2 or an entire zone
	1 day	EU limit value: 125 μg/m^3	Not to be exceeded on more than 3 days per year
		WHO AQG: 20 μg/m^3	

([27]) As WHO has not provided a guideline for As, Ni or C_6H_6, the RLs presented in Table 1.3 were estimated assuming the WHO unit risk for cancer and an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000 (ETC/ACM, 2011).
([28]) Ten in Turkey, five in Bosnia and Herzegovina, three in Serbia and one in Bulgaria.
([29]) In Turkey (10), Bosnia and Herzegovina (five), Bulgaria (two), Serbia (two), Montenegro (one) and Poland (one).
([30]) All, except Andorra, Cyprus, Denmark, Ireland, Latvia, Luxembourg, Malta and Switzerland.

7.2.2 *Carbon monoxide*

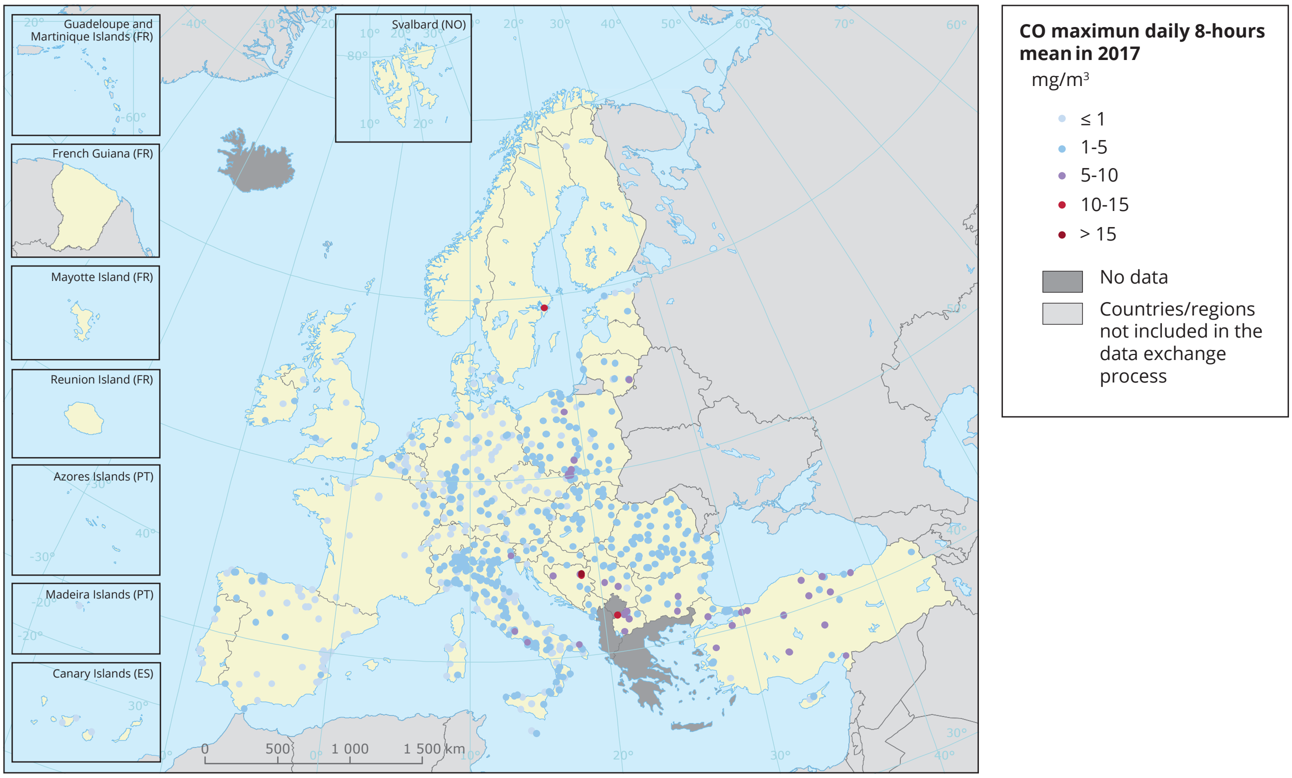
The highest CO levels are found in urban areas, typically during rush hour, or downwind from large industrial emission sources. All EEA-39 countries (except Albania, Greece, Iceland, Kosovo and Liechtenstein), plus Andorra, reported CO data from 809 ([31]) operational stations with more than 75 % of valid data. Only four stations registered concentrations above the CO limit value (Table 7.2) and the identical WHO AQG value in 2017: one urban traffic station and one urban industrial station in Bosnia and Herzegovina, and two more urban traffic stations in North Macedonia (one) and Sweden (one) (Map 7.1).

When concentrations are below the 'lower assessment threshold' (LAT), air quality can be assessed only by means of modelling or objective estimates. At 90 % of locations, maximum daily 8-hour mean concentrations of CO were below the LAT of 5 mg/m³ in 2017 (first two categories of coloured dots in Map 7.1).

Table 7.2 Air quality standards for protecting human health from CO

Pollutant	Averaging period	Standard type and concentration
CO	1 hour	WHO AQG: 30 mg/m³
	Maximum daily 8-hour mean	EU limit value and WHO AQG: 10 mg/m³

Map 7.1 Concentrations of CO, 2017



Note: Observed concentrations of CO in 2017. The map shows the CO maximum daily 8-hour mean. Dots in the last two colour categories correspond to values above the EU annual limit value and the WHO AQG (10 mg/m³). Only stations with more than 75 % of valid data have been included in the map.

Source: EEA, 2019c.

([31]) Portugal reported data from six more stations that were not considered because of their suspicious values.

7.2.3 Benzene

C_6H_6 measurements in 2017 with at least 50 % data coverage were reported from 769 stations in 30 European countries (all EU-28, except Greece, plus Albania, Norway and Switzerland).

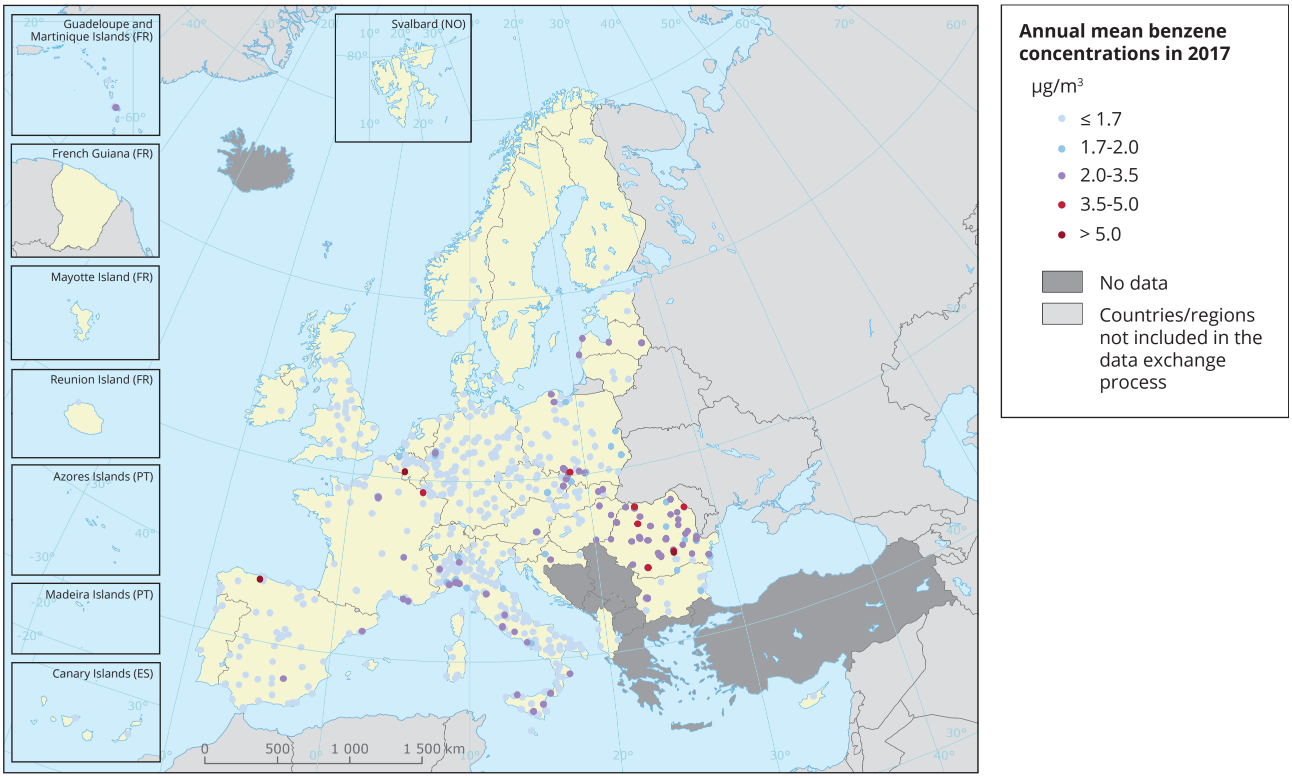
Only three stations measured concentrations above 5.0 µg/m³ — one urban background station in Belgium and two suburban industrial stations in Romania (one) and Spain (one). At 86 % of locations, annual mean concentrations of C_6H_6 were below the LAT of 2 µg/m³ in 2017 (first two categories of coloured dots in Map 7.2).

Regarding the estimated WHO RL (Table 7.3), 18 % of all stations reported concentrations above this RL in 2017, distributed across 15 European countries ([32]) (Map 7.2).

Table 7.3 Air quality standards for protecting human health from C_6H_6

Pollutant	Averaging period	Standard type and concentration
C_6H_6	Calendar year	EU limit value: 5 µg/m³
		RL: 1.7 µg/m³

Map 7.2 Concentrations of C_6H_6, 2017



Note: Observed concentrations of C_6H_6 in 2017. Dots in the last colour category correspond to concentrations above the limit value of 5 µg/m³. Dots in the first colour category correspond to concentrations under the estimated WHO RL (1.7 µg/m³, Table 7.3). Only stations reporting more than 50 % of valid data have been included in the map.

Source: EEA, 2019c.

([32]) In Austria, Belgium, Bulgaria, Croatia, Czechia, France, Germany, Greece, Hungary, Italy, Latvia, Poland, Romania, Slovakia and Spain.

7.2.4 Toxic metals

The monitoring network for toxic metals is not as widespread as that for the rest of the pollutants. This is probably because concentrations are generally low and below the LAT, allowing assessment to be made by modelling or objective estimation. In 2017, between 642 and 670 stations reported measurement data for each toxic metal (As, Cd, Pb and Ni), with a minimum data coverage of 14 %.

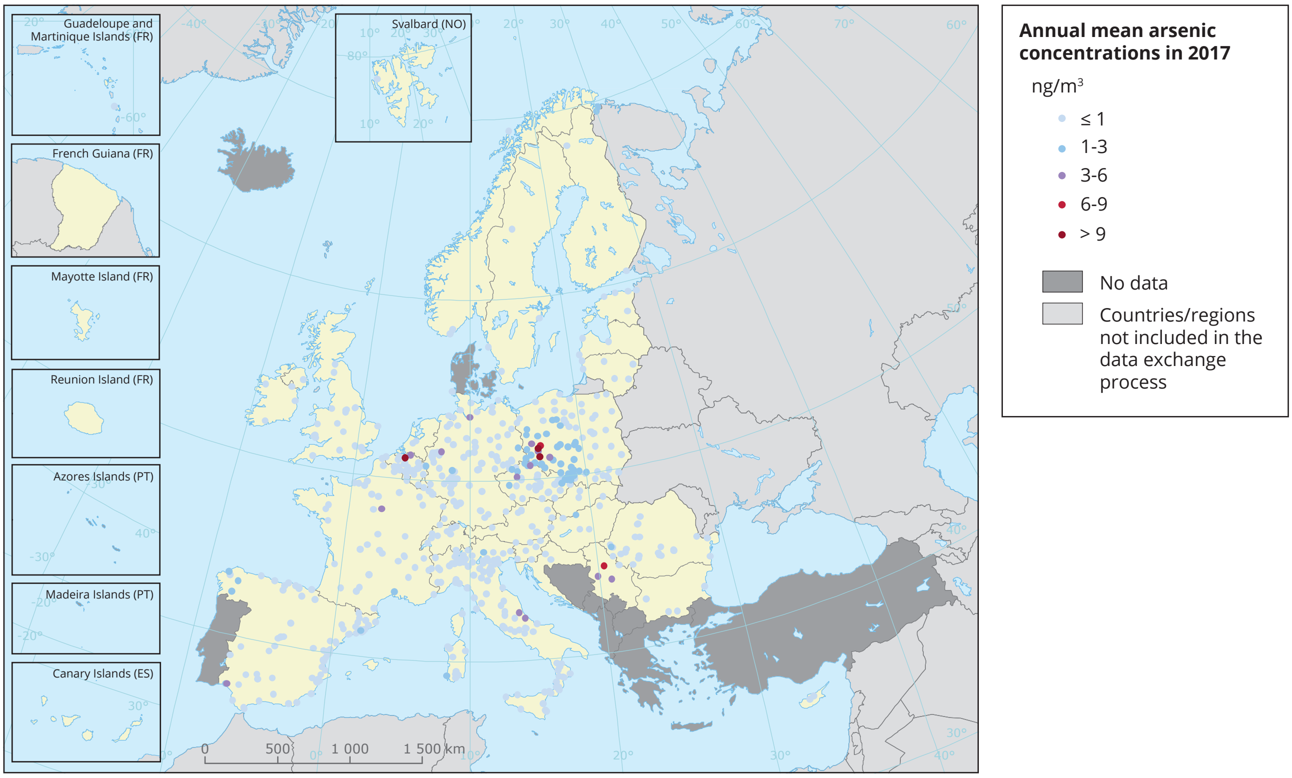
Concentrations of the toxic metals As, Cd, Pb and Ni above the EU standards are highly localised, as can be seen in Maps 7.3 to 7.6. The highest emissions are typically related to specific industrial plants. The results from the 2017 data reported can be summarised as follows:

- Data for As from 645 stations in 27 European countries ([33]) were reported in 2017. Seven stations in Belgium (three), Poland (three) and Serbia (one)

Table 7.4 Air quality standards for protecting human health from toxic metals

Pollutant	Averaging period	Standard type and concentration	Comments
Pb	Calendar year	EU limit value: 0.5 µg/m^3	Measured as content in PM_{10}
		WHO AQG: 0.5 µg/m^3	
As	Calendar year	EU target value: 6 ng/m^3	Measured as content in PM_{10}
		RL: 6.6 ng/m^3	
Cd	Calendar year	EU limit value: 5 ng/m^3	Measured as content in PM_{10}
		WHO AQG: 5 ng/m^3	
Ni	Calendar year	EU limit value: 20 ng/m^3	Measured as content in PM_{10}
		RL: 25 ng/m^3	

Map 7.3 Concentrations of As, 2017



Note: Observed concentrations of As in 2017. Dots in the last two colour categories correspond to concentrations above the EU target value. Only stations reporting more than 14 % of valid data have been included in the map.

Source: EEA, 2019c.

([33]) 24 Member States (all EU-28, except Denmark, Greece, Malta and Portugal), Norway, Serbia and Switzerland.

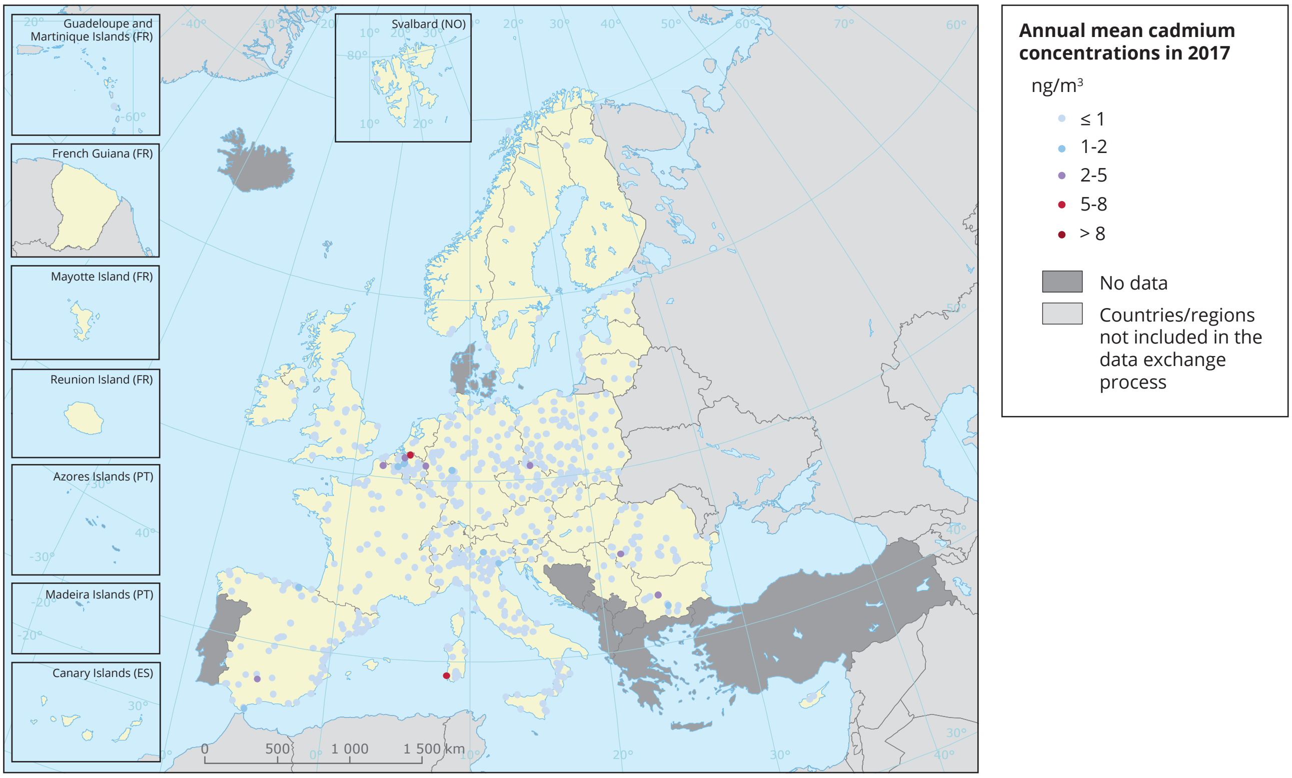
reported concentrations above the target value (6 ng/m³, Table 7.4) in both industrial suburban areas (two Belgian stations) and background urban areas (the other five). Concentrations of As below the LAT (2.4 ng/m³) were reported at 94 % of the stations in 2017 (Map 7.3).

- Cd data from 670 stations in 27 European countries ([34]) were reported in 2017. Concentrations above the target value (5 ng/m³, Table 7.4) were measured at two stations in 2017, in suburban areas, either industrial (Belgium, one station) or background (Italy, one station). At the great majority of stations (98 %), Cd concentrations were below the LAT (2 ng/m³) (Map 7.4).

- Pb data from 642 stations in 24 European countries ([35]) were reported in 2017. No stations reported Pb concentrations above the 0.5 µg/m³ limit value (Table 7.4). Overall, 637 stations (more than 99 % of the total) reported Pb concentrations below the LAT of 0.25 µg/m³ (Map 7.5).

- Ni data from 648 stations in 27 European countries ([36]) were reported in 2017. Concentrations were above the target value of 20 ng/m³ (Table 7.4) at five industrial stations in France (two), Belgium (one), Germany (one) and Norway (one). About 98 % of the stations reported Ni concentrations below the LAT of 10 ng/m³ (Map 7.6).

