

Air quality in Europe — 2015 report

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Caveat

Due to the on-going implementation of a new system for reporting European air quality data, please note that not all data officially reported by countries are necessarily included in this report.

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Contents

Acronyms, units and symbols	5
Acknowledgements	6
Executive summary	7
1 Introduction	11
1.1 Human health	11
1.2 Ecosystems.....	12
1.3 Climate change	12
1.4 The built environment and cultural heritage.....	12
1.5 Air policy	12
1.6 Outline of this report	13
2 Sources and emissions of air pollutants.....	14
2.1 Sources of regulated pollutants	14
2.2 Total emissions of air pollutants	15
2.3 Sectoral emissions of air pollutants.....	15
3 Particulate matter.....	20
3.1 European air quality standards and World Health Organization guidelines for particulate matter.....	20
3.2 Status in concentrations	21
3.2.1 Exceedances of limit and target values.....	21
3.2.2 Relationship of emissions to ambient particulate matter concentrations.....	24
4 Ozone	25
4.1 European air quality standards and World Health Organization guidelines for ozone	25
4.2 Status in concentrations	26
4.2.1 Exceedance of the target values for protection of health	27
4.2.2 Relationship of ozone precursor emissions to ambient ozone concentrations	27
5 Nitrogen dioxide.....	29
5.1 European air quality standards and World Health Organization guidelines for NO ₂	29
5.2 Status in concentrations	30
5.2.1 Exceedances of limit values for the protection of human health.....	30
5.2.2 Relationship of nitrogen oxides emissions and nitrogen dioxide concentrations	32

6	Benzo[<i>a</i>]pyrene	33
6.1	European air quality standards and reference levels for benzo[<i>a</i>]pyrene	33
6.2	Status in concentrations	33
6.2.1	Exceedances of the target value	33
7	Other pollutants: sulphur dioxide, carbon monoxide, toxic metals and benzene	36
7.1	European air quality standards and World Health Organization guidelines	36
7.2	Status in concentrations	37
7.2.1	Sulphur dioxide	37
7.2.2	Carbon monoxide.....	37
7.2.3	Toxic metals.....	38
7.2.4	Benzene	38
8	Population exposure to air pollutants in European urban areas	39
8.1	Particulate matter	39
8.2	Ozone	39
8.3	Nitrogen dioxide.....	40
8.4	Benzo[<i>a</i>]pyrene	40
8.5	Sulphur dioxide	40
8.6	Carbon monoxide	41
8.7	Toxic metals (arsenic, cadmium, lead and nickel).....	41
8.8	Benzene.....	41
9	Health impacts of exposure to fine particulate matter, ozone and nitrogen dioxide ...	42
9.1	Health impacts of current exposure to fine particulate matter, ozone and nitrogen dioxide	42
9.2	Estimated health gains attributable to attainment of fine particulate matter and nitrogen dioxide guidelines or limit values	44
10	Health impacts of exposure to benzo[<i>a</i>]pyrene	46
11	Impacts of air pollution on ecosystems	49
11.1	Vegetation damage by ground-level ozone	49
11.2	Eutrophication	51
11.3	Acidification.....	52
11.4	Environmental impacts of toxic metals	53
11.5	Ecosystem exposure to nitrogen oxides and sulphur dioxide	53
	References	54

Acronyms, units and symbols

$\mu\text{g}/\text{m}^3$	Microgram(s) per cubic metre	LRTAP	Long-range Transboundary Air Pollution
AEI	Average exposure indicator	ng/m^3	Nanogram(s) per cubic metre
AOT40	Accumulated exposure over a threshold of 40 parts per billion. This represents the sum of the differences between hourly concentrations greater than $80 \mu\text{g}/\text{m}^3$ (= 40 parts per billion) and $80 \mu\text{g}/\text{m}^3$ accumulated over all hourly values measured between 8.00 and 20.00 Central European Time	NH_3	Ammonia
AQG	Air Quality Guideline	Ni	Nickel
As	Arsenic	NMVOG	Non-methane volatile organic compound
BaP	Benzo[<i>a</i>]pyrene	NO	Nitrogen monoxide
BC	Black carbon	NO_2	Nitrogen dioxide
C_6H_6	Benzene	NO_x	Nitrogen oxides
Cd	Cadmium	O_3	Ozone
CH_4	Methane	PAH	Polycyclic aromatic hydrocarbon
CO	Carbon monoxide	Pb	Lead
CO_2	Carbon dioxide	PM	Particulate matter
EAP	Environment Action Programme	$\text{PM}_{2.5}$	Particulate matter with a diameter of $2.5 \mu\text{m}$ or less
EC	European Commission	PM_{10}	Particulate matter with a diameter of $10 \mu\text{m}$ or less
EEA	European Environment Agency	ppb	Parts per billion
ETC/ACM	European Topic Centre on Air Pollution and Climate Change Mitigation	RL	Reference level
EU	European Union	SO_2	Sulphur dioxide
Gg	Gigagrams	SO_x	Sulphur oxides
GHG	Greenhouse gas	TSAP	Thematic Strategy on Air Pollution
Hg	Mercury	UN	United Nations
IARC	International Agency for Research on Cancer	UNECE	United Nations Economic Commission for Europe
LAT	Lower assessment threshold	VOC	Volatile organic compound
		WHO	World Health Organization
		YLL	Years of life lost

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Executive summary

Air pollution is both an environmental and a social problem, as it leads to a multitude of adverse effects on human health, ecosystems, the built environment and the climate. Air pollution poses the single largest environmental health risk in Europe today. Air pollutants are emitted from anthropogenic and natural sources; they may be transported or formed over long distances; and they may affect large areas. Some air pollutants persist in the environment for long periods of time and they may accumulate in the environment and in the food chain, affecting humans and animals not only via air intake, but also via water and food intake. Air pollution is, therefore, a complex problem that poses multiple challenges in terms of management and mitigation. Effective action to reduce the impacts of air pollution requires a good understanding of the sources that cause it, as well as up-to-date knowledge of air quality status and its impact on humans and on ecosystems.

The current report presents an overview and analysis of air quality in Europe, with a focus on the latest year for which there are available and processed data, namely 2013. It reviews the progress made towards meeting the requirements of the Air Quality Directives (EU, 2004; EU, 2008). It also gives an overview of 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 39 European countries (⁽¹⁾).

The present analysis indicates that air quality policies have delivered 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 in exceedance of European standards and WHO Air Quality Guidelines (AQGs).

Effective air quality policies require action and cooperation on 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, structural changes, including the optimisation of infrastructures and urban planning, 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 (⁽²⁾).

Europe's air quality today

Particulate matter

The EU limit and target values for particulate matter (PM) continued to be exceeded in large parts of Europe in 2013. The EU daily limit value for PM with a diameter of 10 µm or less (PM₁₀) was exceeded in 22 of the 28 EU Member States, and the target value for PM with a diameter of 2.5 µm or less (PM_{2.5}) was exceeded in 7 Member States. A total of 17% of the EU-28 urban population was exposed to PM₁₀ levels above the daily limit value and approximately 61% was exposed to concentrations exceeding the stricter WHO AQG value for PM₁₀ in 2013. Regarding PM_{2.5}, 9% of the urban population in the EU-28 was exposed to PM_{2.5} levels above the EU target value (which changes to a limit value from 2015 onwards) and approximately 87% was exposed to concentrations exceeding the stricter WHO AQG value for PM_{2.5} in 2013 (Table ES.1).

(¹) The EEA-33 member countries comprise the EU-28 Member States (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, Slovenia, Slovakia, Spain, Sweden and the United Kingdom), plus the remaining five EEA member countries (Iceland, Liechtenstein, Norway, Switzerland and Turkey). The EEA cooperating countries are Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Kosovo, under the UN Security Council Resolution 1244/99, Montenegro and Serbia.

(²) The 2050 vision is set out in the EU's 7th Environment Action Programme (EU, 2013).

Ozone

The EU ozone (O₃) target value for the protection of human health was exceeded in 18 of the 28 EU Member States in 2013. Conformity with the WHO AQG value for O₃ was observed in less than 3% of all stations in Europe in 2013. Some 15% of the EU-28 urban population lives in areas in which the EU O₃ target value threshold for protecting human health was exceeded in 2013. The EU urban population exposed to O₃ levels exceeding the WHO AQG was significantly higher, comprising 98% of the total urban population in 2013 (Table ES.1).

Nitrogen dioxide

The annual limit value for nitrogen dioxide (NO₂) was widely exceeded across Europe in 2013, with 93% of all exceedances occurring close to roads. A total of 19 of the 28 EU Member States recorded exceedances of this limit value at one or more stations. Of the EU-28 urban

population, 9% lives in areas in which the annual EU limit value and the WHO AQG for NO₂ were exceeded in 2013 (Table ES.1).

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

Exposure to benzo[a]pyrene (BaP) pollution is quite significant and widespread, in particular in central and eastern Europe. Approximately half of the BaP measurement stations in Europe were in exceedance of the EU target value in 2013, mostly in urban areas. About 20% of the total European population was exposed to BaP annual mean concentrations above the European target value in 2012 and about 88% lives in areas with concentrations above the estimated reference level⁽³⁾. Considering only urban populations, in 2013 25% of the EU-28 urban population was exposed to BaP concentrations above the target value, and as much as 91% was exposed to BaP concentrations above the estimated reference level (Table ES.1).

Table ES.1 Percentage of the urban population in the EU-28 exposed to air pollutant concentrations above certain EU and WHO reference concentrations (2011–2013)

Pollutant	EU reference value	Exposure estimate	WHO AQG	Exposure estimate
PM _{2.5}	Year (25)	9–14	Year (10)	87–93
PM ₁₀	Day (50)	17–30	Year (20)	61–83
O ₃	8-hour (120)	14–15	8-hour (100)	97–98
NO ₂	Year (40)	8–12	Year (40)	8–12
BaP	Year (1 ng/m ³)	25–28	Year (RL, 0.12 ng/m ³)	85–91
SO ₂	Day (125)	<1	Day (20)	36–37

Key: < 5% 5–50% 50–75% > 75%

Notes: The estimated range in exposures refers to a recent three year period (2011–2013, except for SO₂ WHO AQG, 2011–2012) and includes variations due to meteorology, as dispersion and atmospheric conditions differ from year to year.

The reference concentrations include EU limit or target levels, WHO air quality guidelines (AQG) and estimated reference levels.

The reference concentrations in brackets are in µg/m³ except for BaP in ng/m³.

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 PM₁₀ the most stringent limit value is for 24-hour mean concentration and for NO₂ it is the annual mean limit value.

As the WHO has not set AQG 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 × 10⁻⁵ (ETC/ACM, 2011).

Source: Based on EEA, 2015d.

⁽³⁾ This level was estimated assuming WHO unit risk for lung cancer for polycyclic aromatic hydrocarbon mixtures, and an acceptable risk of additional lifetime cancer risk of approximately 1 × 10⁻⁵ (ETC/ACM, 2011).

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

The EU-28 urban population was exposed to only a few exceedances of the sulphur dioxide (SO₂) EU daily limit value in 2013. However, 37% of the EU-28 urban population was exposed to SO₂ levels exceeding the WHO AQG in 2012.

Exposure of the European population to carbon monoxide (CO) concentrations above the EU limit value and WHO AQG is very limited, localised and sporadic. No reporting stations in either the EU-28 or EEA-33 groups of countries registered exceedances of the CO limit value in 2013.

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.

Exceedances of the limit value for benzene (C₆H₆) were likewise limited to very few locations in Europe in 2013.

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 since 1990, resulting in generally improved air quality across the region. However, certain sectors have not sufficiently reduced their emissions in order 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 sufficiently decreased to meet air quality standards in many urban areas. Furthermore, emissions of PM_{2.5} and BaP from coal and biomass combustion in households and from commercial and institutional buildings have risen in the EU in the past decade. These sources are now the main contributors to total PM and BaP emissions in the EU.

Although European air quality is projected to improve in future with a full implementation of existing legislation, further efforts to reduce emissions of air pollutants are necessary to assure full compliance with EU air quality standards set for the protection of human health and the environment. For example, non-exhaust emissions of PM from transport (i.e. tyre, road and brake wear) are important and are currently not regulated.

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 problematic pollutants in terms of harm to human health are PM, ground-level O₃ and NO₂. In addition, BaP (an indicator for polycyclic aromatic hydrocarbons (PAHs)) causes adverse health effects, particularly in eastern Europe.

Estimates of the health impacts attributable to exposure to air pollution indicate that PM_{2.5} concentrations in 2012 were responsible for about 432 000 premature deaths originating from long-term exposure in Europe (over 40 countries; see Table 9.2), of which around 403 000 were in the EU-28. In the same year, the estimated impact of exposure to NO₂ (long-term exposure) and O₃ (short-term exposure) concentrations on the population in the same 40 European countries was around 75 000 and 17 000 premature deaths, respectively, and around 72 000 and 16 000 premature deaths, respectively, in the EU-28.

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 O₃, ammonia (NH₃) and NO_x.

Europe's sustained ground-level O₃ concentrations damage agricultural crops, forests and plants by reducing their growth rates. The EU target value for protection of vegetation from O₃ has been exceeded in about 27% of the EU-28 agricultural land area in 2012, mostly in southern and central Europe. The long-term objective for the protection of vegetation from O₃ was exceeded in 86% of the total EU-28 agricultural area, and the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) critical level for the protection of forests was exceeded in 67% of the total EU-28 forest area in 2012.

NO_x, SO₂ and NH₃ 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

Box ES.1 The EU Clean Air Policy Package

In late 2013, the European Commission (EC) proposed a new Clean Air Policy Package. This package updates existing legislation controlling harmful emissions from industry, traffic, energy plants and agriculture, with a view to reducing their impact on human health and the environment. The package has a number of components, including:

- a new clean air programme for Europe, with measures to ensure that existing targets are met in the short term, and new air quality objectives for the period up to 2030; the package also includes support measures to help cut air pollution, with a focus on improving air quality in cities, supporting research and innovation and promoting international cooperation;
- a proposal for a revised National Emissions Ceilings Directive with stricter national emission ceilings for six main pollutants, and provisions for black carbon, which will also help to mitigate climate change;
- a proposal, now adopted, for a new directive to reduce pollution from medium-sized combustion installations of between 1 thermal megawatt (MWth) and 50 MWth, such as energy plants for street blocks or large buildings, and small industrial installations.

If agreed, and assuming full implementation by 2030, compared with business as usual (i.e. implementation of current legislation), the new Clean Air Policy Package is estimated to:

- prevent 58 000 premature deaths;
- save 123 000 km² of ecosystems from nitrogen pollution;
- save 56 000 km² of protected Natura 2000 areas from nitrogen pollution;
- save 19 000 km² of forest ecosystems from acidification.

The health benefits expected from the package will result in savings of between EUR 40 billion and EUR 140 billion in reduced damage costs alone, and will provide about EUR 3 billion in direct benefits as a result of higher workforce productivity, lower healthcare costs, higher crop yields and less damage to buildings. It is also expected that the new Clean Air Policy Package will have a positive net impact on economic growth in Europe: fewer workdays lost will increase productivity and competitiveness and generate new jobs (EC, 2013b).

made in past decades, largely as a result of declining SO₂ emissions. An estimated 7% of the total EU-28 ecosystem area and 5% of the Natura 2000⁽⁴⁾ area were at risk of acidification in 2010. This represents a reduction of 30% and 40%, respectively, from 2005 levels.

Apart from causing acidification, NH₃ 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 European ecosystem areas, and 73% of the area covered by Natura 2000-protected sites, remained exposed to air-pollution levels exceeding eutrophication limits in 2010.

⁽⁴⁾ Natura 2000 is an EU-wide network of nature protection areas (EEA, 2012a) 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.

1 Introduction

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. Air pollutants are emitted from anthropogenic and natural sources; they may be either emitted directly or formed in the atmosphere; 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 on humans, ecosystems and the climate. Effective air quality policies call for action and cooperation on global, European, national and local levels, which extends across most economic sectors and which engages the public. Holistic solutions involving technological development, structural changes, including the optimisation of infrastructures and urban planning, and behavioural changes must be found.

1.1 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. Air pollution as a whole, as well as PM as a separate component of air pollution mixtures, have recently been classified as carcinogenic (IARC, 2013).

The effect of air pollution on health also has considerable economic impacts, cutting lives short, increasing medical costs and reducing productivity



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through working days lost across the economy. 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).

As regards the associated costs of air pollution in Europe, the European Commission estimates that total health-related external costs in 2010 were in the range of EUR 330–940 billion per year, 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 (EC, 2013a).

1.2 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 O₃ damages agricultural crops, forests and plants by reducing their growth rates. The European Commission estimates the cost of crop yield loss for 2010 to be around EUR 3 billion (EC, 2013a). Other pollutants, such as nitrogen oxides (a family of gases collectively known as NO_x), SO₂ and ammonia (NH₃) contribute to the acidification of soil, lakes and rivers, causing the loss of animal and plant life. In addition to causing acidification, NH₃ and NO_x emissions also disrupt land and water 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 Climate change

Several air pollutants are also climate forcers, which have a potential impact on the planet's climate and global warming in the short term (i.e. decades). Tropospheric O₃ and black carbon (BC), a constituent of PM, are examples of air pollutants that are short-lived climate forcers and that contribute directly to global warming. Other PM components, such as organic carbon, ammonium (NH₄⁺), sulphate (SO₄²⁻) and nitrate (NO₃⁻), have a cooling effect.

Measures to cut BC emissions, along with those of other pollutants that cause tropospheric O₃ formation, such as methane (CH₄) (itself a greenhouse gas (GHG)), 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.

1.4 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 are 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 ceramic, 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 and nitrogen oxides, SO_x and NO_x, as well as carbon dioxide (CO₂)). The costs of damage to buildings were estimated to be around EUR 1 billion in 2010 (EC, 2013a).

1.5 Air policy

European air pollution is a well-established environmental policy area; over a number of decades, policies in this area have resulted in decreased emissions of air pollutants and have led to noticeable improvements in air quality.

Current EU air pollution policy is underpinned by the 2005 Thematic Strategy on Air Pollution (TSAP) (EC, 2005) which aims to achieve improvements in 2020 relative to the situation in 2000, with concrete objectives concerning impacts on human health and the environment. The TSAP also established which European legislation and measures are needed to ensure progress towards the long-term goal of the Sixth Environment Action Programme (EAP) (i.e. the EAP that ran from 2002 to 2012), to attain 'levels of air quality that do not give rise to significant negative impacts on, and risks to human health and the environment'. This goal has recently been reinforced in the Seventh EAP (which will run until 2020). To move towards achieving the TSAP objectives, EU air pollution legislation has 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 Air Quality Directives (EU, 2004;



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EU, 2008) and the National Emission Ceilings Directive (EU, 2001). Source-specific legislation also focuses on industrial emissions, road and off-road vehicle emissions, fuel quality standards, etc. Beyond the EU, emissions are also addressed under the 1979 UNECE LRTAP Convention, the Marine Pollution Convention and other international conventions. 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 (EEA, 2014b).

