EEA report

No #/2014

Air quality in Europe — 2014 report



Cover design: EEA

Layout: EEA/..................

**Legal notice**

The contents of this publication do not necessarily reflect the official opinions of the European Commission or other institutions of the European Union. Neither the European Environment Agency nor any person or company acting on behalf of the Agency is responsible for the use that may be made of the information contained in this report.

**Copyright notice**

© EEA, Copenhagen, 2014

Reproduction is authorised, provided the source is acknowledged, save where otherwise stated.

Information about the European Union is available on the Internet. It can be accessed through the Europa server (www.europa.eu).

Luxembourg: Publications Office of the European Union, 2014

ISBN:

ISSN

ISSN

doi:

European Environment Agency

Kongens Nytorv 6

1050 Copenhagen K

Denmark

Tel.: +45 33 36 71 00

Fax: +45 33 36 71 99

Web: eea.europa.eu

Enquiries: eea.europa.eu/enquiries

Table of Contents

[Acknowledgements 5](#_Toc393283279)

[Executive summary 6](#_Toc393283280)

[1. Introduction 10](#_Toc393283281)

[1.1 background 10](#_Toc393283282)

[1.2 Objectives and coverage 11](#_Toc393283283)

[2. Policy response instruments and legislation 12](#_Toc393283284)

[3. Sources and emissions of air pollutants 17](#_Toc393283285)

[3.1 Sources and emissions of particulate matter (PM) and its precursor gases 17](#_Toc393283286)

[3.2. Sources and emissions of O3 precursors 20](#_Toc393283287)

[3.3. Sources of NO2 and NOx emissions 21](#_Toc393283288)

[3.4. Sources of PAHs and BaP emissions 22](#_Toc393283289)

[3.5. Sources and emissions of other pollutants 22](#_Toc393283290)

[4. Vulnerability of humans to air pollution 25](#_Toc393283291)

[4.1 Description of the adverse effects of air pollution on heath 25](#_Toc393283292)

[4.2 European air quality standards for the protection of human health 27](#_Toc393283293)

[4.3 Status and trends in concentrations of health relevant air pollutants 29](#_Toc393283294)

[4.3.1 Particulate matter (PM) 29](#_Toc393283295)

[4.3.2 Ozone (O3) 32](#_Toc393283296)

[4.3.3 Nitrogen dioxide (NO2) 35](#_Toc393283297)

[4.3.4 Benzo(a)pyrene (BaP) 37](#_Toc393283298)

[4.3.5 Other air pollutants 37](#_Toc393283299)

[4.4 Population exposure and impacts on health 39](#_Toc393283300)

[4.4.1 Human exposure to PM pollution in Europe 39](#_Toc393283301)

[4.4.2 Human exposure to O3 pollution in Europe 40](#_Toc393283302)

[4.4.3 Human exposure to NO2 pollution in Europe 41](#_Toc393283303)

[4.4.3 Human exposure to BaP pollution in Europe 41](#_Toc393283304)

[4.4.4 Human exposure to other pollutants in Europe 42](#_Toc393283305)

[5. Vulnerability of ecosystems to air pollution 43](#_Toc393283306)

[5.1 Description of the adverse effects of air pollution on ecosystems 43](#_Toc393283307)

[5.2 European air quality standards for the protection of ecosystems/vegetation 45](#_Toc393283308)

[5.3 Status and trends in ecosystems relevant air pollutants 45](#_Toc393283309)

[5.4 Exposure and impacts on ecosystems 46](#_Toc393283310)

[5.4.1 Extent of ecosystems exposure to O3 concentrations 46](#_Toc393283311)

[5.4.2 Extent of ecosystems exposure to NOx concentrations 47](#_Toc393283312)

[5.4.3 Extent of eutrophication 48](#_Toc393283313)

[5.4.4 Extent of ecosystems exposure to SO2 concentrations 48](#_Toc393283314)

[5.4.5 Extent of acidification 48](#_Toc393283315)

[5.4.6 Extent of exposure of ecosystems to toxic metals 49](#_Toc393283316)

[6. Air pollution effects on climate change 50](#_Toc393283317)

[References 52](#_Toc393283318)

[Annex 1 Trends in PM10, PM2.5, O3 and NO2 by country and station type 60](#_Toc393283319)

# Acknowledgements

This report was prepared by the European Environment Agency's Topic Centre for Air pollution and Climate change Mitigation (ETC/ACM[[1]](#footnote-1)). The coordinator of input from the ETC/ACM was Cristina Guerreiro of the Norwegian Institute for Air Research (NILU).

The authors of the report were Cristina Guerreiro (NILU, Norway), Frank de Leeuw (RIVM, the Netherlands), Valentin Foltescu (EEA), and Jan Horálek (CHMI). The ETC/ACM reviewer was Xavier Querol (CSIC, Spain). The EEA reviewer was Marin Adams.

Thanks are due to Augustin Colette and Laurence Rouil (INERIS) for providing the description and illustration of the most recent pollution episode in France. Thanks are also due to Jean-Paul Hettelingh, Coordination Centre for Effects (CCE at RIVM, the Netherlands), for providing the EEA with the background data for the critical load information presented in this report, and to the European Monitoring and Evaluation Programme (EMEP). Thank you also to Michel Houssiau (EEA) for retrieving relevant data from AirBase and to John van Aardenne for providing relevant input on air pollutants’ contribution to climate forcing.

The EEA project manager was Valentin Foltescu. EEA acknowledges comments received on the draft report from the national reference centres of EEA member countries, the European Commission and WHO. These comments have been included in the final version of the report as far as possible.

# Executive summary

Despite considerable improvements in the past decades, Europe is still far from achieving levels of air quality that do not result in unacceptable risks to humans and the environment. Air pollution is the number one environmental cause of premature death in the Europe, increases the incidence of a wide range of diseases and leads to several environmental impacts, damaging vegetation and ecosystems. This constitutes a substantial loss for the European economy, the productivity of its workforce, the health of Europeans, and Europe’s natural systems. The effects of poor air quality have been felt the most strongly in two main areas. Firstly, these effects have been strongly felt in urban areas, where they cause significant health problems. Secondly, these effects have been felt in ecosystems, where air pollution impairs vegetation growth and where eutrophication due to air pollution has led to biodiversity loss.

This report presents an overview and analysis of air quality in Europe from 2003 to 2012, as well as estimates of urban population and ecosystems’ exposure to air pollution. The evaluation of the status and trends of air quality is based on ambient air measurements, in conjunction with anthropogenic emissions and their trends. It reviews progress towards meeting the requirements of the air quality directives (EU, 2004; EU, 2008c) and gives an overview over policies and measures to improve air quality and minimise air pollution impacts on public health and ecosystems. An overview of the latest findings and estimates of the effects of air pollution on health and its impacts on ecosystems is also given. The analysis covers up to 38 European countries ([[2]](#footnote-2)), including the 28 EU Member States and member countries of the European Environment Agency (EEA-33).

At present, Particulate Matter (PM) and ground-level ozone (O3) are Europe's most problematic pollutants in terms of harm to human health, followed by Benzo(a)pyrene (BaP), an indicator for PAHs (polycyclic aromatic hydrocarbons)and nitrogen dioxide (NO2). In terms of damage to ecosystems, the most important air pollutants are O3, ammonia (NH3) and nitrogen oxides (NOx).

**Population exposure and impacts on health**

European citizens often breathe air that does not meet the European standards. The current pollution levels clearly impact on large parts of the urban population, especially for PM, O3, and BaP. Table ES.1 gives an overview ([[3]](#footnote-3)) of the proportion of the EU urban population exposed to pollutant concentration levels above the limit and target values set in the EU legislation and the World Health Organisation (WHO) air quality guidelines (AQG) in recent years (2010-2012). Figure ES.1 shows the average concentrations ([[4]](#footnote-4)) urban population was exposed to over the last years for PM, O3 and NO2. The development over time, indicates that exposure to PM and O3 has remained more or less stable, with some yearly variations. No clear trend is observed for O3 and only a slowly decreasing trend is observed for PM. Only exposure to NO2 has had a clearly decreasing trend over the last years.

Estimates of the health impacts attributable to the exposure to air pollution indicate that fine particulate matter (PM2.5) concentrations in 2011 were responsible for about 458 000 premature deaths in Europe (over 40 countries ([[5]](#footnote-5))) and around 430 000 in the EU28. The estimated impact of exposure to O3 concentrations ([[6]](#footnote-6)) in 2011 on the European population was about 17 400 premature deaths per year as a total for the same 40 countries, and about 16 160 in the EU28.

**Exposure and impacts on European ecosystems**

Air pollution's most important effects on European ecosystems are eutrophication, acidification and damage to vegetation resulting from exposure to O3. As sulphur dioxide (SO2) emissions have fallen, ammonia (NH3) emitted from agricultural activities and nitrogen oxides (NOX) emitted from combustion processes have become the predominant acidifying and eutrophying air pollutants. Despite cuts in emissions of toxic metals in the EU a significant share of the EU ecosystem area is still at risk of contamination, especially for mercury and to a lesser extent lead.

Ozone is considered to be the most damaging air pollutant to vegetation, with significant effects on the growth of trees, vegetation in general, and important crops including wheat, soybean and rice. In 2011 about 19 % of the agricultural area in EEA-33 was exposed to O3 levels above the target value for protecting vegetation, with the highest impacts in Italy and Spain. The long-term objective was exceeded in 88 % of the agricultural area. In addition, the critical level for the protection of forest was exceeded in 69 % of the total forest area in the EEA-33 and 84 % of the EU Natura 2000 areas in 2011.