Map 7.4 Concentrations of Cd, 2017

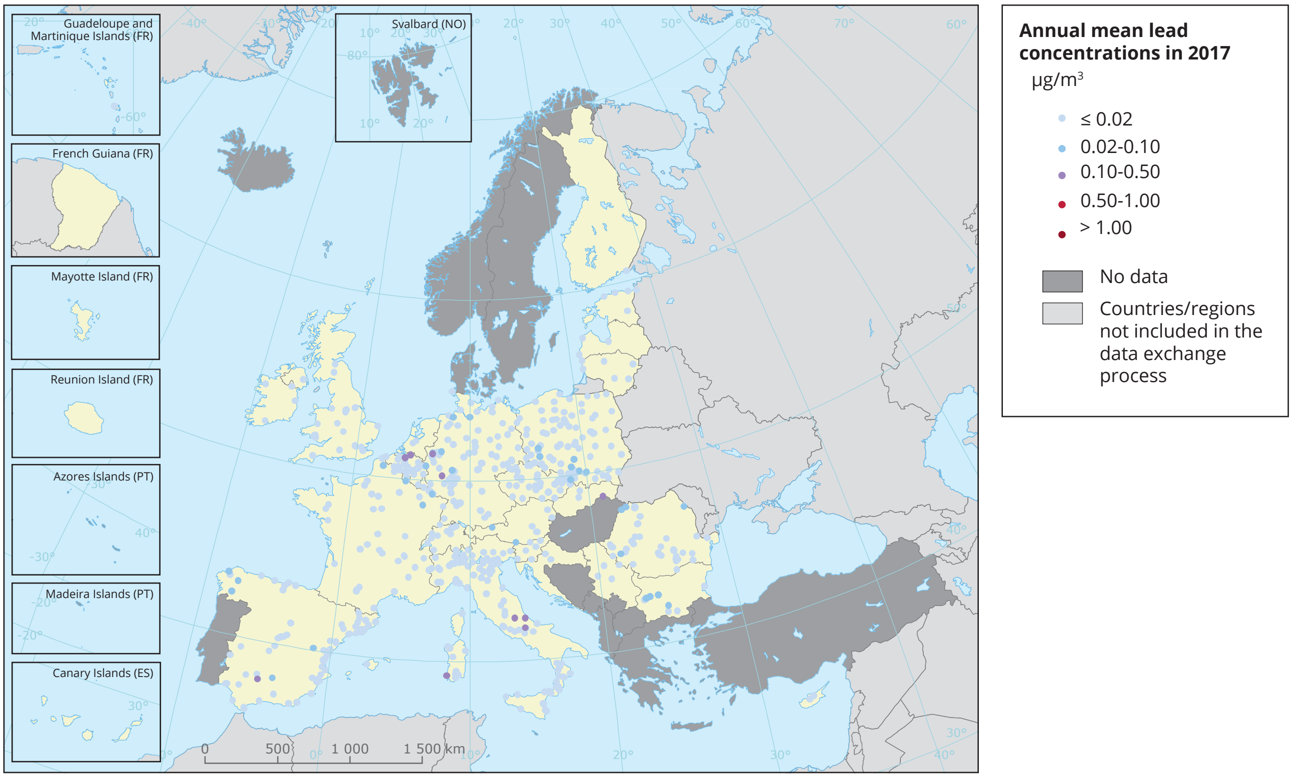


Note: Observed concentrations of Cd in 2017. Dots in the last two colour categories correspond to concentrations above the target value. Only stations reporting more than 14 % of valid data have been included in the map.

Source: EEA, 2019c.

([34]) 24 Member States (all EU-28, except Denmark, Greece, Malta and Portugal), Norway, Serbia and Switzerland.
([35]) 22 Member States (all EU-28, except Denmark, Greece, Hungary, Malta, Portugal and Sweden), Serbia and Switzerland. Sweden reported data from four stations, but they have not been considered because they were reported with the wrong units.
([36]) 24 Member States (all EU-28, except Denmark, Greece, Malta and Portugal), Norway, Serbia and Switzerland.

Map 7.5 Concentrations of Pb, 2017



Note: Observed concentrations of Pb in 2017. Dots in the last two colour categories correspond to concentrations above the EU annual limit value. Only stations reporting more than 14 % of valid data have been included in the map.

Source: EEA, 2019c.

The Ambient Air Quality Directive (EU, 2004) also includes the obligation of setting up at least one background station for the indicative measurement of the total deposition of As, Cd and Ni. In 2017, 13 Member States ([37]) reported total deposition (as precipitation and dry deposition) of As, Cd and Ni. The concentrations can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2019h).

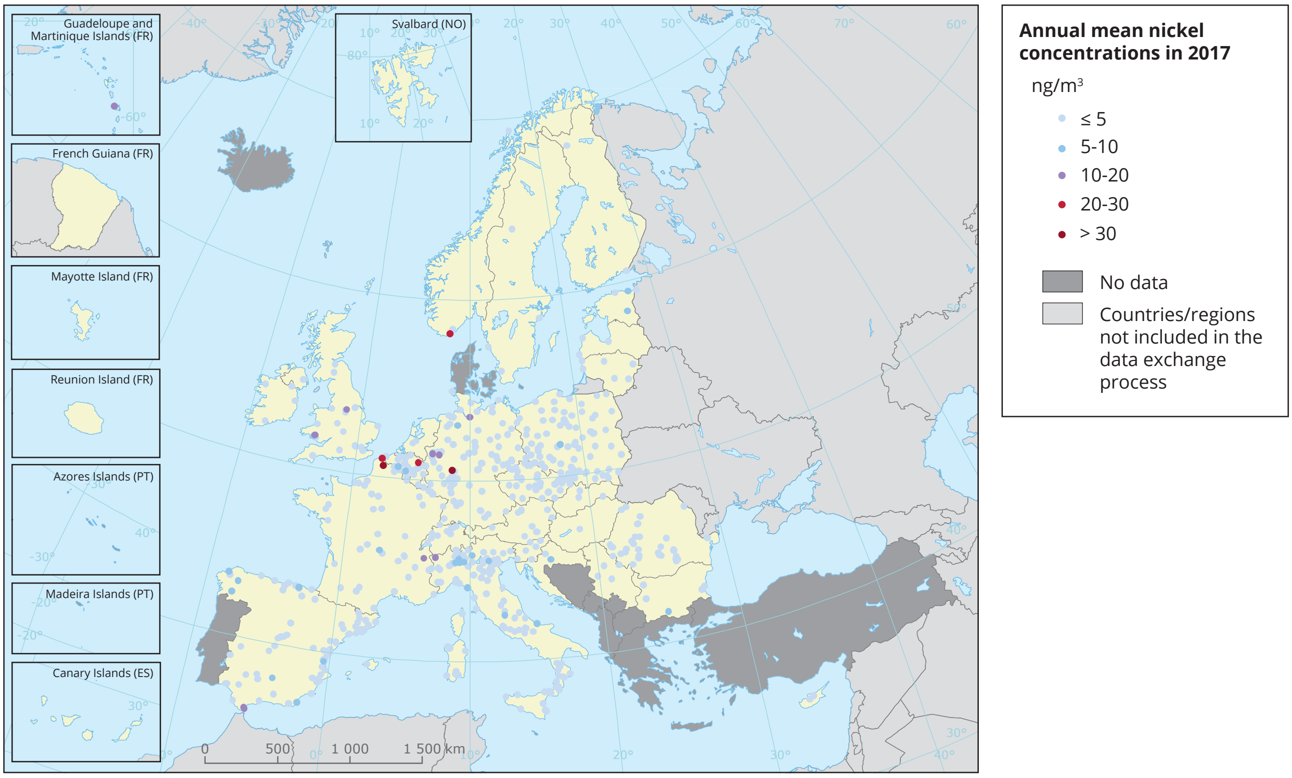
Mercury (Hg) concentrations recorded in the Air Quality e-Reporting Database are very sparse. The Ambient Air Quality Directive (EU, 2004) does not set any standard for Hg, but it calls on EU Member States to perform indicative measurements of total gaseous Hg and total deposition of Hg at one background station at least. It also recommends the measurement of particulate and gaseous divalent Hg. In 2017, Cyprus and Spain reported Hg in PM_{10} (although this was not from background stations); Sweden reported Hg in aerosol; and eight Member States ([38]) reported total deposition of Hg. The concentrations can be found in the EEA's 'Air quality statistics — Expert viewer' (EEA, 2019h).

In addition to reporting the concentration of toxic metals in ambient air, Member States are obliged by the Ambient Air Quality Directive (EU, 2004) to measure and report yearly their deposition onto the ground, in at least one rural background station per 100 000 km^2. The reported data can be found in the EEA's 'Air quality statistics — expert viewer' (EEA, 2019h).

The next chapter provides a deeper insight into toxic metals.

([37]) Austria, Belgium, Denmark, Finland, Germany, Hungary, Ireland, Latvia, Lithuania, Poland, Slovenia, Spain and the United Kingdom.
([38]) Austria, Belgium, Finland, Germany, Lithuania, Poland, Spain and the United Kingdom.

Map 7.6 Concentrations of Ni, 2017



Note: Observed concentrations of Ni in 2017. Dots in the last two colour categories correspond to concentrations above the target value. Only stations reporting more than 14 % of valid data have been included in the map.

Source: EEA, 2019c.

8 Toxic metals in Europe

Toxic metals present a significant risk to both the global environment and human health and are therefore regulated by European legislation and international environmental agreements. Chapter 2 presents the trends in the emissions of toxic metals over time. Chapter 7 presents the usual assessment of concentrations of toxic metals, as regulated by the Ambient Air Quality Directives (EU, 2004, 2008) and reported by the Member States. This chapter offers a broader analysis of toxic metal pollution and summarises associated health and environmental risks, gives an overview of relevant legislation, going beyond the Ambient Air Quality Directives (EU, 2004, 2008), and analyses and reviews available information on the status of and the trends in emissions, atmospheric concentrations and depositions of arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg) and nickel (Ni) in Europe.

Anthropogenic emissions of toxic metals, such as As, Cd, Pb, Hg and Ni, have transformed the global biogeochemical cycles of these metals by introducing considerable quantities of toxic metals into the atmosphere from various combustion processes and industrial activities. Despite considerable reductions in emissions (Chapter 2), thanks to developments in industrial processes and abatement technologies, the ecological and health risks associated with current and historical emissions are still important.

Toxic metals can reside in or be attached to particulate matter (PM), can be transported over long distances, and can remain in the environment, circulating through the air, water and land for many years. Although atmospheric concentrations, and subsequent exposure through inhalation, are usually low, anthropogenic air emissions contribute to the deposition and build-up of metals in soils, sediments and organisms. Toxic metals are persistent in the environment and some bioaccumulate, meaning that concentrations build up in the tissues of living organisms and in the food chain, leading to human exposure by consuming contaminated food.

It takes decades for the reduction of emissions and the deposition of metals to produce the desired effect of fewer environmental and health risks. It is therefore important to continue efforts to reduce anthropogenic emissions in Europe and globally, to avoid creating a large toxicity legacy for future generations.

8.1 Effects on health and ecosystems

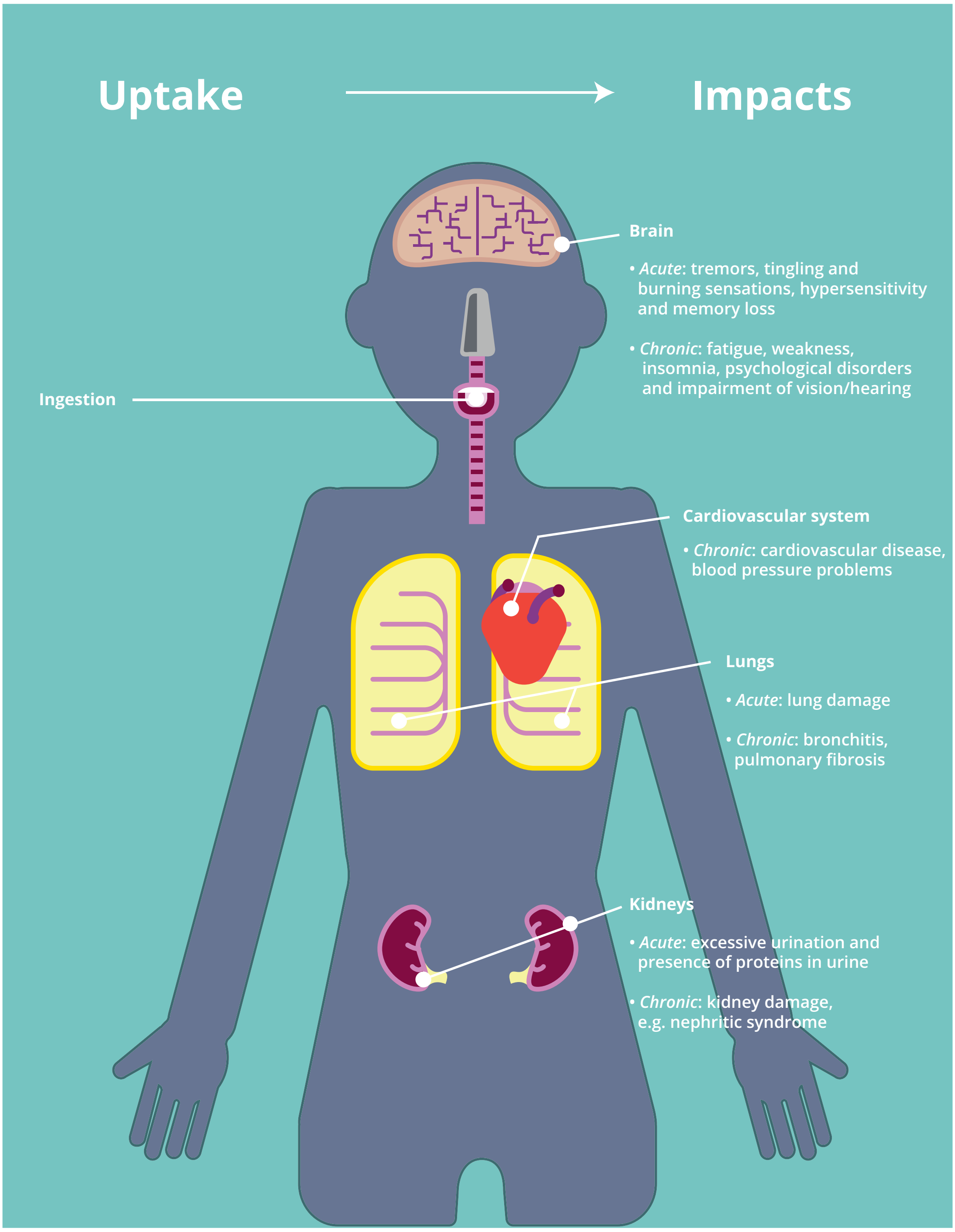
Humans are mostly exposed to toxic metals through ingestion of food and water (inhalation and direct contact are minor routes of exposure). Foetuses may be exposed in the womb to toxic metals present in the mother's blood, which diffuse across the placenta, while infants may be exposed to toxic metals through breastmilk (Farzan et al., 2013). Long-term exposure to As, Cd and Ni can cause cancer (IARC, 2012). Exposure to toxic metals affects several human organs and systems, impairing their function (Sivulka, 2005; Centeno et al. 2006; Barregard et al., 2010; Argos et al., 2010; Tolins et al., 2014; Quansah et al., 2015; Wu et al., 2016; Järup and Åkesson, 2019), such as the kidneys (Cd, Pb, Ni, Hg), the respiratory system (Cd, Ni, Hg), the reproductive system (As, Pb, Hg), the liver (Pb) and the skeletal system (Cd). Exposure to Hg, As and Ni can also increase the risk of cardiovascular disease and events (Sivulka, 2005; Karagas et al., 2012), while As and Ni can cause skin lesions and contact dermatitis (Duda-Chodak, 2008), respectively. Furthermore, exposure to As has also been associated with diabetes (Sung et al., 2015).

As an example, Figure 8.1 illustrates how Hg affects human health, with the principle route of human exposure in Europe being through consuming contaminated seafood.

Pb and Hg are neurotoxic metals that affect mainly the human brain and nervous system. Pb and Hg exposure in the womb or in infancy presents a significant risk to the development of the brain and nervous system in embryos and young children, potentially resulting in a significant reduction in intelligence quotient (IQ), impaired motor skills, delays in language development and memory, or attention deficits (Rubin and Strayer, 2008; Bose-O'Reilly et al., 2010; Grandjean and Herz, 2011). Bellanger et al. (2013)

estimated that nearly 1.9 million European babies are born after exposure to Hg levels above the recommended safe limits ([39]) per year. The authors estimated the annual economic cost of the damage (e.g. reduction in IQ) to be at least EUR 9 billion. Exposure to As has also been associated with neurotoxicity (Tolins et al., 2014) and developmental toxicity (Farzan et al., 2013).

Figure 8.1 The human uptake potential and relevant impacts of Hg



Note: Inhalation is another route of exposure, but it is negligible for the general population.

Source: Adapted from EEA, 2018d.

([39]) Methylmercury exposure during pregnancy below the limit of 0.58 µg/g, measured in the hair of the pregnant mothers, was considered safe.

Nedellec and Rabl (2016) found the costs of damage to human health from anthropogenic emissions of As, Cd, and Pb to be considerably higher than previously thought, as the costs presented by previous studies only accounted for cancers caused by As and Cd and loss of IQ caused by Hg and Pb. In addition, this study selected epidemiological studies targeting the general population, instead of small cohorts of industrial workers, identifying exposure response functions for various exposure levels.

In terms of effects on ecosystems, As, Cd, Pb, Ni and Hg are highly toxic to aquatic life and animals in general, often leading to the same health impacts in terrestrial animals as in humans. Most failures in the chemical status of surface waters can be attributed to three groups of substances: Hg and its compounds, polycyclic aromatic hydrocarbon (PAH), and polybrominated diphenylethers (EEA, 2018e). As and Ni can also impair plant growth and crop yields, while Pb and Cd affect the biodiversity of soil organisms. As, Cd, Pb and Hg are persistent in the environment and bioaccumulate.

8.2 Policies and regulations

Much has been done in recent decades to reduce As, Cd, Hg, Ni and Pb emissions and ambient air concentration and deposition in Europe through improved control and abatement techniques and targeted international and EU legislation. Such legislation includes:

- The 1998 Aarhus Protocol on Heavy Metals to the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) (UNECE, 2012) obliges parties to reduce their emissions of Cd, Hg and Pb. It has shown significant positive effects on emission reductions, for example Pb in petrol was phased out, and industrial installations reduced their dust emissions by employing highly efficient filters. The cooperative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe — the European monitoring and evaluation programme (EMEP) — is a scientifically based and policy-driven programme under the CLRTAP created to solve transboundary air pollution problems, including toxic metals, through international cooperation. EMEP bases its assessments of environmental pollution with toxic metals on both measurements and modelling ([40]).
- The EU Industrial Emissions Directive (integrated pollution prevention and control; EU, 2010) aims to prevent or minimise the pollution of water, air and soil. This directive targets certain industrial, agricultural and waste treatment installations and includes specific provisions on air emissions from large combustion plants and waste incineration.
- The European Pollutant Release and Transfer Register (E-PRTR) Regulation (EU, 2006) includes requirements for reporting emissions of several heavy metals released (and transferred) from certain industrial facilities.
- The Fuel Quality Directives (EU, 1998; amended by EU, 2009) intend to limit emissions of air pollutants due to vehicle fuel combustion, including Pb and other metals.
- The revised National Emission Ceilings (NEC) Directive (EU, 2016) introduced new reporting requirements on annual emissions of Cd, Pb and Hg, and, if available, As, Ni and other toxic metals.
- The Ambient Air Quality Directives were established in 2004 and 2008 (EU, 2004, 2008; see Section 1.5).
- The Minamata Convention (UN, 2013) is a global treaty set up to reduce Hg pollution and protect human health and the environment from the adverse effects of Hg.
- The Mercury Regulation (EU, 2017) outlines rules that aim to put the EU on track to become the first Hg-free economy. This includes putting an end to all uses of Hg in industrial processes and prohibiting any new use of Hg in products and industry, unless it has been proven that the use of Hg is necessary to protect health and the environment. EU legislation is more stringent than the Minamata Convention.