In late 2013, the European Commission proposed a new Clean Air Policy Package for Europe, which aims to ensure compliance with existing legislation by 2020 and to further improve Europe's air quality by 2030 and thereafter (EC, 2013b). The package proposes strengthening the implementation of existing legislation, introducing stricter national emission-reduction commitments and reducing emissions from medium-size combustion plants (see Box ES.1).

It is clear that minimising air pollution and its impacts requires coordinated action at international, European, national, regional and local levels. The national and sub-national authorities are very important in

implementing EU legislation. Moreover, these authorities are often responsible for encouraging and adopting local measures to further protect their populations and the environment.

1.6 Outline of this report

This report presents an updated overview and analysis of air quality in Europe and is focused on the state in 2013 and the development over the past 10 years, since 2004. The evaluation of the status of air quality is based on ambient air measurements, 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 requirements of the two Air Quality Directives presently in force (EU, 2004; EU, 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 EAPs (EU, 2002; EU, 2013).

2 Sources and emissions of air pollutants

Air pollutants may be categorised as either primary air pollutants (i.e. pollutants directly emitted to the atmosphere) or secondary air pollutants, that is, pollutants formed in the atmosphere from the so-called precursor gases (e.g. secondary PM, O₃ and secondary NO₂). Air pollutants can also be classified as natural and anthropogenic as a function of the origin of their emissions or precursors.

2.1 Sources of regulated pollutants

Particulate matter (PM) is both directly emitted to the atmosphere (primary PM) and formed in the atmosphere (secondary PM). The chief precursor gases for secondary PM are SO₂, NO_x (a family of gases that includes nitrogen monoxide (NO) and NO₂), NH₃ and volatile organic compounds (VOCs; a class of chemical compounds whose molecules contain carbon). The main precursor gases NH₃, SO₂ and NO_x react in the atmosphere to form ammonium, sulphate and nitrate 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, 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.

Black carbon (BC) is one of the constituents of fine PM and has a warming effect. BC is a product of incomplete combustion of organic carbon as emitted from traffic, fossil fuels and biomass burning, and industry.

Ground-level (tropospheric) ozone (O₃) is not directly emitted into the atmosphere. Instead, it is formed from complex chemical reactions following emissions of precursor gases such as NO_x and non-methane VOCs (NMVOCs) of both natural (biogenic) and anthropogenic

origin. At the continental scale, CH₄ and CO also play a part in O₃ formation.

The major sources of nitrogen oxides (NO_x) are combustion processes (e.g. in fossil-fuelled vehicles and power plants). Most NO₂ is formed by the oxidation of emissions of NO. NO accounts for the majority of NO_x emissions, although smaller amounts of NO_x emissions are directly emitted as NO₂. This applies for most combustion sources except for newer diesel vehicles, which may emit as much as 55% of their NO_x as NO₂ (Grice et al., 2009), because their exhaust after-treatment systems increase oxidation of NO, which leads to higher direct NO₂ emissions.

Benzo[a]pyrene (BaP) is emitted from the incomplete combustion of various fuels. The main sources of BaP in Europe are domestic home-heating, in particular wood- and coal-burning, waste-burning, coke and steel production, and road traffic. Other sources include outdoor fires and rubber-tyre wear.

Sulphur oxides (SO_x), a family of gases that includes SO₂ and sulphur trioxide (SO₃), are mainly emitted from the combustion of fuels containing sulphur. The main anthropogenic emissions of SO₂ derive from domestic heating, stationary power generation and transport. Volcanoes are the biggest natural source of SO_x.

Carbon monoxide (CO) and benzene (C₆H₆) 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.

C₆H₆ is an additive to petrol, and most of its emissions come from traffic in Europe. These C₆H₆ emissions have declined sharply since the introduction of the Fuel Quality Directive (EU, 2009). In general, contributions to C₆H₆ 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 C₆H₆. Other sources include oil refining, as well as the handling, distribution and storage of petrol.

Methane (CH₄) is a precursor of tropospheric O₃ and also has a warming effect on climate. It is emitted mainly from agriculture, waste management and energy production.

Anthropogenic emissions of 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, 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, O₃ and NO₂ have decreased over the past decade (2004–2013) as a whole in the EU-28 (Figure 2.1 top ⁽⁵⁾) and EEA-33 countries. The smallest reduction was for NH₃ (6%) and the largest was for SO_x (58%). The exception is the total emissions of NH₃ in the EEA-33 countries, which increased by 7% in the same period ⁽⁶⁾.

Regarding the remaining pollutants (heavy metals and BaP), parties under the LRTAP Convention are invited to report emissions data for PAHs (including BaP); this means that reporting of these pollutants is not mandatory as for the rest, but rather is undertaken on a voluntary basis. Emissions of BaP in the EU-28 have increased by 10% (18 tonnes/year) between 2004 and 2013 (Figure 2.1 bottom), whereas the increase in the EEA-33 countries' emissions was 9% (17 tonnes/year) in the same period. The fact that Austria, Belgium, Finland, Greece and Italy did not report their emissions for any of the years leaves a gap for the assessment of both the status and trends of BaP emissions. The reporting countries that contribute the most to BaP emissions in the EU are Poland, Romania, and Germany, all of whose emissions have increased in the past decade.

Figure 2.1 (bottom) shows a decrease in the emissions of As, Cd, Ni, Pb and Hg reported by the EU Member States between 2004 and 2013. The greatest reduction both in EU-28 and EEA-33 countries was for Ni emissions (52%) and the smallest was for emissions of As (18%).

C₆H₆ emissions are not included as an individual pollutant in European emissions inventories covering VOCs, meaning that its emissions are not recorded. In any case, and as mentioned above, C₆H₆ emissions have dropped since the introduction of the revised Fuel Quality Directive (EU, 2009).

2.3 Sectoral emissions of air pollutants

The main source sectors contributing to emissions of air pollutants in Europe are transport, energy, industry, the commercial, institutional and households sector, agriculture and waste. Figure 2.2 shows the development of the emissions of primary PM with a diameter of 10 µm or less (PM₁₀) and PM with a diameter of 2.5 µm or less (PM_{2.5}), NO_x, SO_x, NH₃, NMVOCs, CO and BC from these sectors between 2004 and 2013. Similarly, Figure 2.3 shows the development in emissions of BaP and the toxic metals As, Cd, Ni, Pb and Hg.

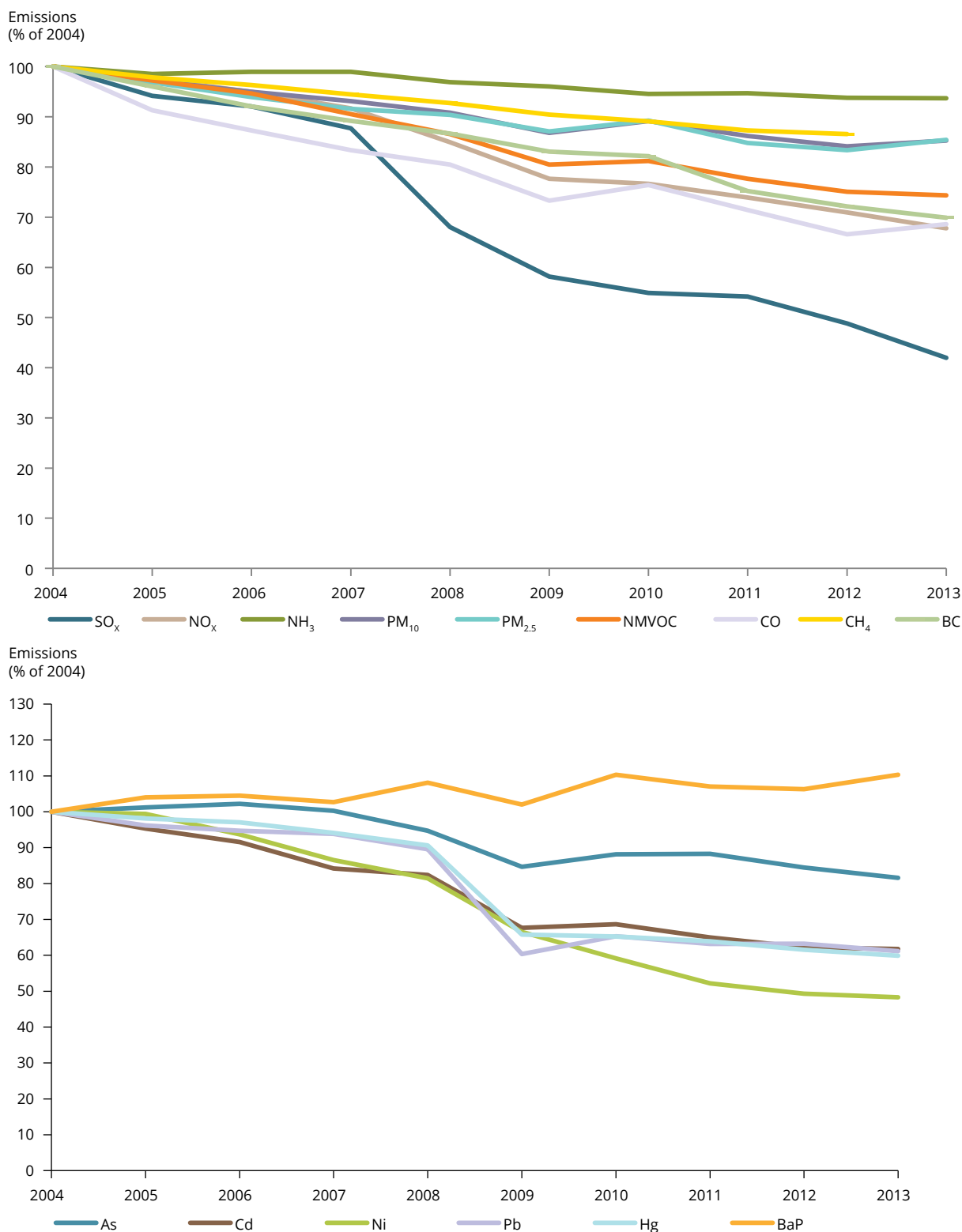
The **transport** sector has considerably reduced its emissions of air pollutants in Europe over the past decade, as Figures 2.2 and 2.3 show, with the exception of BaP emissions, which have increased by 9% in the EU-28 and the EEA-33 countries from 2004 to 2013. The highest emission reductions from transport between 2004 and 2013 were registered for SO_x (67% in the EU-28 and 74% in the EEA-33) and for NMVOCs (59% in the EU-28 and 60% in the EEA-33). The reductions in emissions of As and Hg were the least pronounced 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 2013. However, NO_x emissions, and in particular NO₂ emissions, from road transport have not been reduced as much as expected with the introduction of the vehicle emissions standards (the so called Euro standards) since 1991, since emissions in real-life driving conditions are often higher, especially for diesel vehicles, than those measured during the approval test (see Box 5.1). Transport also remains a very important source of GHGs within the EU; in 2012, GHG emissions from transport were 21% above their 1990 levels (EEA, 2014c).

⁽⁵⁾ Reporting on BC emissions is on a voluntary basis (EEA, 2015c).

⁽⁶⁾ This increase is due to a doubling from 2012 to 2013 in the NH₃ emissions reported by Turkey.

Figure 2.1 Development in EU-28 emissions of SO_x, NO_x, NH₃, PM₁₀, PM_{2.5}, NMVOCs, CO, CH₄ and BC (top) and of As, Cd, Ni, Pb, Hg, and BaP (bottom), 2004–2013 (% of 2004 levels)



Note: CH₄ emissions are total emissions (Integrated Pollution Prevention and Control sectors 1–7) excluding sector 5. Land use, land-use change and forestry, and data are only available until 2012. The present emission inventories include only anthropogenic VOCs emissions. Under the Gothenburg Protocol of the LRTAP Convention, parties are encouraged to report emissions of BC, one of the constituents of PM. It means that reporting on BC emissions has been made on a voluntary basis and has not been made for every country.

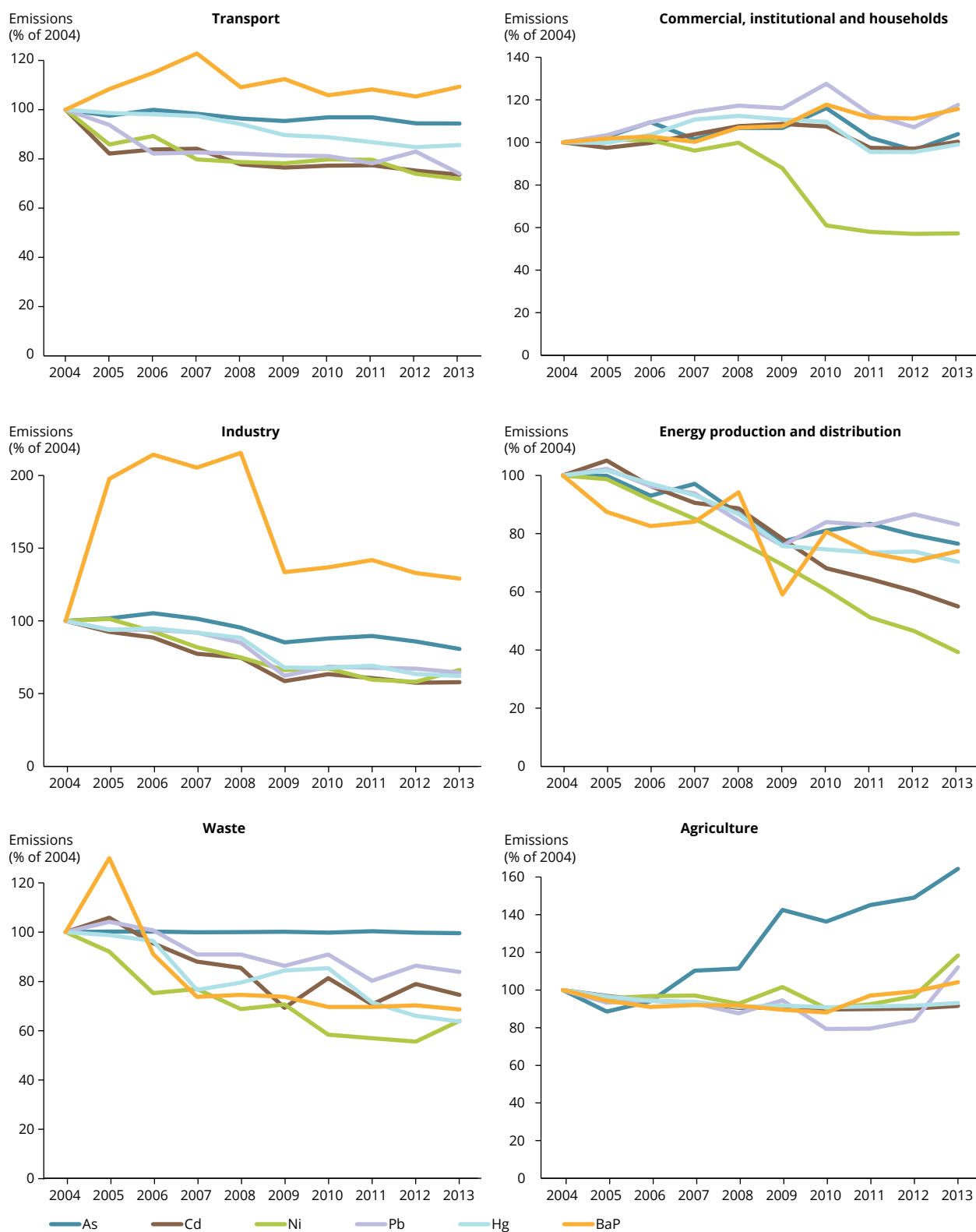
Source: Based on EEA, 2015e.

Figure 2.2 Development in EU-28 emissions from main source sectors of SO_x, NO_x, NH₃, PM₁₀, PM_{2.5}, NMVOCs, CO and BC, 2004–2013 (% of 2004 levels)



Source: Based on EEA, 2015e.

Figure 2.3 Development in EU28 emissions from main source sectors of As, Cd, Ni, Pb, Hg and BaP, 2004–2013 (% of 2004 levels)



Source: Based on EEA, 2015e.

Transport also contributed to 13% and 15% of the total PM₁₀ and PM_{2.5} primary emissions, respectively, in the EU Member States in 2013. Non-exhaust emissions from road traffic (which are not included in Figure 2.2) contribute to total road-traffic emissions. Non-exhaust emissions are estimated to equal about 50% of the exhaust emissions of primary PM₁₀, and about 22% of the exhaust emissions of primary PM_{2.5} (ETC/ACC, 2009). 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 is estimated that nearly 90% of total PM emissions from road traffic will come from non-exhaust sources by 2020 (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 the year 2010) (EEA, 2013c).

The **commercial, institutional and households** fuel combustion sector dominates the emissions of primary PM_{2.5} and PM₁₀, BaP and CO, contributing to 43% and to 58% of the total primary PM₁₀ and PM_{2.5} emissions, respectively, and to 73% and 47% of the total BaP and CO emissions, respectively, in the EU-28 in 2013. Reported BaP emissions have increased by 16% from 2004 to 2013 in the EU-28, and by 14% in the EEA-33 countries. In addition, this sector has increased its emissions of PM₁₀, PM_{2.5}, CO, Pb and As.

The use of household wood and other biomass combustion for heating is growing in some countries, owing to government incentives/subsidies, rising costs of other energy sources, or an increased public perception that it is a 'green' option. Biomass is being promoted as a renewable fuel that can assist with climate change mitigation and contribute to energy security. In Sweden, for example, the use of biomass for district heating has grown from just a few per cent in the 1980s to nearly 50% of the district heating energy mix in 2010, due, in part, to the introduction of a carbon tax in 2001 (OECD/IEA, 2013). Some households have reverted to heating with solid fuels in response to economic hardship. This has happened recently in Greece and Ireland, for instance.

Industry considerably reduced its air pollutant emissions between 2004 and 2013, with the exception

of BaP emissions. It is still the largest source sector of Pb, As, Cd, NMVOC and Ni emissions. In 2013 industry contributed to 52% and 51% of NMVOCs total emissions in EU-28 and EEA-33 countries respectively, 40% and 40% of Ni, 56% and 56% of Cd, 60% and 59% of Pb and 57% and 57% of As. It is also the second-largest source of primary PM, SO_x and Hg emissions, contributing to 22% of PM₁₀, 25% of SO_x, 16% of PM_{2.5} and 41% of Hg total emissions in the EU-28 in 2013. The emissions of BaP have varied considerably in the period but have increased by 29% from 2004 to 2013. Even if industry contributes to only 5% of the total BaP emissions in the EU-28 in 2013, its emissions may contribute greatly to BaP air concentrations and population exposure locally, that is, in the vicinity of the industrial sources.