Concerning eutrophication, calculated exceedances of critical loads ([[7]](#footnote-7)) in 2010 cover most of continental Europe as well as Ireland and southern areas of the United Kingdom and Sweden. 63 % of the EU28 total area of sensitive ecosystems and 73 % of EU Natura 2000 area is at risk of eutrophication (EEA, 2014e). On the other hand, the total area of sensitive ecosystems in the EU28 that was in exceedance of critical loads of acidity in 2010 was down to 7 %, and to 5 % for Natura 2000 areas (EEA, 2014e). Nevertheless, it may still take decades for a full recovery from past acidification of European ecosystems.

**Effects on climate change**

Several air pollutants are also climate forcers, having a potential impact on the planet's climate and global warming in the short term (decades). Ground-level O3 and black carbon, a constituent of PM, are examples of air pollutants that are climate forcers and contribute directly to global warming.

In addition, air pollutants have indirect effects on climate. For example, particles can also cause climate forcing indirectly, through the changes they are causing on cloud properties, including cloud reflectivity and precipitation, and cloud formation and dynamics. Vegetation is an important terrestrial carbon sink and ozone impairs vegetation growth. It is estimated that the indirect impacts of ozone on the global warming potential via its negative impacts on vegetation are of similar magnitude as its direct impacts as a greenhouse gas (Sitch et al., 2007).

Measures to cut black carbon, along with other pollutants leading to O3 formation, among them methane (CH4 itself a greenhouse gas), will have benefits for reducing both health-and ecosystem damages and the extent of global warming. Air quality and climate change can thus be tackled together by policies and measures developed through an integrated approach.

**Main findings in air pollutant concentration status and trends**

**PM**

* The small reductions observed in ambient PM10 concentrations over the period 2003-2012 reflect the slowly declining emissions of primary PM and NH3. In average, fine PM (PM2.5) rural and urban background concentrations have remained at the same level from 2006 to 2012, while a small decline has been observed at traffic stations.
* Twenty one per cent of the EU28 urban population lives in areas where the EU 24-hour limit value for particulate matter (PM10) concentrations was exceeded in 2012. For EEA-33 countries the estimate is 38 %.
* EU urban population exposure to PM levels exceeding the WHO AQG is significantly higher, comprising 69 % and 94 % of the total EU28 urban population in 2012 for PM10 and PM2.5, respectively (Table ES.1 shows the range for 2010 to 2012).

**O3**

* There is no clear trend for O3 concentrations (target value for the protection of health) between 2003 and 2012 in 80 % of the monitoring stations. 18% of the stations registered a decreasing trend, while 2 % registered an increasing trend, most of them in the Iberian Peninsula. It can therefore be concluded that concentrations in the period 2003-2012 do not reflect the European reductions in emissions of O3 precursors in the same period.
* Fourteen per cent of the EU28 urban population lives in areas where the EU O3 target value threshold for protecting human health was exceeded in 2012. The EU urban population exposed to O3 levels exceeding the WHO AQG - which are stricter than the EU target value is significantly higher, comprising 99 % of the total urban population (Table ES.1 shows the range for 2010 to 2012).
* Europe's sustained ambient O3 concentrations continue to cause considerable damage to vegetation growth and crop yields resulting in serious damage, costs to the Europe’s economy and reducing plants’ uptake of carbon dioxide.

**NO2**

* Some cities in Europe show an increase in concentrations of NO2 measured close to traffic. This reflects the increasing numbers of newer diesel vehicles. Exhaust emissions from such vehicles are lower for CO, NMVOCs and PM but may be substantially higher for NO2.
* The decrease in NOX emissions (30 % between 2003 and 2012) is greater than the fall in NO2 annual mean concentrations (ca. 18 %). This is attributed primarily to the increase in NO2 emitted directly into the air from diesel vehicles.
* Eight per cent of the EU28 urban population lives in areas where the annual EU limit value and the WHO AQG for NO2 were exceeded in 2012 (Figure ES.1 shows the range for 2010 to 2012).

**Benzo(a)pyrene (BaP), a polycyclic aromatic hydrocarbon (PAH)**

* Exposure of the European population to BaP concentrations above the target value is significant and widespread, especially in central and eastern Europe. Between 24 % and 28 % of the urban population in the EU was exposed to BaP concentrations above the target value in the period 2010 to 2012. As much as 88 % of the EU urban population was exposed to BaP concentrations above the WHO reference level over the same period.
* The 21 % increase in BaP emissions from 2003 to 2012, driven by the increase (24 %) in BaP emissions from domestic combustion in Europe is therefore a matter of concern, as it is aggravating the exposure of the European population to BaP concentrations, especially in urban areas.

**Other pollutants: SO2, carbon monoxide, toxic metals and benzene**

* In 2012, the EU28 urban population was not exposed to SO2 concentrations above the EU 24-hour limit value. On the other hand 37 % the EU28 urban population was exposed to SO2 levels exceeding the WHO AQG in 2012 (Table ES.1 shows the range for 2010 to 2012).
* The observed EU average reduction in carbon monoxide (CO )daily 8-hour maxima concentrations in the period 2003–2012 of 35 % reflect declining CO emissions of 32 % in the EU28 over the last decade. Exposure of the European population to CO concentrations above the EU limit value and WHO AQG is very limited (Table ES.1), localised and sporadic.
* Concentrations of arsenic, cadmium, lead and nickel in air are generally low in Europe with few exceedances of limit or target values. However, these pollutants contribute to the deposition and build-up of toxic metal levels in soils, sediments and organisms.
* Exceedances of the limit value for benzene were limited to very few locations in Europe in 2012, but 10 to 12 % of the EU28 urban population was still exposed to benzene concentrations above the WHO reference level in 2010 to 2012 (Table ES.1).

# 1. Introduction

## 1.1 background

Air pollution is the number one environmental cause of premature death in the Europe and recent estimates suggest that the disease burden due to air pollution is substantial (Lim et al., 2012). The latest WHO and EC estimates indicate that more than 400 000 premature deaths were attributable to ambient air pollution in Europe (WHO, 2014a; EC, 2013). Heart disease and stroke are the most common reasons of premature death due to air pollution, responsible for 80% of the cases, followed by lung diseases and lung cancer (WHO, 2014a). In addition to causing premature death, air pollution increases the incidence of a wide range of diseases, such as respiratory, cardiovascular and cancer, with both long- and short-term health effects.

WHO’s International Agency for Research on Cancer (IARC) concluded in 2013 that outdoor air pollution is carcinogenic to humans, with the particulate matter component of air pollution most closely associated with increased cancer incidence, especially cancer of the lung. An association has also been observed between outdoor air pollution and increase in cancer of the urinary tract/bladder (WHO, 2014b).

Air pollution’s health effects lead to considerable economic impacts, cutting short lives, increasing medical costs, and reducing productivity through lost working days across the economy. The EC (2013) estimates that in 2010 the total damage costs of the health impacts were in the range €330-940 bn (depending on whether the low or high range of possible impact valuations were taken). Direct economic damage includes for example €15 bn from lost workdays and €4 bn in healthcare costs.

In addition to the impacts on human health, air pollution also has several environmental impacts, affecting the quality of fresh water, soil, and the ecosystem services they host. For example, ground-level ozone damages agricultural crops, forests, and plants, by reducing their growth rates. The EC (2013) estimates the cost of the crop yield loss to be around €3 bn for 2010. Other pollutants, such as nitrogen oxides (a family of gases referred to collectively as NOX), sulphur dioxide (SO2) and ammonia (NH3) contribute to the acidification of soil, lakes and rivers, causing the loss of animal and plant life. In addition to their acidification effects, NH3 and NOX emissions also disrupt land and water ecosystems by introducing excessive amounts of nutrient nitrogen leading to eutrophication, an oversupply of nutrients that can lead to changes in species diversity and invasions of new species.

Air pollution can also damage materials and buildings, including Europe's most culturally significant buildings. Damage to buildings is estimated to be around €1bn in 2010 (EC, 2013). Finally, air pollution has a clear impact on climate, as some air pollutants behave like greenhouse gases. Figure 1.1 and table 1.1 summarise the key effects of the major air pollutants on health, the environment and the climate.

European air policy has achieved successes in the past decades in reducing air pollution. The air is cleaner today than two decades ago. Despite improvements there are substantial remaining impacts and Europe is still far from achieving levels of air quality that do not result in unacceptable risks to humans and the environment. This constitutes a substantial loss for the European economy, the productivity of its workforce, the health of Europeans, and Europe’s natural systems. The effects of poor air quality have been felt the most strongly in two main areas, as outlined above. Firstly, these effects have been strongly felt in urban areas, where they cause significant health problems. Secondly, these effects have been felt in ecosystems, where air pollution impairs vegetation growth and where eutrophication due to air pollution has led to biodiversity loss.

Cross-continental air pollution transport also adversely affects European air quality, as other parts of the world have increased their economic activities and emissions, often using older technologies, more polluting fuels, and with lower environmental standards. International and intercontinental co-operation is therefore necessary and increasingly important to tackle air pollution. In the northern hemisphere, international co-operation has been facilitated by the Convention on Long-Range Transboundary Air Pollution (CLRTAP), which has led to a series of protocols to control emissions of the main air pollutants.

Against the backdrop of these impacts of air pollution, the Air quality in Europe — 2014 report is produced by the EEA to assess the status and impacts of air quality and recent air quality trends. This report provides a more regularly-updated account of air quality than the EEA's less frequent five-yearly 'State of the environment' reports (SOER). The report aims to support policy development and implementation in the field of air quality at both European and national levels.

## 1.2 Objectives and coverage

This report presents an overview and analysis of air quality in Europe from 2003 (or later, pending data availability) to 2012. The evaluation of the status and trends 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. The report also 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, 2008c). It also gives a European overview of the policies and measures already introduced and recently proposed to improve air quality**.**

# 2. Policy response instruments and legislation

***Thematic strategy on air pollution***

The European air pollution policy is a well-established environment policy area that over decades has resulted in decreased emissions of air pollutants and has 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) for achieving improvements in 2020 relative to the situation in 2000, with concrete objectives regarding the impacts on human health and the environment. The TSAP also established which European legislation and measures are needed to ensure progress toward the long-term goal of the previous (6th) Environment Action Programme (EAP, which 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 7th EAP (which will run until 2020). To move toward achieving the TSAP objectives, EU air pollution legislation has followed a twin-track approach of implementing both air-quality standards and emission mitigation controls.