Under the Water Framework Directive (2000/60/EC), there are also a number of specific EU environmental quality standards for heavy metals in inland transitional and coastal waters (set by the Directive on Environmental Quality Standards (2008/105/EC). There are also conventions limiting pollution (including metals) of the marine environment, such as the Helsinki Convention ([41]). Furthermore, the Drinking Water Directive (98/83/EC, amended by EU 2015/1787) sets standards for toxic metals in drinking water, and there are regulations that set the maximum levels of some metals in food (Commission Regulation (EC) No 1881/2006).

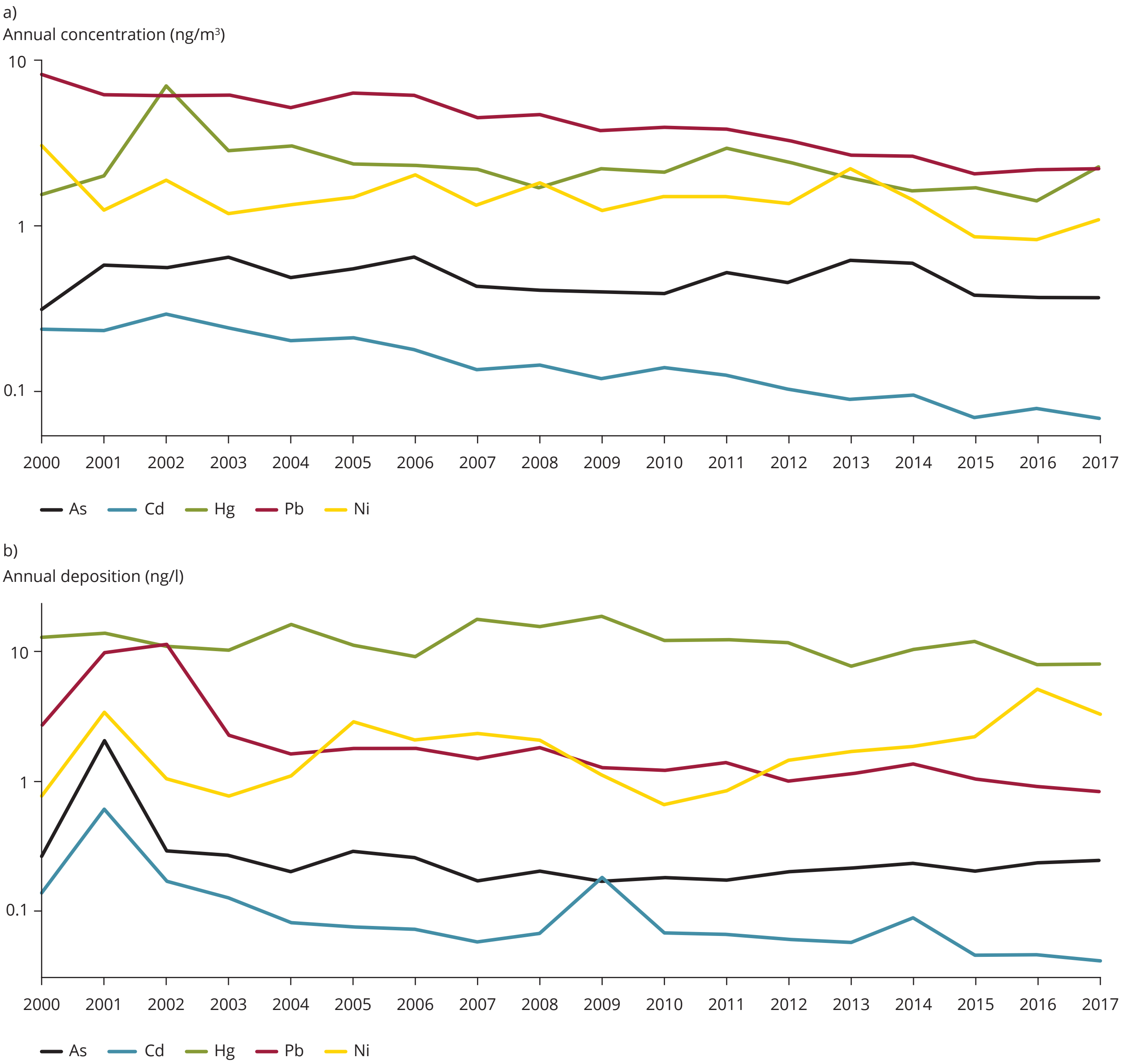
([40]) http://en.msceast.org
([41]) http://www.helcom.fi/Documents/About%20us/Convention%20and%20commitments/Helsinki%20Convention/Helsinki%20Convention_July%202014.pdf

The provisions in several of the regulations mentioned above require Member States to monitor and report emissions, concentrations and deposition of toxic metals. The following assessment of regulated toxic metal pollution in Europe is based on either data reported to the EEA and EMEP, or previous analyses made by EMEP, the EEA or the United Nations Environment Programme, including results from modelling activities, especially under EMEP.

8.3 Assessment of EU regulated toxic metal pollution

Annual mean concentration and deposition levels for EU regulated toxic metals observed in EMEP rural background sites between 2000 and 2017 are presented in Figure 8.2 ([42]). It is important to note that most of the stations are located in central, western, northern and south-west Europe, while in the vast

Figure 8.2 Time series for the annual concentrations (a) and depositions (b) between 2000 and 2017 for EMEP stations (rural background only) with minimum data coverage of 14 %, for As, Cd, Hg, Ni, and Pb



([42]) Only stations with an annual data coverage of 14 % were included in the analysis. The figure is not based on a consistent set of stations throughout the time period, i.e. stations and countries included in the average vary from year to year. The data are available from ebas.nilu.no.

areas of eastern and south-east Europe, measurements are scarce (EMEP, 2018a). These measurements indicate a decrease in concentration and deposition levels between 2000 and 2017 for Cd and Pb, while As, Hg and Ni ([43]) measurements show a larger interannual variability and no clear trend. These results are in line with those obtained for the period 1990-2012 in the EMEP area (Maas and Grennfelt, 2016). Both modelled and measured ambient air concentrations and depositions decreased for Cd and Pb, and very little for Hg, across the EMEP region between 2000 and 2012 (EMEP, 2015). Pb had the highest reduction in terms of deposition (around 50 %) and Hg had the lowest (around 5 %), while Cd deposition was reduced by around 33 % from 2000 to 2012.

Figure 8.3 depicts the annual variation in concentration per station type, based on the data reported by EEA member countries under the Ambient Air Quality Directives for the period 2006-2017 (EEA, 2019c). The assessed data include observations from all kinds of stations in urban or suburban areas (Box 1.1), that is, excluding the rural background sites assessed in Figure 8.2. The highest concentrations are typically measured in industrial sites, as the main emission sources are related to combustion processes and industrial activities (Chapter 2). As expected, the lowest concentrations are measured in the rural background stations presented in Figure 8.2.

The highest concentrations seen in Figure 8.3 are values typically measured in Belgium ([44]) and Poland for As; in Belgium, Bulgaria and Italy for Cd; in Denmark and Italy for Pb; and in Belgium, France, Germany, Italy, Norway and the United Kingdom for Ni. In 2017, the highest concentrations were observed in Poland for As, in Belgium for Cd and Pb, and in France for Ni (Maps 7.3 and 7.4). Atmospheric Hg concentrations are higher in central and eastern Europe, mostly because of higher anthropogenic emissions from coal combustion in this region (UN Environment, 2019b). European and non-European anthropogenic sources contribute almost equally to the total anthropogenic Hg deposition in Europe, which is dominated by emissions from power generation and industrial sectors (EMEP, 2018a).

The largest reductions in concentration for all metals since 2006 have been observed at industrial sites, which is in agreement with the largest emission reductions occurring in the sectors related to industrial and energy production (see Figure 2.3). The total emissions from the sectors related to industrial and energy production have decreased by 23 % for As, 32 % for Cd, 37 % for Hg and Pb, and 59 % for Ni from 2006 to 2017.

For urban and suburban background sites and traffic sites, the decrease observed since 2007 has not been as pronounced as that for industrial sites. Concentration levels for As decreased the least, as seen in the EMEP stations in Figure 8.2, following the same trend as emissions (see Figure 2.1a). For Pb emissions, the most significant reduction is seen in the early 2000s (a 53 % reduction from 2000 to 2007) with the phasing out of Pb in petrol. From 2007 to 2017, Pb emissions decreased by 26 %. The same has been observed for Cd, with a 30 % reduction from 2000 to 2007 and a 17 % reduction from 2007 to 2017. Ni emissions decreased more significantly between 2007 and 2017 (47 %) than between 2000 and 2007 (21 %). It is important to note that, while the total reductions in emissions for metals are mainly driven by emission reductions in the industry and energy production sectors, for the commercial, institutional and households sector, the emissions of Cd and Pb have increased since 2000.

The Aarhus Protocol has been a key driver of these reductions in emissions and concentrations, by imposing stringent limit values for emissions and driving the implementation of best available techniques, such as special filters or scrubbers for combustion sources, or Hg-free processes for controlling emissions of heavy metals and their compounds in existing and new stationary emission sources. The protocol aims to cut emissions of toxic metals from industrial sources (iron and steel industry, non-ferrous metal industry), combustion processes (power generation, road transport) and waste incineration.

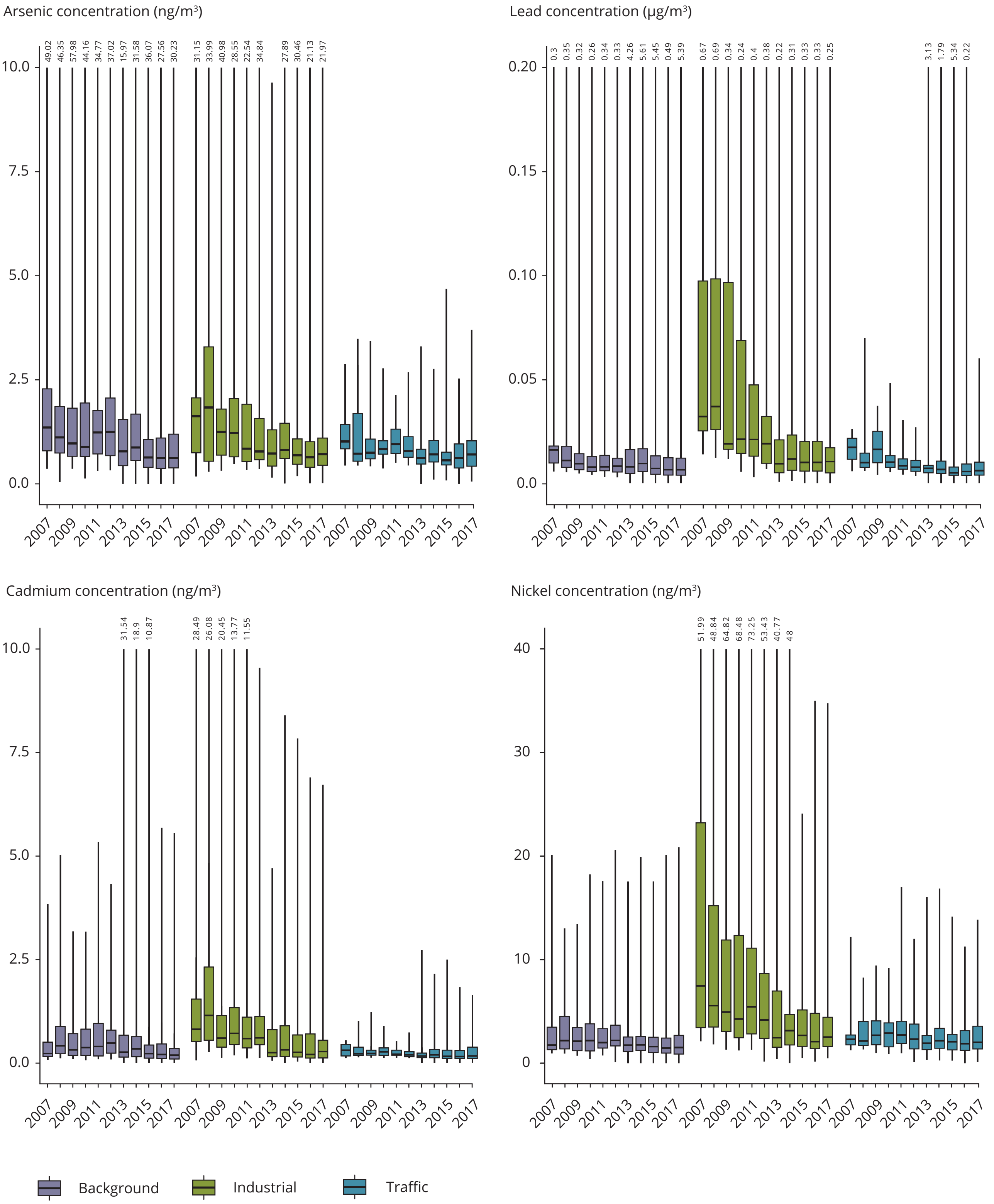
The limited spatial coverage in metal concentration and deposition monitoring, with monitoring sites mostly located in central and northern Europe, is a limitation for the assessment of metal pollution across Europe (EMEP, 2018a). Biomonitoring, for example the European moss survey, can provide better spatial information on toxic metal levels across Europe. Furthermore, the Ambient Air Quality Directive (EU, 2004) allows the use of biomonitoring where regional patterns of the impact on ecosystems are to be assessed.

8.4 Biomonitoring of metal deposition: the European moss survey

Concentrations of pollutants in mosses depend on atmospheric deposition, as mosses have no roots and obtain their nutrients from the atmosphere. Mosses have been used as biomonitors of atmospheric

([43]) The apparent increase in Ni deposition is due to stations in Norway, which recorded higher deposition starting measurements in 2012.
([44]) Measured at an urban background station.

Figure 8.3 Concentrations of toxic metals between 2007 and 2017 for EEA-33 stations



Notes: The boxplots are colour coded by station type: urban and suburban background stations (purple), all industrial stations (green) and all traffic stations (blue), with minimum data coverage of 14 %.

The graph is based on the annual mean concentration values. For each year, the lowest, highest and average values recorded at the EEA-33 stations are given. The rectangles mark the 25th and 75th percentiles. At 25 % of the stations, levels are below the lower percentile; at 25 % of the stations, concentrations are above the upper percentile. The number on top of the line indicates the highest value measured that year when it is higher than the concentration range in the y-axis. Hg measurements were not included, as there have not been sufficient stations measuring Hg over the last 12 years.

Source: EEA, 2019c.

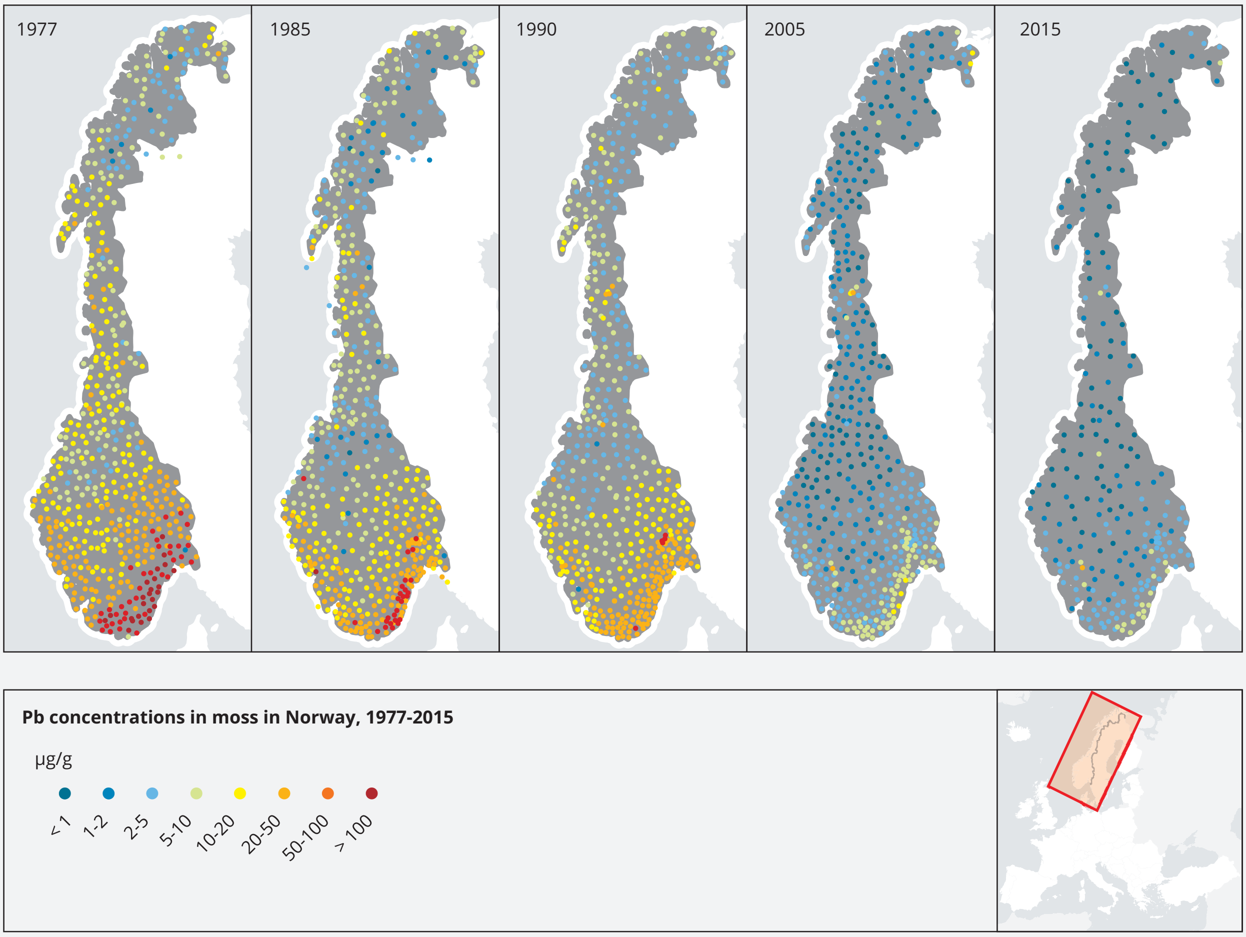
deposition of toxic metals in Europe since 1990 and in the Nordic countries since the late 1960s (Box 8.1). The European moss survey, conducted every 5 years across 32 European countries, provides information on spatial patterns of and temporal trends in atmospheric deposition of air pollutants onto vegetation (Schröder et al., 2010a, 2010b; Harmens et al., 2015a) and its results have been used within the CLRTAP ([45]).

Box 8.1 The Norwegian moss survey

Norway is one of the countries that has the most extensive sampling data set of toxic metals on mosses and soil, allowing for a good assessment of the spatial distribution of and temporal trends in concentrations for toxic metals (Schröder et al., 2016).

Deposition of As, Cd, Ni, Pb and Hg in Norway is higher in the south and lower to the north because of the contribution of long-range transport. Exceptions are areas of local emissions, typically industrial, in Norway or close to its border with Russia. Concentrations of As, Cd, Ni and Pb declined considerably from 1977 to 2015, mostly as a result of the reduction in industrial emissions in Norway and Europe and the international and domestic phasing out of Pb in petrol. No appreciable changes were observed during the period 2005-2015. These observations are illustrated in Map 8.1 for Pb. However, levels of Hg in moss show little temporal and geographical variation. The reason for this may be that the main source is deposition of Hg from the hemispheric pool, which is evenly distributed in the air over the northern hemisphere (Steinnes et al., 2003).

