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Air quality in Europe — 2016 report

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Contents

Acknowledgements **5**

Executive summary **6**

1 Introduction **10**

1.1 Background 10

1.2 Objectives and coverage 10

1.3 Effects of air pollution 11

1.4 Policy and legislation 12

2 Sources and emissions of air pollutants **15**

2.1 Sources of regulated pollutants 15

2.2 Total emissions of air pollutants 16

2.3 Sectoral emissions of air pollutants 16

2.4 Uncertainties in reported emissions 21

3 Residential biomass combustion: an important source of air pollution **22**

3.1 Changes in residential fuel consumption 23

3.2 Air pollutant emissions from residential combustion 23

3.3 Impact on air quality 24

3.4 Mitigating emissions from residential wood combustion 25

3.5 Summary 26

4 Particulate matter **27**

4.1 European air-quality standards and World Health Organization guidelines for particulate matter 27

4.2 Status and trends in concentrations 27

5 Ozone **34**

5.1 European air-quality standards and World Health Organization guidelines for ozone 34

5.2 Status and trends in concentrations 34

6 Nitrogen dioxide **40**

6.1 European air-quality standards and World Health Organization guidelines for NO_2 40

6.2 Status and trends in concentrations 40

7 Benzo[*a*]pyrene 46
7.1 European air-quality standards and reference level for benzo[*a*]pyrene 46
7.2 Status and trends in concentrations 46

8 Other pollutants: sulphur dioxide, carbon monoxide, toxic metals and benzene 49
8.1 European air-quality standards and World Health Organization guidelines 49
8.2 Status and trends in concentrations 51

9 Population exposure to air pollutants in European urban areas 55
9.1 Particulate matter 55
9.2 Ozone 56
9.3 Nitrogen dioxide 56
9.4 Benzo[*a*]pyrene 56
9.5 Sulphur dioxide 57
9.6 Carbon monoxide 57
9.7 Toxic metals (arsenic, cadmium, lead and nickel) 57
9.8 Benzene 57

10 Health impacts of exposure to fine particulate matter, nitrogen dioxide and ozone 58

11 Impacts of air pollution on ecosystems 62
11.1 Vegetation damage by ground-level ozone 62
11.2 Eutrophication 65
11.3 Acidification 66
11.4 Environmental impacts of toxic metals 66
11.5 Ecosystem exposure to nitrogen oxides and sulphur dioxide 67

Abbreviations, units and symbols 68

References 70

Annex 1 Trends in PM_{10}, $PM_{2.5}$, O_3, NO_2 and BaP by country and station type 77

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Executive summary

Air pollution is a very important 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 2014 (see Box ES.1). It reviews the progress made towards meeting the air quality standards established in the two 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 exposure to the air pollutants with the greatest impacts on health in Europe, as well as an overview of the effects of air pollution on human health and on ecosystems. The evaluation of the status of air quality is based on ambient air measurements, in conjunction with data on anthropogenic emissions and their trends. The analysis covers up to 42 European countries, including European Union (EU) Member States (EU-28) and other EEA member countries (EEA-33) as of 2014.

The present analysis indicates that 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, World Health Organization (WHO) Air Quality Guidelines (AQGs).

Box ES.1 New in the *Air quality in Europe — 2016 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 2016 report presents a number of new elements, including:

- updated information on air pollutant emissions, concentrations, and urban population exposure data (for year 2014);
- new concentration maps for carbon monoxide, benzene and the toxic metals arsenic, cadmium, lead and nickel;
- updated assessments of air quality impacts on health, vegetation and ecosystems;
- a review of the emissions and air quality impacts caused by residential biomass combustion;
- trend analyses of particulate matter, ozone, nitrogen dioxide and benzo[*a*]pyrene concentrations.

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 protection of the natural capital and to support economic prosperity, and human well-being and social development, all of which are part of the EU's 2050 vision of living well within the limits of the planet.

Europe's air quality

Particulate matter

Concentrations of particulate matter (PM) continued to exceed the EU limit and target values in large parts of Europe in 2014. For PM with a diameter of 10 µm or less (PM_{10}), concentrations above the EU daily limit value were registered in 21 of the 28 EU Member States, and, for PM with a diameter of 2.5 µm or less ($PM_{2.5}$), concentrations above the target value were registered in four. A total of 16 % of the EU-28 urban population was exposed to PM_{10} levels above the daily limit value and approximately 50 % was exposed to concentrations exceeding the stricter WHO AQG value for PM_{10} in 2014. Regarding $PM_{2.5}$, 8 % of the urban population in the EU-28 was exposed to $PM_{2.5}$ levels above the EU target value (which changed to a limit value from 2015 onwards) and approximately 85 % was exposed to concentrations exceeding the stricter WHO AQG value for $PM_{2.5}$ in 2014 (Table ES.1).

Significant decreasing trends in the PM_{10} annual mean were found in 2000–2014 for 75 % of a consistent set of stations. Similarly, $PM_{2.5}$ concentrations, on average, tended to decrease between 2006 and 2014 for all station types. In fact, on 2014, the number of EU Member States with concentrations above the air-quality standards was lower than in 2013, as was the case for the urban population exposed to levels above those standards. However, current trends indicate that there will still be exceedances in 2020, so more has to be done to reach concentrations below the EU limit values by that year.

Ozone

In 2014, 16 of the 28 EU Member States registered concentrations above the EU ozone (O_3) target value for the protection of human health. Conformity with the WHO AQG value for O_3, which was set for the protection of human health, was observed in fewer than 4 % of all stations in Europe in 2014. Some 8 % of the EU-28 urban population lives in areas in which the EU O_3 target value threshold for protecting human health was exceeded in 2014. The proportion of the EU urban population exposed to O_3 levels exceeding the

Table ES.1 Percentage of the urban population in the EU-28 exposed to air pollutant concentrations above certain EU and WHO reference concentrations (2012–2014)

Pollutant	EU reference value (a)	Exposure estimate (%)	WHO AQG (a)	Exposure estimate (%)
$PM_{2.5}$	Year (25)	8–12	Year (10)	85–91
PM_{10}	Day (50)	16–21	Year (20)	50–63
O_3	8-hour (120)	8–17	8-hour (100)	96–98
NO_2	Year (40)	7–9	Year (40)	7–9
BaP	Year (1)	20–24	Year (0.12) (RL)	88–91
SO_2	Day (125)	< 1	Day (20)	35–49

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 estimated reference levels (RLs).

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 24-hour mean concentration, and for NO_2 it is the annual mean limit value.

The estimated exposure range refers to a recent 3-year period (2012–2014) 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.

Sources: EEA, 2016f.

WHO AQG was significantly higher, comprising 96 % of the total urban population in 2014 (Table ES.1).

Although the numbers for population exposure to O_3 levels above the EU target value have improved from 2013, the current trends show that, in 2020, 7 % of stations will still have values above that target value. This implies that additional measures must be taken to comply with the current EU standards.

Nitrogen dioxide

The annual limit value for nitrogen dioxide (NO_2) was widely exceeded across Europe in 2014, and 94 % of all values above the annual limit value were observed at traffic stations. A total of 17 of the EU-28 recorded concentrations above this limit value at one or more stations. Of the EU-28 urban population, 7 % lives in areas in which the annual EU limit value and the WHO AQG for NO_2 were exceeded in 2014 (Table ES.1).

In 2000–2014, NO_2 concentrations tended to decrease on average at all types of stations, especially at traffic stations. Nevertheless, if these trends continued until 2020, 7 % of stations would still have concentrations above the annual limit value. This calls for additional efforts to reach the EU limit value.

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 20 Member States reported measurements of BaP with enough valid data in 2014. More than one-third of the reported BaP measurement stations in Europe had values above the EU target value in 2014, mostly in urban areas. About 24 % of the European urban population was exposed to BaP annual mean concentrations above the European target value in 2014 and about 88 % to concentrations above the estimated reference level ([1]) (Table ES.1).

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

The EU-28 urban population was not exposed to sulphur dioxide (SO_2) concentrations above the EU daily limit value in 2014. However, 38 % of the EU-28 urban population was exposed to SO_2 levels exceeding the WHO AQG in 2014.

Exposure of the European population to carbon monoxide (CO) concentrations above the EU limit value and WHO AQG is very localised and infrequent. No reporting stations in either the EU-28 or EEA-33 groups of countries registered exceedances of the CO limit value in 2014.

Likewise, no exceedances of the limit value for benzene (C_6H_6) were observed in Europe in 2014.

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.

Sources of air pollution

Transport, industry, power plants, agriculture, households and waste management all contribute to Europe's air pollution. Emissions of the main air pollutants in Europe have declined in recent decades, resulting in generally improved air quality across the region. However, certain sectors have not reduced their emissions enough to meet air-quality standards or have even increased emissions of some pollutants. For example, emissions of nitrogen oxides (NO_X) from road transport have not decreased sufficiently to meet air-quality standards in many urban areas. Emissions of $PM_{2.5}$ and BaP from coal and biomass combustion in households and from commercial and institutional buildings have been sustained and are the main contributors to total PM and BaP emissions in the EU. Furthermore, emissions of ammonia (NH_3) from agriculture remain high and contribute to sustained PM levels and some high-PM episodes in Europe.

Although European air quality is projected to improve in the future with full implementation of existing legislation, further efforts to reduce emissions of air pollutants are necessary to ensure full compliance with the EU air-quality standards set for the protection of human health and the environment. For example, agriculture is the main emitter sector in which emissions of air pollutants have decreased least.

([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).

Impacts of air pollution on health

Air pollution continues to have significant impacts on the health of Europeans, 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 troublesome 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 2013 ([2]) were responsible for about 467 000 premature deaths originating from long-term exposure in Europe (over 41 countries; see Table 10.1), of which around 436 000 were in the EU-28. The estimated impacts on the population in the same 41 European countries of exposure to NO_2 and O_3 concentrations in 2013 were around 71 000 and 17 000 premature deaths per year, respectively, and in the EU-28 around 68 000 and 16 000 premature deaths per year, respectively. These figures do not show significant changes over the years.

Exposure and impacts on European ecosystems

Air pollution continues to damage vegetation and ecosystems. It leads to several important environmental impacts, which affect vegetation 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, NH_3 and NO_X.

Europe's sustained 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 21 % of the EU-28 agricultural land area in 2013 ([3]), mostly in southern Mediterranean regions. The long-term objective for the protection of vegetation from O_3 was exceeded in 81 % 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 2013.

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. Improvements in reducing ecosystem exposure to excess levels of acidification have been made in the past three decades, largely as a result of declining SO_2 emissions. An estimated 7 % of the total EU-28 ecosystem area and 5 % of the Natura 2000 area were at risk of acidification in 2010. This represents reductions of 30 % and 40 %, respectively, from 2005 levels.

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 around 63 % of the total EU-28 ecosystem areas, and 73 % of the area covered by Natura 2000-protected sites, remained exposed to air pollution levels exceeding eutrophication limits in 2010.

Air policy

European air pollution is a well-established environmental policy area. It has followed a twin-track approach, implementing, on the one hand, legal limits for ambient concentrations of air pollutants and, on the other, emission mitigation controls, both to national totals and to specific sources or sectors. Over the last three decades these policies have resulted in decreased emissions of air pollutants and noticeable improvements in air quality.

This European policy is in line with other international instruments and conventions. Furthermore, national, regional and local authorities play a very important role not only in implementing EU legislation but also in adopting additional measures to reduce emissions and further protect their populations and the environment from the impacts of air pollution.

([2]) The methodology uses maps of interpolated air pollutant concentrations, with information on concentrations from the EMEP model. At the time of drafting this report, the most up-to-date data from the EMEP model were used (2013).

([3]) See footnote ([2]).

1 Introduction

1.1 Background

Air pollution is a very important 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 impact humans, ecosystems, the climate and subsequently society and the economy. Effective air-quality policies call for 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 (see Box 1.1) and is focused on the state of air quality in 2014 and its development over the previous 14 years, from 2000 (or later, depending data availability) to 2014. The evaluation of the status of air quality is based on ambient air measurements (see Box 1.2), in conjunction with anthropogenic emissions and their trends. 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, and its impacts on ecosystems.

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 (EAPs) (EU, 2002, 2013).

Box 1.1 European coverage

The report focuses mainly on the EU-28, that is, the 28 Member States of the European Union: 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, that is, the 33 member countries of the European Environment Agency (EEA): the EU-28 plus Iceland, Liechtenstein, Norway, Switzerland and Turkey;
- the EEA-39, that is, the EEA-33 member countries plus the cooperating countries of the EEA: Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Kosovo under the United Nations Security Council Resolution 1244/99, Montenegro and Serbia.

Finally, the health impact assessments and the impacts on ecosystems also consider other European countries such as Andorra, Monaco and San Marino.

Box 1.2 Ambient air measurements

The analysis of concentrations in relation to the legal limit and target values is based on measurements at fixed sampling points. Only measurements data received by 26 April 2016, when the 2014 dataset was frozen and published (EEA, 2016a), were included in the analysis and, therefore, maps, figures and tables.

Fixed sampling points in Europe are situated at four types of sites: traffic-related 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 (SO_2, NO_2, O_3, particulate matter and 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. 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 loss of representativeness (ETC/ACM, 2012a).

For benzene, the required amount of valid data for the analysis is 50 %. For the toxic metals (As, Cd, Ni, Pb) and benzo[*a*]pyrene, 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 particulate matter 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 from natural sources and winter road sanding/salting. Finally, in the cases of NO_2 and benzene, in zones where a postponement has been granted for the attainment of the related limit values, the possibility of increasing the limit value by the margin of tolerance has not been considered either.

1.3 Effects of air pollution

1.3.1 Human health

Air pollution is the single largest environmental health risk in Europe; recent estimates suggest that the disease burden resulting from air pollution is substantial (Lim et al., 2012; WHO, 2014a). Heart disease and stroke are the most common reasons for premature death attributable to air pollution and are responsible for 80 % of cases of premature death; lung diseases and lung cancer follow (WHO, 2014a). 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. The International Agency for Research on Cancer has classified air pollution in general, as well as particulate matter (PM) as a separate component of air pollution mixtures, as carcinogenic (IARC, 2013).

Emerging literature (WHO, 2005, 2013a) shows that air pollution has been associated with health impacts on fertility, pregnancy, and new-borns and children. These include negative effects on neural 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 may be linked to obesity and dementia (RCP, 2016, and references therein).

While air pollution is harmful to all populations, some people suffer more because they live in polluted areas and are exposed to higher levels of air pollution, or they are more vulnerable to the health problems caused by air pollution.

The proportion of the population affected by less severe health impacts is much larger than the proportion of the population affected by more serious health impacts (e.g. those leading to premature deaths). In spite of this, it is the severe outcomes (such as increased risk of mortality and reduced life expectancy) that are most often considered in epidemiological studies and health-risk analyses, because there are usually better data available for the severe effects (EEA, 2013a).

While this report focuses on only ambient (outdoor) air quality, indoor air pollution also poses considerable impacts on health (Lim et al., 2012; WHO, 2013a; RCP, 2016) and is greatly affected by outdoor air pollution.

1.3.2 Ecosystems

Air pollution has several important environmental impacts and may directly affect vegetation, as well as the quality of water and soil and the ecosystem services that they support. For example, ground-level ozone (O_3) damages agricultural crops, forests and plants by reducing their growth rates. Other pollutants, such as nitrogen oxides (NO_X, the sum of nitrogen monoxide (NO) and nitrogen dioxide (NO_2)), sulphur dioxide (SO_2) and ammonia (NH_3), contribute to the acidification of soil, lakes and rivers, causing biodiversity loss. In addition to causing acidification, NH_3 and NO_X emissions also 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.

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. decades). Tropospheric O_3 and black carbon (BC), a constituent of PM, are examples of air pollutants that are short-lived climate forcers and that contribute directly to global warming. Other PM components, such as organic carbon (OC), ammonium (NH_4^+), sulphate (SO_4^{2-}) and nitrate (NO_3^-), have a cooling effect. In addition, changes in weather patterns due to climate change may change the transport, dispersion, deposition and formation of air pollutants in the atmosphere. For example, a warmer climate leads to an increase in ground-level O_3 production, and increased O_3 levels then contribute to more warming.

Measures to cut BC emissions, along with those of other pollutants that cause tropospheric O_3 formation, such as methane (CH_4) (itself a greenhouse gas), will help to reduce health and ecosystem impacts and the extent of global climate warming. Air quality and climate change should therefore be tackled together by policies and measures that have been developed through an integrated approach. These integrated policies would avoid the negative feedbacks of climate on air quality, or vice versa, that have already been evidenced. Examples are the impact on air quality from the large support via taxation of diesel cars (with lower carbon dioxide (CO_2) emissions), or from the increased use of biomass combustion without adequate emission controls.

1.3.4 The built environment and cultural heritage

Air pollution can also damage materials and buildings, including Europe's most culturally 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, biodegradation and soiling. Emissions of air pollutants can be deposited and build up over the years on the surfaces of buildings. The walls, windows and roofs, made mainly of stone, bricks, cement, glass, wood and ceramics, become discoloured and suffer material loss, structural failure and soiling. Of particular importance is soiling caused by particles and corrosion caused by acidifying compounds (mostly sulphur oxides (SO_X) and NO_X).

1.3.5 Economic impacts

The effects of air pollution on health, crops and forests yields, ecosystems, the climate and the built environmental 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 these costs 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 (also referred to as welfare costs) are those associated with increased mortality and morbidity (illness causing, for example, pain and suffering), degradation of air and water quality and consequently ecosystems health, as well as climate change.

The European Commission estimated that total health-related external costs in 2010 were in the range of EUR 330–940 billion, including direct economic damages of EUR 15 billion from lost work days, EUR 4 billion from healthcare costs, EUR 3 billion from crop yield loss and EUR 1 billion from damage to buildings (European Commission, 2013a).

The potential total economic consequences of both market and non-market impacts of ambient air pollution are very significant and underscore the need for strong policy action.

1.4 Policy and legislation

European air pollution is a well-established environmental policy area; over a number of decades,

policies in this area have assisted in reducing emissions of air pollutants and have led to noticeable improvements in air quality. The EU's clean air policy framework sets EU air-quality standards, reinforcing national policies for those aspects of the air-quality problem that Member States cannot handle effectively or efficiently alone. It also aims to implement the EU's international obligations in the field of air pollution, and to integrate environmental protection requirements into, for example, the industry, energy, transport and agriculture sectors.

The seventh Environment Action Programme, 'Living well, within the limits of our planet' (EU, 2013), which will run until 2020, 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.' It further contains shorter-term objectives to be met by 2020, that:

- outdoor air quality in the EU has significantly improved, moving closer to World Health Organization (WHO) recommended levels; and
- air pollution and its impacts on ecosystems and biodiversity are further reduced.

Consistent with these objectives, EU air pollution legislation has, over recent years, followed a twin-track approach of implementing both air-quality standards 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, 2001), for which a revision of the legislation has recently been agreed (see the Clean Air Policy Package below). Source-specific legislation focuses on industrial emissions, road and off-road vehicle emissions, fuel-quality standards, etc. ([4]). 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. In addition, several legal instruments are used to reduce environmental impacts from different activities or to promote environmentally friendly behaviour, and these also contribute indirectly to minimising air pollution. Table 1.1 summarises the coverage of the EU directives and international conventions regulating air pollutant emissions (either directly or indirectly by regulating emissions of precursor gases) and ambient concentrations of air pollutants. The list is not exhaustive.

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 by 2030 in such a way that premature deaths are reduced by more than half of the number in 2005 (European Commission, 2013b).

As a result of the Clean Air Policy Package:

- Directive (EU) 2015/2193 on the limitation of emissions of certain pollutants into the air from medium combustion plants (thermal input from 1 to 50 Thermal Megawatt) entered into force in 2015 (EU, 2015). It regulates emissions of SO_2, NO_X and PM with the aim of reducing those emissions and the risks they pose to human health and the environment. It also lays down rules to monitor emissions of carbon monoxide (CO).
- An agreement has recently been reached for a revision of the 2001 NEC Directive (2001/81/EC). The new directive, on the reduction of national emissions of certain atmospheric pollutants, establishes new national emission reduction commitments applicable from 2020 and stricter commitments from 2030 for SO_2, NO_X, non-methane volatile organic compounds (NMVOCs), NH_3 and PM with a diameter of 2.5 μm or less ($PM_{2.5}$). With the new commitments, the health impact of air pollution is estimated to be reduced by about 50 % in 2030 (compared with 2005).

Beyond these measures, successive packages of legislation have also introduced a new Real Driving Emissions (RDE) test procedure for passenger vehicles starting from 1 September 2017. The procedure is designed to help reduce the current discrepancy seen between emissions measured in real driving and those measured in a laboratory (see also Box 6.1). The RDE therefore helps ensure that NO_X emissions, and in a future stage also particle number emissions, measured during laboratory tests, are consistent with those measured in real driving conditions subject to a 'conformity factor'.

A new regulation on non-road mobile machinery (NRMM) emissions has also recently been agreed within the EU. The regulation updates an earlier NRMM directive (97/68/EC; EU, 1997; amended by

([4]) http://ec.europa.eu/environment/air/legis.htm.

Directive 2012/46/EU; EU, 2012) by introducing more stringent pollution limits for CO, hydrocarbons, NO_X and PM, and deadlines for implementing them, starting from 2018. The regulation addresses emissions from a range of engine classes and equipment including inland waterway vessels, lawn mowers and bulldozers.

Table 1.1 Legislation in Europe regulating emissions and ambient concentrations of air pollutants

Policies \ Pollutants		PM	O_3	NO_2 NO_X NH_3	SO_2 SO_X	CO	Heavy metals	BaP PAH	VOCs
Directives regulating ambient air quality	2008/50/EC (EU, 2008)	PM	O_3	NO_2, NO_X	SO_2	CO	Pb		Benzene
	2004/107/EC (EU, 2004)						As, Cd, Hg, Ni	BaP	
Directives regulating emissions of air pollutants	(EU) 2015/2193 (EU, 2015)	PM		NO_X	SO_2				
	2001/81/EC (EU, 2001)	[a]	[b]	NO_X, NH_3	SO_2				NMVOC
	2010/75/EU (EU, 2010a)	PM	[b]	NO_X, NH_3	SO_2	CO	Cd, Tl, Hg, Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V		VOC
	European standards on road vehicle emissions [c]	PM	[b]	NO_X		CO			VOC, NMVOC
	2012/46/EU (EU, 2012)	PM		NO_X		CO			HC
	94/63/EC (EU, 1994)	[a]	[b]						VOC
	2009/126/EC (EU, 2009c)	[a]	[b]						VOC
	1999/13/EC (EU, 1999a)	[a]	[b]						VOC
	91/676/EEC (EU, 1991)			NH_3					
Directives regulating fuel quality	1999/32/EC (EU, 1999b)	[a]			S				
	2003/17/EC (EU, 2003)	[a]	[b]		S		Pb	PAH	Benzene, VOC
International conventions	MARPOL 73/78 (IMO, 1978)	PM	[b]	NO_X	SO_X				VOC
	CLRTAP (UNECE, 1979)	PM [a]	[b]	NO_2, NH_3	SO_2	CO	Cd, Hg, Pb	BaP	NMVOC

Notes: [a] Directives and conventions limiting emissions of PM precursors, such as SO_2, NO_X, NH_3 and VOCs, indirectly aim to reduce PM ambient air concentrations.

[b] Directives and conventions limiting emissions of O_3 precursors, such as NO_X, VOCs and CO, indirectly aim to reduce troposphere O_3 concentrations.

[c] http://ec.europa.eu/environment/air/transport/road.htm.

2 Sources and emissions of air pollutants

Air pollutants may be categorised as either primary (i.e. pollutants directly emitted to the atmosphere) or secondary (i.e. pollutants formed in the atmosphere from the so-called precursor gases). Secondary air pollutants include secondary PM, O_3 and secondary NO_2. Air pollutants can also be classified as natural or anthropogenic as a function of the origin of their emissions or precursors.

2.1 Sources of regulated pollutants

PM is both directly emitted to the atmosphere (primary PM) and formed in the atmosphere (secondary PM). The main precursor gases for secondary PM are SO_2, NO_X, NH_3 and volatile organic compounds (VOCs; a class of chemical compounds whose molecules contain carbon). The gases NH_3, SO_2 and NO_X react in the atmosphere to form ammonium (NH_4^+), sulphate (SO_4^{-2}) and nitrate (NO_3^-) compounds. These compounds form new particles in the air or condense onto pre-existing ones and form so-called secondary inorganic aerosols. Certain VOCs are oxidised to form less volatile compounds, which form secondary organic aerosols.

Primary PM originates from both natural and anthropogenic sources. Natural sources include sea salt, naturally suspended dust, pollen and volcanic ash. Anthropogenic sources, which are predominant in urban areas, include fuel combustion in thermal power generation, waste incineration, domestic heating for households and fuel combustion for vehicles, as well as vehicle (tyre and brake) and road wear and other types of anthropogenic dust.

BC is one of the constituents of fine PM (or $PM_{2.5}$) and has a warming effect. BC is a product of incomplete combustion of fuels, emitted from traffic, industry and the burning of fossil fuels and biomass.

Ground-level (tropospheric) ozone (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. At the continental scale, CH_4 and CO also play a role in O_3 formation. NO_X also play a role removing ozone in the titration reaction with the emitted NO to form NO_2.

The major sources of NO_X are combustion processes (e.g. in fossil- and bio-fuelled vehicles and power plants). Most NO_2 is formed in situ by the oxidation of NO. NO accounts for the majority of NO_X emissions, although part of the NO_X emissions is directly emitted as NO_2. This 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, which leads to higher direct NO_2 emissions.

Benzo[*a*]pyrene (BaP) is emitted from the incomplete combustion of various fuels. The main sources of BaP in Europe 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.

Sulphur dioxide (SO_2) is mainly emitted from the combustion of fuels containing sulphur. The main anthropogenic emissions of SO_2 derive from stationary power generation, industry, and commercial, institutional and household fuel combustion. Volcanoes are the biggest natural source of SO_2.

CO and benzene (C_6H_6) are gases emitted as a result of the incomplete combustion of fossil fuels and biofuels. Road transport was once a major source of CO emissions, but the introduction of catalytic converters reduced these emissions significantly.

C_6H_6 is an additive to petrol, and most of its emissions in Europe come from traffic. These C_6H_6 emissions have declined sharply since the introduction of the Fuel Quality Directive (EU, 2009a). In general, contributions to C_6H_6 emissions made by domestic heating are small (about 5 % of total emissions) but, in areas in which wood burning accounts for more than half of domestic energy needs, it can be a substantial local source of C_6H_6. Other sources include oil refining, as well as the handling, distribution and storage of petrol.

CH_4 is a precursor of tropospheric O_3 and it is a powerful greenhouse gas (GHG). It is emitted mainly

from agriculture (mostly from ruminant animals), which accounts for about half of the total anthropogenic emissions, followed by waste management and energy production. There are also important natural sources of CH_4, which include boreal and tropical wetlands. Further, an unknown large amount of carbon is bounded in the permafrost layer (e.g. in Siberia) and might be released as CH_4 if the permafrost layer melts as a feedback to climate change (Myhre et al., 2015).

Anthropogenic emissions of toxic metals originate mainly from the combustion of fossil fuels, metal production and waste incineration. The main emissions of arsenic (As) come from metal smelters and the combustion of fuels. Cadmium (Cd) is emitted from non-ferrous metal production, stationary fossil-fuel combustion, waste incineration, iron and steel production and cement production. Nickel (Ni) is emitted from the combustion of fuel oil (e.g. from heating, shipping or power generation), Ni mining and primary production, the incineration of waste and sewage sludge, steel manufacture, electroplating and coal combustion. Lead (Pb) is emitted from fossil-fuel combustion, waste incineration and the production of non-ferrous metals, iron, steel and cement. The largest anthropogenic source of mercury (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, as well as gold production.

2.2 Total emissions of air pollutants

All the primary and precursor emissions contributing to ambient air concentrations of PM, O_3 and NO_2 have decreased ([5]) over the period 2000–2014 as a whole in the EU-28 (Figure 2.1a ([6])). The same is true for the EEA-33 countries, except for NH_3. The smallest reduction in the EU-28 was for NH_3 (8 %) and the largest was for SO_X (69 %). The exceptional increase (by 5 %) in the total emissions of NH_3 in the EEA-33 countries in the same period is due to a doubling between 2012 and 2013 in the NH_3 emissions reported by Turkey, which was kept in 2014 at the same level as in 2013.

Regarding the remaining pollutants (toxic metals and BaP), parties under the Convention on Long-range Transboundary Air Pollution (CLRTAP) are invited to report emissions data for polycyclic aromatic hydrocarbons (PAHs) (including BaP); this means that reporting of these pollutants is not mandatory, as it is for the rest, but voluntary. Emissions of BaP in the EU-28 increased by 1 % between 2000 and 2014 (Figure 2.1b), whereas in the EEA-33 countries' emissions in 2014 were at the same level as in 2000. The fact that Austria, Belgium, Greece and Italy did not report their emissions ([7]) for any of the years leaves a gap in the assessment of both the status and the development of BaP emissions. The reporting Member States that contribute the most to BaP emissions in the EU are Poland, Germany and Romania. Both Poland and Romania have had considerable increases in their emissions in the period 2000–2014.

Figure 2.1b shows a decrease in the emissions of As, Cd, Ni, Pb and Hg reported by the EU Member States between 2000 and 2014. The greatest reductions in both EU-28 and EEA-33 countries were in Pb emissions (61 %) and Ni emissions (60 %) and the smallest was in emissions of As (13 % in the EU-28, 14 % in the EEA-33).

C_6H_6 is not included as an individual pollutant in European emissions inventories covering VOCs, meaning that its emissions are not recorded. In any case, as mentioned above, C_6H_6 emissions have dropped since the introduction of the revised Fuel Quality Directive (EU, 2009a).

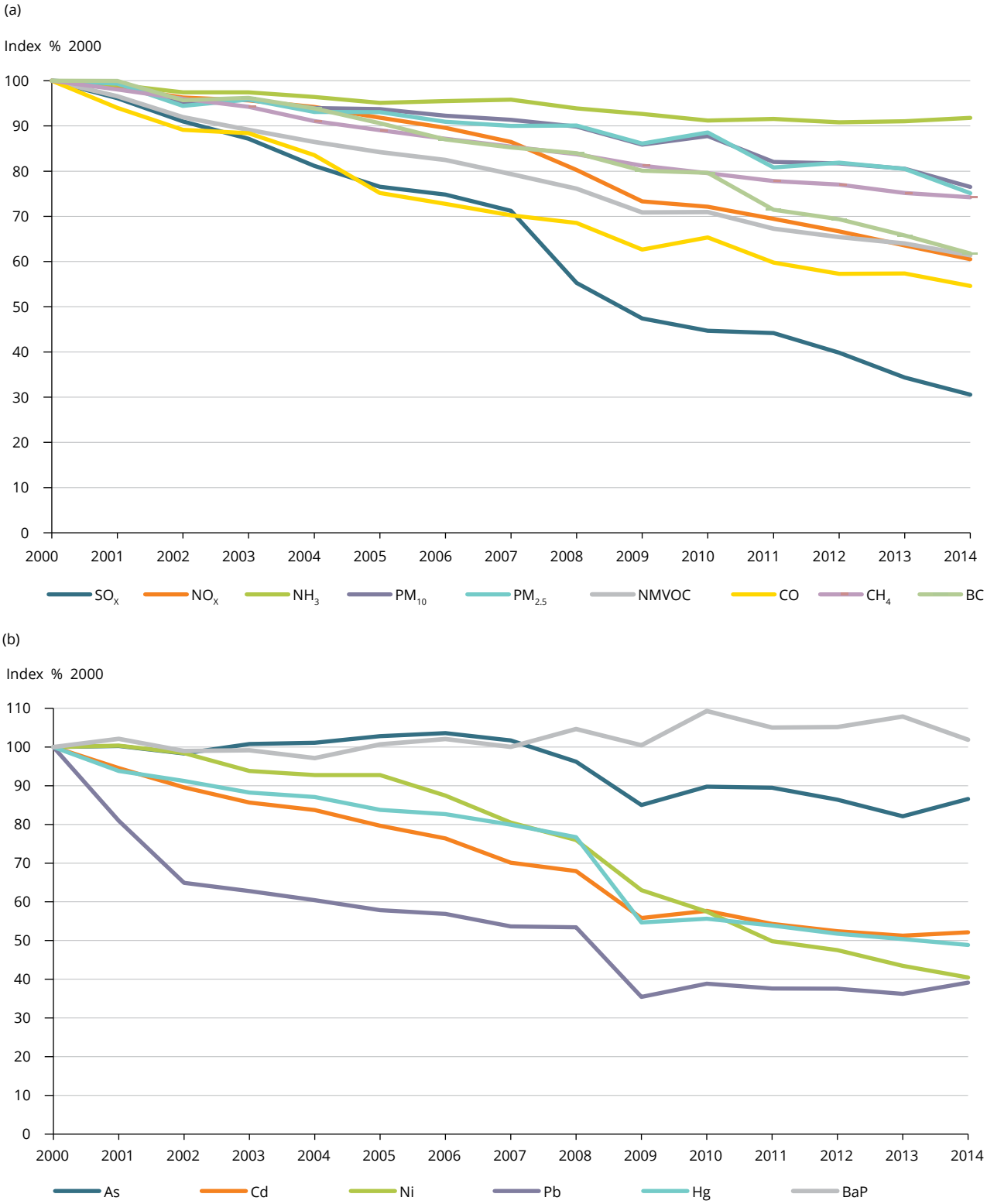
2.3 Sectoral emissions of air pollutants

The main source sectors contributing to emissions of air pollutants in Europe are transport, the commercial, institutional and households sector, industry, energy, agriculture and waste. Figure 2.2 shows the development of the emissions of primary PM_{10} (i.e. PM with a diameter of 10 µm or less), primary $PM_{2.5}$, NO_X, SO_X, NH_3, NMVOCs, CO, BC and CH_4 from these sectors between 2000 and 2014. Similarly, Figure 2.3 shows the development in emissions of BaP and the toxic metals As, Cd, Ni, Pb and Hg.

