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Air quality in Europe — 2017 report

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Executive summary

Air pollution is a key environmental and social issue and, at the same time, it is a complex problem posing multiple challenges in terms of management and mitigation of harmful pollutants. Air pollutants are emitted from anthropogenic and natural sources; they may be either emitted directly (primary pollutants) or formed in the atmosphere (as secondary pollutants). They have a number of impacts on health, ecosystems, the built environment and the climate; they may be transported or formed over long distances; and they may affect large areas. Effective action to reduce the impacts of air pollution requires a good understanding of its causes, how pollutants are transported and transformed in the atmosphere, and how they affect humans, ecosystems, the climate, and subsequently society and the economy.

The current report presents an updated overview and analysis of air quality in Europe from 2000 to 2015. It reviews the progress made towards meeting the air quality standards established in the two European Ambient Air Quality Directives, and towards the long-term objectives of achieving levels of air pollution that do not lead to unacceptable harm to human health and the environment. It also presents the latest findings and estimates on population and ecosystem exposure to the air pollutants with the greatest impacts and effects on human health and the environment (Box ES.1). The evaluation of the status of air quality is based mainly on ambient air measurements, in conjunction with data on anthropogenic emissions and their evolution over time.

Air quality policies have delivered, and continue to deliver, many improvements. Reduced emissions have improved air quality in Europe, and, for a number of pollutants, exceedances of European standards are rare. However, substantial challenges remain and considerable impacts on human health and on the environment persist. A large proportion of European populations and ecosystems are still exposed to air pollution that exceeds European standards and, especially, the World Health Organization (WHO) Air Quality Guidelines (AQGs).

Effective air quality policies require action and cooperation at global, European, national and local levels, which must reach across most economic sectors and engage the public. Holistic solutions must be found that involve technological development and structural and behavioural changes. These will be necessary to achieve human wellbeing and social development, to protect the natural capital and to support economic prosperity, all of which are part of the European Union's (EU) 2050 vision of living well within the limits of the planet.

Box ES.1 New in the Air quality in Europe — 2017 report

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

Based upon the latest official data available from countries, this updated 2017 report presents new information, including:

- updated data on air pollutant emissions and concentrations, and urban population exposure (for the year 2015);
- updated assessments of total population and ecosystems exposure data, and air quality impacts on health (for the year 2014);
- a sensitivity analysis of the health impact assessments, considering two different counterfactual concentrations for particulate matter (PM) with a diameter of 2.5 µm or less ($PM_{2.5}$) and nitrogen dioxide (NO_2).
- a summary of emissions from agriculture and how they impact on air quality and climate change, which in turn impact on agricultural yields. Selected examples of measures that may mitigate emissions of air pollutants and greenhouse gases are provided.

Europe's air quality

Particulate matter

Concentrations of PM continued to exceed the EU limit values in large parts of Europe in 2015. For PM with a diameter of 10 µm or less (PM_{10}), concentrations above the EU daily limit value were registered at 19 % of the reporting stations in 20 of the 28 EU Member States (EU-28) and in five other reporting countries; for PM with a diameter of 2.5 µm or less ($PM_{2.5}$), concentrations above the limit value were registered at 6 % of the reporting stations in three Member States and three other reporting countries.

A total of 19 % of the EU-28 urban population was exposed to PM_{10} levels above the daily limit value and approximately 53 % was exposed to concentrations exceeding the stricter WHO AQG value for PM_{10} in 2015. This represents an increase compared with 2014, but the magnitude of the change may be considered as being within the expected year-to-year variability. Regarding $PM_{2.5}$, 7 % of the urban population in the EU-28 was exposed to levels above the EU limit value, and approximately 82 % was exposed to concentrations exceeding the stricter WHO AQG value for $PM_{2.5}$ in 2015 (Table ES.1). This represents a decrease compared with 2014 but is within the expected year-to-year variability.

Ozone

The year 2015 was a historically warm year globally. On average, over Europe, 2015 was the warmest year on record to that point, with a series of heatwaves affecting Europe from May to September that contributed to several intense tropospheric ozone (O_3) episodes.

In 2015, 18 of the EU-28 and four other European countries registered concentrations above the EU O_3 target value for the protection of human health. The percentage of stations measuring concentrations above this target value was 41 %, higher than the 11 % recorded in 2014, and the highest over the previous 5 years. The WHO AQG value for O_3 was exceeded in 96 % of all the reporting stations.

Some 30 % of the EU-28 urban population lived in areas in which the EU O_3 target value threshold for protecting human health was exceeded in 2015. The proportion of the EU urban population exposed to O_3 levels exceeding the WHO AQG was significantly higher, comprising 95 % of the total urban population in 2015 (Table ES.1).

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 2013 and 2015)

Pollutant	EU reference value (a)	Exposure estimate (%)	WHO AQG (a)	Exposure estimate (%)
$PM_{2.5}$	Year (25)	7-8	Year (10)	82-85
PM_{10}	Day (50)	16-20	Year (20)	50-62
O_3	8-hour (120)	7-30	8-hour (100)	95-98
NO_2	Year (40)	7-9	Year (40)	7-9
BaP	Year (1)	20-25	Year (0.12) RL	85-91
SO_2	Day (125)	< 1	Day (20)	20-38

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

Notes: (a) In µg/m³; except BaP, in ng/m³.

The reference concentrations include EU limit or target values, WHO air-quality guidelines (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 or target values 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 (2013-2015) and includes variations attributable to meteorology, as dispersion and atmospheric conditions differ from year to year.

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

Source: EEA, 2017d.

Nitrogen dioxide

The annual limit value for nitrogen dioxide (NO_2) continues to be widely exceeded across Europe, with around 10 % of all the reporting stations recording concentrations above that standard in 2015 in a total of 22 of the EU-28 and three other reporting countries. 89 % of all concentrations above this limit value were observed at traffic stations.

Nine per cent of the EU-28 urban population lived in areas with concentrations above the annual EU limit value and the WHO AQG for NO_2 in 2015 (Table ES.1).

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

Exposure to benzo[*a*]pyrene (BaP) pollution is quite significant and widespread, in particular in central and eastern Europe. Only 22 Member States and two other countries reported measurements of BaP with enough valid data in 2015. One third of the reported BaP measurement stations in Europe had values above the EU target value in 2015, mostly in urban areas. About 23 % of the European urban population was exposed to BaP annual mean concentrations above the European target value in 2015 and about 88 % to concentrations above the estimated reference level ([1]) (Table ES.1).

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

The EU-28 urban population was not exposed to sulphur dioxide (SO_2) concentrations above the EU daily limit value in 2015. However, 20 % of the EU-28 urban population was exposed to SO_2 levels exceeding the WHO AQG in 2015.

Exposure of the European population to carbon monoxide (CO) concentrations above the EU limit value and WHO AQG is very localised and infrequent. Only four stations (of which three were outside the EU-28) registered concentrations above the EU limit value in 2015.

Likewise, concentrations above the limit value for benzene (C_6H_6) were observed in Europe in 2015, at only two stations (located in the EU-28).

Concentrations of arsenic (As), cadmium (Cd), lead (Pb) and nickel (Ni) in air are generally low in Europe, with few exceedances of limit or target values. However, these pollutants contribute to the deposition and accumulation of toxic metal levels in soils, sediments and organisms.

Impacts of air pollution on health

Air pollution continues to have significant impacts on the health of the European population, particularly in urban areas. It also has considerable economic impacts, cutting lives short, increasing medical costs and reducing productivity through working days lost across the economy. Europe's most serious pollutants in terms of harm to human health are PM, NO_2 and ground-level O_3.

Estimates of the health impacts attributable to exposure to air pollution indicate that $PM_{2.5}$ concentrations in 2014 ([2]) were responsible for about 428 000 premature deaths originating from long-term exposure in Europe (over 41 countries; see Table 10.1), of which around 399 000 were in the EU28. The estimated impacts on the population in these 41 European countries of exposure to NO_2 and O_3 concentrations in 2014 were around 78 000 and 14 400 premature deaths per year, respectively, and in the EU-28 around 75 000 and 13 600 premature deaths per year, respectively.

For this year's report, a sensitivity study has also been performed for the health impacts of $PM_{2.5}$ and NO_2. The lowest concentration used to calculate the health impacts of a pollutant in a baseline scenario is referred to as the counterfactual concentration (C_0). This represents for instance the background pollutant concentration that could occur naturally or the concentration below which the concentration-health response function used to estimate impacts may not be appropriate. In previous reports, for $PM_{2.5}$, a C_0 of 0 µg/m^3 has been considered. That is, impacts have been estimated for the full range of observed concentrations, meaning all $PM_{2.5}$ concentrations from 0 µg/m^3 upwards. But given estimates of what the background concentration in Europe may be and the availability of risk estimates, a sensitivity analysis for an alternative C_0 of 2.5 µg/m^3 has been considered in this report. It corresponds to the lowest concentration

([1]) This level was estimated assuming WHO unit risk (WHO, 2010) for lung cancer for polycyclic aromatic hydrocarbon mixtures, and an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000 (ETC/ACM, 2011).

([2]) 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 (2014).

found in populated areas and represents an estimate of the European background concentration. The premature deaths attributable to $PM_{2.5}$ with a C_0 of 2.5 µg/m³ results in estimates about 18 % lower than using a C_0 of 0 µg/m³.

For NO_2, in previous years the report has estimated health impacts based upon a C_0 of 20 µg/m³, since epidemiological studies have shown that the size of the effect is less certain below that concentration. For the sensitivity calculation performed this year, an alternative C_0 value of 10 µg/m³ has been chosen. This value corresponds to the lowest observed NO_2 value from a recent study for which a significant correlation between NO_2 concentrations and health outcomes was observed. In this case, the health impact results obtained using a C_0 of 10 µg/m³ are around three times higher than those obtained using the C_0 of 20 µg/m³.

Exposure and impacts on European ecosystems

Air pollution also can damage 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 (NH_3) and nitrogen oxides (NO_x).

High ground-level O_3 concentrations damage agricultural crops, forests and plants by reducing their growth rates. The EU target value for protection of vegetation from O_3 was exceeded in about 18 % of the EU-28 agricultural land area in 2014 (2), mostly in southern Mediterranean regions. The long-term objective for the protection of vegetation from O_3 was exceeded in 86 % of the total EU-28 agricultural area, and the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) critical level for the protection of forests was exceeded in 68 % of the total EU-28 forest area in 2014.

NO_x, SO_2 and NH_3 contribute to the acidification of soil, lakes and rivers, causing the loss of animal and plant life and biodiversity. After decades of declining sulphur emissions in Europe, acidification is declining or slowing and some forests and lakes are showing signs of recovery. However, an estimated 7 % of the total of the European ecosystem area was at risk of acidification in 2014. Exceedances of acidity critical loads in north-western Europe were higher in 2014 than in 2013, most likely as an effect of the increased sulphur deposition due to the eruption of the Bardarbunga volcano in Iceland.

Apart from causing acidification, NH_3 and NO_x emissions also disrupt land and water ecosystems by introducing excessive amounts of nutrient nitrogen. This leads to eutrophication, an oversupply of nutrients that can lead to changes in species diversity and to invasions of new species. It is estimated that about 70 % of the European ecosystem area remained exposed to air pollution levels exceeding eutrophication limits in 2014.

Focus on a specific sector: agriculture

The agricultural sector is an important source of both air pollutants and of greenhouse gases (GHGs). These emissions give rise to direct and indirect impacts on human and ecosystems' health and biodiversity, and they contribute to climate change. In turn, some air pollutants and effects of climate change have detrimental effects on agriculture and forestry, which can lead, for example, to significant yield losses and associated costs.

A wide range of technically and economically viable measures are already available to reduce emissions from the agricultural sector, but have yet to be adopted at the scale and intensity necessary to deliver emission reductions. The agricultural sector can and should therefore make a significant contribution to the EU's air quality and climate mitigation efforts. Nevertheless, care must be taken to balance air pollution and climate mitigation with the potential impacts, particularly on food production, and to optimise the different environmental and economic co-benefits of mitigation efforts.

1 Introduction

1.1 Background

Air pollution is a key environmental and social issue and, at the same time, it is a complex problem posing multiple challenges in terms of management and mitigation of harmful pollutants. Air pollutants are emitted from anthropogenic and natural sources; they may be either emitted directly (primary pollutants) or formed in the atmosphere (as secondary pollutants). They have a number of impacts on health, ecosystems, the built environment and the climate; they may be transported or formed over long distances; and they may affect large areas.

Effective action to reduce the impacts of air pollution 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 impact humans, ecosystems, the climate and subsequently society and the economy. Effective air quality policies require action and cooperation at global, European, national and local levels, extending across most economic sectors and engaging the public. Holistic solutions involving technological development, structural changes and behavioural changes must be found.

1.2 Objectives and coverage

This report presents an updated overview and analysis of air quality in Europe ([3]) and is focused on the state of air quality in 2015. The evaluation of the status of air quality is based on ambient air measurements (see Box 1.1), in conjunction with data on anthropogenic emissions and their evolution 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 the effects of air pollution on health (including a sensitivity analysis of two different counterfactual concentrations (C_0) for $PM_{2.5}$ and NO_2), and of ecosystems exposure to air pollution.

The report reviews progress towards meeting the air quality standards established in the two Ambient Air Quality Directives presently in force (EU, 2004, 2008) and 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).

Following on from the chapter in last year's report devoted to residential biomass combustion, this year's report looks in some more detail into another economic sector — agriculture. Agricultural emissions of air pollutants and GHGs, their impacts on health, the environment and climate change, and possible mitigation actions are presented and analysed.

([3]) The report focuses mainly on the EU-28, that is, the 28 Member States of the European Union (EU) (Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, 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). In some cases, the assessment is extended to the EEA-33 countries (the 33 member countries of the European Environment Agency (EEA): the EU-28 plus Iceland, Liechtenstein, Norway, Switzerland and Turkey); or the EEA-39 countries (the EEA-33 member countries plus the cooperating countries of the EEA: Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Kosovo under United Nations Security Council Resolution 1244/99, Montenegro and Serbia). Finally, some information also covers other smaller European countries such as Andorra, Monaco and San Marino. The French overseas regions do not appear in the following maps but they can be found at http://eeadmz1-cws-wp-air.azurewebsites.net/products/data-viewers/statistical-viewer-public/.

Box 1.1 Ambient air measurements

The analysis of concentrations in relation to the defined standards is based on measurements at fixed sampling points. Only measurement data received by 27 April 2017, when the 2015 data reported by countries was published (EEA, 2017a), were originally included in the analysis and, therefore, the maps, figures and tables reflect this data ([4]).

Fixed sampling points in Europe are situated at four types of sites:

- traffic-oriented locations ('traffic');
- urban and suburban background (non-traffic, non-industrial) locations ('urban');
- industrial locations (or other, less defined, locations: 'other'); and
- rural background sites ('rural').

For most of the pollutants (sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), 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 the objective for them of a minimum data capture of 90 % but, for assessment purposes, the more relaxed 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 the toxic metals (arsenic (As), cadmium (Cd), nickel (Ni) and lead (Pb)) 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, neither does it account for the fact that the Ambient Air Quality Directive (EU, 2008) provides the Member States with the possibility of subtracting contributions to the measured concentrations from natural sources and winter road sanding/salting.

1.3 Effects of air pollution

1.3.1 Human health

Air pollution is the single largest environmental health risk in Europe and the disease burden resulting from air pollution is substantial (Lim et al., 2012; WHO, 2014). Heart disease and stroke are the most common reasons for premature death attributable to air pollution and are responsible for 80 % of cases; lung diseases and lung cancer follow (WHO, 2014). In addition to causing premature death, air pollution increases the incidence of a wide range of diseases (e.g. respiratory and cardiovascular diseases and cancer), with both long- and short-term health effects, including at levels below the existing World Health Organization (WHO) guideline values (WHO, 2016a, and references therein). 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).

Various reports (e.g. WHO, 2005, 2013a) show that air pollution has also been associated with health impacts on fertility, pregnancy, and new-borns and children. These include negative effects on neural

([4]) Following the review of the text by the reporting countries, some new values were introduced. These values need to be resubmitted by the Member States to be considered official:
- For PM, a duplicated sampling point from Malta was removed changing the station from above to below the limit value.
- For O_3, Malta submitted correct information for station MT00007, which changed the concentration from below the target value threshold to above, and the Austrian stations with validation flag equal to two were also taken into account.
- For CO, the units of the Slovak stations were changed from mg/m^3 to $\mu g/m^3$.
- For lead, the data reported in ng/m^3 by the Czech Republic, Ireland, Slovenia and the United Kingdom were converted into $\mu g/m^3$ and incorrect data was corrected for Romania, changing the concentrations from above the limit value to below in all cases.
- Belgium corrected the reported As values for seven stations and the Ni values for 11 stations; in this case, there was only one station where the reported concentration was changed from above the target value to below.

development and cognitive capacities, which in turn can affect performance at school and later in life, leading to lower productivity and quality of life. 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, 2016a).

While this report focuses only on ambient (outdoor) air quality, indoor air pollution also poses considerable impacts on health (Lim et al., 2012; WHO, 2013a; RCP, 2016). In some situations, such as combustion of solid fuels in poorly ventilated chimneys and stoves, the sources of outdoor air pollution cause exposure and health impacts in addition to those from the indoor air pollution.

1.3.2 Ecosystems

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

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 (i.e. from less than a year to a few decades). Tropospheric O_3 and black carbon (BC), a constituent of PM, are examples of air pollutants that are short-lived climate forcers 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, changes in weather patterns due to climate change may change the transport, dispersion, deposition and formation of air pollutants in the atmosphere. Finally, increasing temperature, for instance, will increase the emissions of biogenic volatile organic compounds (VOCs).

Air quality and climate change should therefore be tackled together using policies and measures that have been developed through an integrated approach. These integrated policies would avoid the negative feedback of climate on air quality, or vice versa, that has already been evidenced. Examples are the negative impacts that the subsidisation of diesel cars (with lower carbon dioxide (CO_2) but higher PM and NO_x emissions) and the increased use of biomass combustion without adequate emission controls have on air quality.

1.3.4 The built environment and cultural heritage

Air pollution can also 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 our 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).

1.3.5 Economic impacts

The effects of air pollution on health, crops and forests 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. The Organisation for Economic Co-operation and Development (OECD) projects that these costs will increase to reach about 2 % of European gross domestic product (GDP) in 2060 (OECD, 2016), leading to a reduction in capital accumulation and a slowdown in economic growth.

Non-market costs are those associated with increased mortality and morbidity (illness causing, for example, pain and suffering), degradation of air and water quality and consequently the health of ecosystems, as well as climate change.

In 2015, more than 80 % of the total costs (market and non-market) of outdoor air pollution in Europe were related to mortality, while market costs were less than 10 %, (OECD, 2016). OECD (2016) estimates that the total costs for the OECD region amount to USD 1 280 per capita for 2015 and USD 2 880 to USD 2 950 per capita for 2060, corresponding to about 5 % of income in both 2015 and 2060. The non-market costs of outdoor air pollution amount to USD 1 200 per capita in 2015 and are projected to increase to USD 2 610 to USD 2 680 in 2060 in the OECD region (OECD, 2016).

1.4 Policy and legislation

The EU's clean air policy framework sets EU air quality standards, implements the EU's international obligations in the field of air pollution, and integrates environmental protection requirements into other productive sectors.

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.' EU air pollution legislation has followed a twin-track approach of implementing both air quality standards, including an exposure reduction target for $PM_{2.5}$, and emission mitigation controls. The main policy instruments on air pollution within the EU include the Ambient Air Quality Directives (EU, 2004, 2008) and the National Emission Ceilings (NEC) Directive (EU, 2016) ([5]).

Beyond the EU, emissions are also addressed under various international conventions, including the 1979 United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) and its various protocols, among which the 2012 amended Gothenburg Protocol is key in reducing emissions of selected pollutants across the pan-European region.

The Clean Air Policy Package for Europe, published by the European Commission in late 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 (European Commission, 2013). In this context, the EU has recently agreed on a revised National Emissions Ceilings (NEC) Directive (EU, 2016). It sets 2020 and 2030 emission reduction commitments for SO_2, NO_x, non-methane volatile organic compounds (NMVOCs), NH_3 and $PM_{2.5}$. The more ambitious reduction commitments agreed for 2030 are designed, in line with the Clean Air Policy Package, to reduce the health impacts of air pollution by around half compared with 2005. Further, the Directive requires that Member States draw up National Air Pollution Control Programmes that should contribute to the successful implementation of air quality plans established under the EU's Air Quality Directive.

To allow the EU to implement and ratify the Minamata Convention on Mercury (UN, 2013), which entered into force on 18 May 2017, the European Commission adopted on 2 February 2016 a Minamata ratification package including proposed legislation to update EU law where needed to fully conform with the Convention (European Commission, 2016a, 2016b). The Mercury Regulation sets rules that aim to put the EU on track to become the first mercury (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 proven that the use of Hg is needed for the protection of health and the environment.

In addition, European policies targeting air pollution and the reduction of its impacts contribute directly or indirectly to the achievement of several of the Sustainable Development Goals, as illustrated in Figure 1.1. 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).

([5]) More information on these instruments and source-specific legislation on, for instance, industrial emissions, road and non-road vehicle emissions, or fuel-quality standards is available online at http://ec.europa.eu/environment/air/legis.htm?

Figure 1.1 How air pollution relates to the UN Sustainable Development Goals

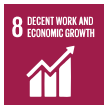
Reducing air pollution can help families become healthier, save on medical expenses, and improve productivity.

Air pollution can cause crop damage and affect food quality and security.

Air pollution poses a major threat to human health. It is linked to respiratory infection and cardiovascular disease. It causes increases in population morbidity and mortality.

Pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from open fires and the combustion of fossil fuels mix with precipitation causing harmful acid rain that can compromise water quality.

Electricity from renewable energy rather than fossil fuels offers significant public health benefits through a reduction in air pollution.



Air pollution impacts on health, crop and forest yields, ecosystems, the climate and the built environment, with consequences for productivity and economic growth. Ambient and indoor air pollution also has negative effects on the working environment and its safety.

Power generation, industry and transportation are large contributors to air pollution. A new focus on decreasing energy consumption and on improving sustainable and public transportation could progressively reduce pollution.

Urban areas significantly contribute to air pollution. Making cities sustainable could progressively improve the air quality.

Chemicals released into the air increase air pollution and contribute to harmful effects on human health. Responsible production and consumption could help to reduce these harmful chemicals.

Combustion of fossil fuels plays a key role in the process of climate change, which places food, air and water supplies at risk, and poses a major threat to human health.

Deposition of air pollutants on water may negatively affect its quality and life under water. It can lead to eutrophication and acidification of fresh water bodies, and accumulation of toxic metals and Persistent Organic Pollutants (POPs) in fresh and marine waters.

Emissions from combustion of fossil fuels mixed with precipitation cause acid rains that pose a major threat to forests and ecosystems.

Source: Adapted from UNICEF, 2016.

2 Sources and emissions of air pollutants

Air pollutants may be categorised as primary (directly emitted to the atmosphere) or secondary (formed in the atmosphere from precursor pollutants). Key primary air pollutants include primary PM, BC, sulphur oxides (SO_x), NO_x (which includes both NO and NO_2), NH_3, CO, methane (CH_4), NMVOCs, C_6H_6, certain metals, and polycyclic aromatic hydrocarbons (PAH, including BaP). Secondary air pollutants include secondary PM, O_3 and NO_2. Air pollutants may have a natural, anthropogenic or mixed origin, depending on their sources or the sources of their precursors.

2.1 Sources of regulated pollutants

The main precursor gases for secondary PM are SO_2, NO_x, NH_3 and VOCs. The gases NH_3, SO_2 and NO_x react in the atmosphere to form NH_4^+, SO_4^{2-} and NO_3^- compounds. These compounds form new particles in the air or condense onto pre-existing ones to form secondary particulate matter (i.e. secondary inorganic aerosols). Certain NMVOCs are oxidised to form less volatile compounds, which form secondary organic aerosols or oxidised NMVOCs.

Primary PM originates from both natural and anthropogenic sources, and it is commonly classified into primary PM_{10} and primary $PM_{2.5}$. Natural sources include sea salt, naturally suspended dust, pollen and volcanic ash, while anthropogenic sources include fuel combustion for power generation, domestic heating and transport, industry and waste incineration, and agriculture, as well as brakes, tyres and road wear and other types of anthropogenic dust. BC is a constituent of $PM_{2.5}$ formed from incomplete fuel combustion, with the main sources including transport and domestic heating.

The major sources of NO_x are combustion processes, which may be stationary or mobile. NO accounts for the majority of NO_x emissions: NO is subsequently oxidised to form NO_2, although some NO_2 is emitted directly. The proportion of NO_2 (i.e. the NO_2/NO_x ratio) in vehicle exhaust is considerably higher in diesel vehicles than in petrol, because their exhaust after-treatment systems increase oxidation of NO generating higher direct NO_2 emissions.

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 such as NO_x and NMVOCs of both natural (biogenic) and anthropogenic origin. NO_x also deplete tropospheric O_3 due to the titration reaction with the emitted NO to form NO_2 and oxygen.

SO_x are primarily emitted from fuel combustion in the form of SO_2. The main anthropogenic sources are stationary power generation, industry, and commercial, institutional and household fuel combustion. The largest natural source of SO_2 is volcanoes.

BaP, CO and C_6H_6 are gases emitted as a result of the incomplete combustion of fossil fuels and biofuels, and C_6H_6 is also emitted from evaporative emissions. The main sources of BaP are domestic heating (in particular wood and coal burning), waste burning, coke production and steel production. Other sources include outdoor fires, road traffic and rubber tyre wear. Road transport was once a major source of CO emissions, but the introduction of catalytic converters has reduced these emissions significantly. Most emissions of C_6H_6 derive from traffic, because it is used as an additive to petrol, although industrial emissions might also have high local impacts.

CH_4 is a GHG and also a precursor of tropospheric O_3. The main source of CH_4 emissions is agriculture (in particular enteric fermentation from ruminant animals, see Chapter 3), followed by waste management. There are also important natural sources of CH_4, including boreal and tropical wetlands.

Anthropogenic emissions of toxic metals originate mainly from fossil fuel combustion, industrial processes and waste incineration. Emissions of As mainly derive from metal smelters and fuel combustion. Cd is emitted from non-ferrous metal production, stationary fossil-fuel combustion, waste incineration, iron and steel production and cement production. Ni is emitted from fuel oil and coal combustion, Ni mining and primary production, incineration of waste and sewage sludge, steel manufacture and electroplating. Pb is emitted from the combustion of fossil fuels, waste incineration and non-ferrous metal, iron, steel and cement production. The largest anthropogenic source of Hg emissions to air on a global scale is the combustion of coal and other fossil fuels. Other sources include metal production, cement production, waste disposal and cremation.

2.2 Total emissions of air pollutants

All primary and precursor emissions contributing to ambient air concentrations of PM, O_3 and NO_2 decreased ([6]) between the years 2000 and 2015 in the EU-28 (Figure 2.1a) ([7]) and the EEA-33. The smallest reduction was for NH_3 (8 % reduction in the EU-28 and 4 % reduction in the EEA-33) and the largest was for SO_x (72 % reduction in the EU-28 and 61 % reduction in the EEA-33).

Regarding the remaining pollutants (As, Cd, Ni, Pb, Hg and BaP), Figure 2.1b shows a decrease in their emissions between the years 2000 and 2015, although emission levels have stabilised since 2011. The greatest reported emission reductions in both the EU-28 and the EEA-33 were for Pb (63 % reduction in both the EU-28 and the EEA-33) and Ni (61 % reduction in both the EU28 and the EEA-33), and the smallest was for BaP (3 % reduction in the EU-28 and 5 % reduction in the EEA-33). Reported BaP emissions have been underestimated because of some missing data ([8]). Although C_6H_6 is not included as an individual pollutant in European emissions inventories, C_6H_6 emissions have dropped sharply since the introduction of the revised Fuel Quality Directive (EU, 2009).

This chapter summarises information on the sources and their emissions of the regulated air pollutants aggregated at the EU-28 and EEA-33 levels. For more detailed information on emissions at country level, please refer to EEA (2017c).