***Legal instruments at the European level***

The main policy instruments on air pollution within the EU include the Ambient Air Quality Directives (AQD) (EU 2004; EU 2008), and the National Emission Ceilings (NEC) Directive (EU, 2001). Source-specific legislation is addressing industrial emissions, road and off-road vehicle emissions, fuel quality standards, etc. Emissions are also addressed internationally under the 1979 Convention on Long-range Transboundary Air Pollution and other conventions. In addition, several legal instruments are used to reduce environmental impacts from different activities or promote environmental friendly behaviour, also contributing indirectly to minimising air pollution.

The European directives currently regulating ambient air concentrations of the main pollutants are designed to avoid, prevent or reduce the harmful effects of air pollutants on human health and the environment by implementing limit or target values for ambient concentrations of air pollutants. They comprise:

• Directive 2008/50/EC on ambient air quality and cleaner air for Europe, which regulates ambient air concentrations of SO2, NO2 and other nitrogen oxides, PM10 and PM2.5, Pb, benzene, CO, and O3 (EU, 2008c);

• Directive 2004/107/EC relating to arsenic (As), cadmium (Cd), mercury (Hg), nickel (Ni) and polycyclic aromatic hydrocarbons PAHs, (including BaP) in ambient air (EU, 2004).

In the case of non-compliance with the air quality limit and target values stipulated in European legislation, air quality management plans must be developed and implemented in the areas where exceedances occur. The plans aim to bring concentrations of air pollutants to levels below the limit and target values. To ensure coherence between different policies, the air quality plans should be consistent (where feasible) and integrated with plans and programmes pursuant to the directives regulating air pollutant emissions. The air quality plans may additionally include specific measures aiming to protect sensitive population groups, e.g. children.

With regard to placing of limits on emissions, several EU directives regulate anthropogenic emissions of pollutants to air, including precursors to key air pollutants such as O3 and PM. The National Emission Ceilings Directive (EU, 2001) in tandem with the Gothenburg Protocol (UNECE, 1999) to the UN Convention on Long-range Transboundary Air Pollution (LRTAP, which was revised in 2012), set national emission limits for SO2, NOX, NMVOCs and NH3 in order to abate acidification, eutrophication and ground-level ozone. The revised Gothenburg Protocol also includes ceilings for PM2.5 emissions. Other directives and international conventions regulate emissions of the main air pollutants from specific sources and sectors, either by setting emission standards, by requiring the use of the best available technology, or by setting requirements on fuel composition. These directives and international conventions include:

• Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) (EU, 2010), targets certain industrial, agricultural, and waste treatment installations.

• The Euro Regulations set standards for road vehicle emissions. The Euro 5 and 6 standards are set in Regulations (EC) No 692/2008 (EU, 2008a) and No 595/2009 (EU, 2009b). The Cars 2020 Communication (EC, 2012) sets out a timetable for the implementation of the Euro 6 vehicle standards in real-world driving conditions, and the revision of the Non-road Mobile Machinery legislation.

• Directive 94/63/EC on the control of VOC emissions resulting from the storage of petrol and its distribution from terminals to service stations (EU, 1994) and Directive 2009/126/EC on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations (EU, 2009a).

• Directive 1999/13/EC on the limitation of emissions of VOCs due to the use of organic solvents in certain activities and installations (EU, 1999a).

• Directive 2012/33/EU (EU, 2012) amending Directive 1999/32/EC as regards the sulphur content of marine fuels, Directive 1999/32/EC on reduction of sulphur content of certain liquid fuels (EU, 1999b), and Directive 2003/17/EC (amending Directive 98/70/EC) relating to the quality of petrol and diesel fuels (EU, 2003a).

• The Marine Pollution Convention, MARPOL73/78 (IMO, 1973), which is the main international convention on preventing pollution by ships from operational or accidental causes. Annex VI sets limits on air pollution from ships for SOX, NOX, VOC and PM from ship exhausts and prohibits deliberate emissions of ozone-depleting substances.

• The 2004 and 2008 air quality directives do not specify an air quality objective for NH3. The Gothenburg Protocol (UNECE, 1999) under the LRTAP convention and the National Emission Ceilings Directive (EU, 2001) set emission reduction targets for NH3 with the aim of reducing acidification and eutrophication. Reporting of NH3 emissions is also required under the Integrated Pollution Prevention and Control (IPPC) Directive (EU, 2008b), now replaced by Directive 2010/75/EU on industrial emissions (EU, 2010).

• The UNECE Protocol on Persistent Organic Pollutants (POPs) obliges parties to reduce their emissions of PAHs to below their levels in 1990 (or an alternative year between 1985 and 1995). For the incineration of municipal, hazardous and medical waste, it lays down specific limit values.

• For international shipping, tighter shipping fuel standards and emission standards at the IMO/ MARPOL level resulted in the recent revision of the Sulphur Content of Fuel Directive (adopted as 2012/33/EU).

In addition to the policy instruments outlined above, there are several EU directives intended to minimise environmental impacts, including on climate change, and/or promote environmental friendly behaviour, which also contribute indirectly to minimise air pollution. Examples are:

• Nitrates Directive (91/676/EEC) concerning the protection of waters against pollution caused by nitrates from agricultural sources (EU, 1991), in particular the implementation of agricultural practices that limit fertiliser application and prevent nitrate losses, leads to a decrease of agricultural emissions of nitrogen compounds to air.

• Energy Taxation Directive (2003/96/EC; EU, 2003b) establishing minimum taxes on motor fuels, heating fuels and electricity, depending on the energy content of the product and the amount of CO2 it emits. It aims at promoting energy efficiency and less polluting energy products.

• The Ecodesign Directive (2009/125/EC) provides consistent EU-wide rules for improving the environmental performance of energy related products through ecodesign. This should benefit both businesses and consumers, by enhancing product quality, achieving energy savings and thereby environmental protection. Energy related products (the use of which has an impact on energy consumption) include energy-using products, which use, generate, transfer or measure energy (electricity, gas, fossil fuel), such as boilers, computers, televisions, transformers, industrial fans, industrial furnaces etc. Other energy related products do not use energy but have an impact on energy and can therefore contribute to saving energy, such as windows, insulation material, shower heads, taps etc. The Ecodesign Directive is complemented and supported by Energy Labelling Directive (92/75/EEC) and End Use Energy Efficiency and Energy Services Directive (2006/32/EC).

Table 1.2 summarises the coverage of the European directives and international conventions regulating air pollutant emissions (either directly or indirectly by regulating emissions of precursor gases) and ambient concentrations of air pollutants. The list is not exhaustive. EEA (2013) includes (in its Annex 2) a more detailed description of the directives regulating fuel quality and emissions to air.

***Policy analysis and developments at the European level***

An interim policy analysis of the prospects in 2012 of reaching the TSAP objectives in 2020 was performed in view of present knowledge, in particular taking into account the impacts of the economic crisis on economic and energy development, and real‐life experience with newly implemented emission regulations. The result of the analysis was that objectives for 2020 established for the protection of human health, eutrophication and forest acidification would not be met without having updated or additional policies and measures. (Rafaj et al., 2012).

In late 2013, the European Commission proposed a new Clean Air Policy Package for Europe which aims to further improve Europe’s air quality by 2030 and thereafter (EC, 2013). The package proposes strengthening the implementation of existing legislation; introducing stricter national emission reduction commitments; and reducing emissions from medium-size combustion plants (Box 2.1).

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Box 2.1

The new clean air policy package proposed in 2013 updates existing legislation that controls 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 revised National Emission Ceilings Directive with stricter national emission ceilings for six main pollutants, and provisions for black carbon which also help to mitigate climate change.
* A proposal for a new Directive to reduce pollution from medium-sized combustion installations between 1 and 50 MWth, such as energy plants for street blocks or large buildings, and small industry installations.

If agreed, and fully implemented by 2030, and compared to business as usual, the new clean air policy package is estimated to:

* avoid 58 000 premature deaths
* save 123 000 km2 of ecosystems from nitrogen pollution,
* save 56 000 km2 protected Natura 2000 areas from nitrogen pollution,
* save 19 000 km2 forest ecosystems from acidification.

Health benefits alone will save society €40-140 billion in 2030 in reduced damage costs and provide about €3 billion in direct benefits due to higher productivity of the workforce, 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, thanks to additional jobs creation due to increased productivity and competitiveness resulting from fewer workdays lost.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

***Policy responses at the national, regional and local levels***

Minimising air pollution and its impacts requires action at international, EU, national, regional and local levels. The national and sub-national authorities are very important actors in implementing EU legislation. Moreover, these can adopt additional measures to further protect their populations and the environment. For example, some countries (e.g., Austria, Sweden, Norway, Denmark, Germany) have issued national emission standards for small residential installations; the most comprehensive at this time is a German law from 2010 (Federal Law Gazette, 2010) (Bond et al., 2013).

***Examples of measures taken to reduce air pollution***

There are many examples of measures in industry, transport, agriculture, power generation, urban planning, waste management, that have been used across Europe to tackle air pollution:

• for industry: clean technologies that reduce emissions; increased efficiency in use of resources and energy; permitting according to best available technologies, etc.

• for transport: shifting to clean modes of power generation; prioritizing rapid urban transit, walking and cycling networks in cities as well as rail interurban freight and passenger travel; shifting to cleaner heavy duty diesel vehicles and low-emissions vehicles and fuels, including fuels with reduced sulphur content; road pricing, parking fees, congestion charges, speed limits, low emission zones, retrofitting;

• for agriculture: Improved storage of manure (e.g. closed tanks) + anaerobic digestion at large farms; improved application of manure on soil, e.g., rapid integration in the soil, direct injection (only at large farms); improved application of urea fertilizer or substitution by ammonium nitrate, etc.