As for industry, **energy production and distribution** has made considerable reductions in its emissions. It is, however, the biggest contributor to SO_x and Hg emissions, representing 56% and 42% of total SO_x and Hg EU-28 emissions in 2013, respectively. The energy sector is the second most significant emitter of Ni and NO_x, contributing to 37% and 21%, respectively, of its total emissions in the EU-28 in 2013. From 2004 to 2013 the energy sector cut its emissions of all pollutants, with the only exception being primary PM₁₀ in the EU-28.

Agriculture is the main sector in which emissions of air pollutants have least decreased. The agricultural sector is by far the greatest emitter of NH₃ and was responsible for 93% of total NH₃ emissions in the EU-28 in 2013. Its NH₃ emissions have decreased by only 6% from 2004 to 2013. European policies have cut PM precursor gas emissions, with the exception of NH₃ from agriculture. Agriculture is now the third most important source of PM₁₀ primary emissions in the EU-28, after the 'Commercial, institutional and household fuel combustion' and industry sectors. Its contribution to PM₁₀ total emissions in the EU-28 was 14% in 2013. Agriculture was also the sector responsible for the greatest CH₄ emissions in the EU-28 in 2012, emitting 50% of total emissions.

The contribution of the **waste sector** to the total emissions of air pollutants is relatively small, with the exception of CH₄. Waste management is the second highest emitter of CH₄, after agriculture, accounting for 31% of the total CH₄ emissions in the EU-28 in 2012. It has cut its CH₄ emissions by 23% from 2003 to 2012.

3 Particulate matter

3.1 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) PM₁₀ concentrations, whereas values for only long-term PM_{2.5} concentration have been set (Table 3.1). The short-term limit value for PM₁₀ (i.e. not more than 35 days per year with a daily average concentration exceeding 50 µg/m³) is the limit value for PM₁₀ that is most often exceeded in Europe. It corresponds to the 90.4 percentile of daily PM₁₀ concentrations in one year. The annual PM₁₀ limit value is set at 40 µg/m³. The deadline for Member States to meet the PM₁₀ 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 exposure concentration obligation for PM_{2.5} (20 µg/m³) is 2015.

The Air Quality Guidelines (AQGs) set by WHO are stricter than the EU air quality standards for PM (Table 3.1). The recommended AQGs should be considered as 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). The PM_{2.5} annual mean guideline corresponds to the lowest levels beyond which total, cardiopulmonary and lung cancer mortality have been shown to increase (with > 95% confidence) in response to long-term exposure to PM_{2.5} (WHO, 2006a).

Table 3.1 Air quality limit and target values, and other environmental objectives, for PM₁₀ and PM_{2.5} as given in the EU Ambient Air Quality Directive and WHO AQGs

		EU Air Quality Directive		WHO AQG
Size fraction	Averaging period	Objective and legal nature and concentration	Comments	
PM ₁₀	1 day	Limit value: 50 µg/m ³	Not to be exceeded on more than 35 days per year	50 µg/m ³ ^(a)
PM ₁₀	Calendar year	Limit value: 40 µg/m ³		20 µg/m ³
PM _{2.5}	1 day			25 µg/m ³ ^(a)
PM _{2.5}	Calendar year	Target value: 25 µg/m ³		10 µg/m ³
PM _{2.5}	Calendar year	Limit value: 25 µg/m ³	To be met by 1 January 2015 (until then, margin of tolerance)	
PM _{2.5}		Exposure concentration obligation ^(b) , 20 µg/m ³	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		

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

^(b) Based on a three-year average.

Source: EU, 2008; WHO, 2006a.

3.2 Status in concentrations

3.2.1 Exceedances of limit and target values

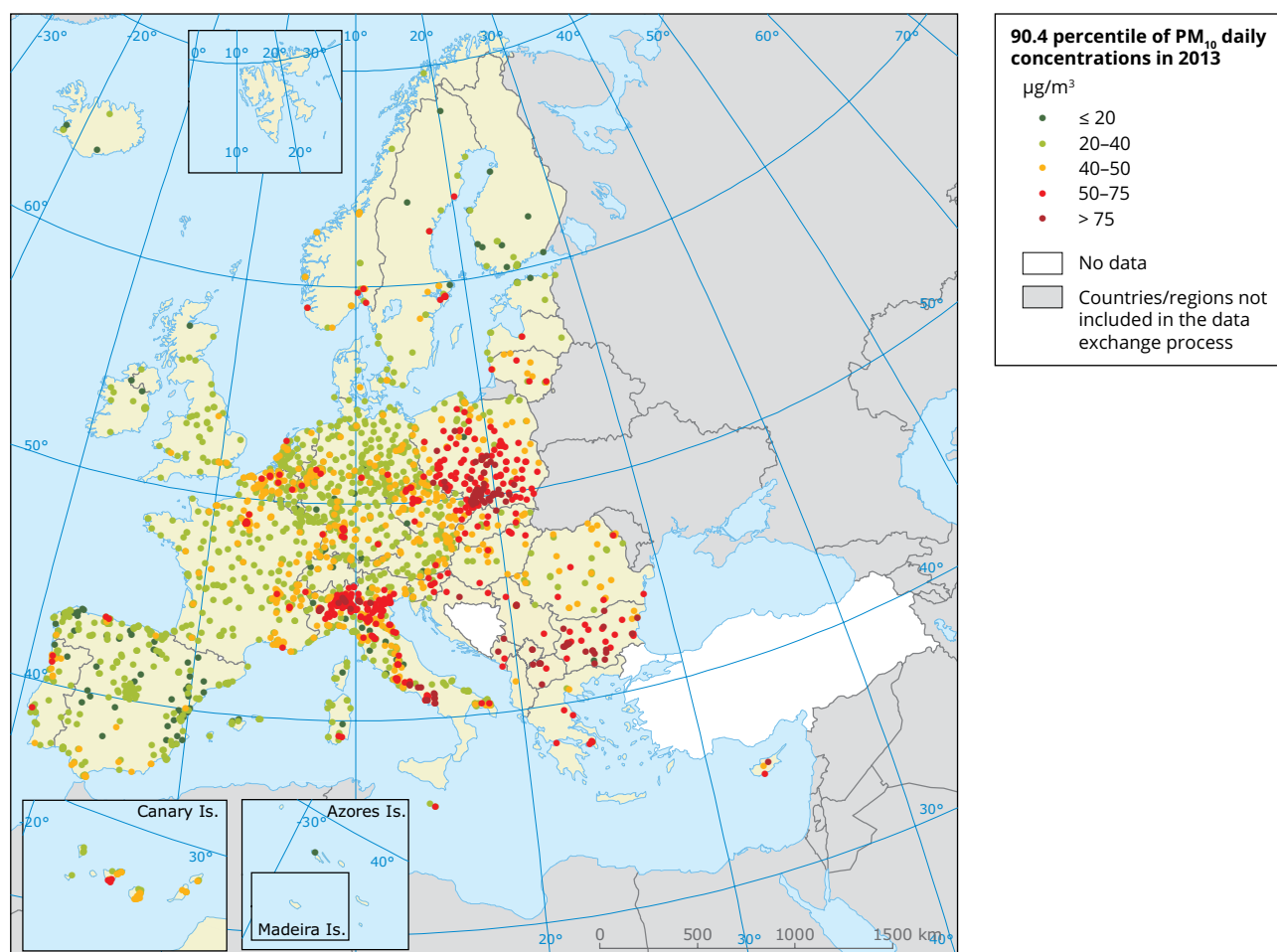
The EU limit value for PM₁₀ (applying from 2005) continues to be exceeded in large parts of Europe in 2013 according to the data of the European air quality database (Air Quality e-reporting database, EEA, 2015a). Map 3.1 shows concentrations of PM₁₀ in relation to the daily limit value, which is more stringent than the annual limit value and, therefore, more frequently exceeded. This daily limit value for PM₁₀ was widely exceeded in Bulgaria, Italy, Poland, Slovakia and the Balkan region but also in several urban regions across Europe, including in the Nordic countries.

Figure 3.1 shows the attainment of the PM₁₀ daily limit value in 2013 for all EU Member States. It indicates

that exceedance of the daily limit value was observed in 22 Member States at one or more stations. Only Denmark, Estonia, Finland, Ireland, Luxembourg and the United Kingdom did not record exceedances of this limit value in 2013. The exceedances occurred in 95% of the cases in urban or suburban areas.

In 2013, the PM_{2.5} concentrations were higher than the target value (annual mean, applicable from 2010, which will be the limit value for PM_{2.5} from 2015) at several stations in Bulgaria, the Czech Republic, Italy and Poland, as well as one station in France, the former Yugoslav Republic of Macedonia, Kosovo under the UN Security Council Resolution 1244/99, Romania, and Slovakia (see the dark red and red dots in Map 3.2). Figure 3.2 shows that exceedance of the target value threshold for PM_{2.5} was observed in seven Member States at one or more stations in

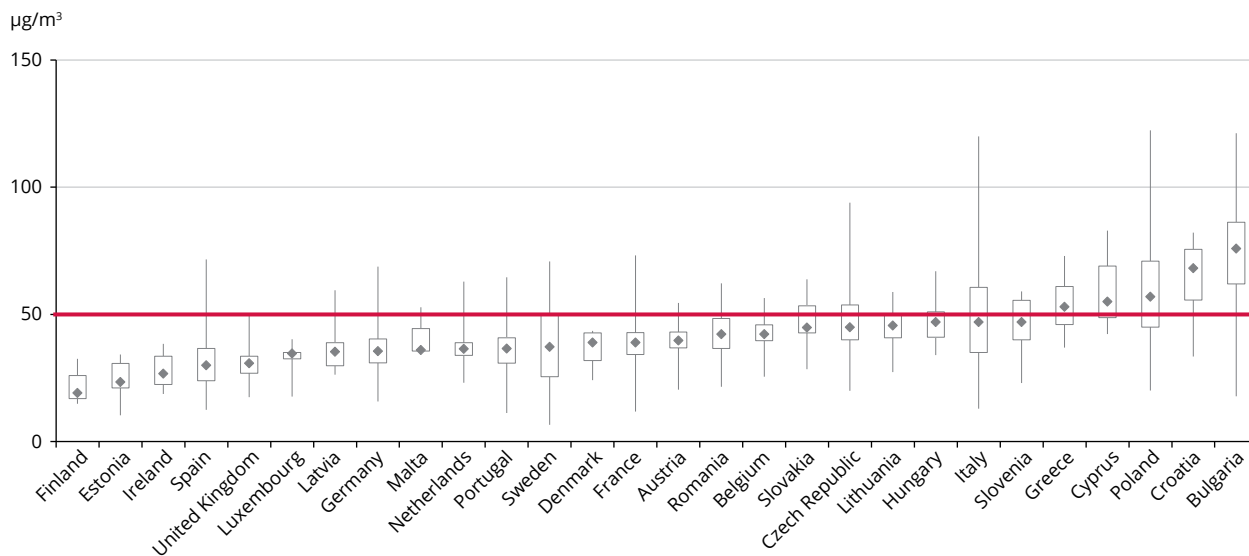
Map 3.1 Concentrations of PM₁₀ in 2013



Notes: The map shows the 90.4 percentile of the data records in one year, representing the 36th highest value in a complete series. It is related to the PM₁₀ daily limit value, allowing 35 exceedances over 1 year of the 50 µg/m³ threshold. The red and dark-red dots indicate stations with exceedances of this daily limit value. Only stations with > 75% of valid data have been included in the map.

Source: Based on Air Quality e-reporting database (EEA, 2015a).

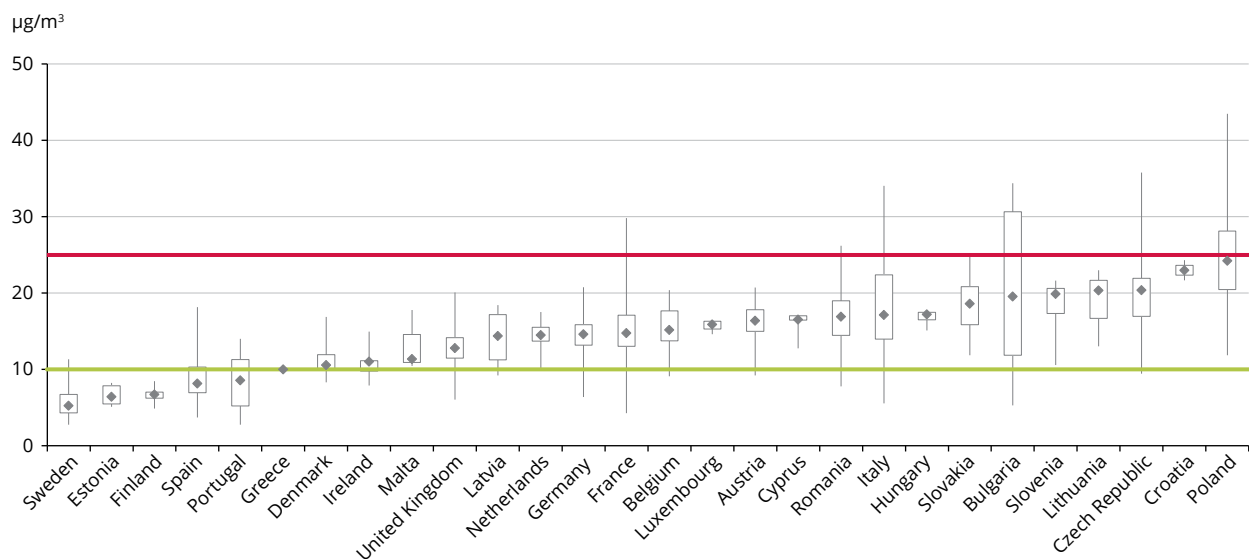
Figure 3.1 Attainment situation for PM₁₀ in 2013 in the EU-28



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 $\mu\text{g}/\text{m}^3$) at the stations are given. The rectangles mark the 25 and 75 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.

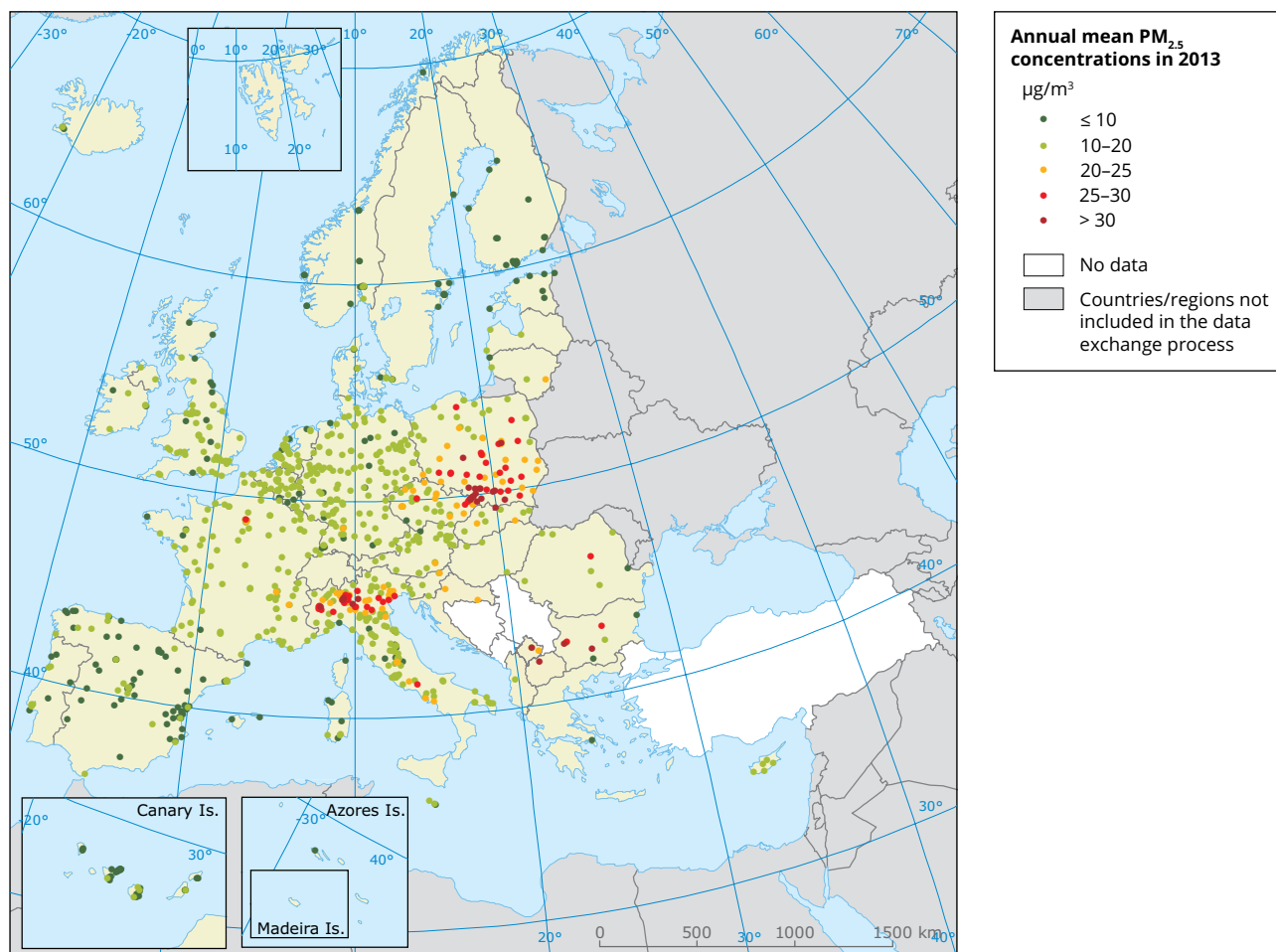
Source: Based on Air Quality e-reporting database (EEA, 2015a).

Figure 3.2 Attainment situation for PM_{2.5} in 2013 in the EU-28



Notes: The graph is based on annual mean concentration values. For each country, the lowest, highest and median values (in $\mu\text{g}/\text{m}^3$) at the stations are given. The rectangles give the 25 and 75 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 green line.

Source: Based on Air Quality e-reporting database (EEA, 2015a).

Map 3.2 Concentrations of PM_{2.5} in 2013

Notes: The dark-red dots indicate stations reporting exceedances of the EU annual target value (25 µg/m³) plus at least 5 µg/m³.
 The red dots indicate stations reporting exceedances of the EU annual target value (25 µg/m³).
 The orange dots indicate stations reporting exceedances of the 2020 EU indicative annual limit value (20 µg/m³).
 The light-green dots indicate stations reporting exceedances of the WHO AQG for PM_{2.5} (10 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: Based on Air Quality e-reporting database (EEA, 2015a).

2013, mostly in eastern Europe. The exceedances also occurred primarily (92% of cases) in urban or suburban areas. The average exposure indicator (AEI) for PM_{2.5} is discussed in Chapter 8 (see Figure 8.1).