Map 8.1 Temporal trends in Pb concentrations in moss in Norway



Source: Steinnes et al., 2016.

([45]) In 2001, the UNECE International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops (ICP Vegetation) took over the coordination of the European moss survey from the Nordic Council of Ministers as requested by the CLRTAP.

Biomonitoring samples analysed by Schroder et al. (2016) indicate that northern European samples tend to have the lowest concentrations of toxic metals, and that the highest concentrations are found in south-eastern Europe, with Hg being the element with the most homogeneous pattern across Europe.

The assessment of the biomonitoring samples from the European moss survey, collected across Europe from 1990 to 2010, concludes that the spatially averaged metal concentrations across Europe have decreased since 1990, with Pb identified as the metal with the highest reduction (77 %) and Hg identified as the metal with the lowest reduction (14 %). Between 1990 and 2010, Cd levels decreased by 51 % and Ni levels by 33 %, while trends in As levels were variable and experienced a small reduction. These trends mostly correspond with the EMEP deposition measurements (EMEP, 2015).

8.5 Conclusions

Toxic metals released into the atmosphere, and subsequently deposited onto soils, water and vegetation, can cause significant environmental and health damage. Air emissions and ambient air concentrations are therefore regulated by European legislation and international environmental agreements.

Emissions of As, Cd, Ni, Pb and Hg have been reduced by 18 %, 42 %, 58 %, 65 % and 45 %, respectively, since 2000, in both the EU-28 and the EEA-33. This has led, on average, to a decrease in air concentrations and depositions, especially in industrial sites, as energy production and industrial activities have been the main anthropogenic sources of these metals in the last decade.

Despite the considerable reduction in emissions of toxic metals to the air in the past two decades, long-term risks remain for human health and ecosystems, because of the build-up of metal contents in soils, sediments and organisms from accumulated anthropogenic emissions. It is therefore necessary to continue efforts to reduce air emissions of toxic metals by focusing on implementing best available techniques and reducing the use of toxic metals in products.

Photo: © Anna Stankiewicz, WaterPIX/EEA

9 Population exposure to air pollutants

Health effects are related to both short- (over a few hours or days) and long-term (over months or years) exposure to air pollution. The Ambient Air Quality Directives and World Health Organization (WHO) define, respectively, air quality standards and guidelines for the protection of human health from both short- and long-term effects, depending on the pollutant and its effects on health (Tables 1.1 and 1.3). These values differ, and the WHO air quality guidelines (AQGs) are generally stricter (for nitrogen dioxide, NO_2, both the annual limit value and the long-term guideline are the same). The WHO AQGs are designed to offer guidance in reducing the health impacts of air pollution and are based on expert evaluation of current scientific evidence. The EU standards are a political compromise that also take into account what is economically feasible and optimum.

9.1 Exposure of the EU-28 population in urban and suburban areas in 2017

The monitoring data reported by the EU-28 (EEA, 2019c) provide the basis for estimating the exposure of the urban population ([46]) to values above the most stringent European air quality standards and WHO AQGs. Exposure is estimated based on measured concentrations at all urban and suburban background monitoring stations for most of the urban population and at traffic stations for populations living within 100 m of major roads. The methodology is described by the EEA (2019b).

Table ES.1 shows the minimum and maximum percentage of the EU-28 urban population exposed to concentrations above certain EU limit or target values and WHO AQG levels (or an estimated reference level, or RL, where no WHO AQG level exists) between 2015 and 2017. The ranges reflect, apart from changes in concentrations, variations attributable to meteorology and changes in the subset of cities and stations included in the year-to-year estimates.

In 2017, the proportion of the EU-28 urban population exposed to particulate matter with a diameter of 10 µm or less (PM_{10}) and particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$) levels above limit values and WHO AQGs showed a slight increase, compared with 2016. This stopped the continuous decreasing trend that has been observed since 2011 (only interrupted in 2015 for PM_{10}). Nevertheless, values are well below those recorded at the beginning of the time series (2000 for PM_{10} and 2006 for $PM_{2.5}$) (EEA, 2019b).

About 17 % of the EU-28 urban population was exposed to **PM_{10}** above the EU daily limit value. The extent of exposure above this EU daily limit value fluctuated between 13 % and 42 % during the period 2000-2017, with 2003 identified as being the year with the highest extent of exposure. Furthermore, 44 % of the same urban population was exposed to concentrations exceeding the stricter WHO AQG value for PM_{10} in 2017. The percentage of the urban population exposed to levels above the WHO annual AQG (20 µg/m^3) ranged between 42 % and 91 % (maximum also reached in 2003) during the period 2000-2017.

About 8 % of the EU-28 urban population was exposed to **$PM_{2.5}$** above the EU limit value in 2017. The percentage was in the range of 6-17 % in 2006-2017. The urban population's exposure to levels above the more stringent WHO AQG for $PM_{2.5}$ was 77 % in 2017, having fluctuated during the period 2006-2017 between 74 % and the initial maximum of 97 % in 2006.

In 2017, about 14 % of the EU-28 population in urban areas was exposed to ozone (**O_3**) concentrations above

([46]) The number of rural stations is too low and/or spatially not representative to estimate the exposure of the rural population.

the EU target value threshold. The percentage of the urban population exposed to O_3 levels above the target value threshold has fluctuated between 7 % and 55 % since 2000. The percentage of the EU-28 urban population exposed to O_3 levels exceeding the WHO AQG value remains very high. It reached 96 % in 2017 and has fluctuated between 94 % and 99 % since 2000.

Little less than 7 % of the EU-28 urban population was exposed to **NO_2** concentrations above the EU annual limit value and the WHO AQG value in 2017, setting a new minimum record. The percentage of the urban population exposed to concentrations above the annual limit value has gradually decreased since the maximum of 31 % in 2003 and has stabilised between 7 % and 9 % since 2012.

In 2017, 17 % of the urban population in the EU-28 was exposed to benzo[*a*]pyrene (**BaP**) annual concentrations above the EU target value (1.0 ng/m^3), and 83 % was exposed to concentrations above the estimated RL (0.12 ng/m^3), reaching some of the lowest values in the given time period. Nevertheless, since 2008, there has been no significant change in the extent of the urban population exposed to high BaP concentrations. Between 17 % and 24 % of the EU-28 urban population was exposed to BaP concentrations above the target value in 2008-2017, whereas 81-91 % of the EU-28 urban population was exposed to BaP concentrations above the estimated RL over the same period.

Exposure to sulphur dioxide (**SO_2**) has decreased over the past few decades, and, since 2007, the exposure of the urban population to concentrations above the EU daily limit value has remained under 0.5 %. The EU-28 urban population exposed to SO_2 levels exceeding the WHO AQG decreased from 85 % of the total urban population in 2000 to 31 % in 2017, which constitutes the highest value in the period 2015-2017.

Based on the available measurements for 2017 and previous years, it can be concluded that the European population's exposure to carbon monoxide (**CO**) and benzene (**C_6H_6**) ambient concentrations above the EU limit values is very localised and infrequent (Sections 8.2.2 and 8.2.3), as the few exceedances are located mainly at traffic and industrial hotspots. Concentrations above the estimated C_6H_6 WHO RL are more current and widespread.

Human exposure to arsenic (**As**), cadmium **(Cd**), lead **(Pb**) and nickel (**Ni**) ambient air concentrations above the EU limit or target values is restricted to a few areas in Europe, and it happens mainly at industrial areas. However, atmospheric deposition of toxic metals contributes to the exposure of ecosystems and organisms to toxic metals, and to bioaccumulation and biomagnification in the food chain, affecting human health (Chapter 8).

9.2 Exposure of total European population in 2016 and changes over time

To estimate the exposure of the total European population ([47]) to the various pollutant standards, an interpolation of annual statistics of reported monitoring data from 2016 has been used. It combines the monitoring data from rural and urban background stations (and traffic stations in the case of NO_2 to take into account hotspots, since traffic is the most important source of NO_2) with results from the European monitoring and evaluation programme (EMEP) chemical transport model ([48]) and other supplementary data (such as altitude and meteorology) (for further details, see ETC/ACM, 2017b, 2019). The maps of spatially interpolated air pollutant concentrations (annual mean concentration for PM_{10}, $PM_{2.5}$ and NO_2, and accumulated O_3 concentration (8-hour daily maximum) in excess of 35 parts per billion ppb, known as SOMO35) for O_3, are presented in Map 9.1. The population exposure is estimated by combining these concentration maps with the population density (based on the Geostat 2011 grid data set; Eurostat, 2014), which is the basis for the health impact assessment estimates presented in Chapter 10 ([49]).

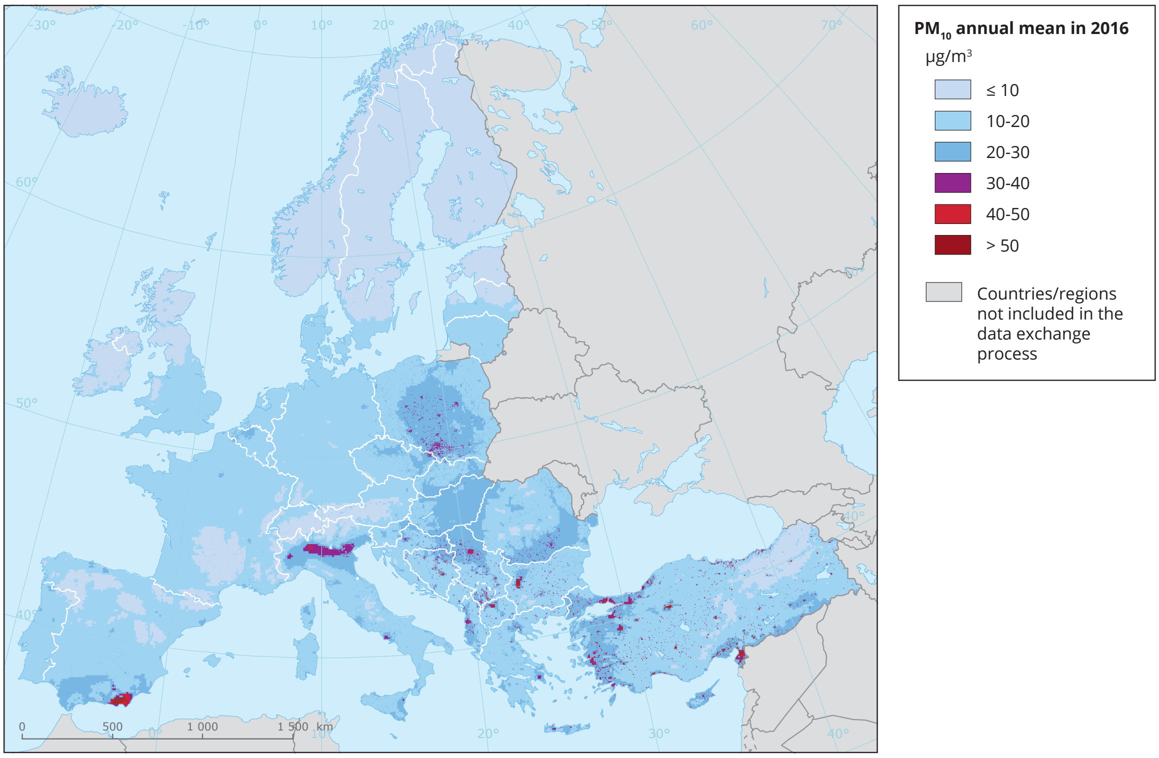
([47]) All European countries (not only EU-28) and all populations (not only urban).

([48]) At the time of drafting this report, the most up-to-date data from the EMEP model were from 2016; this is why exposure of total population is calculated for 2016 and not for 2017, as in the case of the urban population (Section 9.1).

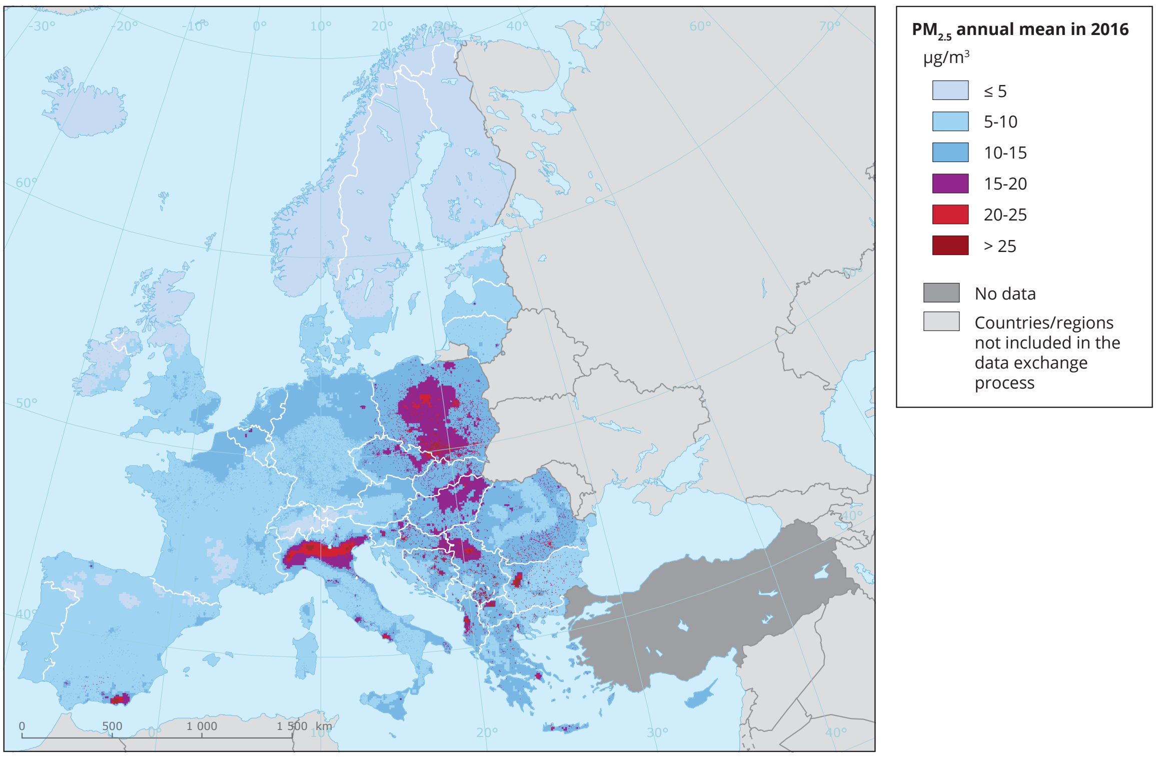
([49]) More detailed information on population exposure to $PM_{2.5}$, NO_2 and O_3 at country level can be found in Tables 3.1, 5.1 and 4.2 in ETC/ACM (2019).

Map 9.1 **Concentration interpolated maps of (a) PM_{10} (annual mean, µg/m³), (b) $PM_{2.5}$ (annual mean, µg/m³), (c) O_3 (SOMO35, µg/m³·days), and (d) NO_2 (annual mean, µg/m³) for 2016**

(a)

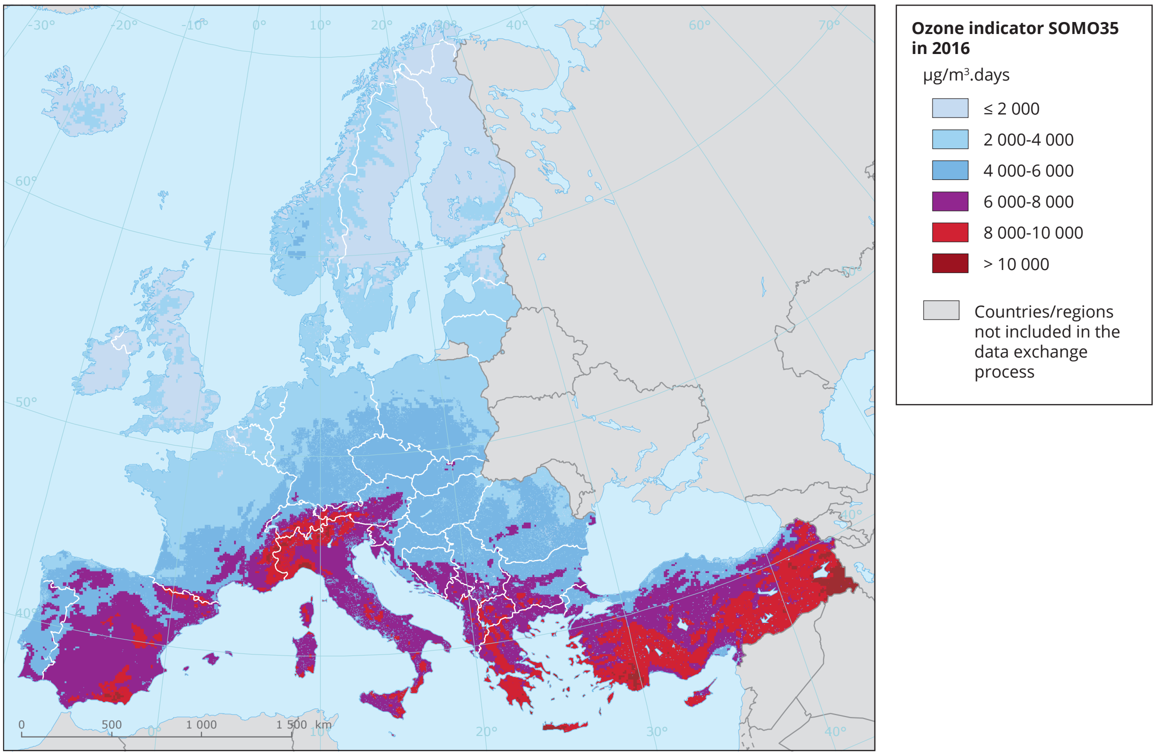


(b)

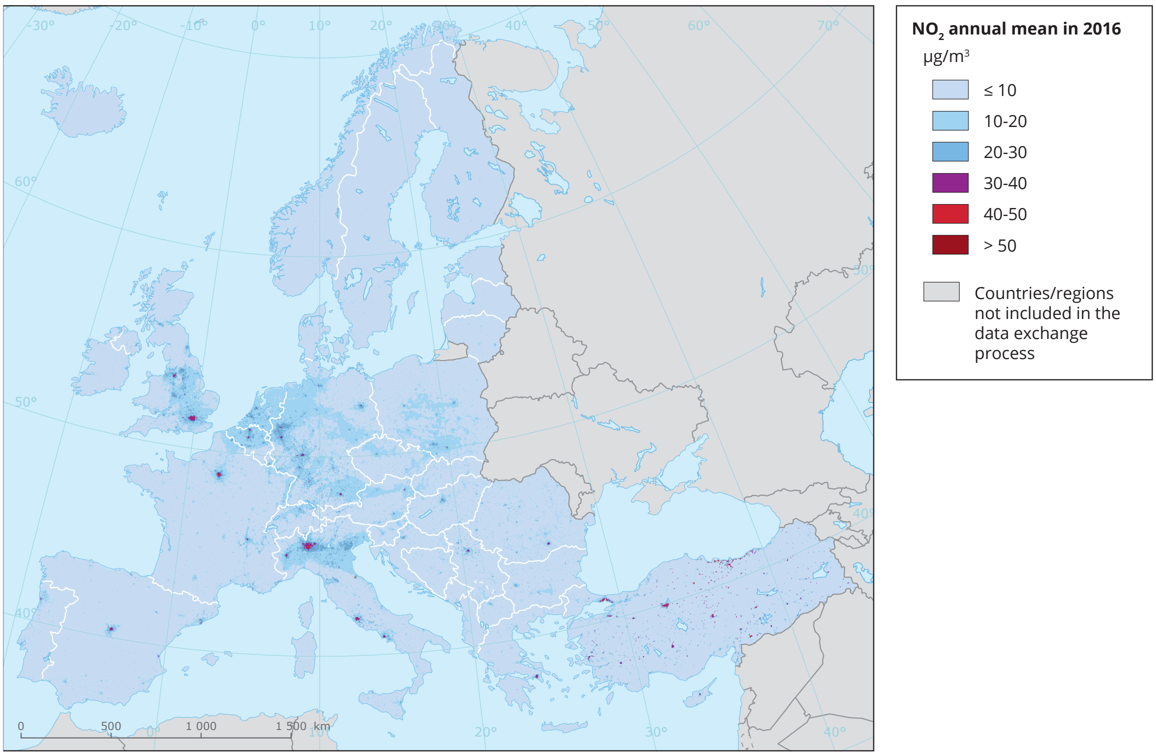


Map 9.1 **Concentration interpolated maps of (a) PM_{10} (annual mean, μg/m³), (b) $PM_{2.5}$ (annual mean, μg/m³), (c) O_3 (SOMO35, μg/m³·days), and (d) NO_2 (annual mean, μg/m³) for 2016 (cont.)**