• for power and heat generation and supply: increased use of low-emissions fuels and renewable combustion-free power sources (like solar, wind or hydropower); co-generation of heat and power; distributed energy generation (e.g. mini-grids and rooftop solar power generation); permitting according to best available technologies; district heating and cooling, fuel taxes, carbon pricing, labels and/or standards for clean small-scale combustion equipment, etc.

• for urban planning: improving the energy efficiency of buildings and making cities more compact, and thus more energy efficient;

• for municipal and agricultural waste management: strategies for waste reduction, waste separation, recycling and reuse or waste reprocessing; improved methods of biological waste management such as anaerobic waste digestion to produce biogas; low cost alternatives to the open incineration of solid waste; where incineration is unavoidable, use of combustion technologies with strict emission controls, etc.

A pilot project, which aimed at improving the knowledge on implementation of air quality legislation, has carried out a review of the main measures adopted at city level by 12 participating cities to manage PM concentrations. It found that most of the measures targeted traffic, e.g. the creation of low emission zones; improvement of public transport; promotion of cycling; management of traffic flow; and change in speed limits. The commercial and residential combustion sector was also targeted by measures, as it was identified in almost every city as the second most important contributor to exceedances of PM10 limit values. Some of the measures that were considered successful by the cities include: ensuring compliance with new low‑sulphur standards for shipping fuels in the port areas; a ban on the marketing, sale, and distribution of bituminous coal; fuel conversion in domestic heating and the creation of district heating (EEA, 2013g).

# 3. Sources and emissions of air pollutants

Air pollutants may be categorised according to whether they are: 1) directly emitted to the atmosphere (e.g. from chimneys), called primary air pollutants; or 2) formed in the atmosphere (e.g. from the oxidation and transformation of primary gaseous emissions), called secondary air pollutants. Examples of secondary air pollutants are secondary particulate matter and ozone, which are formed in the atmosphere from the so-called precursor gases.

## 3.1 Sources and emissions of particulate matter (PM) and its precursor gases

Particulate matter (PM)is either directly emitted to the atmosphere (primary PM), or formed in the atmosphere (secondary PM). The most important precursor gases for secondary PM are SO2, NOX, NH3 and VOCs (volatile organic compounds, a class of chemical compounds whose molecules contain carbon). The main precursor gases SO2, NOX and NH3 react in the atmosphere to form ammonium, sulphate compounds, and nitrate compounds. These compounds then condense into liquid form and form new particles in the air, called secondary inorganic aerosols (SIAs). Certain VOCs are oxidised to form less volatile compounds, which form secondary organic aerosols (SOAs).

Primary PM originate from natural sources or anthropogenic sources. Natural sources include sea salt, naturally suspended dust, pollen, and volcanic ash (see EEA, 2012b). Anthropogenic sources include fuel combustion in thermal power generation, incineration, domestic heating for households, and fuel combustion for vehicles. In cities, important local sources include vehicle exhausts, road dust re-suspension, and the burning of wood, fuel or coal for domestic heating. These are all low-level emitters, below 20 meters, leading to significant impacts on the concentration levels close to ground. The European anthropogenic emissions inventory (a record of what types of emissions are being released by what sources and in which quantities) of primary PM is almost complete, with the exception of non-exhaust emissions (tyre and road wear), which have not been fully reported by all countries. Natural primary emissions of PM (primarily sea salt and naturally suspended soil dust including desert dust) are not part of this inventory. The EU emissions inventory for the period 1990–2012 is available from the EEA (2014d).

Emissions of primary PM fell in the EU28 by 14 % for PM10 and 16 % for PM2.5 between 2003 and 2012 (Figure 3.1). The reductions in the same period for the 33 EEA member countries were 6 % for PM10 and also 16 % for PM2.5. Emissions of the precursor gases SOX and NOX declined by 54 % and 30 % respectively in the period 2003 to 2012 in the EU28, and by 36 % and 26 % in the EEA-33 countries. Emissions of NH3, another precursor gas, have fallen less, declining by only about 8 % in the EU28 and 5 % in the 33 EEA member countries between 2003 and 2012.

Organic precursor gases of secondary organic aerosols (SOAs) are dominated by natural organic emissions but also include an anthropogenic component. Natural VOC emissions are not included in the present emission inventories. The anthropogenic emissions of NMVOCs declined by 28 % in the period 2003 to 2012 in the EU28, and by 26 % in the EEA-33 countries.

***Sectoral emissions of primary PM and precursor gases***

Various source sectors in the economy contribute to the primary anthropogenic PM and precursor gases emissions (Figure 3.2). Commercial, institutional and household fuel combustion dominates the emissions of primary PM10 and PM2.5 and has slightly increased its emissions since 2003 (figure 3.2). This sector's share of the total EU28 primary PM emissions has also increased from 35 % in 2003 to 43 % in 2012 for PM10 and from 45 % to 55 % of the total PM2.5 primary emissions.

Household wood and other biomass combustion for heating is rising in some countries due to government incentives/subsidies, the increasing costs of other energy sources or the public perception that it is a “green” option. Biomass is being touted 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 percent 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 revert to heating with solid fuels in response to economic hardship. This has happened recently in e.g. Greece and Ireland.

The second largest source of emissions of primary PM10 is industry, followed by transport. For PM2.5 both sectors have had roughly similar levels of emissions, with the transport sector having only slightly higher emissions than the industrial sector. Non-exhaust emissions from road traffic, which are not included in Figure 3.2, add to the total road traffic emission contribution. 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 PM2.5 (Hak et al., 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) and it is estimated that nearly 90 % of the total PM emissions from road traffic will come from non-exhaust sources by the end of the decade (Rexeis and Hausberger, 2009). In addition to these PM emissions, emissions from international shipping within European seas may contribute an additional 15% of the total EU28 PM2.5 emissions shown in Figure 3.1 (estimated for the year 2010; EEA, 2013h).

The transport sector is clearly the largest contributor to NOx emissions, accounting for 46 % of the total EU28 emissions in 2012. The energy production and industrial sectors dominate the SOx emissions, with 60% and 24 % of total EU28 emissions in 2012, respectively. The agricultural sector was responsible for 93 % of the total NH3 emissions in the EU28 in 2012 and has only decreased its NH3 emissions by 7 % between 2003 and 2012. Between 2011 and 2012, emissions decreased in the EU28 by 1.5 %, mainly due to emission reductions in France and Germany, despite the fact that some countries increased their emissions, e.g. Italy increased its emissions by 6 % (EEA, 2014c). The Member States that contributed most to NH3 emissions in 2012 were France (18 %), Germany (15 %), Italy (11 %) and Spain (10 %). European policies have cut PM precursor gas emissions significantly, with the exception of NH3.

In March 2014 and similar to March/April 2007 (EEA, 2010a), an important air pollution episode with high PM concentrations occurred over central Europe from the south of the UK and France, to Belgium, the Netherlands, and Germany (see Box 3.1). Air quality modelling and analysis of PM samples allowed understanding the causes of the episode: a combination of unfavourable meteorological conditions and various emissions sources, from agricultural to traffic, in addition to residential heating.

***Box 3.1 Air pollution episodes***

Episodes with enhanced air pollution are a reminder that air pollution is a thing of the present, a significant threat to our health that needs to be dealt with both short-term and long-term action.

Air pollution episodes happen when emissions are suddenly increasing from their baseline levels, when weather conditions favour build-up of pollution in the airmasses or as a combination of both.

In some years in spring the Paris Basin is heavily affected by PM pollution episodes. Most notable PM episodes were recorded in 2003, 2007 and 2014. Here follows a description of the latest major episode, analysed by INERIS, and the actions taken to deal with it.

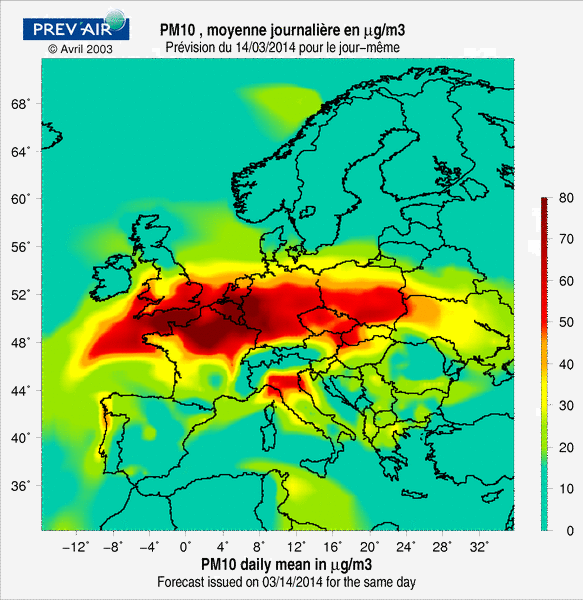
March 2014: In Paris and several French cities various measures to restrict road traffic (including “alternate traffic”) were implemented for more than one week. These exceptional decisions were taken in response to an outstanding particulate matter pollution episode. PM10 concentrations exceeded the regulatory limit value of 50 µg/m3 (daily mean) in several cities and even exceeded by far the 80 µg/m3 which is considered “alert” threshold in France. The highest concentration measured during the episode was 141 µg/m3 (daily mean) at A1 station in Paris on 14 March 2014. The highest hourly value was 227 µg/m3 at A1, recorded on 13 March 2014.

France was not the only European Country concerned by this event. Greatly enhanced PM concentrations were observed in Southern United Kingdom, Belgium, the Netherlands and Germany. The factors leading to such high concentrations levels were a combination of meteorological conditions (stable and calm weather, which prevents air pollution from dispersing, and relatively high temperatures daytime for the period) and various emissions sources. Numerical simulations performed by INERIS and measurements of the chemical composition of PM showed that ammonium nitrate was a main contributor to the episode. Ammonium nitrate results from the chemical interaction between NH3 emissions due to agricultural fertilizer spreading during this period and NOx emissions from traffic. Particulate matter from residential heating was another important source during this early spring period.