The **transport** sector has considerably reduced its emissions of air pollutants in Europe since 2000, as Figures 2.2 and 2.3 show, with the exception of BaP and Cd emissions. BaP emissions increased by 52 % in both the EU-28 and the EEA-33 between 2000 and 2014; and Cd emissions increased by 6 % in both the EU-28 and the EEA-33. The highest emission reductions from transport between 2000 and 2014 were registered for Pb (86 % in the EU-28 and 85 % in the EEA-33), SO_X

([5]) The analysis of the development of emissions in Europe is based on emissions reported by the countries (EEA, 2016c). The nominal increase or decrease in reported emissions is analysed, not statistical trends.
([6]) Reporting on BC emissions is voluntary (EEA, 2016c).
([7]) Finland only reported BaP emissions for 2014, but did not report emissions from the commercial, institutional and household fuel combustion sector.

Figure 2.1 **Development in EU-28 emissions, 2000–2014 (% 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 VOC 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, 2016c, g.

(80 % in the EU-28 and 82 % in the EEA-33) and for NMVOCs (75 % in the EU-28 and 71 % in the EEA-33). The reductions in emissions of As and Hg were the least pronounced (As 5 % and Hg 15 % in the EU-28).

The transport sector is the largest contributor to NO_X emissions, accounting for 46 % of total EU-28 emissions (and 47 % of EEA-33 emissions) in 2014. NO_X emissions from road transport have not been reduced as much as expected with the introduction of the vehicle emissions standards (European standards), since emissions in real-life driving conditions are often higher, especially for diesel vehicles, than those measured during the approval test (see Box 6.1). Transport also remains a very important source of greenhouse gases within the EU; between 1990 and 2014, greenhouse gases from transport increased by 13 % in the EU-28 plus Iceland (EEA, 2016g).

Transport also contributed to 13 % and 15 % of total PM_{10} and $PM_{2.5}$ primary emissions, respectively, in the EU-28 in 2014. Non-exhaust emissions from road traffic (which are not included in Figure 2.2) contribute to the total road-traffic emission contribution. Non-exhaust emissions are estimated to equal about 50 % of the exhaust emissions of primary PM_{10}, and about 22 % of the exhaust emissions of primary $PM_{2.5}$ (ETC/ACC, 2010a). It has been shown that, even with zero tail-pipe emissions, traffic will continue to contribute to PM emissions through non-exhaust emissions (Dahl et al., 2006; Kumar et al., 2013). It has been estimated that nearly 90 % of total PM emissions from road traffic will come from non-exhaust sources by the end of the decade (Rexeis and Hausberger, 2009). In addition, emissions from international shipping within European seas may contribute an additional 15 % of the total $PM_{2.5}$ emissions and as much as an additional 50 % of total NO_X and 75 % of total SO_X emissions in the EU-28 (estimated for 2010) (EEA, 2013b).

The **commercial, institutional and households** fuel combustion sector dominates the emissions of primary $PM_{2.5}$ and PM_{10}, BC, BaP and CO, contributing 40 % and 56 % of the total primary PM_{10} and $PM_{2.5}$ emissions, respectively, and 46 %, 71 % and 45 % of the total BC, BaP, and CO emissions, respectively, in the EU-28 in 2014. Reported BaP emissions increased by 3 % from 2000 to 2014 in the EU-28, and by 2 % in the EEA-33. In addition, this sector increased its emissions of NH_3, Pb, Cd, Hg and As, in both the EU-28 and the EEA-33.

The use of wood and other biomass combustion for household heating is growing in some countries, owing to government incentives/subsidies, rising costs of other energy sources, and an increased public perception that it is a 'green' option. More information on this topic is given in Chapter 3.

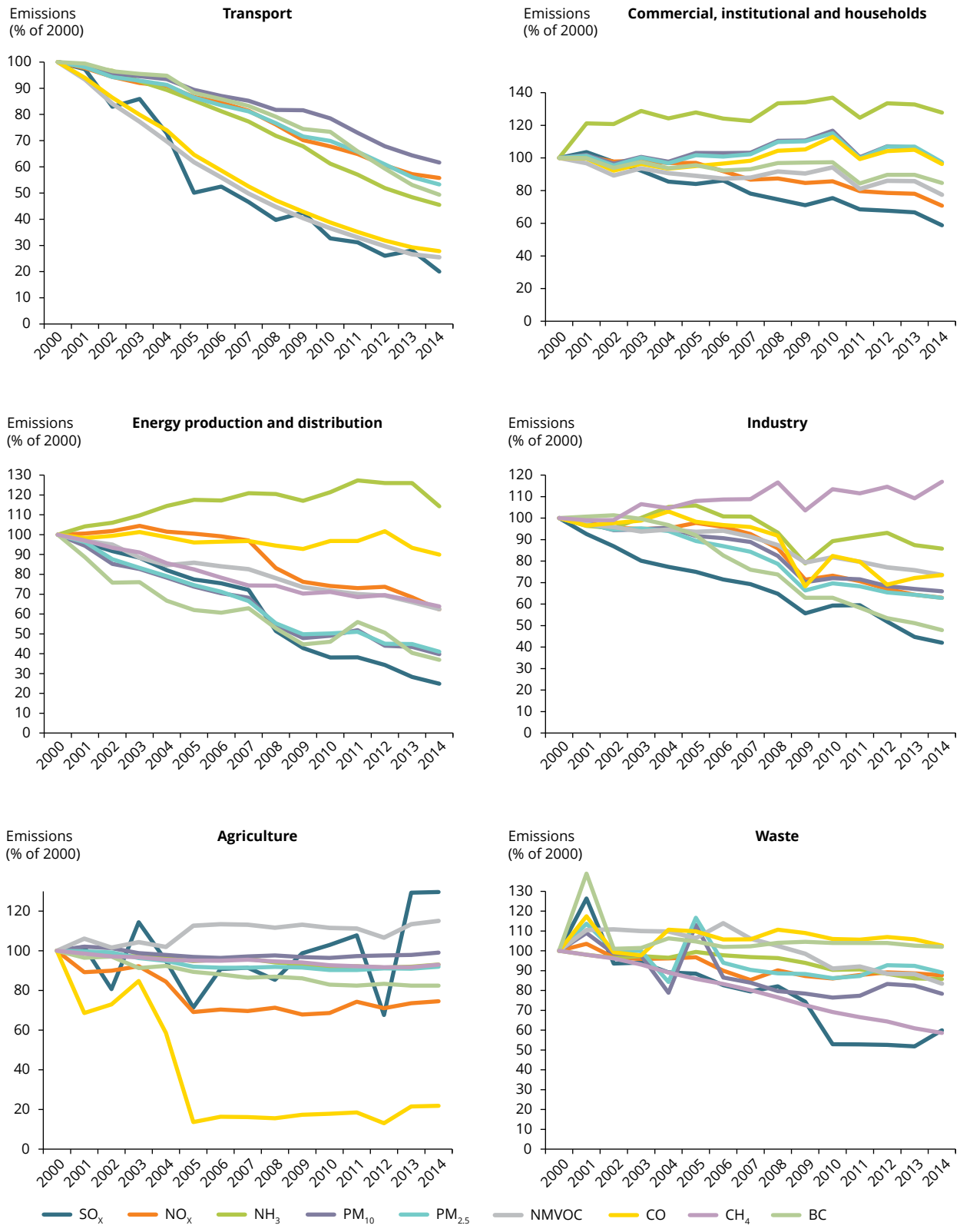
Industry considerably reduced its air pollutant emissions between 2000 and 2014, with the exception of CH_4 and BaP emissions, which increased by 17 % and by 31 %, respectively. It is still the largest source sector of Pb, As, Cd, NMVOC and Hg emissions. In the EU-28 and the EEA-33, industry contributed 51 % and 50 % of NMVOCs, respectively, 43 % and 43 % of Hg, 58 % and 57 % of Cd, 63 % and 63 % of Pb and 61 % and 61 % of As emissions, in 2014. The industry and energy sectors have equivalent contributions of Ni emissions, at 36 % for the EU-28 and the EEA-33 in 2014. The industrial sector is also the second largest source of primary PM and SO_X emissions, contributing 22 % of PM_{10}, 24 % of SO_X and 17 % of $PM_{2.5}$ emissions in the EU-28 in 2014. Although industrial CH_4 emissions have increased by 17 % over the last 15 years, they represented only 0.5 % of total EU-28 emissions of CH_4 in 2014. The emissions of BaP varied considerably in the period but increased by 31 % from 2000 to 2014 in the EU-28.

Like industry, **energy production and distribution** has made considerable reductions in its emissions. It is, however, still the biggest emitter of SO_X (and Ni, see above), contributing 58 % and 61 % of total SO_X emissions in the EU-28 and EEA-33 in 2014, respectively. The energy sector is the second most significant emitter of Hg, As, and NO_X, contributing 40 %, 21 %, and 20 %, respectively, of total emissions in the EU-28 in 2014. From 2000 to 2014, the energy sector cut its emissions of all pollutants, with the only exception being NH_3, to whose emissions it contributes less than 0.5 %.

Agriculture is the main emitter sector in which emissions of air pollutants have decreased least. The agricultural sector is by far the greatest emitter of NH_3 and of CH_4 and was responsible for 94 % and 52 % of total NH_3 and CH_4 emissions in the EU-28 in 2014, respectively. Its NH_3 and CH_4 emissions decreased by only 7 % from 2000 to 2014. Agriculture increased its NMVOC emissions by 15 between 2000 and 2014, contributing to 11 % of total NMVOC emissions in the EU-28 in 2014. Agriculture is the third most important source of PM_{10} primary emissions in the EU-28, after the commercial, institutional and household fuel combustion and industry sectors. Its contribution to total PM_{10} emissions in the EU-28 was 17 % in 2014.

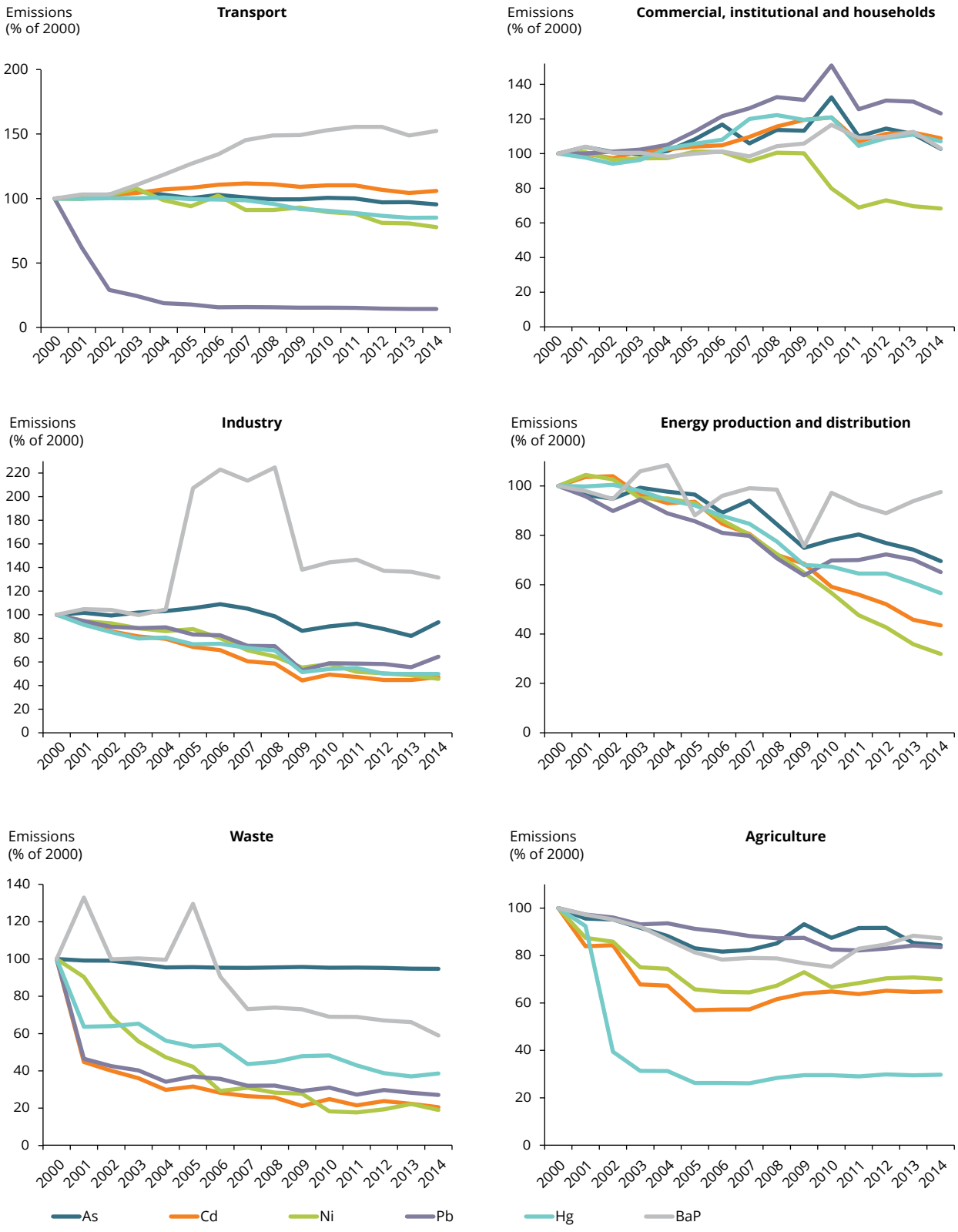
The contribution of the **waste sector** to the total emissions of air pollutants is relatively small, with the exception of CH_4. Waste management is the second highest emitter of CH_4, after agriculture, accounting for 29 % of total CH_4 emissions in the EU-28 in 2014. It cut its CH_4 emissions by 41 % between 2000 and 2014.

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, BC and CH_4, 2000–2014 (% of 2000 levels)**



Source: EEA, 2016c, g.

Figure 2.3 **Development in EU-28 emissions from main source sectors of As, Cd, Ni, Pb, Hg and BaP, 2000–2014 (% of 2000 levels)**



Source: EEA, 2016c.

2.4 Uncertainties in reported emissions

The EEA was not able to quantify the uncertainty of the reported emission data for the whole EU-28, as only 15 countries reported the uncertainty in their emission estimates. The general assessment of completeness shows that, in 2014, Member States reported 33 % of the data incompletely.

Uncertainties in reported BC, metals and BaP emissions are high, as several Member States did not provide data for BC and BaP emissions, and some of these gaps could not be filled with data. The EU-28 total emissions of BC and BaP are therefore underestimated. In certain categories, several countries reported BC values higher than the respective $PM_{2.5}$ values. Since BC is only a part of $PM_{2.5}$, BC emissions cannot be higher than $PM_{2.5}$ emissions, indicating a mistake in reported emissions (EEA, 2016c). Furthermore, there are considerable uncertainties in the estimation of emissions from domestic combustion, which are briefly presented in Section 3.2 and further discussed by the European Topic Centre on Air Pollution and Climate Change Mitigation (ETC/ACM, 2016a).

Photo: © Stefanos Dodouras, My City/EEA

3 Residential biomass combustion: an important source of air pollution

The development of a resilient Energy Union with a forward-looking climate policy is one of the strategic objectives of the EU (European Commission, 2015). To encourage the transition to a more secure, affordable and decarbonised energy system, the EU adopted climate and energy targets for 2020 and 2030 together with a long-term goal of reducing EU-wide greenhouse gas emissions by 80–95 % below 1990 levels by 2050. Meeting these objectives will require switching to low-carbon energy sources and moderating our energy demand through energy- and resource-efficiency improvements and through lifestyle changes. Renewable energy sources are already a major contributor to this energy transition. Compared with fossil fuel alternatives they have a high greenhouse gas mitigation potential (EEA, 2016h).

Biomass covers more of the EU's energy requirements than any other renewable energy resource, and a sizable proportion is directly used by households for heating (EEA, 2016h). Many European citizens perceive biomass as an environmentally friendly fuel option. Further, the recent economic recession also contributed to an increased use of biomass as a residential fuel in some European regions (Paraskevopoulou et al., 2015; Saffari et al., 2013).

Biomass is a renewable source of energy with potential advantages from a climate perspective if it is grown, harvested and used in a sustainable manner ([8]). However, climate-oriented policies may not always work in line with air-quality-oriented policies, and vice versa. The use of biomass (and other fuels, e.g. coal, gas) as residential fuel (see Box 3.1) generates emissions of air pollutants that can contribute considerably to adverse effects on human health. The main harmful pollutants emitted during combustion of wood and coal in residential stoves are fine particulate matter ($PM_{2.5}$), BC and, partly attached to particles, PAHs, especially BaP. PM may be emitted directly from stoves (primary PM) or be formed in the exhaust air and atmosphere after emission (secondary PM). In the atmosphere, PM can even undergo transformations resulting in pollutants with a higher toxicity (Nussbaumer et al., 2008). BC is a component of $PM_{2.5}$ that is also a greenhouse gas.

BaP is a well-known human carcinogen, and the health effects of airborne $PM_{2.5}$ and BC are described in detail by the World Health Organization (WHO, 2014a, 2014c, 2015). Epidemiological studies have shown that pollutants originating from wood and coal combustion significantly increase the risk of respiratory

Box 3.1 Definition of biomass used for heating in residential homes

The guidelines of the Intergovernmental Panel on Climate Change (IPCC, 2006, Table 1.1) provide detailed formal fuel definitions that are commonly used internationally. According to these guidelines, definitions for the residential sector distinguish between (1) *solid fuels*, including mainly coal and coal briquettes, (2) *gaseous fuels*, referring to natural gas, (3) *biomass*, including wood and wood waste, charcoal and other primary solid biomass and (4) *liquid fuels*, mainly petrol or diesel oil.

In this chapter the focus is on biomass used in residential stoves in Europe, i.e. wood or wood waste (woodchips, pellets, etc.) as defined above. Besides wood and wood waste, other types of biomass such as waste from agricultural harvesting or garden pruning waste might also be used for heating private homes. It is in general difficult to quantify the amount of biomass burnt in residential stoves.

([8]) The European Commission report *State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU* (European Commission, 2014) describes the risks to the sustainability of biomass production and use. These risks include unsustainable feedstock production; emissions from land use, land-use change and forestry (LULUCF); performance in terms of life-cycle greenhouse gas emissions; indirect impacts; inefficient bioenergy generation; and air emissions.

disease, chronic obstructive pulmonary disease and cardiovascular disease (Lighty et al., 2000). In Europe, 61 000 premature deaths in 2010 were attributable to outdoor $PM_{2.5}$ pollution originating from residential heating using wood and coal (WHO, 2015).

Emissions from combustion in domestic stoves are usually released by chimneys at relatively low height, i.e. they contribute to local air pollution in residential areas where often many people are exposed. Furthermore these emissions frequently occur in areas where air circulation is limited (e.g. in valleys) and during periods of higher atmospheric stability and thus poor dispersion, i.e. during cold periods or at night. In addition, emissions are highest during the heating period in winter (and winters are longer and colder in northern parts of Europe than in the south).

3.1 Changes in residential fuel consumption

Fuel consumption habits across European regions in private homes can be assessed based on residential fuel use data. The types of fuels that people use to heat their homes have changed over past decades due to economic and social aspects, as well as in response to national or EU policies such as banning or incentivising specific fuel types. Further, exceptionally mild winters, for example in 2013/2014, can result in a decrease in fuel consumption for heating across Europe (EurObserv'ER, 2015).

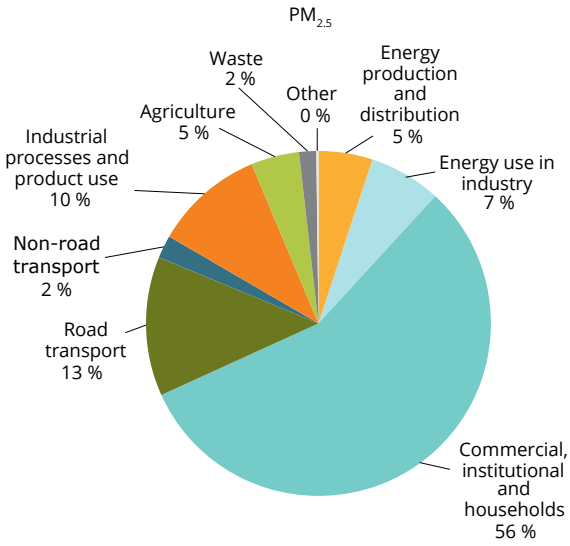
Solid fuel (i.e. coal) consumption for domestic heating followed a clear decline across the EU-28 between 1990 and 2002, before stabilising thereafter. In some countries, the decrease has mainly been due to national policies targeting the use of coal in residences (e.g. the coal ban in Irish cities gradually implemented since 1990; Clancy et al., 2002). However, biomass consumption in private homes rose across the EU-28 in most countries (e.g. in Austria, Bulgaria, Denmark and Norway). In countries such as Croatia, Greece, Hungary and Spain a change in consumption habits led to a decreasing use of biomass since 1990 but increased consumption after 2005. This could be due to the economic recession, to investments in renewable sources prior to the recession based on the environmentally friendly perception of biomass and/or the implementation of local policies such as incentivising the installation of biomass stoves in newly built or refurbished homes. Gaseous fuel consumption remained at similar levels in the EU-28 between 1990 and 2012. Consumption of liquid fuels has decreased since 2000 as households have moved away from oil-burning boilers to electricity, gas, etc.

3.2 Air pollutant emissions from residential combustion

In European emission inventories, combustion of fuels within the residential sector is covered by the so-called 'commercial, institutional and household' sector (see also Chapter 2). In the EU-28, the fuel combustion in this sector is the major source of primary $PM_{2.5}$ and PM_{10}, as well as BC and BaP emissions, contributing 56 %, 40 %, 46 % and 71 % to emissions, respectively (see for example Figure 3.1). PM emissions in this sector have dropped slightly over the last few years (EEA, 2016c), while reported BaP emissions increased by 3 % between 2000 and 2014.

The emission inventories from small combustion installations still suffer from uncertainties, especially for primary $PM_{2.5}$, BaP and BC. These uncertainties result due to the wide variation in emissions per unit fuel that can occur, as well as the statistical information on activity data, i.e. the estimated amount of fuel that people actually burn in residential stoves. Emissions from household stoves are for example very dependent on the stove technology and how well the stove is maintained, the type of wood burned, whether wood is dry or wet, the way in which consumers load the stove etc. In addition, there are major differences between the PM emission inventories reported by different countries with regard to the inclusion or not of the so-called condensable PM fraction. Present international reporting guidance allows reporting of either the smaller primary filterable fraction of PM, or the filterable and condensable (secondary) PM (see Box 3.2).

Figure 3.1 **$PM_{2.5}$ emissions in the EU-28: share by sector group in 2014**



Source: EEA, 2016c.

Box 3.2 Improvements of PM emission inventories in residential combustion

Primary PM consists of soot, organic particles and ash. Soot is mainly composed of elemental carbon (EC; also referred to as BC) and of carbon-based organic matter (OM). Certain (high molecular-weight) PAH compounds are strongly associated with $PM_{2.5}$ (for details see for example ETC/ACM 2012b).

As presented by ETC/ACM (2016a), various studies addressing the dilution of emissions from residential wood combustion show that the semi-volatile organic fraction is dominant. This fraction is formed almost instantaneously by dilution and cooling of the flue gas or exhaust, and more than half of the OM emitted during residential wood combustion evaporates at a temperature of 50 °C. The condensable organic fraction is difficult to measure. It can be largely reduced by an improvement of the combustion conditions.

Another recent study discusses the estimates of PM emissions from wood burning across Europe. A new high-resolution (7 × 7 km) anthropogenic PM emission inventory for Europe was developed. The inventory indicates that about half of the total $PM_{2.5}$ emissions in Europe is carbonaceous PM and that residential wood combustion is the largest organic PM source. The new emission inventory serves as input to European chemical transport models, and substantially improves the agreement between measured and predicted organic PM. This implies that primary organic PM emission inventories need to be revised to include the semi-volatile organic PM fraction. The above-mentioned study concluded that the revised residential wood combustion emissions were higher than those in previous inventories by a factor of two to three if the condensable PM fraction is taken into account.

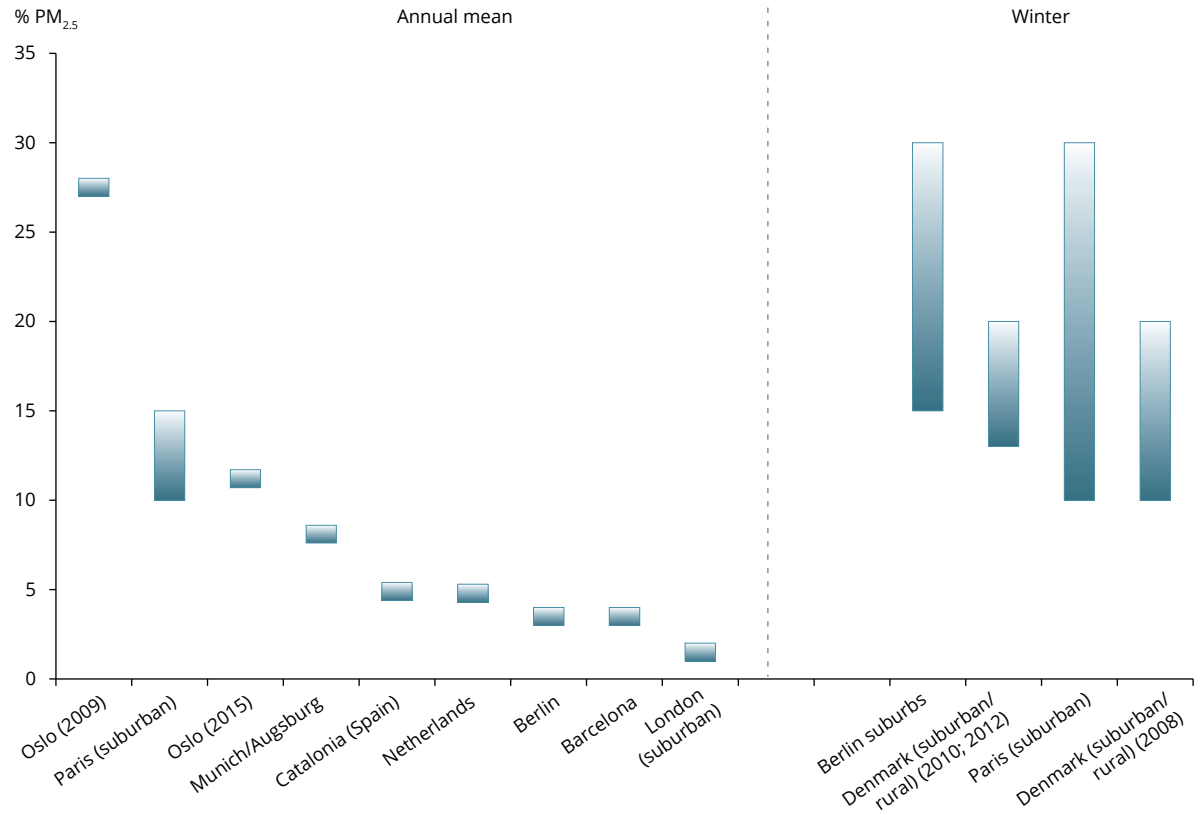
3.3 Impact on air quality

A recent study has shown the correlation between PM (and BaP) emissions and changes in biomass consumption in some countries (ETC/ACM, 2016a). However, a direct relationship between emissions and PM (and BaP) concentrations in the air could not be established with the available data reported to the European air-quality database (EEA, 2016a), by EU Member States and EEA member countries.

Results reported in the scientific literature clearly show that residential combustion of wood has an impact on local- and regional-scale air quality (quantified for PM_{10}, $PM_{2.5}$, OC and EC/BC) (ETC/ACM, 2016a). Contributions from residential wood combustion to PM_{10} and $PM_{2.5}$ concentrations during the winter (heating) period range from < 5 % to 40 % of daily means (see for example Figure 3.2). The highest winter contributions are reported for the Alpine valleys, the Po Valley, Oslo, Zurich and rural areas in Austria and Germany. As expected, the lowest contributions are reported for southern European regions (e.g. Barcelona). Several studies carried out in urban areas (e.g. Vienna, Berlin, Zurich) conclude that the PM_{10} or $PM_{2.5}$ from residential combustion originates mainly from regional-scale transport, and that only a minor proportion is emitted locally.

The data available for OC or EC/BC are scarcer than for PM, but still representative for their respective study areas. In regions such as Lombardy (Italy) or Zürich (Switzerland), wood combustion contributes around 25–35 % to ambient EC mass concentrations. Particularly in central Europe, wood combustion contributes up to 50 % of OC mass concentration during the winter heating period (Austria, Po Valley) (ETC/ACM, 2016a, and references therein).

Figure 3.2 **Studies quantifying the impact of residential combustion on $PM_{2.5}$**



Source: ETC/ACM, 2016a.

3.4 Mitigating emissions from residential wood combustion

There are four main reasons for the relatively high air pollutant emissions from residential wood combustion:

1. the use of non-regulated stoves;
2. combustion under non-optimal conditions (e.g. bad burning/loading practices);
3. the inadequate maintenance of old or new stoves installed in homes;
4. the use of non-standardised biomass (including treated, painted or insufficiently dried wood, or even agricultural waste), which generates persistent organic pollutant and metal emissions, as well as hindering efficient combustion (AIRUSE, 2015; Viana et al., 2013; Kubica et al., 2007).

If old biomass-burning residential stoves are replaced with modern, more efficient ones (particularly pellet stoves; EEA, 2013c; Nussbaumer, 2010), the emission of air pollutants is considerably reduced. These modern stoves, currently available on the European market, meet criteria set by eco-labelling initiatives (see for example Nordic Ecolabel, 2014). Unfortunately, the replacement of stoves is often slow, as they have a long lifetime. With regard to the fuels, it is important that untreated and dry biomass be used, preferably harvested close to the place of consumption to help reduce associated life-cycle emissions (AIRUSE, 2015; Viana et al., 2013). Proper and frequent stove maintenance is also key to ensure proper fuel combustion and minimal emissions of air pollutants. Examples of other types of mitigation measures are presented in Box 3.3.

Box 3.3 Mitigation of air pollutant emissions from biomass burning

At EU level

The *Ecodesign Directive* (EU, 2009b) provides EU-wide rules for improving the environmental performance of energy-related products through eco-design. It refers to energy-using products, that is, products that use, generate, transfer or measure energy (e.g. boilers), as well as to other energy-related products that do not use energy but have an impact on energy. The directive's aim is a transition towards better (more efficient, lower-emission) stoves and boilers over the next decade.

The *Energy Performance of Buildings Directive* (EU, 2010b), although not targeting biomass burning specifically, promotes the improvement of the energy performance of buildings within the EU, to reduce energy consumption for heating.

At national level

National regulations for small combustion installations vary widely in terms of which emissions are regulated and how strictly, or to which product types regulations apply. Almost all of them include only type-testing requirements for new products to be put on the market, but no requirements for existing installations. So far, Germany is the only country in Europe with a regulation that explicitly controls the emissions from existing small combustion installations.

Some countries have set up *labelling schemes* to promote small biomass solid-fuel combustion technology development through voluntary labelling, mostly with a focus on thermal efficiency. Existing labels include the 'Umweltzeichen 37' (Austria) for wood/pellet-fired heaters, 'Flamme Verte' (France), the 'Blue Angel' (Germany) for pellet stoves and pellet boilers, 'DINplus' marking for room heaters and inserts (Germany), the 'sign for ecological safety' for boilers (Poland) and 'P-marking' (Sweden). Transnational labelling schemes include the 'Nordic Swan' for slow heat release, stove and insert appliances (Sweden, Denmark, Finland, Norway) and the label of the European Fireplace Association (EFA), which may be applied to solid fuel heaters all over Europe.

At local level

Local-scale strategies focus mainly on providing *guidance* on the best usage and maintenance of stoves. *Recommendations and incentives* to promote the replacement of old stoves and the use of recommended fuels are provided by, for example, the UK's Department for Environment, Food & Rural Affairs (DEFRA, United Kingdom) or the Madrid (Spain) regional government, and several Norwegian municipalities (ETC/ACM, 2016a).

Bans or restrictions on solid fuel combustion in households in certain areas or periods of time (e.g. during strong air stagnation events) are also implemented in a number of cities (e.g. London, in the United Kingdom; Malmø, in Sweden).

3.5 Summary

The benefits of sustainably-grown biomass combustion are clear from a climate perspective. However, biomass combustion can also lead to higher emissions of certain harmful air pollutants, including PM and BaP. Ensuring strong policy coherence between air and climate policies on the international, national and local scales is therefore important in order that unintended trade-offs are avoided, such as a worsening of air quality as a result of climate policy implementation. Policies concerning domestic fuel use also need to take into account other dimensions, such as social equity, where, for many people using biomass-based heating, alternatives such as electricity or gas, may be unaffordable.

Recent EU legislation, such as changes under the Ecodesign Directive, will play an important role in the development of more efficient and lower emitting domestic stoves and boilers over the next 10 years. Incentive schemes that encourage the replacement of old equipment with newer, more efficient models are encouraged. On the fuel side, the promotion of, for example, wood pellet certification is also a step forward to ensure biomass is sustainably produced and to prevent the combustion of, for example, chemically treated recycled wood. Finally, non-technical measures, such as providing consumers with clear guidance on proper maintenance and burning techniques, can also be affordable actions that may be considered by local and national authorities in order to improve air quality from residential combustion.