The analysis of exceedances is based on measurements at fixed sampling points (7) fulfilling the criterion of > 75% data coverage. It does not account for the fact that the Ambient Air Quality Directive (EU, 2008) provides the Member States with the possibility of subtracting the

contribution of natural sources and winter road sanding/salting when limits are exceeded (EEA, 2012b).

The stricter value of the WHO AQG for annual mean PM₁₀ was exceeded at 67% of the stations and in 27 European countries, out of all countries that reported PM₁₀ data for 2013. The WHO guideline for annual mean PM_{2.5} (see the light green, yellow, orange, red and dark red dots in Map 3.2) was exceeded in 28 of the EEA-33 countries at 81% of the stations.

(7) Fixed sampling points in Europe are situated at four types of sites: traffic-related locations; urban and suburban background (non-traffic, non-industrial) locations; industrial locations (or other less defined locations); and rural background sites.

The rural background concentration of PM represents the PM level in rural areas without direct influence from close anthropogenic sources. It is, therefore, primarily the result of primary or secondary PM transported over larger distances or from natural sources, rather than the result of the contribution from local anthropogenic 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.

The rural background concentration levels of PM vary across Europe. Exceedances of the daily PM₁₀ limit value and the PM_{2.5} target value in the rural background in 2013 occurred in several stations in the Czech Republic and in Italy. Poland also registered exceedances of the PM₁₀ limit value in several rural background stations, whereas Romania and Slovenia registered one exceedance of the PM_{2.5} target value and PM₁₀ limit value, respectively, in their rural background stations.

3.2.2 Relationship of emissions to ambient particulate matter concentrations

Of all main emission sectors, only transport and industry reduced their emissions of primary PM between 2004 and 2013 (see Figure 2.2). The commercial, institutional and household fuel combustion sector is by far the most important sector,

contributing to 43% and 58% of the total EU-28 primary PM₁₀ and PM_{2.5} emissions in 2013, respectively. It may contribute to keeping PM concentrations elevated in both rural and urban areas, despite emission reductions in other sectors.

The contributions from the different emission sources to ambient air concentrations depend not only on the amount of pollutant emitted, but also on the proximity to the source, emission conditions (such as height and temperature), and other factors, such as dispersion conditions and topography. Emission sectors with low emission heights, such as traffic and household emissions, generally make a larger contribution to surface concentrations than emissions from high stacks.

With the exception of NH₃, the reductions in emissions of the PM precursors (NO_x, SO_x and NMVOCs) were much larger than the reductions in primary PM from 2004 to 2013 in the EU-28 (see Figure 2.1). Drops in anthropogenic emissions of primary PM and PM precursors have not led to equivalent drops in concentrations of PM. 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, and as discussed in EEA (2013b), 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.



Photo: © Virgolici Raluca, Environment & Me/EEA

4 Ozone

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

European air quality standards and WHO guidelines for O₃ are shown in Table 4.1. 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/m³). The target value, applied by EU Member States from 1 January 2010, 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 2010. The long-term objective is no exceedance of the threshold level at all. 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 WHO AQG for O₃ is a daily maximum 8-hour mean concentration of 100 µg/m³ (WHO, 2006a), as shown in Table 4.1. This recommended limit was reduced from the previous level of 120 µg/m³, based on recent conclusive associations between daily mortality and lower O₃ concentrations (WHO, 2014b).

The Ambient Air Quality Directive (EU, 2008) also sets targets for the protection of vegetation from high O₃ concentrations accumulated during the growing season (defined as May to July). The vegetation protection value is specified as 'accumulated exposure over threshold' (AOT40). This is calculated as the sum of the differences between hourly concentrations > 80 µg/m³ (= 40 ppb) and 80 µg/m³ accumulated over all hourly values measured during the daylight period of the most intense growing season (May to July). The target value for 2010 was 18 000 (µg/m³).h, determined as a 5-year average. The long-term objective is 6 000 (µg/m³).h, as shown in Table 4.1.

Table 4.1 Air quality standards for O₃ as defined in the EU Ambient Air Quality Directive and WHO AQG

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

Note: AOT40, accumulated O₃ 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.

Source: EU, 2008; WHO, 2006a; WHO, 2008.

In addition to the EU target value, the UNECE LRTAP Convention (UNECE, 1979) defines a critical level for the protection of forests. This level is related to the AOT40 during the months April to September and is set at 10 000 ($\mu\text{g}/\text{m}^3$).h.

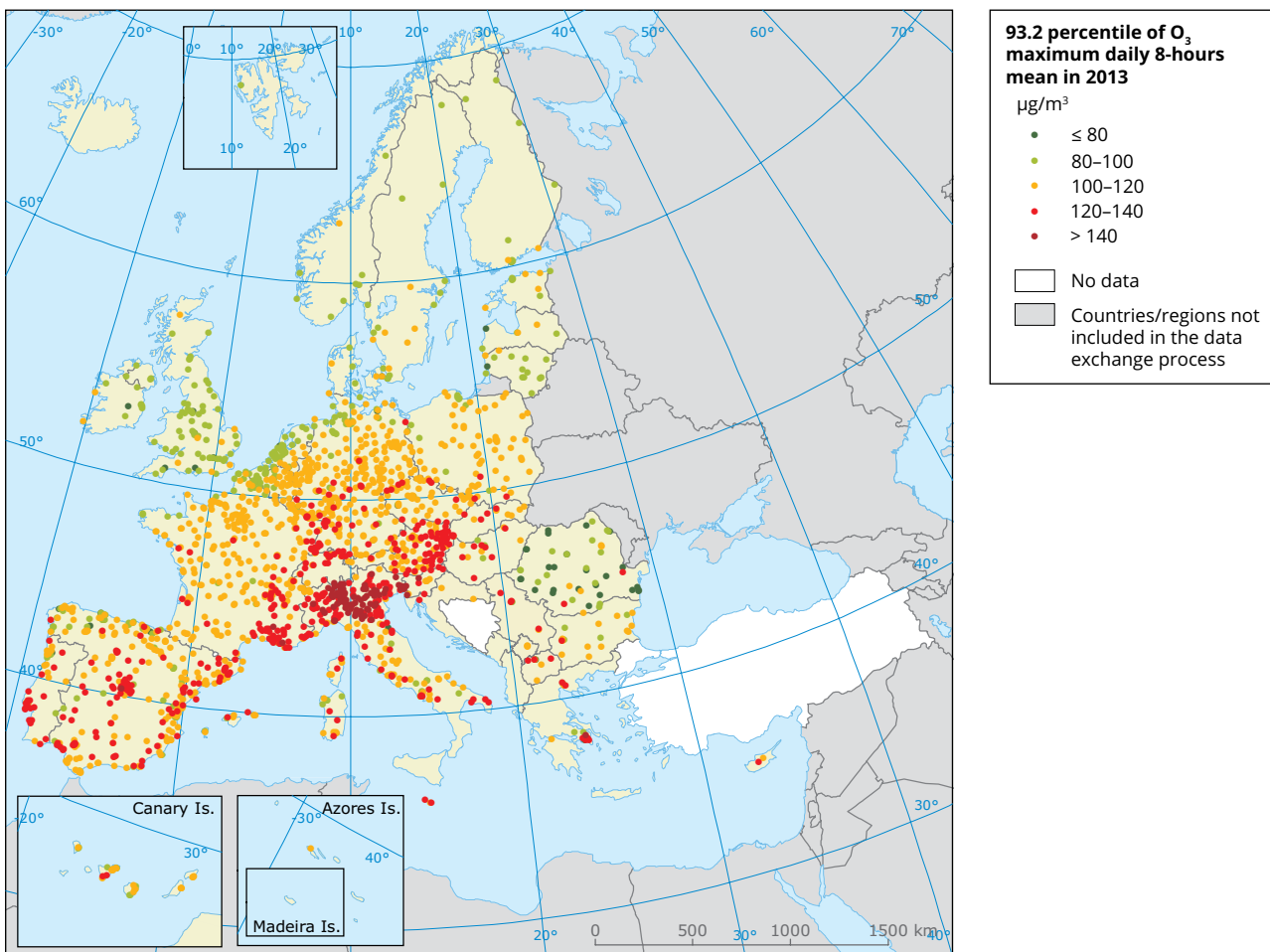
4.2 Status in concentrations

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 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 due to surface deposition and the titration reaction by the emitted NO to form NO_2 . Therefore, in contrast to other pollutants, O_3 concentrations are generally highest at rural locations, lower at urban sites and even lower at traffic locations. The high O_3 concentrations occurring at a few urban stations shown in Map 4.1 are attributable to the O_3 formation that occurs at times in large urban areas during episodes of high solar radiation and temperatures.

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 the 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 case of the 2003 heat wave.

Map 4.1 Concentrations of O_3 in 2013



Notes: 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 $120\text{-}\mu\text{g}/\text{m}^3$ threshold. At sites marked with red and dark-red dots, the 26th highest daily O_3 concentration exceeded the $120\text{-}\mu\text{g}/\text{m}^3$ threshold, implying an exceedance of the target value threshold. Only stations with $> 75\%$ of valid data have been included in the map.

Source: Based on Air Quality e-reporting database (EEA, 2015a).

4.2.1 Exceedance of the target values for protection of health

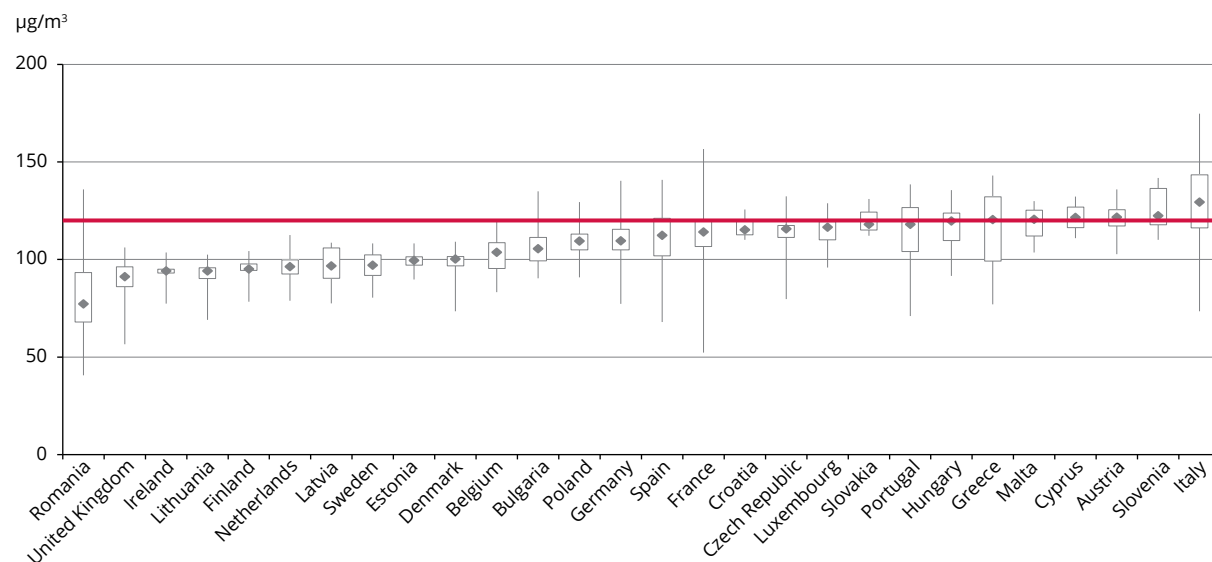
The health-related threshold of the O₃ target value was exceeded more than 25 times in 2013 in 18 ⁽⁸⁾ of the 28 EU countries (see Figure 4.1). In total, 28% of all stations ⁽⁹⁾ reporting O₃ were in exceedance in 2013. Conformity with the WHO AQG value for O₃ (8-hour mean of 100 µg/m³), set for the protection of human health, was observed in < 3% of all stations and in only 8 of 525 rural background stations in 2013. Although the EU target value (120 µg/m³, 25 exceedances allowed) is less ambitious than the WHO AQG, non-attainment cases (i.e. not having achieved the EU air quality standard) are widely found in most EU Member States, as shown in Map 4.1.

4.2.2 Relationship of ozone precursor emissions to ambient ozone concentrations

Reductions in anthropogenic O₃ precursor gas emissions in Europe have not led to equivalent

reductions in O₃ concentrations in Europe, as the relationship of O₃ concentration to the emitted precursors is not linear. One contributing factor for this is an increase in intercontinental transport of O₃ and its precursors in the northern hemisphere (EEA, 2013c). Another factor is the reduction in European NO_x emissions, which has led to an increase in O₃ concentrations in the highly urbanised areas of the southern, central and north-western parts of Europe, including, for example, Belgium, Germany, the Netherlands and the United Kingdom (Bach et al., 2014) and Spain (Querol et al., 2014). Outside these urbanised areas, further NO_x emissions control will lower O₃ concentrations, as NO_x is a precursor of O₃. In addition, other factors are also likely to mask the effects of European measures to reduce anthropogenic O₃ precursor emissions, including climate change/variability, NMVOCs emissions from vegetation (difficult to quantify) and fire plumes from forest and other biomass fires (EEA, 2010). Formation of tropospheric O₃ from increased concentrations of CH₄ may also contribute to the sustained O₃ levels in Europe.

Figure 4.1 Attainment situation for O₃ in 2013 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 give the 25 and 75 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: Based on Air Quality e-reporting database (EEA, 2015a).

⁽⁸⁾ Austria, Bulgaria, Croatia, Cyprus, the Czech Republic, France, Germany, Greece, Hungary, Italy, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia and Spain.

⁽⁹⁾ With data coverage equal to or above 75% for all countries reporting O₃ data to EEA, as shown in Map 4.1.



Photo: © Matteo Carzaniga, Picture2050/EEA

Clearly, O₃ concentrations are not only determined by precursor emissions but also by meteorological conditions, as sunlight and high temperatures favour O₃ formation. Episodes of elevated O₃ levels occur during periods of warm, sunny weather in areas affected by urban/industrial pollution plumes. However, independent of the episodic nature

of O₃ pollution, which is strongly influenced by meteorological conditions, emissions of O₃ precursor gases are sustaining O₃ levels that lead to exceedance of legal concentration thresholds. The O₃ pollution problem requires further mitigation efforts at a local and a regional scale, as well as international cooperation.

5 Nitrogen dioxide

5.1 European air quality standards and World Health Organization guidelines for NO₂

The European air quality standards set by the Ambient Air Quality Directive (EU, 2008) for NO₂, as well as the WHO guidelines, are shown in Table 5.1. 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 NO₂ concentration is set at 40 µg/m³. The 1-hour limit value threshold of 200 µg/m³ can be exceeded on up to 18 days 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 ⁽¹⁰⁾.

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 NO₂ 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 NO₂, as shown in Table 5.1 (WHO, 2006a). The only difference is that WHO AQG does not allow any exceedance of the 1-hour limit value threshold.

Table 5.1 Air quality standards for NO₂ and NO_x as set out in the EU Ambient Air Quality Directive and WHO AQG

Averaging period	EU Air Quality Directive		WHO AQG
	Objective and legal nature	Concentration	
1 hour	Human health limit value	200 µg/m ³ , not to be exceeded on more than 18 hours per year	200 µg/m ³
Calendar year	Human health limit value	40 µg/m ³	40 µg/m ³
1 hour	Alert ^(a) threshold	400 µg/m ³	
Calendar year	Vegetation critical level	30 µg/m ³ ^(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 as µg NO_x/m³.

Source: EU, 2008; WHO, 2006a.

⁽¹⁰⁾ 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).

5.2 Status in concentrations

5.2.1 Exceedances of limit values for the protection of human health

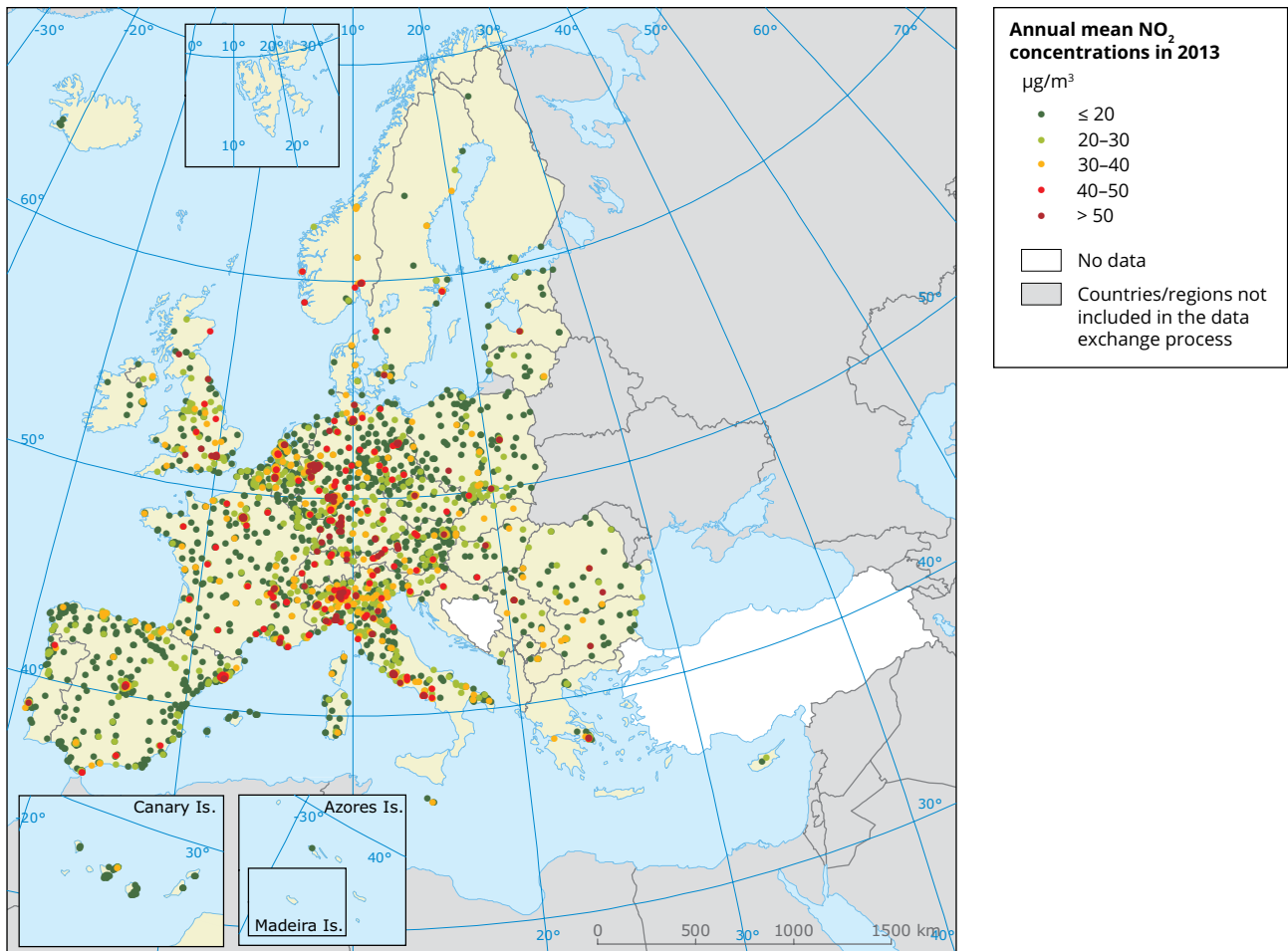
Map 5.1 shows that the annual limit value was widely exceeded across Europe in 2013. Of all stations measuring NO₂ and with sufficient data coverage ⁽¹¹⁾, 14% registered exceedances of the annual mean limit value.