AIRPARIF\* published subsequently conclusions on the “alternate traffic” measure taken by the region on 17 March 2014 so as to reduce air pollution. The measure led to a reduction in traffic by 18 % in Paris, 13 % in the near suburbs, and 9 % in the outer suburbs. PM10 concentrations close to traffic were estimated to have been reduced by around 6% during the whole period with traffic restrictions. Along the Paris ring road the daily average NO2 concentration was also reduced by 10%. The evening rush-hour NO2 peak was reduced by 30%. (AIRPARIF, 2014).

Another notable PM pollution episode occurred just a month later, in April 2014, affecting more the Benelux region as well as Southern United Kingdom. During that episode, an influx of desert dust contributed also to the increase in PM concentrations.

\* AIRPARIF is accredited by the French Ministry of Environment to monitor the air quality in Paris and in the Ile de France region (the capital city region).



Legend: PM10 concentrations forecasted on March 14th, 2014 by the Prev’AIR system run by INERIS. Particulate pollution exceeded the information threshold of 50 µg/m3 over large parts of Europe and locally exceeded the 80 µg/m3alert threshold (in France) for daily mean concentrations.

## 3.2. Sources and emissions of O3 precursors

Unlike primary air pollutants, which are emitted directly into the air, ground-level (tropospheric) O3 is not directly emitted into the atmosphere. Instead, it is formed from complex chemical reactions following emissions of precursor gases such as nitrogen oxides (a family of gases also known as NOX that includes NO and NO2) and non-methane VOCs (NMVOCs). At the continental scale, methane (CH4) and carbon monoxide (CO) also play a role in O3 formation.

The EU28 emissions of air pollutants primarily responsible for the formation of harmful ground level O3 fell significantly in the period 2003–2012. Carbon monoxide emissions were cut by 32 % (Figure 3.1), NMVOCs by 28 %, NOx by 30 % %, and CH4 by 15 % ([[8]](#footnote-8)). Nevertheless, in 2012 NOx emissions remained 4 % above the NEC Directive ceiling (Annex II) to be attained by 2010.

The transport and the energy sectors are the main sectors responsible for emissions of NOx, followed by industry (Figure 3.2). The transport sector is the sector that has achieved the highest reductions in CO (61 %), NMVOCs (63 %), and NOx (34 %) in the period (Figure 3.2). The energy and industry sectors reduced their NOx emissions in the same period by 29 % each.

The 'solvent and product use' sector has been the largest source of NMVOC emissions between 2003 and 2012 and was responsible for 44 % of the total NMVOC emissions in EU28 in 2012. It has reduced its emissions by 18 % from 2003 to 2012 (Figure 3.2), the same reduction registered by the industry sector. The second highest emitter of NMVOCs in 2012 was the commercial, institutional and household fuel combustion sector, responsible for 17% of the EU28 emissions, which only reduced its emissions by 9 % from 2003 to 2012 (Figure 3.2). The transport sector, which used to be the second largest emitter, secured the largest reduction with a 63 % cut of emissions in the period 2003-2012.

Agriculture is the main sector responsible for CH4 emissions in EU28 in 2012, with 50 % of total emissions, followed by the waste (31 %) and energy (19 %) sectors. While the waste and energy sectors have cut their emissions in 2003-2012 by 23 % and 20 %, respectively, agriculture has only cut its CH4 emissions by 6 %.

## 3.3. Sources of NO2 and NOx emissions

Nitrogen dioxide is a reactive gas that is mainly formed by oxidation of nitrogen monoxide (NO). High temperature combustion processes (e.g. those occurring in car engines and power plants) are the major sources of NO and NO2. These two gases are collectively known as NOX. Nitrogen monoxide accounts for the majority of NOX emissions. A small part of NOX emissions is directly emitted as NO2, typically 5–10 % for most combustion sources. Diesel vehicles are an exception, typically emitting a higher proportion of NO2, up to as much as 70 % of their NOX is NO2 (e.g. Grice et al., 2009) because their exhaust after treatment systems increase the direct NO2 emissions. There are clear indications that for traffic emissions the direct NO2 fraction is increasing significantly due to increased penetration of diesel vehicles, especially newer diesel vehicles (Euro 4 and 5). This may lead to more frequent breaching of the NO2 limit values in traffic hotspots.

As shown in Figure 3.1, EU28 emissions of NOX fell by 30 % in the period 2003–2012 and by 3 % from 2011 to 2012. Nevertheless, total NOX emissions in 2012 were about 4 % higher than the emissions ceiling for 2010 for the EU as a whole set in the NEC Directive (EU, 2001).

Transport is the sector that emits the most NOX, accounting for 46 % of the total EU28 emissions in 2012, followed by the energy sector and industry sector, which contributed 22 % and 15 % of total NOX emissions in 2012 in the EU28, respectively (Figure 3.2). These three sectors have substantially reduced their emissions since 2003. Over the period 2003–2012, emissions from transport decreased by 34 %, and emissions from industry and energy sectors fell by 29 %. The commercial, institutional and household fuel combustion sector also registered a decline in NOx emissions of 22 % in the period. The agriculture sector is the sector with the smallest decrease in NOX emissions in the period (5 %).

Actual emissions from vehicles (often termed 'real world emissions') may exceed the allowed test cycle emissions specified in the Euro emission standards for each vehicle type. This is particularly the case for NOX emissions from light-duty diesel vehicles (EC, 2013). EU Member States regularly update the emission 'factors' (values used to estimate how much of a particular pollutant is present in emissions of a particular type) used in their emission inventories and their previously reported emissions. Reported developments in emissions should therefore include 'real world' emission factors.

In addition to the NOx emissions shown in Figures 3.1 and 3.2, emissions from international shipping within European seas may contribute an additional 2000 to 4000 kilo tonnes NOx per year (estimated for the year 2010; EEA, 2013h). This means that the total NOx emissions in the EU28 could be almost 50% higher than presented in Figure 3.1 when accounting for international shipping within European seas.

## 3.4. Sources of PAHs and BaP emissions

Benzo(a)pyrene is anaromatic hydrocarbon (PAH) and is found in fine particulate matter. Its origin is incomplete combustion of various fuels. The main sources of BaP in Europe are domestic home heating, in particular wood burning, waste burning, coke and steel production and road traffic. Other sources include outdoor fires and rubber tyre wear.

Emissions of BaP in the EU28 and the EEA-33 countries have increased by 21 % and 19 % respectively, between 2003 and 2012. The main emission sector is the 'commercial, institutional and household fuel combustion' sector, responsible for 85 % of the total emissions of BaP in 2012 in the EU28 (Figure 3.3). This sector increased its emissions of BaP by 24 % between 2003 and 2012. As discussed in chapter 3.1, this increase may be due to an increase in the use of solid fuels (e.g. wood) for domestic heating either due to government incentives to increase the use of renewable energy, or due to increasing costs of other energy sources and in response to economic hardship.

From 2011 to 2012 there was an increase of 2.4 % in BaP emissions in the EU28, as a result of an increase in 13 countries. The countries contributing the most to BaP emissions in the EU28 in 2012 are Poland (24 %), Romania (21 %), and Germany (18 %), and their emissions increased from 2011 to 2012 by 1 %, 2 %, and 8 %, respectively (EEA, 2014c).

## 3.5. Sources and emissions of other pollutants

***Sulphur dioxide***

Sulphur dioxide is emitted when fuels containing sulphur are burned. The key manmade contributions to ambient SO2 derive from sulphur containing fossil fuels and biofuels used for domestic heating, stationary power generation, and transport. Volcanoes are the most important natural source.

EU28 emissions of SOX (a family of gases that includes SO and SO2) have fallen substantially since 2003 (Figure 3.1). Total EU emissions of SOX in 2012 were 54 % less than in 2003. The reduction of EEA-33 emissions of SOX in the same period was 36 %. The energy sector is still the main source of SOX emissions, accounting for 60 % of EU28 emissions in 2012 (Figure 3.2), although its emissions have fallen by 61 % since 2003. The next largest sector is industry, accounting for 24 % of EU28 SOX emissions in 2012, and a reduction of 36 % of its emissions between 2003 and 2012.

In addition to the emissions SOx emissions shown in Figures 3.1 and 3.2, the emissions from international shipping within European seas may contribute to an additional 1000 to 3000 kilotonnes SOx per year (estimated for the year 2010; EEA, 2013h). This means that the total SOx emissions in the EU28 could be up to 75% higher than presented in Figure 3.1 when accounting for international shipping within European seas.

***Carbon monoxide***

Carbon monoxide is a gas emitted due to incomplete combustion of fossil fuels and biofuels. Road transport was once a significant source of CO emissions, but the introduction of catalytic converters reduced these emissions significantly. CO concentrations tend to vary with traffic patterns during the day. The highest CO levels are found in urban areas, typically during rush hours at traffic locations. The CO emission reduction in the period 2003–2012 was 32 % in the EU28 and 27 % in the EEA-33 (Figure 3.1). Commercial, institutional and household fuel combustion was Europe's largest CO source in 2012, accounting for 44 % of the total EU28 CO emissions, which increased by 9 % in from 2003 to 2012. The transport sector, which used to be the highest emitter of CO, has had a very significant reduction in CO emissions (61 % from 2003 to 2012), resulting from the application of the Euro standards (Figure 3.2).

***Toxic metals***

Most of the anthropogenic arsenic (As) emissions are released from metal smelters and the combustion of fuels. Pesticides used to be an important source of As, but restrictions in various countries have reduced its role. Tobacco smoke may contain As, making it a source of As exposure in ambient air. Figure 3.1 shows the development in As emissions reported by the EU28 Member States between 2003 and 2012 as a percentage of 2003 emissions. Arsenic emissions in EU28 and EEA-33 were reduced by about 9 % from 2003 to 2012.