4 Particulate matter

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

The Ambient Air Quality Directive (EU, 2008) sets limit values for both short-term (24-hour) and long-term (annual) PM_{10} concentrations, whereas values for long-term $PM_{2.5}$ concentrations only have been set (Table 4.1). The short-term limit value for PM_{10} (i.e. not more than 35 days per year with a daily average concentration exceeding 50 µg/m³) is the limit value that is most often exceeded in Europe. It corresponds to the 90.4 percentile of daily PM_{10} concentrations in one year. The annual PM_{10} limit value is set at 40 µg/m³. The deadline for Member States to meet the PM_{10} limit values was 1 January 2005. The deadline for meeting the target value for $PM_{2.5}$ (25 µg/m³) was 1 January 2010, and the deadline for meeting the limit value (25 µg/m³) and the exposure concentration obligation for $PM_{2.5}$ (20 µg/m³) was 2015.

The Air Quality Guidelines (AQGs) set by the WHO are stricter than the EU air-quality standards for PM (Table 4.1). The recommended AQGs should be considered an acceptable and achievable objective to minimise health effects. Their aim is to achieve the lowest concentrations possible, as no threshold for PM has been identified below which no damage to health is observed (WHO, 2014b).

4.2 Status and trends in concentrations

4.2.1 Concentrations in relation to limit and target values

PM_{10} concentrations continued to be above the EU limit value in large parts of Europe in 2014 according to the data of the European air-quality database (Air Quality e-Reporting Database, EEA, 2016a). Map 4.1 shows concentrations of PM_{10} in relation to the daily limit

Table 4.1 Air quality limit and target values, and other environmental objectives, for PM_{10} and $PM_{2.5}$ as given in the EU Ambient Air Quality Directive and WHO AQGs

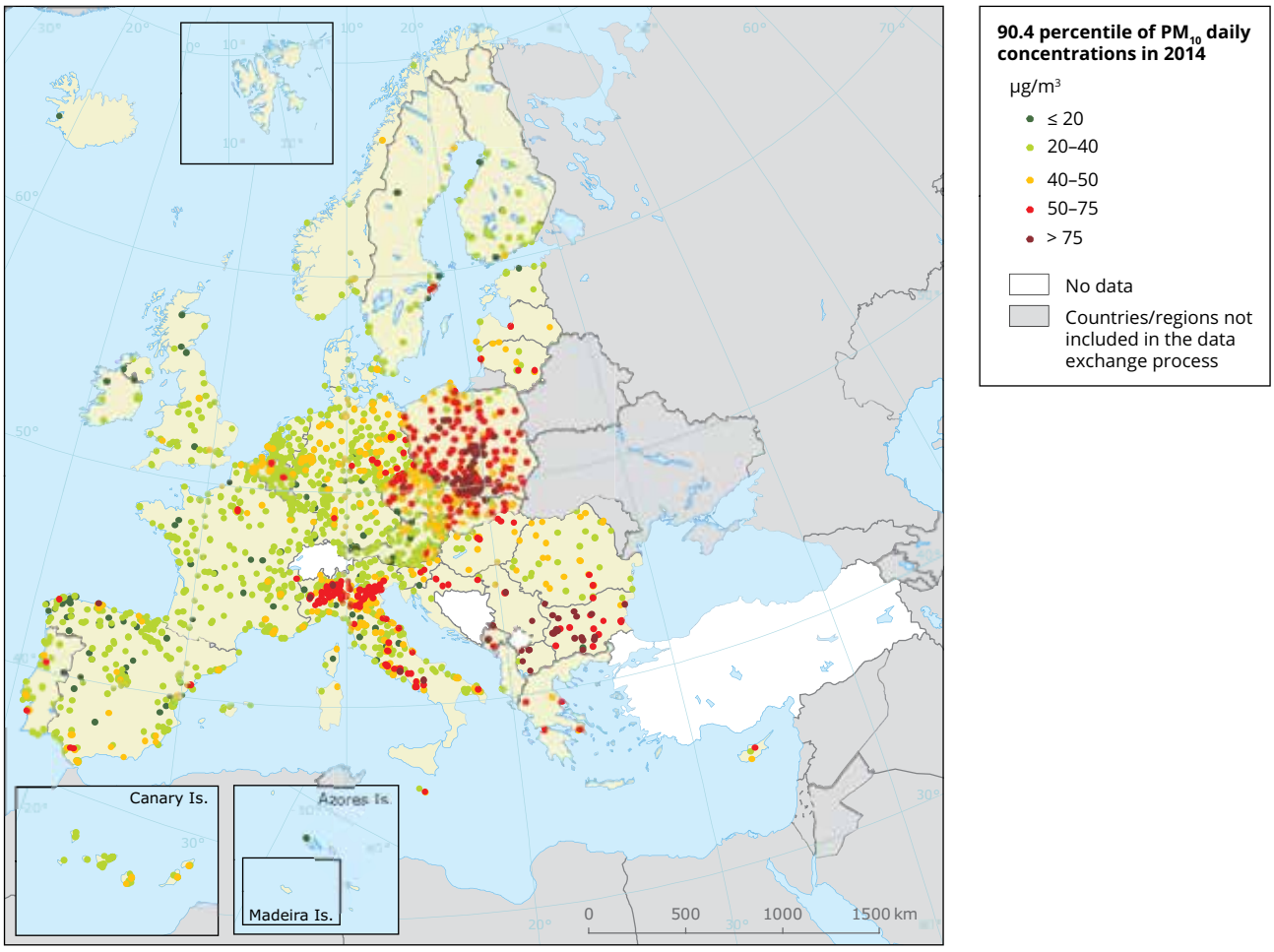
Size fraction	Averaging period	EU Air Quality Directive		WHO guidelines (µg/m³)
		Objective and legal nature and concentration	Comments	
PM_{10}	1 day	Limit value: 50 µg/m³	Not to be exceeded on more than 35 days per year	50 (a)
PM_{10}	Calendar year	Limit value: 40 µg/m³		20
$PM_{2.5}$	1 day			25 (a)
$PM_{2.5}$	Calendar year	Target value: 25 µg/m³		10
$PM_{2.5}$	Calendar year	Limit value: 25 µg/m³	To be met by 1 January 2015 (until then, margin of tolerance)	
$PM_{2.5}$		Exposure concentration obligation (b), 20 µg/m³	To be met by 2015	
$PM_{2.5}$		Exposure reduction target (b), 0–20 % reduction in exposure (depending on the average exposure indicator in the reference year) to be met by 2020		

Note: (a) 99th percentile (3 days/year).

(b) Based on a 3-year average.

Sources: EU, 2008; WHO, 2006.

Map 4.1 Concentrations of PM_{10} in 2014



Note: Observed concentrations of PM_{10} in 2014. 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.

Source: EEA, 2016a.

value. There were stations with concentrations above this daily limit value for PM_{10} in 21 Member States ([9]) (see Figure 4.1). Some 94 % of the cases were observed in urban or suburban areas.

Concentrations above the PM_{10} annual limit value were monitored in 2014 in 4 % of all the reporting stations ([10]). Of these stations, 93 % were in urban areas.

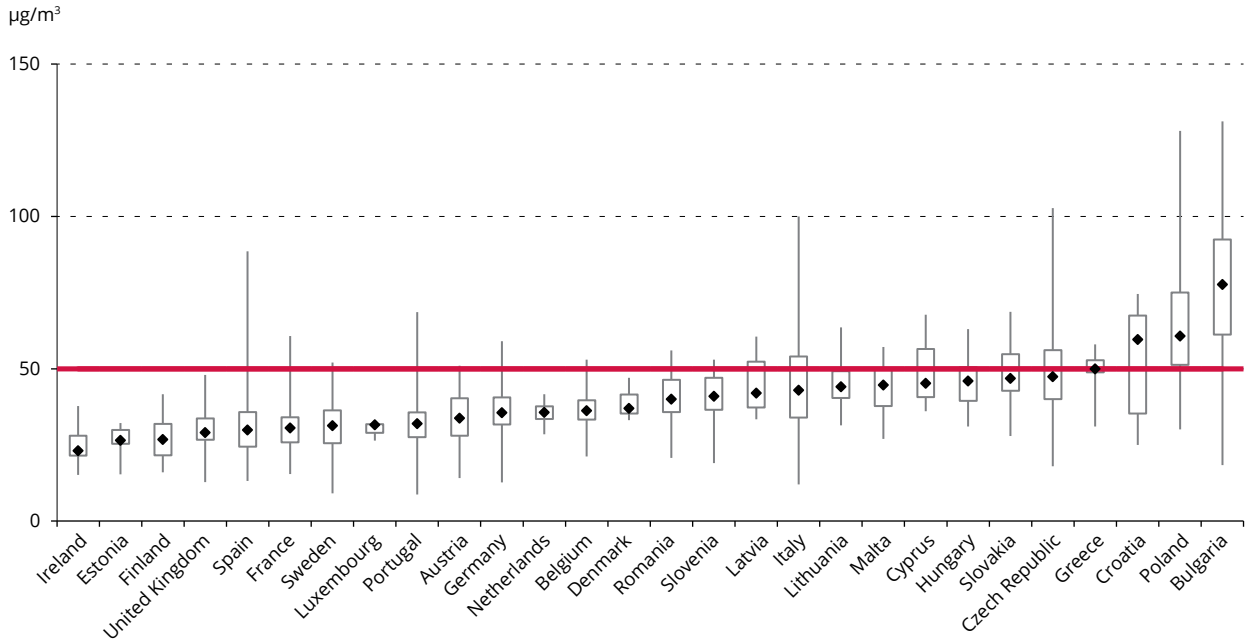
In 2014, the $PM_{2.5}$ concentrations were higher than the target value (annual mean, which has been the limit value for $PM_{2.5}$ from 2015 on) in four Member States ([11]) (see Figure 4.2 and the red and dark red dots

([9]) PM_{10} concentrations above the daily limit value were widely distributed in Bulgaria, the Czech Republic, Italy, Poland, Slovakia and the western Balkan cooperating countries (except Albania). In addition, they were found in several stations in Belgium, Croatia, France, Germany, Greece, Hungary, Latvia, Lithuania, Portugal, Romania, Slovenia, Spain and Sweden; and one station each in Austria, Cyprus and Malta. Only the Member States Denmark, Estonia, Finland, Ireland, Luxembourg, the Netherlands and the United Kingdom, together with Albania, Iceland and Norway, did not record values above this limit value in 2014.

([10]) These stations were located mainly in Bulgaria and Poland. There were several stations with concentrations above the PM_{10} annual limit value in the former Yugoslav Republic of Macedonia and the Czech Republic, three in Italy, two in Montenegro and one each in Cyprus, France, Serbia, Slovakia and Spain.

([11]) These concentrations were observed at several stations in Bulgaria, the Czech Republic, Italy and Poland, as well as one station in the former Yugoslav Republic of Macedonia.

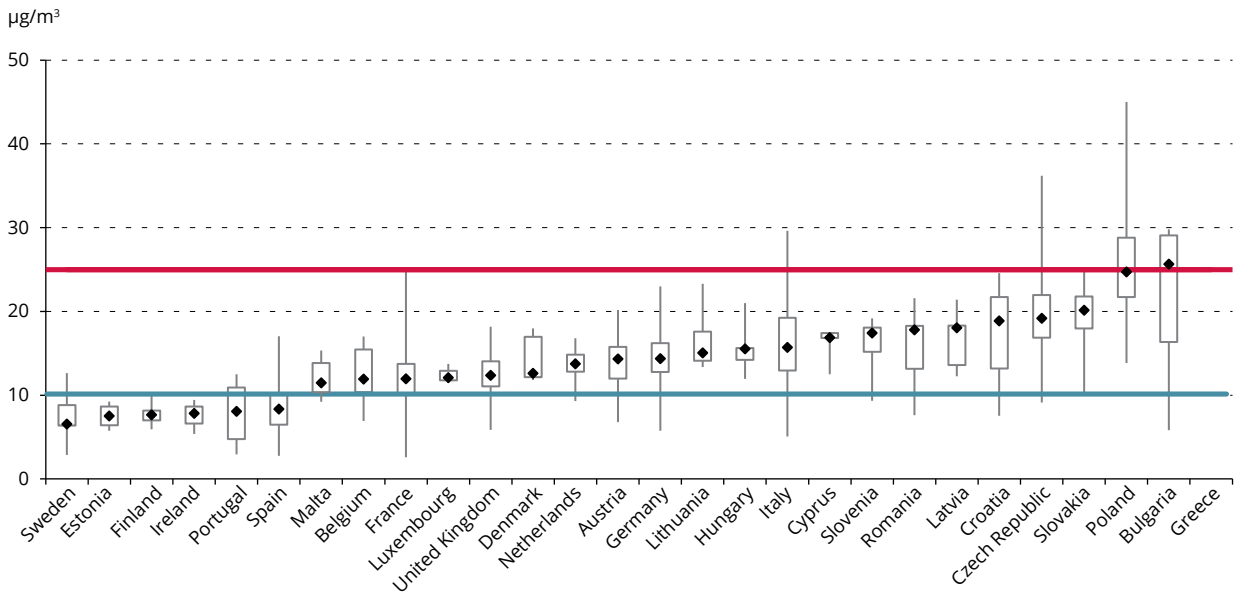
Figure 4.1 PM_{10} concentrations in relation to the daily limit value in 2014 in the EU-28



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 percentile 90.4 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.

Source: EEA, 2016a.

Figure 4.2 $PM_{2.5}$ concentrations in relation to the target value in 2014 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 target value set by EU legislation is marked by the red line. The WHO AQG is marked by the blue line.

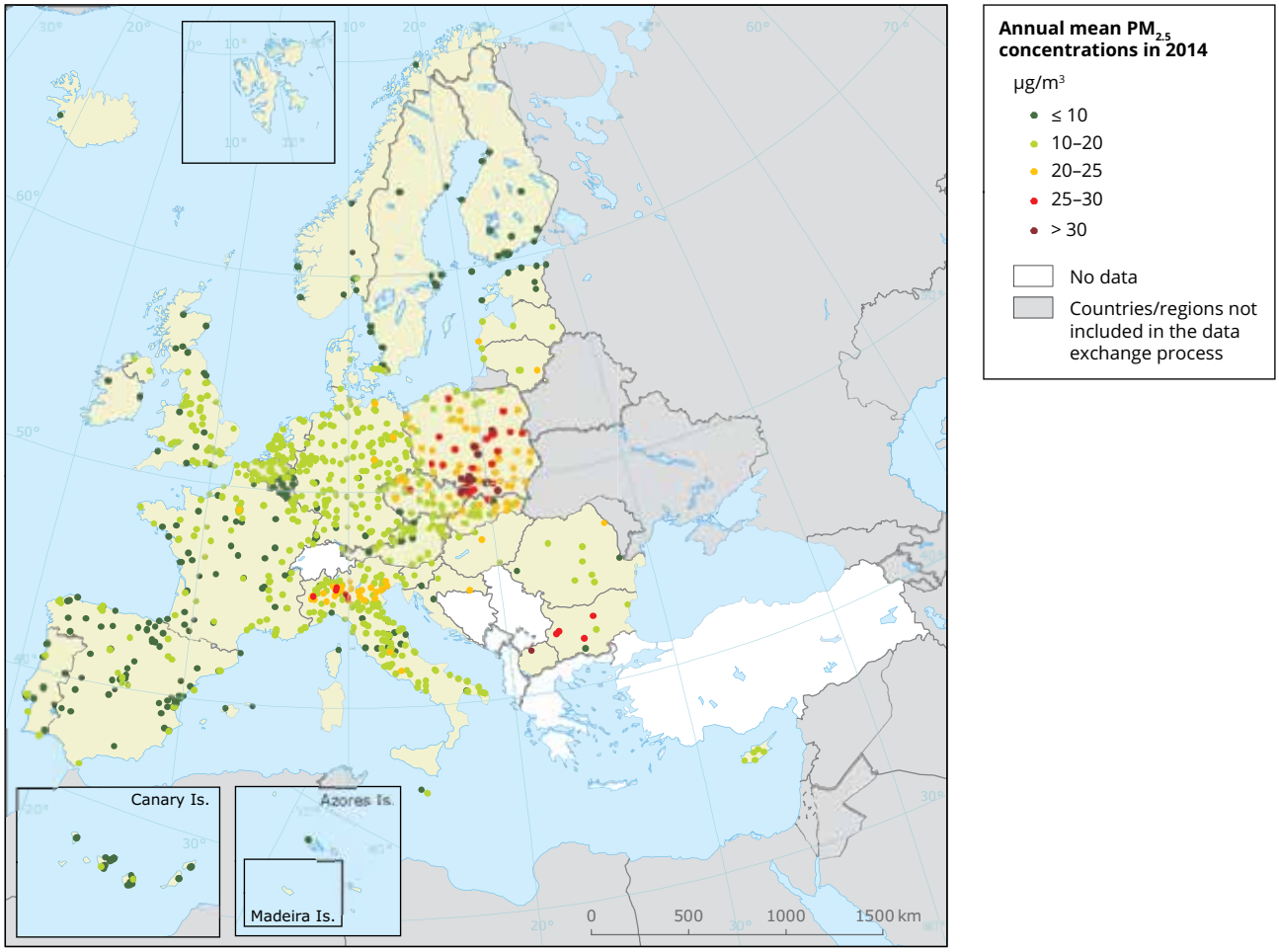
Source: EEA, 2016a.

in Map 4.2). These values above the target value also occurred primarily (96 % of cases) in urban or suburban areas. The average exposure indicator (AEI) for $PM_{2.5}$ is discussed in Chapter 9 (see Figure 9.1).

The stricter value of the WHO AQG for annual mean PM_{10} (20 µg/m³) was exceeded at 55 % of the stations and in 31 reporting countries (including four outside the EU-28). Only Albania, Estonia and Iceland had all their reported concentrations below the WHO AQG. The WHO guideline for $PM_{2.5}$ annual mean (10 µg/m³; see the light green, yellow, red and dark red dots in Map 4.2) was exceeded at 74 % of the stations, located in 26 of the 30 countries reporting $PM_{2.5}$ data with a minimum data coverage of 75 % of valid data. Only Estonia, Finland, Iceland and Ireland did not report any exceedance of the WHO AQG for $PM_{2.5}$ ([12]).

The rural background concentration of PM represents the PM level in rural areas without direct influence from close anthropogenic sources. It is, therefore, mostly the result of primary or secondary PM transported over larger distances or from natural sources. Although rural background levels of PM are considerably lower than urban and suburban levels, they may be elevated in some European regions and they constitute a substantial part of the PM concentrations measured in cities. The origin and composition of PM in rural background areas must, therefore, be taken into account in air-quality and health-risk assessment and management.

Map 4.2 Concentrations of $PM_{2.5}$ in 2014



Notes: The red and dark red dots indicate stations reporting concentrations above the EU annual target 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, 2016a.

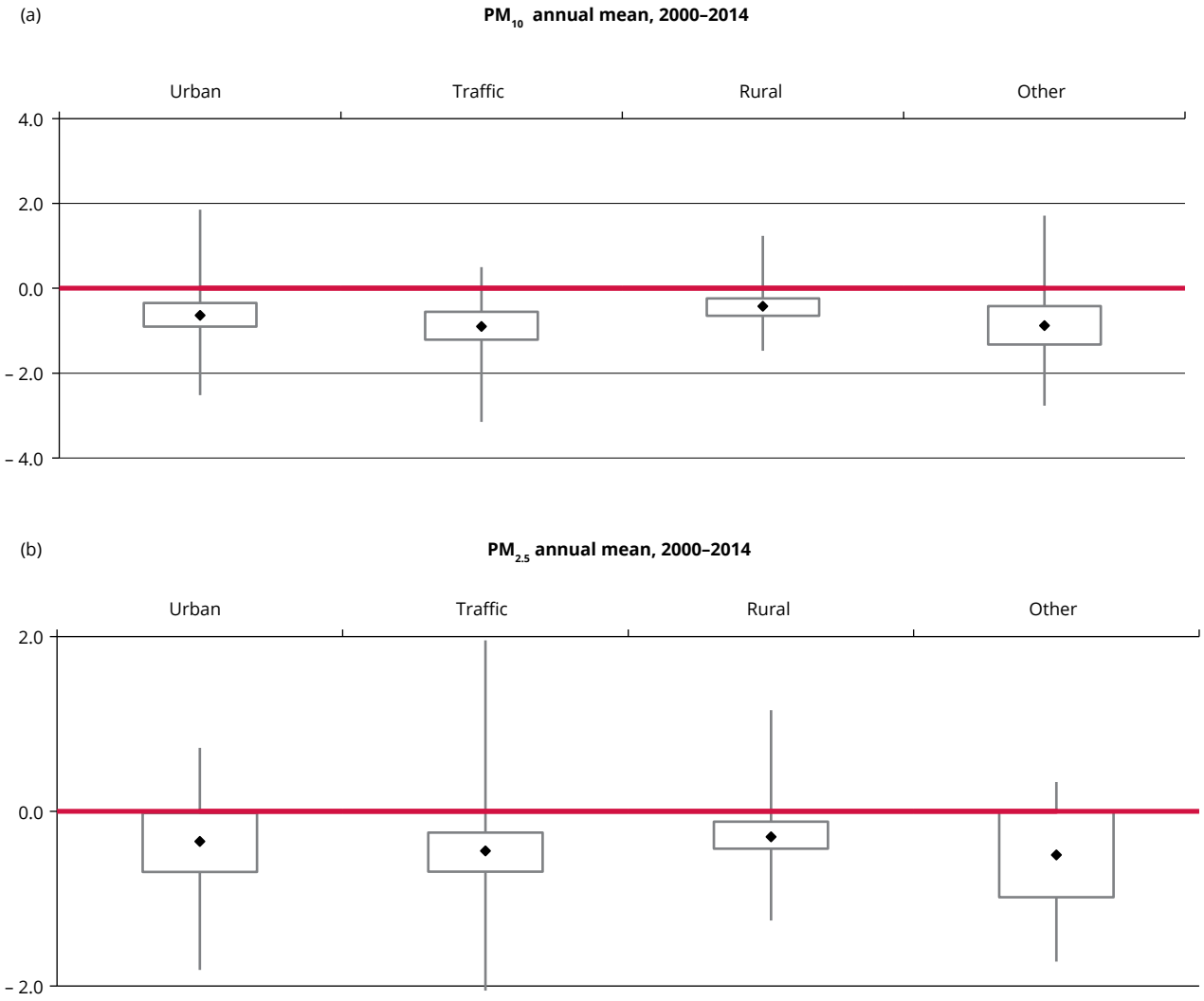
([12]) The series reported for three stations by Greece and four by Albania do not reach the minimum data coverage of 75 % of valid data. Together with the other 24 Member States, the former Yugoslav Republic of Macedonia and Norway also exceeded the WHO AQG for $PM_{2.5}$.

The rural background concentration levels of PM vary across Europe. Concentrations above the daily PM_{10} limit value in the rural background in 2014 occurred in several stations in the Czech Republic, Croatia and Italy, and in one station in Poland. There was also one rural background station, in the Czech Republic, with concentrations above the PM_{10} annual limit value. Regarding $PM_{2.5}$, only two rural background stations, both in the Czech Republic, registered concentrations above the target value.

4.2.2 Trends in ambient particulate matter concentrations

The average trends in PM_{10} annual mean concentrations from 2000 to 2014 are presented in Figure 4.3a, for urban background, traffic, rural background and other (mostly industrial) stations. A significant downward trend is observed at 75 % of all stations, and fewer than 1 % of the stations register a significant increasing trend ([13]). Trends in the 90.4 percentile of daily mean PM_{10}

Figure 4.3 Trends in PM annual mean concentrations by station type: (a) PM_{10}, 2000–2014; (b) $PM_{2.5}$, 2006–2014



Note: The graphs are based on annual mean concentration trends for PM_{10} (a) and $PM_{2.5}$ (b); they present the range of concentration changes per year (in µg/m³/year) for each station type (urban, traffic, rural and other — mostly industrial). The trends are calculated based on the data officially reported by the EU Member States with a minimum data coverage of 75 % of valid data per year, for at least 11 years of the 15-year period for PM_{10} and for at least 7 years of the 9-year period for $PM_{2.5}$. The diagram indicates the lowest and highest trends, the means and the lower and upper quartiles, for each station type. The lower quartile splits off the lowest 25 % of the data and the upper quartile splits off the highest 25 % of the data.

([13]) A consistent set of 839 stations with data for 2000–2014 was used for the trend analysis, with a minimum data coverage of 75 % of valid data per year, for at least 11 years of the 15-year period. Of these, 640 stations registered a significant trend using the Mann–Kendall test.

Photo: © Zsuzsanna Rózsa, My City/EEA

concentrations are more sensitive to meteorological variability and have therefore a larger uncertainty; 63 % of the stations show a significant downward trend.

Tables A1.1 and A1.2 (Annex 1) show the average trends by country and by station type for, respectively, annual mean and 90.4 percentile of daily mean PM_{10}, from 2000 to 2014. On average, urban background stations registered decreases of – 0.6 and – 0.9 µg/m^3/year, respectively, in annual mean and 90.4 percentile values of PM_{10}, whereas for urban traffic sites the average changes reached –0.9 and –1.4 µg/m^3/year. The decrease in PM_{10} concentrations was particularly marked in Italy, Portugal and Spain. On the other hand, the tables show that Poland registered an average increase in PM_{10} concentrations in rural background stations, while urban stations registered an average decrease. No other country registered statistically significant average increasing trends in PM_{10}.

$PM_{2.5}$ concentrations, on average, tended to decrease between 2006 ([14]) and 2014 for all station types (see Figure 4.3b). The observed trends in $PM_{2.5}$ and PM_{10} concentrations show a consistent pattern: the largest average trend is found at traffic and industrial stations and the smallest trend is found at rural stations. Table A1.3 (Annex 1) shows the trends for $PM_{2.5}$ annual mean by country and by station type for 2006–2014. Several countries have registered increasing $PM_{2.5}$ annual mean concentrations at one or more station types in the same period, but most of the stations do not register a statistically significant trend. The available data for $PM_{2.5}$ are too limited to allow firm conclusions about the observed trends in the different countries, but it is clear that in general there is a tendency for levels to decrease.

PM trend analysis could be used, subject to those limitations, to estimate how PM concentrations might

([14]) The period 2006–2014 was chosen to maximise the number of available stations for the trend analysis: 214 stations in 24 countries. As routine monitoring of $PM_{2.5}$ started in Europe during the first decade of this century, the limited data set for 2000–2014 (58 stations in 12 countries) does not allow any conclusion on trends for each country or station type. However, the data set over this 15-year period suggests decreasing tendencies at traffic and rural stations. At urban stations, a more mixed pattern is found.

develop during future years, assuming changes continue at the same pace as over the period 2000–2014. This would help inform us on progress towards meeting one of the goals of the Clean Air Policy Package for Europe, namely fulfilling the air-quality standards by 2020 (European Commission, 2013b, Section 1.4). Averaged over 2010–2014, 2.7 % of the stations (in a consistent set) registered concentrations above the PM_{10} annual limit value. This extrapolation of the observed trend to 2020 shows the proportion of stations with concentrations above the annual limit value would be reduced to 1.6 %. Similarly, the proportion of stations with concentrations above the PM_{10} daily limit value would be reduced from 16 % to 6 % in 2020, while for $PM_{2.5}$ it would drop from 6.4 % to 3.0 %. These changes assume a business as usual scenario, without additional measures and assuming the variations are the same as in the past. The change can be accelerated if further measures to improve air quality are taken at all administrative levels.

4.2.3 Relationship of emissions to ambient particulate matter 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 2014 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 be explained in part by uncertainties in the reported emissions of primary PM from the commercial, institutional and household fuel combustion sector.

Furthermore, as discussed by the EEA (2012), intercontinental transport of PM and its precursor gases from outside Europe may also influence European ambient PM levels, pushing up PM concentration levels, in spite of falling emissions in Europe. In addition, natural sources contribute to background PM concentrations and their contribution is not affected by mitigation efforts on anthropogenic emissions. Finally, when it comes to secondary PM ([15]), reduction in sulphur emissions has contributed to a PM composition shift, from ammonium sulphate to ammonium nitrate, so that reductions in emissions are not directly transferred to decreases in concentrations (EMEP, 2016).

Between 2000 and 2014, primary PM_{10} emissions decreased by 23 % in the EU-28 (15 % in the EEA-33), and between 2006 and 2014, primary $PM_{2.5}$ emissions decreased by 17 % in the EU-28 (18 % in the EEA-33). In the same periods, on average, PM_{10} concentrations ([16]) declined by 34 % in the EU-28 (34 % in all countries considered in the trend analyses; see Tables A1.1 and A1.2), and $PM_{2.5}$ concentrations ([17]) declined by 20 % in the EU-28 (20 % in all countries considered in the trend analyses; see Table A1.3), also indicating the reduction in secondary PM.

The analysis of PM trends in terms of the individual contributors (i.e. from emissions of primary PM or precursor gases) is difficult, as monitoring data on PM composition are scarcely reported under the Ambient Air Quality Directive (EU, 2008). However, long time series have been reported under the CLRTAP and recently the European Monitoring and Evaluation Programme (EMEP, 2016) has evaluated the air pollution trends at rural locations. Between 2002 and 2012, averaged trends in sulphate, nitrate and NH_3 were – 0.072, – 0.012 and – 0.012 µg/m³/year, respectively. The total trend in these secondary inorganic aerosols (– 0.096 µg/m³/year) might account for about one third (one fifth) of the rural background trend of $PM_{2.5}$ (PM_{10}) concentrations.

The reduction in SO_2 emissions has given the largest contribution to the decrease in secondary inorganic aerosol concentrations. Emissions have strongly decreased (69 %) between 2000 and 2014, resulting in 60 % lower SO_2 concentrations. According to EMEP (2016), decreases in sulphate concentrations are lower (39 % for 2002–2012). The reduction in NO_X emissions between 2000 and 2014 was less pronounced (39 %). Measured NO_X concentrations (sum of NO and NO_2) between 2000 and 2014 decreased less (30 %) and again the reduction in nitrate concentration was lower, as estimated by EMEP (2016): 7 % for 2002–2012. For the third precursor gas, NH_3, EU-28 emissions decreased by only 8 % between 2000 and 2014, and EMEP (2016) estimated that the reduction in gaseous ammonia summed to ammonium between 2002 and 2012 was 14 %.

([15]) The proportion of secondary $PM_{2.5}$ reaches around 70 % in urban background and more than 80 % in the regional background.
([16]) For the same consistent set of stations used in the trend analysis of PM_{10} in Section 4.2.2.
([17]) For the same consistent set of stations used in the trend analysis of $PM_{2.5}$ in Section 4.2.2.

5 Ozone

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

European air-quality standards and WHO guidelines for O_3 are shown in Table 5.1. The Ambient Air Quality Directive (EU, 2008) sets out targets for the protection of human health and for the protection of vegetation.

For health protection, a maximum daily 8-hour mean threshold is specified (120 µg/m^3) in the Ambient Air Quality Directive (EU, 2008). The target value is that the threshold should not be exceeded at a monitoring station on more than 25 days per year (corresponding to the 93.2 percentile), determined as a 3-year average starting from 1 January 2010. The long-term objective (for which no date is set by the Ambient Air Quality Directive (EU, 2008)) is no exceedance of the threshold level at all. The WHO AQG for O_3 is a daily maximum 8-hour mean concentration of 100 µg/m^3 (WHO, 2006).

For health protection, there are also two other types of thresholds: 'public information' and 'alert' thresholds. When the public information threshold is breached, the authorities in that country are obliged to notify their citizens, using a public information notice. When the alert threshold is exceeded for three consecutive hours, the country affected is required to draw up a short-term action plan in accordance with specific provisions established in the Ambient Air Quality Directive (EU, 2008).

The Ambient Air Quality Directive (EU, 2008) also sets targets for the protection of vegetation from high O_3 concentrations accumulated during the growing season (defined as May to July). The vegetation protection value is specified as 'accumulated exposure over a threshold of 40 parts per billion (ppb)' (AOT40). This is calculated as 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 during the daylight period of the most intensive growing season (May to July). The target value for 2010 was 18 000 (µg/m^3).h, determined as a 5-year average. The long-term objective (for which no date is set by the Ambient Air Quality Directive (EU, 2008)) is 6 000 (µg/m^3).h, as shown in Table 5.1. The assessment of vegetation exposure to O_3 levels above these standards is given in Section 11.1.

In addition to the EU target value, the CLRTAP (UNECE, 1979) defines a critical level (CL) for the protection of forests. This CL is related to the AOT40 during April to September and is set at 10 000 (µg/m^3).h. The exposure of forests to O_3 levels above the CL is assessed in Section 11.1.

5.2 Status and trends in 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. 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.

The high O_3 concentrations occurring at urban stations, especially in the case of exceedance of the information threshold (Table 5.1) are attributable to the O_3 formation that occurs at times in large urban areas during episodes of high solar radiation and temperatures. Local and regional emissions of precursor gases play a major role in ozone 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. Hot, dry summers with long-lasting periods of high air pressure over large parts of Europe lead to elevated O_3 concentrations, as in the 2003 heat wave.