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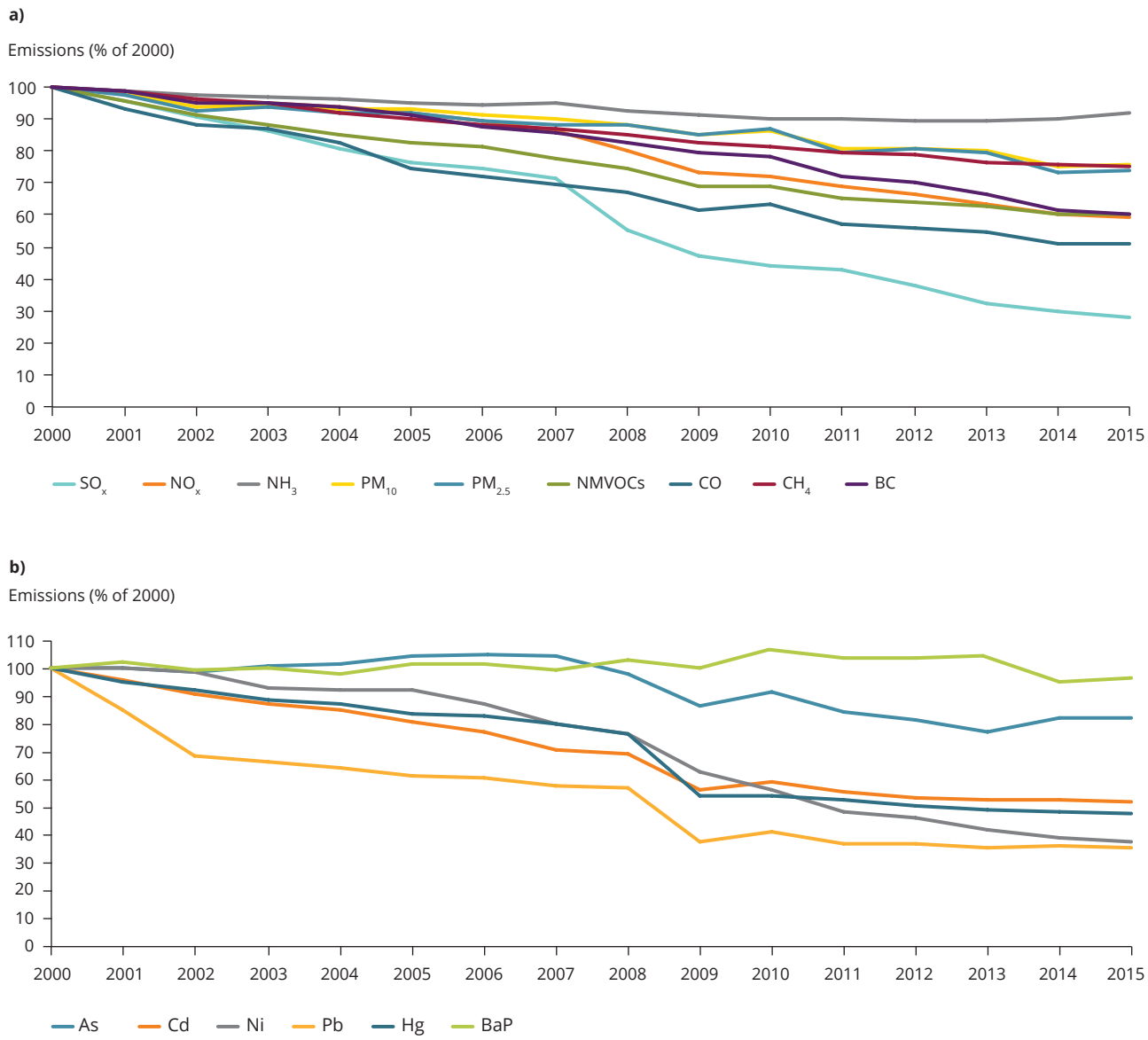
([6]) The analysis of the development of emissions in Europe is based on emissions reported by the countries (EEA, 2017c). The nominal increase or decrease in reported emissions is analysed, not statistical trends.
([7]) Reporting on BC emissions is voluntary (EEA, 2017c).
([8]) Austria, Greece, Italy and Spain did not provide data for BaP, and gap-filling was not possible (EEA, 2017c).

Figure 2.1 **Development in EU-28 emissions, 2000-2015 (% of 2000 levels): ([a]) SO_x, NO_x, NH_3, PM_{10}, $PM_{2.5}$, NMVOCs, CO, CH_4 and BC; ([b]) As, Cd, Ni, Pb, Hg and BaP**



Notes: 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 VOCs emissions. Under the CLRTAP Gothenburg Protocol, parties are encouraged to report emissions of BC, one of the constituents of PM. It means that reporting on BC emissions has been voluntary and has not been compulsory for every country.

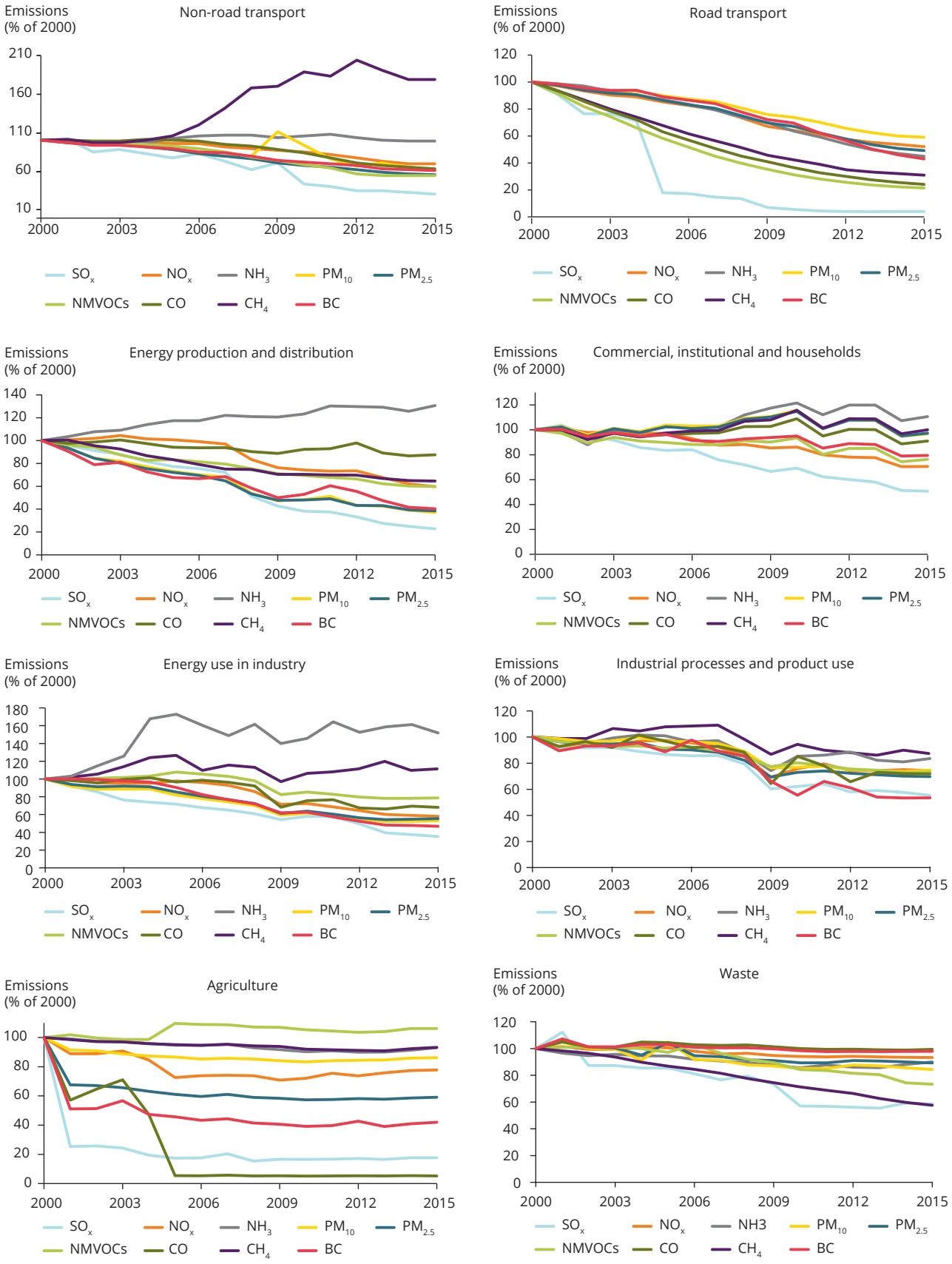
Sources: EEA, 2017c, 2017e.

2.3 Sectoral emissions of air pollutants

The main source sectors contributing to emissions of air pollutants in Europe are non-road and road transport, the commercial, institutional and households sector, energy production and distribution, energy use in industry, industrial processes and product use, agriculture and waste. Figure 2.2 shows the evolution of the emissions of SO_x, NO_x, NH_3, primary PM_{10}, primary $PM_{2.5}$, NMVOCs, CO, CH_4 and BC from these sectors between the years 2000 and 2015. Similarly, Figure 2.3 shows the evolution in emissions from 2000 to 2015 of the toxic metals As, Cd, Ni, Pb and Hg, and BaP.

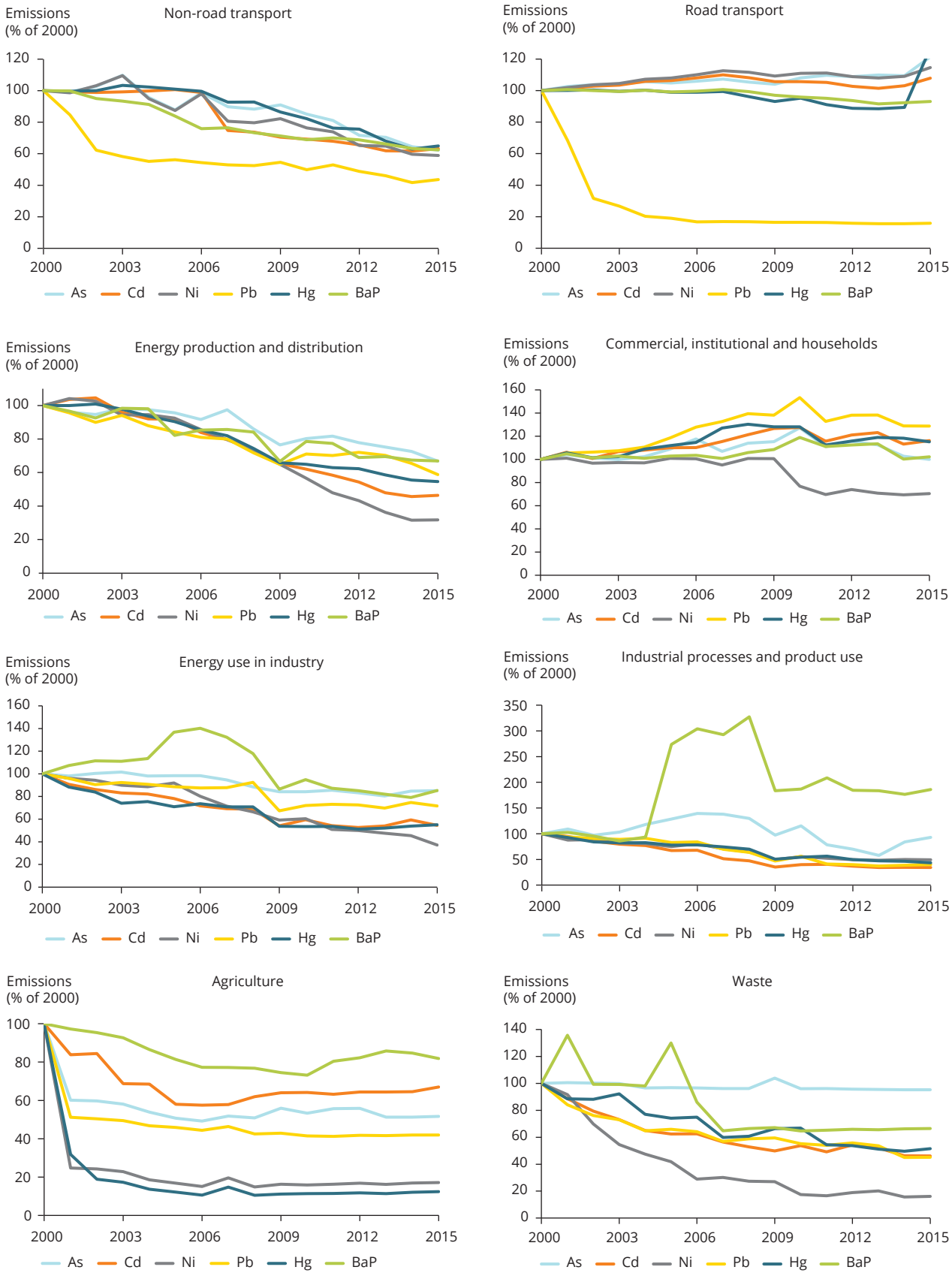
The contributions from the different emission source sectors to ambient air concentrations and air pollution impacts depend not only on the amount of pollutant emitted, but also on the proximity to the source,

Figure 2.2 **Development in EU-28 emissions from main source sectors of SO_x, NO_x, NH_3, PM_{10}, $PM_{2.5}$, NMVOCs, CO, CH_4 and BC, 2000-2015 (% of 2000 levels)**



Sources: EEA, 2017c, e.

Figure 2.3 **Development in EU-28 emissions from main source sectors of As, Cd, Ni, Pb, Hg and BaP, 2000-2015 (% of 2000 levels)**



emission conditions (e.g. height and temperature) and other factors such as dispersion conditions and 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.

The **road transport** sector was the largest contributor to total NO_x emissions and the second largest emitter of BC in 2015 (Figure 2.4). As Figures 2.2 and 2.3 show, emissions from the road transport sector have been reduced considerably (by more than 25 %) since the year 2000, with the exception of As, Hg, Ni and Cd emissions. On the other hand, road transport made only a minor contribution to the total BaP, As, Hg and Cd emissions in the EU-28, as shown in Figure 2.5. The highest emission reductions between the years 2000 and 2015 were registered for SO_x, Pb and NMVOCs. The situation and development of the emissions of this sector in the EU-28 and the EEA-33 are quite similar.

The contribution of the **non-road transport** (aviation (landing and take-offs), railways, national shipping including international inland waterways and fishing) sector to total emissions of air pollutants is relatively small, as shown in Figures 2.4 and 2.5. Emissions from this sector have been reduced by more than 30 % between 2000 and 2015 for all pollutants, except NH_3 (Figures 2.2 and 2.3).

The **commercial, institutional and households** fuel combustion sector was the largest contributor to total primary $PM_{2.5}$, primary PM_{10}, BC, CO and BaP emissions in the EU-28 in 2015, as shown in Figures 2.4 and 2.5. In the EEA-33, contributions were 57 %, 35 %, 45 %, 48 % and 74 % for primary $PM_{2.5}$, primary PM_{10}, BC, CO and BaP emissions, respectively. Emissions of PM in this sector remained relatively constant between the years 2000 and 2015, although SO_x emissions reduced by 49 % in the EU-28 (37 % reduction in EEA-33). In contrast, the sector increased its emissions of NH_3, Pb, Cd, and Hg between the years 2000 and 2015 in both the EU-28 and the EEA-33.

The **industrial processes and product use** sector was the largest contributor to total emissions of NMVOCs, while the **energy use in industry** sector was the largest contributor to total As, Cd and Pb emissions in the EU-28 in 2015, as shown in Figures 2.4 and 2.5. In the EEA-33, the industrial processes and product use sector contributed to 47 % of total NMVOC emissions. The energy use in industry sector's relative contributions to total As, Cd, and Pb emissions were 43 %, 35 %, and 35 %, respectively in both the EU-28 and the EEA-33. The sectors considerably reduced their air pollutant emissions between the years 2000 and 2015, with the largest reduction in energy use in industry registered for SO_x. The exception was for BaP emissions from the industrial processes and product use sector, where reported emissions between the years 2000 and 2015 increased by 86 % in the EU-28 (32 % increase in the EEA-33); and for NH_3 emissions in energy use in industry (52 % increase in both the EU-28 and the EEA-33).

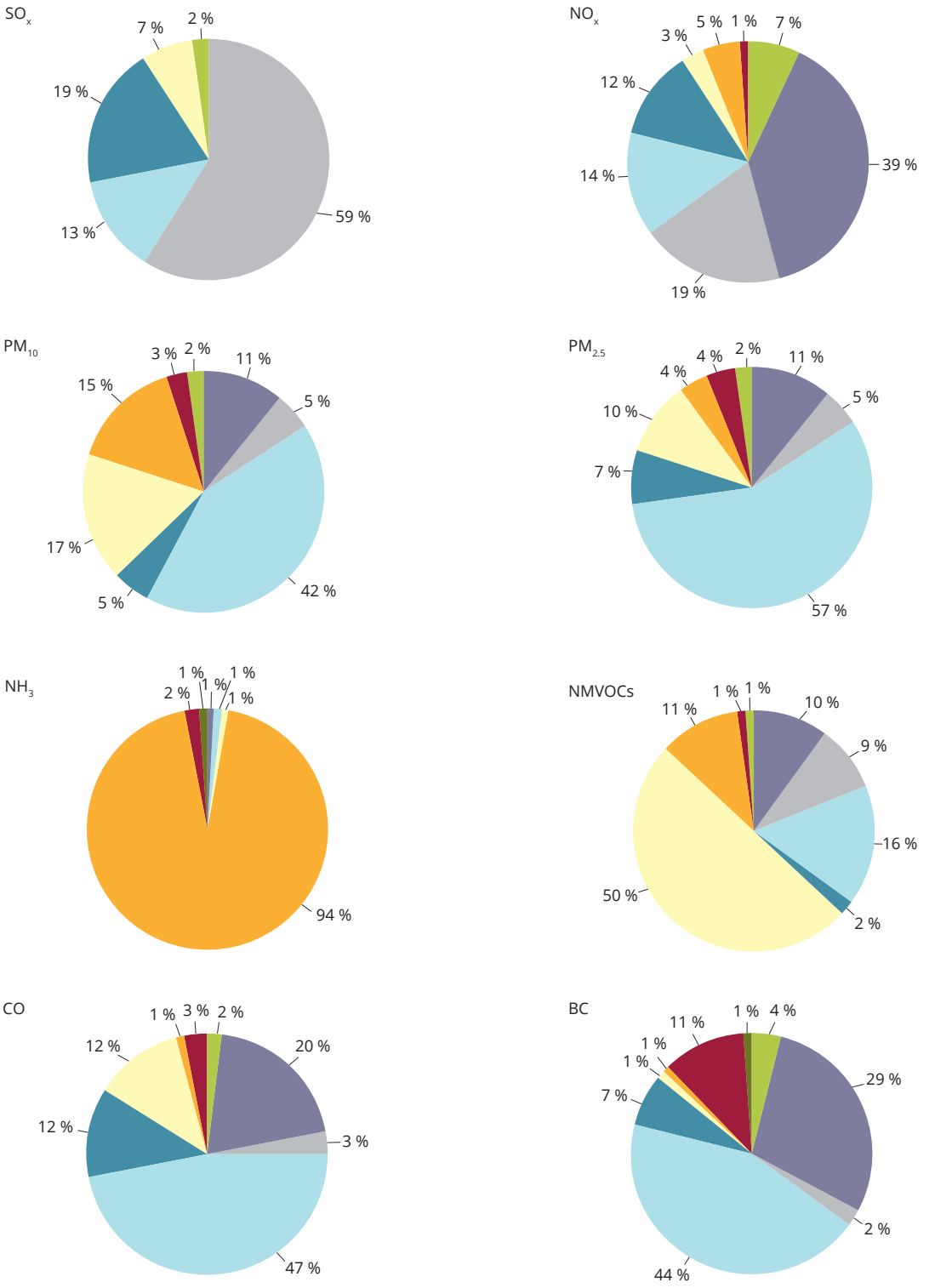
Photo: © Miha Palir, NATURE@work /EEA

The **energy production and distribution** sector is the largest contributor to total SO_x Ni and Hg emissions, contributing to 59 %, 37 % and 39 % of total SO_x, Ni, and Hg emissions, respectively, in the EU-28 in 2015. Between the years 2000 and 2015, the sector made reductions in all emissions apart from NH_3, to whose total emissions it contributes only < 0.5 %.

The **agricultural** sector is the largest contributor to total NH_3 and CH_4, accounting for 94 % of total NH_3 emissions in the EU-28 and EEA-33 and 53 % of total CH_4 emissions in the EU-28 (54 % in EEA33) in 2015. Reported NH_3 and CH_4 emissions both decreased by only 7 % between the years 2000 and 2015 in the EU-28 (3 % reductions in the EEA-33), while NMVOC emissions increased by 6 % in the EU-28 (10 % increase in the EEA-33). For more information on agriculture and its contribution to air pollution, see Chapter 3.

The contribution of the **waste sector** to total emissions of air pollutants is relatively small, with the exception of CH_4, where it accounted for 27 % of total EU-28 and EEA-33 emissions in 2015. Reported CH_4 emissions decreased by 42 % between 2000 and 2015 in the EU-28 (39 % in the EEA-33).

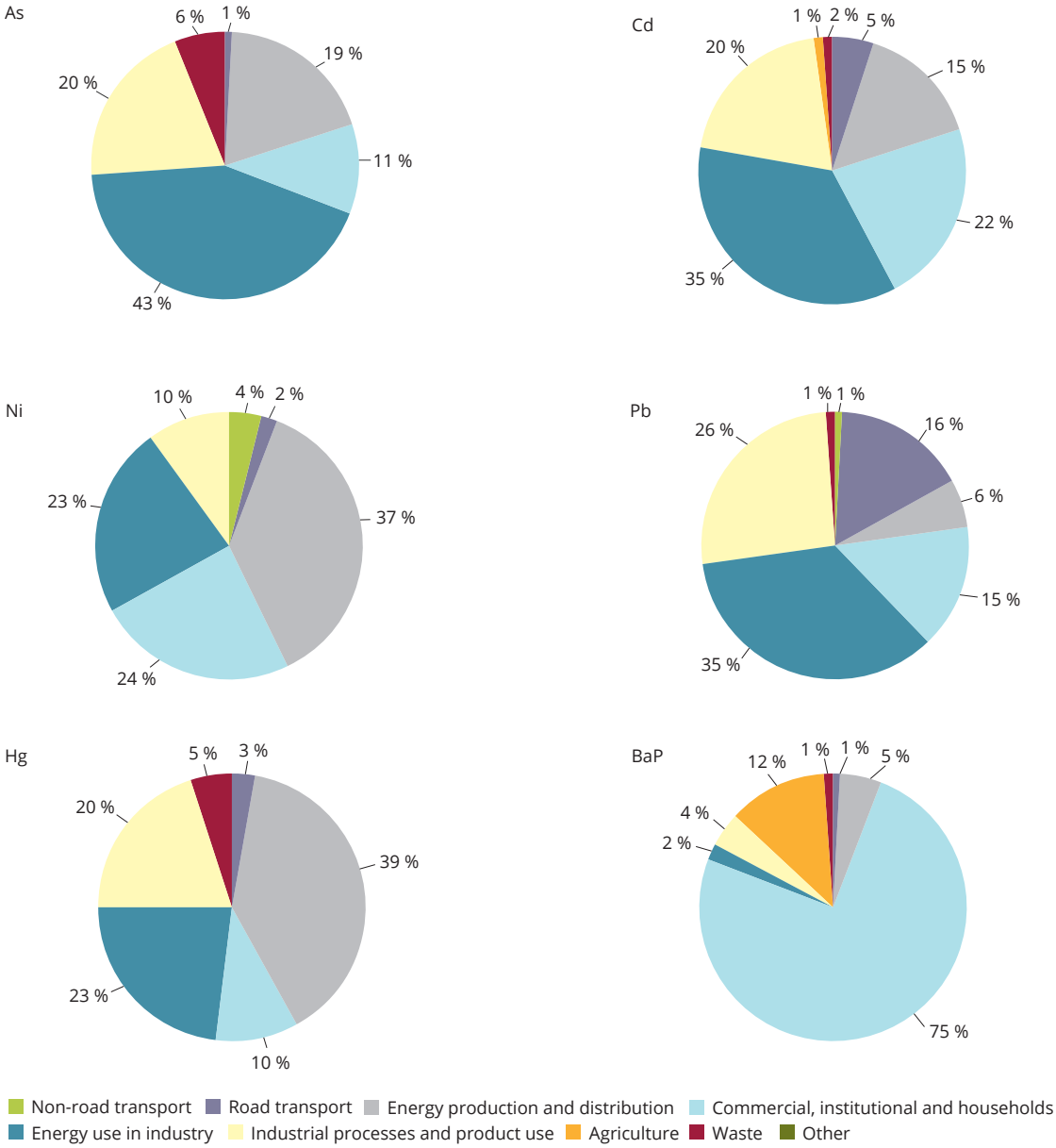
Figure 2.4 **Contribution to EU-28 emissions from main source sectors in 2015 of SO_x, NO_x, PM_{10}, $PM_{2.5}$, NH_3, NMVOCs, CO and BC**



Note: For CH_4, please see Figure 3.4.

Sources: EEA, 2017c, 2017e.

Figure 2.5 **Contribution to EU-28 emissions from main source sectors in 2015 of As, Cd, Ni, Pb, Hg and BaP**



Source: EEA, 2017c.

3 Agriculture: an important source of air pollution and greenhouse gases

Agriculture provides humans with food, but also with a source of bioenergy, etc. It contributes to rural development and landscape management; it is essential to human wellbeing. Agriculture covers around 40 % of the EU's land area (Eurostat, 2016). While overall agricultural production has increased in the EU, the number of farms and farmers have decreased over past decades, and the average farm size in Europe has become larger. There has been a reduction in the share of utilised agricultural area cultivated by smaller farms, and, in 2013, very large farms (bigger than 100 hectares) constituted 3 % of all holdings but farmed half of the utilised agricultural area in the EU-28 (Eurostat, 2016).

Agriculture contributes to and is affected by air pollution and climate change. Depending on the policy framework and management practices, agriculture is a considerable source of both air pollution and GHGs emitted to the air.

The most important air pollutants deriving from agriculture are NH_3 and PM. NH_3 also plays a decisive role in the formation of PM in the atmosphere (secondary PM), as NH_3 determines the amounts of ammonium sulphate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3) available in the atmosphere to increase PM mass concentrations. Other air pollutants emitted from agriculture, such as NO_x, SO_x and NMVOCs may also contribute to the formation of secondary inorganic and organic PM. The most important GHG emissions from agriculture are CH_4 and nitrous oxide (N_2O), followed by a less important contribution from CO_2.

Emissions of NO_x, NMVOCs and CH_4 contribute to tropospheric O_3 formation, a secondary air pollutant that has negative effects on human health, climate and vegetation, including crops (Dentener et al., 2006). Emissions of N_2O contribute considerably to stratospheric O_3 depletion (Portmann et al., 2012).

This chapter describes emissions from the agricultural sector and emission changes in the main air pollutants (NH_3, NMVOCs, PM, and BaP,) and GHGs (CH_4 and N_2O); discusses the sector's impacts on the environment and human health; briefly explains how air pollution and climate change affect agriculture; and summarises economically feasible mitigation measures and best practices in agriculture.

3.1 Air pollutant emissions from agriculture

In the EU-28 ([9]), 94 % of NH_3 emissions stemmed from agriculture in 2015 (see Figure 2.4). The agricultural sector also contributes to primary PM, NMVOCs and BaP emissions (EEA, 2017g).