The anthropogenic sources of cadmium (Cd) include non-ferrous metal production, stationary fossil fuel combustion, waste incineration, iron and steel production, and cement production. Cadmium emissions in the EU28 and the EEA-33 countries decreased by 27 % and 26 % between 2003 and 2012, respectively (Figure 3.1).

Major anthropogenic emission sources of lead (Pb) include fossil fuel combustion, waste incineration and production of non-ferrous metals, iron, steel and cement. Industry is the most important emission sector for Pb, accounting for 46 % of the total Pb emissions in the EU28 in 2012 (Figure 3.3). Lead emissions decreased in the EU28 and EEA-33 by 19 % between 2003 and 2012 (Figure 3.1).

The largest anthropogenic source of mercury (Hg) emissions to air on a global scale is the combustion of coal and other fossil fuels. Others sources include metal production, cement production, waste disposal and cremation. In addition, gold production makes a significant contribution to global air emissions of Hg. Mercury emissions in the EU28 and in the EEA-33 decreased by 25 % between 2003 and 2012 (Figure 3.1). The most important emission sectors for Hg in 2012 were industry and energy production, accounting for 33 % and 34 % of the total EU28 emissions in 2012 (Figure 3.3).

The main anthropogenic sources of nickel (Ni) emissions into the air are combustion of oil for the purposes of heating, shipping or power generation; Ni mining and primary production; incineration of waste and sewage sludge; steel manufacture; electroplating; and coal combustion. Nickel emissions decreased in the EU28 and EEA-33 countries by 44 % between 2003 and 2012 (Figure 3.1). The most important emission sector for Ni in 2012 were industry and energy production, account for 31 % and 35 % of the total EU28 emissions in 2012 (Figure 3.3).

***Benzene***

Incomplete combustion of fuels is the largest source of benzene (C6H6). Benzene is an additive to petrol, and 80–85 % of C6H6 emissions are due to vehicle traffic in Europe. Other sources of C6H6 include domestic heating and oil refining, as well as the handling, distribution and storage of petrol. In general the contributions to C6H6 emissions made by domestic heating are small (about 5 % of total emissions) but with sharp differences depending on the region. In areas where wood burning accounts for more than half of domestic energy needs, wood combustion can be an important local source of benzene (Hellén et al., 2008). Benzene emissions are not included as an individual pollutant in European emissions inventories covering VOC. This means that C6H6 emissions are not recorded.

# 4. Vulnerability of humans to air pollution

## 4.1 Description of the adverse effects of air pollution on heath

There is a large body of evidence on the health impacts of air pollution, as knowledge in this area has increased considerably in recent decades. The latest WHO review on the health effects of air pollution (WHO, 2013) concludes that a considerable amount of new scientific information on the health effects of particulate matter (PM), ozone (O3) and nitrogen dioxide (NO2), observed at levels commonly present in Europe, has been published in the recent years. This new evidence supports the scientific conclusions of the WHO air quality guidelines, last updated in 2005, and indicates that health effects can occur at air pollution concentrations lower than those used to establish the 2005 guidelines. It also provides scientific arguments for decisive action to improve air quality and thereby reduce the burden of disease associated with air pollution in Europe.

Most of the health impact studies reviewed by the WHO are focused on respiratory and cardiovascular effects attributed to exposure to air pollution (WHO, 2005, 2006a, 2006b, 2007, 2008), but evidence is also growing for a range of other effects, caused by exposure to air pollutants at different times in life, ranging from prenatal exposure all the way through childhood and adult life.

Recent studies of air pollution suggest that exposure in early life can significantly affect child development, trigger disease later in life, and the effect of air pollution on pregnancy may be comparable to that of passive smoking (EEA, 2013b).

Exposure to air pollutants during pregnancy has been associated with reduced foetal growth, pre-term birth and spontaneous abortions (WHO, 2005). Pregnancy‑induced hypertension (pre-eclampsia) can be augmented by exposure to air pollution (Pereira et al., 2012). Reduced birth weight and length of new‑borns was associated with exposure to traffic‑related air pollutants, particularly during early pregnancy (Aguilera et al., 2010). In Scandinavia, exposure to air pollutants such as O3 and NO2 was shown to shorten the gestation period and was linked to pre-term birth; the effect of O3 was most prominent for exposure in the first pregnancy trimester. The associations between air pollution (black smoke) and birth weight are of the same order of magnitude as those reported for passive smoking (Pearce et al., 2012). There are indications that the new-born's immune system might be affected, resulting in weakened immune responses. Furthermore, maternal exposure to air pollution during pregnancy increases the risk of the child developing allergies and asthma later in life (Jedrychowski et al., 2010; Baïz et al., 2011). Significantly reduced birth weight was linked to prenatal exposure to airborne polycyclic aromatic hydrocarbons (PAHs) in an international study from Poland (Krakow) and the US (New York) (Choi et al., 2006). Prenatal exposure to airborne PAHs is also suggested to adversely affect cognitive development in young children (Edwards et al., 2010). Impacts of air pollution on the developing foetus are particularly worrying, as they do not only affect the child's development, but can also trigger diseases (like asthma or diabetes) later in life (Chiusolo et al., 2011).

Even weak associations may have strong public health implications, since air pollution affects the whole population, especially in major cities, and people are exposed daily. The mechanisms by which adverse effects of air pollution may act on the nervous system have recently been documented (Genc et al., 2012) and a few epidemiological studies report positive associations between exposure to air pollution and impaired cognitive function (Van Kempen et al., 2012) pointing to the need for more studies to better understand these effects.

Health effects are related both to short-term and long-term exposure to air pollution. Short-term (exposure over a few hours or days) is linked with acute health effects, while long-term exposure (over months or years) is linked with chronic health effects. Health impacts of air pollution can be quantified and expressed as mortality and morbidity. Mortality reflects reduction in life expectancy by shortened life linked to premature death due to air pollution exposure, while morbidity relates to illness occurrence, ranging from minor effects such as coughing to serious conditions that may require hospitalization.

Epidemiological studies attribute the most severe health effects of air pollution to PM. The evidence base for an association between PM and short-term (as well as long-term) health effects has become much stronger in later years. Recent long-term studies show associations between PM and mortality at levels well below the current annual WHO air quality guideline level for PM (10 μg/m3). This corroborates earlier scientific evidence, and the WHO has therefore suggested that exposure to PM — even in very small amounts — causes adverse health effects (WHO, 2006a, 2006b, 2013). The latest study from the World Health Organization (WHO, 2013) links long-term exposure to fine particles (PM2.5) with cardiovascular and respiratory premature deaths, as well as increased sickness, such as childhood respiratory diseases.

2.5

Ozone (O3) also has a marked effect on human health, with recent epidemiological studies indicating considerably larger mortality effects than previously thought (WHO, 2013). High concentration levels of ozone cause breathing problems, reduce lung function, and lead to lung diseases like asthma (WHO, 2008). Short-term exposure to current summer ozone concentrations in Europe has adverse health effects on pulmonary function, leading to lung inflammation and respiratory symptoms. These symptoms in turn result in increased medication usage, morbidity and mortality. New evidence has also emerged detailing the negative effects of long-term exposure to ozone on mortality and reproductive health.

Several studies, reviewed by the WHO (2013) and not previously considered for the air quality guidelines, or published since 2004, have documented associations between short-term and long-term exposure to NO2 with mortality and morbidity. Both short- and long-term studies have found these associations with adverse effects at concentrations that were at or below the current EU limit values (WHO, 2013). Faustini et al. (2014) has concluded that there is evidence of a long-term effect of NO2 on mortality as great as that of PM2.5. Furthermore, they found that there is evidence of an independent effect of NO2 emerging from multipollutant models, indicating that NO2 is not only an air pollutant indicator for the health effects from traffic/combustion related pollution but is directly responsible for health effects.

Air pollution as a whole and also PM as a separate component of the air pollution have been classified recently as carcinogenic (IARC press release, 2013). Some polycyclic aromatic hydrocarbons (PAHs) are potent carcinogens, and they are often attached to airborne particles. The WHO (2013) continues to recommend BaP as an indicator for carcinogenic PAHs, even if it may only explain about half of the PAH overall carcinogenic potency. In addition, WHO (2013) 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 particles.

Arsenic exposure is associated with increased risk of skin and lung cancer. Cadmium is associated with kidney and bone damage and has also been identified as a potential human carcinogen, causing lung cancer. Lead exposure has developmental and neurobehavioral effects on foetuses, infants and children, and can also elevate blood pressure in adults. Mercury is toxic in the elemental and inorganic forms, but the main concern is associated with mercury's organic compounds, especially methyl mercury. Methyl mercury accumulates in the food chain, for example in predatory fish in lakes and seas and passes through ingestion to humans. Nickel is a known carcinogen and also has other non-cancerous effects, for example on the endocrine system. Air pollution is only one source of exposure to these metals, but their persistence and potential for long‑range atmospheric transport means that atmospheric emissions of toxic metals affect even the most remote regions (WHO, 2007).

Figure 1.1 summarises the key health effects of the air pollutants regulated in the air quality directives (EC, 2004 and EC, 2008). Of particular concern in Europe are particulate matter (PM), ground-level ozone (O3), benzo(a)pyrene (BaP) and nitrogen dioxide (NO2).

It is important to note that the proportion of the population exposed to lower levels of air pollution and affected by less severe health impacts is much larger than the proportion of the population affected by the more severe events leading to more serious health impacts (see Figure 1.2). Due to the large population exposed, the less severe health effects have strong public health implications, especially in major cities. The overall damage costs of the less severe health impacts may therefore be higher than the sum of the most severe effects. 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 analysis. This is usually because of the better availability of data on these severe effects (EEA, 2013a).