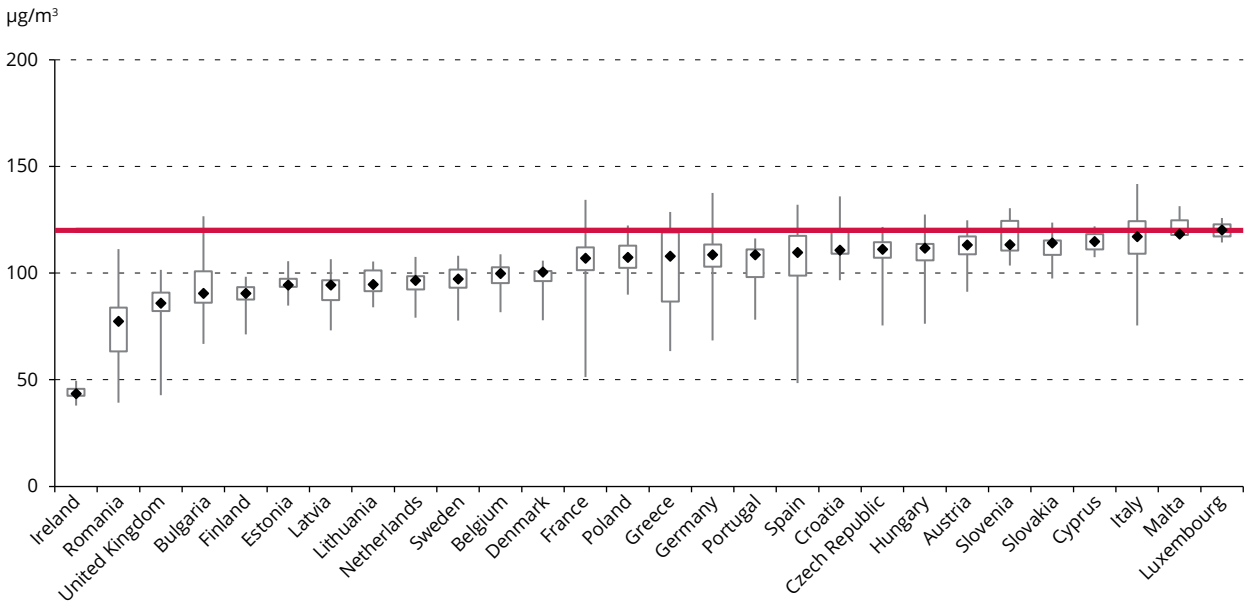
Table 5.1 Air-quality standards for O_3 as defined in the EU Ambient Air Quality Directive and WHO air quality guidelines

Averaging period	EU Air Quality Directive		WHO AQG	UNECE CLRTAP critical level
	Objective and legal nature	Concentration		
Maximum daily 8-hour mean	Human health long-term objective	120 µg/m³	100 µg/m³	
	Human health target value	120 µg/m³, not to be exceeded on more than 25 days per year averaged over 3 years		
AOT40 accumulated over May to July	Vegetation long-term objective	6 000 (µg/m³).h		10 000 (µg/m³).h (protection of forests)
	Vegetation target value	18 000 (µg/m³).h averaged over 5 years		
1 hour	Information threshold	180 µg/m³		
	Alert threshold	240 µg/m³		

Notes: AOT40, accumulated O_3 exposure 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 8:00 and 20:00 Central European Time.

Sources: EU, 2008; WHO, 2006.

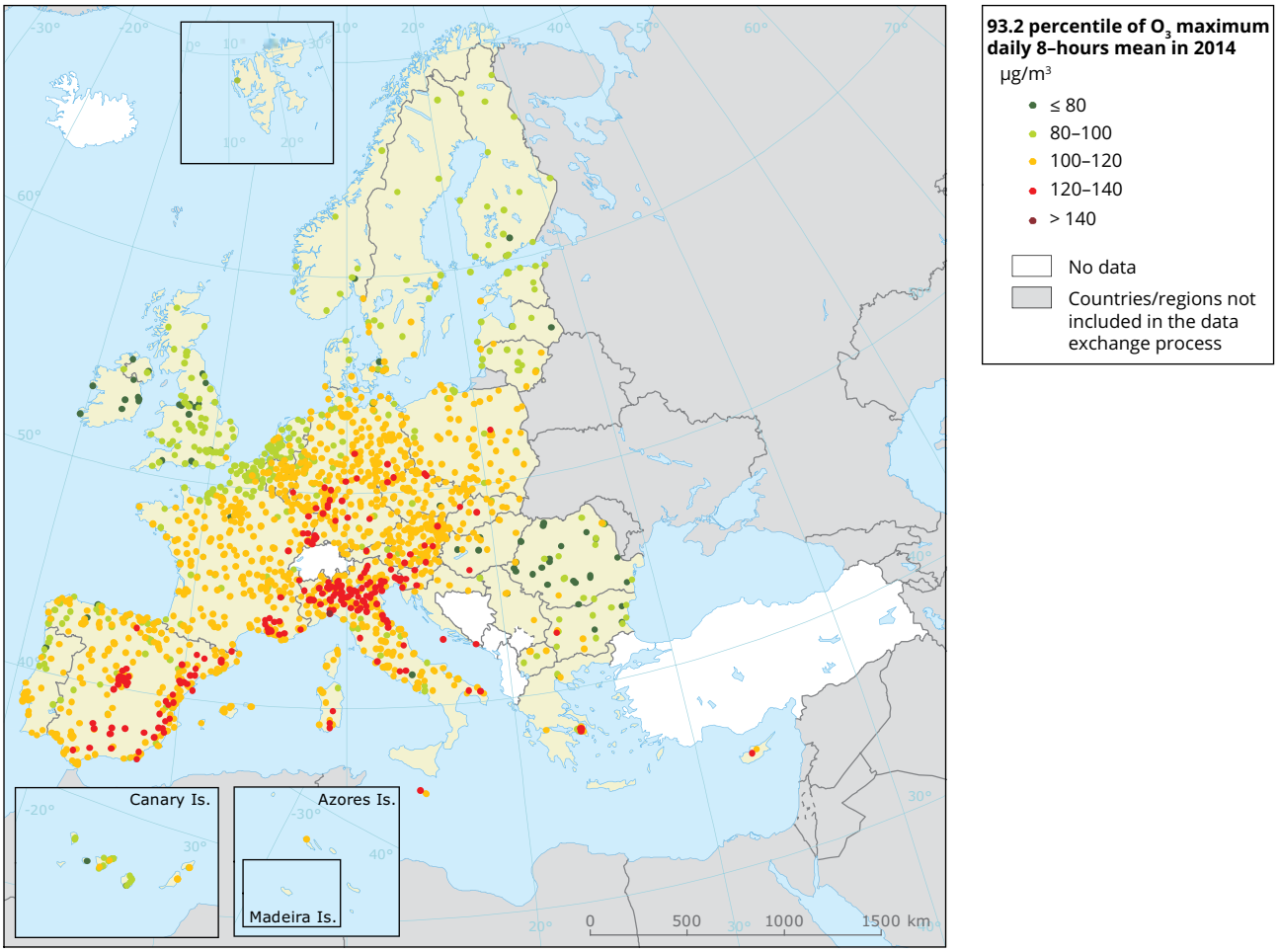
Figure 5.1 O_3 concentrations in relation to the target value in 2014 in the EU-28



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.

Source: EEA, 2016a.

Map 5.1 Concentrations of O_3 in 2014



Notes: Observed concentrations of O_3 in 2014. 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 concentration 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.

Source: EEA, 2016a.

5.2.1 Concentrations in relation to the target values for protection of health

In 2014, 16 countries ([18]) of the EU-28 (see Figure 5.1 and Map 5.1) registered concentrations above the O_3 target value more than 25 times. In total, 11 % of all stations ([19]) reporting O_3 showed concentrations above the target value for the protection of human health in 2014, which is considerably fewer stations than in 2013. On the other hand, only 14 % of all stations fulfilled the long-term objective (no exceedance of the threshold level). Of these fulfilling stations, 59 % were in background areas, 21 % were industrial and 20 % were traffic 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 fewer than 4 % of all stations and in only 5 of 503 rural background stations in 2014, four in the island of Ireland (Ireland and the United Kingdom) and one in Norway.

([18]) Austria, Bulgaria, Croatia, Cyprus, the Czech Republic, France, Germany, Greece, Hungary, Italy, Luxembourg, Malta, Poland, Slovakia, Slovenia and Spain.
([19]) With data coverage equal to or above 75 % for all countries reporting O_3 data to EEA, as shown in Map 5.1.

5.2.2 Trends in ambient ozone concentrations

The concentrations and long-term trends of O_3 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 ozone concentrations in Europe, unlike for any other air pollutants. As mentioned in Section 2.1, emissions of VOCs, including methane, 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 NO_2 (O_3 titration).

The importance of each of these processes is different for the various O_3 metrics and is reflected in the results of a trend analyses. Table 5.2 shows the trends ([20]) for different metrics for each station type, illustrating the dependence and variability of O_3 trends on the temporal and spatial scales.

At rural sites, the trend is a declining one for all O_3 metrics considered (see also Figure 5.2), reflecting the decline in precursor emissions. The largest decrease is observed for metrics based on the highest concentrations, for which the reduction in photochemical production at the European level is more important than changes in the tropospheric background. On the other hand, the trend in O_3 mean concentration is small and frequently not significant ([21]). At traffic stations, where the local titration effect dominates, there is an upward trend in the annual averaged concentrations. On metrics mainly calculated from summertime values (AOT40 and the maximum daily 8-hour average (MDA8)), the trends are negative for both AOT40 and MDA8 (indicating reduced local ozone formation in summertime). The behaviour at urban and suburban stations falls between the traffic and rural situations (Table 5.2 and Figure 5.2). For more detail on the regional distribution of the observed O_3 trends, Tables A1.4 and A1.5 (Annex 1) show the average trends by country and by station type for the 93.2 percentile of O_3 concentrations and of SOMO35 ([22]) values, respectively, over 2000 to 2014.

Some of these observations in O_3 trends are also confirmed by other studies. For example, Simpson et al. (2014) found generally increasing O_3 concentrations of 0.2–0.8 µg/m³/year up to the 95th O_3 percentile, and O_3 reductions of 1–3 µg/m³/year above the 95th percentile, using a subset of 14 EMEP stations and comparing the period 1990–2009. The EMEP (2016) analysis of an extended set of observations from the EMEP regional network shows that, between 1990 and 2012, high O_3 concentrations declined by about 10 %, such that the number of days exceeding the WHO guideline of 100 µg/m³ was reduced by about 20 % since the start of the 1990s. Between 2002 and 2012, the median SOMO35 across EMEP stations decreased by 30 %, while annual mean O_3 concentrations increased in the 1990s and levelled off in the 2000s.

Table 5.2 Ozone trends ([a]) (2000–2014) for different aggregated values (metrics) and station types

Metric	Traffic	Urban and suburban background	Rural background
	Slope (2σ)	Slope (2σ)	Slope (2σ)
AOT40 ([b])	– 0.05 (0.06)	– 0.29 (0.03)	– 0.42 (0.04)
SOMO35 ([b])	0.04 (0.05)	– 0.17 (0.02)	– 0.32 (0.03)
Annual mean	0.50 (0.08)	0.09 (0.02)	– 0.21 (0.03)
Annual mean MDA8 ([c])	0.49 (0.10)	– 0.05 (0.03)	– 0.33 (0.04)
93.2 percentile	0.05 (0.16)	– 0.68 (0.06)	– 0.86 (0.07)
Max MDA8	– 0.51 (0.29)	– 1.49 (0.12)	– 1.56 (0.15)

Notes: ([a]) Trends and the 95 % confidence interval (slope ± 2σ) are given in (µg/m³/year).

([b]) To ease the comparison with the other statistics, the SOMO35 and AOT40 trends have been scaled by 365 (days) and 1 104 (hours, corresponding to the 12 hours from 8:00 to 20:00 during the 92 days in May–July), respectively.

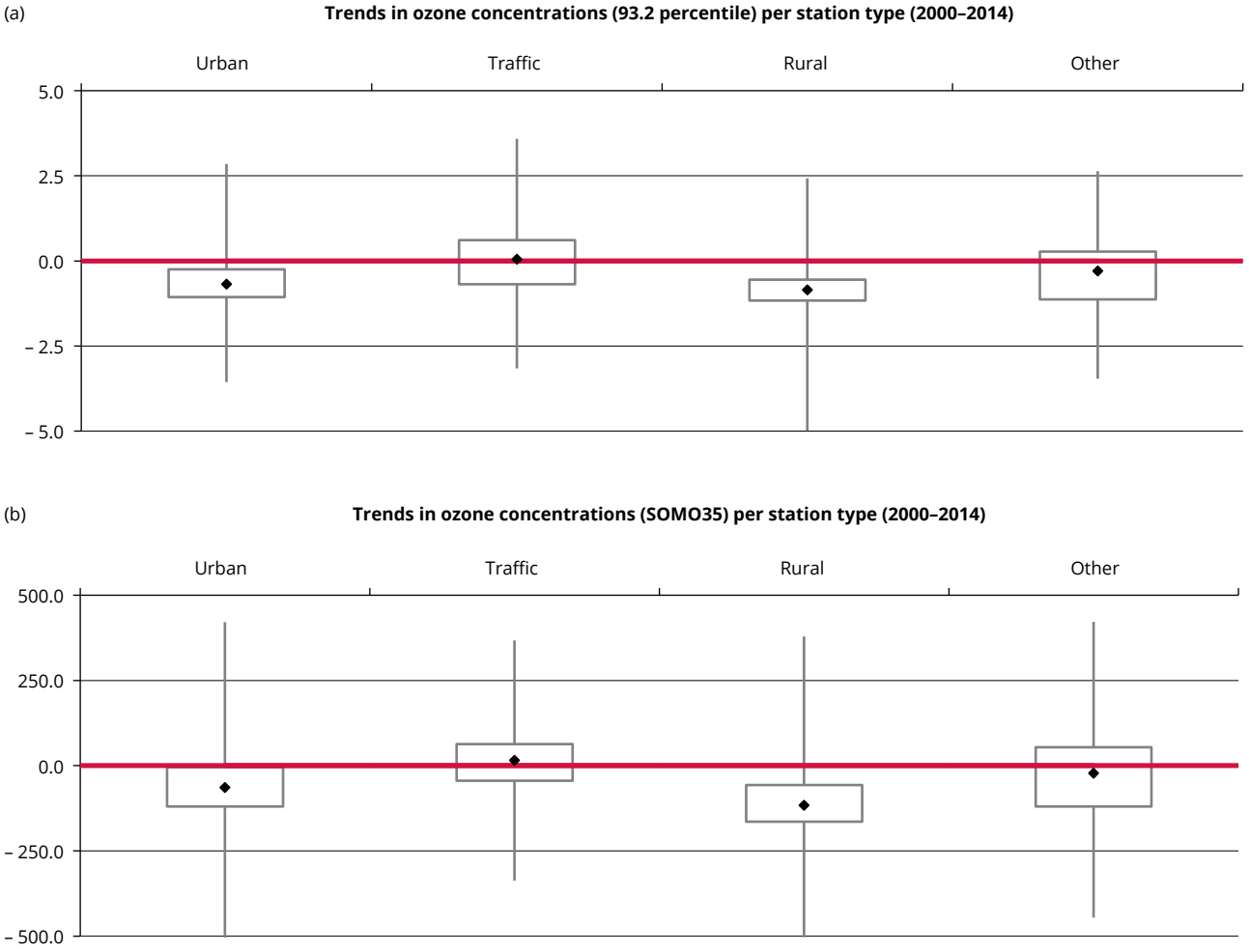
([c]) MDA8, maximum daily 8-hour average.

([20]) A consistent set of 1 088 stations with data for 2000–2014 was used in the trend analysis, with a minimum data coverage of 75 % of valid data per year, for at least 11 years of the 15-year period. Of these, only 41 % (447 stations) registered a significant trend, using the Mann–Kendall test.

([21]) Here a trend is called significant when the probability of having an upward or downward trend is 95 %.

([22]) SOMO35 is the accumulated O_3 concentration (daily maximum 8-hour) in excess of 35 ppb (i.e. 70 µg/m³ for O_3).

Figure 5.2 **Trends in the 93.2 percentile of the maximum daily 8-hour O_3 concentrations (a) and O_3 SOMO35 values (b) by station type, 2000–2014**



Note: The graph is based on the 93.2 percentile of the maximum daily 8-hour O_3 concentration trends (a) and on the trends in O_3 SOMO35 values (b). It presents the range of concentration changes (in µg./m³/year, a; (µg./m³).day/year, b) for each station type. The trends are calculated based on the data officially reported by the countries with a minimum data coverage of 75 % of valid data per year, for at least 11 years of the 15-year period. The diagram indicates the lowest and highest trends, the means and the lower and upper quartiles, for each station type. The lower quartile splits off the lowest 25 % of the data, and the upper quartile splits off the highest 25 % of the data.

In many cases the observed O_3 trend is statistically not significant, which means that the uncertainty in the estimated slope is large. The estimated trends can be used to predict how ozone concentrations might develop during future years, assuming that the changes would continue at the same pace as over the period 2010–2014 and recognising the large uncertainties associated with current trend analysis. Averaged over 2010 to 2014, 21 % of the stations (in a consistent set) exceeded the O_3 target value. Based on the above assumptions the predicted future trend to 2020 suggests that the proportion of stations above the target value would be reduced to 7 %. A similar estimate for the O_3 indicator AOT40 for the protection of crops shows concentrations above this indicator at 19 % of the stations in 2014, which would be reduced to 8 % in 2020. As pointed out in Section 4.2.2 about PM_{10}, these changes assume a business as usual scenario and they could be accelerated if further measures to improve air quality are taken at all administrative levels.

5.2.3 Relationship of ozone precursor emissions and concentrations to ambient ozone concentrations

Reductions in anthropogenic O_3 precursor gas emissions in Europe have not led to equivalent reductions in O_3 concentrations in Europe, as the relationship of O_3 concentration to the emitted precursors is not linear, meteorology plays a key role in ozone's chemistry, and hemispheric background concentrations are also important.

At traffic locations, the interaction between O_3 and NO_X is the dominant process. The fact that NO_X traffic emissions have been reduced, and particularly the ratio of NO to NO_X emissions has decreased (for diesel vehicles), leads to less O_3 being consumed in the titration reaction with NO. Thus, O_3 concentrations near sources of traffic emissions have increased in several traffic stations (see also Figure 5.2). On metrics mainly calculated from summertime values (AOT40 and the MDA8), the reduction in photochemical formation is stronger than this effect of the NO_X titration, resulting in less production of O_3.

For the other O_3 precursors (NMVOCs) the Ambient Air Quality Directive (EU, 2008) requires the Member States to measure the ambient concentration of VOC compounds at least at one station, in order to analyse trends in O_3 precursors, check the efficiency of emission reductions and the consistency of emission inventories, and help attribute emission sources to observed pollution concentrations. However, this requirement has been implemented to a limited extent. Long time series are available for the less reactive aromatic compounds (benzene, toluene). At 80 % of the benzene stations ([23]) a significant downward trend is observed. A smaller number of time series is available for toluene ([24]) and a significant downward trend is observed at all of these stations. Between 2000 and 2014, both benzene and toluene show a decrease of more than 70 %, which reflects mainly the reduction close to traffic sources, taking into consideration the station selection. For the period 2005–2014, twice as large and more representative benzene and toluene data sets are available. Although observed trends are smaller during those 10 years, they are still significant at the majority of stations, confirming the decrease in concentrations.

There is no separate emission inventory of the different VOC compounds, as emissions are reported for the sum of all emitted NMVOCs. Between 2000 and 2014, transport reduced its NMVOC emissions by 75 % in the EU-28, which is reflected in the decrease in benzene and toluene concentrations over the same period. On the other hand, total NMVOCs emissions have been reduced by about 39 % in the EU-28. From 2005 to 2014, the relative reductions are a little smaller: 27 % and 59 % reductions in total and transport sector emissions, respectively. The observed trend at traffic stations corresponds to the trend in emissions.

For the more reactive VOCs (i.e. alkanes and alkenes with two to four carbon atoms), the set of stations is too small (fewer than five stations) to enable a representative trend analysis for the European situation. Nevertheless, concentrations are shown to reduce at urban and traffic stations and increase (in propane and butane concentrations) at rural stations.

EMEP (2016) also found, despite a relative scarcity of long-term observations of NMVOCs concentrations, a significant decrease in NMVOCs concentrations in the EMEP region of 40 % over 2002–2012. As pointed out in the study cited, it is very likely that a major driver of the observed decreases was the European vehicle emission standards, which led to significant NMVOCs emission reductions. On the other hand, other factors related to gas extraction, refineries and handling could have contributed to increase some specific NMVOCs such as ethane and propane.

In addition to anthropogenic NMVOCs emissions, biogenic VOCs are also involved in the formation of O_3 and are extremely important for summertime O_3 production. Biogenic VOCs emissions are controlled by land use, temperature and solar radiation. As biogenic VOCs play a role as O_3 precursors, the effect of reductions in anthropogenic NMVOCs on O_3 production can be dampened at times and locations where biogenic VOCs emissions are high, namely in the summer and in highly vegetated regions (Peñuelas and Staudt, 2010). This adds to the complexity of analysing O_3 formation and trends.

([23]) In 101 out of a total of 127 stations measuring benzene, of which 55 are urban or suburban traffic stations.
([24]) In 35 stations, of which 22 are traffic stations.

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 NO_2 (and NO_x), as well as the WHO guidelines, are shown in Table 6.1. The directive sets short-term (1-hour) and long-term (annual mean) limit values for the protection of human health. The limit value for the annual mean NO_2 concentration is set at 40 µg/m³. The 1-hour limit value threshold of 200 µg/m³ can be exceeded up to 18 times per year (corresponding to the 99.8 percentile of hourly concentrations in one year) before the limit value is breached. The limit values were to be met by EU Member States by 1 January 2010 ([25]).

The Ambient Air Quality Directive (EU, 2008) also defines an 'alert' threshold value of 400 µg/m³. When this threshold is exceeded over three consecutive hours in areas of at least 100 km² or in an entire air-quality management zone, authorities have to implement short-term action plans. These action plans may include measures in relation to motor-vehicle traffic, construction works, ships at berth and the use of industrial plants or products and domestic heating. The framework of these plans may also consider specific actions for the protection of sensitive population groups, including children, by reducing their exposure to high NO_2 levels.

The threshold values used in the human health objectives set by the Ambient Air Quality Directive (EU, 2008) are identical to the WHO AQG for NO_2 (WHO, 2006), as shown in Table 6.1. The only difference is that the WHO AQG does not allow any exceedance of the 1-hour limit value threshold.

6.2 Status and trends in concentrations

6.2.1 Concentrations in relation to the limit values for the protection of human health

Map 6.1 shows that the stations with concentrations above the annual limit value were widely distributed across Europe in 2014. Of all stations measuring NO_2 and with a minimum coverage of 75 % of valid data, 12 % registered concentrations above the annual limit value.

Table 6.1 Air-quality standards for NO_2 (and NO_x) as set out in the EU Ambient Air Quality Directive and WHO air quality guidelines

Averaging period	EU Air Quality Directive		WHO AQG µg/m³
	Objective and legal nature	Concentration µg/m³	
1 hour	Human health limit value	200, not to be exceeded on more than 18 hours per year	200
	Alert ([a]) threshold	400	
Calendar year	Human health limit value	40	40
Calendar year	Vegetation critical level	30 ([b])	

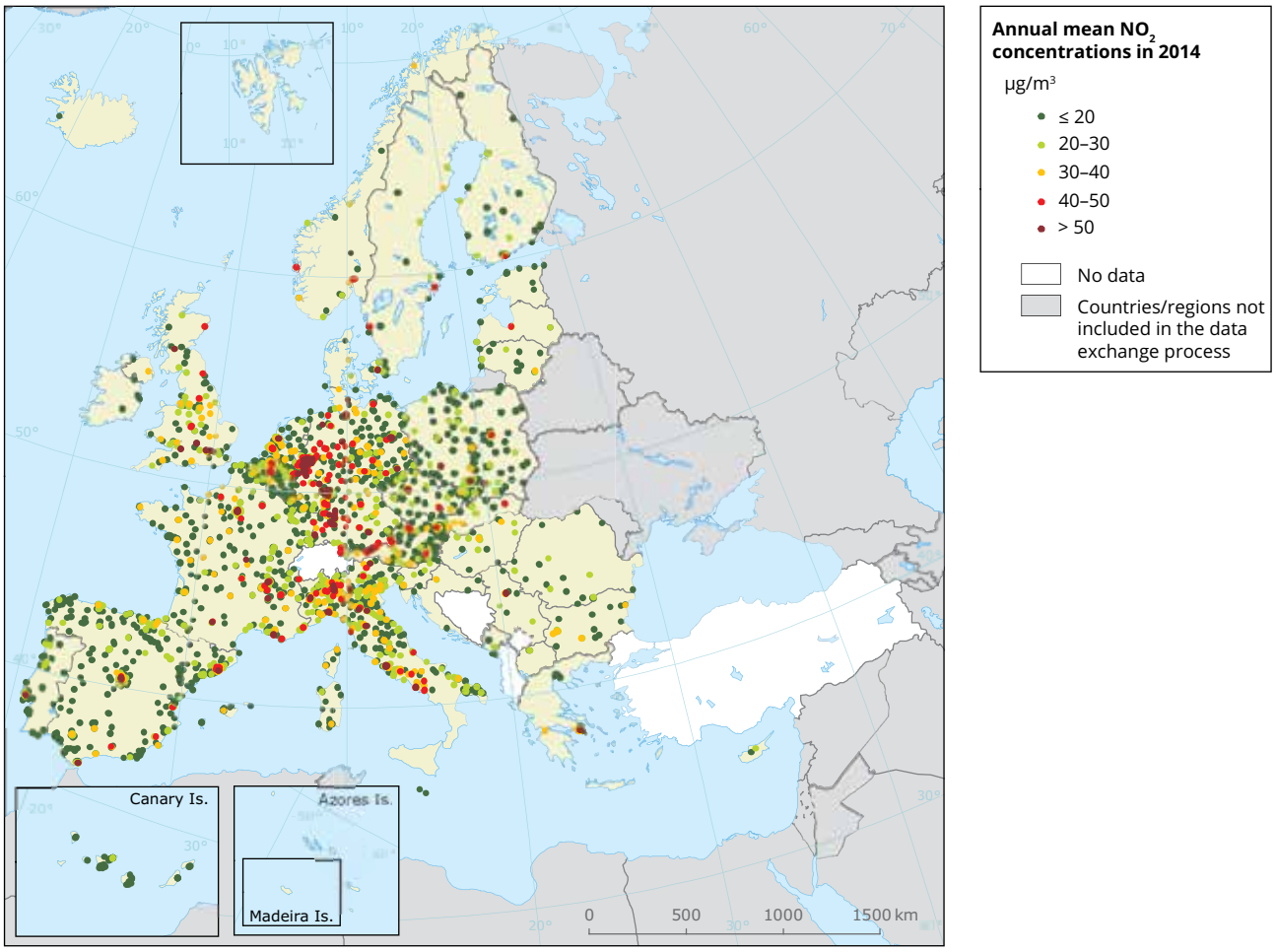
Notes: ([a]) To be measured over 3 consecutive hours at locations representative of air quality over at least 100 km² or an entire zone or agglomeration, whichever is the smaller.

([b]) As NO_x, expressed in µg/m³.

Sources: EU, 2008; WHO, 2006.

([25]) Exceptions apply for the stations in the few air-quality zones for which the European Commission has granted a time extension for this limit value (http://ec.europa.eu/environment/air/quality/legislation/time_extensions.htm). These exceptions are not taken into account in the assessment analysis.

Map 6.1 Concentrations of NO_2 in 2014



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.

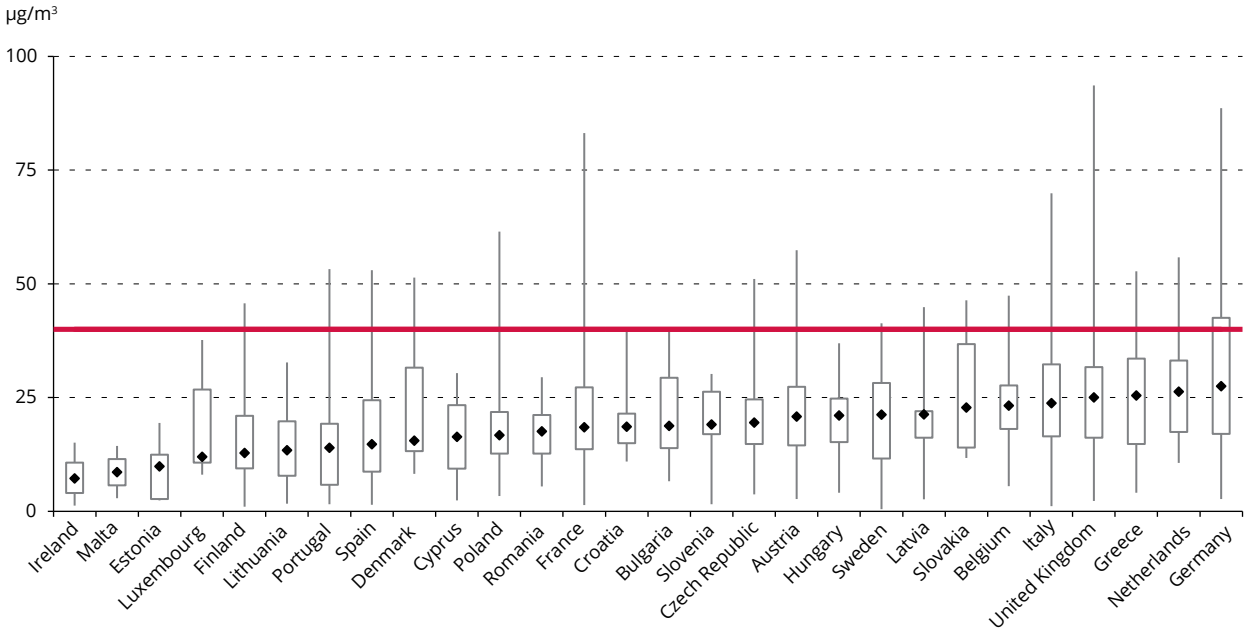
Source: EEA, 2016a.

None of these concentrations above the annual limit value were observed at rural background stations. The highest concentrations, as well as 94 % of all values above the annual limit value, were observed at traffic stations. Nevertheless, concentrations above 55 µg/m³ were also measured at one urban background station in Serbia and another in the United Kingdom. Traffic is a major source of NO_2 and of NO, which reacts with O_3 to form NO_2. Traffic emissions are close to the ground, contributing relatively more to NO_2 ground-level concentrations (and therefore human exposure) than, for example, high industrial stacks, emissions from which are diluted before reaching the ground. In traffic and urban areas with fresh inputs of NO, some of the O_3 present is depleted during the oxidation of NO to NO_2.

Figure 6.1 shows a summary of the observed annual mean NO_2 values for 2014 for all EU Member States. Seventeen ([26]) of the 28 EU Member States recorded concentrations above the annual limit value (equal to the WHO AQG) at one or more stations. This was also the case in Norway and Serbia. These findings demonstrate that NO_2 concentrations still need to be substantially reduced in large areas of Europe (focusing on traffic and urban locations) for the annual limit value to be met.

([26]) Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Latvia, the Netherlands, Poland, Portugal, Slovakia, Spain, Sweden and the United Kingdom.

Figure 6.1 NO_2 concentrations in relation to the annual limit value in 2014 in the EU-28



Notes: The graph is based on the annual mean concentration values for each Member State. For each Member State, 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.

Source: EEA, 2016a.

The hourly limit value threshold for NO_2 is less stringent. Concentrations above this limit value were observed in 2014 in 0.5 % of all the reporting stations, mostly at urban traffic stations except for two (urban and suburban) background stations. They were observed in seven Member States ([27]).

6.2.2 Trends in ambient NO_2 concentrations

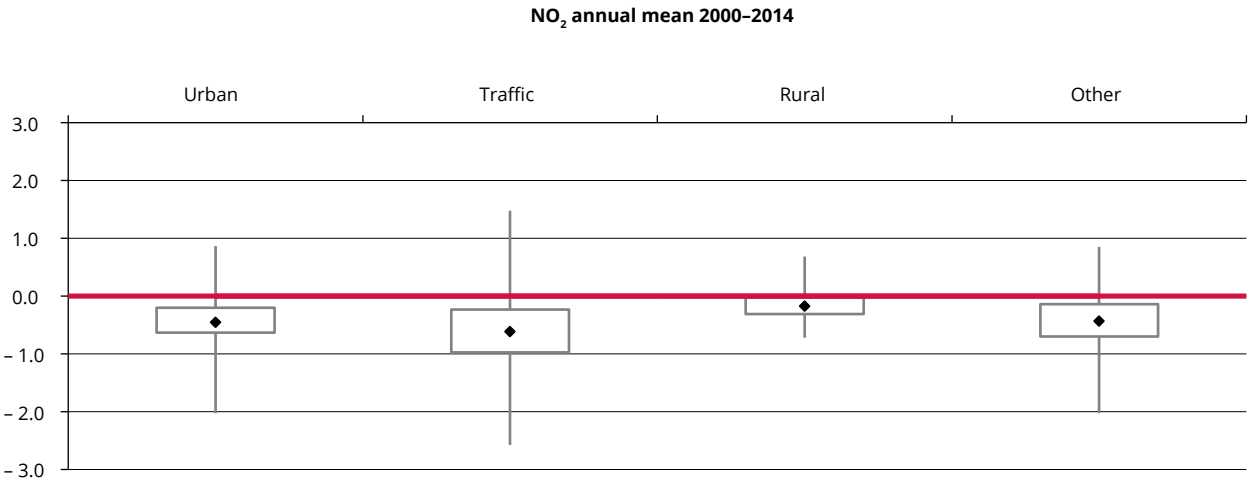
The average trends in NO_2 annual mean concentrations over 2000–2014 are summarised in Figure 6.2 for different types of stations ([28]). It shows that there is an average downward trend in NO_2 concentrations at all types of station. The observed annual mean NO_2 concentrations show a significant negative trend at 70 %, 61 % and 55 % of the urban, traffic and rural stations, respectively. In absolute terms the downward trend was stronger at traffic stations than at urban stations, since concentrations close to traffic are considerably higher. In relative terms the opposite was found: the relative change in urban concentrations is – 24 %, while it is – 20 % at traffic stations, for the whole 15-year period. This reflects the increase in the NO_2/NO_X emission ratio from diesel cars, offsetting the decrease in NO_X emissions, which is large (39 % in total and 44 % for EU-28 traffic emissions).

Table A1.6 (Annex 1) shows the calculated NO_2 annual mean trends by country and by station type over 2000–2014. All countries had an average downward trend at urban and suburban background and traffic stations. On the other hand, a few countries (Hungary, Ireland, Latvia, Lithuania, Luxembourg, Poland and Slovenia) registered increasing trends at rural background stations, but these were mostly not significant.