(c)



(d)



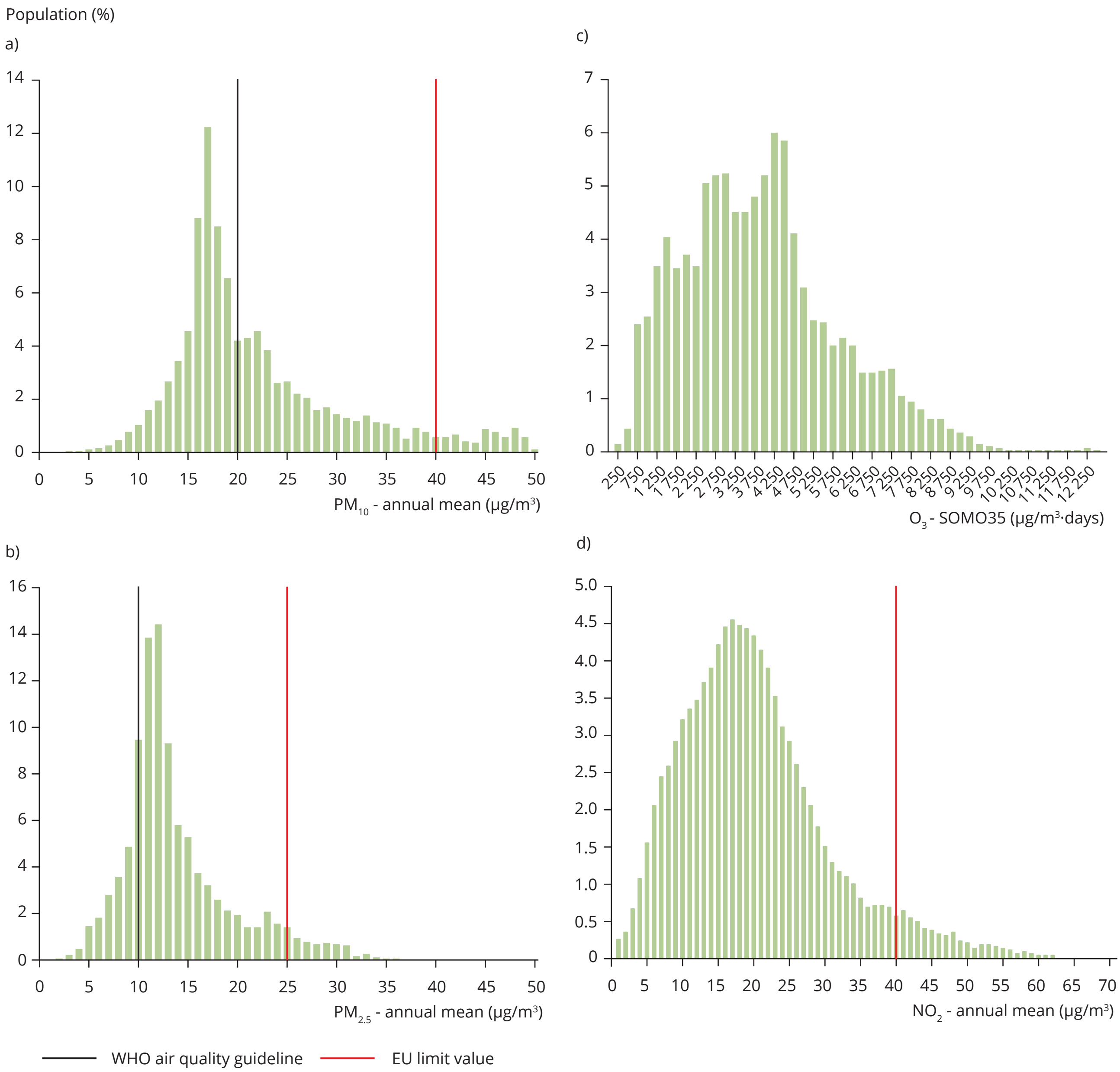
Note: Turkey is not included in the map of annual average $PM_{2.5}$, because there was a large uncertainty in the modelling results, due to the lack of rural background stations in the country.

Source: ETC/ACM, 2019.

Figure 9.1 shows the European population frequency distribution for each exposure class in 2016. About 44 % of the European population (and 38 % of the EU-28 population) was exposed in 2016 to PM_{10} annual average concentrations above the WHO AQG (bars to the right of the line at 20 µg/m³ in Figure 9.1a). The population exposure exceeding the EU limit value (bars to the right of the line at 40 µg/m³ in Figure 9.1a) was about 9 % for the population of the total European area considered and about 1 % for the EU-28.

When it comes to $PM_{2.5}$, around 75 % of the population of the total European area considered (excluding Turkey) and of the EU-28 were exposed in 2016 to annual mean concentrations above the WHO AQG (bars to the right of the line at 10 µg/m³ in Figure 9.1b). In addition, 5 % of the total population and 4 % of the EU-28 population were exposed to concentrations above the EU limit value (bars to the right of the line at 25 µg/m³ in Figure 9.1b).

Figure 9.1 Frequency distribution of the total population exposure to (a) PM_{10} (annual mean), (b) $PM_{2.5}$ (annual mean), (c) O_3 (SOMO35) and (d) NO_2 (annual mean) in 2016



Note: The graphs should be read in combination with the four maps in Map 9.1.

Source: ETC/ACM, 2019.

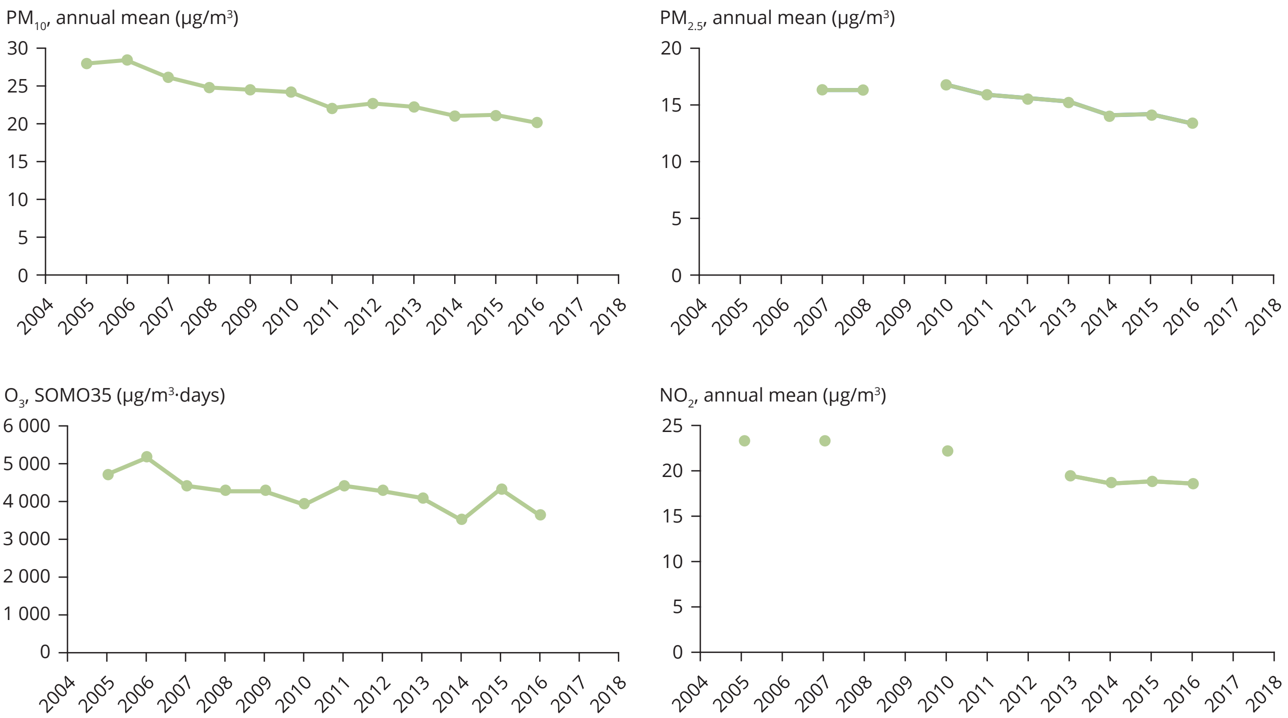
For O_3 (Figure 9.1c), it has been estimated that, in 2016, about 14 % of the European population and 12 % of the EU-28 population lived in areas with SOMO35 values above 6 000 µg/m^3·days ([50]).

Finally, for NO_2, it has been estimated that, in 2016, about 5 % of the European population and about 3 % of the EU-28 population lived in areas with annual average concentrations above the EU limit value (bars to the right of the line at 40 µg/m^3 in Figure 9.1d). It should be mentioned that, in contrast to the other pollutants, the NO_2 mapping methodology incorporates monitoring data from not only rural and urban background stations but also traffic locations (ETC/ACM, 2017b).

The results from the maps prepared in previous years enable an analysis of changes in total European population exposure over time (Figure 9.2). Exposure to both PM_{10} and $PM_{2.5}$ shows a steady decrease over time. For exposure to O_3 (expressed as SOMO35), a small decreasing trend is also observed in spite of year-to-year variability. For NO_2, exposures in the last 4 years available show barely any variation, but they are well below the values observed in the previous years (ETC/ACM, 2019).

Although the spatial distributions of PM, O_3 and NO_2 concentrations differ widely, the possibility of an accumulation of risks resulting from high exposures to all three pollutants cannot be excluded. The maps for the three most frequently exceeded EU standards (PM_{10} daily limit value, O_3 target value and NO_2 annual limit value) have been combined. This shows the following results: out of the total population of 538 million in the model area ([51]), 3.3 % (17.9 million) live in areas where two or three of these air quality standards are exceeded; and 2.5 million people live in areas where all three standards are exceeded. The worst situation is observed in Greece, where 5.4 % of the population live in areas where all three standards are exceeded; this is followed by Italy (in particular the Po valley), where it is also the case for 3.3 % of the population (2.0 million inhabitants).

Figure 9.2 Changes in total European population exposure to PM_{10}, $PM_{2.5}$, (annual mean), O_3 (SOMO35) and NO_2 (annual mean) from 2005 to 2016



Note: Exposure is expressed as population averaged concentrations. The total European population does not include Turkey, since, in the years before 2016, it was not included in the interpolated maps.

Source: ETC/ACM, 2019.

([50]) The comparison of the 93.2 percentile of maximum daily 8-hour means with the SOMO35 results for all background stations shows that there is no simple relationship between the two indicators; however, it seems that the O_3 target value threshold (120 µg/m^3) is related, to some extent, to SOMO35 in the range 6 000-8 000 µg/m^3·days (ETC/ACM, 2019).

([51]) Turkey has not been included in these calculations because of the lack of $PM_{2.5}$ information in the interpolated map.

10 Health impacts of exposure to fine particulate matter, ozone and nitrogen dioxide

It is well documented that exposure to air pollution may lead to adverse health effects, such as premature mortality and morbidity, mainly related to respiratory and cardiovascular diseases (WHO, 2006b, 2008, 2013b). Mortality reflects a reduction in life expectancy owing to premature death as a result of exposure to air pollution, whereas morbidity relates to the occurrence of illness and years lived with a disease or disability, ranging from subclinical effects (e.g. inflammation) and symptoms such as coughing to chronic conditions that may require hospitalisation. Even less severe effects might have strong public health implications, because air pollution affects the whole population on a daily basis.

Methods to quantify mortality and morbidity effects are available, and they are based on air pollution concentration, basic demographic and health data, and the relationship between the ambient concentrations and each specific health outcome. This can be translated into number of human lives lost or costs associated with mortality and morbidity. A number of studies (e.g. WHO and OECD, 2015) also show that, after monetising the health effects, the total external costs caused by mortality outweigh those arising from morbidity. In this report, the focus is, as in previous years, on estimating the premature mortality related to air pollution, focusing on particulate matter (PM), nitrogen dioxide (NO_2), and ozone (O_3). Exposure to other air pollutants, such as benzene (C_6H_6) or polycyclic aromatic hydrocarbons (PAHs) (in particular benzo[*a*]pyrene, BaP), also has strong health impacts; however, under the current European air quality conditions, their impact on total air pollution-related mortality is small compared with PM, NO_2, and O_3, and may, in part, be already included in estimates of the effects of PM.

10.1 Methodology used to assess health impacts

The impacts attributable to exposure to $PM_{2.5}$, NO_2 and O_3 in Europe for 2016 ([52]) presented in this report are based on mortality endpoints (see Box 10.1). This assessment required information on air pollution, demographic data, health/mortality data and the relationship between exposure to ambient pollutant concentrations and a health outcome. The maps of annual mean concentrations for $PM_{2.5}$, NO_2 and SOMO35, used in the assessment are presented in Section 9.2. The demographic data and life expectancy data were taken from Eurostat (2019f, 2019g), and the mortality data were taken from WHO (2019c). The exposure-response relationship and the population at risk have been selected following a recommendation from the Health Risks of Air Pollution in Europe (HRAPIE) project (WHO, 2013b). For $PM_{2.5}$, all-cause (natural) mortality is considered in ages above 30, for all concentrations, assuming an increase in the risk of mortality of 6.2 % for a 10 μg/m^3 increase in $PM_{2.5}$. For NO_2, all-cause (natural) mortality is considered in ages above

Box 10.1 Mortality endpoints

Premature deaths are deaths that occur before a person reaches an expected age. This expected age is typically the life expectancy for a country stratified by sex. Premature deaths are considered preventable if their causes can be eliminated.

Years of life lost (YLL) is defined as the years of potential life lost due to premature death. It is an estimate of the average number of years that a person would have lived if he or she had not died prematurely. YLL takes into account the age at which deaths occur and is greater for deaths at a younger age and lower for deaths at an older age. It gives, therefore, more nuanced information than the number of premature deaths alone.

([52]) In the methodology used, the air pollutant concentrations are obtained from interpolated maps (see Section 9.2 and Map 9.1). To produce these maps, information from the EMEP model is needed and, at the time of drafting this report, the most up-to-date data from the EMEP model were from 2016 (ETC/ACM, 2019).

30, for concentrations above 20 µg/m^3, assuming an increase in the risk of mortality of 5.5 % for a 10 µg/m^3 increase in NO_2. For O_3, all-cause (natural) mortality is considered for all ages, assuming an increase in the risk of mortality of 0.29 % for a 10 µg/m^3 increase in O_3 values over 35 ppb ([53]). A detailed description of the methodology can be found in ETC/ACM (2016) and EEA (2018f).

The relative risks described in the paragraph above have an uncertainty that is expressed as confidence intervals (CIs). These CIs provide the upper and lower boundaries of the 95 % CI of the estimate, taking into account only the uncertainty in the relative risks. These CIs are 4.0-8.3 % for $PM_{2.5}$, 3.1-8.0 % for NO_2, and 0.14-0.43 for O_3.

Quantifications of health impacts are done individually for these air pollutants, and they cannot be added together, as they exhibit some degree of correlation, positive or negative. For example, when adding together the values for $PM_{2.5}$ and NO_2, this may lead to double counting of the effects of NO_2 up to 30 % (WHO, 2013b).

10.2 Health impact assessment results

The results of the health impact assessment related to $PM_{2.5}$, NO_2, and O_3 exposure are presented in Tables 10.1 and 10.2 for 41 European countries. These tables show the population-weighted concentration and the estimated number of attributable premature deaths (Table 10.1), and the number of years of life lost (YLL) and the YLL per 100 000 inhabitants (Table 10.2) because of exposure to $PM_{2.5}$, NO_2 and O_3 concentration levels in 2016.

In the 41 countries listed, 412 000 premature deaths are attributed to $PM_{2.5}$ exposure, 71 000 to NO_2 exposure, and 15 100 to O_3 exposure. In the EU-28, the premature deaths attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 374 000, 68 000, and 14 000, respectively. In line with the small decreases in concentrations, the estimated numbers attributable to $PM_{2.5}$, NO_2 and O_3 are slightly lower than those estimated for 2015.

In the 41 countries assessed, 4 223 000 YLL are attributed to $PM_{2.5}$ exposure, 707 000 to NO_2 exposure, and 147 000 to O_3 exposure (Table 10.2). In the EU-28, the YLL attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 3 848 000, 682 000, and 137 000, respectively.

The largest contribution to the uncertainties in the estimates of premature deaths and YLL is related to the choice of the relative risk coefficients. In the results presented below, the uncertainties in health outcomes (expressed as 95 % CIs) are estimated as:

- for the EU-28 estimates of premature deaths, 248 000-489 000 for $PM_{2.5}$, 39 000-97 000 for NO_2 and 6 700-20 800 for O_3;
- for the 41 European countries estimates of premature deaths, 273 000-537 000 for $PM_{2.5}$, 41 000-100 000 for NO_2 and 7 300-22 400 for O_3.

The largest health impacts in terms of premature deaths and YLL attributable to $PM_{2.5}$ are estimated for the countries with the largest populations, namely Germany, Italy, Poland, France and the United Kingdom. However, in relative terms, when considering YLL per 100 000 inhabitants, the largest impacts are observed in central and eastern European countries where the highest concentrations are also observed, namely Kosovo, Serbia, Bulgaria, Albania and North Macedonia. The smallest relative impacts are found in countries situated in the north and north-west of Europe, namely Iceland, Norway, Sweden, Ireland and Finland.

For NO_2, the largest impacts from exposure are seen in Italy, Germany, the United Kingdom, Spain and France. When considering YLL per 100 000 inhabitants, the highest rates are found in Monaco, Greece, Italy, Serbia, Cyprus and the United Kingdom.

Regarding O_3, the countries with the largest impacts are Italy, Germany, Spain, France and Poland; and the countries with the highest rates of YLL per 100 000 inhabitants are Greece, Albania, Monaco, Kosovo, Italy and Montenegro. The countries with the smallest impacts are Andorra, Iceland and Ireland.

([53]) In 2017 and 2018, a sensitivity analysis was performed using various concentrations above which to consider the health impacts (EEA, 2017b, 2018c), namely the effects from 2.5 µg/m^3 of $PM_{2.5}$ and from 10 µg/m^3 of NO_2. The results of a similar analysis, together with those considering O_3 values over 10 ppb, are shown this year in Annex 3.