## 4.2 European air quality standards for the protection of human health

***Particulate matter***

The air quality directives (EU, 2004 and EU, 2008c) set limit values, target values, long-term objectives, information thresholds and alert threshold values for the protection of human health presented in Table 4.2. The pollutants covered by the 2008 directive EU (2008c) are PM10, PM2.5, O3, NO2, SO2, CO, benzene and Pb. Directive EU (2004) sets target values for As, Cd, Ni and BaP as annual means.

For PM10 there are limit values for short-term (24 hour) and long-term (annual) exposure, while for PM2.5 there are only values for long-term exposure. 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 PM10 limit value most often exceeded in European cities and urban areas. (This daily limit value corresponds to the 90.4 percentile of daily PM10 concentrations in one year). The deadline for Member States to meet the PM10 limit values was 1 January 2005. The deadline for meeting the target value for PM2.5 (25 µg/m3) was 1 January 2010, while the deadlines for meeting the other limit and 'obligation' values for PM2.5 are 2015 (20 µg/m3) or 2020.

The WHO advised in particular that the levels at which the PM limit and target values are set in the Ambient Air Quality Directive (EU, 2008c) are not sufficient to adequately protect human health (WHO, 2013). Thus, even full compliance with the existing limit and target values, substantial health impacts would remain.

The World Health Organization (WHO) set stricter Air Quality Guidelines (AQG) than the EU air quality standards, as shown in Table 4.3. The recommended AQG should represent an acceptable and achievable objective to minimise health effects. The 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, 2014c). The PM2.5 annual mean guideline correspond to the lowest levels at which total, cardiopulmonary, and lung cancer mortality have been shown to increase with more than 95% confidence in response to long-term exposure to PM2.5.

Besides the guideline values, three interim targets (IT) were defined by the WHO for PM (Table 4.3), in order to incentivise countries to implement successive and sustained abatement measures to progressively reduce population exposures to PM. Progress towards the guideline values, however, should be the ultimate objective. The annual mean IT-1 levels are estimated by the WHO (2006a) to be associated with about 15% higher long-term mortality than at the AQGs. In addition to other health benefits, the annual mean IT-2 levels are estimated to lower the risk of premature mortality by approximately 6% [2–11%] relative to the IT-1 level, and the same is estimated for IT-3 levels compared to IT-2 levels (WHO, 2006a). The 24 hours mean IT-1, IT-2, and IT-3 levels are expected to translate into roughly a 5%, 2.5%, and 1.2% increase in daily mortality over the AQG, respectively (WHO, 2006a).

***Ozone***

For O3, a daily maximum eight-hour average threshold is specified (120 µg/m3) in the 2008 directive (EU, 2008c), as shown in Table 4.2. The target value, to be applied by 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 93.15 percentile), determined as a three-year average starting from 2010. The long-term objective (LTO) is that the threshold level should not be exceeded 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 on the website of the country’s relevant air quality authority. When the alert threshold is exceeded, the country affected is requested to draw up a short-term action plan according to specific provisions defined in the 2008 Air Quality Directive.

The WHO air quality guideline for O3 is an 8-hour mean concentration of 100 µg/m3 (WHO, 2006a), as shown in Table 4.3. This recommended limit was reduced from the previous level of 120 µg/m3, based on conclusive associations between daily mortality and lower ozone concentrations (WHO, 2014c).

***Nitrogen dioxide***

European air quality standards for NO2 as set by the 2008 Air Quality Directive (EU, 2008c) are shown in Table 4.2. For NO2, two limit values and an alert threshold are defined for the protection of human health. The limit values are specified using criteria of short‑term (one-hour) and long-term (annual mean) exposure, and Member States were obliged to meet them by 1 January 2010. The one-hour limit value threshold can be exceeded up to 18 times per year (corresponding to the 99.8 percentile of hourly concentrations in one year) before the limit value is breached.

The 2008 Air Quality Directive (EU, 2008c) 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 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 aiming at 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 2008 Air Quality Directive are identical to the WHO air quality guidelines for NO2, shown in Table 4.3 (WHO, 2006).

***Benzo(a)pyrene***

The target value for BaP for the protection of human health is set to 1 ng/m3 (EU, 2004) as an annual mean (Table 4.2). The WHO has not defined a guideline for BaP, which is a potent carcinogen. The WHO reference level presented in Table 4.3 was estimated assuming an additional lifetime cancer risk of approximately 1 x 10-5.

***Other pollutants (SO2, CO, toxic metals and benzene)***

Table 4.2 presents also the European air quality limit values for SO2, CO, Pb and benzene defined in the Air Quality Directive (EU, 2008c) and the target values for As, Cd, and Ni in ambient air (EU, 2004), for health protection.

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 remedy the high levels of SO2.

The European limit value for CO is the maximum allowable daily eight-hour mean, to be met by 2005. The limit value for benzene is defined as an annual mean, since benzene is a carcinogen with long term effects. The limit value should have been met by 2010. The European air quality target values for As, Cd, and Ni, and the limit value for Pb are specified as maximum annual averages, which countries were to meet by 2013, except for the limit value for Pb which was to be met by 2005.

No EU target or limit value has been set for Hg concentrations in air. A protocol on heavy metals including Hg was adopted in 2003 within the framework of the UNECE LRTAP. It aimed at limiting emissions of Hg.

Table 4.3 shows the WHO air quality guidelines and reference levels for SO2, CO, benzene and toxic metals. (WHO, 2006). The WHO air quality guidelines for SO2 are significantly more stringent than the limit values set by the 2008 Air Quality Directive.

As for PAHs, the WHO has not defined a guideline for benzene, which is a carcinogen. The WHO reference level presented in Table 4.3 was estimated assuming an additional lifetime cancer risk of approximately 1 x 10-5.

## 4.3 Status and trends in concentrations of health relevant air pollutants

### 4.3.1 Particulate matter (PM)

***Exceedances of limit and target values***

The EU limit values (applying from 2005) and target value (applying from 2010) for PM (the former for PM10 and the latter for PM2.5) were exceeded widely in Europe in 2012, as the data of the European air quality database, AirBase (Mol and Hooydonk, 2013), and Map 4.1 and Map 4.2 show. The analysis here is based on measurements at fixed sampling points[[9]](#footnote-9) and does not account for the fact that the Air Quality Directive (EU, 2008c) provides the Member States with the possibility of subtracting the contribution of natural sources (8) and winter road sanding/salting when limits are exceeded (EEA, 2012b).The PM10 24-hour limit value is more stringent than the annual limit value and is more frequently exceeded. The daily limit value for PM10 (applying from 2005) was exceeded most often (red and dark red dots on Map 4.1) in Bulgaria, Poland, Italy, Slovakia, the Balkan region, Turkey and also in several urban regions from the Iberian Peninsula to the Nordic countries.

In 2012, within the EU28 (and EEA-33) countries the PM10 24-hour limit value was exceeded at 27 % (31%) of urban background sites, 22 % (22 %) of traffic sites, 17 % (18 %) of 'other' sites (mostly industrial) and even at 7 % (7 %) of rural sites. In total, exceedances were registered at 21 % of the EU28 stations and 24 % of the stations in the EEA-33 countries. This corresponds to a considerable reduction of stations in exceedance compared to 2011, which was a “peak year” in the period 2008 to 2012.

Figure 4.2 shows for all Member States the attainment of the PM10 24-hour limit value in 2012. It indicates that exceedance of the daily limit value was observed in 21 Member States at one or more stations. Only Estonia, Finland, Ireland, UK, Luxembourg, Denmark and Croatia did not record exceedances of this limit value. The only country with PM10 concentration data for 2001, 2005, 2010, 2011 and 2012, which did not register an exceedance of the PM10 24‑hour limit value in any of the years, was Ireland.

There are more monitoring stations measuring PM10 than measuring PM2.5, but the number of PM2.5 monitoring stations has increased in recent years. For PM2.5 in 2012 there were 926 stations fulfilling the criterion of more than 75 % data coverage. (The data coverage gives the fraction of the year for which valid concentration data are available at each location). This marks an increase by 172 stations compared to the 754 stations that in 2010 measured PM2.5 with minimum 75 % data coverage.

In 2012, the PM2.5 concentrations were higher than the target value threshold at several stations in Bulgaria, the Czech Republic, Italy, Poland, Romania and Slovakia, as well as one station in France (dark red, red and orange dots in Map 4.2). Figure 4.3 shows that exceedance of the target value threshold for PM2.5 was observed in eight Member States at one or more stations in 2012, mostly in Eastern Europe. The only country with PM2.5 data for 2001, 2005, 2010, 2011 and 2012 that did not register an exceedance of this target value for PM2.5 in any of these years was Finland.

The PM2.5 target value threshold was exceeded in 2012 at 4 % of traffic sites, 13 % of urban background sites, 5 % of 'other' (mostly industrial) sites, and 4 % of rural sites in the EU28, and similarly in the EEA-33 countries. In total exceedances were registered in 9 % of the stations in the EU28.

The stricter value of the WHO guideline for annual mean PM10 was exceeded at 66% of the stations and in all 33 EEA member countries, with the exception of Ireland and Estonia. The WHO guideline for annual mean PM2.5 (pale green, yellow, orange, red and dark red dots in Map 4.2) was exceeded at 80 % of the stations, and in all countries with measurements with the exception of Finland and Estonia.

***Rural PM background level and secondary PM from precursor gases***

The rural background concentration of PM represents the PM level in rural areas. Contributions to PM from urban emissions build on the rural 'background' level to produce the concentrations occurring in urban areas (more generally called urban background concentrations). However, while local control efforts can reduce urban contributions to PM, they will have limited effects on the rural background level, a portion of which is also the result of natural factors.