Averaged over 2010–2014, 9 % of the stations (in a consistent set) showed concentrations above the NO_2 annual mean limit value. Assuming we can extrapolate the observed trend over those five years to 2020, the proportion of stations with concentrations above

([27]) Spain (five stations), Germany (three) and France, Hungary, Italy, Portugal and the United Kingdom (one station each).
([28]) Based on a consistent set of 1 261 stations with data for 2000–2014, with a minimum data coverage of 75 % of valid data per year, for at least 11 years of the 15-year period.

Figure 6.2 Trends in NO_2 annual mean concentrations by station type, 2000–2014



Note: The graph is based on the annual mean concentration trends. It presents the range of concentration changes (in µg/m³/year) for each station type. The trends are calculated based on the officially reported data by the countries with a minimum data coverage of 75 % of valid data per year, for at least 11 years of the 15-year period. The diagram indicates the lowest and highest trends, the means and the lower and upper quartiles, per station type. The lower quartile splits off the lowest 25 % of the data, and the upper quartile splits off the highest 25 % of the data.

the annual limit value would only be reduced to 7 % in 2020. As for the cases of PM and ozone, this shows the importance of new measures that are to be implemented in order to meet the goals stated in the Clean Air Policy Package for Europe (European Commission, 2013b) (see also Box 6.1).

6.2.3 Relationship of nitrogen oxides emissions and nitrogen dioxide concentrations

As is true of 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). The transport sector contributed the highest share of NO_x emissions (46 % in the EU-28) in 2014, followed by the energy and industry sectors (see Section 2.3). Furthermore, the contribution of the transport sector to ambient NO_2 concentrations, especially in urban areas, is considerably higher, because these are emitted close to the ground and distributed over large areas.

The average decrease in annual mean NO_2 concentrations measured over all stations in Europe is slower than the decrease in NO_x emissions (see Section 4.2.3). This may be partly attributed to the increase in the proportion of NO_2 in the NO_x emissions from diesel vehicles (Grice et al., 2009; ETC/ACC, 2010b).

Box 6.1 Nitrogen oxides from road transport

For certain pollutants, such as NO_X and CO_2, there is a wide gap between official emission measurements and the average real-world driving emissions. This gap has increased in recent years, counteracting the effect of more stringent emission regulations. The amount of fuel that cars use on the road, and hence also the CO_2 emissions, was in 2014 around 40 % higher than the official measurements (EEA, 2016d). The differences are even higher for NO_X emissions, in particular for diesel vehicles, where average real-world emissions can be more than four times or higher than those measured in the laboratory under test conditions.

As illustrated in Figure 6.3, real-world NO_X emissions from petrol cars in the EU have decreased significantly since 2000, in line with the increasingly stringent emissions limits. In contrast, NO_X emissions from diesel cars have not improved much over the same period, meaning reductions have not been as large as planned in legislation. In addition, until the Euro 6 regulations came into force, diesel cars were already permitted to emit three times as much NO_X as petrol cars (EEA, 2015b).

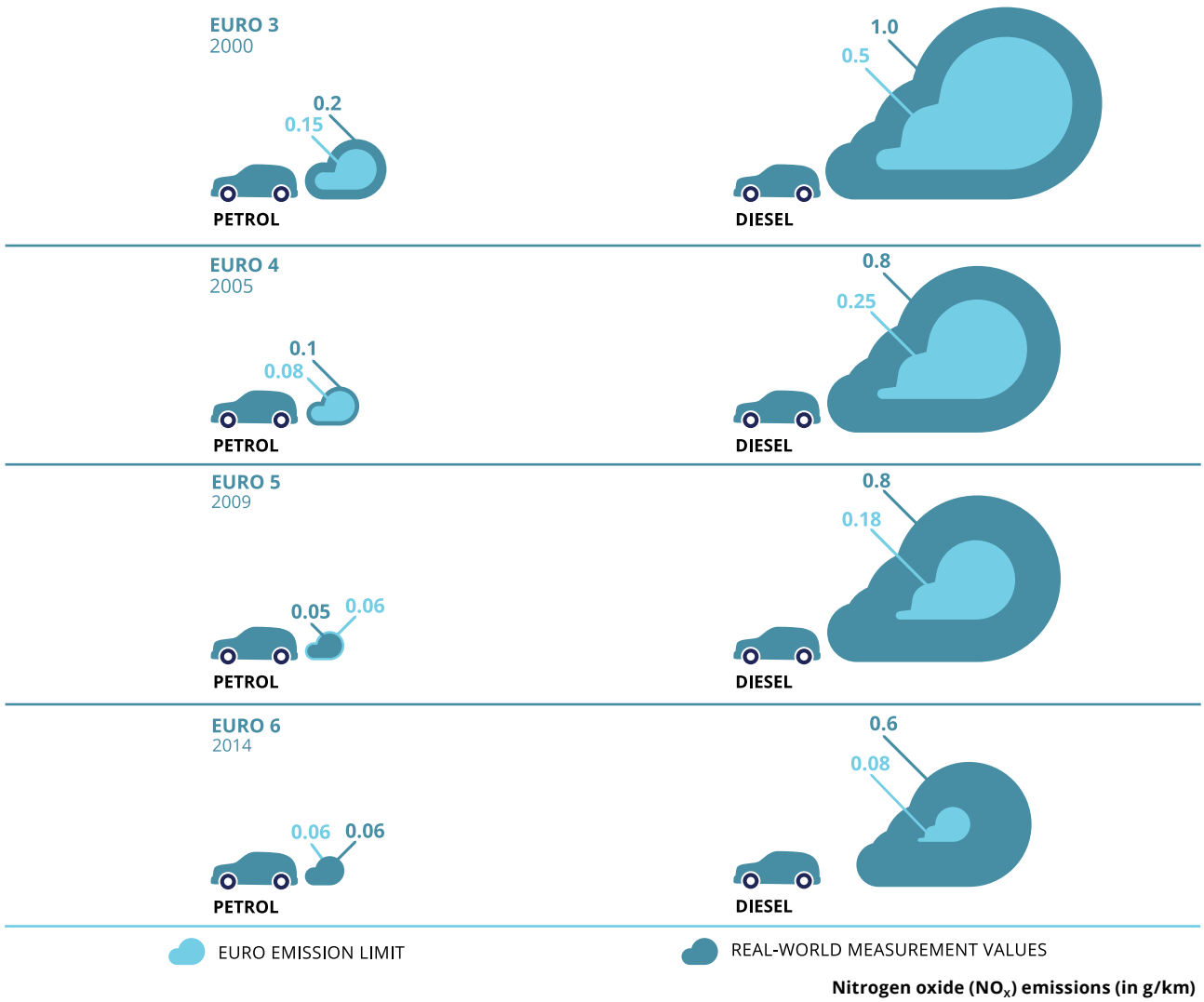
The discrepancy between real-world and test-cycle emissions has been highlighted for a number of years (EEA, 2005; Rubino et al., 2007, 2009; Weiss et al., 2011a,b, 2012; Vojtisek-Lom et al., 2009). The 'New European Drive Cycle' (NEDC) test cycle used over past decades within the EU to measure emissions in the laboratory is not representative of real-world driving conditions, and the test procedure contains flexibilities that manufacturers can exploit to get lower emission results. Furthermore, in some cases there is evidence that emissions are optimised for the test conditions only. These include, for example, manufacturers enabling exhaust after-treatment systems only within a certain temperature range used when the vehicle is tested.

Diesel vehicles accounted for about 52 % of new cars sold in the EU in 2014 (EEA, 2016e). The fact that NO_X emissions from diesel cars are considerably higher than intended in the Euro 5 and Euro 6 regulations for diesel vehicles affects the ability of Member States to comply with the limit and target values set by the Ambient Air Quality Directive for NO_2 in particular, but also for ambient air concentrations of O_3, PM_{10} and $PM_{2.5}$, for which NO_X is a precursor.

Improvements in engine technology have reduced exhaust emissions, but are generally insufficient in themselves to meet the required exhaust emission limits. In addition, exhaust after-treatment technologies (e.g. selective catalytic reduction and diesel particulate filters) are now necessary and allow the required emission standards to be met, if they are correctly used.

Two initiatives are planned in Europe to ensure a better consistency between official and real-world driving vehicle emissions: changing the official test procedure to one that is more representative of real-world emissions; and introducing a procedure for measuring the real driving emissions of vehicles on the road (EEA, 2016d). Stricter approval and market surveillance of motor vehicles is also planned, to better harmonise enforcement practices across EU Member States and which would increase the opportunities for vehicle recalls in case of non-compliance.

Figure 6.3 Comparison of NO_x standards and emissions for different Euro classes



Source: EEA, 2016d.

7 Benzo[*a*]pyrene

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

BaP is a potent carcinogen. The target value for BaP for the protection of human health is set at 1 ng/m^3 ([29]) (EU, 2004) as an annual mean (Table 7.1). The WHO has not recommended a guideline value for BaP. The estimated reference level presented in Table 7.1 (0.12 ng/m^3) was estimated assuming WHO unit risk (WHO, 2010) for lung cancer for PAH mixtures and an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000 (ETC/ACM, 2011).

7.2 Status and trends in concentrations

BaP is a PAH mainly found in fine PM. The Air Quality Directive (EU, 2004) prescribes that BaP concentration measurements should be made in the PM_{10} fraction. Despite this requirement, available data in any PM fraction were used in the current analysis. The justification is that most of the BaP is present in $PM_{2.5}$ and 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 ([30]).

7.2.1 Concentrations in relation to the target value

Ambient air concentrations of BaP are high across large parts of Europe, mostly as a result of emissions from the domestic combustion of coal and wood. Only 20 ([31]) EU-28 countries, together with Norway, reported BaP data with sufficient data coverage ([32]) for 2014. This is fewer than in 2013. As Map 7.1 shows, more than a third of the reported BaP measurement stations in Europe measured annual concentrations above 1.0 ng/m^3 in 2014. Values above 1.0 ng/m^3 were measured mainly at urban and suburban stations; 94 % of all stations with values above 1.0 ng/m^3 were in urban and suburban locations, and 79 % of all values above 1.0 ng/m^3 were measured at suburban and urban background stations. As in previous years, these values above 1.0 ng/m^3 are most predominant in central and eastern Europe (Austria, Bulgaria, Croatia, the Czech Republic, Hungary, Italy, Lithuania, and Poland), although they are also seen in Finland, Germany, Ireland and the United Kingdom.

Figure 7.1 shows the annual mean BaP values for 2014 for all EU Member States. It shows that average annual concentrations of BaP exceeded 1.0 ng/m^3 in the 12 countries mentioned above. The average concentration measured at Polish stations is 4.8 times as high as the target value.

Table 7.1 Air quality target value for BaP, as set out in the EU Air Quality Directive, and estimated reference level

Averaging period	EU Air Quality Directive	Reference level ([a])
Annual mean (ng/m^3)	1 ([b])	0.12

Notes: ([a]) As the WHO has not set an AQG for BaP, the reference level 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.

([b]) Measured as content in PM_{10}.

Source: EU, 2004b; ETC/ACM, 2011.

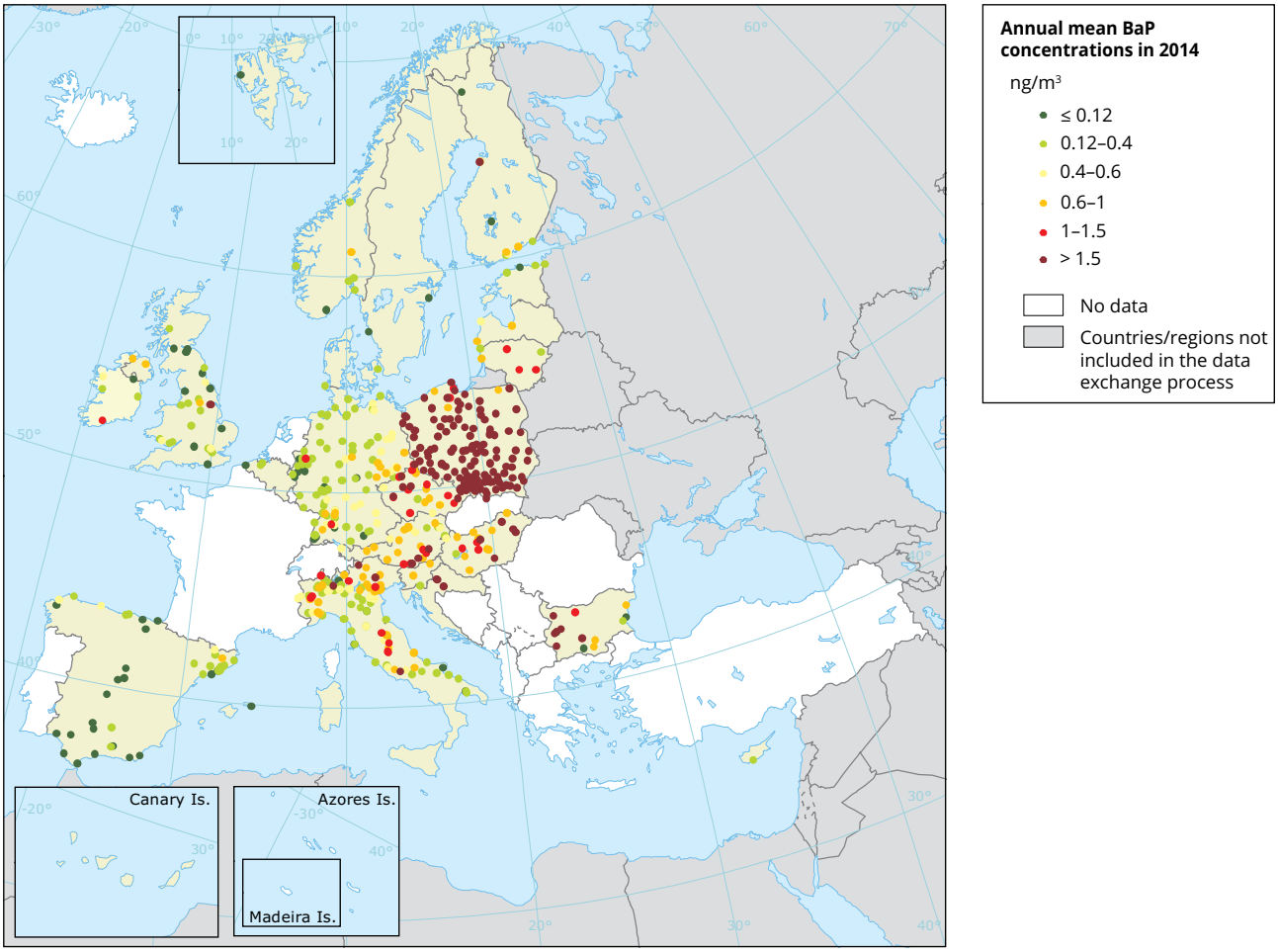
([29]) The target value is set at 1 ng/m^3, so this implies that for attainment analyses, all concentrations up to 1.49 would be rounded to 1 and this would imply below or equal to the target value. Nevertheless, for this assessment a value of 1.0 ng/m^3 is considered, so values equal or higher than 1.1 are considered as above 1.0.

([30]) For more information, see discussion by ETC/ACM, 2015.

([31]) France, Greece, Luxembourg, Malta, the Netherlands, Romania and Slovakia did not submit data. Portugal submitted data from one station with coverage below 14 %.

([32]) 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.

Map 7.1 Concentrations of BaP in 2014



Notes: Dark green dots correspond to concentrations under the estimated reference level (0.12 ng/m³). 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, 2016a.

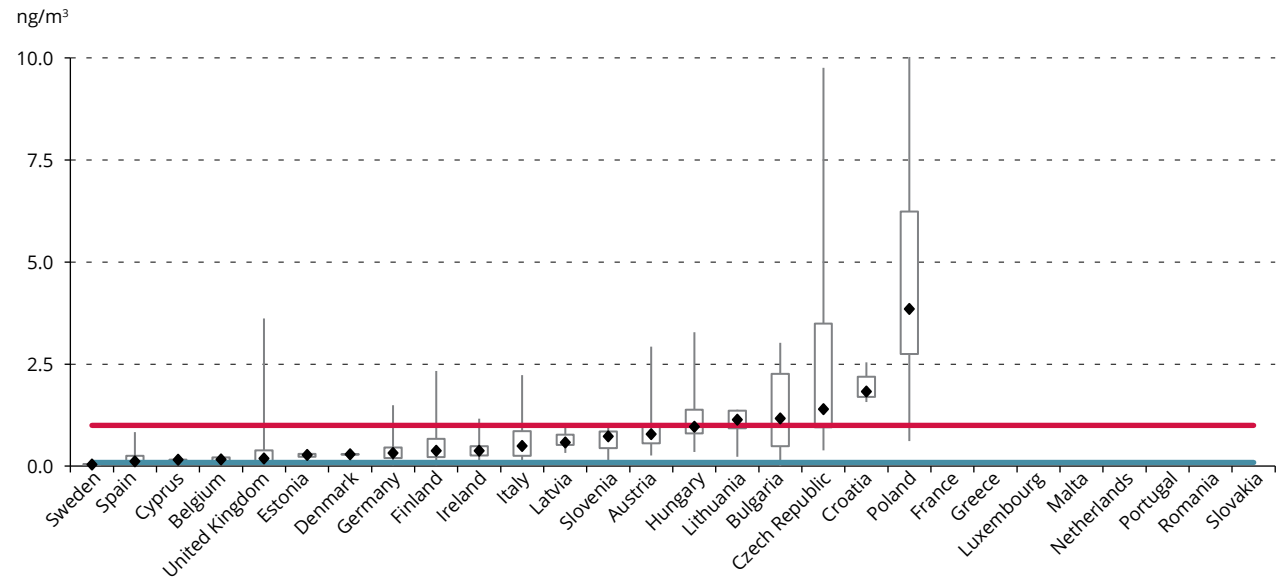
7.2.2 Trends in ambient BaP concentrations

The average trends in BaP annual mean concentrations over 2007–2014 are summarised in Figure 7.2 for different types of stations ([33]). On average, concentrations of BaP have decreased for all types of stations. BaP showed a downward trend at two thirds of the rural and urban stations between 2007 and 2014. At 22 % of these stations the downward trend was statistically significant.

Table A1.7 (Annex 1) shows the calculated BaP annual mean trends by country over the same 8-year period. Most countries had an average downward trend. See also the discussion in Section 3.3 on the relationships between concentrations and reported emission trends.

([33]) Based on a consistent set of 289 stations with data for 2007–2014, with a minimum data coverage of 14 % of valid data per year, for at least six years of the 8-year period.

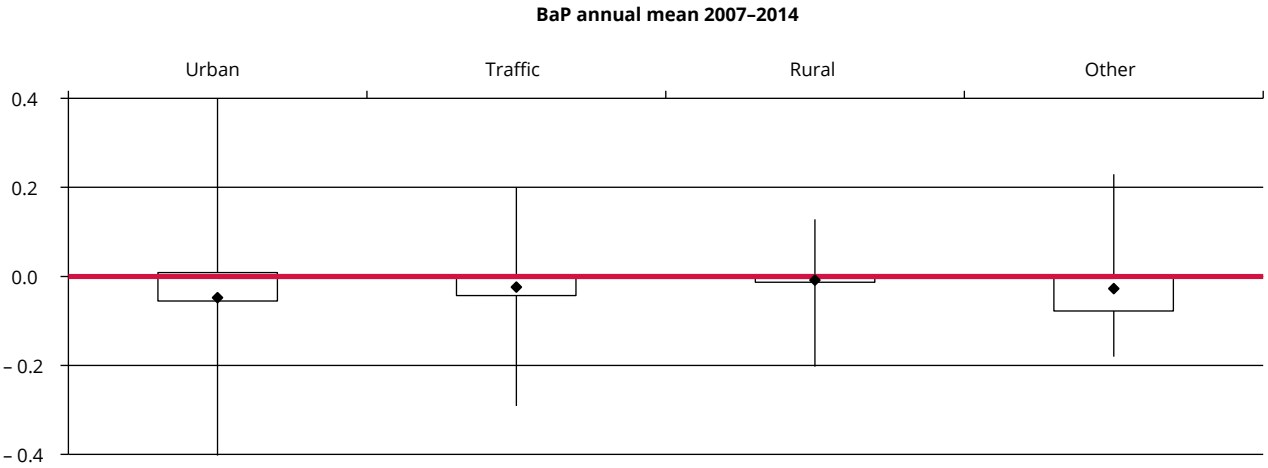
Figure 7.1 BaP concentrations in 2014 in the EU-28



Notes: The graph is based on the annual mean concentration values for each Member State. For each Member State, 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 .

Source: EEA, 2016a.

Figure 7.2 Trends of BaP annual mean concentrations by station type, 2007–2014



Notes: The graph is based on the annual mean concentration trends. It presents the range of concentration changes (in ng/m³/year) for each station type. The trends are calculated based on the data officially reported by the countries with a minimum data coverage of 14 % of valid data per year, for at least 6 years of the 8-year period. The diagram indicates the lowest and highest trends, the means and the lower and upper quartiles, for each station type. The lower quartile splits off the lowest 25 % of the data, and the upper quartile splits off the highest 25 % of the data.

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

8.1 European air-quality standards and World Health Organization guidelines

Table 8.1 presents the European air-quality standards and the WHO guidelines for SO_2. The limit values for SO_2 are specified for 1-hour averages and for 24-hour averages. Countries were obliged to meet both health protection limits by 2005. There is also an 'alert' threshold value of 500 µg/m³. When this alert threshold is exceeded over three consecutive hours, authorities have to implement action plans to lower the high levels of SO_2. The WHO AQG for SO_2 (WHO, 2006) is significantly more stringent than the limit values set by the Ambient Air Quality Directive (EU, 2008).

Table 8.2 presents the limit values for CO, Pb and C_6H_6 and the target values for As, Cd and Ni established in the Ambient Air Quality Directives (EU, 2004, 2008) for health protection, as well as the WHO AQGs for CO, Cd and Pb and the reference levels for As, Ni and C_6H_6. The European limit value and the WHO guideline for the maximum daily 8-hour mean of CO are the same and should have been met by 2005 (EU, 2008).

The limit value for C_6H_6 is set as an annual mean, given that C_6H_6 is a carcinogen with long-term effects. It should have been met by 2010. As for PAHs, the WHO has not provided a guideline for C_6H_6, and the reference level presented in Table 8.2 was 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).

The Air Quality Directive (EU, 2004) set target values for long-term exposure to the toxic metals As, Cd and Ni, to be met by 2013, and the Ambient Air Quality Directive (EU, 2008) set a limit value for Pb, also as an annual mean, to be met by 2005. 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. A protocol on heavy metals, including Hg, was adopted in 2003 under the UNECE CLRTAP. It aimed to limit emissions of Hg.

Table 8.1 Air-quality standards for SO_2 as given in the EU Ambient Air Quality Directive and WHO air quality guidelines

Averaging period	EU Air Quality Directive		WHO AQG (µg/m³)
	Objective and legal nature	Concentration (µg/m³)	
10 minutes			500
1 hour	Human health limit value	350, not to be exceeded on more than 24 hours per year	
	Alert threshold (a)	500	
1 day	Human health limit value	125, not to be exceeded on more than 3 days per year	20
Calendar year	Vegetation critical level	20	
Winter (1 October–31 March)	Vegetation critical level	20	

Note: (a) To be measured over 3 consecutive hours at locations representative of air quality over at least 100 km² or an entire zone or agglomeration, whichever is the smaller.

Sources: EU, 2008; WHO, 2006.

Table 8.2 EU air-quality standards, WHO air quality guidelines and estimated reference levels for CO, toxic metals and benzene

	Averaging period	EU limit value	EU target value [a]	WHO AQG	Reference level [b]
CO	1 h			30 mg/m³	
	Maximum daily 8-hour mean	10 mg/m³		10 mg/m³	
Arsenic	Annual		6 ng/m³		6.6 ng/m³
Cadmium	Annual		5 ng/m³	5 ng/m³ [c]	
Nickel	Annual		20 ng/m³		25 ng/m³
Lead	Annual	0.5 µg/m³ [a]		0.5 µg/m³	
Benzene	Annual	5 µg/m³			1.7 µg/m³

Notes: Units in ng/m³, except for CO (mg/m³) and lead and benzene (µg/m³).

[a] Measured as contents in PM_{10}.

[b] As the WHO has not set an AQG for As, Ni or benzene, the reference level is estimated assuming an acceptable risk of additional lifetime cancer risk of approximately 1 in 100 000.

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

Sources: EU, 2004, 2008; WHO, 2000, 2006a; ETC/ACM, 2011.

Photo: © Giulia D'Addario, My City/EEA

8.2 Status and trends in concentrations

8.2.1 Sulphur dioxide

SO_2 concentrations are generally well below the limit values for the protection of human health. The four existing SO_2 monitoring stations in Iceland registered concentrations above the daily limit value, due to the eruption at Holuhraun (see Box 8.1). In addition, one industrial station in Bulgaria, out of some 1 350 stations measuring SO_2 in 34 European countries ([34]), also registered concentrations above this limit value.

8.2.2 Carbon monoxide

The highest CO levels are found in urban areas, typically during rush hour at traffic locations or downwind from large industrial emissions. Of the 786 operational stations with more than 75 % of valid data in 32 EEA member and cooperating countries ([35]), only one station, an urban industrial station located in the former Yugoslav Republic of Macedonia, registered concentrations above the CO limit value and the WHO AQG value in 2014.

Averaged for all station types, CO concentrations decreased by around 45 % from 2000 to 2014, in line with the decrease in total emissions. In rural background stations alone, the decrease was less pronounced (around 11 %), since concentrations are very low and close to the detection limit.

8.2.3 Toxic metals

Monitoring data for toxic metals are missing for parts of Europe. This is probably because concentrations are generally low and below the lower assessment threshold ([36]) (LAT) specified in the Ambient Air Quality Directives, allowing assessment to be made by modelling or objective estimates. In 2014,

Box 8.1 SO_2 emissions from the Bárðarbunga eruption at Holuhraun, Iceland

The eruption of the Icelandic volcano Bárðarbunga, at the Holuhraun fissure, from 31 August 2014 to February 2015, was a so-called fissure eruption, emitting a large amount of SO_2 into the lowermost troposphere. It was the largest eruption in Iceland for more than 200 years, emitting a total of 11 ± 5 Mt SO_2, equivalent to more than the total anthropogenic SO_2 emissions in Europe in 2011 (Gíslason et al., 2015). Schmidt et al. (2015) estimated that during the eruption the daily volcanic SO_2 emissions exceeded European anthropogenic emissions by at least a factor of three.

Measurements show that the ground-level concentration of SO_2 exceeded the hourly limit value of 350 µg/m³ over much of Iceland for days to weeks during the six months of eruption. Prior to the Bárðarbunga eruption, monitoring stations in Iceland had never recorded exceedance of the 350 µg/m³ hourly limit. Elevated dissolved sulphuric acid (H_2SO_4), hydrogen chloride (HCl), hydrogen fluoride (HF) and metal concentrations were measured in snow and precipitation in Iceland. The lowest pH of fresh snowmelt at the eruption site was 3.3, and 3.2 in precipitation 105 km away from the source (Gíslason et al., 2015).

The volcanic SO_2 emissions were transported over long distances and detected by air-quality monitoring stations up to 2 700 km away from the source. This was, for example, the case at five stations in Austria on 22 September, which measured hourly concentrations above 200 µg/m³ in both rural and suburban background areas. Abnormally high SO_2 concentrations were measured in many European countries on different days in September 2014. Peak hourly mean concentrations were measured between 4 and 11 September in Ireland (up to 500 µg/m³, including peaks on 16 and 18 September) and Finland (up to 180 µg/m³, including on 30 September). During 18–30 September 2014, high SO_2 hourly mean concentrations were measured in Norway (up to 1 200 µg/m³), Scotland (above 300 µg/m³), the Czech Republic (up to 300 µg/m³, as well as peaks from 10 to 15 September), Belgium (up to 246 µg/m³), Germany (up to 145 µg/m³), the Netherlands (up to 114 µg/m³), England (above 80 µg/m³) and to a lesser extent France and Sweden (EEA, 2016a; Schmidt et al., 2015; Ialongo et al., 2015).

Satellite observations and dispersion model simulations also confirm that Bárðarbunga-Holuhraun volcanic emissions were transported from Iceland to parts of Europe (Schmidt et al., 2015; Ialongo et al., 2015).

([34]) EU-28, Albania, the former Yugoslav Republic of Macedonia, Iceland, Montenegro, Norway and Serbia.
([35]) EU-28 (except Croatia), Albania, the former Yugoslav Republic of Macedonia, Montenegro, Norway and Serbia.
([36]) The 'lower assessment threshold' is the level defined in the Ambient Air Quality Directives (EU, 2004, 2008) below which modelling or objective-estimation techniques alone may be used to assess ambient air quality.

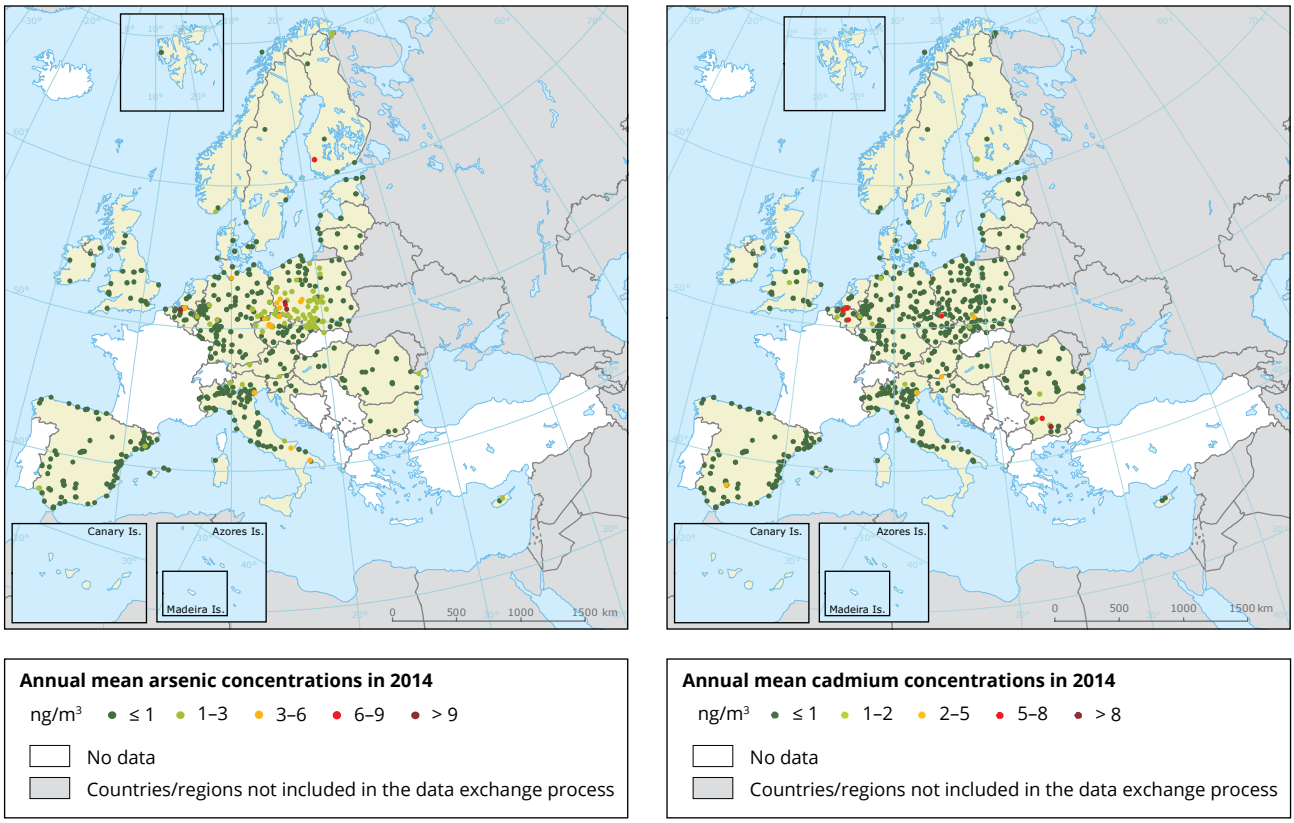
between 447 and 475 stations reported measurement data for each toxic metal (As, Cd, Pb and Ni), with a minimum data coverage of 14 %.

A problem in analysing the data of these pollutants is that it is not always certain (from the data made available by the countries) whether the concentrations have been measured in the PM_{10} fraction (as required by the directives) or in another (undefined) size fraction (e.g. particles of all sizes).

The air pollution problem caused by the toxic metals As, Cd, Pb and Ni is highly localised, as can be seen in Maps 8.1 and 8.2. That is because problems are typically related to specific industrial plants. The results from the reported 2014 data ([37]) can be summarised as follows:

- There were no stations reporting **Pb** concentrations above the 0.5 µg/m³ limit value in 2014. Some 97 % of the stations reported Pb concentrations below the LAT of 0.25 µg/m³.
- **As** concentrations below the LAT (2.4 ng/m³) were reported at 91 % of the stations in 2014. Seven stations reported concentrations above the target value (6 ng/m³), in both industrial and background urban areas, in Belgium (three), Poland (three) and Finland (one).
- **Cd** concentrations above the target value (5 ng/m³) were monitored at fewer than 10 stations in 2014. They were observed in seven stations in industrial or background urban/suburban areas. The countries reporting these concentrations above the

Map 8.1 Concentrations of arsenic and cadmium in 2014



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 8.2.

Only stations reporting more than 14 % of valid data have been included in the maps.

Source: EEA, 2016a.

([37]) Only 20 Member States have been included in the full analysis for As, Cd, Ni and Pb. France, Greece, Luxembourg, Malta and Slovakia did not submit data for any of the four metals. Portugal submitted data from one station with coverage below 14 %. Croatia and Hungary did not submit Pb data. Regarding the other EEA countries, Norway submitted data for As, Cd and Ni.