No exceedances occurred at rural background stations. The highest concentrations, as well as 93% of all exceedances, occurred at traffic stations. Traffic is a major source of NO₂ and of NO, which reacts with

O₃ to form NO₂. Traffic emissions are close to the ground, contributing relatively more to NO₂ ground concentrations, 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 O₃ present is therefore depleted during the oxidation of NO to NO₂.

Figure 5.1 shows the attainment of annual mean NO₂ values for 2013 for all EU Member States. It clearly indicates that exceedance of the annual limit value (equal to the WHO AQG) was observed in most Member States at one or more stations in 2013. Nineteen ⁽¹²⁾ of the 28 EU Member States recorded exceedances of the limit value at one or more stations.

Map 5.1 Concentrations of NO₂ in 2013

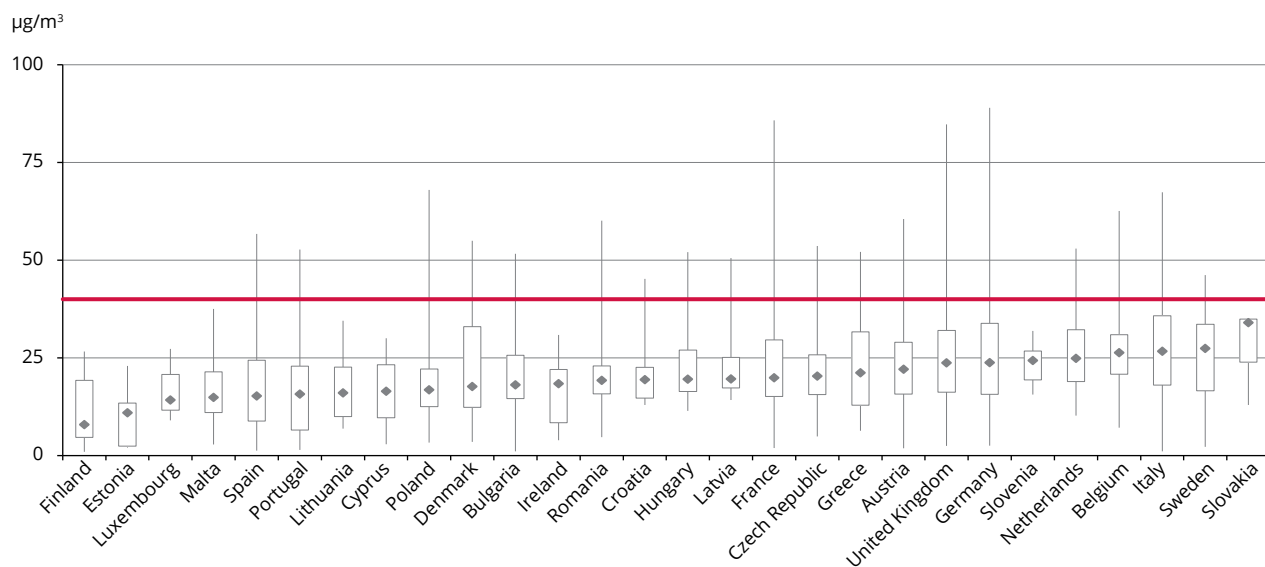


Notes: Red and dark-red dots correspond to exceedances of the EU annual limit value and the WHO AQG (40 µg/m³). Only stations reporting hourly data and with > 75% of valid data have been included in the map.

Source: Based on Air Quality e-reporting database (EEA, 2015a).

⁽¹¹⁾ Sufficient data coverage for this analysis means fulfilling the criterion of > 75% data coverage (the data coverage gives the fraction of the year for which valid concentration data are available at each location).

⁽¹²⁾ Austria, Belgium, Bulgaria, Croatia, the Czech Republic, Denmark, France, Germany, Greece, Hungary, Italy, Latvia, the Netherlands, Poland, Portugal, Romania, Spain, Sweden and the United Kingdom.

Figure 5.1 Attainment situation for NO₂ in 2013 in the EU-28

Notes: The graph is based on the annual mean concentration values (calculated from hourly data) for each Member State. For each country, the lowest, highest and median values (in µg/m³) at the stations are given. The rectangles give the 25 and 75 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: Based on Air Quality e-reporting database (EEA, 2015a).



Photo: © Juan Merallo Grande

Box 5.1 Nitrogen oxides from road transport

The road transport sector emits around 40% of Europe's NO_x emissions, comprising a mixture of NO and NO₂. Although NO is not harmful to health at the concentrations typically found in the atmosphere, NO₂ is associated with a range of environmental and health problems, as described elsewhere in this report. Of the emitted NO_x from vehicles, around 80% comes from diesel-powered vehicles, for which the proportion of harmful NO₂ in the NO_x is far higher than the proportion found in the emissions from petrol vehicles.

Over the past years, increasingly strict vehicle emission standards (i.e. the so-called 'Euro' standards) have been introduced in Europe in order to limit the amount of air pollution emitted by vehicles. In order to be placed on the EU market, vehicle models are first tested under laboratory conditions using a pre-defined 'test-cycle' and their emissions are measured. Recently, there has been increasing public attention on the current vehicle emissions testing regime. It is clear that both the on-road fuel consumption and emissions from European cars can be significantly higher than the official vehicle test measurements would indicate. The amount of fuel that cars use on the road, and hence also the CO₂ emissions, can be 20–30% higher than the official measurements. The differences are even higher for NO_x emissions, in particular for diesel vehicles. Real-life measurements have shown that NO_x emissions from diesel vehicles can be, on average, as much as four or five times higher under real driving conditions. Petrol vehicles broadly meet the 'Euro' standards under real driving conditions. Such differences are attributable to a variety of factors, including the fact that the current laboratory test cycle used in Europe is not very representative of how people drive their cars in real life. Furthermore, current legislation affords manufacturers a number of flexibilities, which enable them to optimise vehicles for the testing procedure.

In order to address these issues, Europe will change the test cycle used to measure vehicle emissions in the future to ensure that it better reflects real-world driving conditions and to remove many of the existing testing flexibilities. In addition, a new real driving emissions testing procedure will shortly be implemented, which will also provide a valuable assessment of the NO_x levels during the on-road performance of vehicles compared with laboratory testing.

These findings demonstrate that NO₂ 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.

The hourly limit value threshold for NO₂ is less stringent. Only three urban/suburban background stations and 2% of traffic stations reported exceedances of this limit value in 2013.

5.2.2 Relationship of nitrogen oxides emissions and nitrogen dioxide concentrations

As is the case for PM, the contribution from the different emission sources and sectors to ambient air concentrations depends not only on the amount

of pollutant emitted, but also on the emission conditions (e.g. emission height). The transport sector contributed the highest share of NO_x emissions (46% in the EU-28) in 2013, followed by the energy and industry sectors (see Section 2.3). Furthermore, the contribution of the transport sector to ambient NO₂ concentrations, especially in urban areas, is considerably higher, owing to the fact that these are emissions close to the ground and distributed over large areas.

The average decrease in annual mean NO₂ concentrations measured over all stations in Europe is slower than the decrease in NO_x emissions. The main reason for it may be attributed to the increase in the share of NO₂ in the NO_x emissions from diesel vehicles (Grice et al., 2009; ETC/ACC, 2010).

6 Benzo[a]pyrene

6.1 European air quality standards and reference levels for benzo[a]pyrene

The target value for BaP for the protection of human health is set at 1 ng/m³ (EU, 2004) as an annual mean (Table 6.1). WHO has not drafted a guideline for BaP, which is a potent carcinogen. The estimated reference level presented in Table 6.1 (0.12 ng/m³) was estimated assuming WHO unit risk for lung cancer for PAH mixtures and an acceptable risk of additional lifetime cancer risk of approximately 1×10^{-5} (ETC/ACM, 2011).

6.2 Status 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 PM₁₀ 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 PM₁₀, 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 (ETC/ACM, 2015b).

6.2.1 Exceedances of 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. As Map 6.1 shows, about half of the BaP measurement



Photo: © Shutterstock

stations in Europe continue measuring concentrations above the target value threshold (1 ng/m³ annual average, to be met by 2013) in 2013. Exceedances were measured mainly at urban and suburban stations, with 97% of all stations in exceedance

located in urban and suburban locations, and 87% of all exceedances measured at suburban and urban background stations. As in previous years, exceedances are most predominant in central and eastern Europe (Austria, Bulgaria, Croatia,

Table 6.1 Air quality target value for BaP, as set out in the EU Air Quality Directive, and estimated reference level

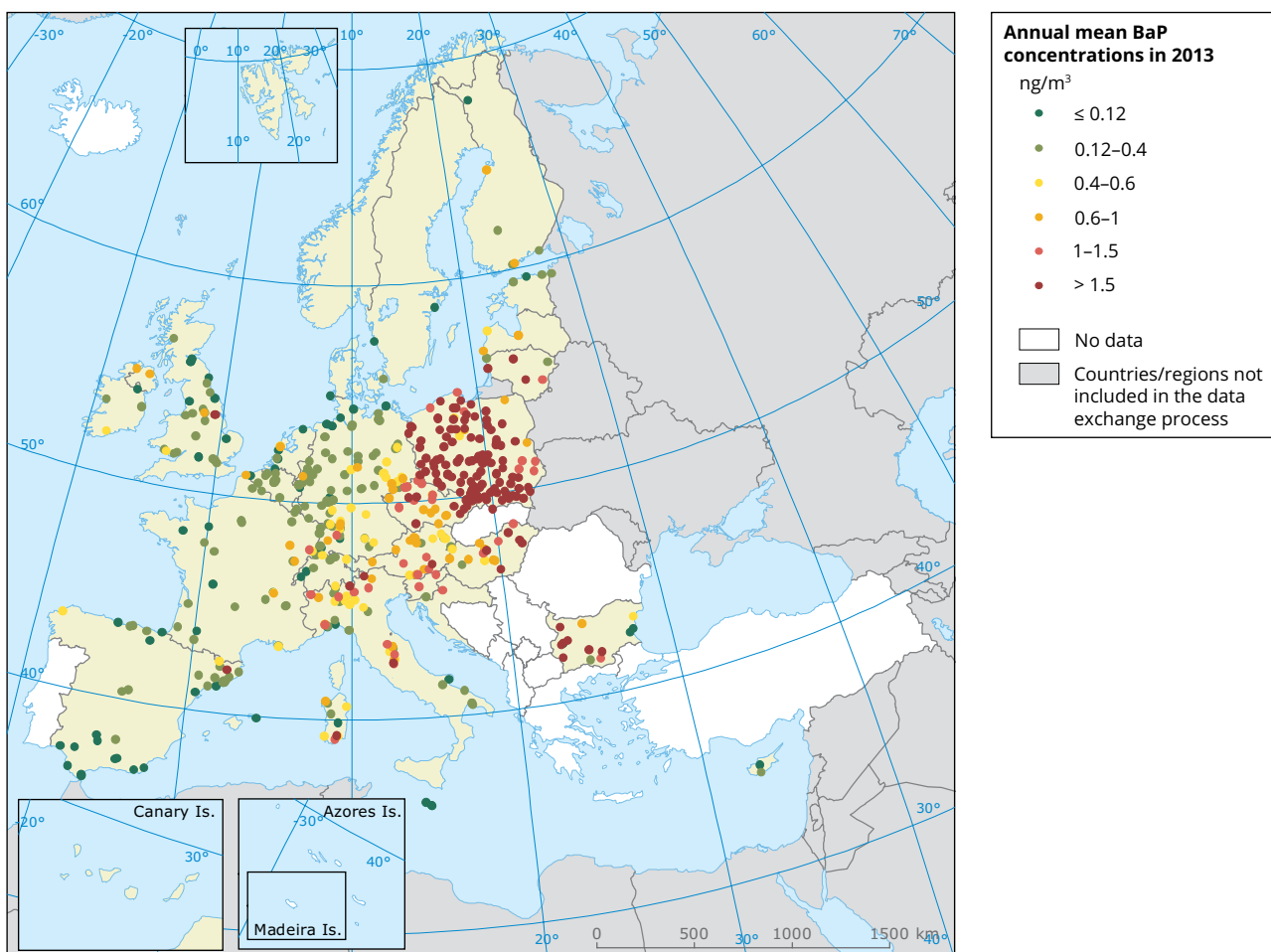
Averaging period	EU Air Quality Directive	Reference level ^(a)
Annual mean (ng/m ³)	1 ^(b)	0.12

Notes: ^(a) As 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 1×10^{-5} .

^(b) Measured as content in PM₁₀.

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

Map 6.1 Concentrations of BaP in 2013



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 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.

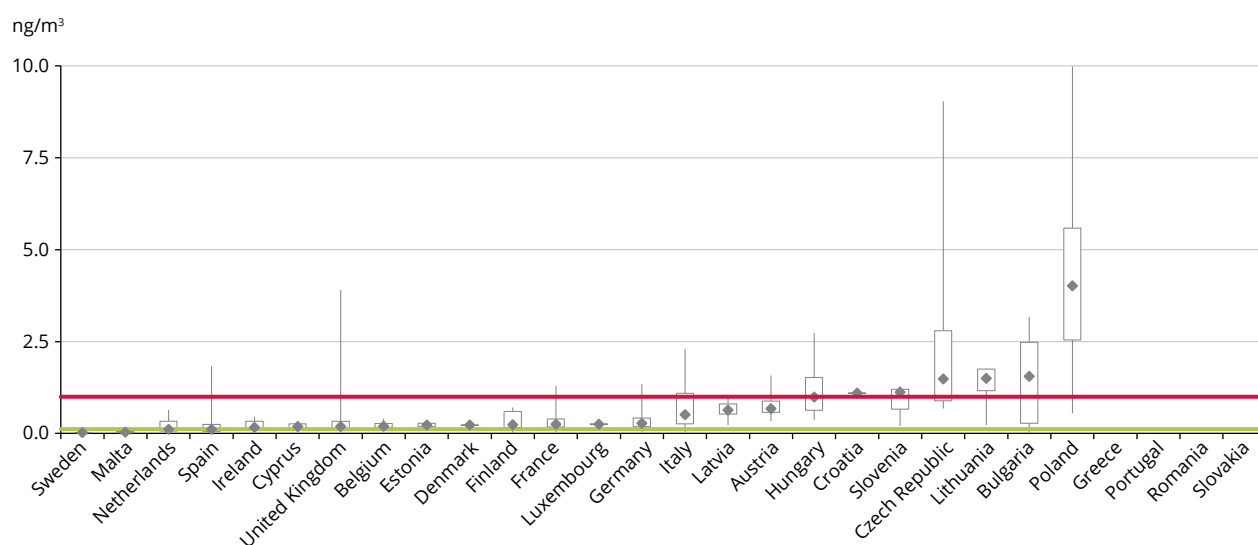
Source: Based on Air Quality e-reporting database (EEA, 2015a).

the Czech Republic, Hungary, Italy, Lithuania, Poland and Slovenia), although there are also exceedances in France, Germany, Spain and the United Kingdom.

Figure 6.1 shows the annual mean BaP values for 2013 for all EU Member States. It shows that average annual concentrations of BaP exceeded the target value in the 13 countries mentioned above. The average

concentration measured at Polish stations is 4.6 times higher than the target value. Only 24 of the EU-28 Member States reported BaP data with sufficient data coverage ⁽¹³⁾ for 2013. Reported monitored data are missing from a large part of south-eastern Europe. For example, no measurements are reported from Romania, a country with high estimated BaP concentrations, as discussed in Chapter 10.

Figure 6.1 Attainment situation for BaP in 2013 in the EU-28



Notes: The graph is based on the annual mean concentration values for each Member State. For each country, the lowest, highest and median values (in ng/m³) at the stations are given. The rectangles give the 25 and 75 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 the green line.

Source: Based on Air Quality e-reporting database (EEA, 2015a).

⁽¹³⁾ 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.

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

7.1 European air quality standards and World Health Organization guidelines

Table 7.1 presents the European air quality standards and the WHO guidelines for SO₂. The limit values for SO₂ 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 SO₂. The WHO AQG for SO₂ (WHO, 2006a) is significantly more stringent than the limit values set by the Ambient Air Quality Directive (EU, 2008).

Table 7.2 presents the limit values for CO, Pb and C₆H₆ and the target values for As, Cd and Ni established in the Air Quality Directives (EU, 2004; EU, 2008) for health protection, as well as the WHO AQGs for CO, Cd and Pb and the reference levels for As, Ni and C₆H₆. 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 C₆H₆ is set as an annual mean, given that C₆H₆ is a carcinogen with long-term effects. It should have been met by 2010. As for PAHs, WHO has not provided a guideline for C₆H₆, and the estimated reference level presented in Table 7.2 was estimated assuming WHO unit risk for cancer and an acceptable risk of additional lifetime cancer risk of approximately 1×10^{-5} (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) sets 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 LRTAP Convention. It aimed to limit emissions of Hg.

Table 7.1 Air quality standards for SO₂ as given in the EU Ambient Air Quality Directive and WHO AQG

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

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.

Source: EU, 2008; WHO, 2006a.

Table 7.2 EU air quality standards, WHO AQGs 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/m ³	
	Maximum daily 8-hour mean	10 mg/m ³		10 mg/m ³	
Arsenic	Annual		6 ng/m ³		6.6 ng/m ³
Cadmium	Annual		5 ng/m ³	5 ng/m ³ ^(c)	
Nickel	Annual		20 ng/m ³		25 ng/m ³
Lead	Annual	0.5 µg/m ³ ^(a)		0.5 µg/m ³	
Benzene	Annual	5 µg/m ³			1.7 µg/m ³

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

^(a) Measured as contents in PM₁₀.

^(b) As 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 1×10^{-5} .

^(c) AQG set to prevent any further increase of cadmium in agricultural soil, likely to increase the dietary intake of future generations.

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



Photo: © Stephen Connell, ImaginAIR /EEA

7.2 Status in concentrations

7.2.1 Sulphur dioxide

The hourly and the daily limit values for the protection of human health were exceeded at only two urban stations in Bulgaria in 2013, out of some 1 390 stations measuring SO₂ in 35 European countries. SO₂ concentrations are generally well below the limit values for health protection.