Table 10.1 Premature deaths attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28, 2016

		$PM_{2.5}$		NO_2		O_3	
Country	**Population (1 000)**	**Annual mean ([a])**	**Premature deaths ([b])**	**Annual mean ([a])**	**Premature deaths ([b])**	**SOMO35 ([a])**	**Premature deaths ([b])**
Austria	8 700	12.0	5 300	18.9	1 000	4 522	270
Belgium	11 311	12.7	7 600	21.7	1 600	2 203	180
Bulgaria	7 154	22.3	13 100	18.8	1 100	3 347	280
Croatia	4 191	19.4	5 300	15.2	260	4 996	190
Cyprus	1 184	13.7	580	24.0	240	5 612	30
Czechia	10 554	16.6	9 600	15.2	240	4 353	350
Denmark	5 707	9.2	2 700	10.4	80	2 293	90
Estonia	1 316	5.9	500	7.8	< 1	1 949	20
Finland	5 487	5.1	1 500	8.0	< 1	1 510	60
France	64 977	10.9	33 200	17.3	7 500	3 420	1 400
Germany	82 176	11.6	59 600	20.2	11 900	3 368	2 400
Greece	10 784	19.6	12 900	19.6	2 900	6 871	640
Hungary	9 830	17.5	12 100	16.6	770	3 952	380
Ireland	4 726	6.8	1 100	11.0	50	1 323	30
Italy	60 666	16.6	58 600	22.1	14 600	6 058	3 000
Latvia	1 969	10.9	1 700	12.0	60	2 773	60
Lithuania	2 889	11.8	2 600	11.7	20	2 456	70
Luxembourg	576	11.4	230	20.7	50	2 211	10
Malta	450	11.1	210	14.9	< 1	5 985	20
Netherlands	16 979	11.3	9 200	20.5	1 500	2 428	270
Poland	37 967	20.6	43 100	15.2	1 500	3 699	1 100
Portugal	9 809	8.3	4 900	15.3	610	4 074	320
Romania	19 761	16.8	23 400	17.6	2 600	2 485	490
Slovakia	5 426	17.6	4 800	13.5	20	4 232	160
Slovenia	2 064	16.0	1 700	15.4	70	5 007	70
Spain	44 145	11.1	24 100	20.0	7 700	5 212	1 500
Sweden	9 851	5.7	2 900	10.7	30	1 819	120
United Kingdom	65 379	9.5	31 800	21.8	11 800	1 161	530
Albania	2 876	22.3	5 100	13.7	70	5 475	180
Andorra	73	12.1	40	18.2	< 1	4 423	< 5
Bosnia and Herzegovina	3 516	28.7	5 400	13.2	20	4 409	120
Iceland	333	4.8	60	10.1	< 1	499	< 5
Kosovo	1 772	27.1	3 800	14.4	20	4 769	100
Liechtenstein	38	10.3	20	17.8	< 1	4 945	< 5
Monaco	38	14.3	30	26.8	10	7 186	< 5
Montenegro	622	20.3	630	11.9	< 1	5 269	20
North Macedonia	2 071	34.6	3 400	17.4	110	4 434	70
Norway	5 211	5.9	1 300	12.4	130	1 502	50
San Marino	33	14.3	30	16.3	< 1	5 667	< 5
Serbia	7 076	24.6	13 700	19.4	1 500	3 508	280
Switzerland	8 327	10.1	3 700	19.7	620	4 842	240
EU-28	**506 028**	**12.9**	**374 000**	**16.3**	**68 000**	**3 547**	**14 000**
Total	**538 014**	**14.4**	**412 000**	**16.3**	**71 000**	**3 811**	**15 100**

Notes: ([a]) The annual mean (in µg/m^3) and the SOMO35 (in µg/m^3·days), expressed as population-weighted concentration, is obtained according to the methodology described by ETC/ACM (2019) and references therein and not only from monitoring stations.

([b]) Total and EU-28 premature deaths are rounded to the nearest thousand (except for O_3, nearest hundred). The national totals are rounded to the nearest hundred or ten.

Table 10.2 Years of life lost (YLL) attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28

	$PM_{2.5}$		NO_2		O_3	
Country	**YLL**	**YLL/10^5 inhabitants**	**YLL**	**YLL/10^5 inhabitants**	**YLL**	**YLL/10^5 inhabitants**
Austria	52 000	598	10 400	120	2 800	32
Belgium	75 800	670	16 400	145	1 900	17
Bulgaria	32 900	1 858	10 800	151	3 000	42
Croatia	51 100	1 219	2 500	60	1 900	45
Cyprus	5 600	473	2 300	194	340	29
Czechia	101 000	957	2 500	24	3 800	36
Denmark	27 800	487	870	15	990	17
Estonia	5 400	410	< 5	< 1	250	19
Finland	15 500	282	< 5	< 1	630	11
France	353 000	543	79 500	122	16 100	25
Germany	591 400	720	118 100	144	24 400	30
Greece	126 100	1 169	27 900	259	6 500	60
Hungary	130 000	1 322	8 300	84	4 200	43
Ireland	12 000	254	560	12	350	7
Italy	550 600	908	137 500	227	29 100	48
Latvia	17 300	879	660	34	630	32
Lithuania	26 400	914	180	6	790	27
Luxembourg	2 500	434	490	85	70	12
Malta	2 400	533	< 5	< 1	190	42
Netherlands	92 500	545	14 700	87	2 900	17
Poland	517 700	1 364	18 500	49	13 800	36
Portugal	46 000	469	5 700	58	3 200	33
Romania	252 400	1 277	27 800	141	5 600	28
Slovakia	55 200	1 017	270	5	2 000	37
Slovenia	18 900	916	810	39	840	41
Spain	244 000	553	77 800	176	16 300	37
Sweden	25 000	254	240	2	1 100	11
United Kingdom	317 600	486	117 500	180	5 600	9
Albania	50 400	1 753	730	25	1 700	59
Andorra	440	602	< 5	< 1	20	27
Bosnia and Herzegovina	58 100	1 652	250	7	1 300	37
Iceland	560	168	< 5	< 1	10	3
Kosovo	37 200	2 100	240	14	910	51
Liechtenstein	200	532	5	< 1	10	27
Monaco	270	707	120	314	20	52
Montenegro	7 400	1 189	< 5	< 1	300	48
North Macedonia	35 200	1 699	1 100	53	760	37
Norway	12 100	232	1 200	23	440	8
San Marino	260	788	< 5	< 1	10	30
Serbia	135 800	1 919	14 800	209	2 900	41
Switzerland	36 500	438	6 100	73	2 500	30
EU-28	**3 848 000**	**800**	**682 000**	**100**	**149 000**	**30**
Total	**4 223 000**	**900**	**707 000**	**100**	**160 000**	**30**

Note: Total and EU-28 YLL figures are rounded to the nearest thousand or hundred. National data are rounded to the nearest hundred or ten.

10.3 Benefit analysis for $PM_{2.5}$

$PM_{2.5}$ is the pollutant with the highest impact in terms of premature deaths, with the health impacts of exposure at current $PM_{2.5}$ concentrations presented in Section 10.2. This section presents the results of a hypothetical assessment of the potential minimum health benefits of meeting the World Health Organization (WHO) air quality guideline (AQG) for $PM_{2.5}$ across Europe. It provides an updated estimate of a similar exercise that was described in EEA (2015b).

For the current exercise, calculations of premature deaths and YLL were made based on the assumption that all $PM_{2.5}$ concentrations for 2016 over 10 µg/m^3 are at 10 µg/m^3, while the concentrations below 10 µg/m^3 remain unchanged. The rest of the methodology was followed as explained in the first paragraph for $PM_{2.5}$ under Section 10.1.

It is important to note that the estimated benefits present a minimum expected benefit, and are likely to be underestimated. This is because measures required to bring down concentrations above the WHO AQG would also further reduce concentrations elsewhere that are currently below 10 µg/m^3. With the methodology applied, these additional benefits are not captured and as such, the exercise underestimates the actual expected benefits of reaching the $PM_{2.5}$ WHO AQG.

In an exercise in which all concentrations are equal to or below the WHO AQG for $PM_{2.5}$, premature deaths and YLL in the EU-28 would decrease by 27 % and 28 %, respectively, while premature deaths and YLL in the 41 European countries would decrease by 30 %, when compared with the current results for 2016 (Table 10.3). Consequently, it is estimated that the EU-28 and all the 41 European countries would have benefits of 102 000 and 122 000 fewer premature deaths, respectively, when compared with the status in 2016. The benefits would be higher in those countries where concentrations are well above the WHO AQG for $PM_{2.5}$, compared to countries where concentrations are below or slightly above the WHO AQG for $PM_{2.5}$.

Table 10.3 Premature deaths and YLL attributable to $PM_{2.5}$ exposure in 41 European countries and the EU-28, with and without attaining the WHO AQG of 10 µg/m^3 across Europe

		Current situation for 2016	Situation in which the WHO AQG is fully attained
EU-28	Premature deaths	374 000	272 000
	YLL	3 848 000	2 777 000
Total	Premature deaths	412 000	290 000
	YLL	4 223 000	2 957 000

Note: Totals for EU-28 Member States ('EU-28') and 41 European countries ('Total').

11 Exposure of ecosystems to air pollution

Air pollution leads to environmental degradation and has impacts on natural ecosystems and biodiversity. Ground-level ozone (O_3) can damage crops, forests and other vegetation, impairing their growth and impacting on biodiversity.

The deposition of nitrogen compounds can cause eutrophication, an oversupply of nutrients. Like sulphur compounds, nitrogen compounds also have acidifying effects. Both eutrophication and acidification can affect terrestrial and aquatic ecosystems and may lead to changes in species diversity and invasions by new species (Duprè et al., 2010). Acidification may also lead to increased mobilisation of toxic metals in water or soils, which increases the risk of uptake in the food chain.

Toxic metals and persistent organic compounds (POPs), in addition to their environmental toxicity, tend to bioaccumulate in animals and plants and to biomagnify, implying that concentrations in the tissues of organisms increase at successively higher levels in the food chain.

11.1 Vegetation exposure to ground-level ozone

High levels of O_3 damage plant cells, impairing plants' reproduction and growth, thereby reducing agricultural crop yields, forest growth and biodiversity ([54]). In many parts of central and southern Europe, EU Natura 2000 grasslands are at risk as a result of exposure to current O_3 levels, which can change plant community composition and change flowering and seed production in some species (Harmens et al., 2016).

Changing climatic conditions and the increase in emissions of carbon dioxide (CO_2) and other pollutants, such as reactive nitrogen, modify the responses of vegetation to O_3. In addition to affecting plant growth, these modifiers influence the amount of O_3 taken up by leaves, thus altering the magnitude of effects on plant growth, crop yields and ecosystem services (Harmens et al., 2015b).

The standards set by the EU to protect vegetation from high O_3 concentrations are shown in Table 1.2. In addition, the UNECE CLRTAP (UNECE, 1979) defines a critical level (CL) for the protection of forests. For convenience, they are summarised in Table 11.1.

Maps produced to calculate vegetation exposure to O_3 up to 2015 did not include Turkey. The maps produced from 2016 onwards do. The following analyses will therefore be carried out: one in which Turkey is excluded (which will be named EEA-32), so a comparison can be made with previous years, and one in which Turkey is included (EEA-33) to obtain the complete picture.

Table 11.1 Air quality standards for protecting vegetation and forests from O_3

Pollutant	Averaging period	Standard type and concentration	Comments
O_3	AOT40 ([a]) accumulated over May to July	EU target value, 18 000 µg/m³·hours	Averaged over 5 years ([b])
		EU long-term objective, 6 000 µg/m³·hours	
	AOT40 ([a]) accumulated over April to September	CL for the protection of forests: 10 000 µg/m³·hours	Defined by the CLRTAP

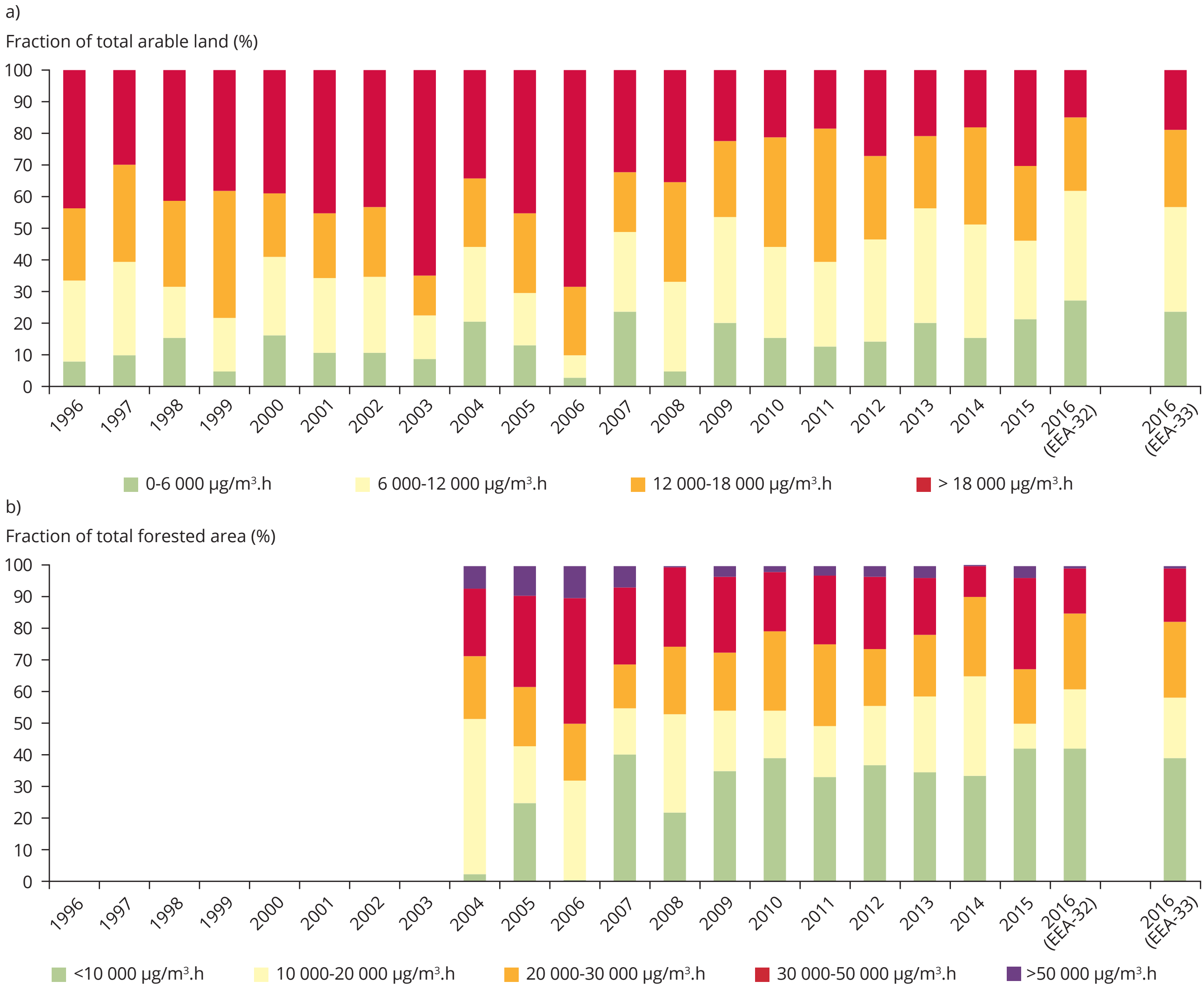
Notes: ([a]) AOT40 is an indication of accumulated O_3 exposure, expressed in µg/m³·hours, over a threshold of 40 parts per billion (ppb). It is the sum of the differences between hourly concentrations > 80 µg/m³ (40 ppb) and 80 µg/m³ accumulated over all hourly values measured between 08.00 and 20.00 (Central European Time).

([b]) In the context of this report, only yearly AOT40 concentrations are considered, so no average over 5 years is presented.

([54]) Several effects of damage to vegetation by ground-level O_3 were described in the *Air quality in Europe — 2015 report* (EEA, 2015b).

Since 2000, the AOT40 value (accumulated exposure over a threshold of 40 ppb) of 18 000 µg/m³·hours has been exceeded in a substantial part of the European agricultural area, as shown in Figure 11.1a (highest parts of the bars), albeit with large year-to-year variations. In 2016 ([55]), the AOT40 value of 18 000 µg/m³·hours was exceeded in about 15 % of all agricultural land in the EEA-32 and 19 % of all agricultural land in the EEA-33. The situation for the EEA-32 has fluctuated between the minimum percentage observed in 2016 and a maximum of 69 %, which was observed in 2006. The long-term objective was exceeded in 2016 in 73 %

Figure 11.1 Exposure of (a) agricultural area and (b) forest area to O_3 (AOT40) in the EEA member countries



Notes: (a) In the Ambient Air Quality Directive (EU, 2008), the target value for protection of vegetation is set at 18 000 µg/m³.hours, averaged over 5 years, whereas the long-term objective is set at 6 000 µg/m³.hours. Only yearly values of the AOT40 are considered in the graph, without any averaging over years.

Owing to a lack of detailed land cover data and/or rural O_3 data, Iceland and Norway were not included in the calculations until 2007; Switzerland was not included until 2008; Turkey has been included only in 2016, which is why two columns for that year are shown — one without Turkey (EEA-32), so a comparison can be made with previous years, and one including Turkey (EEA-33) for a complete overview.

(b) The UNECE CLRTAP (UNECE, 1979) has set a CL for the protection of forests at 10 000 µg/m³·hours.

Bulgaria, Greece and Romania were added to the calculations in 2005, Iceland and Norway were added in 2007, and Switzerland was added in 2008. Turkey has been included only in 2016; for this reason, there are two columns shown for that year — one without Turkey (EEA-32), so a comparison can be made with previous years, and one including Turkey (EEA-33) for a complete overview. Calculations of forest exposure are not available for the years prior to 2004.

Source: EEA, 2019j.

([55]) In the methodology used, the AOT40 is calculated from interpolated maps. To produce these maps, information on the spatial distribution of concentrations from the EMEP model is needed and, at the time of drafting this report, the most up-to-date data from the EMEP model were from 2016 (ETC/ACM, 2019).

of the agricultural area of the EEA-32 and 76 % of the agricultural area of the EEA-33 (all bars in Figure 11.1a, except the green bars). This value also fluctuated for the EEA-32 between the minimum percentage observed in 2016 and a maximum of 98 %, which was observed in 2006.

When it comes to all the European countries considered in the 2016 calculations and the EU-28 (Map 11.1; ETC/ACM, 2019), the total agricultural area is 2 443 805 km^2 and 1 990 139 km^2, respectively. Of these, 19 % (459 700 km^2) and 15 % (295 735 km^2), respectively, were exposed to AOT40 values above the target value threshold, and 77 % and 73 % were exposed to AOT40 values above the long-term objective.