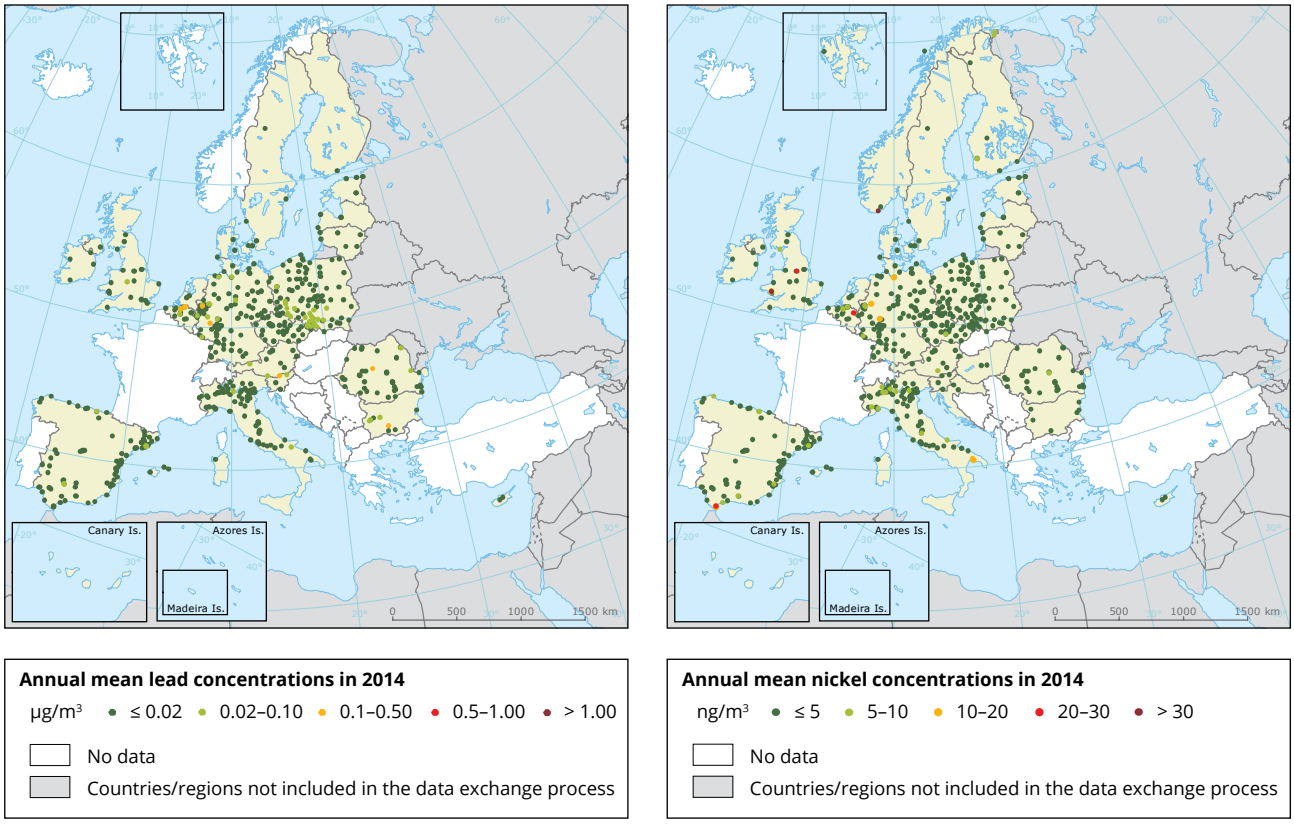
target value in 2014 were Belgium (four), Bulgaria (two) and the Czech Republic (one). At the great majority of the stations (95 %), Cd concentrations were below the LAT (2 ng/m³).

- **Ni** concentrations were above the target value of 20 ng/m³ at five stations, in Belgium (one), Norway (one), Spain (one) and the United Kingdom (two) ([38]). Some 98 % of the stations reported Ni concentrations below the LAT of 10 ng/m³.

- **Hg** concentrations recorded in the Air Quality e-Reporting Database are 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 40 stations ([39]) reported data on Hg in air with sufficient data coverage (14 %), of which about 89 % were classified as background stations. Reported concentrations of Hg in air in 2014 ranged from below the detection limit to 15 ng/m³ (observed at an urban industrial station in the United Kingdom).

While a steady decrease is registered for concentrations and deposition of Pb (7–9 %) and Cd (4–8 %), the reduction of modelled and measured Hg air concentrations was low (less than 0.5 % per year) over the last 20 years. Current Hg deposition fluxes are to a very large extent caused by sources outside the EMEP region and transported to Europe. Measurements of Ni and As in mosses over the last 15 years also reflect a decline in Ni and As deposition (de Wit et al., 2015).

Map 8.2 Concentrations of lead and nickel in 2014



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 8.2.

Only stations reporting more than 14 % of valid data have been included in the maps.

Source: EEA, 2016a.

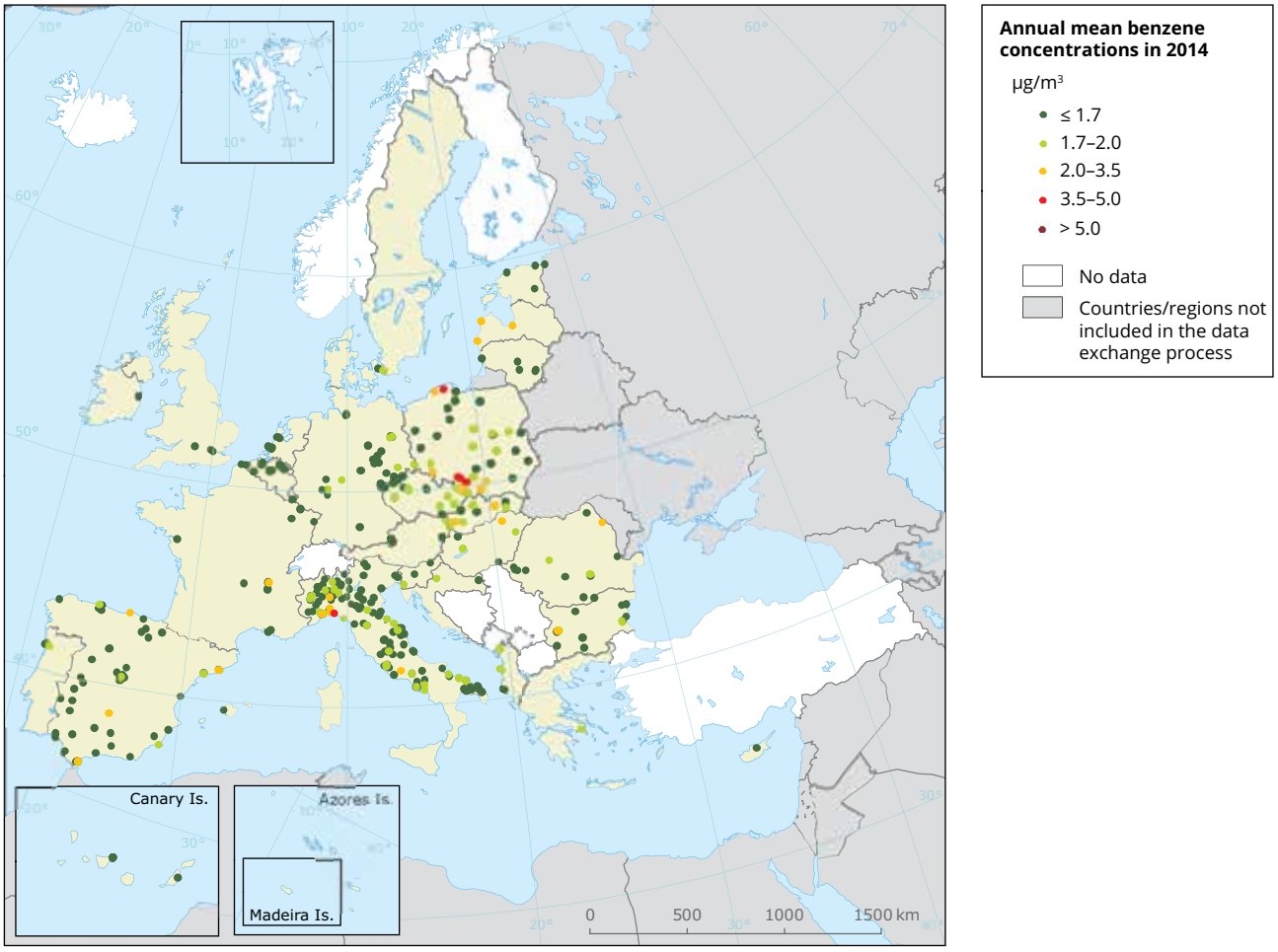
([38]) All were industrial stations except one urban background station in the United Kingdom

([39]) In Belgium, Croatia, Cyprus, Finland, Germany, Ireland, Lithuania, Malta, Slovenia, Spain, Sweden and the United Kingdom. Furthermore, Austria, Finland, Germany, Hungary, Lithuania, the Netherlands, Poland, Slovenia, Spain and the United Kingdom have reported data on Hg in deposition.

8.2.4 Benzene

C_6H_6 is measured at a relatively small number of stations. Only stations with at least 50 % data coverage were used in the analysis, i.e. around 400 stations. When concentrations are below the LAT, air quality can be assessed by means of indicative or discontinuous measurements, by modelling or by objective estimates. At 86 % of locations, annual mean concentrations of C_6H_6 were below the LAT of 2 µg/m³ in 2014 (Map 8.3). No values above the limit value were reported in 2014. Over 2000–2014, benzene concentrations showed a decrease of more than 70 % (see Section 5.2.3).

Map 8.3 Concentrations of benzene in 2014



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, 2016a.

9 Population exposure to air pollutants in European urban areas

Health effects are related to both short-term and long-term exposure to air pollution. Short-term exposure (over a few hours or days) is linked with acute health effects, whereas long-term exposure (over months or years) is linked with chronic health effects. The Ambient Air Quality Directives and the WHO define respectively, air-quality standards and guidelines, for the protection of human health. 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.

The monitoring data reported by the countries (EEA, 2016a) provide the basis for estimating the exposure of the urban European population to exceedances of the most stringent European air-quality standards and WHO guidelines. 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 (2016f).

Table ES.1 shows the percentage of the EU-28 urban population exposed to concentrations above certain EU limit or target values, WHO AQG levels and estimated reference levels between 2012 and 2014.

9.1 Particulate matter

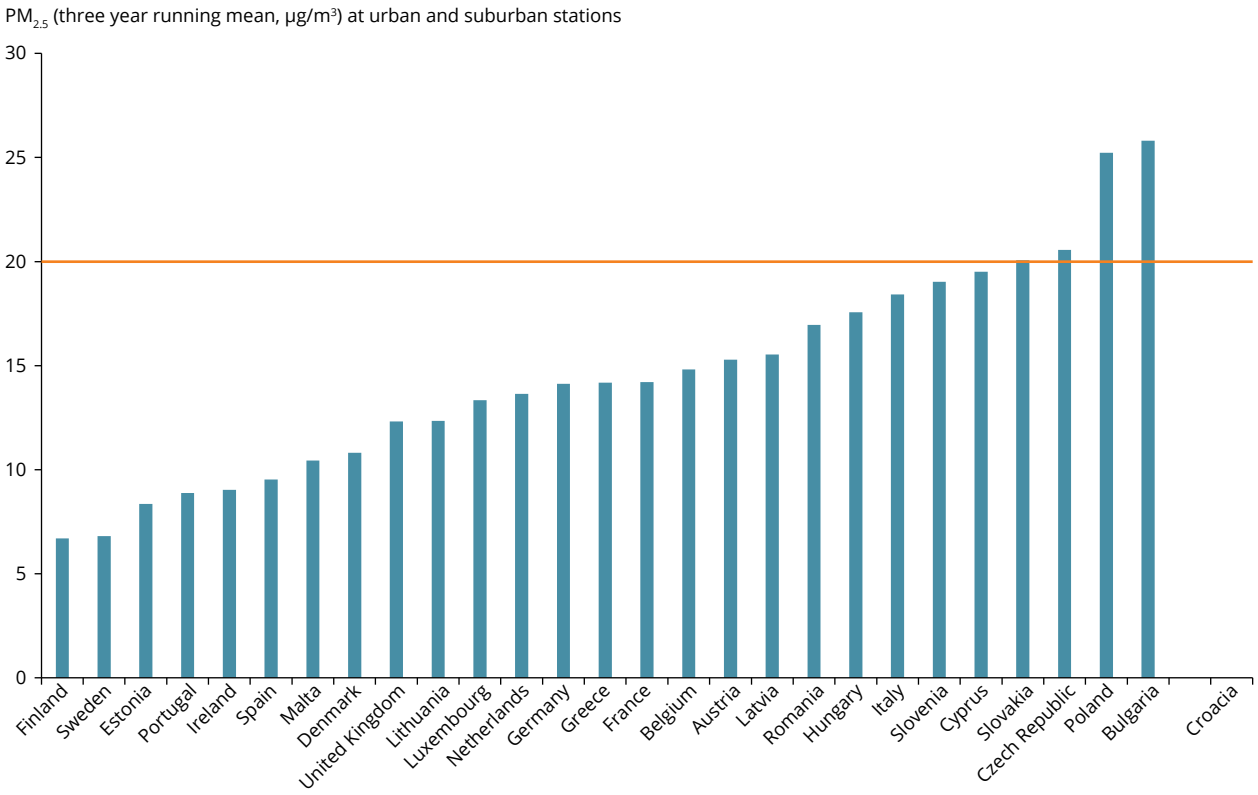
In 2014, about 16 % of the EU-28 urban population was exposed to PM_{10} above the EU daily limit value (i.e. 50 µg/m^3 not to be exceeded on more than 35 days per calendar year, for short-term exposure). The extent of exposure above this EU daily limit value fluctuated between 16 % and 42 % over 2000–2014, and between 16 % and 21 % from 2012 to 2014 (Table ES.1). Furthermore, up to 50 % of the same urban population was exposed to concentrations exceeding the stricter WHO AQG value for PM_{10} (annual mean, for long-term exposure) in 2014. The percentage of the urban population exposed to levels above the WHO annual AQG (20 µg/m^3) ranged between 50 % and 92 % in 2000–2014, and between 50 % and 63 % in 2012–2014 (Table ES.1). These ranges partly reflect variations attributable to meteorology and changes in the subset of cities and stations included in the year-to-year estimates. It should be noted that 2014 was the year with the lowest percentages of urban population exposed to PM_{10} concentrations exceeding the EU limit value and WHO guideline. It was the first time that less than half of the European urban population was exposed to concentrations exceeding the WHO guideline for long-term exposure (annual mean).

For $PM_{2.5}$, the Ambient Air Quality Directive (EU, 2008) introduced a target value (25 µg/m^3 annual mean) to be attained by 2010, which became a limit value starting in 2015 (see Table 4.1). In 2014, about 8 % of the EU-28 urban population was exposed to $PM_{2.5}$ above the target value. The percentage of the EU-28 urban population exposed to levels above the $PM_{2.5}$ target value was in the range of 8 % to 12 % in 2012–2014. The urban population's exposure to levels above the more stringent WHO AQG (10 µg/m^3 as annual mean) for $PM_{2.5}$ fluctuated between 85 % and 91 % in 2012–2014 (Table ES.1). Similarly to PM_{10}, 2014 (together with 2013) saw the lowest percentages of urban population exposure to $PM_{2.5}$ (both the EU target value and the WHO AQG).

The Ambient Air Quality Directive (EU, 2008) also set the national exposure reduction target and the exposure concentration obligation for human exposure to $PM_{2.5}$ based on the AEI, set at national level. The AEI is an averaged level of concentrations (over a 3-year period), measured at urban background monitoring stations (representative of general urban population exposure) selected for this purpose by every national authority. In the absence of a calculated AEI for every country, Figure 9.1 shows instead the 3-year averaged concentrations from measurements at all urban and suburban background stations with 75 % of valid data. Figure 9.1 is therefore not necessarily based on the same set of stations as the countries use to report the AEI but it is used as an approximation. It indicates that in three EU Member States the average urban concentrations in 2012–2014 were above 20 µg/m^3 ([40]).

([40]) 20 µg/m^3 is the legally binding level for the exposure concentration obligation to be met by 2015.

Figure 9.1 **Urban and suburban background $PM_{2.5}$ concentrations presented as 3-year averages in the EU-28 (2012–2014), as an approximation of the average exposure indicator**



Note: The 3-year running mean of $PM_{2.5}$ concentrations is calculated as the average over all operational urban or suburban background stations within a Member State in the period 2012–2014.

Source: EEA, 2016a.

9.2 Ozone

In 2014, about 8 % of the EU-28 population in urban areas was exposed to O_3 concentrations above the EU target value threshold. This percentage represents the minimum value since 2000. The percentage of the urban population exposed to O_3 levels above the target value threshold has fluctuated between 8 % and 55 % since 2000. Table ES.1 shows the range in 2012–2014 (8 % to 17 %). These variations are partly caused by meteorological variation.

The percentage of the EU-28 urban population exposed to O_3 levels exceeding the WHO AQG value is significantly higher than for the EU target value, as the WHO AQG is much stricter (see Table 5.1). About 96 % of the total EU-28 urban population was exposed to O_3 levels exceeding the WHO AQG in 2014, and proportions fluctuated between 94 % and 99 % between 2000 and 2014.

9.3 Nitrogen dioxide

About 7 % of the EU-28 urban population was exposed to NO_2 above the EU annual limit value and the WHO NO_2 AQG value (both 40 µg/m³ as an annual mean) in 2014. The percentage of the urban population exposed to concentrations above the annual limit value fluctuated between this minimum value of 7 % and 31 % in 2000–2014, and between 7 % and 9 % in 2012–2014 (Table ES.1). The range partly reflects variations caused by meteorology and the decreasing concentrations of NO_2 at urban locations.

9.4 Benzo[*a*]pyrene

Between 20 % and 24 % of the urban population in the EU-28 was exposed to BaP concentrations above 1.0 ng/m³ as an annual mean in 2012–2014, whereas 88 % to 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. The proportions of the EU-28 urban population exposed to BaP levels exceeding the EU target value and the estimated reference level were 24 % and 88 %, respectively, in 2014.

9.5 Sulphur dioxide

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 been under 0.5 %.

The EU-28 urban population exposed to SO_2 levels exceeding the WHO AQG (20 µg/m^3 as a daily mean) in 2012–2014 amounted to 35–49 % of the total urban population (Table ES.1). SO_2 levels have decreased since 2000, when 85 % of the EU-28 urban population was exposed to SO_2 levels exceeding the WHO AQG.

9.6 Carbon monoxide

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, and is limited to a very few areas near traffic and industry. In 2014, the only concentration above the limit value was registered at an urban industrial station in the former Yugoslav Republic of Macedonia.

9.7 Toxic metals (arsenic, cadmium, lead and nickel)

Human exposure to As, Cd, Pb and Ni ambient air concentrations above the limit or target values is a local problem, 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, thus affecting human health.

9.8 Benzene

Exposure in Europe to C_6H_6 concentrations above the limit value is limited to a few local areas with higher concentrations, which are often close to traffic or industrial sources. In 2014, no exceedances of the limit value were observed.

Photo: © Lorenzo Gaudenzi, My City/EEA

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

The health impacts of air pollution can be quantified and expressed as 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 occurrence of illness and years lived with a disease or disability, ranging from subclinical effects 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, especially in major cities where concentrations tend to be higher than in rural areas (with the exception of ozone). Most of the evidence on the health impacts of pollution tends to focus on premature mortality, as well as respiratory, cardiovascular and cerebrovascular effects attributed to exposure to air pollution (WHO, 2008, 2013b), but evidence also exists of a range of other effects.

The health impacts from air pollution can be estimated using different health outcomes (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 2013 ([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 (annual mean concentration for $PM_{2.5}$ and NO_2, and SOMO35 for O_3; ETC/ACM, 2016b) are based on the Air Quality e-Reporting Database (EEA, 2016a) monitoring data measured at regional and urban background stations in 2013, auxiliary information, such as meteorological data, and concentrations modelled with the EMEP chemical dispersion model. The demographic data and the health-related data were taken from the United Nations (UN, 2015) and the WHO (2016), 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). For $PM_{2.5}$, impacts have been estimated for the full range of observed concentrations, meaning all $PM_{2.5}$ is considered, even that of natural origin; for NO_2, impacts have been estimated for levels above 20 µg/m^3 ([42]). A further description and details on the methodology are given by the ETC/ACM (2016c).

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 premature deaths, in addition to the population for each country for

Box 10.1 Different ways of estimating health impacts

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 years that a person would have lived if he or she had not died prematurely. YLL take into account the age at which deaths occur, giving greater weight to deaths at a younger age and lower weight to 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. 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 2013 (ETC/ACM, 2016c)

([42]) The studies in HRAPIE showed that for NO_2 the size of the effect is less certain below 20 µg/m^3. However, this recommendation might be too conservative (Héroux et al., 2015) and there is continued work to provide more guidance on this.

comparison between countries. In the 41 countries listed, 467 000 premature deaths are attributed to $PM_{2.5}$ exposure, 71 000 to NO_2 exposure and 17 000 to O_3 exposure. In the EU-28, the premature deaths attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 436 000, 68 000 and 16 000, respectively ([43]).

Table 10.2 presents the estimated number of years of life lost (YLL) and the YLL per 100 000 inhabitants due to exposure to $PM_{2.5}$, NO_2 and O_3 in Europe for 2013. In total, in the 41 countries assessed, 4 982 000 YLL are attributed to $PM_{2.5}$ exposure, 756 000 YLL to NO_2 exposure and 192 000 YLL to O_3 exposure. In the EU-28, the YLL attributed to $PM_{2.5}$, NO_2 and O_3 exposure are 4 668 000, 723 000 and 179 000, respectively ([44]).

For $PM_{2.5}$, the highest numbers of YLL are estimated for the countries with the largest populations (Germany, Italy, France and the United Kingdom). 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. Kosovo under the UN SCR 1244/99, Bulgaria, the former Yugoslav Republic of Macedonia, Poland, Serbia, Hungary, Romania, Greece, the Czech Republic and Slovakia.

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

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, most of the countries in the Western Balkans and Hungary.

The impacts estimated for each pollutant may not be added to determine the total impact attributable to exposure to these three pollutants, because concentrations are (sometimes strongly) correlated. This may lead to a double counting of up to 30 % of the effects of $PM_{2.5}$ and NO_2 (WHO, 2013b). This possible double counting has not been corrected for.

Variations from one year to another are proportional, in the case of $PM_{2.5}$, to the changes in population and weighted-population concentrations. This is not the case for NO_2, for which only concentrations above 20 µg/m^3 are considered. In this case, the most determining factor is the percentage of the population exposed to levels above 20 µg/m^3.

([43]) These figures have the following confidence intervals (CIs; the CI gives the upper and lower boundaries of the 95 % confidence interval of the estimate taking into account only the uncertainty in the relative risk):
- for premature deaths in all the countries attributed to $PM_{2.5}$, 310 000–608 000; to NO_2, 41 000–102 000; and to O_3, 8 000–26 000;
- for premature deaths in the EU-28 attributed to $PM_{2.5}$, 289 000–569 000; to NO_2, 39 000–97 000; and to O_3, 8 000–24 000.

([44]) With the following CIs:
- for YLL in all the countries attributed to $PM_{2.5}$, 3 307 000–6 495 000; to NO_2, 436 000–1 077 000; and to O_3, 93 000–284 000;
- for YLL in the EU-28 attributed to $PM_{2.5}$, 3 098 000–6 087 000; to NO_2, 417 000–1 030 000; and to O_3, 86 000–265 000.

Table 10.1 Premature deaths attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28 in 2013

Country	Population	$PM_{2.5}$		NO_2		O_3	
		Annual mean ([c])	Premature deaths	Annual mean ([c])	Premature deaths	SOMO35 ([c])	Premature deaths
Austria	8 451 860	15.7	6 960	19.3	910	5 389	330
Belgium	11 161 642	16.6	10 050	23.6	2 320	2 520	210
Bulgaria	7 284 552	24.1	13 700	16.5	570	4 082	330
Croatia	4 262 140	16.8	4 820	15.8	160	5 989	240
Cyprus	865 878	17.1	450	7.3	< 5	7 900	30
Czech Republic	10 516 125	19.6	12 030	17.1	330	4 266	370
Denmark	5 602 628	9.6	2 890	13.0	60	2 749	110
Estonia	1 320 174	7.8	690	10.8	< 5	2 545	30
Finland	5 426 674	5.9	1 730	9.4	< 5	2 011	80
France	63 697 865	14.5	45 120	18.7	8 230	4 098	1 780
Germany	80 523 746	14.2	73 400	20.4	10 610	3 506	2 500
Greece	11 003 615	19.7	13 730	14.6	1 490	8 532	840
Hungary	9 908 798	18.2	12 890	16.8	390	4 604	460
Ireland	4 591 087	9.2	1 520	11.6	30	2 043	50
Italy	59 685 227	18.2	66 630	24.5	21 040	6 576	3 380
Latvia	2 023 825	12.8	2 080	13.7	110	2 614	60
Lithuania	2 971 905	13.9	3 170	11.5	< 5	2 703	90
Luxembourg	537 039	14.3	280	23.4	80	3 167	10
Malta	421 364	12.5	230	12.0	< 5	7 403	20
Netherlands	16 779 575	14.3	11 530	21.3	1 820	2 410	270
Poland	38 062 535	22.8	48 270	16.1	1 610	3 792	1 150
Portugal	9 918 548	10.0	6 070	14.0	150	5 091	420
Romania	20 020 074	18.5	25 330	17.9	1 900	2 221	430
Slovakia	5 410 836	20.1	5 620	16.0	< 5	5 116	200
Slovenia	2 058 821	17.4	1 960	17.6	150	6 540	100
Spain	44 454 505	11.0	23 940	18.0	4 280	5 895	1 760
Sweden	9 555 893	6.0	3 020	11.5	< 5	2 317	160
United Kingdom	63 905 297	11.8	37 930	22.8	11 940	1 606	710
Albania	2 874 545	20.3	2 010	15.9	10	7 179	100
Andorra	76 246	11.9	40	14.3	< 5	7 303	< 5
Bosnia and Herzegovina	3 839 265	16.0	3 620	15.7	80	5 670	180
former Yugoslav Republic of Macedonia	2 062 294	30.4	3 360	20.8	210	6 326	100
Iceland	321 857	6.5	80	14.3	< 5	1 473	< 5
Kosovo ([a])	1 815 606	28.0	3 530	19.3	230	5 691	100
Liechtenstein	36 838	11.4	20	22.7	10	5 221	< 5
Monaco	36 136	13.8	20	23.2	10	7 795	< 5
Montenegro	620 893	17.1	600	17.2	30	6 674	30
Norway	5 051 275	7.1	1 590	14.4	170	2 443	70
San Marino	33 562	15.1	30	15.4	< 5	5 067	< 5
Serbia	7 181 505	21.1	10 730	20.2	1 340	4 505	320
Switzerland	8 039 060	13.9	4 980	22.4	1 140	4 919	240
Total ([b])			**467 000**		**71 000**		**17 000**
EU-28 ([b])			**436 000**		**68 000**		**16 000**

Notes: ([a]) Under the UN Security Council Resolution 1244/99.

([b]) Total and EU-28 figures are rounded up or down to the nearest thousand. The national totals to the nearest ten.

([c]) The annual mean (in $\mu g/m^3$) and the SOMO35 (in $(\mu g/m^3)$.day), expressed as population-weighted concentration, is obtained according to the methodology described by ETC/ACM (2016b), and not only from monitoring stations.

Table 10.2 Years of life lost (YLL) attributable to $PM_{2.5}$, NO_2 and O_3 exposure in 41 European countries and the EU-28 in 2013

Country	$PM_{2.5}$		NO_2		O_3	
	YLL	YLL/100 000 inhabitants	YLL	YLL/100 000 inhabitants	YLL	YLL/100 000 inhabitants
Austria	72 600	859	9 500	112	3 600	43
Belgium	103 600	928	23 900	214	2 300	21
Bulgaria	136 500	1 874	5 700	78	3 500	48
Croatia	47 800	1 122	1 600	37	2 500	58
Cyprus	4 700	540	< 10	0	300	37
Czech Republic	129 600	1 233	3 600	34	4 100	39
Denmark	31 600	563	600	12	1 300	23
Estonia	7 300	556	< 10	0	300	25
Finland	18 300	337	< 10	0	900	16
France	504 000	791	91 900	144	20 900	33
Germany	759 000	943	109 700	136	27 200	33
Greece	135 900	1 235	14 700	134	8 600	78
Hungary	138 700	1 400	4 200	42	5 100	51
Ireland	17 300	376	300	6	600	12
Italy	695 500	1 165	219 700	368	36 500	61
Latvia	22 000	1 085	1 200	57	600	32
Lithuania	31 600	1 063	< 10	0	900	30
Luxembourg	3 100	585	800	157	100	19
Malta	2 400	571	< 10	0	200	50
Netherlands	125 200	746	19 800	118	3 100	18
Poland	578 500	1 520	19 300	51	14 400	38
Portugal	62 700	632	1 600	16	4 500	45
Romania	265 700	1 327	19 900	100	4 800	24
Slovakia	63 100	1 167	< 10	0	2 400	45
Slovenia	21 400	1 037	1 700	80	1 200	56
Spain	253 100	569	45 300	102	19 300	43
Sweden	29 400	307	< 10	0	1 600	17
United Kingdom	407 400	637	128 300	201	8 100	13
Albania	21 000	730	100	3	1 200	43
Andorra	500	658	< 10	0	< 100	59
Bosnia and Herzegovina	38 700	1 007	900	23	2 000	52
former Yugoslav Republic of Macedonia	35 800	1 734	2 200	109	1 200	57
Iceland	900	269	< 10	0	< 100	9
Kosovo [a]	35 100	1 935	2 300	128	1 100	60
Liechtenstein	200	632	< 100	159	< 100	42
Monaco	300	760	< 100	160	< 100	62
Montenegro	6 700	1 083	300	52	400	64
Norway	16 200	321	1 700	34	800	16
San Marino	300	979	< 10	0	< 100	47
Serbia	107 000	1 490	13 400	186	3 400	47
Switzerland	51 400	639	11 700	146	2 700	33
Total [b]	**4 982 000**		**756 000**		**192 000**	
EU-28 [b]	**4 668 000**		**723 000**		**179 000**	

Note: YLL and YLL per 100 000 inhabitants: all-cause mortality.

[a] Under the UN Security Council Resolution 1244/99.

[b] Total and EU-28 figures are rounded up or down to the nearest thousand. YLL are rounded to the next hundred.

11 Impacts of air pollution on ecosystems

Air pollution also harms the environment. The atmospheric deposition of sulphur and nitrogen compounds has acidifying effects on soils and freshwaters. Acidification may lead to increased mobilisation of toxic metals, which increases the risk of uptake in the food chain. The deposition of nitrogen compounds can also lead to eutrophication, an oversupply of nutrients that may lead to changes in species diversity and to invasions of new species. It is estimated that 63 % of the total sensitive ecosystem area and even 73 % of the EU Natura 2000 ([45]) area was exposed to eutrophication in 2010 (EEA, 2014). Ground-level O_3 can damage crops and other vegetation, impairing their growth. In addition, toxic metals and persistent organic pollutants may have severe impacts on ecosystems. This is mainly because of their environmental toxicity, and in some cases also 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 concentration of a pollutant in the tissues of organisms at successively higher levels in the food chain.

The impacts of air pollution on the environment depend not only on the air pollutant emission rates but also on the location, potency, lifetime and reaction products of the emissions. Factors such as meteorology, physiography and topography are also important, as these determine the transport, chemical transformation and deposition of air pollutants. Furthermore, the environmental impacts of air pollution also depend on the sensitivity of ecosystems to toxins (e.g. O_3 and metals), acidification and eutrophication.

Determining the extent to which air pollutants affect biodiversity is complicated. Different pollutants affect species in a variety of ways. The mixture of air pollutants and their products to which organisms are exposed varies in composition, and each combination has a slightly different effect. Different pollutants in combination can sometimes have a greater effect (also called a cocktail effect) than the sum of the effects each one of them would have separately, while in other combinations they can cancel each other out.

11.1 Vegetation damage by ground-level ozone

Deposition on the Earth's surface is one of the principal mechanisms for removing O_3 from the atmosphere, in particular through absorption by plants. This absorption damages plant cells, impairing their ability to grow. In some sensitive plants, O_3 can cause leaves to exhibit what appear to be burn marks. By impairing plants' reproduction and growth, high levels of O_3 can thus lead to reduced agricultural crop yields, decreased forest growth and reduced biodiversity ([46]).