7.2.2 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 815 operational stations with > 75% data coverage (i.e. each station produced valid data at least 75% of the time) in the 39 EEA member and cooperating countries, only one station, an urban industrial station located in the former Yugoslav Republic of Macedonia, reported an

exceedance of the CO limit value and the WHO AQG value in 2013.

Average CO concentrations have decreased at all station types except for rural stations, where concentrations are very low and close to the detection limit. On average, the CO maximum daily 8-hour concentrations have decreased by about one-third in the EU over the past decade. These reductions in concentrations are in line with the reported reductions in total emissions.

7.2.3 Toxic metals

The number of monitoring stations measuring toxic metals has increased since 2004, but monitoring data for parts of Europe are still missing. This is probably due to the fact that concentrations are generally low and below the lower assessment threshold⁽¹⁴⁾ (LAT) specified in the Air Quality Directives, allowing assessment to be made by modelling or objective estimates. In 2013, between 530 and 690 stations reported measurement data for each toxic metal (As, Cd, Pb and Ni) with a minimum data coverage of 14% (i.e. at least 14% of 365 days, meaning at least 51 days of the data, produced by each monitoring station, was valid).

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 on the PM₁₀-particle size fraction (as required by the directive) or on 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, because problems are typically related to specific industrial plants. The results from the reported 2013 data can be summarised as follows:

- **As** concentrations below the LAT (2.4 ng/m³) were reported at > 90% of the stations in 2013. Approximately 12 stations reported concentrations exceeding the target value set for 2013 (6 ng/m³). The exceedances occurred both in industrial and urban areas. Exceedances of the target value were observed in Belgium, Finland and Poland.
- **Cd** concentrations exceeded the target value at fewer than ten stations in 2013. Exceedances beyond the 5 ng/m³ target value were observed

in Belgium, Bulgaria, the Czech Republic, France and Germany. At the majority of the other stations (approximately 95%), Cd concentrations were below the LAT (2 ng/m³).

- **Pb** concentrations exceeded the 0.5 µg/m³ limit value at fewer than 10 stations in 2013, at traffic, industrial and urban background stations. All the exceedances were in Italy. Some 98% of the stations reported Pb concentrations below the LAT of 0.25 µg/m³.
- **Ni** concentrations exceeded the target value of 20 ng/m³ at two industrial stations, in Germany and Italy.
- **Hg** concentrations recorded in the Air Quality e-reporting database are sparse, despite the fact that 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 50 stations (in Belgium, Croatia, Cyprus, Finland, Germany, Lithuania, Malta, Poland, Slovenia, Sweden and the United Kingdom) reported Hg data with sufficient data coverage (14%), of which about 80% were classified as background stations. Background concentrations of Hg (measured as total gaseous Hg) in air in 2013 ranged from below the detection limit to 3.3 ng/m³ (observed at an urban background station in the United Kingdom). One urban traffic station in Croatia registered a concentration of 20 ng/m³ Hg in air and one urban industrial in the United Kingdom registered 23.5 ng/m³.

7.2.4 Benzene

C₆H₆ is measured at a relatively small number of stations, for example, at 646 stations in 2013. Only those stations with at least 50% data coverage were used in the analysis. 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 85% of locations, annual mean concentrations of C₆H₆ were below the LAT of 2 µg/m³.

The Ambient Air Quality Directive (EU, 2008) sets an annual average concentration limit value of 5 µg/m³ for C₆H₆ in ambient air. The limit value was exceeded at only two urban stations; one in Germany (industrial) and one in Italy (traffic). No exceedances of the limit value were observed at rural stations.

⁽¹⁴⁾ The 'lower assessment threshold' is the level defined in the Air Quality Directives (EU, 2004; EU, 2008) below which modelling or objective-estimation techniques alone may be used to assess ambient air quality.

8 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. Depending on the pollutant and its health effects, the Air Quality Directives and WHO define short- and long-term standards and guidelines, respectively, for the protection of human health.

The monitoring data reported by the countries (EEA, 2015a) 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 (2015d).

Table ES.1 shows the percentage of the EU-28 urban population exposed to concentrations above the EU limit or target values, WHO AQG levels and estimated reference levels between 2011 and 2013.

8.1 Particulate matter

In 2013, about 17% of the EU-28 urban population was exposed to PM₁₀ above the EU daily limit value (i.e. 50 µg/m³ not to be exceeded on more than 35 days a calendar year, for short-term exposure). The extent of exposure above this EU daily limit value has fluctuated between 17% and 38% between 2004 and 2013, and between 17% and 30% from 2011 to 2013 (Table ES.1). Furthermore, up to 61% of the same urban population was exposed to concentrations exceeding the stricter WHO AQG value for PM₁₀ (annual mean, for long-term exposure) in 2013. The percentage of urban population exposed to levels above the WHO annual AQG (20 µg/m³) ranged between 61% and 87% in 2004–2013, and

between 61% and 83% from 2011 to 2013 (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.

For PM_{2.5}, the Ambient Air Quality Directive (EU, 2008) introduced a target value (25 µg/m³ annual mean) to be attained by 2010, which will become a limit value starting in 2015 (see Table 3.1). In 2013, about 9% of the EU-28 urban population was exposed to PM_{2.5} above the target value threshold. The percentage of the EU-28 urban population exposed to levels above the PM_{2.5} target value (25 µg/m³) was in the range of 9% to 14% from 2011 to 2013. In terms of urban population exposure to levels above the more stringent WHO AQG (10 µg/m³ as annual mean) for PM_{2.5}, it has fluctuated between 87% and 93% from 2011 to 2013 (Table ES.1).

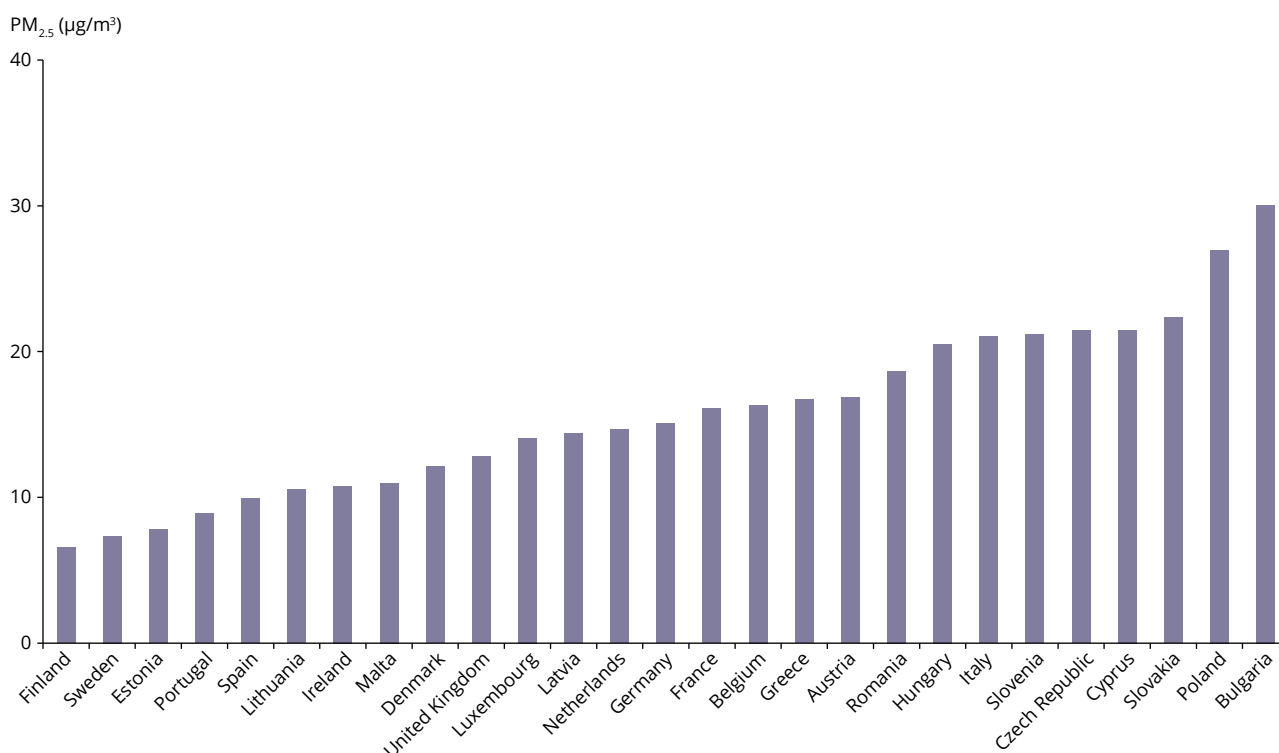
The Ambient Air Quality Directive (EU, 2008) also set the national exposure reduction target and the exposure concentration obligation for human exposure to PM_{2.5} based on the AEI set at national level. The AEI is an averaged level of concentrations (over a 3-year period), measured at selected urban background monitoring stations (representative of general urban population exposure). Figure 8.1⁽¹⁵⁾ indicates that in eight EU Member States, the average urban concentrations in the period 2011–2013 were above 20 µg/m³. This is the legally binding level for this exposure concentration obligation to be met in the EU by 2015.

8.2 Ozone

In 2013 about 15% of the EU-28 population in urban areas was exposed to O₃ concentrations above the EU target value threshold. The percentage of the urban population exposed to O₃ levels above the target value threshold has fluctuated between 14% and 45% since 2004. Table ES.1 shows the range from 2011 to 2013. These variations are partly caused by meteorological variability.

⁽¹⁵⁾ The levels presented are based on measurements at all urban and suburban background stations with 75% data coverage and are not based on a stable set of stations for the 3-year average. Figure 8.1 is therefore not necessarily based on the same set of stations as the countries used for compliance checking.

Figure 8.1 Urban and suburban background PM_{2.5} concentrations presented as 3-year averages (2011–2013) in the EU-28 ^(a), as an approximation of the Average Exposure Indicator



Notes: ^(a) EU-28 except Croatia.

The 3-year running mean of PM_{2.5} concentrations is calculated as the average over all operational (sub)urban background stations within a Member State in the period 2011–2013.

Source: Based on Air Quality e-reporting database (EEA, 2015a).

The EU-28 urban population exposed to O₃ levels exceeding the WHO AQG value is significantly higher than for the EU target value, as the WHO AQG is much stricter (see Table 4.1). About 98% of the total EU-28 urban population was exposed to O₃ levels exceeding the WHO AQG in 2013, and proportions fluctuated between 95% and 99% from 2004 to 2013. Table ES.1 shows the range from 2011 to 2013. As explained in Section 4.2, people living in rural and mountainous areas are more likely to be exposed to high O₃ levels than those living in urban areas. The percentage of the European population living outside urban areas and exposed to concentrations above the EU target value and WHO AQG is therefore expected to be higher than in urban areas.

8.3 Nitrogen dioxide

About 9% of the EU-28 urban population was exposed to NO₂ above the EU annual limit value and the WHO NO₂ AQG value (both 40 µg/m³ as an annual mean) in 2013. The fraction of the urban population exposed to concentrations above the annual limit value fluctuated

between 8% and 20% between 2004 and 2013, and between 8% and 12% in the period 2011–2013 period (Table ES.1). The range partly reflects variations caused by meteorology.

8.4 Benzo[a]pyrene

Between 25% and 28% of the urban population in the EU-28 was exposed to BaP concentrations above the target value (1 ng/m³ as annual mean) from 2011 to 2013, whereas 85% to 91% of the EU-28 urban population was exposed to BaP concentrations above the estimated reference level (0.12 ng/m³ as annual mean) over the same period. The proportion of the EU-28 urban population exposed to BaP levels exceeding both the EU target value and the estimated reference level was 25% and 91%, respectively, in 2013.

8.5 Sulphur dioxide

There has been a trend for decreasing exposure to SO₂ 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 SO₂ levels exceeding the WHO AQG (20 µg/m³ as daily mean) in 2011–2012 amounted to about 36–37% of the total urban population (Table ES.1). Proportions have been constantly decreasing since 2004, when 64% of the EU-28 urban population was exposed to SO₂ levels exceeding the WHO AQG.

8.6 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.

8.7 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 in the food chain, thus affecting human health.

8.8 Benzene

Exposure to C₆H₆ in Europe is limited to a few local areas with higher concentrations, which are often close to traffic or industrial sources.



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

Most of the health impact studies reviewed by WHO are focused on natural, non-accidental, mortality, respiratory and cardiovascular effects attributed to exposure to air pollution (WHO, 2005; WHO, 2006a; WHO, 2006b; WHO, 2008), but evidence is also growing for a range of other effects.

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 illness occurrence and years lived with a disease or disability, ranging from minor effects, such as coughing, to chronic conditions that may require hospitalisation. Even less severe effects might have strong public health implications, because air pollution affects the whole population on a daily basis, especially in major cities where concentrations tend to be higher than in rural areas.

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

The health impacts from air pollution can be estimated using different health outcomes (Box 9.1). The health impacts estimated for this report are those attributable to exposure to PM_{2.5}, O₃ and (for the first time) NO₂ in Europe for 2012. Such an assessment required information on air pollution, demographic data and the relationship between exposure to ambient pollutant concentrations and a health outcome. In this assessment, the demographic data and the

health-related data were taken from the United Nations (UN) (2012) and WHO (2013b), respectively. The recommendations from a report on health risks from air pollution by the WHO (2013c) were used. For PM_{2.5} impacts have been estimated for the full range of observed concentrations. For NO₂ the recommendation by the WHO (2013c) that the NO₂ impact should be calculated for levels above 20 µg/m³ was followed. However, this recommendation, which ignores potential impacts at lower concentrations, may be too conservative, as indicated by Heroux et al. (2015). The air pollutants concentration maps (annual mean concentration for PM_{2.5} and NO₂; and accumulated O₃ concentration (daily maximum 8-hour) in excess of 35 parts per billion (ppb) (70 µg/m³) for O₃) used in the assessment were prepared by the ETC/ACM. They are based on the Air Quality e-reporting database (EEA, 2015a) monitoring data measured at regional and urban background stations, auxiliary information, such as meteorological data, and concentrations modelled with the European Monitoring and Evaluation Programme (EMEP) chemical dispersion model (ETC/ACM, 2015a).

The results of the health impact assessment are presented in Tables 9.1 and 9.2. Table 9.1 shows, for each pollutant, the population-weighted concentration, the estimated number of YLL and the YLL per 100 000 inhabitants. In total, in the 40 countries assessed, 4 804 000 YLL are attributed to PM_{2.5} exposure, and 828 000 YLL and 215 000 YLL are attributed to NO₂ and O₃ exposure, respectively. In the EU-28, the attributed YLL to PM_{2.5}, NO₂ and O₃ exposure are 4 494 000, 800 000 and 197 000, respectively.

Box 9.1 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.

Table 9.1 Years of life lost (YLL) attributable to PM_{2.5}, O₃ and NO₂ exposure in 2012 in 40 European countries and the EU-28

Country	PM _{2.5}			O ₃			NO ₂		
	Annual mean	YLL	YLL/10 ⁵ inhabitants	SOMO35	YLL	YLL/10 ⁵ inhabitants	Annual mean	YLL	YLL/10 ⁵ inhabitants
Austria	14.8	65 400	776	5 419	3 800	46	18.81	7 000	83
Belgium	15.8	99 500	894	2 050	2 100	19	23.41	24 200	218
Bulgaria	24.9	141 500	1 937	5 960	5 900	81	16.38	7 100	97
Croatia	16.8	46 900	1 099	7 143	3 200	74	14.89	500	12
Cyprus	25.0	8 000	729	8 369	500	47	9.42	0	0
Czech Republic	18.8	116 300	1 106	4 806	4 700	44	17.14	3 200	31
Denmark	10.0	31 400	562	2 662	1 300	24	12.90	500	10
Estonia	7.9	7 000	532	2 310	300	24	10.30	0	0
Finland	7.1	20 800	385	1 650	700	14	10.12	0	0
France	14.7	508 900	778	3 635	21 100	32	18.71	89 900	137
Germany	13.3	645 200	802	3 357	25 100	31	20.63	112 400	140
Greece	19.2	116 700	1 057	9378	9 200	84	15.46	13 900	126
Hungary	18.9	141 900	1431	6 342	7 700	77	16.57	8 000	81
Ireland	8.1	14 400	315	1 479	500	11	10.76	0	0
Italy	18.9	652 200	1 095	7 328	40 500	68	25.30	237 300	399
Latvia	12.4	19 900	976	3 103	800	40	13.65	1 000	50
Lithuania	12.9	25 100	839	3 358	1 000	35	9.88	0	0
Luxembourg	12.6	2 800	524	2 561	100	16	21.79	600	122
Malta	12.4	2 300	551	8 022	300	64	15.61	0	0
Netherlands	13.7	112 700	673	1 949	2 700	16	23.26	31 000	185
Poland	23.9	560 400	1 472	4 045	16 100	42	16.72	20 000	53
Portugal	9.9	59 900	570	4 240	4 000	38	15.45	5 200	49
Romania	20.8	279 700	1 395	3 967	9 900	49	16.22	16 600	83
Slovakia	20.5	65 400	1 209	6 103	3 400	63	15.97	600	12
Slovenia	17.7	19 900	967	7 092	1 200	61	16.65	300	17
Spain	11.9	274 100	586	5 850	21 900	47	17.88	63 600	136
Sweden	7.2	35 200	370	2 233	1 700	18	12.49	100	1
United Kingdom	11.9	420 800	661	1 183	7 200	11	23.32	156 900	246
Albania	21.1	24 500	854	8 760	2 300	81	16.33	1 200	42
Andorra	15.9	600	838	8 058	100	71	14.74	0	0
Bosnia and Herzegovina	18.5	41 200	1 074	7 322	2 700	71	14.90	900	23
Iceland	4.7	600	181	1 242	30	8	9.00	0	0
former Yugoslav Republic of Macedonia, the	29.2	32 200	1 560	8 472	1 800	89	19.13	2 300	111
Liechtenstein	10.2	200	546	5 132	20	43	20.59	0	94
Monaco	18.2	300	957	6 979	20	62	24.34	100	213
Montenegro	18.7	6 800	1 093	8 584	600	93	15.47	200	36
Norway	7.2	16 400	327	2 128	800	16	13.38	2 000	39
San Marino	16.7	300	978	6 048	20	56	17.65	0	0
Serbia ^(a)	24.3	140 200	1 557	6 844	7 000	77	18.61	11 500	127
Switzerland	12.6	46 500	582	4 990	3 100	39	21.58	10 200	128
Total ^(b)		4 804 000	895		215 000	40		828 000	154
EU-28 ^(b)		4 494 000	898		197 000	39		800 000	160

Notes: ^(a) Including Kosovo, under the UN Security Council Resolution 1244/99.