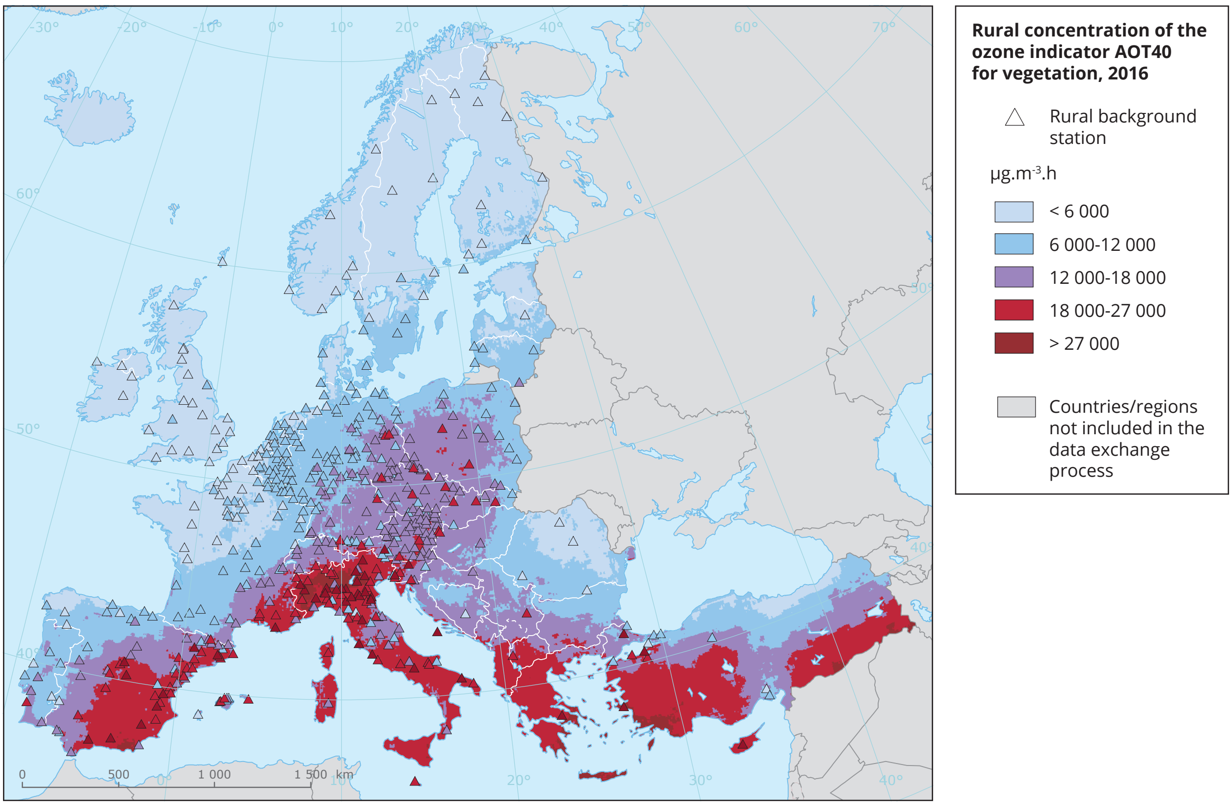
The exceedances since 2004 of the CL for the protection of forest areas are even more pronounced than in the case of the target value for the protection of vegetation, as shown for the EEA-32 in Figure 11.1b (note that only the lowest parts of the bars correspond to exposures below the CL). In 2016, the CL was exceeded in 58 % of the total forest area in the EEA-32 and 61 % of the total forest area in the EEA-33. For the EEA-32, this is the minimum value observed during the time series, together with 2015.

The CL was also exceeded in 63 % of the total forest area in all European countries and in 62 % of the EU-28 forest area (i.e. 1 060 363 km^2 and 860 541 km^2, respectively) in 2016 (Map 11.2; ETC/ACM, 2019).

Furthermore, within the International Co-Operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests), O_3 measurements are carried out at 233 forest monitoring sites in 18 countries under the 1999 Gothenburg Protocol. Consistent with the results shown in Figure 11.1b, trend analysis of ICP Forests data reveals a slight but significant decrease in growing season (April to September) O_3 concentrations between 2000 and 2014 (0.63 ppb per year). This monitoring network also found an increasing trend when moving from northern Europe towards southern Europe, with the highest concentrations observed in Italy, southern Switzerland, Czechia, Slovakia, Romania and Greece (ICP Forests, 2018a).

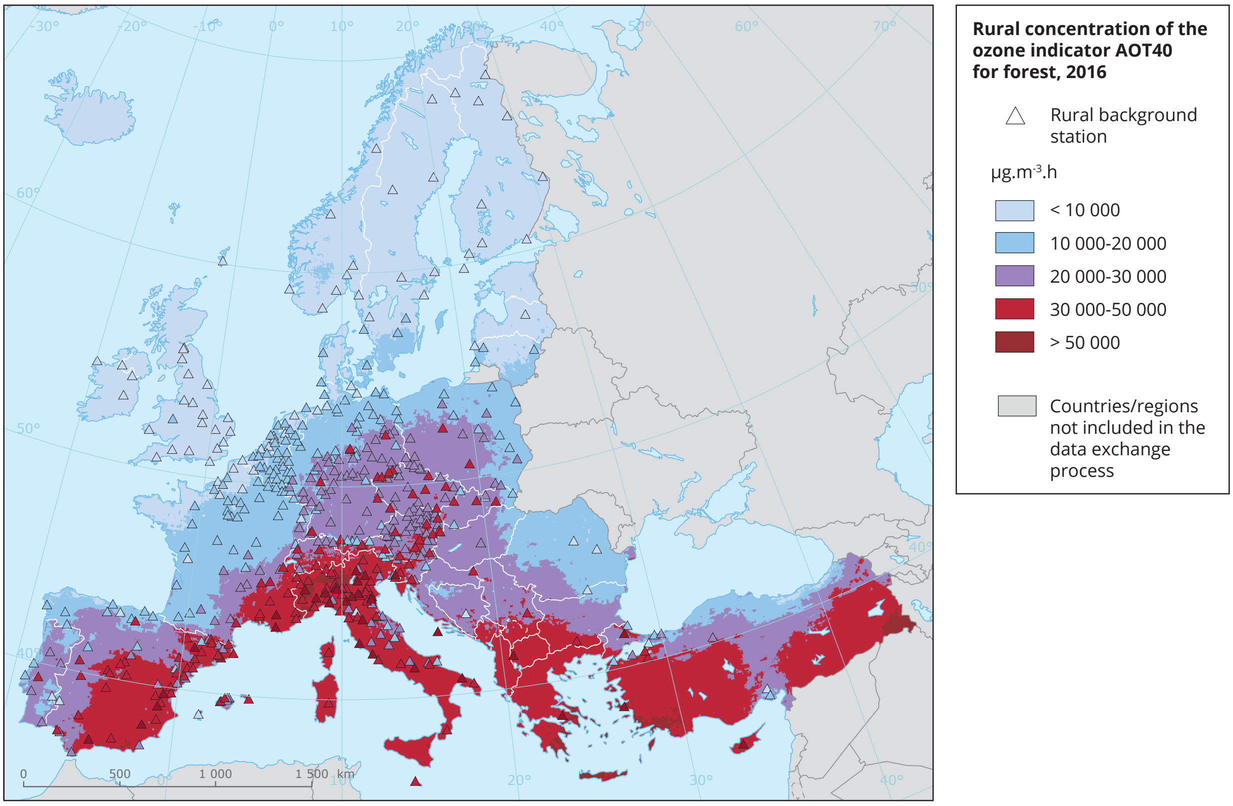
Nevertheless, how this exposure affects crops is uncertain. According to current scientific knowledge, the so-called phytotoxic O_3 dose flux-approach is a better indicator of O_3 damage to vegetation. This methodology estimates the amount of O_3 that actually enters the plant via small pores (stomata) on the leaves'

Map 11.1 Rural concentration of the O_3 indicator AOT40 for crops and vegetation, 2016



Source: ETC/ACM, 2019.

Map 11.2 Rural concentration of the O_3 indicator AOT40 for forests, 2016



Source: ETC/ACM, 2019.

surface. This amount depends on the opening and closing of the stomata under, for example, different temperature, humidity and light intensity conditions (ICP Vegetation, 2017). Wheat yield loss decreased significantly for AOT40 between 1990 and 2010; however, when using a metric related to the flux, the trend is much smaller and not significant, leading to crop yield losses of the order of 13-14 % in Europe (ETC/ACM, 2018c).

11.2 Eutrophication

Air pollution contributes to eutrophication (an excess of nutrient nitrogen), as the nitrogen emitted to the air as nitrogen oxides (NO_X) and ammonia (NH_3) is deposited on soils, vegetation surfaces and waters.

Eutrophication (and acidification) effects due to deposition of air pollution are estimated using the 'critical load' concept. This term describes the ecosystem's ability to absorb eutrophying nitrogen pollutants (or acidifying pollutants, in the case of acidification) deposited from the atmosphere, without the potential to cause negative effects on the natural environment. Exceedances of these spatially determined critical loads are estimated using ecosystem classification methods and model calculations.

Deposition of inorganic nitrogen on the forest floor decreased by about 24 % in highly polluted areas and by about 16 % at less polluted measurement sites, between 2000 and 2015. Overall, the decrease in nitrate (NO_3^-) (26 %) has been greater than that of ammonium (NH_4^+) (18 %) (ICP Forests, 2018b).

EMEP (2018b) estimated that critical loads for eutrophication were exceeded in virtually all European countries and over about 62 % of the European (approximately 73 % of the EU-28) ecosystem area in 2016. The highest exceedances in 2016 occurred again in the Po valley (Italy), in the Dutch-German-Danish border areas and in north-eastern Spain.

11.3 Acidification

Air pollution contributes to acidification through the emission of nitrogen and sulphur compounds into the atmosphere, which transform into nitric acid and sulphuric acid, respectively. When these airborne acids fall onto the Earth and its waters as acid deposition, they reduce the pH levels of soil and water.

Owing to the considerable reductions in emissions of sulphur oxides (SO_X) over the past three decades, nitrogen compounds emitted as NO_X have become the principal acidifying components in both terrestrial and aquatic ecosystems, in addition to their role in causing eutrophication. However, emissions of SO_X, which have a higher acidifying potential than NO_X, still contribute to acidification.

Similar to eutrophication effects, acidification effects are estimated using the concept of 'critical load' (Section 11.2). EMEP (2018b) estimated that exceedances of the critical loads for acidification occurred over about 5 % of the European ecosystem area and over 7 % of the EU-28 ecosystem area in 2016. Hotspots of exceedances occurred again in the Netherlands and its borders with Germany and Belgium, southern Germany and also Czechia in 2016. However, most of Europe did not exceed the critical loads for acidification in 2016.

11.4 Vegetation exposure to nitrogen oxides and sulphur dioxide

CLs for NO_X and sulphur dioxide (SO_2) for the protection of vegetation are set by the Ambient Air Quality Directive (EU, 2008), as shown in Table 1.2. For convenience, they are summarised in Table 11.2. The sampling points targeting the protection of vegetation must be situated more than 20 km away from agglomerations or more than 5 km away from other built-up areas, major industrial sites and major roads, which corresponds to rural background stations (Box 1.1).

The NO_X annual CL for the protection of vegetation (30 μg/m^3) was exceeded in 2017 at 10 rural background stations in Italy (four), the Netherlands (three), Germany (one) and Switzerland (two).

ETC/ACM (2019) estimated that in most areas of Europe the annual NO_X means are below 20 μg/m^3. However, in the Po valley, the southern part of the Netherlands, northern Belgium, the German Ruhr region and a few rural areas close to major cities, NO_X concentrations above the CL were estimated for 2016 (Map 5.2 in ETC/ACM, 2019). Vegetation in those areas would be exposed to concentrations above the CL.

In 2017, there were no exceedances of the SO_2 CLs in any of the reported rural background stations ([56]).

11.5 Environmental impacts of toxic metals

As explained in Chapter 8, toxic metal pollutants can cause harmful effects in plants and animals, in addition to humans. Although their atmospheric concentrations may be low, they still contribute to the deposition and build-up of toxic metals in soils, sediments and organisms. For instance, lead (Pb) and cadmium (Cd) affect the biodiversity of soil species and reduce plant growth. In addition, these metals tend to accumulate in plant tissues and transfer to human organisms through food chains. Mercury (Hg) in water bodies accumulates in fish and affects human health through fish consumption (EMEP, 2018a).

The EMEP model (EMEP, 2018a) estimated the 2016 deposition of Pb, Cd and Hg in ecosystems and found that deposition differs significantly for different ecosystems. For example, considering Hg deposition, hotspots of deposition in inland waters are located in some regions of northern Italy, the Balkans and the Caucasus. In general, deposition in forests is much higher than in inland waters and reaches the highest values over western and central Europe.

Table 11.2 Air quality standards for protecting vegetation from NO_X and SO_2

Pollutant	Averaging period	Standard type and concentration	Comments
NO_X	Calendar year	EU CL: 30 μg/m^3	
SO_2	Winter	EU CL: 20 μg/m^3	1 October to 31 March
	Calendar year	EU CL: 20 μg/m^3	

([56]) 257 for the annual critical load from 32 reporting countries (all EU-28 — except Croatia and Greece — and Bosnia and Herzegovina, North Macedonia, Norway, Serbia, Switzerland and Turkey); and 147 for the winter critical load from 11 EU Member States: Austria, Bulgaria, Czechia, Estonia, France, Germany, Ireland, Luxembourg, Poland, Spain and the United Kingdom.

Abbreviations, units and symbols

$\mu g/m^3$	Microgram(s) per cubic metre
AEI	Average exposure indicator for $PM_{2.5}$ concentrations
AOT40	Accumulated exposure over a threshold of 40 ppb. This represents the sum of the differences between hourly concentrations > 80 $\mu g/m^3$ (40 ppb) and 80 $\mu g/m^3$ accumulated over all hourly values measured between 08.00 and 20.00 Central European Time
AQG	Air quality guideline
As	Arsenic
BaP	Benzo[*a*]pyrene
BC	Black carbon
CAMS	Copernicus Atmosphere Monitoring Service
C_6H_6	Benzene
Cd	Cadmium
CH_4	Methane
CI	Confidence interval
CL	Critical level
Cl^-	Chloride
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	Carbon monoxide
CO_2	Carbon dioxide
ECO	Exposure concentration obligation
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
ETC/ACM	European Topic Centre for Air Pollution and Climate Change Mitigation
ETC/ATNI	European Topic Centre on Air pollution, Noise, Transport and Industrial Pollution
EU	European Union

GDP	Gross domestic product
GVA	Gross value added
Hg	Mercury
HRAPIE	Health Risks of Air Pollution in Europe
K^+	Potassium
LAT	Lower assessment threshold
mg/m^3	Milligram(s) per cubic metre
Mg^{2+}	Magnesium
NEC	National Emission Ceilings (Directive)
NERT	National exposure reduction target
ng/m^3	Nanogram(s) per cubic metre
NH_3	Ammonia
NH_4^+	Ammonium
Ni	Nickel
NMVOC	Non-methane volatile organic compound
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_3^-	Nitrate
NO_X	Nitrogen oxides
O_3	Ozone
PAH	Polycyclic aromatic hydrocarbon
Pb	Lead
PM	Particulate matter
$PM_{2.5}$	Particulate matter with a diameter of 2.5 μm or less
PM_{10}	Particulate matter with a diameter of 10 μm or less
POP	Persistent organic pollutant
ppb	Parts per billion
RL	Reference level
SDG	Sustainable Development Goal

SO_2	Sulphur dioxide
SO_4^{-2}	Sulphate
SOMO35	Accumulated O_3 concentration (8-hour daily maximum) in excess of 35 ppb
SO_X	Sulphur oxides
TOE	Tonnes of oil equivalent
UN	United Nations
UNEA	United Nations Environment Assembly
UNECE	United Nations Economic Commission for Europe
VOC	Volatile organic compound
WHO	World Health Organization
YLL	Years of life lost

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Annex 1 Air quality monitoring stations reporting 2017 data

This annex presents the number of stations with 2017 data above the data coverage considered for the assessment officially reported by the EEA-39 member countries or cooperating countries and the voluntary reporting country of Andorra and for the EU-28 Member States. The stations are shown according to their classification by station type and area type for the main pollutants. The definition of station type and area type can be found in Box 1.1. The same information is presented for the stations with concentrations above the EU legal standards and/or the WHO air quality guidelines (AQGs) or reference levels (RLs) (Tables 1.1, 1.2 and 1.3). Please note that some countries may have more stations in place that are not officially reported to the EEA.

PM_{10}

Total reporting stations with valid data for the daily limit value

	Traffic	Industrial	Background	Total
Urban	667	160	1 011	1 838
Suburban	74	149	384	607
Rural	9	76	356	441
Total	750	385	1 751	**2 886**

Total reporting stations with concentrations above the daily limit value

	Traffic	Industrial	Background	Total
Urban	135	39	362	536
Suburban	6	16	58	80
Rural	1	2	27	30
Total	142	57	447	**646**

Total reporting stations with valid data for the annual limit value

	Traffic	Industrial	Background	Total
Urban	680	157	1 025	1 862
Suburban	75	154	388	617
Rural	9	77	362	448
Total	764	388	1 775	**2 927**

Total reporting stations with concentrations above the annual limit value

	Traffic	Industrial	Background	Total
Urban	42	15	139	196
Suburban	1	4	3	8
Rural	0	1	2	3
Total	43	20	144	**207**

Total reporting stations with concentrations above the WHO AQG for long exposure

	Traffic	Industrial	Background	Total
Urban	431	99	597	1 127
Suburban	26	83	168	277
Rural	4	24	65	93
Total	461	206	830	**1 497**

EU-28 reporting stations with valid data for the daily limit value

	Traffic	Industrial	Background	Total
Urban	624	145	851	1620
Suburban	53	140	367	560
Rural	9	74	336	419
Total	686	359	1 554	**2 599**

EU-28 reporting stations with concentrations above the daily limit value

	Traffic	Industrial	Background	Total
Urban	109	25	230	364
Suburban	6	14	56	76
Rural	1	2	24	27
Total	116	41	310	**467**

EU-28 reporting stations with valid data for the annual limit value

	Traffic	Industrial	Background	Total
Urban	637	142	865	1 644
Suburban	54	145	371	570
Rural	9	75	339	423
Total	700	362	1 575	**2 637**

EU-28 reporting stations with concentrations above the annual limit value

	Traffic	Industrial	Background	Total
Urban	20	2	34	56
Suburban	1	3	2	6
Rural	0	1	0	1
Total	21	6	36	**63**

EU-28 reporting stations with concentrations above the WHO AQG for long exposure

	Traffic	Industrial	Background	Total
Urban	403	84	454	941
Suburban	25	81	165	271
Rural	4	24	57	85
Total	432	189	676	**1 297**

$PM_{2.5}$

Total reporting stations

	Traffic	Industrial	Background	Total
Urban	294	58	526	878
Suburban	41	66	176	283
Rural	5	31	199	235
Total	340	155	901	**1 396**

Total reporting stations with concentrations above the annual limit value

	Traffic	Industrial	Background	Total
Urban	22	5	54	81
Suburban	1	1	9	11
Rural	0	0	6	6
Total	23	6	69	**98**

Total reporting stations with concentrations above the WHO AQG for long exposure

	Traffic	Industrial	Background	Total
Urban	226	30	395	651
Suburban	20	46	134	200
Rural	4	18	85	107
Total	250	94	614	**958**

EU-28 reporting stations

	Traffic	Industrial	Background	Total
Urban	273	54	499	826
Suburban	24	60	166	250
Rural	5	29	189	223
Total	302	143	854	**1 396**

EU-28 reporting stations with concentrations above the annual limit value

	Traffic	Industrial	Background	Total
Urban	14	2	49	65
Suburban	1	1	8	10
Rural	0	0	5	5
Total	15	3	62	**80**

EU-28 reporting stations with concentrations above the WHO AQG for long exposure

	Traffic	Industrial	Background	Total
Urban	212	26	374	612
Suburban	20	46	132	198
Rural	4	18	80	102
Total	236	90	586	**912**

O_3

Total reporting stations

	Traffic	Industrial	Background	Total
Urban	110	89	695	894
Suburban	9	61	402	472
Rural	4	36	497	537
Total	123	186	1 594	**1 903**

Total reporting stations with concentrations above the target value

	Traffic	Industrial	Background	Total
Urban	5	5	116	126
Suburban	0	4	100	104
Rural	0	6	142	148
Total	5	15	358	**378**

Total reporting stations with concentrations above the long-term objective

	Traffic	Industrial	Background	Total
Urban	64	43	557	664
Suburban	8	52	365	425
Rural	3	31	443	477
Total	75	126	1 365	**1 566**

Total reporting stations with concentrations above the WHO AQG for long exposure

	Traffic	Industrial	Background	Total
Urban	91	81	649	821
Suburban	9	59	389	457
Rural	4	36	488	528
Total	104	176	1 526	**1 806**