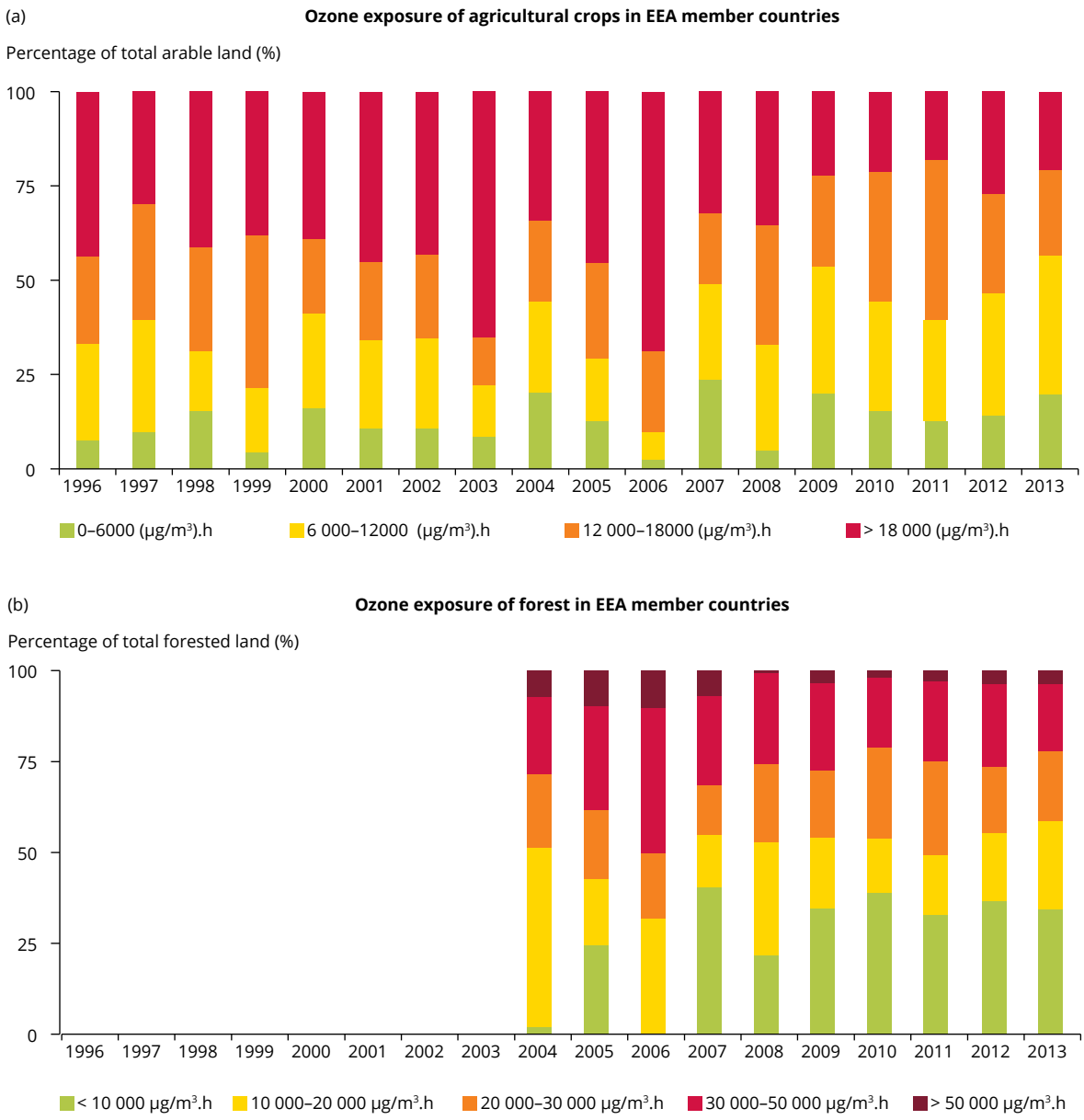
The EU has the objective of protecting vegetation from high O_3 concentrations accumulated over the growing season (defined as May to July, when typically higher O_3 concentrations coincide with the predominant growing periods in the EU). The vegetation protection value is specified as AOT40 (see Table 5.1). The vegetation protection value is calculated as the sum of the differences between hourly concentrations above 80 µg/m^3 (= 40 ppb) and 80 µg/m^3 accumulated over all hourly values measured during the daylight period of the most intensive growing season. The target value for 2010 was 18 000 (µg/m^3).h, calculated as an average over five years (2010–2014). The long-term objective, with no defined date, is to achieve a target value of 6 000 (µg/m^3).h, as shown in Table 5.1. In addition to the EU target value, the UNECE CLRTAP (UNECE, 1979) defines a CL for the protection of forests. This CL is a function of the AOT40 during April–September and is set at 10 000 (µg/m^3).h (UNECE, 2011).

([45]) Natura 2000 is an EU-wide network of nature protection areas (EEA, 2016i) established under the 1992 Habitats Directive (EU, 1992). The aim of the network is to ensure the long-term survival of Europe's most valuable and threatened species and habitats.

([46]) Several effects of damages to vegetation by ground-level ozone were described in the *Air quality in Europe — 2015 report* (EEA, 2015a).

Since 2000, the AOT40 value of 18 000 (µg/m³).h 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, 2016b). In 2013, it was exceeded in about 22 % of all European countries and in 21 % of the EU-28 (i.e. 475 368 km² and 422 491 km², respectively, of all agricultural land, mostly in southern Mediterranean regions) (Map 11.1). O_3 levels vary considerably from year to year, mostly owing to meteorological variations. In 2013, the total area with agricultural crops above the target value was less than in 2012 (30 %) and in

Figure 11.1 Exposure of (a) agricultural area and (b) forest area to O_3 (AOT40) in the EEA-33 member countries, 1996/2004 to 2013 ((µg/m³).h)



Notes: (a) In the Ambient Air Quality Directive (EU, 2008), the target value for protection of vegetation is set at 18 000 (µg/m³).h, averaged over 5 years, whereas the long-term objective is set at 6 000 (µg/m³).h. 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 has set a critical level for the protection of forests at 10 000 (µg/m³).h. 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.

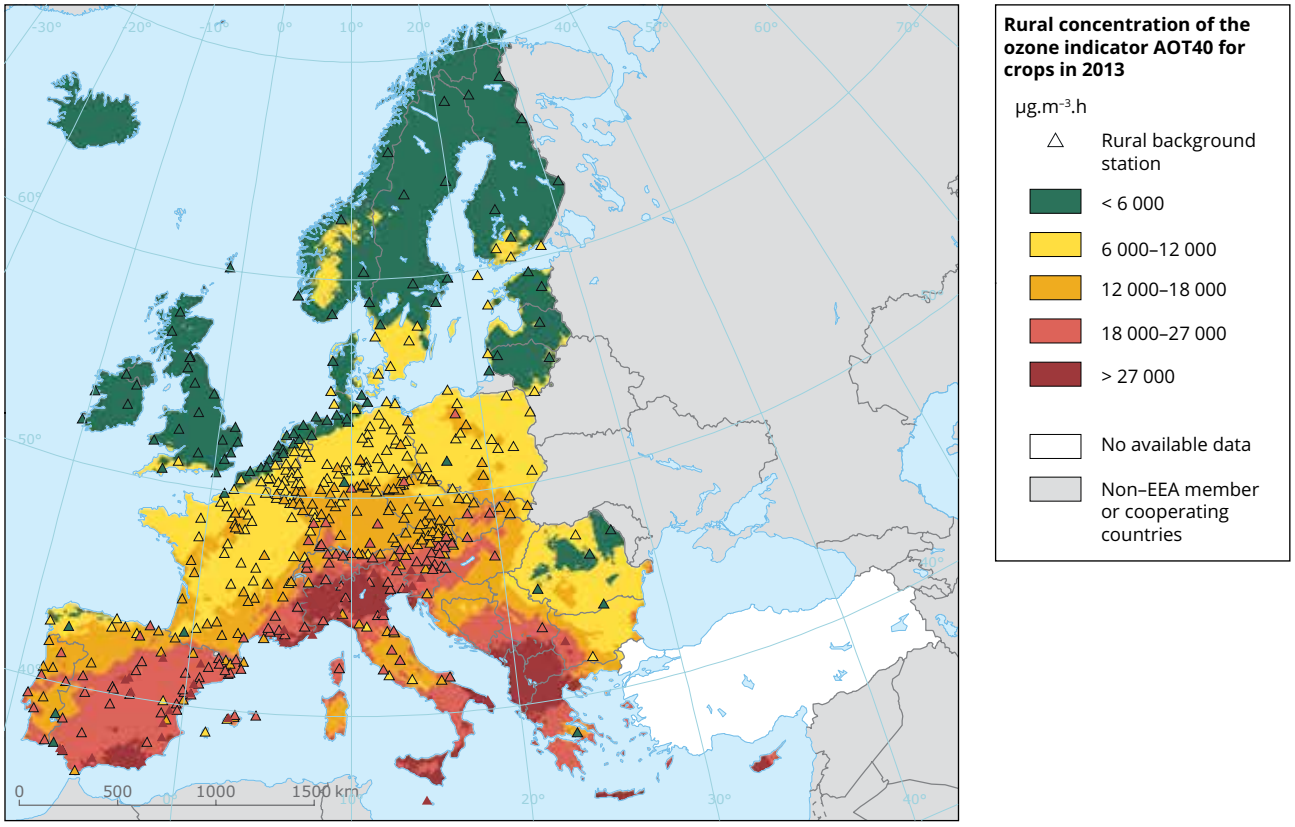
Source: EEA, 2016b (CSI 005).

2005–2009 (26 % to 69 %) ([47]). The long-term objective was exceeded in 81 % of both the total European and the EU-28 agricultural area in 2013 (ETC/ACM, 2016b).

The NEC Directive (EU, 2001) contains two interim objectives (to be met in 2010) concerning vegetation-related O_3 exposure. The first is to reduce it by one third in all grid cells by 2010 compared with 1990, while the second addresses the absolute concentration limits to be attained by 2010. Based on a model calculation, the first objective has been met in the EU except in parts of Spain and Portugal. The second objective — no exceedance of a critical level of 20 000 (µg/m³).h during the summer season — has clearly not been achieved in most of Europe (EEA, 2016b).

The exceedances since 2004 of the CL for the protection of forest areas are even more pronounced than in the case of protection to 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 CL). Whereas in 2004 and 2006, almost all forests were exposed to levels exceeding the CL, since 2007 22 % to 40 % are exposed to levels lower than the CL. The total EEA-33 (except Turkey) forested area with concentrations below the CL is 34 % of a total area of 1.44 million km². The CL was exceeded in 67 % and 68 % of the total European and EU-28 forest area, respectively (i.e. 1 019 956 km² and 909 741 km², respectively) in 2013 (Map 11.2). The CL was not exceeded (green areas) in 2013 in most of Iceland and Ireland, great parts of Finland, Lithuania and the United Kingdom and parts of Denmark, Estonia, Latvia, Norway, Sweden and the Atlantic coasts of northwest Europe. In southern Europe, levels may be as high as four or five times above the critical level (red and dark red areas in Map 11.2) (ETC/ACM, 2016b).

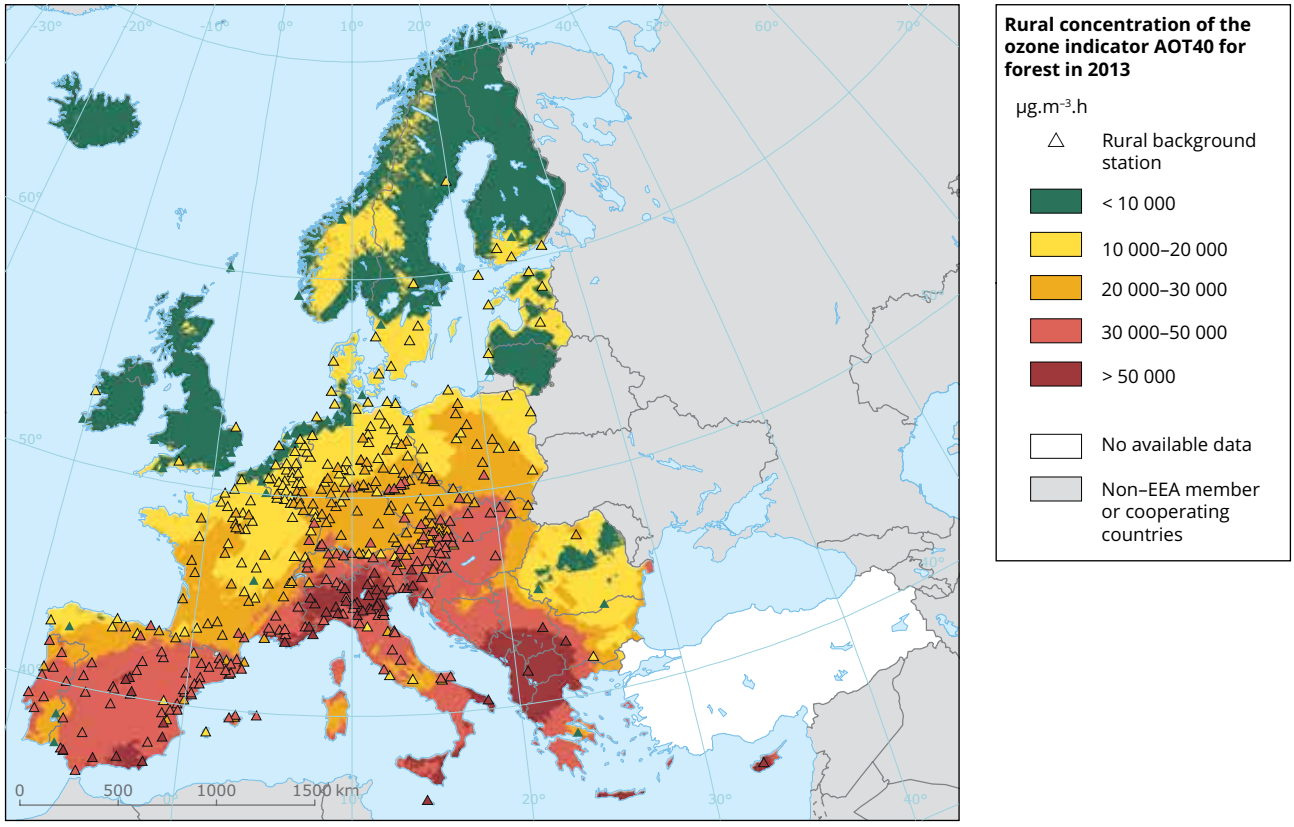
Map 11.1 Rural concentration of the O_3 indicator AOT40 for crops in 2013



Source: ETC/ACM, 2016b.

([47]) The exceedance in 69 % of the agricultural area occurred in summer 2006, which had favourable meteorological conditions for O_3 formation, resulting in exceptionally high concentrations (ETC/ACC, 2009a).

Map 11.2 Rural concentration of the O_3 indicator AOT40 for forests in 2013



Source: ETC/ACM, 2016b.

11.2 Eutrophication

Eutrophication refers to an excess of nutrients in the soil or water. It threatens biodiversity through the excessive growth of a few species that thrive in the presence of the added nutrients, to the detriment of a larger number of species that have long been part of the ecosystem but are accustomed to a lower-nutrient environment. The two major causes of eutrophication are excess nutrient nitrogen (mainly nitrates and ammonium) and excess phosphates in ecosystems. Air pollution contributes to the excess of nutrient nitrogen, as the nitrogen emitted to the air, namely NO_X (mainly from combustion of fuels) and NH_3 (mostly from livestock breeding and mineral fertiliser application), deposits on soils, vegetation surfaces and waters.

Atmospheric nitrogen deposition contributes to eutrophication in freshwater and in the sea. Eutrophication often leads to algal 'blooms', that is, the rapid growth of algae which form dense patches near the surface of the water and prevent light from penetrating into deeper layers of the water.

Eutrophication (and acidification) effects are estimated using the 'critical load' concept, a term that describes the ecosystem's ability to absorb eutrophying nitrogen (or acidifying, in the case of acidification) pollutants that have been 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.

The EEA (2014) estimated that 63 % of the total EU-28 ecosystem area and 73 % of the Natura 2000 area were at risk of eutrophication in 2010, owing to excessive atmospheric nitrogen covering most of continental Europe as well as Ireland and southern areas of the United Kingdom and Sweden. Since, these figures were 67 % and 78 %, respectively, for 2005, the reduction in the ecosystem area at risk of eutrophication has merely been moderate. The risks of ecosystem eutrophication and its geographical coverage have therefore diminished only slightly over the past 10 years, and eutrophication is still widespread

across Europe. Furthermore, the projections for 2020 and 2030 indicate that ecosystems' exposure to eutrophication will still be widespread (EEA, 2016b; Maas and Grennfelt, 2016). This conflicts with the EU's long-term objective of not exceeding critical loads of airborne acidifying and eutrophying substances in European ecosystem areas (EU, 2001, 2002; 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 much of these airborne acids is to fall to 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.

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.

The EEA (2014) estimated that 7 % of the total EU-28 ecosystem area and 5 % of the Natura 2000 area were at risk of acidification in 2010. This represents reductions of 30 % and 40 %, respectively, from 2005 levels. Compared with 1990, the area of sensitive ecosystems in the EU-28 in which the acidity critical load was exceeded had declined by 94 % in 2010. This improvement is primarily attributed to sharp reductions in SO_X emissions over the past 20 years. However, soil and surface water acidification remains an issue in the most sensitive areas of Nordic countries, the United Kingdom and central Europe. Recovery of acidified soils and waters will take decades to centuries, because of depleted base cations in soils and waters (from the earlier deposition of acidifying compounds), which recover through the slow process of mineral weathering. Further reductions in nitrogen and sulphur emissions will improve the situation and shorten the time needed for recovery (Maas and Grennfelt, 2016).

The area at risk is projected to be reduced to about 2 % in 2020 under the revised Gothenburg Protocol and including the implementation of current legislation. A further decrease to 1 % could be achieved in 2030 under Maximum Feasible Reductions (Hettelingh et al., 2015).

11.4 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 time 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 fish — then human consumption of that fish may present a serious risk to health.

Atmospheric deposition of toxic metals into the environment contributes to the exposure of ecosystems and organisms to the metals and, therefore, to the risk of bioaccumulation and biomagnification. Some ecosystem areas are at risk owing to the atmospheric deposition of Cd, Pb and Hg.

The proportion of national ecosystem areas in Europe exceeding critical loads for Cd is < 1 % in most countries, except countries that have set lower critical loads than other countries (Slootweg et al., 2010).

For Pb, the area and extent of the exceedances of critical loads are much higher. Atmospheric deposition of Pb exceeds the critical loads in > 12 % of the EU ecosystem area (Slootweg et al., 2010).

The largest exceedances of toxic metal critical loads involve Hg. Almost half of all EEA member and cooperating countries ([48]) have exceedances of critical loads for Hg across nearly 90 % or more of their ecosystem areas. In total, the atmospheric deposition of Hg exceeds the critical loads across 54 % of the EU ecosystem area (Slootweg et al., 2010).

([48]) Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Denmark, the former Yugoslav Republic of Macedonia, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Romania, Slovenia and Spain.

Photo: © Aliyah Mahmood, My City/EEA

11.5 Ecosystem exposure to nitrogen oxides and sulphur dioxide

Three CLs are set by the Ambient Air Quality Directive (EU, 2008) for the protection of vegetation: one for the NO_X (annual mean, see Table 6.1); and two for SO_2 (annual and winter means ,Table 8.1). Member States were obliged to meet the vegetation protection limits by 2005.

The NO_X annual CL for the protection of vegetation was exceeded in 2014 at six rural background stations. Only two of them, located in Italy, are used for the protection of vegetation.

In 2014 there were no exceedances of the SO_2 annual critical level in any of the stations used for the protection of vegetation.

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 parts per billion. This represents the sum of the differences between hourly concentrations > 80 µg/m^3 (= 40 parts per billion) and 80 µg/m^3 accumulated over all hourly values measured between 08:00 and 20:00 Central European Time
AQG	Air Quality Guideline
As	Arsenic
BaP	Benzo[*a*]pyrene
BC	Black carbon
C_6H_6	Benzene
Cd	Cadmium
CH_4	Methane
CI	Confidence interval
CL	Critical level
CLRTAP	Convention on Long-range Transboundary Air Pollution
CO	Carbon monoxide
CO_2	Carbon dioxide
EC	Elemental carbon
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
ETC/ACM	European Topic Centre on Air Pollution and Climate Change Mitigation
EU	European Union
Hg	Mercury
LAT	Lower assessment threshold
MDA8	Maximum daily 8-hour average ozone concentration
NEC	National Emission Ceilings
ng/m^3	Nanogram(s) per cubic metre
NH_3	Ammonia

NH_4^+	Ammonium
Ni	Nickel
NMVOC	Non-methane volatile organic compound
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_3^-	Nitrate
NO_X	Nitrogen oxides
NRMM	Non-road mobile machinery
O_3	Ozone
OC	Organic carbon
OECD	Organisation for Economic Co-operation and Development
OM	Organic matter
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
ppb	Parts per billion
RDE	Real Driving Emissions
RL	Reference level
SO_2	Sulphur dioxide
SO_4^{-2}	Sulphate
SOMO35	Accumulated O_3 concentration (daily maximum 8-hour) in excess of 35 ppb
SO_X	Sulphur oxides
UN	United Nations
UNECE	United Nations Economic Commission for Europe
VOC	Volatile organic compound
WHO	World Health Organization
YLL	Years of life lost

References

AIRUSE, 2015, 'Deliverable 26: Biomass burning in Southern Europe' (http://airuse.eu/wp-content/uploads/2015/02/08_B4_Biomass-Burning-Southern-Europe.pdf) accessed 20 July 2016.

Clancy, L., Goodman, P., Sinclair, H. and Dockery, D. W., 2002, 'Effect of air-pollution control on death rates in Dublin, Ireland: an intervention study', *Lancet*, (360) 1 210–1 214.

Dahl, A., Gharibi, A., Swietlicki, E., Gudmundsson, A., Bohgard, M., Ljungman, A., Blomqvist, G. and Gustafsson, M., 2006, 'Traffic-generated emissions of ultrafine particles from pavement–tire interface', *Atmospheric Environment*, (40) 1 314–1 323.

European Commission, 2005, Communication from the Commission to the Council and the European Parliament 'Thematic Strategy on air pollution' (COM(2005) 0446 final 21.9.2005) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52005DC0446:EN:NOT) accessed 21 July 2015.

European Commission, 2013a, Commission Staff Working Document, Impact Assessment — Accompanying the Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions — a Clean Air Programme for Europe, SWD (2013) 531, European Commission, Brussels (http://ec.europa.eu/environment/archives/air/pdf/Impact_assessment_en.pdf) accessed 21 July 2016.

European Commission, 2013b, 'The Clean Air Package' (http://ec.europa.eu/environment/air/clean_air_policy.htm) accessed 21 July 2016.

European Commission, 2014, Commission Staff Working Document 'State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU', SWD (2014) 259 final, European Commission, Brussels (https://ec.europa.eu/energy/sites/ener/files/2014_biomass_state_of_play_.pdf), accessed 28 September 2016.

European Commission, 2015, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee the Committee of the Regions and the European Investment Bank — State of the Energy Union 2015, COM(2015) 572 final.

EEA, 2005, *The European environment — state and outlook 2005*, European Environment Agency.

EEA, 2012, *Air quality in Europe — 2012 report*, EEA Report No 4/2012, European Environment Agency (http://www.eea.europa.eu/publications/air-quality-in-europe-2012) accessed 21 July 2016.

EEA, 2013a, *Environment and human health*, Joint EEA-JRC report, EEA Report No 5/2013, European Environment Agency.

EEA, 2013b, *The impact of international shipping on European air quality and climate forcing*, EEA Technical report No 4/2013, European Environment Agency.

EEA, 2013c, *EMEP/EEA air pollutant emission inventory guidebook — 2013*, EEA Technical report No 12/2013, European Environment Agency (http://www.eea.europa.eu/publications/emep-eea-guidebook-2013) accessed 20 July 2016.

EEA, 2014, *Effects of air pollution on European ecosystems, Past and future exposure of European freshwater and terrestrial habitats to acidifying and eutrophying air pollutants*, EEA Technical report No 11/2014, European Environment Agency.

EEA, 2015a, *Air quality in Europe — 2015 report*, EEA Report No 5/2015, European Environment Agency (http://www.eea.europa.eu/publications/air-quality-in-europe-2015) accessed 13 July 2016.

EEA, 2015b, *Evaluating 15 years of transport and environmental policy integration — TERM 2015: Transport indicators tracking progress towards environmental targets in Europe*, EEA Report No 7/2015, European Environment Agency (http://www.eea.europa.eu/publications/term-report-2015) accessed 9 July 2016.

EEA, 2016a, *Air Quality e-Reporting Database* (http://www.eea.europa.eu/data-and-maps/data/aqereporting-2) accessed 26 October 2016.

EEA, 2016b, *Exposure of ecosystems to acidification, eutrophication and ozone* (Indicator CSI 005), European Environment Agency (http://www.eea.europa.eu/data-and-maps/indicators/exposure-of-ecosystems-to-acidification-3/assessment-1) accessed 20 July 2016.

EEA, 2016c, *European Union emission inventory report 1990–2014 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP)*, EEA Report No 16/2016, European Environment Agency.

EEA, 2016d, *Explaining road transport emissions — A non-technical guide*, European Environmental Agency.

EEA, 2016e, 'Reported CO_2 emissions from new cars continue to fall' (http://www.eea.europa.eu/highlights/reported-co2-emissions-from-new) accessed 20 July 2016.

EEA, 2016f, *Exceedance of air quality limit values in urban areas* (Indicator CSI 004), European Environment Agency.

EEA, 2016g, *Annual European Union greenhouse gas inventory 1990–2014 and inventory report 2016*, European Environment Agency (http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2016) accessed 28 July 2016.

EEA, 2016h*, Renewable energy in Europe 2016, Recent growth and knock-on effects*, EEA Report No 4/2016, European Environment Agency (http://www.eea.europa.eu/publications/renewable-energy-in-europe-2016).

EEA, 2016i, NATURA 2000, (http://www.eea.europa.eu/data-and-maps/data/natura-7) accessed 12 October 2016.

EMEP, 2016, *Air pollution trends in the EMEP region between 1990 and 2012*, Colette, A., Aas, W., Banin, L., Braban, C.F., Ferm, M., González Ortiz, A., Ilyin, I., Mar, K., Pandolfi, M., Putaud, J.-P., Shatalov, V., Solberg, S., Spindler, G., Tarasova, O., Vana, M., Adani, M., Almodovar, P., Berton, E., Bessagnet, B., Bohlin-Nizzetto, P., Boruvkova, J., Breivik, K., Briganti, G., Cappelletti, A., Cuvelier, K., Derwent, R., D'Isidoro, M., Fagerli, H., Funk, C., Garcia Vivanco, M., González Ortiz, A., Haeuber, R., Hueglin, C., Jenkins, S., Kerr, J., de Leeuw, F., Lynch, J., Manders, A., Mircea, M., Pay, M.T., Pritula, D., Putaud, J.-P., Querol, X., Raffort,V., Reiss, I., Roustan, Y., Sauvage, S., Scavo, K., Simpson, D., Smith, R.I., Tang, Y.S., Theobald, M., Tørseth, K., Tsyro, S., van Pul, A., Vidic, S., Wallasch, M., Wind, P., European Monitoring and Evaluation Programme EMEP/CCC-Report 1/2016, Norway.

ETC/ACC, 2009a, *European air quality maps of ozone and PM_{10} for 2006 and their uncertainty analysis*, de Smet, P., Horálek, J., Coňková, M., Kurfürst, P., de Leeuw, F., Denby, B., Technical Paper 2008/8, European Topic Centre on Air and Climate Change.

ETC/ACC, 2009b, *Indicators on urban air quality: A review of current methodologies*, de Leeuw, F. and Fiala, J., Technical Paper 2009/8, European Topic Centre on Air and Climate Change.

ETC/ACC, 2010a, *Traffic and air quality contribution of traffic to urban air quality in European cities*, Hak, C., Larssen, S., Randall, S., Guerreiro, C., Denby, B. and Horálek, J., Technical Paper 2009/12, European Topic Centre on Air and Climate Change.

ETC/ACC, 2010b, *Status and trends of NO_2 ambient concentrations in Europe*, Guerreiro, C., Horálek, J., de Leeuw, F., Hak, C., Nagl, C., Kurfürst, P. and Ostatnicka, J., Technical Paper 2010/19, European Topic Centre on Air and Climate Change.

ETC/ACM, 2011, *Evaluation of current limit and target values as set in the EU Air Quality Directive*, de Leeuw, F. and Ruyssenaars, P., Technical Paper 2011/3, European Topic Centre on Air Pollution and Climate Change Mitigation.

ETC/ACM, 2012a, *AirBase: a valuable tool in air quality assessments at a European and local level*, Frank de Leeuw, Technical Paper 2012/4, European Topic Centre on Air Pollution and Climate Change Mitigation.

ETC/ACM, 2012b, *Particle number (PNC) and black carbon (BC) in European urban air quality networks,* Viana, M., Querol, X., Alastuey, A., Reche, C., Favez, O., Malherbe, L., Ustache, A., Bartonova, A., Liu, H-Y., Guerreiro, C., Technical Paper 2012/6, European Topic Centre on Air Pollution and Climate Change Mitigation.

ETC/ACM, 2015, *Mapping ambient concentrations of benzo(a)pyrene in Europe — Population exposure and health effects for 2012*, Guerreiro, C., Horálek, J., de Leeuw, F. and Couvidat, F., Technical Paper 2014/6, European Topic Centre on Air Pollution and Climate Change Mitigation (http://acm.eionet.europa.eu/reports/ETCACM_TP_2014_6_BaP_HIA) accessed 13 July 2016.

ETC/ACM, 2016a, *Contribution of residential combustion to ambient air pollution and greenhouse gas emissions*, Viana, M., Alastuey, A., Querol, X., Guerreiro, C., Vogt, M., Colette, A., Collet, S., Albinet, A., Fraboulet, I.,

Lacome, J., Tognet, F., de Leeuw, F., Technical Paper 2015/1, European Topic Centre on Air Pollution and Climate Change Mitigation.

ETC/ACM, 2016b, *European air quality maps of PM and ozone for 2013 and their uncertainty*, Horálek, J., de Smet, P., Kurfürst, P., de Leeuw, F. and Benešová, N., Technical Paper 2015/5, European Topic Centre on Air Pollution and Climate Change Mitigation.

ETC/ACM, 2016c, Quantifying the health impacts of ambient air pollution — Methodology and input data, de Leeuw, F. and Horálek, J., Technical Paper 2016/5, European Topic Centre on Air Pollution and Climate Change Mitigation.

EU, 1991, Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (OJ L 375, 31.12.1991, pp. 1–8). (http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:31991L0676) accessed 13 July 2016.

EU, 1992, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, pp. 7–50) (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043) accessed 21 July 2016.

EU, 1994, Directive 94/63/EC of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations (OJ L 365, 20.12.2014, p. 24–33) (http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:31994L0063) accessed 12 October 2016.

EU, 1997, Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery (OJ L 059 , 27.02.1998, pp. 1–86).

EU, 1999a, Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations (OJ L 85, 29.3.1999, p. 1–22) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31999L0013:EN:NOT) accessed 13 July 2016.

EU, 1999b, Council Directive 1999/32/EC of 26 April 1999 relating to a reduction in the sulphur content of certain liquid fuels and amending Directive 93/12/EEC (OJ L 121, 11.5.1999, pp. 13–18) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31999L0032:EN:NOT) accessed 13 July 2016.

EU, 2001, Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants (OJ L 309, 27.11.2001, p. 22–30) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:309:0022:0030:EN:PDF) accessed 21 July 2016.

EU, 2002, Decision No 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme (OJ L 242, 10.9.2002, p. 1–15). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002D1600:EN:NOT) accessed 21 July 2016.

EU, 2003, Directive 2003/17/EC of the European Parliament and of the Council of 3 March 2003 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels (OJ L 76, 22.3.2003, p. 10–19) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32003L0017:EN:NOT) accessed 13 July 2016.

EU, 2004, Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (OJ L 23, 26.1.2005, pp. 3–16) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:023:0003:0016:EN:PDF) accessed 21 July 2016.

EU, 2008, Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (OJ L 152, 11.6.2008, pp. 1–44) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF) accessed 21 July 2016.

EU, 2009a, Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC (OJ L 140, 5.6.2009, pp. 88–113) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0088:0113:EN:PDF) accessed 21 July 2016.

EU, 2009b, Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign

requirements for energy-related products (OJ L 285, 31.10.2009, pp. 10–35) (http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0125&from=EN) accessed 21 July 2016.

EU, 2009c, Directive 2009/126/EC of the European Parliament and of the Council of 21 October 2009 on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations (OJ L 285, 31.10.2009, pp. 36–39) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0036:0039:EN:PDF) accessed 21 July 2016.

EU, 2010a, Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (OJ L 334, 17.12.2010, pp. 17–119) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:en:PDF) accessed 21 July 2016.

EU, 2010b, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (OJ L 153, 18.6.2010, pp. 13–35) (http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN) accessed 7 July 2016.

EU, 2012, Directive 2012/46/EU of the European Parliament and of the Council of 6 December 2012 amending Directive 97/68/EC of the European Parliament and of the Council on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery (OJ L 353, 21.12.2012, pp. 80–127) (http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0046&from=EN) accessed 13 July 2016.

EU, 2013, Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet' (OJ L 354, 20.12.2013, pp. 171–200) (http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013D1386&from=EN) accessed 21 July 2016.

EU, 2015, Directive (EU) 2015/2193 on the limitation of emissions of certain pollutants into the air from medium combustion plants (OJ L 313, 28.11.2015, pp. 1–19) (http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L2193&from=EN) accessed 13 July 2016.

EurObserv'ER, 2015, *Solid Biomass Barometer,* December 2015 (http://www.eurobserv-er.org/solid-biomass-barometer-2015/) accessed 28 September 2016.

Gíslason, S. R., Stefánsdóttir, G., Pfeffer, M. A., Barsotti, S., Jóhannsson, Th., Galeczka, I., Bali, E., Sigmarsson, O., Stefánsson, A., Keller, N. S., Sigurdsson, Á., Bergsson, B., Galle, B., Jacobo, V. C., Arellano, S., Aiuppa, A., Jónasdóttir, E. B., Eiríksdóttir, E. S., Jakobsson, S., Guðfinnsson, G. H., Halldórsson, S. A., Gunnarsson, H., Haddadi, B., Jónsdóttir, I., Thordarson, Th., Riishuus, M., Högnadóttir, Th., Dürig, T., Pedersen, G. B. M., Höskuldsson, Á. and Gudmundsson, M. T., 2015, 'Environmental pressure from the 2014–15 eruption of Bárðarbunga volcano, Iceland', *Geochemical Perspectives Letters*, (1) 84–93.