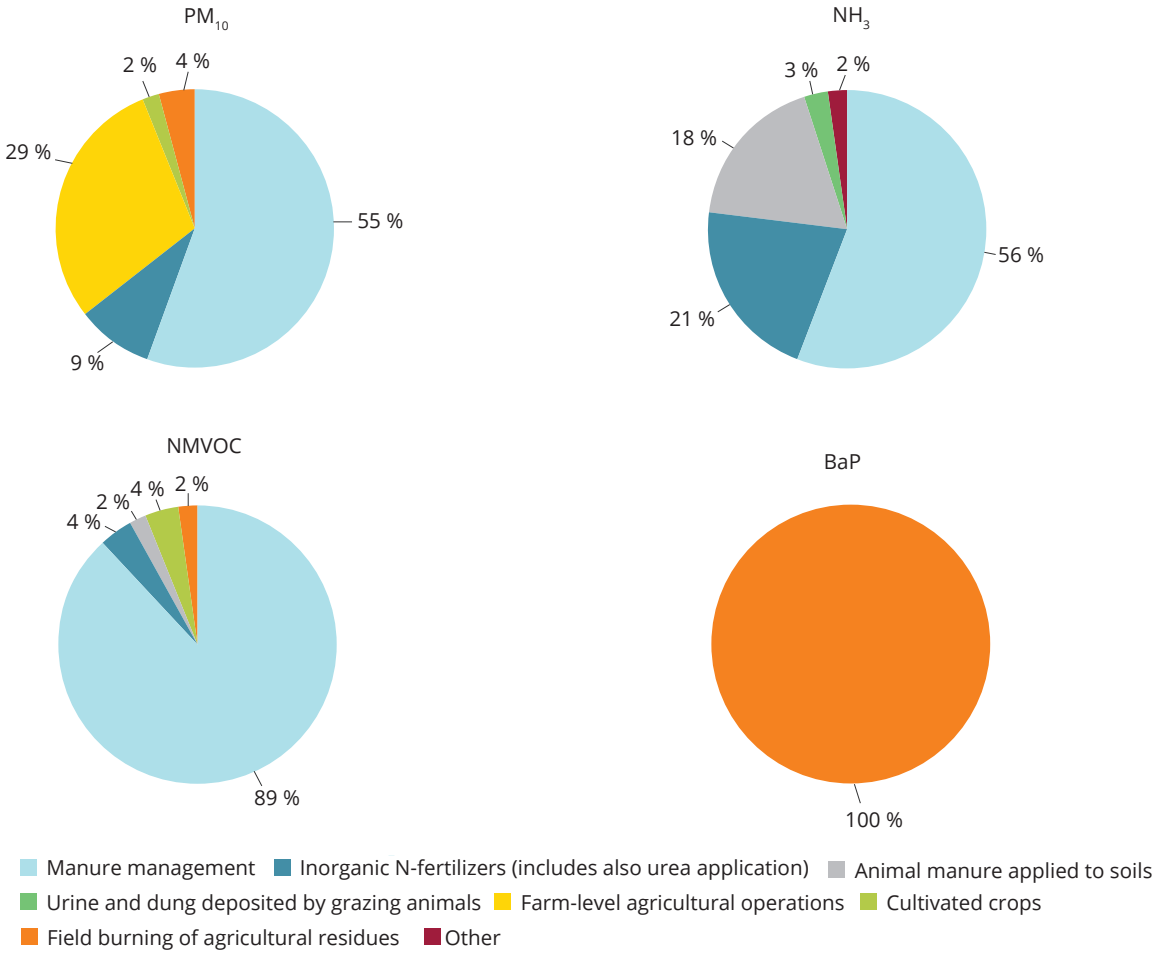
Figure 2.4 shows that agriculture is the third most important source of primary PM_{10} emissions in the EU (15 % of EU total emissions in 2015). The sector is also the second largest source of BaP (12 % of total EU emissions in 2015, figure 2.5) and a key source of NMVOC emissions (11 % of EU totals in 2015 (Figure 2.4)).

A number of studies have confirmed that NH_3 emissions from agriculture contribute to episodes of high PM concentrations experienced across certain regions of Europe each spring, and during those episodes, to exceedances of PM_{10} daily limit values set in the EU's Air Quality Directive (see the example described in Box 3.1 and the 2015 main episodes summarised in Box 4.1). NH_3 emissions contribute, therefore, to both negative short- and long-term impacts on human health (Lelieveld et al., 2015; see also Chapters 9 and 10 of this report).

Figure 3.1 shows the contribution of key sub-sectors towards total EU agricultural emissions of NH_3, NMVOCs, BaP and PM_{10} in 2015. NH_3 is mainly emitted

([9]) Greece did not submit any emission data for the year 2015 or for earlier years in 2017.

Figure 3.1 **Agriculture sub-sectoral contribution to the total EU-28 agricultural PM_{10}, NH_3, NMVOCs, and BaP emissions in 2015**



Source: EEA, 2017c.

from manure management (56 %) and use of inorganic nitrogen fertilisers (21 %). Emissions arise primarily from the decomposition of urea in animal wastes and uric acid in poultry wastes. They depend on animal species, age, weight, diet, housing system, waste management and liquid manure storage techniques (EEA, 2017h). Primary PM_{10} is mainly emitted by manure management (55 %), followed by farm-level agricultural operations (29 %). Manure management is also the biggest source of NMVOC emissions from agriculture. BaP is almost wholly emitted from field burning of agricultural residues.

Over the period 2000-2015, emissions in the agricultural sector in the EU-28 reduced as follows: NH_3 by 7 %, PM_{10} by 14 % and BaP by 18 % (Figures 2.2 and 2.3). However, reported EU NMVOC emissions from agriculture increased by 6 % (Figure 2.2).

Box 3.1. Reducing fertiliser use can reduce PM_{10} concentrations

The European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM) (2016a) has simulated PM_{10} concentrations in Europe for a period (mid February to mid April 2011) where high PM_{10} concentrations were measured over large areas (Figure 6 in ETC/ACM, 2016a).

An additional scenario was also modelled to simulate the decrease in mean PM_{10} concentrations resulting from a hypothetical 80 % reduction in NH_3 emissions from reduced fertiliser use during the same study period. Here, fertiliser refers mainly to field-applied fresh manure. This NH_3 emission reduction was modelled over a region covering Austria, Benelux, the Czech Republic, England, northern France, Germany, Hungary, northern Italy, Poland and Slovakia.

The reduction in NH_3 emissions led to a decrease of up to 7 µg/m^3 PM_{10} above the northern Adriatic Sea and a relative decrease of up to 27 % above the English Channel (figure 7 in ETC/ACM, 2016a). This simulation illustrates how NH_3 emissions from agriculture can significantly contribute to episodes with elevated PM_{10} concentrations in Europe during spring months. This also has an impact on the number of exceedances of the EU's PM_{10} daily limit value. With respect to potential mitigation measures, these results demonstrate the relevance of targeting the spreading of manure over short periods, particularly in spring.

The NEC Directive (EU, 2016) contains emission ceilings for single EU Member States and the EU-28 as a whole from 2010 until the end of 2019. In 2015, the total EU emissions of NH_3 in 2015 were below this ceiling, although for individual Member States, a number have reported total emissions exceeding their respective ceilings. For all years from 2020 to 2029, the EU will have to reduce its total NH_3 emissions by 6 % compared with 2005 and by 19 % for all years from 2030 onwards. NH_3 emissions have decreased in the EU since 1990, but not by anywhere near the same extent as the other pollutants covered by the directive. For the second consecutive year, emissions of NH_3 have for example actually increased across the EU, by 1.7 % from 2014 to 2015, due to higher emissions from the agricultural sector (EEA, 2017h). A main reason for the high or even rising NH_3 emissions in some countries is the increasing number of big pig or poultry facilities without implementing measures and/or technologies to limit emissions. During the negotiations for the revision of the NEC Directive, the Member States in the Council opted to remove the Commission's initial proposal of cutting the emissions of the O_3 precursor CH_4 by 33 % by 2030 compared with 2005 levels.

3.2 Greenhouse gas emissions from agriculture

The main GHGs emitted from the agricultural sector are CH_4 and N_2O. In Europe, agriculture accounts for 10 % of GHG emissions (Figure 3.2). In 2015, 53 % of CH_4 and 78 % of N_2O emissions derived from agriculture in the EU. CH_4 and N_2O have a much higher global warming potential per unit mass than CO_2 ([10]). In addition to being a climate forcer, CH_4 is a ground-level O_3 precursor.

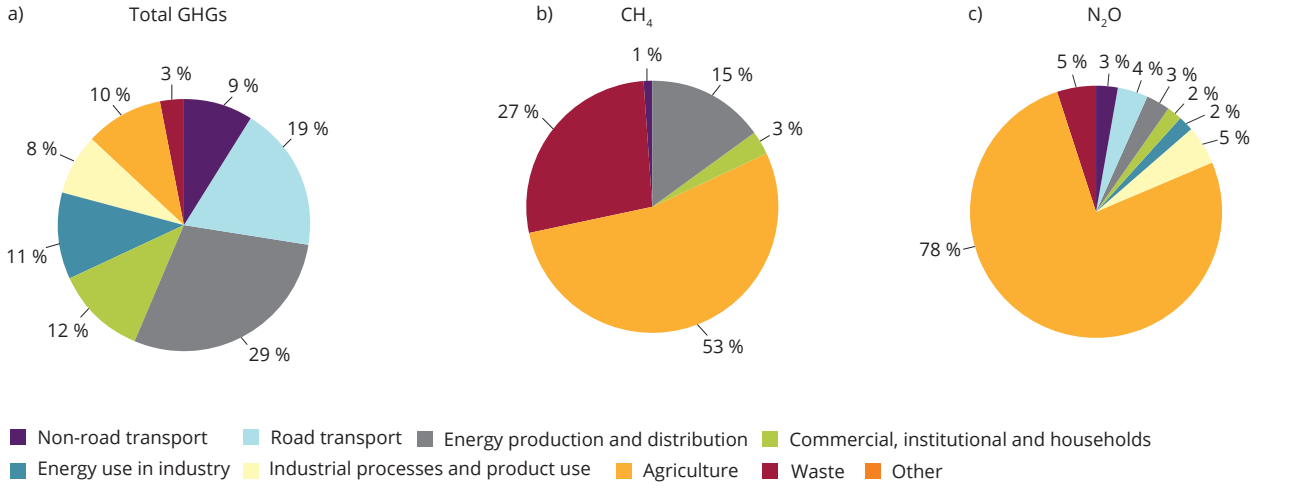
Figure 3.3 shows the contribution of selected agricultural sub-sectors to total EU emissions of GHGs, CH_4 and N_2O for 2015. Enteric fermentation, agricultural soils and manure management contributed 44 %, 37 % and 15 % of total agricultural GHG emissions, respectively. Rice cultivation and field burning of agricultural residues account for the rest.

In Europe, the main source of CH_4 emissions is enteric fermentation (fermentative digestion) by ruminant livestock and stored manures, which accounted for 80 % of total EU agricultural CH_4 in 2015 (Figure 3.3). N_2O is mainly generated by the microbial transformation of nitrogen in soils and manures and is often enhanced where available nitrogen exceeds plant requirements, especially under wet conditions (Smith et al., 2007). In 2015, agricultural soils were the source of 88 % of agricultural N_2O emissions in the EU. In the agricultural sector, CO_2 is released mainly from microbial decay or burning of plant litter and soil organic matter.

Between the years 2000 and 2015, reported EU-28 agricultural sector emissions of CH_4 and N_2O reduced by 7 % (Figure 2.2) and 5 %, respectively.

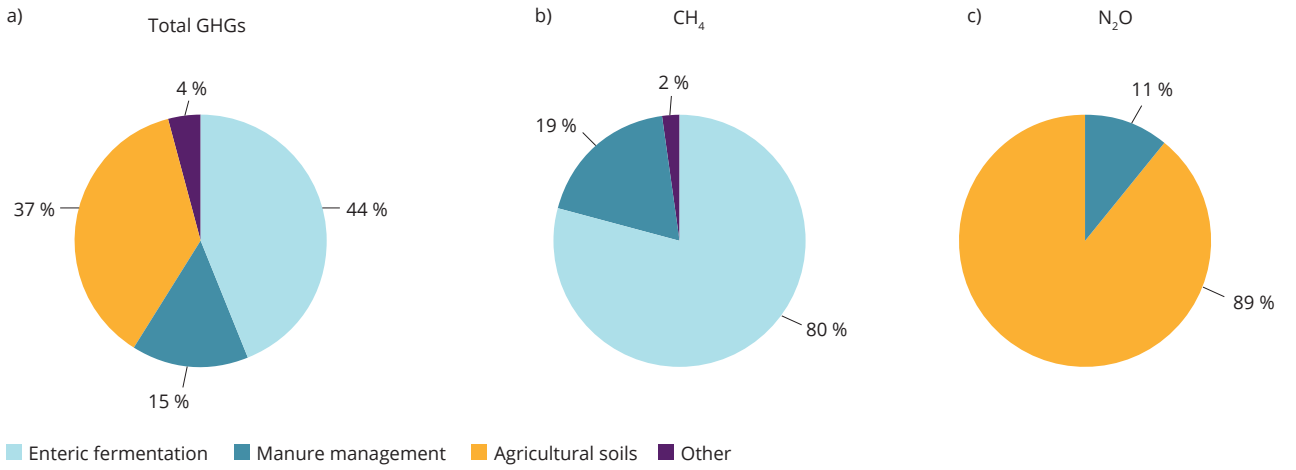
([10]) For example, 1 kilogramme of CH_4 has 25 times the global warming potential of 1 kilogramme of CO_2, and 1 kilogramme of N_2O has 298 times the global warming potential of 1 kilogramme of CO_2 (IPCC, 2014).

Figure 3.2 **Sectoral contribution to the total EU-28 emissions in 2015: (a) GHGs (CO_2-eq), (b) CH_4, and (c) N_2O**



Source: EEA, 2017e.

Figure 3.3 **Agriculture sub-sectoral contribution to the total EU-28 agricultural emissions in 2015: (a) GHGs (CO_2-eq), (b) CH_4 and (c) N_2O**



Source: EEA, 2017e.

3.3 Agricultural emission impacts on health, the environment and climate, and air pollution impacts on agriculture

The agricultural sector is a source of air pollution, but it is also impacted by air pollutants. On the one hand, agricultural activities contribute to direct and indirect negative effects on human health, vegetation and ecosystems, biodiversity, and the climate at the local, regional and global scales (Erisman et al., 2008; Sutton et al., 2011). On the other hand, some air pollutants and implications of climate change have detrimental effects on agriculture (EEA, 2015a).

PM and O_3 are two of Europe's most problematic pollutants in terms of harm to human health. As mentioned above, agriculture is the main emitter of NH_3, an important precursor of secondary PM, and agriculture contributes considerably to primary PM emissions. In addition, agriculture contributes to O_3 formation, through its emissions of the O_3 precursors NO_x and CH_4. CH_4 is relatively long lived in the atmosphere (around 12 years) and it is transported over long distances in the atmosphere, leading to O_3 formation on the regional/hemispheric/global scale.

The use of pesticides in agricultural applications leads to emissions of persistent organic pollutants

(POPs) to the air, water, and soils. POPs are chemical substances that persist in the environment and have the potential to accumulate in the food chain (biomagnification) and thus pose a risk of causing adverse effects to human health and the environment. Some of the POPs used in pesticides have already been considerably reduced or phased out (e.g. the insecticide dichlorodiphenyltrichloroethane, DDT) as a result of the 2001 Stockholm Convention on POPs (UNEP, 2015, 2017; EEA, 2016a).

The impact of agricultural emissions on human health is mainly linked to exposure to atmospheric PM, both to primary PM emissions and to the formation of secondary PM from gaseous precursors (mainly NH_3). Secondary PM may account for up to 50 % of ambient $PM_{2.5}$ mass concentrations in certain European regions (Putaud et al., 2010), with NH_3 contributing through secondary PM formation to 10-20 % of the $PM_{2.5}$ mass in densely populated areas in Europe and even higher contributions in areas with intensive livestock farming (Hendriks et al., 2013). WHO (2013a) emphasises the importance of secondary PM, together with BC and secondary organic aerosols, as having 'substantial exposure and health research finding associations and effects'.

In terms of damage to vegetation and ecosystems, the most harmful air pollutants are O_3, NH_3 and NO_x. Direct exposure to O_3 is considered to be more damaging to vegetation and crops than exposure to any other air pollutant (Ainsworth et al., 2012). (See Section 11.1 for more information). NH_3 in the atmosphere can be transported over long distances and, when deposited on land or water, it can cause acidification and eutrophication in sensitive ecosystems such as nutrient-poor freshwaters and grasslands (Sutton et al., 2011; Webb et al., 2014). (See Sections 11.2 and 11.3 for more information).

Anthropogenic emissions of N_2O contribute to the destruction of O_3 in the upper part of the atmosphere, the stratosphere (Erisman et al., 2008; Velthof et al., 2014). In areas with a 'thin' stratospheric O_3 layer, excessive ultraviolet (UV) radiation ([11]) inhibits the growth processes of almost all green plants, thus stratospheric O_3 depletion can lead to loss of plant species and reduced crops yields.

PM in the atmosphere can affect the climate, e.g. reducing incoming solar radiation, affecting cloud formation and precipitation patterns, thus affecting the hydrological cycle and water availability (Fuzzi et al., 2015). Climate change effects such as rising temperatures and changes in seasonality, as well as an increase in the occurrence of extreme events, such as heatwaves, droughts, storms and floods, will affect agriculture (EEA, 2015a; EEA, 2017f). The combined effects of air pollution and climate change on agriculture, including extreme climate events and changes in pests and diseases, are yet to be fully understood and quantified.

Air pollutant emissions in general lead to direct and indirect effects on the productivity of agricultural and other plants. Ground-level O_3 is the main air pollutant responsible for crop and forest yield losses (Mills and Harmens, 2011; Ainsworth et al., 2012; Wilkinson et al., 2012). Directly emitted or formed in the atmosphere, PM may affect crops by its deposition on leaves, reducing the amount of sunlight reaching the leaves and thus affecting their growth.

3.4 Mitigation of emissions from agriculture

A large number of projects and studies have identified various measures to mitigate emissions of air pollutants and GHGs from the agriculture sector. As one selected example, the EU LIFE+ project 'AgriClimateChange' (2013; European Parliament, 2014) identified a number of different measures:

- agronomic measures, including: (i) nitrogen balance at farm level; (ii) introduction of leguminous plants on arable land to improve fertility and increase carbon sequestration; (iii) conservation of agriculture based on no-tillage methods to increase carbon sequestration; and (iv) implementation of cover crops to restore fertility and reduce the need to use nitrogen fertilisers;
- livestock measures, including: (i) manure storage covering; (ii) manure spreading closer to the ground; and (3) use of manure and farm residues to feed biogas plants;
- energy measures: (i) use of biomass for heating; (ii) photovoltaic installations; (iii) reducing fuel consumption; and (iv) reducing electricity consumption;
- agri-environmental measures such as maintaining and encouraging farms to develop low-carbon farming practices based on farmers' skills and interests.

([11]) UV-B (medium wavelengths) is mostly absorbed by the stratospheric O_3 layer.

The AgriClimateChange project found that the hypothetical implementation of 128 actions across four selected countries would deliver an average reduction of 10 % of GHG emissions and 10 % of energy consumption at the farm level. Such reductions are consistent with the EU's mitigation and energy reduction commitments: the European Strategy 20-20-20, which aims, inter alia, to achieve 20 % more efficient energy consumption and the Roadmap 2050 towards a low-carbon economy, which suggests, for the agricultural (farming) sector, a reduction in GHG emissions of 36-37 % by 2030 and 42-49 % by 2050.

Measures such as covering liquid manure storage facilities can decrease NH_3 emissions significantly, but have a relatively low GHG emission reduction potential (0.1 Tg CO_2-eq/year). Modern application techniques of manure on soils (injecting instead of spraying) also have a high potential to reduce NH_3 emissions. Both measures are easy to implement. However, they are costly and thus mainly an option on big, industrial-scale farms. Nitrogen balance at farm level (e.g. avoiding urea fertiliser losses) has a high potential to reduce both GHG and NH_3 emissions.

NH_3 abatement measures would be more effective if they targeted primarily a small number of industrial-scale farms, considering that 80 % of European NH_3 emissions are generated by less than 10 % of the farms (Maas and Greenfelt, 2016). Conservation tillage can significantly reduce the amount of coarse PM emitted, with some farms achieving approximately 52-85 % reductions in primary PM_{10} emissions (Baker et al., 2005; Madden et al., 2008).

The application of six measures with relative low implementation costs, i.e. nitrogen balance, low-carbon agri-environmental measures, electricity reduction, fuel consumption reduction, leguminous plants and manure spreading, could reduce GHG emissions in the EU by 61.7 Tg CO_2-eq/year (European Parliament, 2014). The advantage is that all these measures are easy (or average for leguminous plants) for farmers to implement. Other measures, such as manure storage and photovoltaic installations, are also easy to implement, but are medium- to high-cost measures. The implementation of cover crops has a high GHG emissions reduction potential at a low to average cost. Similarly, the implementation of biogas plants also has a high potential to reduce GHG emissions, but it is difficult for farmers and is, moreover, expensive.

Some of the energy measures to reduce GHG emissions will also help in reducing air pollutant emissions (e.g. fuel and electricity reduction and the use of solar energy). However, the implementation of measures such as the combustion of biomass can have a negative impact, as it results in higher emissions of pollutants, such as PM and PAHs (including BaP), to the atmosphere compared with the combustion of other fuels, such as gas (EEA, 2016b; ETC/ACM, 2016b).

A number of the abovementioned air pollutant emission abatement measures are also considered in the revised Gothenburg Protocol (UNECE, 2017) to the CLRTAP (see its Annex IX) as measures to control NH_3 emissions. The NEC Directive (EU, 2016), revised to bring it into line with the Gothenburg Protocol, also includes those measures in its Annex III, Part 2, as part of the National Air Pollution Control Programmes that Member States have to develop and implement in order to limit their anthropogenic emissions (see also Section 1.4).

Agricultural mitigation measures often have synergies with sustainable development policies. Many options have co-benefits (e.g. improved efficiency, reduced cost, environmental co-benefits) as well as trade-offs (e.g. increasing other forms of pollution); therefore, a coherent policy approach to mitigation needs to be taken when implementing, evaluating and developing EU policies.

3.5 Summary

The agricultural sector is an important source of air pollutants (NH_3, PM_{10}, PAHs, and NMVOCs) and of GHGs (CH_4 and N_2O). Agricultural activities' contributions to air pollution give rise to direct and indirect impacts on human and ecosystems' health and biodiversity, and they contribute to climate change. In turn, some air pollutants and effects of climate change have detrimental impacts on agriculture and forestry, which can lead, for example, to considerable yield losses and associated costs.

A wide range of mitigation actions, including technically and economically viable measures, are already available to reduce emissions from the agricultural sector, but have yet to be adopted at the scale and intensity, especially for large farming units, necessary to deliver significant emission reductions. The agricultural sector can and should therefore make a significant contribution to the EU's air quality and climate mitigation efforts. Nevertheless, care must be taken to balance air pollution and climate mitigation with the potential impacts, particularly on food production, and to optimise the different environmental and economic co-benefits of mitigation efforts.

4 Particulate matter

Table 4.1 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/m³	Not to be exceeded on more than 35 days per year
	Calendar year	Limit value: 40 µg/m³	
$PM_{2.5}$	Calendar year	Limit value: 25 µg/m³	
		Exposure concentration obligation: 20 µg/m³	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/m³	Not to be exceeded on more than 25 days/year, averaged over 3 years ([b])
		Long term objective: 120 µg/m³	
	1 hour	Information threshold: 180 µg/m³	
		Alert threshold: 240 µg/m³	
NO_2	1 hour	Limit value: 200 µg/m³	Not to be exceeded on more than 18 hours per year
		Alert threshold: 400 µg/m³	To be measured over 3 consecutive hours over 100 km² or an entire zone
	Calendar year	Limit value: 40 µg/m³	
BaP	Calendar year	Target value: 1 ng/m³	Measured as content in PM_{10}
SO_2	1 hour	Limit value: 350 µg/m³	Not to be exceeded on more than 24 hours per year
		Alert threshold: 500 µg/m³	To be measured over 3 consecutive hours over 100 km² or an entire zone
	1 day	Limit value: 125 µg/m³	Not to be exceeded on more than 3 days per year
CO	Maximum daily 8-hour mean	Limit value: 10 mg/m³	
C_6H_6	Calendar year	Limit value: 5 µg/m³	
Pb	Calendar year	Limit value: 0.5 µg/m³	Measured as content in PM_{10}
As	Calendar year	Target value: 6 ng/m³	Measured as content in PM_{10}
Cd	Calendar year	Target value: 5 ng/m³	Measured as content in PM_{10}
Ni	Calendar year	Target value: 20 ng/m³	Measured as content in PM_{10}

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

([b]) In the context of this report, only the maximum daily 8-hour means in 2015 are considered, so no average over 2013-2015 is presented.

Sources: EU, 2004, 2008.

4.1 European air quality standards and World Health Organization guidelines for particulate matter

The legal standards set by the Ambient Air Quality Directive (EU, 2008) for both PM_{10} and $PM_{2.5}$ can be found in Table 4.1. and the Air Quality Guidelines (AQGs) set by the WHO in Table 4.2.

4.2 Status of concentrations

The EEA received PM_{10} data for 2015 with sufficient valid measurements from 2 380 stations located in all the EU-28 and the following reporting countries: Albania, Andorra, Bosnia and Herzegovina, Iceland (only considered for the annual mean), the former Yugoslav Republic of Macedonia, Kosovo under United Nations Security Council Resolution (UNSCR) 1244/99, Montenegro, Norway, Serbia and Switzerland.

PM_{10} concentrations continued to be above the EU limit value in large parts of Europe in 2015. Map 4.1 shows concentrations of PM_{10} in relation to the daily limit value. There were 19 % of stations with concentrations above this daily limit value for PM_{10} in 20 Member States (see Figure 4.1) and five other reporting countries ([12]). 95 % of those stations were either urban (78 %) or suburban (17 %). Some of these high daily mean PM_{10} levels were observed during high PM_{10} pollution episodes in winter and autumn 2015, as explained in Box 4.1.

Table 4.2 WHO air quality guidelines (AQG) and estimated reference levels (RL) ([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	

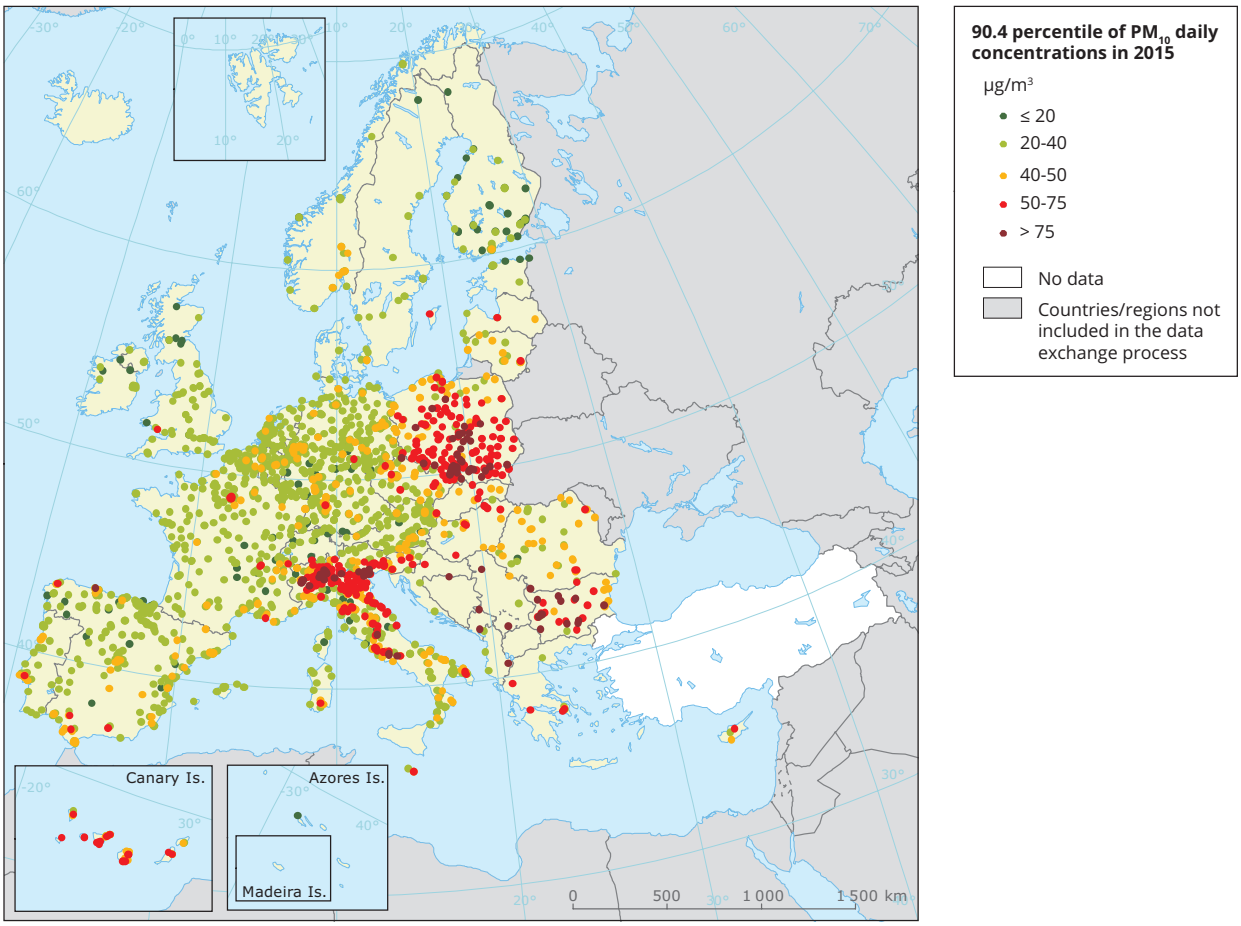
Notes: ([a]) As the WHO has not set an AQG for BaP, C_6H_6, As and Ni, the reference level was estimated assuming an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000.