EU-28 reporting stations

	Traffic	Industrial	Background	Total
Urban	89	81	647	817
Suburban	8	59	390	457
Rural	4	36	462	502
Total	101	176	1 449	**1 776**

EU-28 reporting stations with concentrations above the target value

	Traffic	Industrial	Background	Total
Urban	3	2	108	113
Suburban	0	4	97	101
Rural	0	6	125	131
Total	3	12	330	**345**

EU-28 reporting stations with concentrations above the long-term objective

	Traffic	Industrial	Background	Total
Urban	54	37	532	623
Suburban	8	50	353	411
Rural	3	31	417	451
Total	65	118	1 302	**1 485**

EU-28 reporting stations with concentrations above the WHO AQG for long exposure

	Traffic	Industrial	Background	Total
Urban	77	73	617	767
Suburban	8	57	377	442
Rural	4	36	457	497
Total	89	166	1 451	**1 706**

NO_2

Total reporting stations with valid data for the annual limit value

	Traffic	Industrial	Background	Total
Urban	883	165	930	1 978
Suburban	105	173	430	708
Rural	16	109	449	574
Total	1 004	447	1 809	**3 260**

Total reporting stations with concentrations above the annual limit value and the identical WHO AQG value for long term exposure

	Traffic	Industrial	Background	Total
Urban	266	1	41	308
Suburban	12	0	3	15
Rural	6	0	0	6
Total	284	1	44	**329**

Total reporting stations with valid data for the hourly limit value

	Traffic	Industrial	Background	Total
Urban	763	165	922	1 850
Suburban	90	173	427	690
Rural	12	109	417	538
Total	865	447	1 766	**3 078**

Total reporting stations with concentrations above the hourly limit value

	Traffic	Industrial	Background	Total
Urban	17	1	20	38
Suburban	0	0	0	0
Rural	0	0	1	1
Total	17	1	21	**39**

EU-28 reporting stations with valid data for the annual limit value

	Traffic	Industrial	Background	Total
Urban	840	155	847	1 842
Suburban	85	164	411	660
Rural	16	107	420	543
Total	941	426	1 678	**3 045**

EU-28 reporting stations with concentration above the annual limit value and the identical WHO AQG value for long term exposure

	Traffic	Industrial	Background	Total
Urban	243	0	19	262
Suburban	12	0	2	14
Rural	6	0	0	6
Total	261	0	21	**282**

EU-28 reporting stations with valid data for the hourly limit value

	Traffic	Industrial	Background	Total
Urban	720	155	839	1 714
Suburban	70	164	408	642
Rural	12	107	392	511
Total	802	426	1 639	**2 867**

EU-28 reporting stations with concentrations above the hourly limit value

	Traffic	Industrial	Background	Total
Urban	11	0	2	13
Suburban	0	0	0	0
Rural	0	0	0	0
Total	11	0	2	**13**

BaP

Total reporting stations

	Traffic	Industrial	Background	Total
Urban	134	32	309	475
Suburban	8	30	89	127
Rural	1	7	102	110
Total	143	69	500	**712**

Total reporting stations with concentrations above the target value

	Traffic	Industrial	Background	Total
Urban	22	9	141	172
Suburban	0	7	25	32
Rural	0	1	13	14
Total	22	17	179	**218**

Total reporting stations with concentrations above the WHO AQG RL

	Traffic	Industrial	Background	Total
Urban	123	27	274	424
Suburban	7	26	81	114
Rural	1	4	53	58
Total	131	57	408	**596**

EU-28 reporting stations

	Traffic	Industrial	Background	Total
Urban	131	32	305	468
Suburban	8	30	86	124
Rural	1	7	97	105
Total	140	69	488	**697**

EU-28 reporting stations with concentrations above the target value

	Traffic	Industrial	Background	Total
Urban	22	9	141	172
Suburban	0	7	25	32
Rural	0	1	13	14
Total	22	17	179	**218**

EU-28 reporting stations with concentrations above the WHO AQG RL

	Traffic	Industrial	Background	Total
Urban	121	27	271	419
Suburban	7	26	79	112
Rural	1	4	51	56
Total	129	57	401	**587**

Annex 2 Air pollutant concentrations in some European cities

In the following graphs, for each reporting country, some information on urban background concentrations of particulate matter (PM), and ozone (O_3); and some information on traffic concentrations of nitrogen dioxide (NO_2) is provided.

For PM and O_3, each graph shows the most polluted, least polluted and the most populated cities, with data for each country, as well as the average concentration for all cities in each country. For each city, all the urban and suburban background stations with more than 75 % of valid data for the relevant pollutant have been considered. Countries are ranked by the average increasing value of the cities. The figure in brackets after the country indicates the number of cities considered.

For NO_2, the graph shows the city in each country with the traffic station reporting the highest and the lowest concentrations. Countries are ranked by increasing maximum NO_2 concentrations.

Figure A2.1 Annual mean concentrations of PM_{10} in some cities of EEA-33 countries in 2017 (average of (sub)urban background stations)

Figure A2.2 Annual mean concentrations of $PM_{2.5}$ in some cities of EEA-33 countries in 2017 (average of (sub)urban background stations)

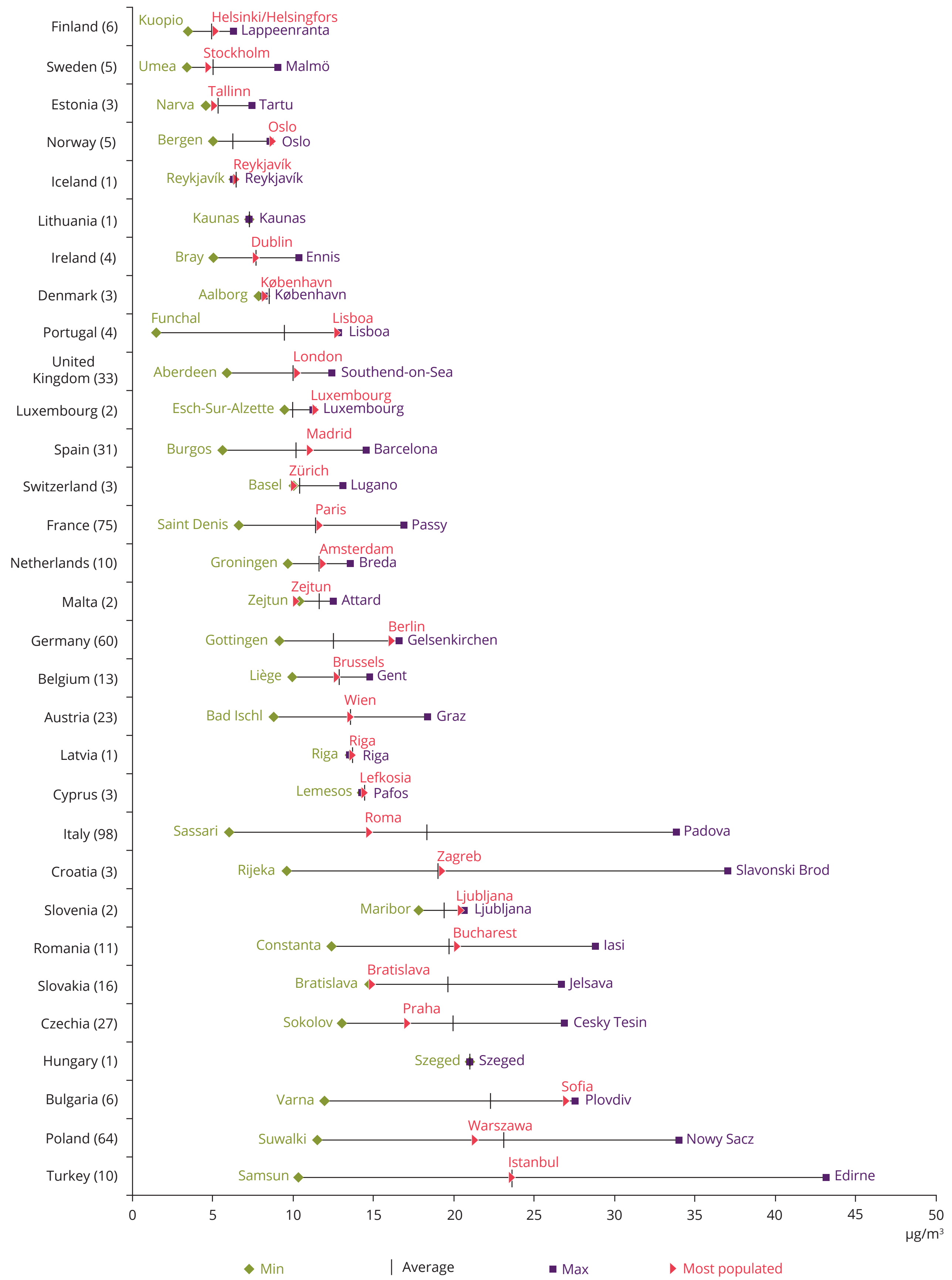


Figure A2.3 Annual mean concentrations of O_3 in some cities of EEA-33 countries in 2017 (average of (sub)urban background stations)

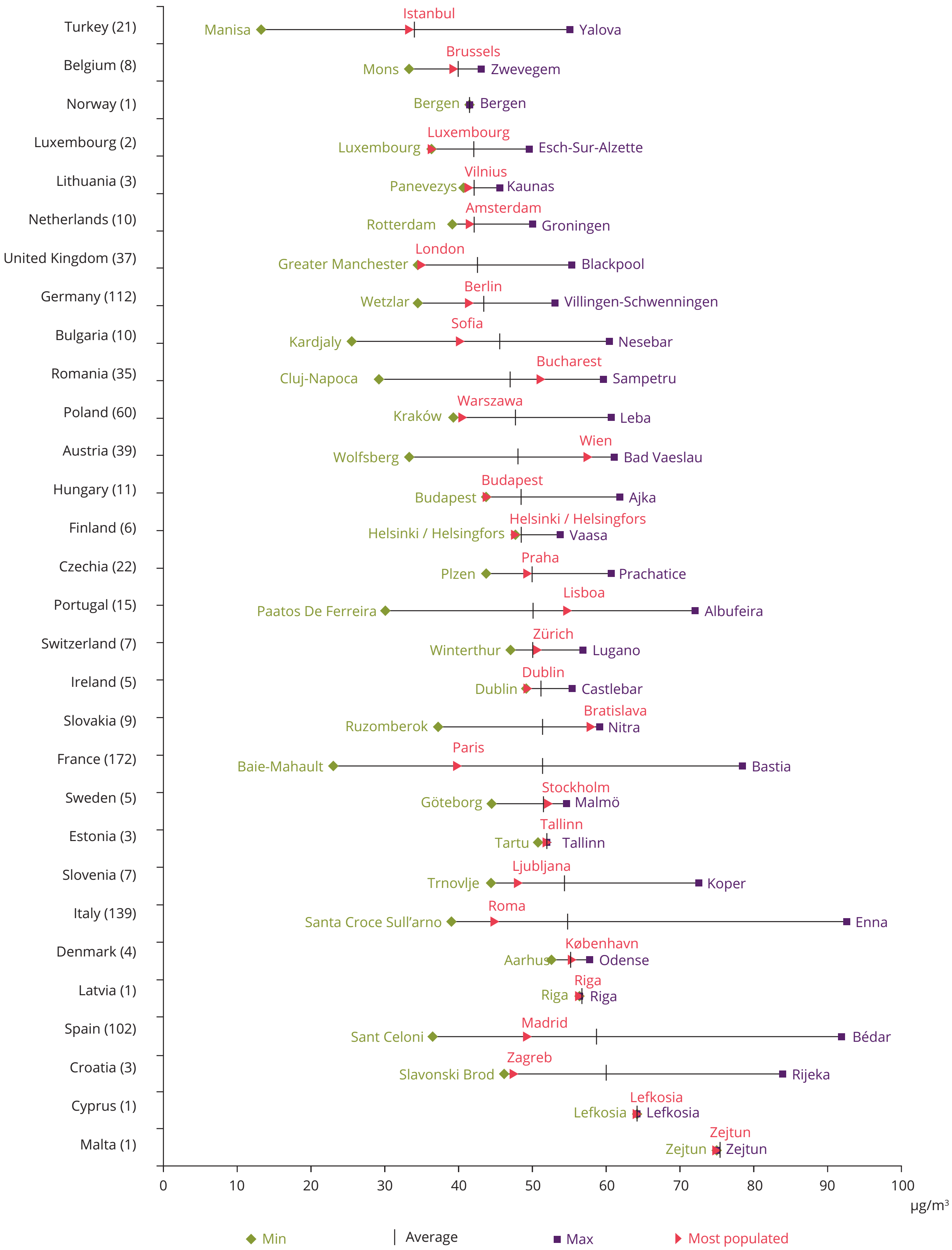
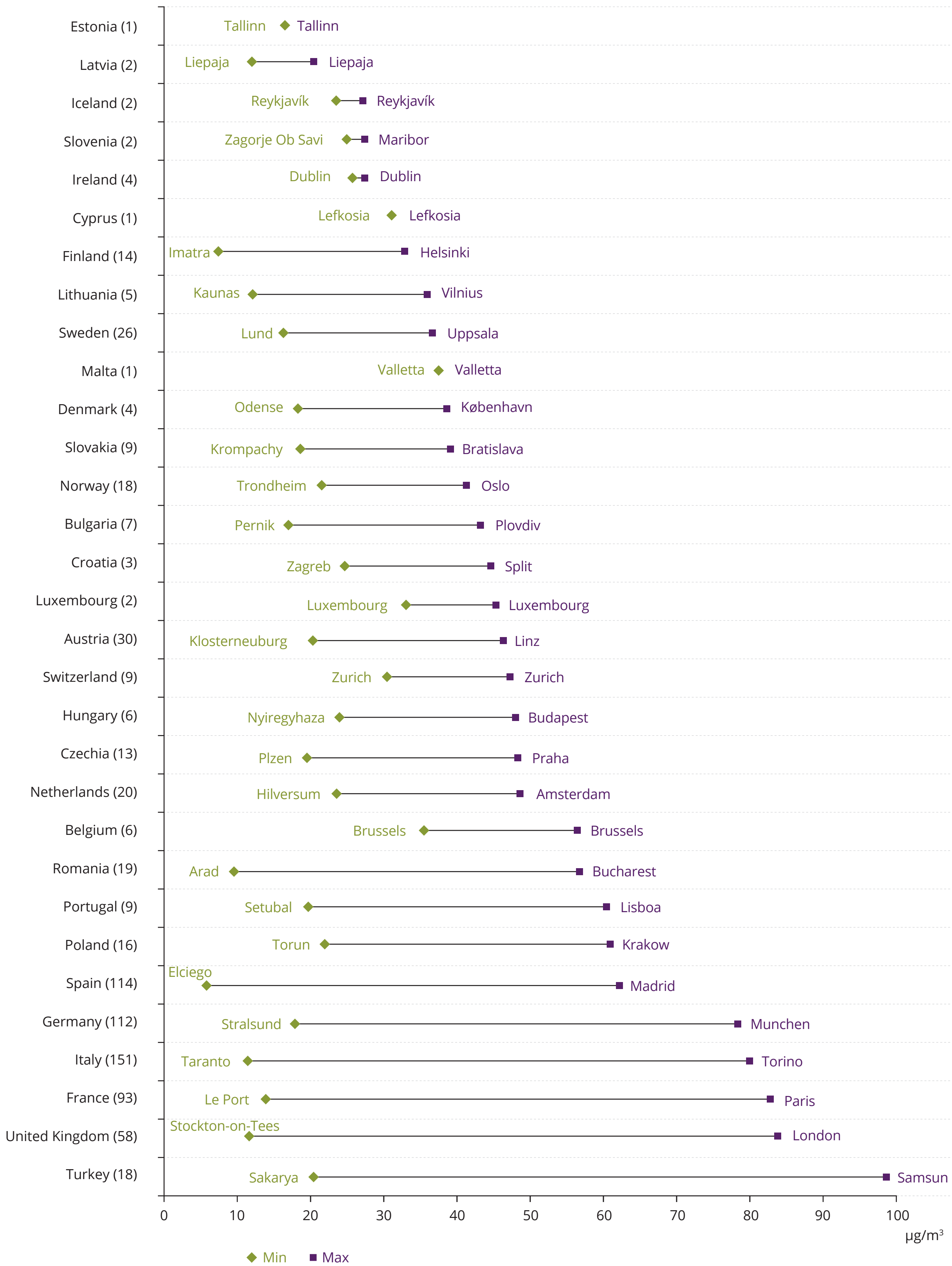


Figure A2.4 Annual mean concentrations of NO_2 in some cities of EEA-33 countries in 2017 (maximum and minimum concentrations at traffic stations)



Annex 3 Sensitivity analysis of the health impact assessments

The recommendations from the HRAPIE report (WHO, 2013b) indicate that the quantification of long-term effects of particulate matter with a diameter of 2.5 µm or less ($PM_{2.5}$), nitrogen dioxide (NO_2) and ozone (O_3) should be estimated for all concentration levels, annual levels above 20 µg/m³ and concentrations above 35 parts per billion (ppb), respectively. The results using those recommendations are presented in Section 10.2.

To assess how sensitive the estimations are, additional calculations were undertaken, following the same methodology as that described in Section 10.1 but with different starting thresholds. Table A3.1 summarises the estimated health impacts of concentrations equal to or above 2.5 and 10 µg/m³ for $PM_{2.5}$ and NO_2, respectively, and of SOMO10 (the annual average of daily maximum running 8-hour average O_3 concentrations above 10 ppb) for O_3. These values should be compared with the values in Tables 10.1 and 10.2. The rationale for choosing 2.5 µg/m³ for $PM_{2.5}$ is that the European $PM_{2.5}$ background concentration level is estimated to be, on average, 2.5 µg/m³ (ETC/ACM, 2017c). For NO_2, Raaschou-Nielsen et al. (2012) showed an increase in all-cause mortality when NO_2 concentrations were lower than 20 µg/m³, with 10 µg/m³ being the lowest value observed affecting their study participants. Finally, for O_3, the HRAPIE project (WHO, 2013b) recommends using SOM10 as an alternative to the assessment of only SOMO35. The REVIHAAP review (WHO, 2013a) also suggests that there is no specific threshold for effects, and small O_3 concentrations might affect human health.

The number of premature deaths and years of life lost (YLL) attributable to $PM_{2.5}$ exposure when including the full range of concentration for $PM_{2.5}$ is around 20 % higher than estimated, based on concentrations equal to or above 2.5 µg/m³. For NO_2, the estimations considering only concentrations above 20 µg/m³ are at least three times lower than when assuming a threshold of 10 µg/m³. The results in Tables 10.1 and 10.2 indicate that in many countries concentrations do not exceed 20 µg/m³, and, therefore, the estimations of premature deaths and YLL attributable to NO_2 above that concentration are very low. Finally, for O_3, estimating health effects based on SOMO10 provides a number of premature deaths and YLL that are about five times higher than an estimation based on SOMO35.

Table A3.1 Estimated number of premature deaths and years of life lost attributable to $PM_{2.5}$ (from a concentration of 2.5 µg/m³), NO_2 (from a concentration of 10 µg/m³) and O_3 (for SOMO10), reference year 2016

	Pollutant and concentration threshold		
	$PM_{2.5}$	**NO_2**	**O_3**
	2.5 µg/m³	**10 µg/m³**	**SOMO10**
Total			
Premature deaths	342 000	269 000	73 000
Years of life lost	3 484 000	2 445 000	774 000
EU-28			
Premature deaths	310 000	241 000	68 000
Years of life lost	3 154 000	2 321 000	727 000

Note: Totals for 41 European countries ('Total') and EU-28 Member States ('EU-28').

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