Grice, S., Stedman, J., Kent, A., Hobson, M., Norris, J., Abbott, J. and Cooke, S., 2009, 'Recent trends and projections of primary NO_2 emissions in Europe', *Atmospheric Environment*, (43) 2 154–2 167.

Héroux, M.-E., Anderson, H. T., Atkinson, R., Brunekreef, B., Cohen, A. Forastiere, F., Hurley, F. Katsouyanni, K., Krewski, D., Krzyzanowski, M., Künzli, N., Mills, I., Querol, X., Ostro, B. and Walton, H., 2015, 'Quantifying the health impacts of ambient air pollutants: recommendations of a WHO/Europe project', *International Journal of Public Health*, (60) 619–627.

Hettelingh, J-P., Posch, M., Slootweg, J., Reinds, G. J., de Vries, W., Le Gall, A.-C. and Maas, R., 2015, 'Effects-based integrated assessment modelling for the support of European air pollution abatement policies', in: de Vries, W., Hettelingh, J-P. and Posch, M. (eds), *Critical loads and dynamic risk assessments: Nitrogen, acidity and metals in terrestrial and aquatic ecosystems*, Springer, Dordrecht .

Ialongo, I., Hakkarainen, J., Kivi, R., Anttila, P., Krotkov, N. A., Yang, K., Li, C., Tukiainen, S., Hassinen, S. and Tamminen, J., 2015, 'Validation of satellite SO_2 observations in northern Finland during the Icelandic Holuhraun fissure eruption', *Atmospheric Measurement Techniques Discussions*, 8(1), 599–621.

IARC, 2013, Press Release No 221, International Agency for Research on Cancer (http://www.iarc.fr/en/media-centre/iarcnews/pdf/pr221_E.pdf) accessed 12 October 2016.

IMO, 1978, *1973 International Convention for the Prevention of Pollution from Ships (MARPOL)* and *Protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships*, International Maritime Organization, London.

IPCC, 2006, *2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 2 — Energy), Prepared by the National Greenhouse Gas Inventories Programme,*

Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds.) Published: IGES, Japan.

Kubica, K., Paradiz, B. and Dilara, P., 2007, *Small combustion installations: Techniques, emissions and measures for emission reduction*, EUR 23214, JRC, Ispra, Italy.

Kumar, P., Pirjola, L., Ketzel, M. and Harrison, R. M., 2013, 'Nanoparticle emissions from 11 non-vehicle exhaust sources – A review', *Atmospheric Environment*, (67) 252–277.

Lighty, J. S., Veranth, J. M. and Sarofim, A. F., 2000, 'Combustion aerosols: factors governing their size and composition and implications to human health', *Journal of the Air & Waste Management Association*, (50) 1 565–1 618.

Lim, Stephen S. et al., 2012, 'A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010', *The Lancet*, 380(9859) 2 224–2 260.

Maas, R. and Grennfelt, P. (eds), 2016, *Towards cleaner air*, Scientific Assessment Report 2016, EMEP Steering Body and Working Group on Effects of the Convention on Long-Range Transboundary Air Pollution, Oslo.

Myhre, C. L., Hermansen, O., Fiebig, M., Lunder, C., Fjæraa, A. M., Stebel, K., Platt, S. M., Hansen, G., Svendby, T., Schmidbauer, N. and Krognes, T., 2015, *Monitoring of greenhouse gases and aerosols at Svalbard and Birkenes in 2014 — Annual report*, NILU — Norwegian Institute for Air Research, NILU OR 26/2015 (http://miljodirektoratet.no/Documents/publikasjoner/M454/M454.pdf) accessed 12 October 2016.

Nordic Ecolabel, 2014, 'Nordic ecolabelling of stoves' (http://www.nordic-ecolabel.org/criteria/product-groups/?p=2) accessed 12 October 2016.

Nussbaumer, T., 2010, Overview on Technologies for Biomass Combustion and Emission Levels of Particulate Matter - Prepared for Swiss Federal Office of Environment as a Contribution to the Expert Group on Techno-Economic Issues (EGTEI) under the Convention on Long-Range Transboundary Air Pollution, Zürich.

Nussbaumer, T., Czasch, C., Kippel, N., Johansson, L. and Tullin, C., 2008, 'Particulate emissions from biomass combustion on IEA countries — Survey on measurements and emission factors', on behalf of International Energy Agency (IEA) Bioenergy Task 32, Swiss Federal Office of Energy (SFOE), Zürich.

OECD, 2016, *The economic consequences of outdoor air pollution*, OECD Publishing, Paris.

Paraskevopoulou, D., Liakakou, E., Gerasopoulos, E. and Mihalopoulos, N., 2015, 'Sources of atmospheric aerosol from long-term measurements (5 years) of chemical composition in Athens, Greece', *Science of the Total Environment*, (527–528C) 165–178.

Peñuelas, J. and Staudt, M., 2010, 'BVOCs and global change', *Trends in Plant Science*, (15) 133–144.

Querol, X., Alastuey, A., Reche, C., Orío, A., Pallarés, M., Reina, F., Diéguez, J. J., Mantilla, E., Escudero, M., Alonso, L., Gangoiti, G. and Millán, M., 2016, 'On the origin of the highest ozone episodes in Spain', *Science of the Total Environment*, (572), 379–389.

RCP, 2016, *Every breath we take: the lifelong impact of air pollution*, Report of a working party, Royal College of Physicians London, (https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution) accessed 17 July 2016.

Rexeis, M. and Hausberger, S., 2009, 'Trend of vehicle emission levels until 2020 — Prognosis based on current vehicle measurements and future emission legislation', *Atmospheric Environment*, (43) 4 689–4 698.

Rubino, L., Bonnel, P., Hummel, R., Krasenbrink, A., Manfredi, U., de Santi, G., Perotti, M. and Bomba, G., 2007, *PEMS light-duty vehicles application: Experiences in downtown Milan*, Technical Papers 2007-24-0113, SAE International.

Rubino, L., Bonnel, P., Hummel, R., Krasenbrink, A., Manfredi, U. and de Santi, G., 2009, 'On-road emissions and fuel economy of light-duty vehicles using PEMS: chase-testing experiment', *SAE International Journal of Fuels and Lubricants*, (1) 1 454–1 468.

Saffari, A., Daher, N., Samara, C., Voutsa, D., Kouras, A., Manoli, E., Karagkiozidou, O., Vlachokostas, C., Moussiopoulos, N., Shafer, M. M., Schauer, J. J. and Sioutas, C., 2013, 'Increased biomass burning due to the economic crisis in Greece and its adverse impact on wintertime air quality in Thessaloniki', *Environmental Science & Technology*, (47) 13 313–13 320.

Schmidt, A., Leadbetter, S., Theys, N., Carboni, E., Witham, C. S., Stevenson, J. A., Birch, C. E., Thordarson, T., Turnock, S., Barsotti, S., Delaney, L., Feng, W., Grainger, R. G., Hort, M. C., Höskuldsson, Á., Ialongo, I., Ilyinskaya, E., Jóhannsson, T., Kenny, P., Mather, T. A., Richards, N. A. D. and Shepherd, J., 2015, 'Satellite detection, long-range transport, and air quality impacts of volcanic sulphur dioxide from the 2014–2015 flood

lava eruption at Bárðarbunga (Iceland)', *Journal of Geophysical Research: Atmospheres*, (120), 9 739–9 757.

Simpson, D., Arneth, A., Mills, G., Solberg, S. and Uddling, J., 2014, 'Ozone — the persistent menace: interactions with the N cycle and climate change', *Current Opinion in Environmental Sustainability*, (9–10) 9–19.

Slootweg, J., Maximilian, P. and Hettelingh, J. (eds), 2010, *Progress in the modelling of critical thresholds and dynamic modelling, including impacts on vegetation in Europe*, CCE Status Report No 680359001, Coordination Centre for Effects, Bilthoven, Netherlands.

UN, 2015, *World population prospects: The 2015 revision*, United Nations, Department of Economic and Social Affairs, Population Division, New York, NY, USA.

UNECE, 1979, *Convention on Long-range Transboundary Air Pollution*, United Nations Economic Commission for Europe, Geneva (http://live.unece.org/fileadmin/DAM/env/lrtap/full%20text/1979.CLRTAP.e.pdf) accessed 4 September 2015.

UNECE, 2011, 'Chapter 3: Mapping critical levels for vegetation', in: *Manual on methodologies and criteria for modelling and mapping critical loads & levels and air pollution effects, risks and trends*, United Nations Economic Commission for Europe, Geneva (http://icpvegetation.ceh.ac.uk/manuals/mapping_manual.html) accessed 4 September 2015.

Viana, M., Karanasiou, A. and Querol, X., 2013, 'Biomass burning practices in 11 major European cities and their impact on PMx and BaP', Workshop 'Wood burning, Elemental/Black/Brown Carbon', Ghent, Belgium, 2–3 December.

Vojtisek-Lom, M., Fenkl, M., Dufek, M. and Mareš, J., 2009, *Off-cycle, real-world emissions of modern light duty diesel vehicles*, Technical Papers 2009-24-0148, SAE International.

Weiss, M., Bonnel, P. Hummel, R., Manfredi, U., Colombo, R., Lanappe, G., Le Lijour, P. and Sculati, M., 2011a, *Analyzing on-road emissions of light-duty vehicles with Portable Emissions Measurement Systems (PEMS)*, Technical and Scientific Report 62639, EUR 24697 EN, JRC, Ispra, Italy.

Weiss, M., Bonnel, P., Hummel, R., Provenza, A. and Manfredi, U., 2011b, 'On-road emissions of light-duty vehicles in Europe', *Environmental Science & Technology*, (45) 8 575–8 581.

Weiss, M., Bonnel, P., Provenza, A., Lambrecht, U., Alessandrini, S., Carriero, M., Colombo, R., Forni, F., Kühlwein, J., Lanappe, G., Le Lijour, P., Manfredi, U., Montigny, F. and Sculati, M., 2012, 'Will Euro 6 reduce the NO_x emissions of new diesel cars in Europe? Insights from on-road tests with Portable Emissions Measurement Systems (PEMS)', *Atmospheric Environment*, (62) 657–665.

WHO, 2000, *Air quality guidelines for Europe*, World Health Organization, Regional Office for Europe, Copenhagen (http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf) accessed 4 September 2015.

WHO, 2005, *Effects of air pollution on children's health and development — a review of the evidence*, World Health Organization, Regional Office for Europe, Copenhagen.

WHO, 2006, *Air Quality Guidelines: Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulphur dioxide*, World Health Organization, Regional Office for Europe, Copenhagen.

WHO, 2008, *Health risks of ozone from long-range transboundary air pollution*, World Health Organization, Regional Office for Europe, Copenhagen.

WHO, 2010, *WHO guidelines for indoor air quality: selected pollutants*, World Health Organization, European Centre for Environment and Health, Bonn.

WHO, 2013a, *Review of evidence on health aspects of air pollution — REVIHAAP Project*, Technical Report, World Health Organization, Regional Office for Europe, Copenhagen.

WHO, 2013b, *Health risks of air pollution in Europe — HRAPIE project: New emerging risks to health from air pollution — results from the survey of experts*, World Health Organization, Regional Office for Europe, Copenhagen.

WHO, 2014a, *Burden of disease from Ambient Air Pollution for 2012 — Summary of results*, World Health Organization (http://www.who.int/phe/health_topics/outdoorair/databases/AAP_BoD_results_March2014.pdf) accessed 4 September 2015.

WHO, 2014b, *Ambient (outdoor) air quality and health*, Fact sheet No 313, Updated March 2014, World Health Organization (http://www.who.int/mediacentre/factsheets/fs313/en/) accessed 4 September 2015.

WHO, 2014c, *Household fuel combustion – WHO Guidelines for Indoor Air Quality*, World Health Organization, WHO Document Production Services, Geneva, Switzerland.

WHO, 2015, *Residential heating with wood and coal: health impacts and policy options in Europe and North America*, World Health Organization, Regional Office for Europe, Copenhagen.

WHO, 2016, *European Detailed Mortality Database*, update July 2016, Copenhagen, WHO Regional Office for Europe (http://data.euro.who.int/dmdb/) accessed 25 July 2016

de Wit, H. A., Hettelingh, J. P. and Harmens, H. (eds), 2015, *Trends in ecosystem and health responses to long-range transported atmospheric pollutants*, Topic group Effects of air pollution, Geographical area Europe and North America, Report No 6946-2015, ICP Waters report 125/2015, Norwegian Institute for Water Research, Oslo.

Annex 1 Trends in PM_{10}, $PM_{2.5}$, O_3, NO_2 and BaP by country and station type

Table A1.1 Averaged trends in PM_{10} annual mean concentrations and 95 % confidence intervals, by country and by station type, 2000–2014 (µg/m³/year)

	(Sub)urban background				(Sub)urban traffic				Rural background			
	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ
All	484	363	– 0.64	0.03	224	182	– 0.90	0.05	131	95	– 0.43	0.04
EU-28 ([a])	472	357	– 0.65	0.03	216	177	– 0.92	0.05	124	89	– 0.43	0.04
AT	30	28	– 0.76	0.09	24	20	– 0.87	0.12	11	7	– 0.47	0.14
BE	12	10	– 0.95	0.19	6	6	– 0.87	0.16	3	3	– 0.83	0.36
BG	4	0	– 0.42	1.12	2	0	– 0.67	2.12				
CH	11	6	– 0.41	0.11	6	4	– 0.48	0.15	7	6	– 0.47	0.11
CY									1	1	– 0.68	0.53
CZ	32	16	– 0.64	0.14	14	11	– 0.83	0.19	10	5	– 0.47	0.23
DE	134	113	– 0.56	0.04	56	53	– 0.83	0.06	51	35	– 0.36	0.05
DK					3	3	– 0.90	0.24				
EE	1	1	– 0.64	0.61								
ES	23	19	– 1.02	0.15	21	19	– 1.45	0.19	13	10	– 0.30	0.08
FI	5	4	– 0.16	0.07	12	5	– 0.22	0.07	1	0	0.07	0.26
FR	122	93	– 0.57	0.05	21	17	– 0.69	0.13	4	3	– 0.56	0.27
GR	2	2	– 1.96	0.54								
HU	5	1	– 0.01	0.60	3	1	– 0.45	0.53				
IE	2	2	– 0.31	0.25	2	2	– 0.87	0.46				
IS					1	0	– 0.17	0.79				
IT	31	26	– 1.08	0.14	20	17	– 1.33	0.19	4	3	– 0.86	0.63
LT	2	1	– 0.13	0.57	4	0	– 0.12	0.69				
NL	3	3	– 0.88	0.18	7	7	– 1.03	0.15	15	14	– 0.69	0.10
NO					1	1	– 0.92	0.26				
PL	19	7	– 0.37	0.26	2	0	– 0.42	1.70	3	2	0.76	0.44
PT	10	8	– 1.08	0.24	6	6	– 1.84	0.32	3	3	– 0.80	0.50
RS	1	0	0.19	3.07								
SE	3	2	– 0.34	0.15	3	3	– 1.56	0.33				
SI	3	3	– 1.09	0.29	2	2	– 1.87	0.64	1	1	– 0.36	0.37
SK	11	3	– 0.69	0.35	3	1	– 0.45	0.59				
UK	18	15	– 0.51	0.09	5	4	– 0.72	0.26	4	2	– 0.31	0.20

Notes: ([a]) Excluding Croatia, Latvia, Luxembourg, Malta and Romania.
Nstat is the number of monitoring stations used to calculate the average trend.
Nsign is the number of monitoring stations where a significant (upward or downward) trend has been observed with a 95 % probability.
The 95 % confidence intervals are defined as slope ± 2σ.
A consistent set of stations was used in calculations: in operation for at least 11 years, with data coverage of 75 % or more for each year.
National trends are calculated by averaging the trends estimated at individual stations.
Stations located outside continental Europe (French overseas departments, Canary Islands, Azores and Madeira) are excluded. In 2006, France introduced a nationwide system to correct PM_{10} measurements. French PM_{10} data prior to 2007 have been corrected here using station-type dependent factors (ETC/ACC, 2009b).

Source: EEA, 2016a.

Table A1.2 Averaged trends of 90.4 percentile of daily PM_{10} concentrations and 95 % confidence intervals, by country and by station type, 2000–2014 (µg/m³/year)

	(Sub)urban background				(Sub)urban traffic				Rural background			
	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ
All	481	274	– 0.89	0.06	224	166	– 1.39	0.10	132	85	– 0.65	0.09
EU-28 (a)	469	270	– 0.91	0.06	215	160	– 1.41	0.10	125	81	– 0.65	0.09
AT	30	21	– 1.24	0.19	24	18	– 1.50	0.25	11	8	– 0.77	0.28
BE	12	10	– 1.13	0.33	6	6	– 1.06	0.34	4	3	– 1.20	0.67
BG	4	1	– 0.28	2.50	2	0	– 0.20	5.09				
CH	11	4	– 0.48	0.22	6	4	– 0.61	0.34	7	4	– 0.67	0.21
CY									1	0	– 0.92	1.32
CZ	31	8	– 0.71	0.32	14	12	– 1.32	0.39	10	4	– 0.53	0.48
DE	133	86	– 0.79	0.08	56	47	– 1.17	0.13	51	33	– 0.56	0.11
DK					3	3	– 1.38	0.47				
EE	1	1	– 1.19	0.91								
ES	23	21	– 1.81	0.25	21	17	– 2.32	0.34	13	11	– 0.63	0.16
FI	5	3	– 0.27	0.17	12	5	– 0.42	0.19	1	0	0.16	0.56
FR	122	56	– 0.62	0.08	21	11	– 0.72	0.21	4	1	– 0.53	0.50
GR	2	2	– 3.06	1.00								
HU	5	1	0.04	1.27	3	1	– 1.05	1.00				
IE	2	1	– 0.74	0.74	2	2	– 1.59	0.94				
IS					1	0	– 0.94	1.53				
IT	31	24	– 1.87	0.29	20	16	– 2.19	0.37	4	3	– 1.31	1.18
LT	2	0	– 0.43	0.89	4	0	– 0.54	0.90				
NL	3	3	– 1.29	0.42	7	7	– 1.42	0.25	15	13	– 1.03	0.21
NO					2	2	– 2.07	0.47				
PL	18	7	– 0.59	0.54	2	0	– 0.70	3.24	3	1	1.26	1.02
PT	10	8	– 2.22	0.44	6	6	– 3.12	0.61	3	3	– 1.53	1.02
RS	1	0	1.16	6.93								
SE	3	2	– 0.41	0.29	3	3	– 3.75	0.83				
SI	3	2	– 1.22	0.55	2	2	– 2.43	1.19	1	0	0.04	0.96
SK	11	2	– 0.87	0.67	2	0	0.00	0.88				
UK	18	11	– 0.54	0.14	5	4	– 0.98	0.37	4	1	– 0.34	0.27

Notes: (a) Excluding Croatia, Latvia, Luxembourg, Malta and Romania.
Nstat is the number of monitoring stations used to calculate the average trend.
Nsign is the number of monitoring stations where a significant upward or downward trend has been observed with a 95 % probability.
The 95 % confidence intervals are defined as slope ± 2σ.
A consistent set of stations is used in calculations: in operation for at least 11 years, with data coverage of 75 % or more for each year.
National trends are calculated by averaging the trends estimated at individual stations.
Stations located outside continental Europe (French overseas departments, Canary Islands, Azores and Madeira) are excluded.
In 2006, France introduced a nationwide system to correct PM_{10} measurements. French PM_{10} data prior to 2007 have been corrected here using station-type dependent factors (ETC/ACC, 2009b).

Source: EEA, 2016a .

Table A1.3 Averaged trends of $PM_{2.5}$ annual mean concentrations and 95% confidence intervals, by country and by station type, 2006–2014 (µg/m³/year)

	(Sub)urban background				(Sub)urban traffic				Rural background			
	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ
All	112	31	– 0.34	0.11	55	27	– 0.45	0.15	47	21	– 0.29	0.12
EU-28 (a)	110	30	– 0.35	0.11	48	21	– 0.45	0.17	47	21	– 0.29	0.12
AT	4	2	– 0.66	0.60	4	2	– 0.84	0.43	1	0	– 0.20	0.95
BE	7	4	– 0.69	0.37	2	0	– 0.40	0.61	5	4	– 0.85	0.33
BG	1	1	– 1.75	1.85					1	1	– 0.37	0.42
CY									1	0	– 0.26	0.96
CZ	15	3	– 0.05	0.28	4	3	– 0.59	0.50	4	2	0.47	0.63
DE	31	5	– 0.30	0.21	12	5	– 0.53	0.35	6	1	– 0.07	0.30
DK	1	0	0.15	0.66	1	0	0.02	0.83				
EE	1	0	0.49	0.74								
ES	3	3	– 0.98	0.48	1	0	– 0.39	0.83	16	10	– 0.30	0.14
FI	2	2	– 0.26	0.13	2	1	– 0.20	0.18	3	0	– 0.03	0.33
FR	17	0	0.00	0.34	4	0	– 0.19	0.92				
HU	1	0	– 0.26	2.00	1	0	– 0.49	0.53				
IT	15	6	– 0.78	0.33	6	2	– 0.61	0.58	2	0	– 0.70	0.82
LT					2	2	1.60	0.62				
LU												
MT					1	1	– 0.79	0.50				
NL	5	3	– 0.46	0.37								
NO	2	1	– 0.17	0.22	7	6	– 0.44	0.12				
PL					1	0	0.18	0.58				
PT	1	0	– 0.34	0.63	2	2	– 1.18	0.85	4	2	– 0.68	0.61
SE	2	1	– 0.42	0.41	2	2	– 0.93	0.49	1	1	– 0.49	0.43
SI	1	0	– 0.72	1.68	1	0	– 0.54	1.55	1	0	– 0.35	1.35
SK	2	0	– 0.17	1.39								
UK	1	0	0.33	0.63	2	1	– 0.52	0.90	2	0	– 0.17	0.48

Notes: (a) Excluding Croatia, Greece, Ireland, Latvia and Romania.
Nstat is the number of monitoring stations used to calculate the average trend.
Nsign is the number of monitoring stations where a significant upward or downward trend has been observed with a 95 % probability.
The 95 % confidence intervals are defined as slope ± 2σ.
A consistent set of stations is used in calculations: in operation for at least 7 years, with data coverage of 75 % or more for each year.
National trends are calculated by averaging the trends estimated at individual stations.
Stations located outside continental Europe (French overseas departments, Canary Islands, Azores and Madeira) are excluded.

Source: EEA, 2016a.

Table A1.4 Averaged trends of the 93.2 percentile of the maximum daily 8-hour O_3 concentrations and 95% confidence intervals, by country and by station type, 2000–2014 (µg/m³/year)

	(Sub)urban background				(Sub)urban traffic				Rural background			
	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ
All	636	227	– 0.68	0.06	106	35	0.05	0.16	346	185	– 0.86	0.07
EU-28 (a)	623	225	– 0.69	0.06	99	34	0.05	0.17	330	177	– 0.86	0.07
AT	42	28	– 0.76	0.14	5	3	– 0.77	0.51	43	37	– 0.92	0.12
BE	10	1	– 0.97	0.55	4	1	– 0.59	0.71	15	4	– 0.77	0.37
BG	3	1	1.12	1.38	2	0	2.23	2.94	1	1	– 1.63	1.74
CH	13	2	– 0.51	0.35	6	1	– 0.05	0.45	10	4	– 0.87	0.35
CY									1	0	– 0.46	1.41
CZ	22	10	– 0.83	0.25	3	1	– 0.96	0.88	17	14	– 1.15	0.30
DE	141	55	– 0.66	0.10	14	4	– 0.07	0.39	75	52	– 0.85	0.13
DK	3	0	– 0.11	0.56	1	0	0.38	0.84	1	0	– 0.34	1.19
EE	1	0	– 0.63	1.59					3	2	– 0.54	0.42
ES	47	19	– 0.49	0.23	50	19	0.22	0.22	34	14	– 0.63	0.22
FI	3	1	0.00	0.35					9	3	– 0.55	0.34
FR	216	69	– 0.69	0.10					40	16	– 0.92	0.24
GR	6	3	– 1.97	0.72	4	2	– 1.49	0.96				
HU	5	0	0.19	1.09					1	0	– 1.18	1.62
IE	2	0	– 0.62	1.07					4	0	– 0.56	0.85
IT	49	23	– 1.19	0.33	3	1	– 0.55	1.16	16	6	– 1.48	0.65
LT	1	0	– 0.96	2.01	3	0	0.47	1.29	3	1	– 0.54	0.48
LU									1	0	– 0.77	1.13
LV									1	1	1.72	1.03
MK					1	0	0.64	3.34				
NL	5	0	– 0.78	0.71	3	0	0.12	0.82	20	7	– 0.76	0.30
NO									6	4	– 0.66	0.26
PL	9	4	– 0.62	0.46					9	6	– 1.08	0.44
PT	16	4	– 0.47	0.47	3	2	1.23	0.93	4	3	– 2.26	1.51
SE	3	0	– 0.08	0.74	1	1	1.68	1.18	6	2	– 0.58	0.41
SI	4	1	– 0.56	0.70	1	0	– 0.07	1.53	3	1	– 0.87	0.62
SK	4	0	– 0.64	0.74					5	2	– 1.09	0.56
UK	31	6	– 0.42	0.23	2	0	– 0.23	0.80	18	5	– 0.47	0.25

Notes: (a) Excluding Croatia, Malta and Romania.
Nstat is the number of monitoring stations used to calculate the average trend.
Nsign is the number of monitoring stations where a significant upward or downward trend has been observed with a 95 % probability.
The 95 % confidence intervals are defined as slope ± 2σ.
A consistent set of stations is used in calculations: in operation for at least 11 years, with data coverage of 75 % or more for each year.
National trends are calculated by averaging the trends estimated at individual stations.
Stations located outside continental Europe (French overseas departments, Canary Islands, Azores and Madeira) are excluded.

Source: EEA, 2016a.

Table A1.5 Averaged trends of O_3 SOMO35 values and 95% confidence intervals by country and by station type, 2000–2014 ((µg/m³)·day/year),

	(Sub)urban background				(Sub)urban traffic				Rural background			
	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ
All	635	181	– 64	7	106	32	16	17	347	171	– 117	11
EU-28 (a)	622	178	– 65	7	99	31	14	17	331	158	– 117	11
AT	42	27	– 107	19	5	4	– 89	50	43	38	– 184	23
BE	10	2	– 51	34	4	1	– 51	47	15	5	– 79	30
BG	3	1	144	136	2	0	233	300	1	0	– 344	518
CH	13	3	– 43	40	6	1	19	39	10	8	– 130	49
CY									1	0	– 126	343
CZ	22	12	– 131	35	3	1	– 85	98	17	14	– 201	51
DE	141	32	– 50	11	14	1	– 5	31	75	40	– 87	16
DK	3	0	– 3	67	1	0	17	27	1	0	– 7	149
EE	1	0	– 57	195					3	2	– 81	65
ES	47	18	– 43	39	50	19	28	25	34	13	– 80	42
FI	3	0	– 2	35					10	5	– 76	39
FR	216	49	– 56	11					41	9	– 97	32
GR	6	2	– 256	141	4	2	– 75	120				
HU	5	1	32	166					1	0	– 242	350
IE	2	0	– 82	124					4	2	– 80	62
IT	49	18	– 137	45	3	0	44	157	15	5	– 228	114
LT	1	0	– 163	227	3	0	35	110	3	1	– 67	74
LU									1	0	– 104	226
LV									1	1	263	198
MK					1	0	183	535				
NL	5	0	– 74	55	3	1	– 6	50	20	8	– 79	29
NO									6	5	– 96	34
PL	9	4	– 101	58					9	5	– 156	67
PT	15	6	– 11	57	3	1	113	86	4	1	– 384	208
SE	3	0	11	84	1	1	205	122	6	1	– 62	59
SI	4	0	– 73	113	1	0	– 5	191	3	1	– 197	113
SK	4	0	– 84	140					5	3	– 169	104
UK	31	6	– 41	18	2	0	– 17	46	18	4	– 62	30

Notes: (a) Excluding Croatia, Malta and Romania.
Nstat is the number of monitoring stations used to calculate the average trend.
Nsign is the number of monitoring stations where a significant upward or downward trend has been observed with a 95 % probability.
The 95 % confidence intervals are defined as slope ± 2σ.
A consistent set of stations is used in calculations: in operation for at least 11 years, with data coverage of 75 % or more for each year.
National trends are calculated by averaging the trends estimated at individual stations.
Stations located outside continental Europe (French overseas departments, Canary Islands, Azores and Madeira) are excluded.

Source: EEA, 2016a.

Table A1.6 Averaged trends of NO_2 annual mean concentrations and 95% confidence intervals, by country and by station type, 2000–2014 (µg/m³/year)

	(Sub)urban background				(Sub)urban traffic				Rural background			
	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ	Nstat	Nsign	slope	2σ
All	679	482	– 0.46	0.02	344	216	– 0.62	0.04	238	139	– 0.18	0.02
EU-28 (a)	665	472	– 0.46	0.02	334	211	– 0.62	0.05	226	132	– 0.18	0.02
AT	46	28	– 0.25	0.04	31	14	– 0.29	0.10	28	5	– 0.02	0.03
BE	13	12	– 0.55	0.08	8	7	– 0.59	0.14	9	9	– 0.46	0.07
BG	4	2	– 0.60	0.67	3	1	– 0.31	0.77				
CH	12	10	– 0.33	0.08	7	4	– 0.34	0.14	10	6	– 0.18	0.07
CZ	30	19	– 0.26	0.05	13	11	– 0.69	0.15	15	6	– 0.13	0.06
DE	155	107	– 0.31	0.02	73	53	– 0.60	0.07	67	48	– 0.22	0.02
DK	3	3	– 0.49	0.16	5	3	– 0.57	0.23	1	1	– 0.11	0.10
EE	1	1	– 0.14	0.17					3	0	– 0.02	0.03
ES	41	25	– 0.59	0.10	46	27	– 0.67	0.11	19	10	– 0.01	0.06
FI	4	4	– 0.43	0.11	7	6	– 0.39	0.16	6	1	– 0.03	0.04
FR	210	183	– 0.54	0.02	49	32	– 0.60	0.09	14	11	– 0.28	0.06
GR	6	6	– 1.20	0.22	5	5	– 2.20	0.63				
HU	6	2	– 0.22	0.34	5	4	– 0.30	0.39	1	0	0.02	0.20
IE	1	0	– 0.32	0.49	3	0	– 0.09	0.81	2	0	0.04	0.11
IS	1	0	– 0.62	0.59	1	1	– 1.00	0.58				
IT	69	48	– 0.83	0.11	47	29	– 0.92	0.21	14	9	– 0.40	0.15
LT					1	0	– 0.59	0.99	3	2	0.03	0.08
LU									1	0	0.04	0.24
LV	2	0	– 0.30	0.46					1	0	0.01	0.06
NL	7	6	– 0.63	0.12	7	7	– 0.82	0.16	20	19	– 0.33	0.04
NO	1	0	– 0.34	0.57	2	0	– 0.35	0.51	2	1	– 0.02	0.02
PL	15	3	– 0.02	0.11	3	1	– 0.47	0.47	9	2	0.01	0.06
PT	12	3	– 0.16	0.18	8	3	– 0.44	0.26	3	2	– 0.10	0.19
SE	4	4	– 0.44	0.11	4	1	– 0.15	0.19	3	2	– 0.09	0.03
SI	3	0	– 0.06	0.32	1	1	– 0.40	0.52	1	0	0.18	0.41
SK	3	1	– 0.14	0.71	2	1	– 0.51	0.98				
UK	30	15	– 0.33	0.08	13	5	– 0.44	0.24	6	5	– 0.28	0.10

Notes: (a) Excluding Cyprus, Croatia, Malta and Romania.
Nstat is the number of monitoring stations used to calculate the average trend.
Nsign is the number of monitoring stations where a significant upward or downward trend has been observed with a 95 % probability.
The 95 % confidence intervals are defined as slope ± 2σ.
A consistent set of stations is used in calculations: in operation for at least 11 years, with data coverage of 75 % or more for each year.
National trends are calculated by averaging the trends estimated at individual stations.
Stations located outside continental Europe (French overseas departments, Canary Islands, Azores and Madeira) are excluded.

Source: EEA, 2016a.

Table A1.7 Averaged trends of BaP annual mean concentrations and 95% confidence intervals, by country averaged for all station types, 2007–2014 (ng/m³/year)

	Nstat	Nsign	slope	2σ
All	289	81	– 0.033	0.027
EU-28 ([a])	282	76	– 0.033	0.028
AT	18	7	– 0.064	0.089
BE	8	3	– 0.029	0.015
BG	4	0	– 0.015	0.790
CH	7	5	– 0.036	0.012
CY	1	0	0.067	0.080
CZ	27	4	– 0.032	0.055
DE	86	35	– 0.029	0.015
DK	1	0	– 0.003	0.029
EE	1	0	– 0.004	0.015
ES	6	3	– 0.006	0.004
FI	4	1	– 0.015	0.042
HU	14	0	– 0.045	0.109
IE	1	0	– 0.002	0.054
IT	28	7	0.005	0.016
LT	5	2	0.092	0.044
LU	3	0	– 0.006	0.021
LV	2	1	– 0.023	0.029
NL	2	1	– 0.009	0.009
PL	36	4	– 0.116	0.179
SE	2	0	– 0.005	0.015
SI	3	0	0.026	0.041
UK	30	8	– 0.007	0.026

Notes: ([a]) Excluding Croatia, France, Greece, Malta, Portugal, Romania and Slovakia.
Nstat is the number of monitoring stations used to calculate the average trend.
Nsign is the number of monitoring stations where a significant upward or downward trend has been observed with a 95 % probability.
The 95 % confidence intervals are defined as slope ± 2σ.
A consistent set of stations is used in calculations: in operation for at least 6 years, with data coverage of 14 % or more for each year.
National trends are calculated by averaging the trends estimated at individual stations.

Source: EEA, 2016a.

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