([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.

([12]) Albania, Bosnia and Herzegovina, Kosovo under UNSCR 1244/99, Montenegro and Serbia.

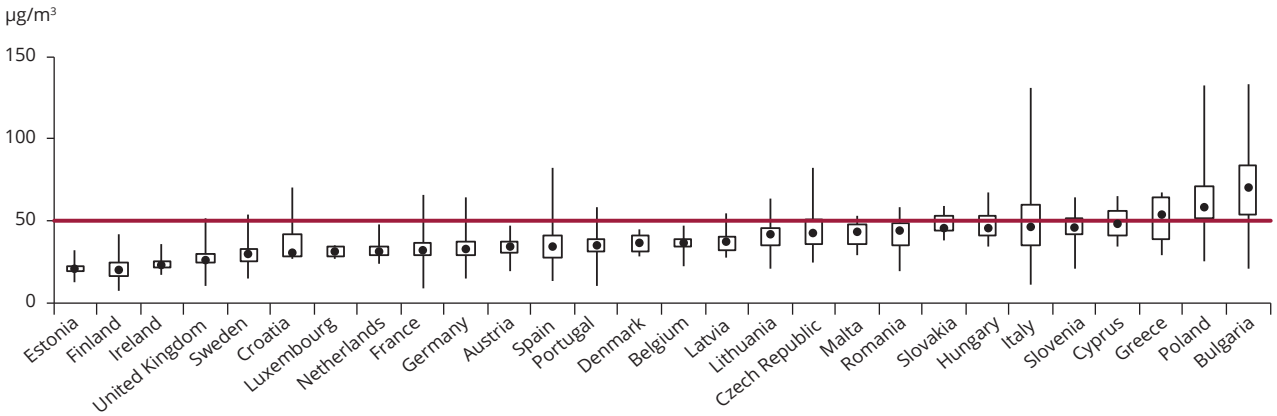
Map 4.1 Concentrations of PM_{10}, 2015 — daily limit value



Note: Observed concentrations of PM_{10} in 2015. 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. The red and dark red dots indicate stations with concentrations above this daily limit value. Only stations with more than 75 % of valid data have been included in the map. The stations from the former Yugoslav Republic of Macedonia are not included due to technical issues.

Source: EEA, 2017a.

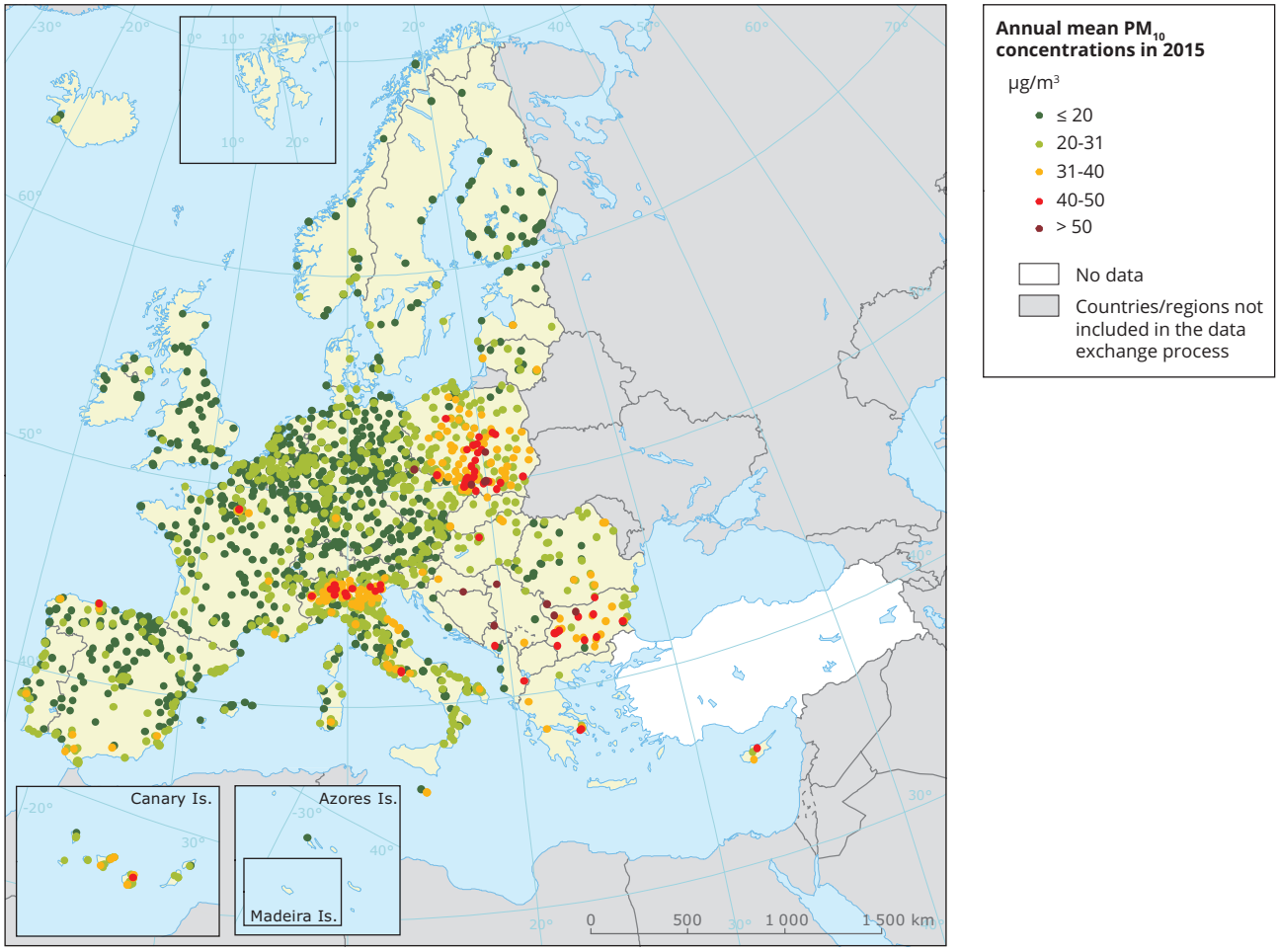
Figure 4.1 PM_{10} concentrations in relation to the daily limit value in 2015 in the EU-28



Notes: The graph is based, for each Member State, on the 90.4 percentile of daily mean concentration values corresponding to the 36th highest daily mean. For each country, the lowest, highest and median 90.4 percentile values (in µg/m³) at the 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 red line. The graph should be read in relation to map 4.1 as the country situation depends on the number of stations considered.

Source: EEA, 2017a.

Map 4.2 Concentrations of PM_{10}, 2015 — annual limit value



Notes: The dark red and red dots indicate stations reporting concentrations above the EU annual limit value (40 µg/m³). The dark green dots indicate stations reporting values below the WHO AQG for PM_{10} (20 µg/m³). Only stations with > 75 % of valid data have been included in the map. The stations from the former Yugoslav Republic of Macedonia are not included due to technical issues.

Source: EEA, 2017a.

Concentrations above the PM_{10} annual limit value (40 µg/m³) were monitored in 2015 in only 3 % of all the reporting stations ([13]). The stricter value of the WHO AQG for PM_{10} annual mean (20 µg/m³) was exceeded at 54 % of the stations and in all the reporting countries except Estonia and Ireland (see Map 4.2).

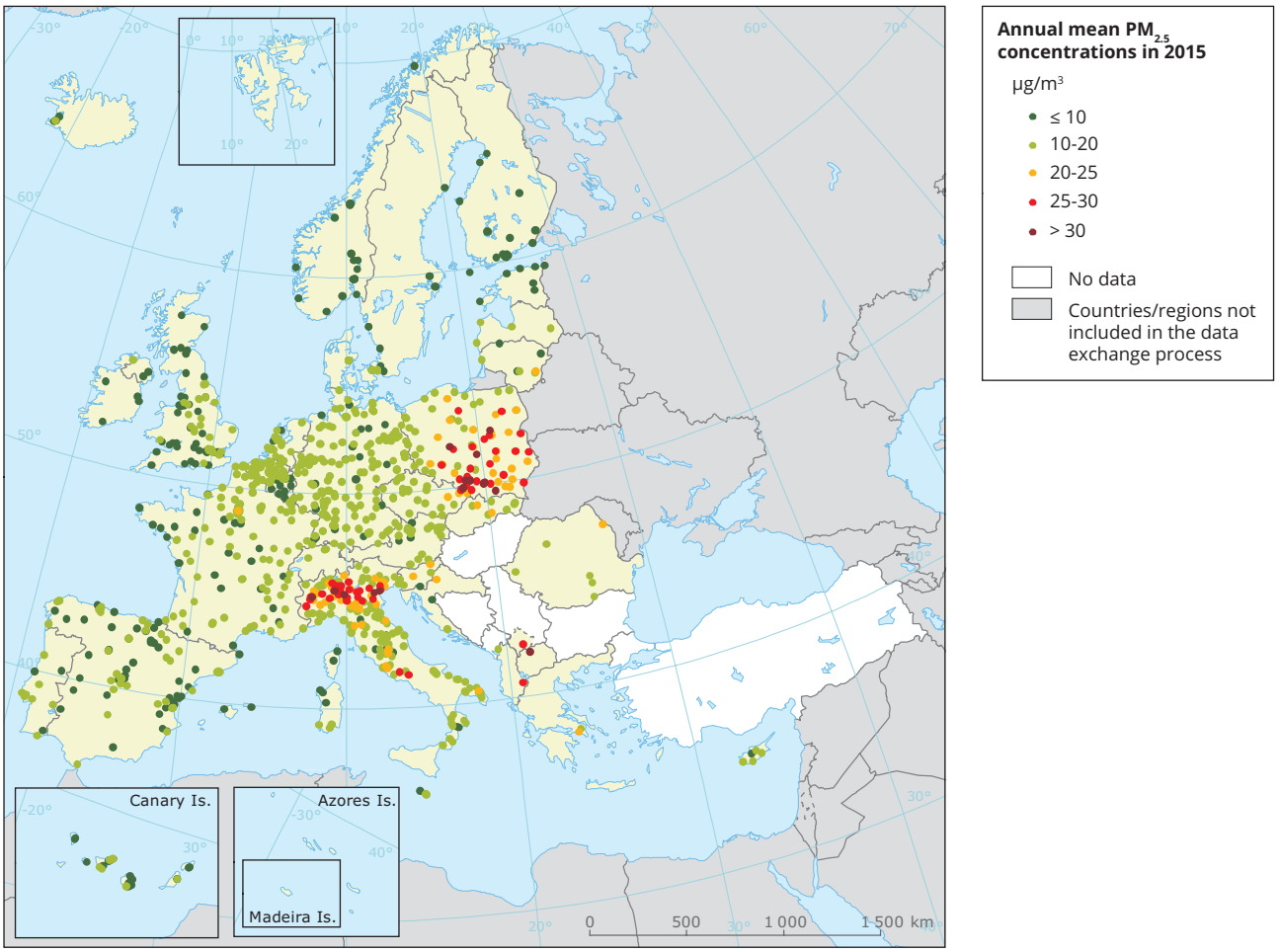
Regarding $PM_{2.5}$, data with a minimum coverage of 75 % of valid data were received from 1 103 stations located in all the EU-28 except Bulgaria and Hungary, as well as Albania, the Former Yugoslav Republic of Macedonia, Iceland, Kosovo under UNSCR 1244/99, Norway and Switzerland.

In 2015, the $PM_{2.5}$ concentrations were higher than the limit value in three Member States (see Figure 4.2) and three other reporting countries ([14]) (see Map 4.3). These values above the limit value were registered in around 6 % of all the reporting stations and also occurred primarily (93 % of cases) in urban or suburban areas.

([13]) These stations were located mainly in Bulgaria, Italy and Poland. There was also at least one station with values above the PM_{10} annual limit value in the Member States Cyprus, the Czech Republic, France, Greece, Hungary, and Spain and in the cooperating countries of Albania, Bosnia and Herzegovina, Montenegro and Serbia (see Map 4.2).

([14]) Albania, the Former Yugoslav Republic of Macedonia and Kosovo under UNSCR 1244/99.

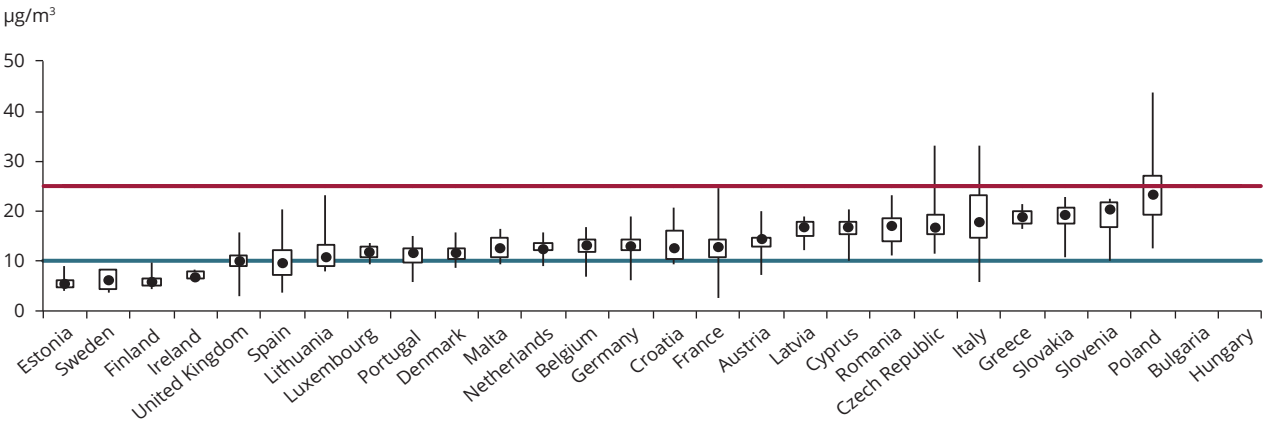
Map 4.3 Concentrations of $PM_{2.5}$, 2015



Notes: The dark red and red dots indicate stations reporting concentrations above the EU annual limit value (25 µg/m³). The dark green dots indicate stations reporting values below the WHO AQG for $PM_{2.5}$ (10 µg/m³). Only stations with > 75 % of valid data have been included in the map.

Source: EEA, 2017a.

Figure 4.2 $PM_{2.5}$ concentrations in relation to the limit value in 2015 in the EU-28



Notes: The graph is based on annual mean concentration values. For each country, the lowest, highest and median values (in µg/m³) at the 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 red line. The WHO AQG is marked by the blue line.

The graph should be read in relation to map 4.3 as the country situation depends on the number of stations considered.

Source: EEA, 2017a.

The WHO guideline for $PM_{2.5}$ annual mean (10 µg/m^3; see Map 4.3) was exceeded at 75 % of the stations, located in 27 of the 32 countries reporting $PM_{2.5}$ data. Estonia, Finland, Ireland, Norway and Sweden did not report any exceedance of the WHO AQG for $PM_{2.5}$.

The rural background concentration levels of PM vary across Europe. Concentrations above the daily PM_{10} limit value in the rural background in 2015 occurred in several stations in Italy and the Czech Republic, and in one station each in Poland, Malta and Spain. There was also one rural background station, in the Czech Republic, with concentrations above the PM_{10} annual limit value. Regarding $PM_{2.5}$, five rural background stations, four in Italy and one in the Czech Republic, registered concentrations above the limit value.

4.3 $PM_{2.5}$ average exposure indicator

The Ambient Air Quality Directive (EU, 2008) also sets two additional standards for $PM_{2.5}$, the exposure concentration obligation (ECO) and the national exposure reduction target (see Table 4.1). Both standards are based on the average exposure indicator (AEI), set 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, the AEI 2010, which refers to a 2-year average (2009 and 2010) instead of the 3-years average, or the AEI 2011 (the average from 2009 to 2011). For comparability issues, 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.

Figure 4.3 shows the AEI for every EU-28 Member State calculated for 2015 (average 2013-2015) and the situation in relation to the ECO. Blue bars show the AEI 2015 using the stations designated for this purpose by the Member States ([15]), while orange dots show instead the 3-year (2013-2015) 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.

Box 4.1 PM_{10} pollution episodes in 2015

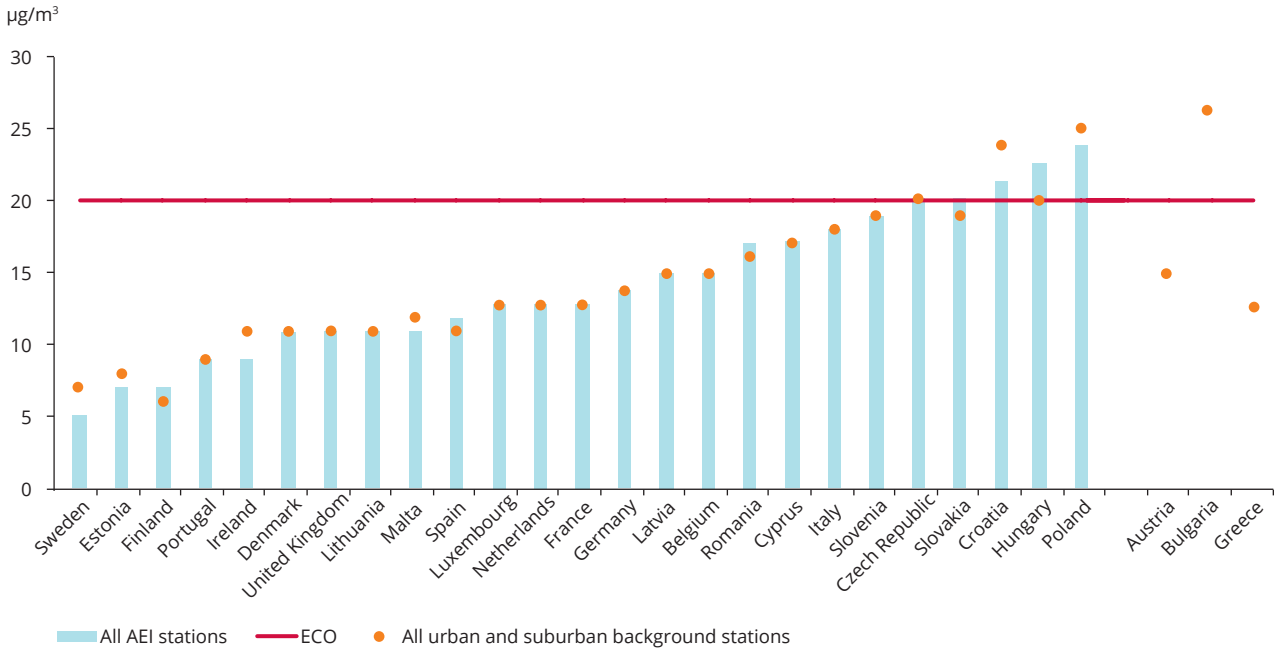
The Copernicus Atmosphere Monitoring Service (CAMS) (2016) identified three significant PM_{10} pollution episodes in winter (February and March) and autumn 2015. The February episode (12-20 February) affected most of Europe and was due to a complex combination of different anthropogenic and natural sources. Emissions from residential combustion were the most important source contribution to this episode, especially in southern and eastern Europe, followed closely by the contribution of NH_3 emissions from agriculture. In central Europe, however, agricultural emissions were the main anthropogenic source. In addition, a Saharan dust intrusion affected PM_{10} pollution levels over southern and western Europe.

The March episode (17 to 20 March) occurred over central and eastern Europe, including northern Italy, and led to very high PM_{10} daily concentrations in Benelux and parts of France and Germany. It was mainly due to agricultural emissions in these areas, with high PM_{10} levels, while in eastern Europe the main anthropogenic contribution came from residential combustion. The natural contribution from Saharan dust also played a significant role in the elevated PM_{10} concentrations in some areas.

The autumn episode (29 October to 7 November) was divided into two different episodes: 29 to 31 October, over central and northern Europe, and 3-7 November, affecting mostly eastern and southern Europe. The first part of this episode was dominated by agricultural emissions in northern and central Europe and, to a lesser extent, by residential emissions. The second part of this autumn episode was dominated by agricultural emissions, with significant contributions from residential and industrial emissions. In addition, a Saharan dust intrusion was identified reaching as far north as Germany.

([15]) No AEI stations designated by Austria, Bulgaria, and Greece.

Figure 4.3 Average Exposure Indicator in 2015 and exposure concentration obligation



Notes: Blue bars show the average exposure indicator (AEI) calculated in 2015 (averages 2013-2015) using the stations designated for this purpose by the Member States (except for Austria, Bulgaria, and Greece, where no stations have been designated).

Orange dots show urban and suburban background $PM_{2.5}$ concentrations presented as 3-year averages in the EU-28 (2013-2015) as an approximation of the AEI in 2015 and to facilitate comparison with information provided in previous Air Quality in Europe reports.

The red line represents the exposure concentration obligation, set at 20 µg/m³.

For Hungary and Bulgaria, which did not report $PM_{2.5}$ data in 2015, the AEI 2014 (average 2012-2014) is presented.

Source: EEA, 2017a.

For the 25 Member States for which the AEI could be calculated with the stations designated for this purpose, the AEI was above the exposure concentration obligation in Croatia (the AEI 2015 was 21 µg/m³) Hungary (22 µg/m³ for the AEI 2014 (average 2012-2014), since Hungary did not report $PM_{2.5}$ data in 2015) and Poland (the AEI 2015 was 23µg/m³). Furthermore, based on the average of $PM_{2.5}$ concentrations measured at urban background stations, Bulgaria was also above the exposure concentration obligation with an estimated AEI of 26 µg/m³.

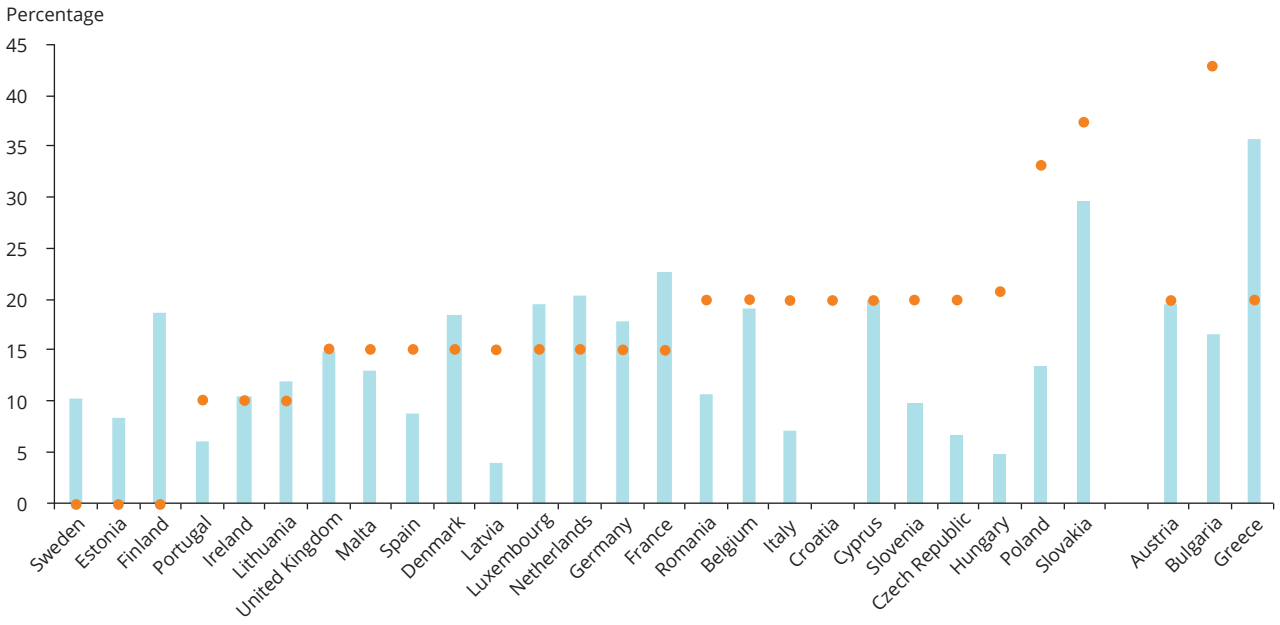
Figure 4.4 shows the path of the Member States towards meeting the respective national exposure reduction targets. This reduction target is expressed as a percentage of the initial AEI 2010 (here, as above, AEI 2011 has been used for the comparison except for Croatia for which 2015 is the AEI reference year). Orange dots indicate the percentage of AEI reduction to be attained in 2020 (average 2018-2020) and the blue bars indicate the reduction of the AEI 2015 as a percentage of the AEI 2011. It shows that half of the 25 Member States with designated stations to calculate the AEI ([16]) have already attained the corresponding national exposure reduction target.

4.4 Contribution of PM precursor emissions, natural factors and meteorological variability to the developments in ambient PM concentrations

With the exception of NH_3, the reductions in emissions of the secondary PM precursors (NO_x, SO_x and NMVOCs) were much larger than the reductions in primary PM from 2000 to 2015 in the EU-28 (see Figure 2.1). A linear relationship between the reductions in anthropogenic emissions of primary PM and its precursor gases and the reductions in ambient air concentrations of PM is not to be expected. This can

([16]) Cyprus, Denmark, Estonia, Finland, France, Germany, Ireland, Lithuania, Luxembourg, the Netherlands, Sweden and the United Kingdom. Greece is also included if instead the urban and suburban background stations are considered.

Figure 4.4 **Percentage of reduction of AEI2015 in relation to AEI2011 and distance to the national exposure reduction target**



Notes: The blue bars indicate the reduction of the AEI 2015 as a percentage of the AEI 2011(except for Croatia for which the reference year is 2015 and not 2011). The orange dots indicate the reduction to be obtained in the AEI 2020 as a percentage of the AEI 2011 (or AEI 2015 for Croatia). If the bar is above the dot, the national exposure reduction target has already been reached in 2015.

For Austria, Bulgaria, and Greece, where no stations have been designated for the AEI calculation, all urban and suburban background stations have been used instead.

For Hungary and Bulgaria, which did not report $PM_{2.5}$ data in 2015, the AEI 2014 (average 2012-2014) is presented.

be explained in part by uncertainties in the reported emissions of primary PM. Furthermore, natural sources, which are not targeted by mitigation efforts, can contribute to background PM concentrations. Finally, when it comes to secondary PM ([17]), a reduction in sulphur emissions has contributed to a shift in PM composition from $(NH_4)_2SO_4$ to NH_4NO_3; therefore, reductions in emissions are not directly transferred to decreases in concentrations (EMEP, 2016a).