^(b) 'Total' and 'EU-28' figures are rounded up or down to the nearest thousand.

Population-weighted concentration (in µg/m³ for PM_{2.5} and NO₂ or (µg/m³).day for O₃), YLLs and YLL per 100 000 inhabitants; all-cause mortality.

SOMO35, sum of means over 35 ppb (of daily maximum 8-hour O₃ concentrations).

Table 9.2 Premature deaths attributable to PM_{2.5}, O₃ and NO₂ exposure in 2012 in 40 European countries and the EU-28

Country	PM _{2.5}	O ₃	NO ₂
Austria	6 100	320	660
Belgium	9 300	170	2 300
Bulgaria	14 100	500	700
Croatia	4 500	270	50
Cyprus	790	40	0
Czech Republic	10 400	380	290
Denmark	2 900	110	50
Estonia	620	30	0
Finland	1 900	60	0
France	43 400	1 500	7 700
Germany	59 500	2 100	10 400
Greece	11 100	780	1 300
Hungary	12 800	610	720
Ireland	1 200	30	0
Italy	59 500	3 300	21 600
Latvia	1 800	60	90
Lithuania	2 300	80	0
Luxembourg	250	10	60
Malta	200	20	0
Netherlands	10 100	200	2 800
Poland	44 600	1 100	1 600
Portugal	5 400	320	470
Romania	25 500	720	1 500
Slovakia	5 700	250	60
Slovenia	1 700	100	30
Spain	25 500	1 800	5 900
Sweden	3 700	160	10
United Kingdom	37 800	530	14 100
Albania	2 200	140	270
Andorra	60	4	0
Bosnia and Herzegovina	3 500	200	70
former Yugoslav Republic of Macedonia, the	3000	130	210
Iceland	100	2	0
Liechtenstein	20	1	3
Monaco	30	2	7
Montenegro	570	40	20
Norway	1 700	70	200
San Marino	30	2	0
Serbia ^(a)	13 400	550	1100
Switzerland	4 300	240	950
Total ^(b)	432 000	17 000	75 000
EU-28 ^(b)	403 000	16 000	72 000

Notes: ^(a) Including Kosovo, under the UN Security Council Resolution 1244/99.

^(b) 'Total' and 'EU-28' figures are rounded up or down to the nearest thousand.

In a similar way, Table 9.2 shows the estimated number of premature deaths. In the 40 countries considered, 432 000 premature deaths are attributed to PM_{2.5} exposure and 75 000 and 17 000 premature deaths to NO₂ and O₃ exposure, respectively. The estimated number of premature deaths in EU-28 attributed to PM_{2.5}, NO₂ and O₃ exposure are 403 000, 72 000, and 16 000, respectively.

As regards PM_{2.5}, the highest numbers of YLL are estimated for the countries with the largest populations (United Kingdom, France, Italy, and Germany). 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.

Regarding O₃, the countries with the largest impacts are Italy, Germany, Spain, France, and Poland; and the countries with the highest rate of YLL per 100 000 inhabitants are the countries in the Western Balkans, Hungary and Italy.

The largest health impact attributable to NO₂ exposure is seen in the well-known NO₂ hot-spot regions (i.e. the Benelux, Italy (Po valley) and the United Kingdom (London), as well as the Ruhr area in Germany). Averaged over the EU-28, the NO₂ contribution to the burden of disease is about four times as large as the O₃ contribution and five to six times smaller than the PM_{2.5} contribution. The YLL estimated for each pollutant may not be added to determine the total YLL attributable to exposure to these three pollutants. As concentrations are (sometimes strongly) correlated, it is difficult to quantify the impact of one single pollutant. This may lead to a double counting of up to 30% of the effects of PM_{2.5} and NO₂ (WHO, 2013c).

9.2 Estimated health gains attributable to attainment of fine particulate matter and nitrogen dioxide guidelines or limit values

For each of the pollutants, additional calculations have been made to explore what the reduction in YLL or premature deaths would be, when the various limit or target values are met.

For PM_{2.5}, the following options have been considered:

Scenario A): it is assumed that the annual WHO AQG of 10 µg/m³ has been met;

Scenario B): it is assumed that the annual EU limit value of 25 µg/m³ has been met;

Scenario C): it is assumed that the exposure concentration obligation (AEI value of $20 \mu\text{g}/\text{m}^3$) is attained;

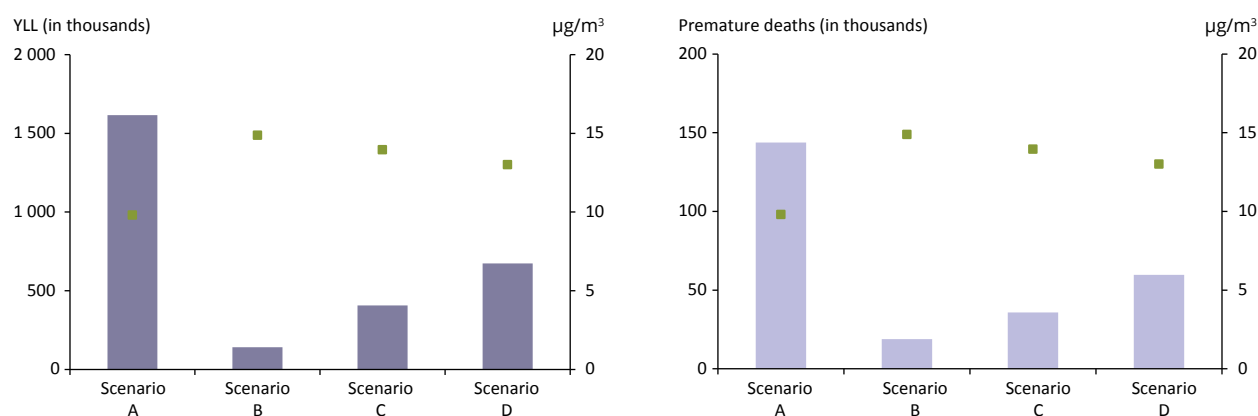
Scenario D): it is assumed that the (country-specific) exposure reduction target is attained in 2020.

Results from these sensitivity calculations are summarised in Figure 9.1. Meeting the annual WHO AQG throughout the EU-28 would lead to the averaged $\text{PM}_{2.5}$ concentrations dropping by about one-third, to the gain of 1 616 000 life years (144 000 premature deaths) compared with the current (2012) situation. Most countries will have benefits in this scenario A, although in the few countries in which the maximum concentration is already around $10 \mu\text{g}/\text{m}^3$, there are no or limited benefits. With respect to meeting the EU reference levels (scenarios B to D), the smallest benefits are expected when meeting the limit value of $25 \mu\text{g}/\text{m}^3$ (to be met in 2015, scenario B), given that, in many

countries in 2012, peak values were below the limit value and no further gain in life years was expected. The attainment of the exposure concentration obligation (scenario C) would lead to a gain in 407 000 life years (36 000 premature deaths) in the EU-28. However, meeting the exposure reduction targets (scenario D) would lead to the concentration dropping from an EU-28 average of $15.3 \mu\text{g}/\text{m}^3$ in 2012 to $13.0 \mu\text{g}/\text{m}^3$ in 2020, with an estimated 674 000 life years (60 000 premature deaths) gained in the EU-28.

For NO_2 , the estimated health gain attributable to compliance with the NO_2 annual mean limit value of $40 \mu\text{g}/\text{m}^3$ at all locations is approximately 205 000 life years for the EU-28, compared with the current 2012 situation. As potential impacts at concentrations below $20 \mu\text{g}/\text{m}^3$ are ignored (see above) the benefits might be underestimated. This health gain is higher than the health gain achieved with the least ambitious attainment scenario for $\text{PM}_{2.5}$ (scenario B).

Figure 9.1 Estimated health benefits attributable to different attainment scenarios of $\text{PM}_{2.5}$ (left: years of life gained and right: premature deaths saved)



Notes: Dark purple bars: years of life gained in the EU-28 compared with the 2012 reference scenario (left figure).
 Light purple bars: number of premature deaths saved in the EU-28 compared with the 2012 reference scenario (right figure).
 Green dots: population-weighted concentration (both figures, in $\mu\text{g}/\text{m}^3$).
 Scenario A, assuming that WHO AQG of $10 \mu\text{g}/\text{m}^3$ has been met.
 Scenario B, assuming that the EU limit value of $25 \mu\text{g}/\text{m}^3$ has been met.
 Scenario C, assuming that the exposure concentration obligation (AEI value of $20 \mu\text{g}/\text{m}^3$) is attained.
 Scenario D, assuming that the (country-specific) exposure reduction target is attained in 2020.

10 Health impacts of exposure to benzo[a]pyrene

PAHs are persistent organic pollutants, that is, organic substances that: (1) are toxic; (2) are persistent in the environment; (3) bioaccumulate in the food chain; (4) can be transported in the atmosphere over long distances; and (5) are likely to cause adverse human health or environmental effects near to and distant from their sources. Some PAHs are potent carcinogens and they are often attached to airborne particles. BaP has been classified as carcinogenic to humans (IARC, 2012) and it is the most widely investigated PAH, as a marker of the carcinogenic risk of PAHs in ambient air. In addition, WHO (2013a) has found new evidence linking PAH exposure to cardiovascular morbidity and mortality, although, at present, the effects of PAH exposure cannot be easily separated from those of other particles. The Air Quality Directive (EU, 2004) sets an annual target value for BaP (see Table 6.1), in order to avoid, prevent or reduce the harmful effects of PAHs on human health and the environment as a whole.

Emissions of BaP have increased in the past decade as a result of an increase in emissions from domestic combustion (see Chapter 2). It is, therefore, increasingly important to understand human exposure to BaP and its health effects in order to develop climate and air pollution mitigation policies that are able to reduce climate change without aggravating the impacts of air pollution. ETC/ACM (2015b) estimated the European population exposure to BaP ambient air concentrations both in urban and rural areas by combining measurements and modelled data for 2012. On that basis, the potential health impacts of BaP in Europe were estimated.

Table 10.1 shows the percentage of European population exposed to different BaP annual mean concentration intervals. It also shows the population-weighted concentration, that is, the average BaP concentration that the average European inhabitant was exposed to in 2012. The population-weighted concentration of BaP, averaged over the whole of Europe, was about 0.84 ng/m³. About 20% of the European population was exposed to BaP annual mean concentrations above the target value of 1 ng/m³ in 2012, and only about 12% of the European population live in areas in which concentrations are below the estimated reference level of 0.12 ng/m³. The estimated exposure map for Europe (Map 10.1) shows that the population-weighted concentration of BaP is very high and above 1.5 ng/m³ in large regions of central and eastern Europe, including the Baltic countries (especially Lithuania). Both the percentage of inhabitants living in the areas above the target value (20%) and the average population-weighted concentration in Europe (7.5 times higher than the reference level) are high (ETC/ACM, 2015b).

The analysis of the uncertainties of the estimated BaP concentrations undertaken by ETC/ACM (2015b) shows that in large parts of Europe, the relative standard error exceeds the 60% required in the Air Quality Directive (EU, 2004). The high uncertainty is mostly due to the low density of the measurement network. The Air Quality Directive (EU, 2004) sets a LAT⁽¹⁶⁾ of 0.4 ng/m³ for the assessment of concentrations and exposure and does not require monitoring for lower levels. This threshold is

Table 10.1 Population exposure and population-weighted concentration for BaP annual mean in 2012, based on the interpolated concentration map

BaP: annual mean, exposed population (%)						BaP population-weighted concentration
< 0.12 ng/m ³	0.12–0.4 ng/m ³	0.4–0.6 ng/m ³	0.6–1.0 ng/m ³	1.0–1.5 ng/m ³	> 1.5 ng/m ³	
11.7%	46.7%	10.4%	10.7%	6.8%	13.6%	0.84 ng/m ³

Source: ETC/ACM, 2015b.

⁽¹⁶⁾ The LAT is the level defined in the Air Quality Directives (EU, 2004; EU, 2008), below which modelling or objective-estimation techniques alone may be used to assess ambient air quality.

higher than the estimated reference level of 0.12 ng/m^3 . Therefore, in large parts of Europe BaP concentrations are not measured or the measurement density is very low, which increases the uncertainties in the interpolated concentration map and population exposure estimate. In addition, there are also lack of measurement stations in areas in which high concentrations are expected, for example in Bulgaria, Romania, other Balkan states and the Baltic states. It is particularly desirable to establish stations in densely populated areas and in areas in which higher concentrations are expected, in order to produce more reliable population exposure estimates.

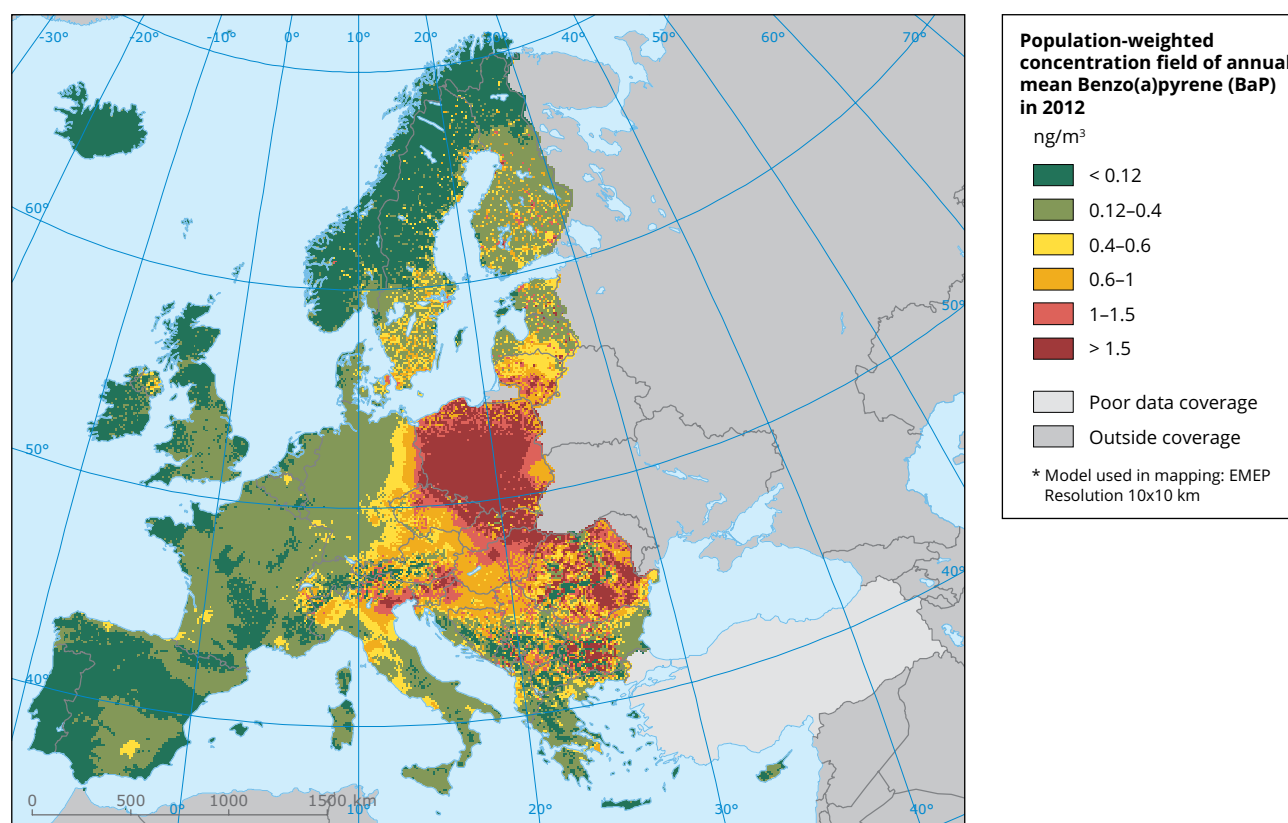
ETC/ACM (2015b) estimated the health effects of exposure to BaP air concentrations for lung cancer incidence using the exposure-response function recommended by WHO and the BaP concentration map shown in Map 10.1. The estimated number of lung cancer incidences was 550 ⁽¹⁷⁾ for Europe in 2012. The

largest health impacts can be found in the central and eastern European countries. About 50% of incidences occurred in Poland and Romania.

This study's estimated lung cancer incidence attributable to BaP exposure is low compared with the health impacts presented in Chapter 9. Nevertheless, the impacts of exposure to PAHs (of which BaP is an indicator) will be larger, for the following reasons:

- PAHs have several health impacts, which could not be included in the study, owing to the lack of reliable exposure-response functions. In addition to lung cancer, there are other health impacts, such as increased incidence of skin and bladder cancer; genotoxicity and mutagenicity; and effects on children's cognitive development; and exposure to PAHs is also linked to cardiovascular morbidity and mortality ⁽¹⁸⁾ (WHO, 2010).

Map 10.1 Population-weighted concentration field of annual mean BaP in 2012



Notes: Dark-green areas correspond to concentrations under the estimated reference level (0.12 ng/m^3). Dark-red areas correspond to concentrations exceeding the 2004 AQ Directive target value of 1 ng/m^3 .

Source: ETC/ACM, 2015b.

⁽¹⁷⁾ The 95% confidence interval is 180 to 940 lung cancer incidences for the assessment area shown in Map 10.1 for 2012.

⁽¹⁸⁾ At present, however, the effects of PAH exposure cannot be easily separated from those of particles.

- BaP is a marker for total exposure to carcinogenic PAHs but it contributes to only part of the total carcinogenic potential of PAHs (WHO, 2010; Holland et al., 2001; Pufelete et al., 2004).
- Intake only via inhalation is considered in this study. Airborne PAHs are deposited on soil and water and may be bioaccumulated in the food chain. Humans are, therefore, also exposed to airborne PAHs through the consumption of food and water.



Photo: © NILU

11 Impacts of air pollution on ecosystems

Air pollution also harms the environment, and it is estimated that 71% of the EU Natura 2000 area was exposed to eutrophication in 2010 (EC, 2013a). Ground-level O₃ can damage crops and other vegetation, impairing their growth. The atmospheric deposition of sulphur and nitrogen compounds has acidifying effects on soils and freshwaters. Acidification may lead to an 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. In addition, toxic metals and persistent organic pollutants may have severe impacts on ecosystems. This is mainly due to their environmental toxicity, but in some cases it is also due to their tendency to bioaccumulate, a process whereby the toxin cannot be digested and excreted by animals and, therefore, slowly accumulates in the animal's system, causing chronic health problems.

The impacts of air pollution on the environment depend not only on the air pollutant emission rates but also on the location and conditions of the emissions. Factors such as meteorology 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 O₃ exposure, acidification, eutrophication and toxic metals.