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. It estimated that the contribution of intercontinental inflow of PM and its precursors to the PM_{10} concentration trends was negligible in the 1990s but had some impact in the 2000s, reducing slightly the PM concentrations. Meteorology had an impact on the trends, but this was much smaller than the impact of European emission changes, except in the 1990s for the Iberian Peninsula and to some extent for France, where the decreasing effects of meteorology on concentrations were of the same magnitude as those of the emission changes. Meteorology contributed to a decrease in PM_{10} average concentrations in the 1990s (except in the Mediterranean subregion and eastern Europe, where it increased the PM_{10} concentration) and it led to an increase in the 2000s, except for the Iberian Peninsula, Scandinavia and eastern Europe.

The modelled attribution for each aerosol compound contributing to the PM_{10} mix showed that European anthropogenic emission changes also dominated the evolution of secondary PM and secondary organic aerosols, contributing in all cases to a decrease in the concentrations of those compounds. The changes in desert dust and sea salt are primarily attributed to meteorological variability, and they are strongest in the case of desert dust for the Iberian Peninsula (decreasing) and the Mediterranean subregion (increasing) and in the case of sea salt for England and Scandinavia (decreasing in both cases).

([17]) The proportion of secondary $PM_{2.5}$ may reach around 70 % in some urban background areas and more than 80 % in regional background areas.

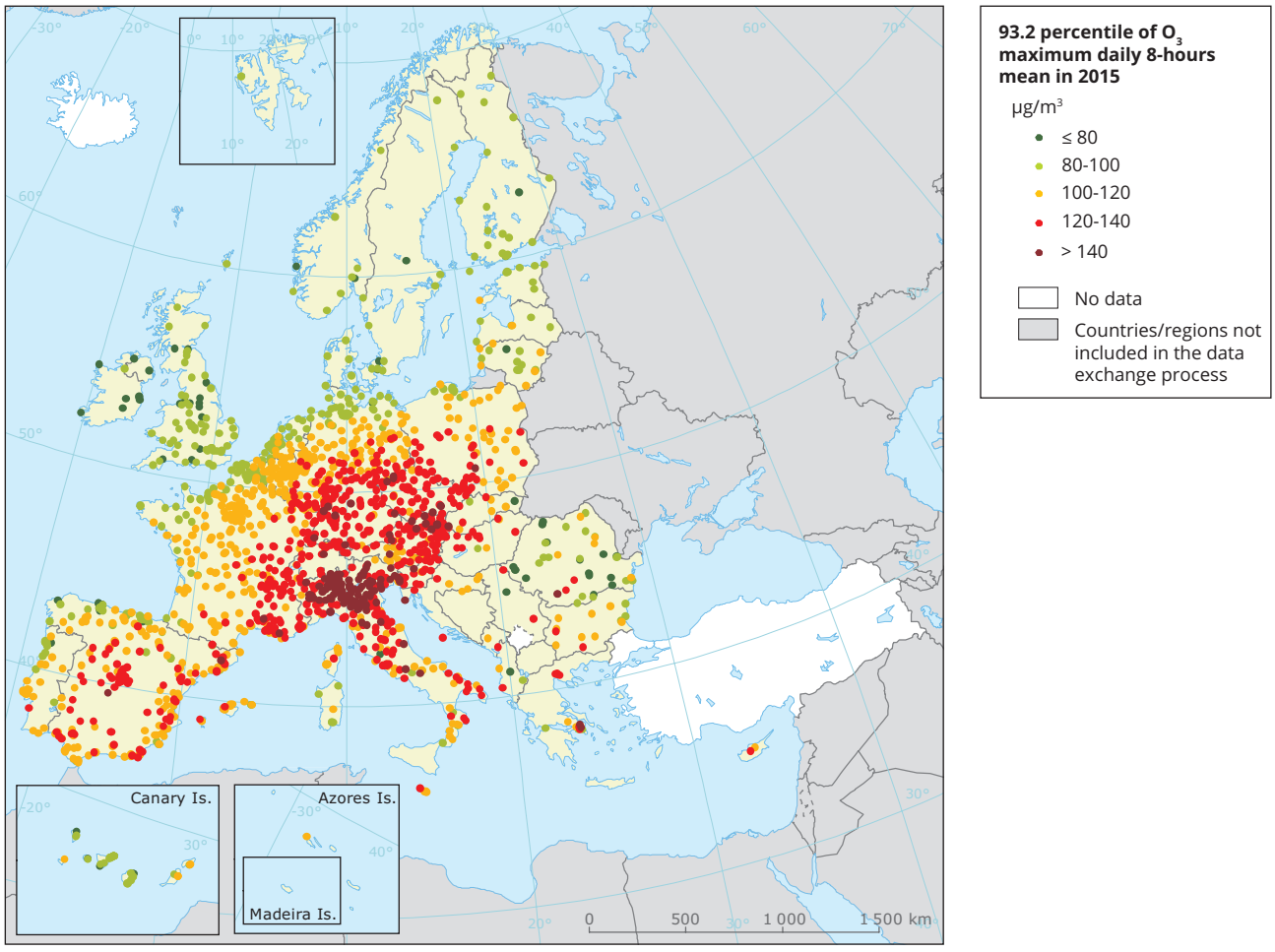
5 Ozone

5.1 European air quality standards and World Health Organization guidelines for ozone

The European air quality standards for the protection of health and the WHO guidelines for O_3 are shown in Tables 4.1 and 4.2, respectively.

The Ambient Air Quality Directive (EU, 2008) also sets targets for the protection of vegetation, shown in Table 11.1. In addition, the CLRTAP (UNECE, 1979) defines a critical level for the protection of forests (see Table 11.1). 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.

Map 5.1 Concentrations of O_3 in 2015



Notes: Observed concentrations of O_3 in 2015. 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, allowing 25 exceedances over the 120-µg/m³ threshold. At sites marked with red and dark-red dots, the 26th highest daily O_3 concentrations were above the 120-µg/m³ threshold, implying an exceedance of the target value threshold. Only stations with more than 75 % of valid data have been included in the map. The stations from the former Yugoslav Republic of Macedonia are not included due to technical issues.

Source: EEA, 2017a.

5.2 Status of concentrations

Data for O_3 in 2015 were reported from 1 814 stations in the EU-28 Member States and eight additional reporting countries: Albania, Andorra, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Montenegro, Norway, Serbia and Switzerland.

Eighteen Member States (see Figure 5.1) and four other reporting countries ([18]) (see also Map 5.1) registered concentrations above the O_3 target value more than 25 times. In total, 41 % 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 2015, which is considerably more stations than over the previous 5 years. In addition, only 13 % of all stations fulfilled the long-term objective (no exceedance of the threshold level). 88 % of the stations with values above the long-term objective were background stations.

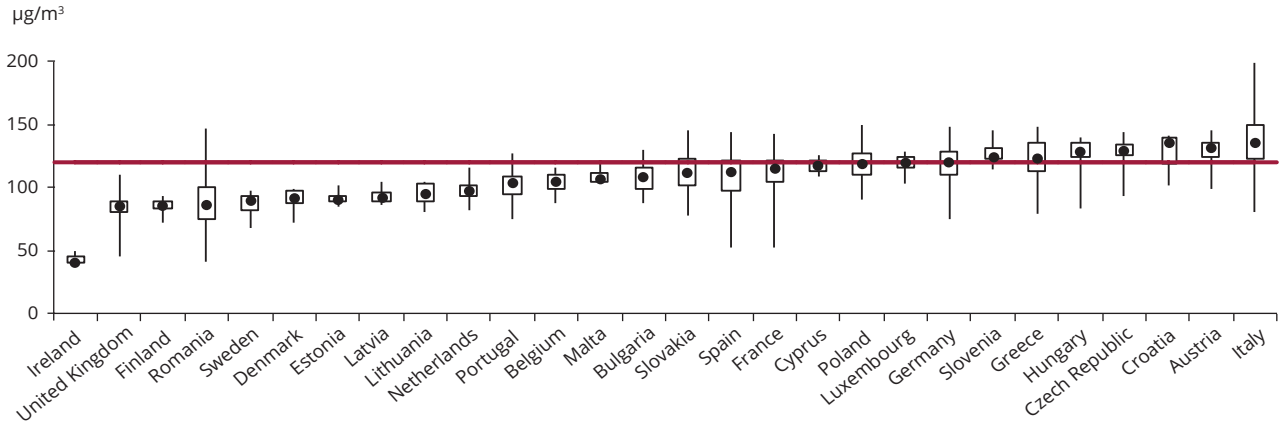
Conformity with the WHO AQG value for O_3 (8-hour mean of 100 µg/m³), set for the protection of human health, was observed in 4 % of all stations and in only 8 of 495 rural background stations in 2015.

The year 2015 was characterised by the World Meteorological Organization as being a historically warm year globally. On average over Europe, 2015 was (together with 2014) the warmest year to that point (EEA, 2016c) and the series of heatwaves affecting Europe from May to September 2015 resulted in high tropospheric O_3 levels (CAMS, 2016). CAMS (2016) estimated that the largest O_3 episode in 2015 occurred between 1 July and 5 July over central Europe and northern Italy and was mainly due to traffic and, to a lesser extent, industrial emissions.

5.3 Contribution of ozone precursor emissions, intercontinental inflow and meteorological variability to the developments in ambient ozone concentrations

Given that the formation of O_3 requires sunlight, O_3 concentrations show a clear increase as one moves from the northern parts to the southern parts of Europe, with the highest concentrations in some Mediterranean countries and in summer time. The concentration of O_3 typically increases with altitude in the first few kilometres of the troposphere. Higher concentrations of O_3 can therefore be observed at high-altitude stations. Close to the ground and the NO_x sources, O_3 is depleted by surface deposition and the titration reaction of the emitted NO to form NO_2. Therefore, in contrast to other pollutants, O_3 concentrations are generally highest in rural locations, lower in urban sites and even lower in traffic locations.

Figure 5.1 O_3 concentrations in relation to the target value in 2015 in the EU-28



Notes: The graph is based, for each Member State, on the 93.2 percentile of maximum daily 8-hour mean concentration values, corresponding to the 26th highest daily maximum of the running 8-hour mean. For each country, the lowest, highest and median values (in µg/m³) at the 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 red line.

The graph should be read in relation to map 5.1 as the country situation depends on the number of stations considered.

Source: EEA, 2017a.

([18]) Albania, Andorra, Serbia and Switzerland.

O_3 concentrations are the result of a hemispheric background and the balance of formation and destruction from precursor emissions on local and regional scales. Meteorological conditions strongly influence its formation and degradation. The hemispheric background is a dominant factor for O_3 concentrations in Europe, in contrast to other air pollutants. As mentioned in Section 2.1, emissions of VOCs, including CH_4 and biogenic emissions, NO_x and CO, result in the photochemical formation of O_3. These processes are important on the continental and regional scales and are particularly important during summer periods. On the local scale, O_3 depletion may occur because of the chemical interaction with freshly emitted NO to form secondary NO_2 (O_3 titration). The high O_3 concentrations occurring at urban stations, especially in the case of exceedance of the information threshold (Table 4.1), are attributable to the O_3 formation that occurs at times in large urban areas during episodes of high solar radiation and temperature. Local and regional emissions of precursor gases play a major role in O_3 formation, especially downwind of large urbanised or industrialised areas, as shown for Spain by Querol et al. (2016). Differences in the distribution of O_3 precursor emission sources and climatic conditions in Europe result in considerable regional differences in O_3 concentrations. Year-to-year differences in O_3 levels are also induced by meteorological variations.

The EuroDelta-Trends modelling experiment (ETC/ACM, 2017a) estimated that the impact of the reduction of European anthropogenic O_3 precursor emissions dominated the modelled net reduction in O_3 levels between 1990 and 2010 ([19]), whereas the inflow from outside Europe had a smaller influence. It also estimated that, whereas in the 1990s the intercontinental inflow of O_3 contributed to increasing the O_3 annual mean in Europe, it acted in the opposite way in the 2000s and contributed to a decrease in annual mean O_3 levels. Nevertheless, the role of meteorological variability exceeded that of the intercontinental inflow in the 1990s, being at least as important in the increase of the O_3 annual mean.

The summertime O_3 peak episodes are caused by anthropogenic emissions (of NO_x and VOC) and at the same time are strongly linked to the weather conditions and favoured by episodes of warm, stagnant high pressure. The EuroDelta-Trends modelling experiment concluded that the downwards trend in O_3 episodes during 1990-2010 was mainly driven by changes in emissions, whereas trends in meteorology led to an additional O_3 reduction in the 1990s and the influence of meteorological variability was smaller in the 2000s ([20]). In this case, the intercontinental inflow contribution is, in general, negligible.

Photo: © Ján Gmiterko, NATURE@work /EEA

([19]) The annual mean O_3 level over England was an exception to this, as, due to the titration effect with reduced NO_x, the reduction in emissions led to an increase in annual mean concentrations.

([20]) An exception was the Iberian Peninsula, where the decrease in the 1990s was caused mainly by meteorology.

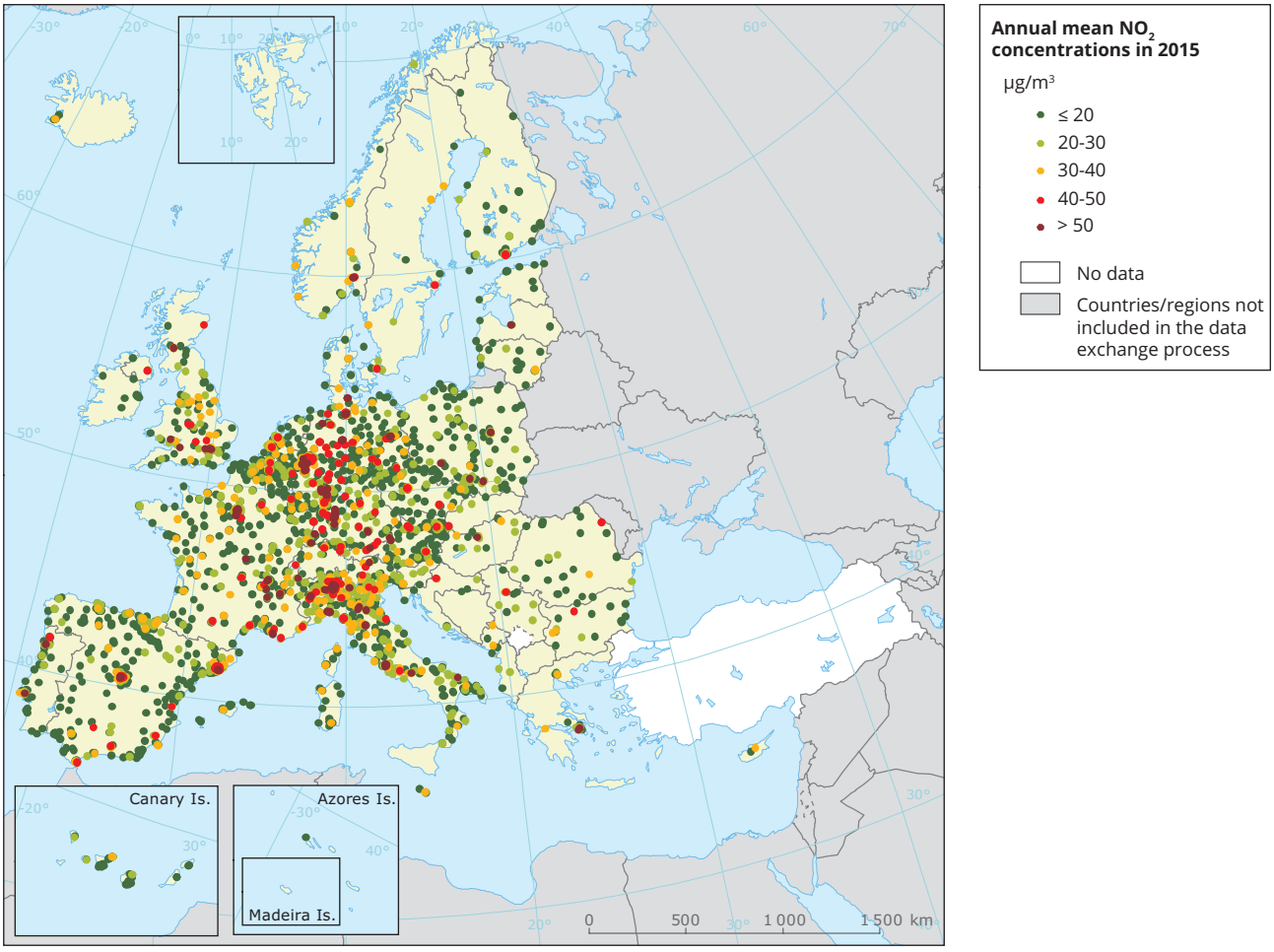
6 Nitrogen dioxide

6.1 European air quality standards and World Health Organization guidelines for NO_2

The European air quality standards set by the Ambient Air Quality Directive (EU, 2008) for the protection of human health and the WHO guidelines for NO_2 are shown in Tables 4.1 and 4.2, respectively.

The Ambient Air Quality Directive (EU, 2008) also sets a critical level for NO_x for the protection of vegetation, shown in Table 11.1. The vegetation exposure to NO_x

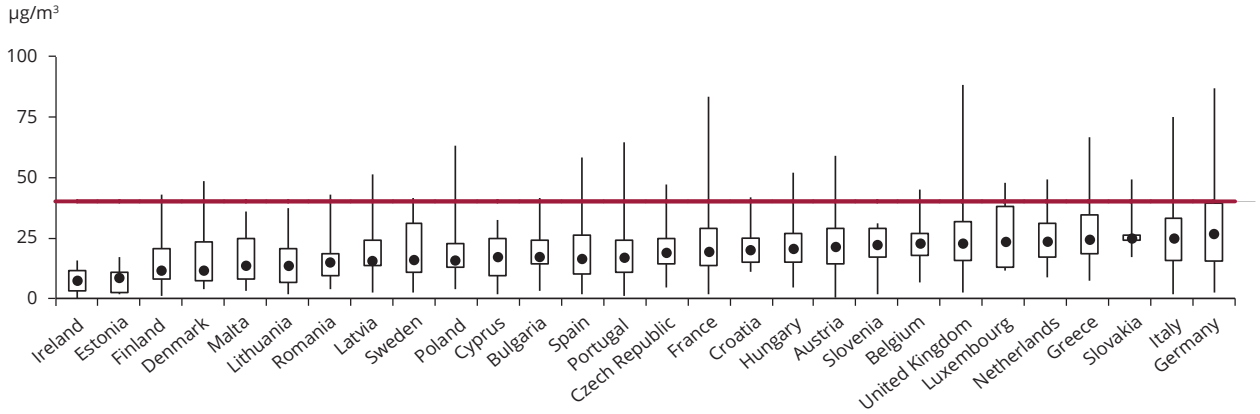
Map 6.1 Concentrations of NO_2, 2015



Notes: Red and dark red dots correspond to values above the EU annual limit value and the WHO AQG (40 µg/m³). Only stations with > 75 % of valid data have been included in the map. The stations from the former Yugoslav Republic of Macedonia are not included due to technical issues.

Source: EEA, 2017a.

Figure 6.1 NO_2 concentrations in relation to the annual limit value in 2015 in the EU-28



Notes: The graph is based on the annual mean concentration values for each MS. For each country, the lowest, highest and median values (in µg/m³) at the 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 (equal to the WHO AQ guideline) is marked by the red line.

The graph should be read in relation to map 6.1 as the country situation depends on the number of stations considered.

Source: EEA, 2017a.

concentrations above this standard is assessed in Section 11.4.

6.2 Status of concentrations

All EU-28 Member States and nine other reporting countries (Albania, Andorra, Bosnia and Herzegovina, Iceland, the former Yugoslav republic of Macedonia, Montenegro, Norway, Serbia and Switzerland) submitted NO_2 data in 2015 with a minimum coverage of 75 % of valid data (a total of 2 680 stations). Twenty-two of the EU-28 (see Figure 6.1) recorded concentrations above the annual limit value. This was also the case in Norway, Switzerland and Serbia, as can also be seen in Map 6.1. It happened in 10.5 % of all the stations measuring NO_2. Map 6.1 also shows that the stations with concentrations above the annual limit value were widely distributed across Europe in 2015.

None of the stations with concentrations above the annual limit value were rural background stations. The highest concentrations, as well as 89 % of all values above the annual limit value, were observed at traffic stations. Traffic is a major source of NO_2 and of NO, which reacts with O_3 to form NO_2. Furthermore, 98 % of the stations with values above the annual limit value were urban (or suburban). Therefore, reductions in NO_2 concentrations need to be focused on traffic and urban locations for the annual limit value to be met.

Concentrations above the hourly limit value were observed in 2015 in 0.9 % of all the reporting stations, mostly at urban traffic stations, except for three urban background stations in Madrid. They were observed in seven countries ([21]).

6.3 Contribution of NO_x emissions to the development in ambient NO_2 concentrations

As is true for PM, the contributions from the 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), meteorology and distance to the receptor site. The road transport sector contributed the highest share of NO_x emissions (39 % in the EU-28) in 2015, followed by the energy production and distribution, and the commercial, institutional and households sectors (see Section 2.3). However, the contribution of the road transport sector to ambient NO_2 concentrations, especially in urban areas, is considerably higher, because its emissions are close to the ground and are distributed over densely populated areas.

([21]) These were observed mainly in Spain, France and Germany. There was also at least one station in Italy, Norway, Portugal and the United Kingdom.

7 Benzo[*a*]pyrene

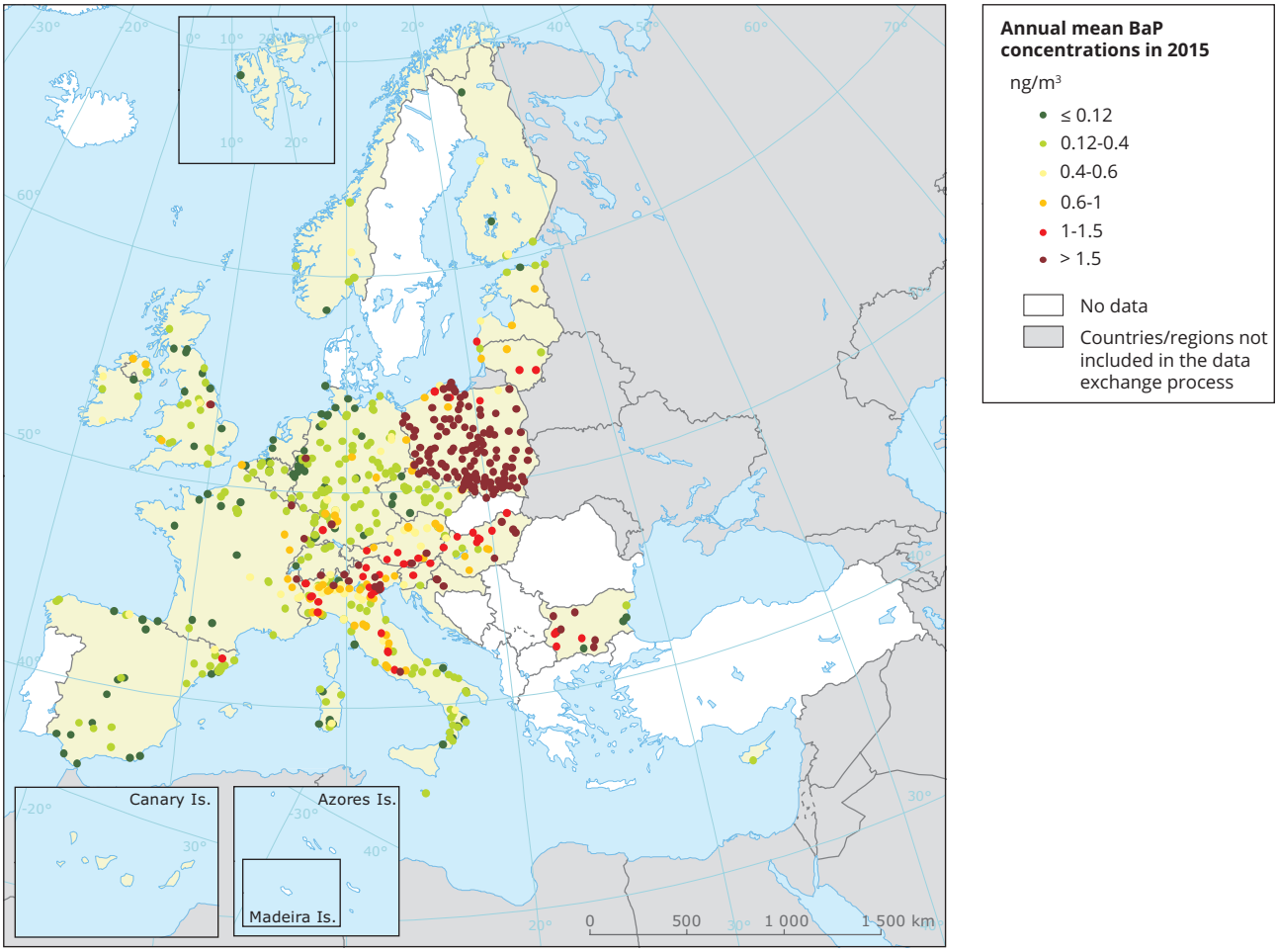
7.1 European air quality standard and reference level for benzo[*a*]pyrene

The target value for BaP for the protection of human health and the estimated reference level ([22]) are presented in Tables 4.1 and 4.2.

7.2 Status of concentrations

Twenty-two Member States (all except Denmark, Greece, Portugal, Romania, Slovakia and Sweden) and two other reporting countries (Norway and Switzerland) reported BaP

Map 7.1 Concentrations of BaP, 2015



Notes: Dark green dots correspond to concentrations under the estimated reference level (0.12 ng/m³) ([23]). Dark red dots correspond to concentrations exceeding the 2004 EU AQ 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, 2017a.

([22]) The estimated reference level (0.12 ng/m³) 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).

data ([23]) with sufficient data coverage ([24]) for 2015, from a total of 657 stations.

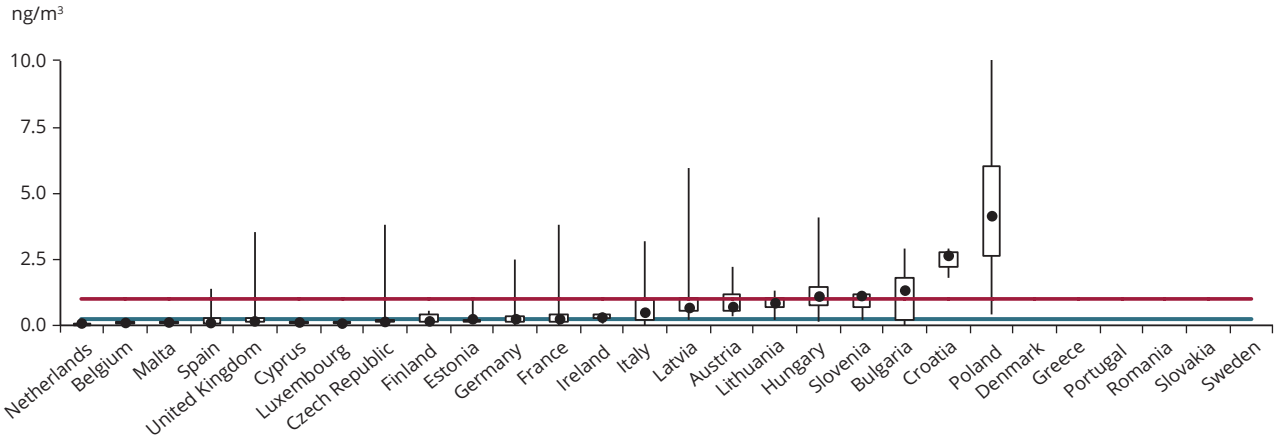
Annual concentrations exceeded 1.0 ng/m³ in 2015 in 14 Member States (see Figure 7.1). As in previous years, values above 1.0 ng/m³ are most predominant in central and eastern Europe. The concentrations measured at Polish stations continue to be very high, well above the target value.

As Map 7.1 shows, values above 1.0 ng/m³ were measured at 32 % of the reported BaP measurement stations, mainly at urban and suburban stations (94 % of all stations with values above 1.0 ng/m³ were in urban and suburban locations).

Regarding the reference level, all reporting countries, except the Netherlands, have at least one station with concentrations above 0.12 ng/m³. Only 16 % of the reported stations in 2015 had annual concentrations below the reference level.

Ambient air concentrations of BaP are high mostly as a result of emissions from the domestic combustion of coal and wood (see Chapter 2 and EEA, 2016b), although for some specific countries (mostly in southern Europe) the contribution of agricultural waste burning is also relevant (see also Chapter 3).

Figure 7.1 BaP concentrations in 2015 in the EU-28



Notes: The graph is based on the annual mean concentration values for each Member State. For each country, the lowest, highest and median values (in ng/m³) at the 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 set by EU legislation is marked by the red line. The estimated air-quality reference level is marked by a blue line.

The graph should be read in relation to map 7.1 as the country situation depends on the number of stations considered.

Source: EEA, 2017a.

([23]) BaP is a PAH found mainly in fine PM. The Air Quality Directive (EU, 2004) prescribes that BaP concentration measurements should be made in the PM_{10} fraction. Going beyond this requirement, available data 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).

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

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

8.1 European air quality standards and World Health Organization guidelines

Table 4.1 presents the European air quality standards for SO_2, CO, Pb, C_6H_6, As, Cd and Ni established in the Ambient Air Quality Directives (EU, 2004, 2008) for health protection ([25]).

Table 4.2 shows the WHO AQGs for SO_2, CO, Cd and Pb and the reference levels for As, Ni and C_6H_6 ([26]).

The Ambient Air Quality Directive (EU, 2008) also sets standards for SO_2 for the protection of vegetation, shown in Table 11.1. The vegetation exposure to SO_2 levels above these standards is assessed in Section 11.4.

8.2 Status and trends in concentrations

8.2.1 Sulphur dioxide

Thirty-seven European countries ([27]) reported measurements of SO_2 with data coverage over 75 % in 2015 from 1 322 stations.

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 2015, six stations ([28]) registered concentrations above the hourly limit value. Four stations ([29]) also registered concentrations above the daily limit value for SO_2.

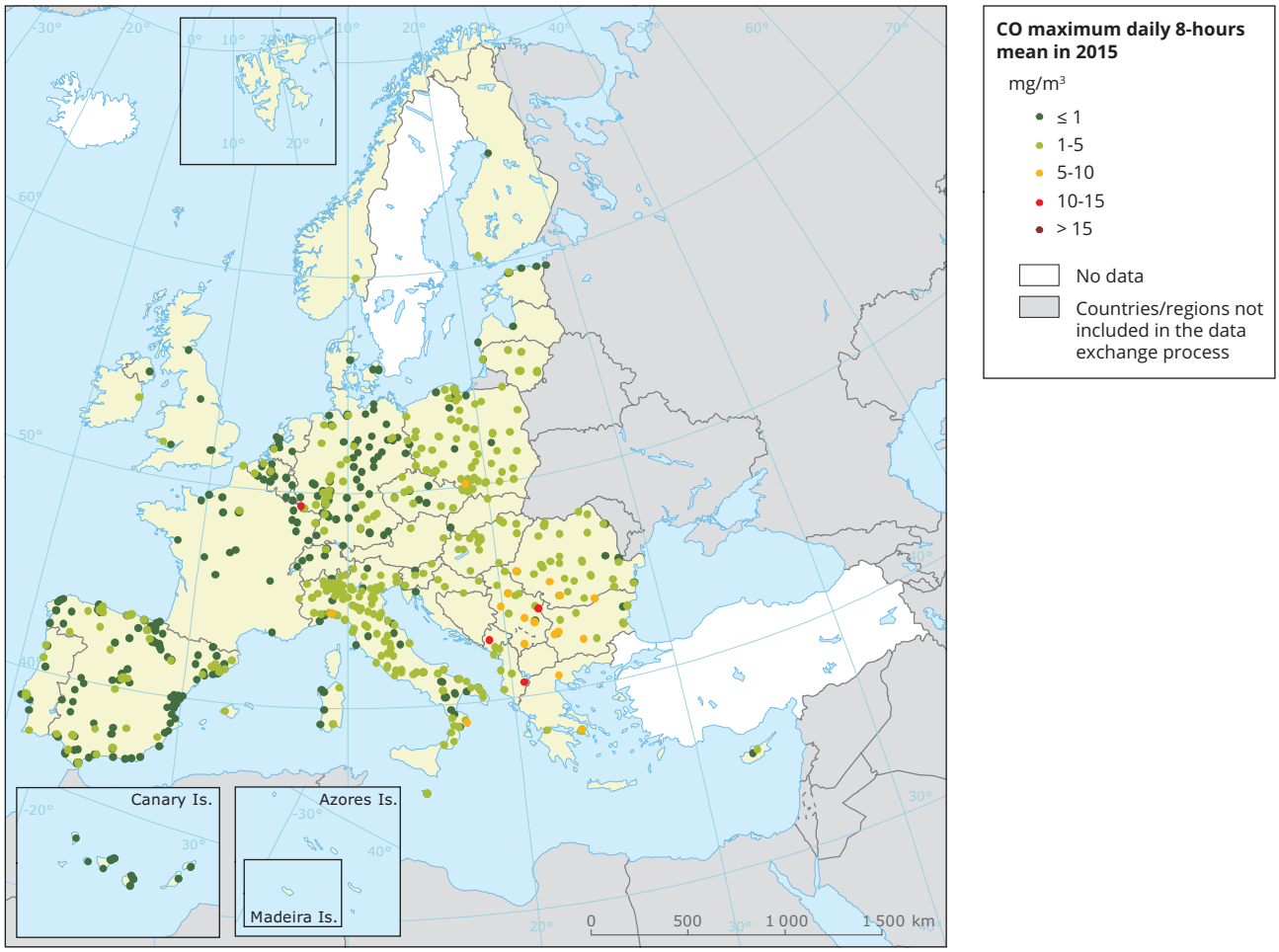
In addition, 30 % of all SO_2 stations measured SO_2 concentrations above the WHO air quality guideline of 20 µg/m^3 for daily mean concentrations in 2015.

8.2.2 Carbon monoxide

The highest CO levels are found in urban areas, typically during rush hour, or downwind from large industrial emission sources. Of the 776 operational stations with more than 75 % of valid data in 36 EEA member and cooperating countries ([30]), only four stations, one suburban background station in Albania and three urban background stations in Germany, Montenegro and Serbia, registered concentrations above the CO limit value and the WHO AQG value in 2015 (Map 8.1).

([25]) No EU target or limit value has been set for Hg concentrations in air. However, the Air Quality Directive (EU, 2004) determines methods and criteria for the assessment of concentrations and deposition of Hg.
([26]) As the WHO has not provided a guideline for As, Ni or C_6H_6, the reference levels presented in Table 4.2 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).
([27]) All EU-28, except Slovakia, and Andorra, Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia (not processed due to technical issues), Kosovo under UNSCR 1244/99, Iceland, Montenegro, Norway, Switzerland and Serbia.
([28]) In Bosnia and Herzegovina, Bulgaria, France, Montenegro, Norway and Serbia.
([29]) Those in Bulgaria, France, Montenegro and Serbia.
([30]) All EU-28 (except Sweden), Andorra, Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Kosovo under UNSCR 1244/99, Montenegro, Norway, Serbia and Switzerland. When concentrations are below the 'lower assessment threshold' (LAT), air quality can be assessed by means of only modelling or objective estimates. At 97 % of locations, annual mean concentrations of CO were below the LAT of 5 µg/m^3 in 2015 (dark green and green dots in Map 8.1).

Map 8.1 Concentrations of CO, 2015



Notes: Red dots correspond to values above the EU annual limit value and the WHO AQG (10 mg/m³). Only stations with > 75 % of valid data have been included in the map. The stations from the former Yugoslav Republic of Macedonia are not included due to technical issues.

Source: EEA, 2017a.

8.2.3 Benzene

C_6H_6 measurements in 2015 with at least 50 % data coverage were reported from 586 stations in 29 European countries ([31]).

Only two industrial urban stations in Croatia and France measured concentrations above the annual limit value (5 µg/m³).

Regarding the estimated WHO reference level (Table 4.2), 21 % of all stations reported concentrations above this reference level in 2015, distributed over 15 European countries ([32]) (Map 8.2).

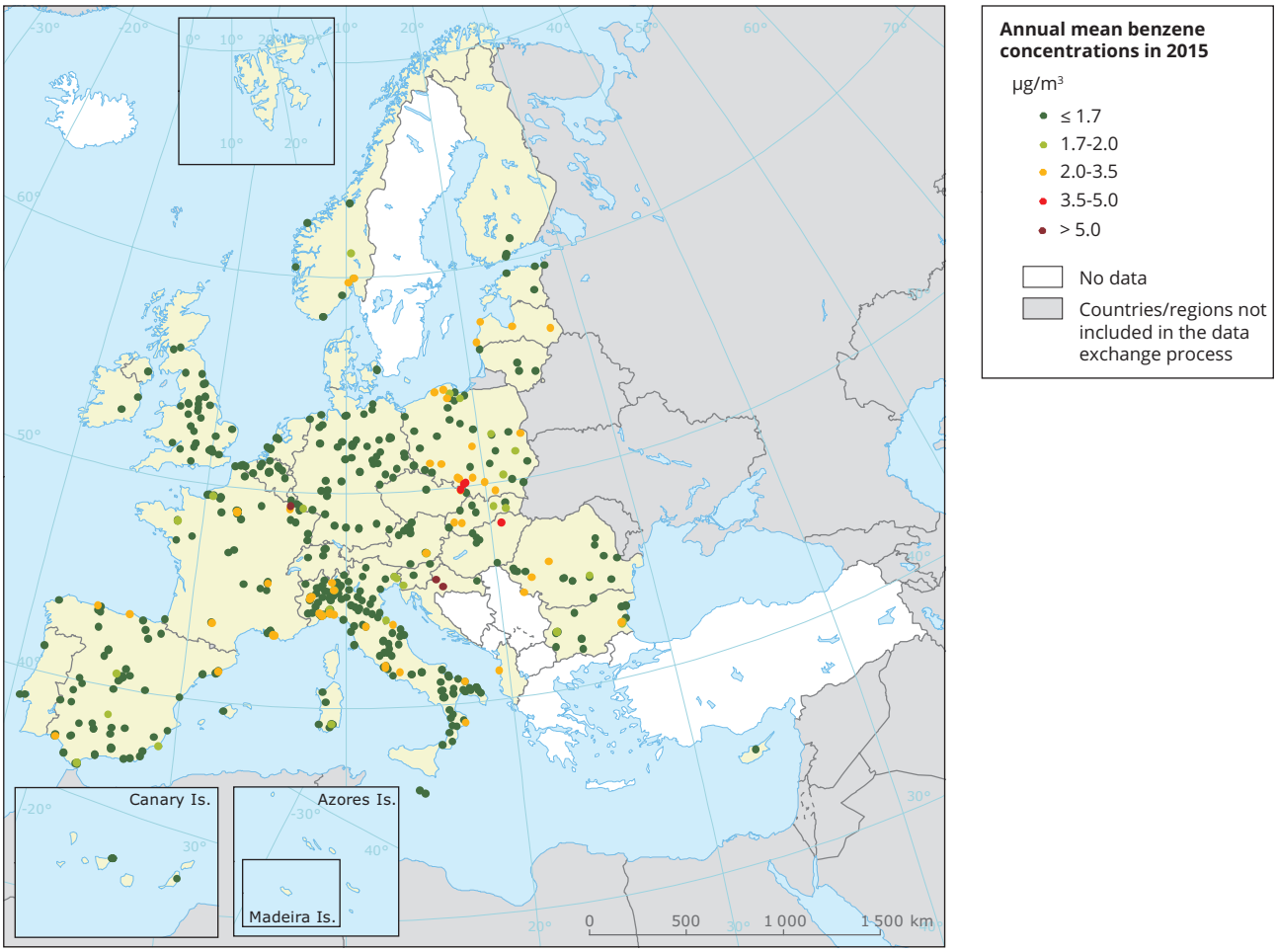
8.2.4 Toxic metals

Monitoring data for toxic metals are missing for parts of Europe. This is probably because concentrations are generally low and below the LAT, allowing assessment to be made by modelling or objective estimates. In 2015, between 584 and 619 stations reported measurement data for each toxic metal

([31]) They included all EU-28 (except Croatia, Greece and Sweden), Albania, Norway and Switzerland. When concentrations are below the LAT, air quality can be assessed by means of only modelling or objective estimates. At 89 % of locations, annual mean concentrations of C_6H_6 were below the LAT of 2 µg/m³ in 2015 (dark green and green dots in Map 8.2).

([32]) In Albania, Austria, Bulgaria, Croatia, the Czech Republic, France, Germany, Hungary, Italy, Latvia, Norway, Poland, Romania, Slovakia, and Spain.

Map 8.2 Concentrations of benzene, 2015



Notes: Dark red dots correspond to concentrations above the limit value of 5 µg/m³. Dark green dots correspond to concentrations under the estimated WHO reference level (1.7 µg/m³). Only stations reporting more than 50 % of valid data have been included in the map.

Source: EEA, 2017a.

(As, Cd, Pb and Ni), with a minimum data coverage of 14 %.

The air pollution problems caused by the toxic metals As, Cd, Pb and Ni in terms of ambient air concentrations are highly localised, as can be seen in Maps 8.3 and 8.4. That is because problems are typically related to specific industrial plants. The results from the reported 2015 data can be summarised as follows:

- Data for **As** from 619 stations in 27 European countries ([33]) were reported in 2015. Seven stations reported concentrations above the target value (6 ng/m³) in both industrial and background urban areas in Belgium (three), Poland (two) and Finland (two). Concentrations of As below the LAT (2.4 ng/m³) were reported at 94 % of the stations in 2015 (see Map 8.3).

- **Cd** data from 619 stations in 27 European countries ([34]) were reported in 2015. Concentrations above the target value (5 ng/m³) were measured at six stations in 2015, in industrial or background suburban areas. The countries reporting these concentrations above the target

([33]) 24 Member States (All EU-28 except Greece, Malta, Portugal and Slovakia), Norway, Serbia and Switzerland.
([34]) 24 Member States (All EU-28 except Greece, Malta, Portugal and Slovakia), Norway, Serbia and Switzerland.

value in 2015 were Belgium (three), Bulgaria (one), Italy (one), and Spain (one). At the great majority of the stations (98 %), Cd concentrations were below the LAT (2 ng/m³) (see Map 8.3).

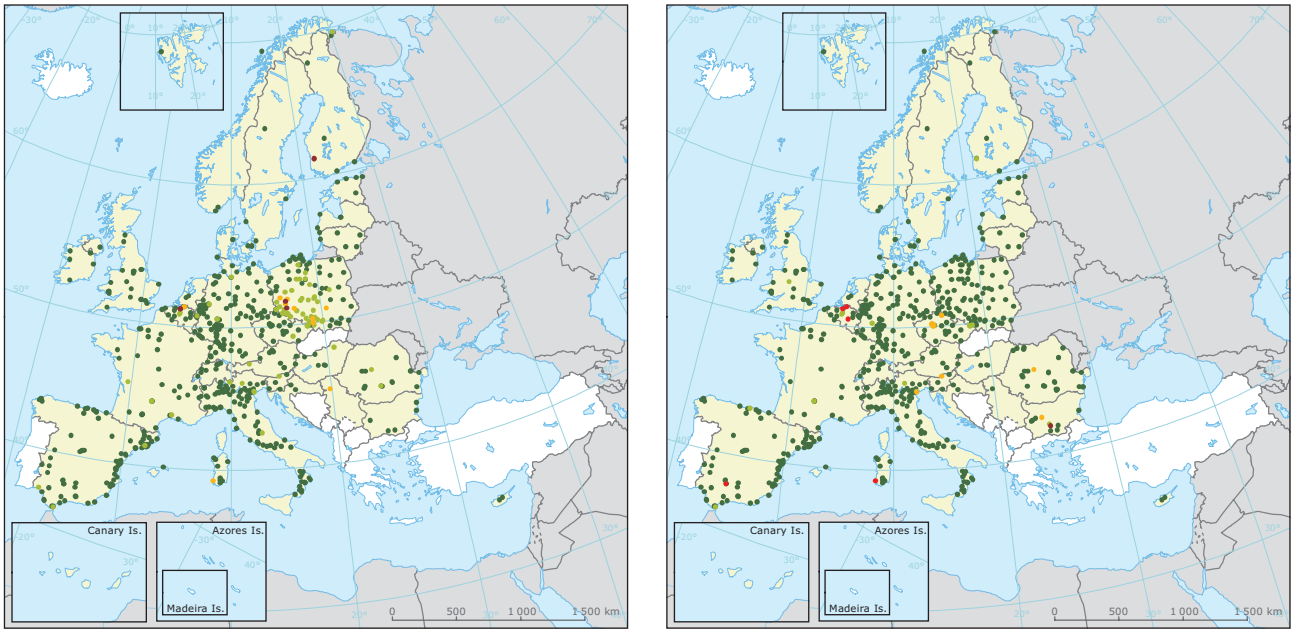
- Twenty-four European countries ([35]) reported **Pb** data in 2015 from 584 stations. Only one urban background station in Belgium reported Pb concentrations above the 0.5 µg/m³ limit value. About 99 % of the stations reported Pb concentrations below the LAT of 0.25 µg/m³ (see Map 8.4)

- **Ni** data from 595 stations in 26 European countries ([36]) were reported in 2015. Concentrations were above the target value of 20 ng/m³ at two industrial stations, in Norway (one) and the United Kingdom (one). About 97 % of the stations reported Ni concentrations below the LAT of 10 ng/m³ (see Map 8.4)

- **Hg** concentrations recorded in the Air Quality e-Reporting Database are very sparse, although the Air Quality Directive (EU, 2004) calls on EU Member States to perform (indicative) measurements of Hg at one background station at least. In total, around 24 stations ([37]) reported data on Hg in air with sufficient data coverage (14 %), of which about 92 % were classified as background stations. Reported concentrations of Hg in air in 2015 ranged from below the detection limit to 9 ng/m³ (observed at an urban traffic station in Zagreb, Croatia).

In 2013, governments worldwide agreed to a global, legally binding treaty to prevent emissions and releases of Hg. The Minamata Convention on Mercury (UN, 2013) for the reduction of Hg emissions and exposure entered into force on 18 May 2017, when the EU, together with several Member States, ratified it. As a result, it is expected that European monitoring of Hg in the atmosphere will be strengthened.

Map 8.3 Concentrations of arsenic and cadmium, 2015

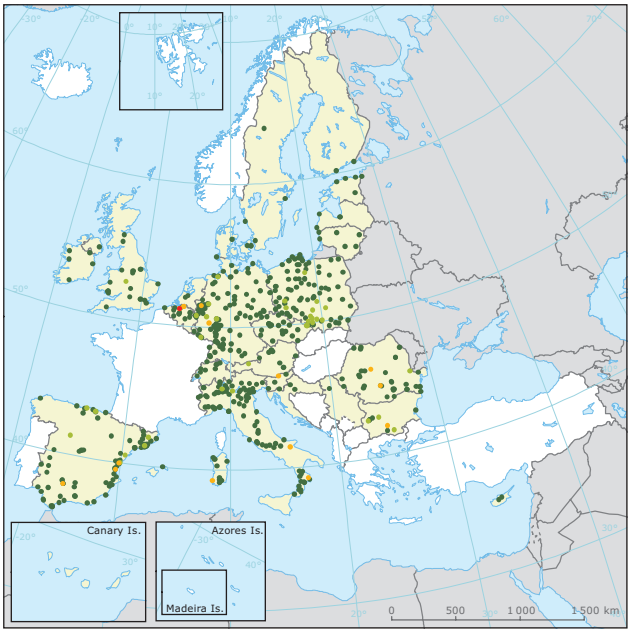


Notes: The maps show the corresponding annual mean concentrations. Red and dark red dots correspond to concentrations above the target values as presented in Table 4.1 Only stations reporting more than 14 % of valid data have been included in the maps.

Source: EEA, 2017a.

([35]) 22 Member States (All EU-28 except Greece, Hungary, Malta, Portugal and Slovakia. France reported only annual means and were not taken into account), Serbia and Switzerland.
([36]) 23 Member States (all EU-28 except the Czech Republic, Greece, Malta, Portugal and Slovakia), Norway, Serbia and Switzerland. France reported one exceedance but not the station where it happened.
([37]) In Belgium, Croatia, Cyprus, Finland, Germany, Lithuania, Malta, Poland, Slovenia, Sweden and the United Kingdom.

Map 8.4 Concentrations of lead and nickel, 2015

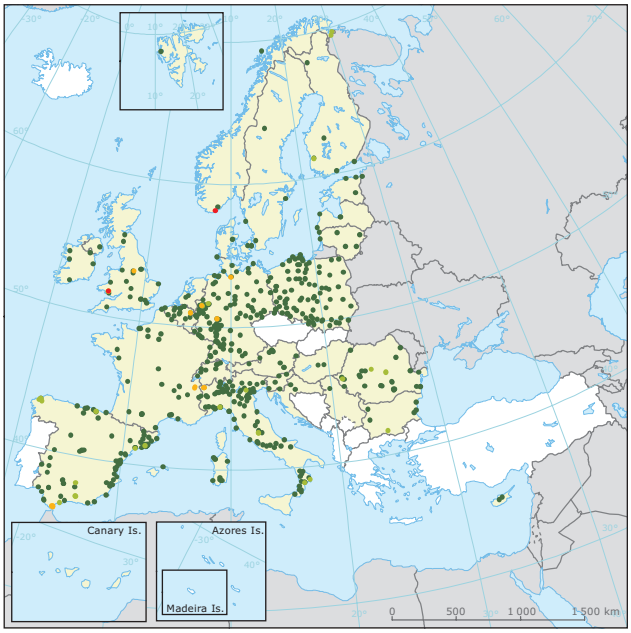


Annual mean lead concentrations in 2015

µg/m³ ● ≤ 0.02 ● 0.02-0.10 ● 0.10-0.50 ● 0.50-1.00 ● > 1.00

No data

Countries/regions not included in the data exchange process



Annual mean nickel concentrations in 2015

ng/m³ ● ≤ 5 ● 5-10 ● 10-20 ● 20-30 ● > 30

No data

Countries/regions not included in the data exchange process

Notes: The maps show the corresponding annual mean concentrations. Red and dark red dots correspond to concentrations above the limit or target values as presented in Table 4.1. Only stations reporting more than 14 % of valid data have been included in the maps.

Source: EEA, 2017a.

Photo: © Elena Prodromou, NATURE@work /EEA

9 Population exposure to air pollutants

Health effects are related to both short- and long-term exposure to air pollution. Short-term exposure (over a few hours or days) is linked to acute health effects, whereas long-term exposure (over months or years) is linked to chronic health effects. The Ambient Air Quality Directives and WHO define, respectively, air quality standards and guidelines for the protection of human health (see Tables 4.1 and 4.2, respectively). These standards and guidelines may be set for the protection of human health from both short- and long-term effects, depending on the pollutant and its health effects.

9.1 Exposure of the EU-28 population in urban areas in 2015

The monitoring data reported by the EU-28 (EEA, 2017a) provide the basis for estimating the exposure of the urban population to exceedances of the most stringent European air quality standards and WHO AQG. The exposure is estimated based upon 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 (2017d).

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, WHO AQG levels and an estimated reference level between 2013 and 2015. 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 2015, about 19 % 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 16 % and 43 % over 2000-2015, with 2014 the year with the lowest extent of exposure. Furthermore, 53 % of the same urban population was exposed to concentrations exceeding the stricter WHO AQG value for PM_{10} in 2015. The percentage of the urban population exposed to levels above the WHO annual AQG (20 µg/m^3) ranged between 50 % and 92 % in 2000-2015.

About 7 % of the EU-28 urban population was exposed to $PM_{2.5}$ above the limit value in 2015. The percentage was in the range of 7-16 % in 2006-2015. The urban population's exposure to levels above the more stringent WHO AQG for $PM_{2.5}$ fluctuated between 82 % and 97 % in 2006-2015. It should be noted that 2015 registered the lowest percentage of urban population exposure to $PM_{2.5}$ (for both the EU target value and the WHO AQG).

In 2015, about 30 % of the EU-28 population in urban areas was exposed to O_3 concentrations above the EU target value threshold, which is a considerable increase compared with the 7 % registered in 2014. 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 is significantly higher. About 95 % of the total EU-28 urban population was exposed to O_3 levels exceeding the WHO AQG in 2015, and proportions fluctuated between 94 % and 99 % in the period 2000-2015.

About 9 % of the EU-28 urban population was exposed to NO_2 concentrations above the EU annual limit value and the WHO NO_2 AQG value in 2015. 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 %.

Between 17 % and 25 % of the urban population in the EU-28 was exposed to BaP annual concentrations above 1.0 ng/m^3 in 2008-2015, whereas 81-91 % of the EU-28 urban population was exposed to BaP concentrations above the estimated reference level (0.12 ng/m^3 as annual mean) over the same period (Table ES.1). The percentages in 2015 were 20 % and 85 %, respectively.

Exposure to SO_2 has tended to decrease over the past few decades, and, since 2007, the exposure of the urban population to concentrations above the daily limit value has remained under 0.2 %. The EU-28 urban population exposed to SO_2 levels exceeding the WHO AQG in 2013-2015 amounted to 20-38 % of the total

urban population (Table ES.1). The lowest estimate was in 2015 (20 %), confirming a decreasing trend since 2000, when 85 % of the EU-28 urban population was exposed to SO_2 levels exceeding the WHO AQG.

Based on the available measurements, it can be concluded that the European population's exposure to CO ambient concentrations above the limit value is very localised and infrequent (see Section 8.2.2).

Exposure in Europe to C_6H_6 concentrations above the limit value is limited to a few localised areas with higher concentrations, which are often close to traffic or industrial sources. Concentrations above the estimated WHO reference level are more widespread (see Section 8.2.3).

Human exposure to As, Cd, Pb and Ni ambient air concentrations above the limit or target values is restricted to a few areas in Europe and is typically caused by specific industrial plants. 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.

9.2 Exposure of total European population in 2014

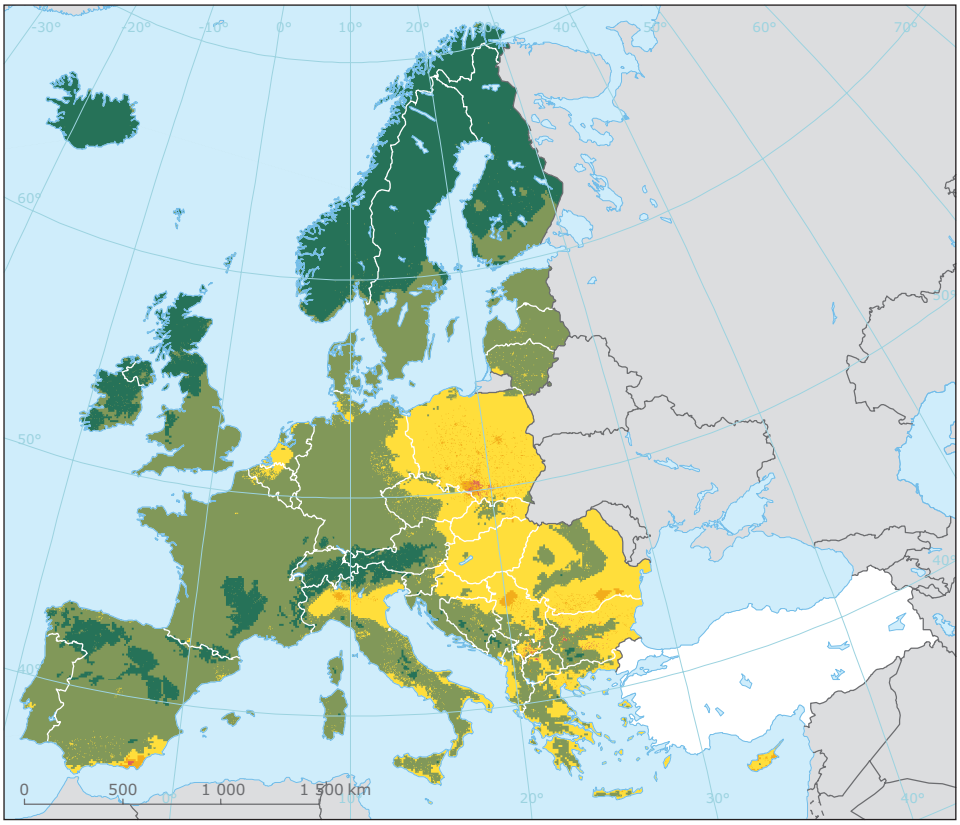
To estimate the exposure of the total European population ([38]) to the different pollutant standards, an interpolation of annual statistics of reported monitoring data from 2014 is used, combining these monitoring data at regional and urban background stations (and traffic in the case of NO_2) with results from the European Monitoring and Evaluation Programme (EMEP) chemical transport model and other supplementary data (such as altitude and meteorology) (for further details, see ETC/ACM, 2017b, 2017c, 2017d). 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) (SOMO35) for O_3) are presented in Figure 9.1. Combining these concentration maps with the population density (based on the GEOSTAT 2011 grid dataset; Eurostat, 2014), the population exposure can be estimated.