11.1 Vegetation damage by ground-level ozone

The principal mechanism for removing O₃ from the atmosphere is deposition on the Earth's surface, in particular through absorption by plants. This absorption damages plant cells, impairing their ability to grow. In some sensitive plants, O₃ can cause leaves to exhibit what appear to be burn marks. By impairing plants' reproduction and growth, high levels of O₃ can thus lead to reduced agricultural crop yields, decreased forest growth and reduced biodiversity.

Direct exposure to O₃ is considered to be more damaging to vegetation than exposure to any other air pollutant (Ainsworth et al., 2012). Mills and Harmens (2011) calculated that (assuming that soil moisture is not limiting to production), the effect of O₃ on wheat resulted in European production losses of 27 million tonnes of grain in 2000. The study showed that effects on wheat crops would be greatest in France, Germany, Bulgaria, the United Kingdom, Italy, Poland, and Spain. O₃-induced growth reductions also result in an economic loss for forest owners. For example, the annual economic loss for owners of Swedish forests has been estimated to be approximately EUR 40 million (Karlsson, 2005). Harmens and Mills (2012) concluded that today's levels of O₃ exposure in northern and central Europe have the potential to reduce the rate of increase in forests' living biomass by roughly 10% compared with pre-industrial O₃ exposure levels. Harmens and Mills (2012) estimated that between 1990 and 2000, the reduction in carbon stored in vegetation that can be accounted for by O₃ concentrations was around 6% globally and almost 4% in Europe.

The EU has the objective of protecting vegetation from high O₃ concentrations accumulated over the growing season (i.e. May to July). The vegetation protection value is specified as AOT40 (see Table 4.1). The vegetation protection value is calculated as the sum of the differences between hourly concentrations > 80 µg/m³ (= 40 ppb) and 80 µg/m³ accumulated over all hourly values measured during the daylight period of the most intense growing season. The target value for 2010 was 18 000 (µg/m³).h, calculated as an average over 5 years (2010–2014). The long-term objective is set to 6 000 (µg/m³).h, as shown in Table 4.1. In addition to the EU target value, the UNECE LRTAP Convention (UNECE, 1979) defines a critical level for the protection of forests. This level is specified as the AOT40 during the period April–September and is set to 10 000 (µg/m³).h (UNECE, 2011).

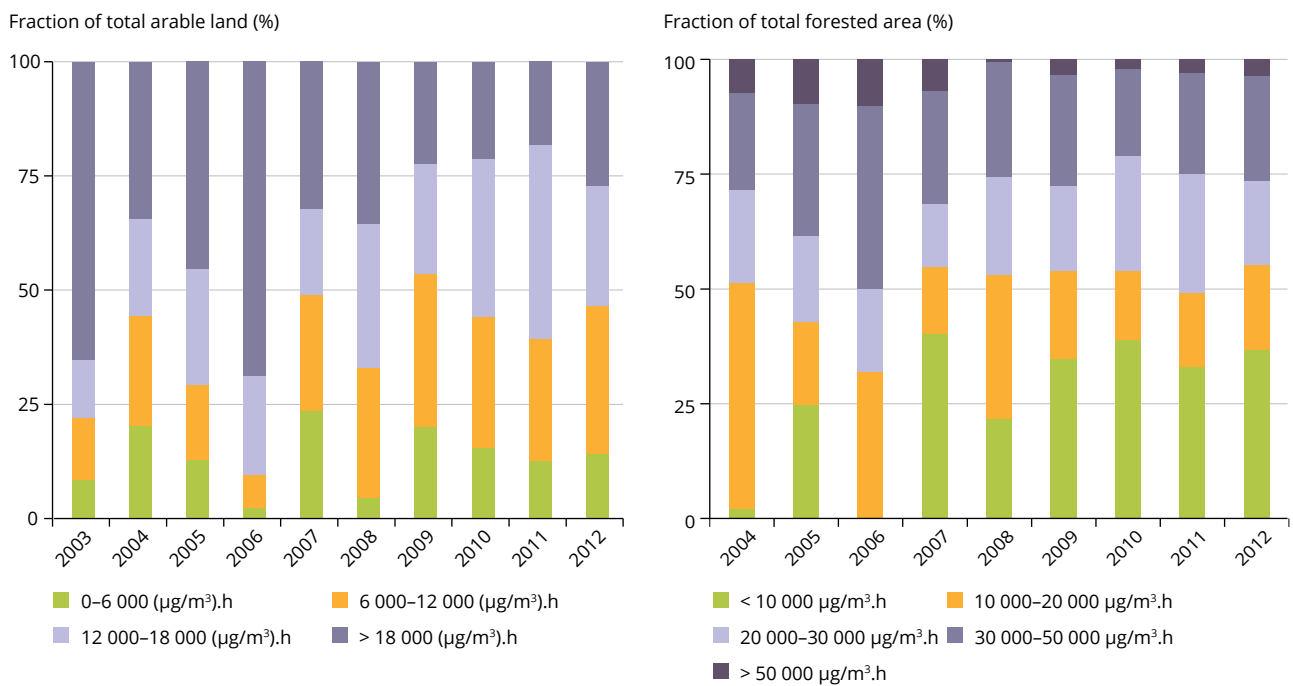
The threshold used for the AOT40 target value (applicable from 2010) for the protection of vegetation was exceeded to a substantial degree (33% of the rural stations) in 2012. The highest measured values (in Italy) exceeded 47 000 µg/m³.h, which is more than twice the target threshold.

The UNECE LRTAP Convention critical level for the protection of forests was exceeded at 85% of the rural stations in 2012. For this forest-protection objective, there is a much higher number of exceedances than for the EU target value for the protection of vegetation.

Since 2003, the target value for protecting vegetation from high O₃ concentrations has been exceeded in a substantial part of the European agricultural area, as shown in Figure 11.1 (left). The exceedances since 2004 of the critical level for the protection of forest areas are even more pronounced, as shown in Figure 11.1 (right), note that only the green parts of the bars correspond to compliance with the critical level).

In 2012, the target value for protecting vegetation was exceeded in about 30% of all European and in 27% of EU-28 countries (i.e. 645 747 km² and 557 865 km², respectively), of all agricultural land, mostly in the southern Mediterranean and central Europe (Map 11.1). O₃ levels vary considerably from year to year, mostly owing to meteorological variations. 2012 registered an increase in the total area with agricultural crops above the target value (30%) compared with the period 2009–2011 (19% to 26%), but it is lower than in the period 2005–2008 (36% to 69%)⁽¹⁹⁾. The long-term objective was exceeded in 86% of the total European and the EU-28 agricultural area in 2012 (ETC/ACM, 2015a).

Figure 11.1 Exposure of agricultural area (left) and exposure of forest area (right) to O₃ (AOT40 in µg/m³.h) in the EEA-33 member countries in the period 2003/04 to 2012



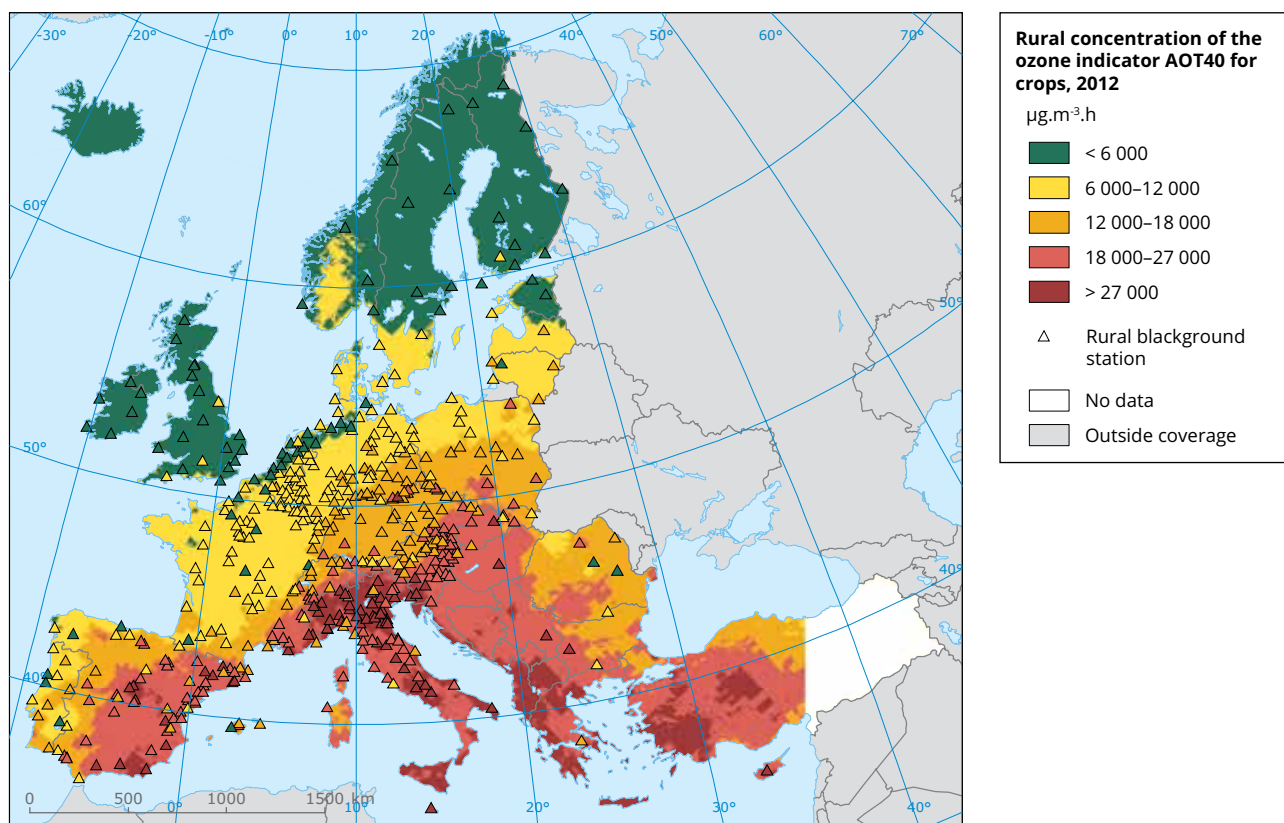
Notes: Exposure expressed as AOT40: accumulated O₃ exposure over a threshold of 40 ppb in µg/m³.hour.

Right figure: In the Ambient Air Quality Directive (EU, 2008), the target value for protection of vegetation is set to 18 000 (µg/m³).h, averaged over 5 years, whereas the long-term objective is set to 6 000 (µg/m³).h. Owing to lack of detailed land cover data and/or rural O₃ data, Iceland and Norway were not included until 2006. Switzerland has not been included in the analysis for the period 2004–2007 for the same reasons. Owing to lack of data, Turkey is not included during the entire period. Croatia has been included since 2011.

Left figure: UNECE LRTAP Convention has set a critical level for the protection of forest to 10 000 (µg/m³).h. Since 2004, a growing number of EEA member countries have been included. 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 lack of detailed land cover data and/or rural O₃ data. Calculations of forest exposure are not available for years prior to 2004.

Source: EEA, 2015b.

⁽¹⁹⁾ The 69% of the agricultural area in exceedance occurred in summer 2006, which had favourable meteorological conditions for O₃ formation, resulting in exceptionally high concentrations.

Map 11.1 Rural concentration of the O₃ indicator AOT40 for crops in 2012

Source: ETC/ACM, 2015a.

The UNECE LRTAP Convention critical level for the protection of forest was exceeded in 65% and 67% of the total European and EU-28 forest area, respectively (i.e. 987 446 km² and 888 196 km², respectively) in 2012 (Map 11.2). The attainment areas in 2012 were, as in previous years, in the northern part of Europe. The highest exceedances occurred in Italy, the Western Balkans and Spain. In 19 EEA member countries, all the forest areas in their territories were in exceedance (ETC/ACM, 2015a).

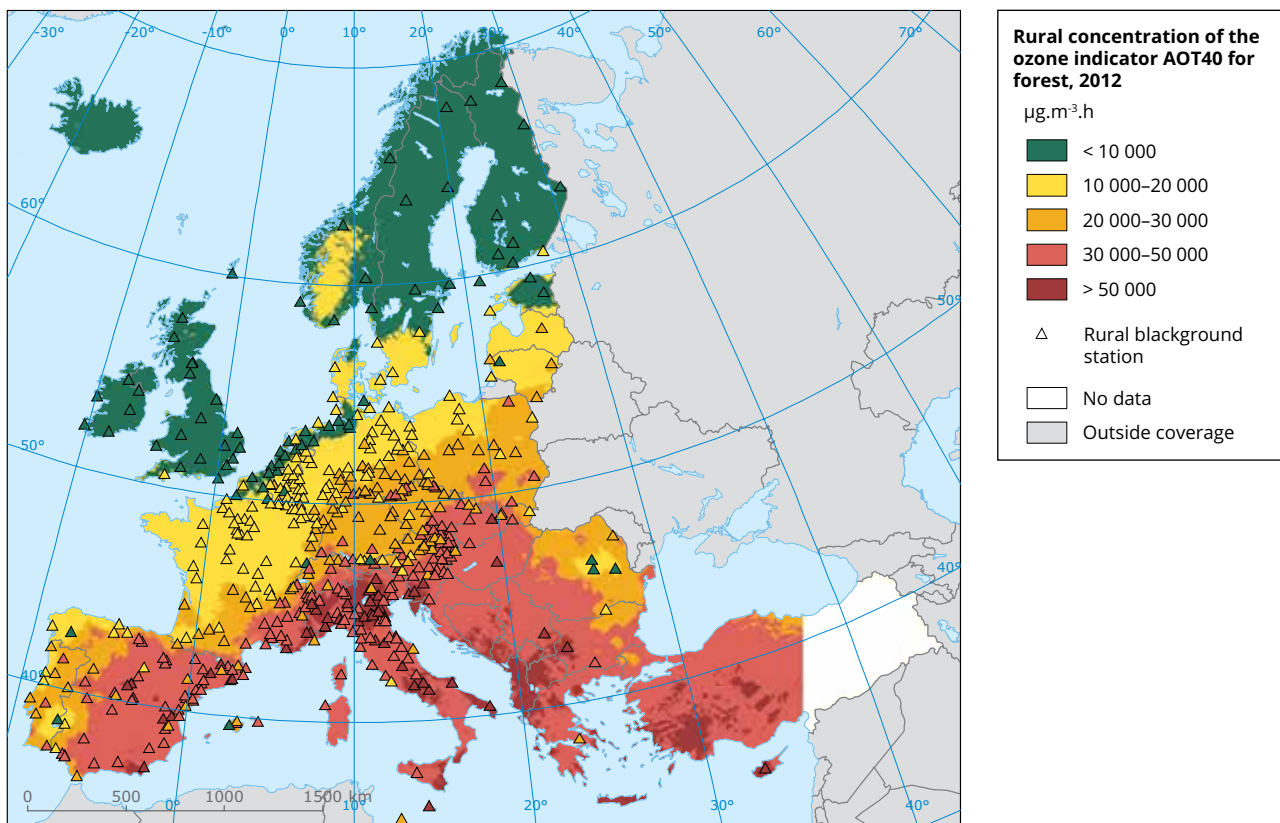
11.2 Eutrophication

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 NH₃ (mostly from livestock breeding), deposits on soils, vegetation surfaces and waters.

Atmospheric nitrogen deposition contributes to eutrophication in freshwater and in the sea. Eutrophication often leads to algae '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. The fact that light is unable to penetrate into the water may lead to the reduction, and sometimes extinction, of aquatic plants, as they are unable to survive without this light. Another problem arises when the algae begin to die and deposit on the floor of lakes and rivers. Bacteria then take over the ecosystem, decomposing the organic material of the dead algae and using up large amounts of dissolved oxygen in the process. The high oxygen demand attributable to the increased bacterial activity may lead to a severe reduction in the oxygen available to other life forms, and, in severe cases, causes fish

Map 11.2 Rural concentration of the O₃ indicator AOT40 for forest in 2012



Source: ETC/ACM, 2015a.

to suffocate. As more fish die, the number of these bacteria increases even more, intensifying the problem in a vicious cycle.

Eutrophication effects are estimated using the 'critical load' concept (De Vries et al., 2015), a term that describes the ecosystem's ability to absorb eutrophying nitrogen 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 ecosystem. Such exceedances are estimated using ecosystem classification methods and model calculations.

An earlier EEA study (EEA, 2014a) estimates that 63% of the total EU-28 ecosystem area and 73% of Natura 2000 area was 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. The reduction of ecosystem area at risk of eutrophication

has merely been moderate. For 2005, the study estimated that 67% of EU-28 ecosystem area and 78% of the Natura 2000 area were at risk of eutrophication. The risks of ecosystem eutrophication and its geographical coverage have thereby diminished only slightly over the past decade, and it is still widespread across Europe.

Furthermore, the projections for 2020 indicate that ecosystems exposure to eutrophication will still be widespread (EEA, 2015b). 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; EU, 2002; EC, 2005).

11.3 Acidification

The emission of nitrogen and sulphur into the atmosphere creates nitric acid and sulphuric acid, respectively. These compounds 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 decades, nitrogen compounds emitted as NO_x and NH₃ 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 NH₃, still contribute to acidification.

As with eutrophication effects, acidification effects are estimated using the concept of 'critical load' (De Vries et al., 2015), which describes an ecosystem's ability to absorb acidifying pollutants that have been deposited from the atmosphere without negative effects on the natural environment. Exceedance of these spatially determined critical loads presents a risk of damage. Such exceedances are also estimated using information on ecosystem classification and model calculations.

EEA (2014a) 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 a reduction by 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 two decades. The analysis does not address the fact, however, that despite ecosystems receiving depositions of acidifying substances that will not exceed critical loads in future, it may still take decades for a full ecosystem recovery from past acidification.

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 (i.e. they gradually accumulate in plants and animals and cannot be excreted by them). This means that plants and animals can be poisoned over a long period of 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 presents a serious risk to health.

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

The share 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).

As regards 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-33 member and cooperating countries⁽²⁰⁾ have exceedances of critical loads for Hg across nearly 90% or more of their ecosystem area. In total, the atmospheric deposition of Hg exceeds the critical loads across 54% of the EU ecosystem area (Slootweg et al., 2010).

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 of 30 µg/m³ (Table 5.1); and two for SO₂, the annual and winter means of which must not exceed 20 µg/m³ (Table 7.1). Member States were obliged to meet the vegetation protection limits by 2005.

The NO_x annual critical level for the protection of vegetation was exceeded in 2013 at 13 rural background stations (18 in rural areas), mainly in Italy, but also in Germany, the Netherlands and Switzerland.

In 2013, the highest concentrations and exceedances of the annual critical level for the protection of vegetation from SO₂ occurred in Romania, Poland and Serbia, with six exceedances recorded in total. As in previous years, none of these exceedances occurred at rural locations, where the critical loads are supposed to apply.

⁽²⁰⁾ Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Denmark, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, the former Yugoslav Republic of Macedonia, the Netherlands, Poland, Romania, Slovenia and Spain.

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