Figure 9.2 shows the population frequency distribution for exposure class in 2014. About 44 % of the European

Photo: © Edgaras Vaicikevicius, My City /EEA

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

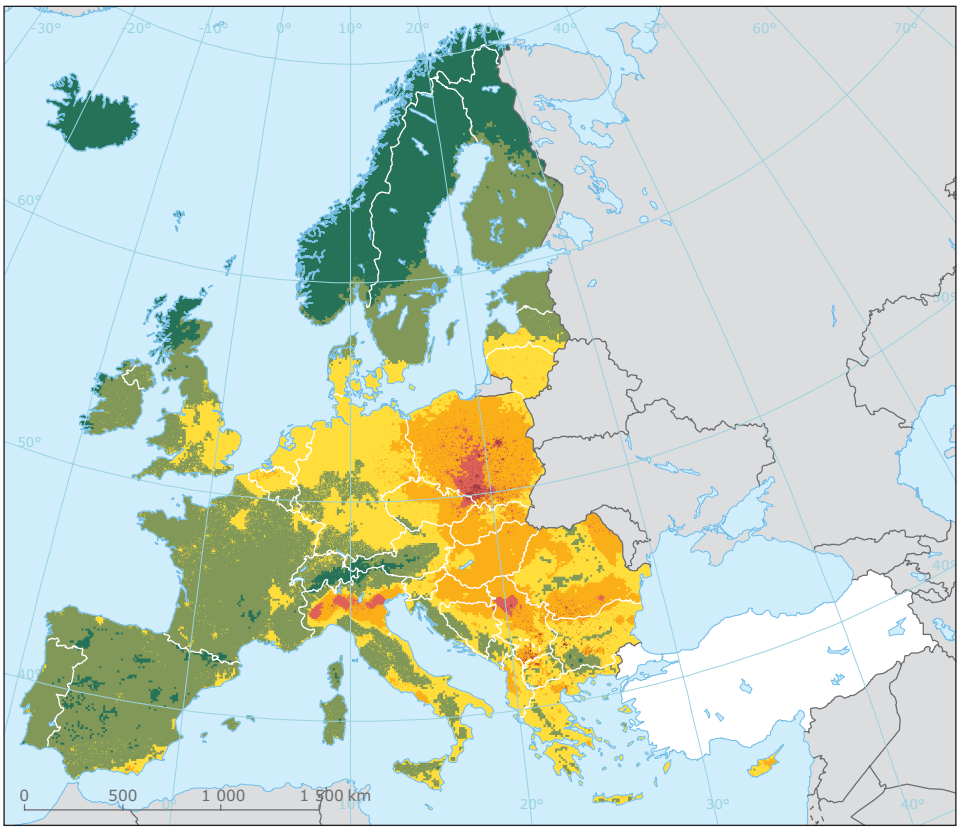
Figure 9.1 **Concentration interpolated maps of PM_{10} (annual mean, µg/m³), $PM_{2.5}$ (annual mean, µg/m³), NO_2 (annual mean, µg/m³), and O_3 (SOMO35, µg/m³ .days) for the year 2014**



PM_{10} annual mean in 2014

µg/m³

- ≤ 10
- 10-20
- 20-30
- 30-40
- 40-50
- > 50
- No available data
- Countries/regions not included in the data exchange process

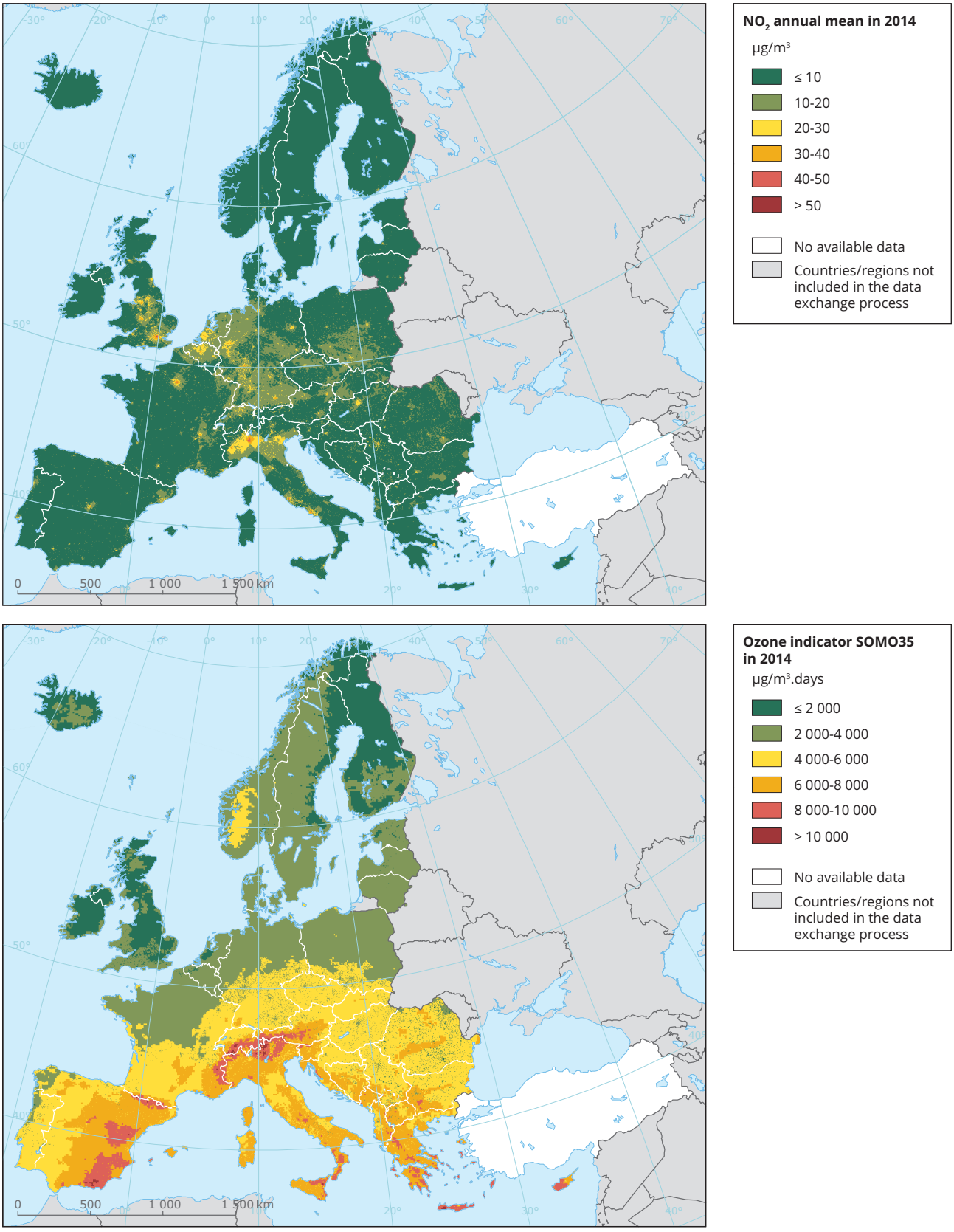


$PM_{2.5}$ annual mean in 2014

µg/m³

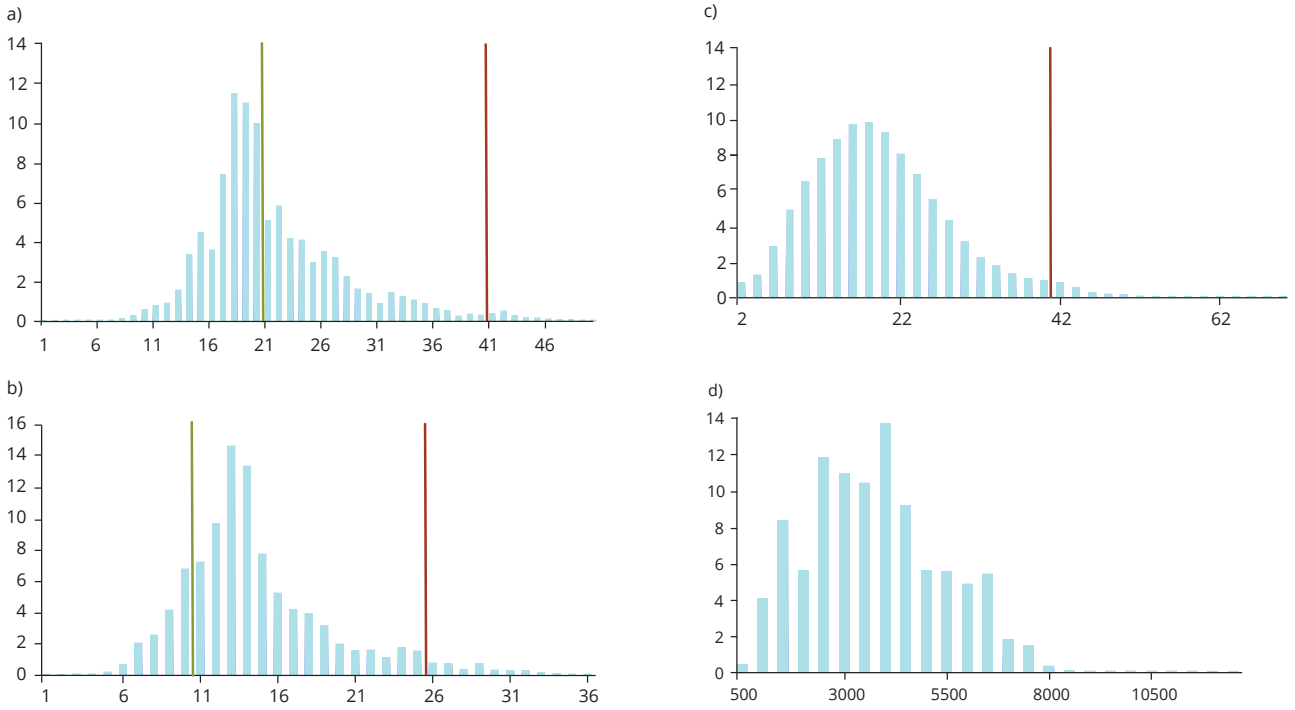
- ≤ 5
- 5-10
- 10-15
- 15-20
- 20-25
- > 25
- No available data
- Countries/regions not included in the data exchange process

Figure 9.1 **Concentration interpolated maps of PM_{10} (annual mean, µg/m³), $PM_{2.5}$ (annual mean, µg/m³), NO_2 (annual mean, µg/m³), and O_3 (SOMO35, µg/m³ .days) for the year 2014 (cont.)**



Sources: ETC/ACM, 2017b, 2017d.

Figure 9.2 **Frequency distribution of the total population exposure to (a) PM_{10} (annual mean), (b) $PM_{2.5}$ (annual mean), (c) NO_2 (annual mean) and (d) O_3 (SOMO35) in 2014**



population (and 43 % of the EU-28 population) was exposed in 2014 to PM_{10} annual average concentrations above the WHO AQG (bars to the right of the green line in Figure 9.2a). The population exposure exceeding the EU limit value (bars to the right of the red line in Figure 9.2a) was about 2 % for the population of the total of European area considered and the EU-28.

When it comes to $PM_{2.5}$, about 83 % of the European population (and 84 % for the EU-28) was exposed in 2014 to annual mean concentrations above the WHO AQG (bars right of the green line in Figure 9.2b) and 4 % of the European (and EU-28) population exposure exceeded the EU target value.

For NO_2, it has been estimated that, in 2014, about 2 % of the European population (and 3 % of the EU-28 population) lived in areas with annual average concentrations above the EU limit value (see Figure 9.2c). It should be mentioned that, in contrast to the other pollutants, the NO_2 mapping methodology incorporates monitoring data from not only the rural and urban background stations but also traffic locations (ETC/ACM, 2017c).

Finally, for O_3 (Figure 9.2d), it has been estimated that, in 2014, about 9 % of the European population lived in areas with SOMO35 values above 6 000 µg/m^3 .d ([39]).

Comparing the results in 2014 of the total EU-28 population exposure and the urban EU-28 population exposure for $PM_{2.5}$ and NO_2 ([40]) (see EEA, 2016b), the percentage of those exposed is higher at urban levels, as would be expected because of the higher concentrations found in urban environments (EEA, 2016b).

([39]) 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 relation between the two indicators; however, it seems that the target value of the 93.2 percentile of maximum daily 8-hour means

([40]) These were directly comparable, since the same statistics (annual mean) were used in both cases. For PM_{10} and O_3, two different statistics are used for the total and the urban population exposure.

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

The health impacts of air pollution can be quantified and expressed in different ways. These include estimates of premature mortality and morbidity. Mortality reflects reduction in life expectancy owing to premature death as a result of air pollution exposure, 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.

Most of the evidence on the health impacts attributable to exposure to ambient air pollution tends to focus on all-cause, as well as on cause-specific (in particular respiratory, cardiovascular and lung cancer), premature mortality and morbidity (WHO, 2006b, 2008, 2013b). There is growing evidence however that exposure may lead to a range of other effects. A number of studies (e.g. Amann, 2014) also show that, after monetising the health effects, the total external costs caused by mortality outweighs those from morbidity. In this report, the focus is on estimating the premature mortality related to air pollution.

10.1 Methods used to assess health impacts

The health impacts from air pollution can be estimated using different health metrics (Box 10.1). The health impacts estimated for this report are those attributable to exposure to $PM_{2.5}$, NO_2 and O_3 in Europe for 2014 ([41]). This assessment required information on air pollution, demographic data and the relationship between exposure to ambient pollutant concentrations and a health outcome. The maps of air pollutant concentrations used in the assessment are those presented in Section 9.2 (annual mean concentration for $PM_{2.5}$ and NO_2, and SOMO35 for O_3; see Figure 9.1). The demographic data and the health-related data were taken from the UN (2015c) and WHO (2017), respectively. The exposure-response relation and the population at risk have been selected in accordance with the recommendation given by the Health Risks of Air Pollution in Europe (HRAPIE) project (WHO, 2013b). A further description and details of the methodology are given by the ETC/ACM (2016c).

The lowest concentration used to calculate the health impacts of a pollutant in a baseline scenario is referred to as the counterfactual concentration

Box 10.1

Premature deaths are deaths that occur before a person reaches an expected age. This expected age is typically the age of standard life expectancy for a country and gender. Premature deaths are considered to be preventable if their cause can be eliminated.

Years of life lost (YLL) are defined as the years of potential life lost owing 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.

([41]) In the methodology used, the air pollutant concentrations are obtained from interpolated maps (see Figure 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 2014 (ETC/ACM, 2017b).

(C_0), and represents for instance the pollutant concentration that could be achieved by changes in the environment or the concentration below which the concentration-health response function may not be appropriate, due to the lack of epidemiological data (WHO, 2016b).

As in previous years' reports, for $PM_{2.5}$, a C_0 of 0 µg/m³ has been used in the estimation of health-related impacts. That is, impacts have been estimated for the full range of observed concentrations, meaning all $PM_{2.5}$ concentrations from 0 µg/m³ upwards. The premature deaths attributable to $PM_{2.5}$ can then be seen as those deaths that could have been avoided had concentrations been reduced to 0 µg/m³ everywhere in Europe. This, however, is not necessarily a realistic assumption, given estimates of what the natural European background concentration may be and the availability of risk estimates, which are limited to the range of exposures observed in epidemiological studies. Therefore, to provide a sensitivity analysis, a C_0 of 2.5 µg/m³ has also been considered in this report. It corresponds to the lowest concentration found in populated areas (ETC/ACM, 2017b) and represents an estimate of the European background concentration. This is also in line with some other recent studies ([42]).

Following the HRAPIE recommendation (WHO, 2013b), and as in previous years, the NO_2 health impact has been calculated applying a C_0 of 20 µg/m³. The material available in the HRAPIE review did not exclude a health effect occurring below 20 µg/m³; the studies rather showed that the size of the effect is less certain below 20 µg/m³. However, this C_0 of 20 µg/m³ might be too high, as indicated by more recent studies (e.g. Héroux et al., 2015). As above, a sensitivity calculation has been performed using an alternative C_0 of 10 µg/m³. This value corresponds to the lowest observed value in a study (Raaschou-Nielsen et al., 2012) that showed a significant correlation between NO_2 concentrations and health outcomes at this concentration level.

Results of the sensitivity analysis performed using the different counterfactual concentrations of $PM_{2.5}$ and NO_2 are presented in Tables 10.1 and 10.2 for the number of premature deaths and YLL, respectively. For the whole modelled area, the calculation of the premature deaths attributable to $PM_{2.5}$ with C_0 of 2.5 µg/m³ results in estimates about 18 % lower than those obtained using a C_0 of 0 µg/m³. In the case of NO_2, the estimated health impacts using a C_0 of 10 µg/m³ are around three times higher than those for a C_0 of 20 µg/m³. Note that, in the following sections of this chapter, the numbers related to $PM_{2.5}$ and NO_2 impacts refer to the estimate made following the same approach as in previous years, that is, C_0 of 0 µg/m³ for $PM_{2.5}$ and C_0 of 20 µg/m³ for NO_2.

The impacts estimated for the different pollutants cannot be simply added to determine the estimated total health impact attributable to exposure. For example, as concentrations of $PM_{2.5}$ and NO_2 are (sometimes strongly) correlated, the impacts estimated for these cannot be aggregated. Doing so may lead to a double counting of up to 30 % of the effects of NO_2 (WHO, 2013b) ([43]).

10.2 Health impact assessment results

The results of the health impact assessment are presented in Tables 10.1 and 10.2 for 41 European countries, for the 41 counties as a whole (Total) and for the EU-28. Table 10.1 presents for each pollutant, the population-weighted concentration and the estimated number of attributable premature deaths for 2014. It also shows the population for each country. In the 41 countries listed, 428 000 premature deaths are attributed to $PM_{2.5}$ exposure; 78 000 premature deaths are attributed to NO_2; and 14 400 premature deaths to O_3 exposure. In the EU-28, the premature deaths attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 399 000, 75 000, and 13 600, respectively.

([42]) The number of premature deaths attributable to $PM_{2.5}$ presented in previous *Air quality in Europe* reports sometimes differ to those estimated in other international or national studies. One reason for such differences is the application of different values of C_0 used in the respective assessments. In the health impact assessments made for the Clean Air Package (European Commission, 2013), impacts are estimated for the (modelled) anthropogenic contribution to $PM_{2.5}$, which implies that a (natural) background contribution (C_0) is not considered. In the 2013 study of the global burden of disease (Burnett et al., 2014), impacts for example were estimated only above a C_0 of 5.8-8.8 µg/m³. In the *Global burden of disease study* 2015 (GBD 2015 Risk Factors Collaborators, 2016) the C_0 range was lowered to 2.4-5.9 µg/m³.

([43]) Alternative calculations done for NO_2 using a relative risk adjusted downwards by 30 % (1.039, 95% CI 1.022-1.056) to account for this overlap, resulted in impacts that were about 30 % lower.

Table 10.1 Premature deaths attributable to $PM_{2.5}$ [a], NO_2 [a] and O_3 exposure in 41 European countries and the EU-28, 2014

		$PM_{2.5}$			NO_2			O_3	
Country	**Population (1 000)**	**Annual mean [e]**	**Premature deaths [a]**		**Annual mean [e]**	**Premature deaths [a]**		**SOMO35 [e]**	**Premature deaths**
			C_0 = 0	**C_0 = 2.5**		**C_0 = 20**	**C_0 = 10**		
Austria	8 507	12.9	5 570	4 520	19.2	1 140	3 630	4 423	260
Belgium	11 181	13.7	8 340	6 860	21.9	1 870	6 470	2 297	190
Bulgaria	7 246	24	13 620	12 280	16.5	740	3 570	2 519	200
Croatia	4 247	15.6	4 430	3 750	15.7	300	1 650	4 503	180
Cyprus	1 172 [d]	17	600	518	12.8	20	130	5 426	30
Czech Republic	10 512	18.6	10 810	9 430	16.8	550	3 640	3 822	310
Denmark	5 627	11.6	3 470	2 740	11	130	790	2 611	110
Estonia	1 316	8.7	750	540	9	10	130	1 991	20
Finland	5 451	7.4	2 150	1 440	8.3	40	450	1 615	60
France	63 798	11	34 880	27 170	17.7	9 330	23 420	3 786	1 630
Germany	80 767	13.4	66 080	54 180	20.2	12 860	44 960	3 287	2 220
Greece	10 927	17	11 870	10 190	14.9	1 660	4 280	5 926	570
Hungary	9 877	17.3	11 970	10 310	17.1	1 210	4 560	3 620	350
Ireland	4 606	9	1 480	1 070	6.1	10	160	868	20
Italy	60 783	15.8	59 630	50 550	22.5	17 290	42 480	5 569	2 900
Latvia	2 001	14.1	2 190	1 810	12.3	60	530	2 213	50
Lithuania	2 943	15.5	3 350	2 830	12.5	60	700	2 457	70
Luxembourg	550	11.9	230	190	19.9	40	180	2 872	10
Malta	425	12	220	180	16	10	100	6 946	20
Netherlands	16 829	13.8	11 200	9 240	21.9	2 560	8 610	2 244	250
Poland	38 018	23	46 020	41 300	15.1	1 700	10 200	3 425	970
Portugal	9 919	8.7	5 170	3 710	13.7	610	2 640	3 519	280
Romania	19 947	17.5	23 960	20 680	16.5	1 860	8 430	1 842	350
Slovakia	5 416	19.1	5 160	4 520	15.2	100	1 330	4 344	160
Slovenia	2 061	15.1	1 710	1 440	15	60	570	5086	80
Spain	44 229	10.7	23 180	17 910	19.9	6 740	19 470	5 436	1 600
Sweden	9 645	7.6	3 710	2 510	9.9	130	990	2 318	150
United Kingdom	64 351	11.6	37 600	29 730	22.2	14 050	35 250	1 337	590
Andorra	77	10	40	30	15	< 1	20	6 692	< 5
Albania	2 896	16.5	1 670	1 430	14.8	90	500	4 376	60
Bosnia and Herzegovina	3 827	15.3	3 450	2 910	15.1	110	1 220	3 852	120
former Yugoslav Republic of Macedonia	2 066	27.4	3 060	2 800	16	60	640	3 215	50
Iceland	326	6.6	80	50	10.9	< 5	30	218	<1
Kosovo [b]	1 805	26.4	3 290	3 000	13.6	10	490	3 149	60
Liechtenstein	37	9	20	10	18.5	< 5	10	4 360	<5
Monaco	38	12.9	20	20	24.5	< 10	20	7 112	<5
Montenegro	622	15.6	550	470	14	< 5	160	4 012	20
Norway	5 108	7.2	1 560	1 030	12.4	190	880	2 113	60

Table 10.1 Premature deaths attributable to $PM_{2.5}$ (a), NO_2 (a) and O_3 exposure in 41 European countries and the EU-28, 2014 (cont.)

		$PM_{2.5}$			NO_2			O_3	
Country	**Population (1 000)**	**Annual mean (e)**	**Premature deaths (a)**		**Annual mean (e)**	**Premature deaths (a)**		**SOMO35 (e)**	**Premature deaths**
			C_0 = 0	**C_0 = 2.5**		**C_0 = 20**	**C_0 = 10**		
San Marino	33	13.5	30	20	14.7	< 5	10	5 949	< 5
Serbia	7 147	21.5	10 770	9 580	19.6	1 380	4 600	2 668	190
Switzerland	8 140	11.6	4 240	3 340	20.9	980	3 560	4 417	220
Total (c)	**534 471**	**14.1**	**428 000**	**356 000**	**18.6**	**78 000**	**241 000**	**3 501**	**14 400**
EU-28 (c)	**502 351**	**14.0**	**399 000**	**332 000**	**18.7**	**75 000**	**229 000**	**3 507**	**13 600**

Notes: (a) For $PM_{2.5}$, calculations have been made using a counterfactual concentration (C_0) of 0 µg/m³, as in previous years and a C_0 of 2.5 µg/m³ to take into account the estimated European background concentration. For NO_2, calculations have been made using C_0 values of 20 and 10 µg/m³ (see explanations in the main text).

(b) Under the UN Security Council Resolution 1244/99.

(c) Total and EU-28 figures are rounded to the nearest thousand (except for ozone, nearest hundred). The national totals to the nearest 10.

(d) Includes the areas of the Republic of Cyprus not under the effective control of the Government of the Republic of Cyprus.

(e) The annual mean (in µg/m³) and the SOMO35 (in µg/m³ .days), expressed as population-weighted concentration, is obtained according to the methodology described by ETC/ACM (2017b) and not only from monitoring stations.

Table 10.2 presents the estimated number of YLL and the YLL per 100 000 inhabitants due to exposure to $PM_{2.5}$, NO_2 and O_3 for 2014. In total, in the 41 countries assessed, 4 574 100 YLL are attributed to $PM_{2.5}$ exposure, 827 500 to NO_2 exposure, and 153 400 to O_3 exposure. In the EU-28, the YLL attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 4 278 800, 798 500 and 145 200, respectively.

The uncertainties in the estimates of premature deaths and YLL are similar to the uncertainties (expressed as 95 % confidence interval) in the relative risk factors: ±35 % ($PM_{2.5}$), ±45 % (NO_2) and ±50 % (O_3). As mentioned above, there might be a bias in the NO_2 estimates due to the correlation with PM.

For $PM_{2.5}$, the highest numbers of premature deaths and YLL are estimated for the countries with the largest populations (Germany, Italy, Poland, the United Kingdom and France). However, in relative terms, when considering YLL per 100 000 inhabitants, the largest impacts are observed in the central and eastern European countries where the highest concentrations are also observed, i.e. Bulgaria, Kosovo under UNSCR 1244/99, the former Yugoslav Republic of Macedonia, Serbia, Poland and Hungary. The lowest relative impacts are found in the countries at the northern and north-western edges of Europe: Iceland, Norway, Ireland, Sweden and Finland.

The largest health impacts attributable to NO_2 exposure are seen in Italy, the United Kingdom, Germany, France and Spain. When considering YLL per 100 000 inhabitants, the highest rates are found in Italy, the United Kingdom, Serbia, Belgium and Germany.

Regarding O_3, the countries with the largest impacts are Italy, Germany, France, Spain and Poland; and the countries with the highest rates of YLL per 100 000 inhabitants are Greece, Italy, Malta, Slovenia and Croatia.

Table 10.2 Years of life lost (YLL) attributable to $PM_{2.5}$ ([a]), NO_2 ([a]) and O_3 exposure in 41 European countries and the EU-28, 2014

	$PM_{2.5}$, C_0 = 0 µg/m³		$PM_{2.5}$, C_0 = 2.5 µg/m³		NO_2 (C_0 = 20)		NO_2 (C_0 = 10)		O^3	
Country	**YLL**	**YLL/ 10^5 inhab.**	**YLL**	**YLL/ 10^5 inhab.**	**YLL**	**YLL/ 10^5 inhab.**	**YLL**	**YLL/ 10^5 inhab.**	**YLL**	**YLL/ 10^5 inhab.**
Austria	58 400	687	47 400	557	12 000	141	38 032	447	2 800	32
Belgium	86 000	769	70 800	633	19 300	172	66 695	597	2 000	18
Bulgaria	135 700	1 873	122 400	1 689	7 300	101	35 574	491	2 000	28
Croatia	43 900	1 035	37 200	875	3 000	71	16 415	387	1 800	41
Cyprus	6 300	537	5 400	461	170	15	1 388	118	280	24
Czech Republic	116 100	1 105	101 300	964	5 900	56	39 136	372	3 300	32
Denmark	37 800	672	29 900	531	1 500	26	8 601	153	1 200	21
Estonia	8 000	605	5 700	434	120	9	1 376	105	250	19
Finland	22 500	412	15 000	275	390	7	4734	87	660	12
France	389 600	611	303 500	476	104 200	163	261 601	410	18 200	29
Germany	687 700	851	563 900	698	133 800	166	467 917	579	23 100	29
Greece	117 500	1 075	100 900	924	16 400	150	42 353	388	5 700	52
Hungary	129 400	1 310	111 400	1 128	13 100	133	49 301	499	3 800	38
Ireland	16 800	365	12 200	265	170	4	1812	39	220	5
Italy	622 400	1 024	527 700	868	180 500	297	443 439	730	30 300	50
Latvia	22 800	1 137	18 900	943	580	29	5 544	277	490	24
Lithuania	33 100	1 125	28 000	950	580	20	6 933	236	730	25
Luxembourg	2 600	467	2 000	372	440	81	1 922	350	80	15
Malta	2 300	546	1 900	435	140	32	1 069	251	180	43
Netherlands	121 700	723	100 400	597	27 800	165	93 549	556	2 700	16
Poland	553 100	1 455	496 300	1 306	20 400	54	122 600	322	11 700	31
Portugal	52 400	529	37600	379	6 200	62	26 772	270	2 900	29
Romania	251 100	1 259	216 700	1 087	19 500	98	88 381	443	3 700	18
Slovakia	58 400	1 077	51 100	943	1 200	21	15 039	278	1 800	34
Slovenia	18 700	907	15 700	762	700	34	6 259	304	870	42
Spain	244 700	553	189 100	427	71 100	161	205 474	465	16 800	38
Sweden	36 200	375	24 400	253	1 300	14	9 616	100	1 500	15
United Kingdom	403 800	627	319 300	496	150 800	234	378 579	588	6 300	10
Andorra	430	558	320	422	< 1	< 1	198	258	40	50

Table 10.2 Years of life lost (YLL) attributable to $PM_{2.5}$ ([a]), NO_2 ([a]) and O_3 exposure in 41 European countries and the EU-28, 2014 (cont.)

	$PM_{2.5}$, C_0 = 0 µg/m³		$PM_{2.5}$, C_0 = 2.5 µg/m³		NO_2 (C_0 = 20)		NO_2 (C_0 = 10)		O^3	
Country	**YLL**	**YLL/ 10^5 inhab.**	**YLL**	**YLL/ 10^5 inhab.**	**YLL**	**YLL/ 10^5 inhab.**	**YLL**	**YLL/ 10^5 inhab.**	**YLL**	**YLL/ 10^5 inhab.**
Albania	17 400	601	14 900	514	910	31	5 219	180	640	22
Bosnia and Herzegovina	36 900	964	31 100	812	1 200	32	13 075	342	1 300	34
former Yugoslav Republic of Macedonia	32 600	1 578	29 800	1 444	670	33	6 832	331	550	26
Iceland	900	276	560	173	40	12	311	96	< 5	1
Kosovo ([b])	32 900	1 824	30 000	1 663	100	6	4 860	269	560	31
Liechtenstein	180	485	130	352	10	19	152	409	10	32
Monaco	270	712	220	579	80	222	265	705	20	54
Montenegro	6 200	997	5200	844	40	7	1 783	287	220	35
Norway	15 800	309	10 400	203	2 000	39	8 857	173	630	12
San Marino	290	880	240	722	10	19	92	283	20	53
Serbia	107 800	1 508	95 900	1 342	13 800	194	46 024	644	1 900	26
Switzerland	43 700	537	34 500	424	10 100	124	36 737	451	2 300	28
Total ([c])	**4 574 100**	**856**	**3 809 300**	**713**	**827 500**	**155**	**2 564 500**	**480**	**153 400**	**29**
EU-28 ([c])	**4 278 800**	**852**	**3 556 000**	**708**	**798 500**	**159**	**2 440 100**	**486**	**145 200**	**29**

Notes: ([a]) For $PM_{2.5}$, calculations have been made using a counterfactual concentration (C_0) of 0 µg/m³, as in previous years, and a C_0 = 2.5 µg/m³ to take into account the estimated European background concentration. For NO_2, calculations have been made using C_0 values of 20 and 10 µg/m³ (see explanations in the main text).

([b]) Under the UN Security Council Resolution 1244/99.

([c]) Total and EU-28 YLL figures are rounded to the nearest hundred.

11 Exposure of ecosystems to air pollution

Air pollution leads to environmental degradation, including the degradation of natural ecosystems. The atmospheric deposition of sulphur and nitrogen compounds has acidifying effects on soils and freshwaters, affecting biodiversity and life on land and water (Duprè et al., 2010). The deposition of nitrogen compounds can also cause eutrophication, an oversupply of nutrients that may lead to changes in species diversity and invasions by new species. The effects of air pollutants on aquatic ecosystems include the loss of biota sensitive to acidification, as well as increased phytoplankton and harmful algal blooms, which may impact on fisheries, water-based recreational activities and tourism (Greaver et al., 2012). Acidification may also lead to increased mobilisation of toxic metals in water or soils, which increases the risk of uptake in the food chain.

Ground-level O_3 can damage crops, forests and other vegetation, impairing their growth. In addition, toxic metals and POPs may have severe impacts on ecosystems. This is mainly because of their environmental toxicity and, in some cases, their tendency to bioaccumulate, a process whereby the toxin cannot be digested and excreted by an animal and, therefore, slowly accumulates in the animal's system, causing chronic health problems. Biomagnification within the food chain may also occur, i.e. increasing concentrations of a pollutant in the tissues of organisms 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 ([44]).

The standards set by the EU to protect vegetation from high O_3 concentrations are shown in Table 11.1. In addition, the UNECE CLRTAP (UNECE, 1979) defines a critical level for the protection of forests. This critical level is a function of the accumulated exposure over a threshold of 40 ppb (AOT40) during April to September and is set at 10 000 µg/m³.hours (UNECE, 2011).

Table 11.1 Air quality standards, for the protection of vegetation, as given in the EU Ambient Air Quality Directive and the 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 accumulated ozone exposure, expressed in µg/m³ .hours, over a threshold of 40 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).

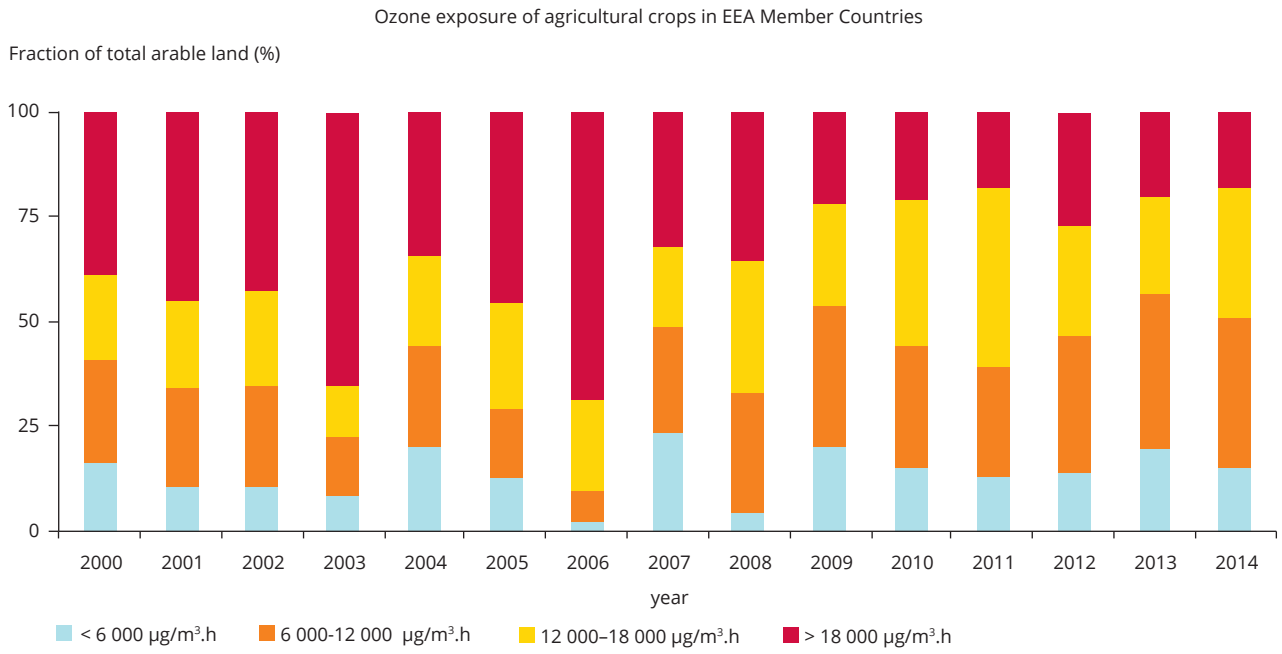
([b]) In the context of this report, only the AOT40 concentrations in 2015 are considered, so no average over 2011-2015 is presented.

Sources: EU, 2008; UNECE, 2011.

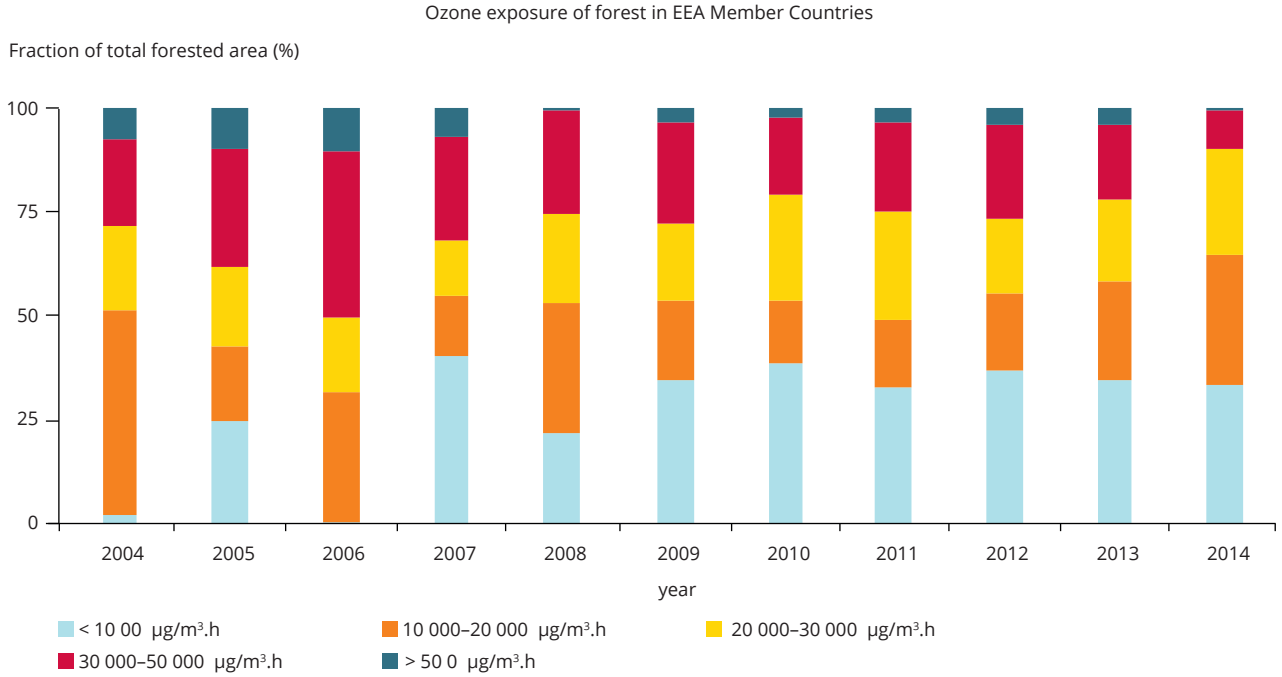
([44]) Several effects of damages to vegetation by ground-level O_3 were described in the *Air Quality in Europe — 2015 Report* (EEA, 2015b).

Figure 11.1 Exposure of (a) agricultural area and (b) forest area to O_3 (AOT40) in the EEA-33 member countries, 2000/04 to 2014 (µg/m³ .hours)

a)



b)



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. Owing to a lack of detailed land cover data and/or rural O_3 data, Iceland and Norway were not included until 2007; Switzerland was not included until 2008; and Turkey is not included throughout the entire period.

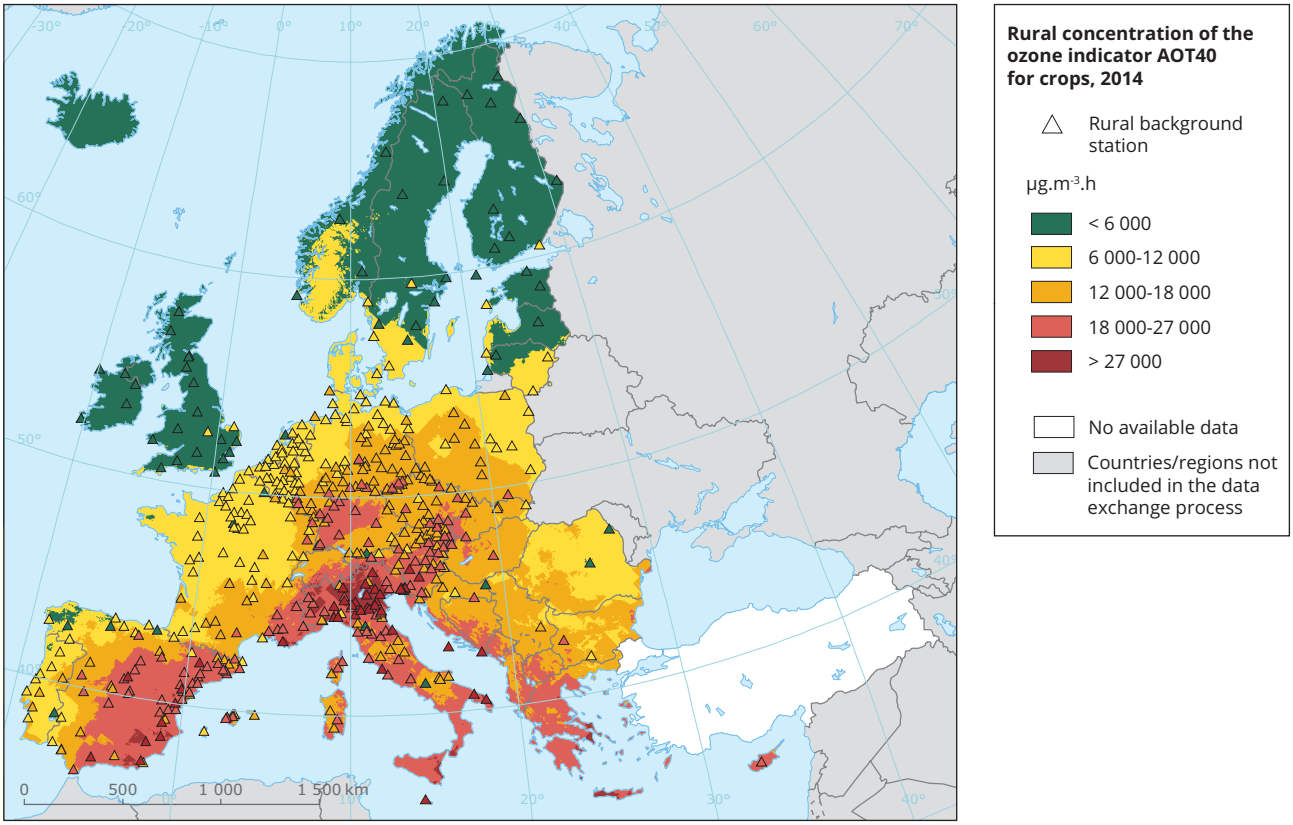
(b) The UNECE CLRTAP (UNECE, 1979) has set a critical level for the protection of forests at 10 000 µg/m³ .hours. In 2005, Bulgaria, Greece and Romania were added; in 2007, Iceland and Norway; and, in 2008, Switzerland. Since 2008, only Turkey has not been included as a result of a lack of detailed land cover data and/or rural O_3 data. Calculations of forest exposure are not available for the years prior to 2004.

Source: EEA, 2017b (CSI 005).

Since 2000, the AOT40 value of 18 000 (µg/m³) . hours has been exceeded in a substantial part of the European agricultural area, as shown in Figure 11.1a (red parts of the bars) for the EEA-33 member countries (except Turkey; EEA, 2017b). In 2014 ([45]), this value was exceeded in about 18 % of all agricultural land in all European countries and 18 % of the EU-28 (i.e. 383 466 km² and 370 769 km², respectively, mostly in southern Mediterranean regions) (Map 11.1). O_3 levels vary considerably from year to year, mostly owing to meteorological variations. In 2014, the total area with agricultural crops above the target value was the lowest since 2000. The long-term objective was exceeded in 86 % of both the total European and the EU-28 agricultural area in 2014 (ETC/ACM, 2017b).

The exceedances since 2004 of the critical level for the protection of forest areas are even more

Map 11.1 Rural concentration of the O_3 indicator AOT40 for crops, 2014



Source: ETC/ACM (2017b).

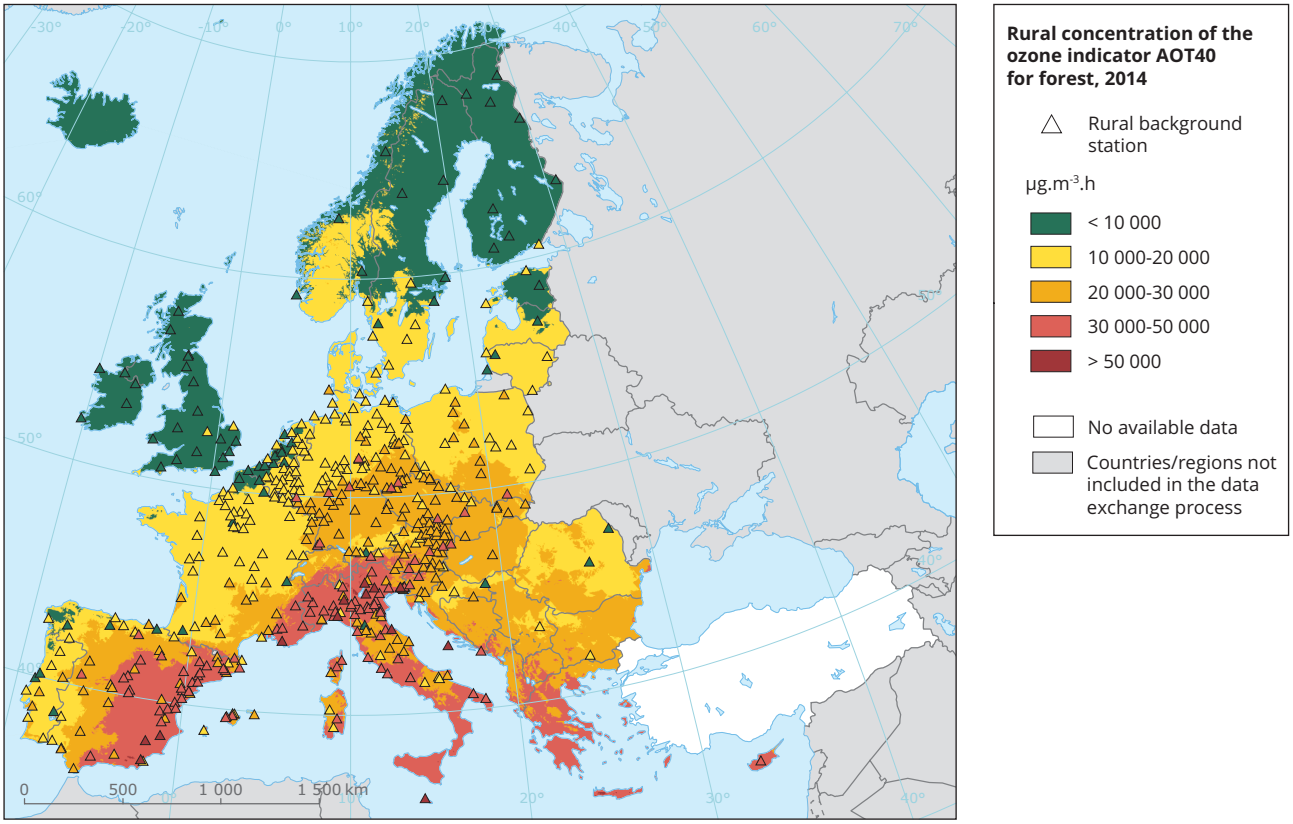
([45]) In the methodology used, the AOT40 is calculated from interpolated maps. To produce these maps, information on the spatial distribution of concentrations from the EMEP model is needed and, at the time of drafting this report, the most up-to-date data from the EMEP model were from 2014 (ETC/ACM, 2017b).

pronounced than in the case of the target value for the protection of vegetation, as shown for the EEA-33 in Figure 11.1b (note that only the green parts of the bars correspond to exposures below the critical level). In 2014, the total EEA-33 (except Turkey) forested area with concentrations below the critical level was 33 % of a total area of 1.45 million km^2. The critical level was exceeded in 68 % of the total European and EU-28 forest area (i.e. 1 035 457 km^2 and 910 420 km^2, respectively) in 2014 (Map 11.2). The critical level was not exceeded (green areas) in 2014 in Iceland, Ireland, Finland, the United Kingdom, most of Estonia, parts of Norway and Sweden and in small coastal areas. In southern Europe, levels may be as high as four or five times above the critical level (red areas in Map 11.2) (ETC/ACM, 2017b).

11.2 Eutrophication

Eutrophication refers to an excess of nutrients in the soil or water, which has several impacts on terrestrial and aquatic ecosystems, including threatening biodiversity (for more information, see EEA, 2016b). Air pollution contributes to the excess of nutrient nitrogen, as the nitrogen emitted to the air as NO_x and NH_3 is deposited on soils, vegetation surfaces and waters.

Map 11.2 Rural concentration of the O_3 indicator AOT40 for forests, 2014



Source: ETC/ACM, 2017b.

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 present a risk of damage or change to the existing ecosystems. Such exceedances are estimated using ecosystem classification methods and model calculations.

EMEP (2016b) estimated that critical loads for eutrophication were exceeded in virtually all European countries and over about 70 % of the European ecosystem area in 2014, confirming that deposition of atmospheric nitrogen remains a threat to ecosystem health in terms of eutrophication. In 2014, the highest exceedances occurred in the Po Valley (Italy), the Dutch-German border and the Caucasus region. Projections for 2020 and 2030 indicate that ecosystems' exposure to eutrophication will still be widespread (Maas and Grennfelt, 2016; EEA, 2017b). This is in conflict with the EU's long-term objective of not exceeding critical loads of airborne acidifying and eutrophying substances in European ecosystem areas (European Commission, 2005).

11.3 Acidification

The emission of nitrogen and sulphur into the atmosphere creates nitric acid and sulphuric acid, respectively. The fate of a great amount of these airborne acids is to fall onto the earth and its waters as acid deposition, reducing the pH level of the soil and water and leading to acidification. Acidification damages plant and animal life, both on land and in water.

After decades of declining sulphur emissions in Europe, acidification is declining or slowing so that some forests and lakes are showing signs of recovery (Maas and Greenfelt, 2016). Owing to the considerable SO_x emission reductions over the past three decades, nitrogen compounds emitted as NO_x and NH_3 have become the principal acidifying components in both terrestrial and aquatic ecosystems, in addition to their role causing eutrophication. However, emissions of SO_x, which have a higher acidifying potential than NO_x and NH_3, still contribute to acidification.

Like eutrophication effects, acidification effects are estimated using the concept of 'critical load' (see Section 11.2). EMEP (2016b) estimated that exceedances of the critical loads for acidification occurred over about 7 % of the European ecosystem area in 2014. Hotspots of exceedances occurred in the Netherlands and its areas that border Germany and Belgium, as well as in southern Germany and north-western Turkey. Exceedances of critical loads for acidity in north-western Europe were higher than in 2013, due to high 2014 depositions, most likely an effect of the increased sulphur deposition due to the eruption of the Bardarbunga volcano in Iceland (see also EEA, 2016b). Looking forward, only 4 % of the EU-28 ecosystem area (3 % in EEA member countries) is projected to exceed acidification critical loads in 2020 if current legislation is fully implemented (EEA, 2017b).

11.4 Vegetation exposure to nitrogen oxides and sulphur dioxide

Critical levels for NO_x and SO_2 are set by the Ambient Air Quality Directive (EU, 2008) for the protection of vegetation, as shown in Table 11.1.

The NO_x annual critical level for the protection of vegetation was exceeded in 2015 at six rural background stations in Italy (four) and Switzerland (two).

ETC/ACM (2017b) estimated that in most areas of Europe the annual NO_x means are below 20 µg/m^3. However, in the Po Valley, the western part of the Netherlands and around Haskovo in Bulgaria, elevated NO_x concentrations above the critical level were estimated for 2014.

In 2015, there were no exceedances of the SO_2 annual or winter critical levels in any of the reported rural background stations.

11.5 Environmental impacts of toxic metals

Although the atmospheric concentrations of As, Cd, Pb, Hg and Ni may be low, they still contribute to the deposition and build-up of toxic metal contents in soils, sediments and organisms. These toxic metals do not break down in the environment and some bioaccumulate and biomagnify. This means that plants and animals can be poisoned over a long period through long-term exposure to even small amounts of toxic metals. If a toxic metal has bioaccumulated in a particular place in the food chain — for example in a type of fish — then human consumption of that fish may present a serious risk to health.

For further information of exceedances of metals critical loads, please see EEA (2016b).

Abbreviations, units and symbols

µg/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 µg/m^3 (40 ppb) and 80 µg/m^3 accumulated over all hourly values measured between 08:00 anar Quality Guideline
As	Arsenic
BaP	Benzo[*a*]pyrene
BC	Black carbon
C_0	Counterfactual concentration
CAMS	Copernicus Atmosphere Monitoring Service
C_6H_6	Benzene
Cd	Cadmium
CH_4	Methane
CL	Critical level
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	Carbon monoxide
CO_2	Carbon dioxide
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
ETC/ACM	European Topic Centre for Air Pollution and Climate Change Mitigation
EU	European Union
GHG	Greenhouse gas
Hg	Mercury
HRAPIE	Health Risks of Air Pollution in Europe
LAT	Lower assessment threshold

mg/m^3	Miligram(s) per cubic metre
NEC	National Emission Ceilings
ng/m^3	Nanogram(s) per cubic metre
NH_3	Ammonia
NH_4^+	Ammonium
NH_4NO_3	Ammonium nitrate
$(NH_4)_2SO_4$	Ammonium sulphate
Ni	Nickel
NMVOC	Non-methane volatile organic compound
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_3^-	Nitrate
NO_x	Nitrogen oxides
N_2O	Nitrous oxide
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
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
POPs	Persistent organic pollutants
ppb	Parts per billion
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
Tg	Teragram(s)
UN	United Nations

UNECE	United Nations Economic Commission for Europe
UNSCR	United Nations Security Council Resolution
USD	United States dollars
VOC	Volatile organic compound
WHO	World Health Organization
YLL	Years of life lost

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