The rural background concentration level of PM constitutes a substantial part of the PM concentrations measured in cities. Rural concentrations vary across Europe. The highest measured PM10 and PM2.5 annual mean concentrations at rural background sites in 2012 were in Italy and the Czech Republic, with annual means above the PM10 limit value of 40 µg/m3 and the PM2.5 target value threshold of 25 µg/m3. In addition to primary PM emissions (natural and anthropogenic), rural PM concentrations are determined by contributions from secondary particles, both secondary inorganic aerosols (SIAs) and secondary organic aerosols (SOAs). The latter are partly formed from organic gases emitted from anthropogenic sources and natural sources relating primarily to terrestrial vegetation. The SIA and SOA contribution varies substantially across Europe and from season to season. The SIA contribution is higher in winter, due to increased emissions from combustion in the cold season, and the SOA contribution is generally higher in summer, when emissions from terrestrial vegetation are larger, increasing from the northern parts to the southern parts of the continent.

The chemical composition of PM varies Europe: on average there is more carbonaceous matter (PM made up of carbon in different forms) in PM10 in central Europe, more nitrate in it in north-western Europe, and more mineral dust in it in southern Europe (EMEP, 2011; Putaud et al., 2010). The contribution of sea salt to PM mass is highly dependent on distance to the sea, i.e. it varies from about 0.5 % of aerosol mass at some inland sites to around 15 % at sites close to the coast (Tørseth et al., 2012). Wind‑blown desert dust from Africa is the largest PM10 component in rural background southern sites of the Mediterranean, where it makes up between 35 % and 50 % of PM10 (Pey et al., 2013). Carbonaceous matter is a significant component of the PM mass, accounting for between 10 % and 40 % of the PM10 at the EMEP sites (Yttri et al., 2007), and between 35 % and 50 % of the PM10 in southern sites of the Mediterranean. Furthermore, PM chemical composition measurements show that there is a clear decrease in the relative contribution of –sulphate and nitrate to PM10 when one moves away from rural sites and toward urban and traffic sites. In contrast, the contribution of carbon particles to the total PM10 ratio increases as one moves from rural to traffic sites (Putaud et al., 2010).

***Trends in PM concentrations***

The average trends in PM10 annual mean concentrations since 2003 is presented in Figure 4.4, for traffic, urban background, rural background and other (mostly industrial) stations. On average, all station types show decreasing concentrations since 2003, but some stations of all station types have registered an increase. Table A1.2 and Table A1.3 (Annex 1) show the average trends by countries and by station type for PM10, for the period 2003–2012. The tables show that Poland had an increase in PM10 and PM2.5 concentrations, with some stations registering significant trends. No other country registered significant average increasing trends in PM.

PM2.5 concentrations, on average, tended to decrease during the period 2006–2011 for traffic and other (mostly industrial) stations, but increase for urban and rural background stations (Figure 4.4). Table A1.3 (Annex 1) shows the trends for mean annual PM2.5 by country and by station type for the period 2006–2011. Several countries have registered increasing trends of PM2.5 annual mean concentrations for one or more station types in the period 2006–2011. This is the case for France, Germany, Belgium, Austria, Hungary, the Czech Republic, Slovakia, Denmark and Poland. There was a slight upward tendency observed in PM2.5 concentrations at rural sites between 2006 and 2012 (Figure 4.4). The available data for PM2.5 are too limited to draw firm conclusions about the observed trends, as in some cases they were based on measurements from only one or two stations, but the development is clearly not satisfactory across Europe.

***Relationship of emissions to ambient PM concentrations***

Emissions of primary PM from commercial, institutional and household fuel combustion have increased slightly since 2003 (Figure 3.2).This means that this source may contribute to keeping PM concentrations elevated in both rural and urban areas, despite emission reductions in other sectors. Contrastingly, diminishing primary PM emissions from transport may compensate for that increase, especially in urban areas.

The reductions in emissions of the PM precursors NOX and SOX were much larger than the reductions in primary PM from 2003 to 2012. Meanwhile the reduction in NH3 emissions was small (about 8 %) between 2003 and 2012 in the EU28 and even smaller (5 %) in the EEA-33.

There is a conundrum in the relationship between PM concentrations on the one hand and emissions of primary PM and PM precursors on the other hand. Sharp falls in emissions have not led to equally sharp falls in concentrations of PM. Part of this conundrum can be explained by uncertainties in the reported emissions of primary PM from the commercial, institutional and household fuel combustion sector. In addition, and as discussed in EEA (2013c), intercontinental transport of PM and its precursor gases from outside Europe may also influence European ambient levels, pushing up PM concentration levels in spite of falling emissions in Europe.

Bessagnet et al. (2014) have modelled the sensitivity of PM concentrations across Europe to reductions in NH3 emissions from agriculture. The results, from three different chemistry transport models, show that the revised Gothenburg Protocol will only reduce the number of exceedances of PM10 daily limit values in Europe by 14 to 22 % in 2020 compared to 2009 and by 19 to 28 % for the exceedances of the PM2.5 annual limit value, pointing at a need for further measures to comply with the EU limit values. The same study shows also that PM concentrations and the number of exceedances can be considerably reduced if NH3 emissions from agriculture would be reduced beyond the emission targets for 2020 set in the revised Gothenburg Protocol. As an example, a further reduction (above and beyond the reduction planned in the revised Gothenburg Protocol) of 30 % in NH3 agriculture emissions in the EU would result in a further reduction of between 5 % and 9 % in the number of stations in exceedance of the PM10 daily limit value. Such a further reduction in NH3 would also result in a reduction of between 3 % and 10 % in the number of stations in exceedance of the PM2.5 limit value of 20 µg/m3 (which the relevant European directive declares should be met by 1 January 2020). Finally, this further reduction would also reduce the annual mean PM2.5 concentrations by up to 11 % in central and western Europe, compared to the Gothenburg Protocol scenario for 2020.

### 4.3.2 Ozone (O3)

Since the formation of O3 requires sunlight, O3 concentrations show a clear increase as one moves from the northern parts to the southern parts of the continent, with the highest concentrations in some Mediterranean countries. The concentration of O3 typically increases with altitude in the first kilometres of the troposphere. Close to the ground, O3 is depleted due to surface deposition and the titration reaction by the emitted NO to form NO2. Higher concentrations of ozone can therefore be observed at high altitude stations.

In contrast to other pollutants, O3 concentrations are generally highest at rural locations, lower at urban sites, and even lower concentrations at traffic locations. This is because at short distances from NOX sources, as is the case at urban background and more so at traffic stations, O3 is depleted through the titration reaction by the freshly emitted NO The high O3 concentrations occurring at a few urban stations shown in Map 4.3 are due to the O3 formation that occurs at times in large urban areas during episodes of high solar radiation and temperatures.

Differences in the distribution and magnitude of O3 precursor emission sources, the chemical composition of the air and climatic conditions along the north-south and east-west directions in Europe result in considerable regional differences in summer O3 concentrations. Year-to-year differences in the O3 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 O3 concentrations.

***Exceedance of the target values for protection of health***

The health-related threshold of the O3 target value (applicable from 2010) was exceeded more than 25 times in 2012 at 36 % of the rural stations, 22 % of urban background stations, 21 % of industrial sites, and 15 % of traffic sites in the EU28. The situation is similar for EEA-33 countries. There is a considerable increase in exceedances at traffic stations compared to 2011, i.e. from 9 % in 2011 to 15 % in 2012, which is not registered in other stations types. This is probably due to the increase in diesel vehicles in some countries, which have a much higher NO2/NO emission ratio leading to lower NO emissions and therefore lower O3 depletion close to traffic sources. On the other hand, the percentage of background stations in exceedance has actually decreased slightly from 2011 to 2012, from 24 % to 22 % at the urban background locations and from 40 % to 36 % at rural locations. In total, 24 % of the O3 stations in EU28 and EEA-33 were in exceedance in 2012. Conformity with the WHO AQG value for O3 (8‑hour mean of 100 µg/m3) set for the protection of human health was observed only at two out of 507 rural background stations in 2012. Two percent and 9 % of (sub)urban background and traffic stations, respectively, measured concentrations that did not exceed the WHO AQG in 2012. Although the EU target value (120 μg/m3, 25 exceedances allowed) is less ambitions than the WHO AQG, non-attainment situations (i.e. not having achieved the less ambitious EU air quality standard) are widely found in most of the EU Member States as shown in Map 4.3.

***Trends in O3 concentrations***

Due to its lifetime in the atmosphere (ca. 22 days) the concentrations and long-term trends of ozone are the net result of a hemispheric background level (here understood as representative of continental to hemispheric scales) and more local/regional effects. The background tropospheric ozone concentrations at all northern mid-latitudes sites have increased in all seasons at approximately 1% per year in the last 50 years (Parrish et al., 2012). The fact that background measurements of tropospheric ozone around the world show approximately the same rate of increase is a strong indication that the increase in ozone background concentrations is a global phenomenon. At most European sites the rate of increase has slowed over the last decade, to the extent that at present O3 is decreasing at some sites, particularly in summer.

Table A1.4 (Annex 1) shows the average trends by country and by station type for the maximum daily 8-hour mean O3 concentrations over the period 2003–2012([[10]](#footnote-10)). Increasing trends were registered at traffic stations in several countries: Bulgaria, Denmark, Finland, Greece, Lithuania, Portugal, Sweden, and Slovenia. The increasing O3 levels at traffic locations are mainly attributable to a reduced depletion of O3 by NO as a result of the decrease in traffic NOX emissions (de Leeuw, 2012). Greece, Hungary and Latvia also registered an increase in the maximum daily 8-hour mean O3 concentrations in rural background stations. Only Hungary registered an increasing trend at urban background stations.

Figure 4.7 shows the trends of the maximum daily 8-hour mean O3 concentrations at different station types over the period 2003–2012 ([[11]](#footnote-11)). This indicator is directly related to the target value for O3, as 25 days per year are allowed to have exceedances of the target value threshold of 120 μg/m3. Figure 4.7 shows small downward trend at the aggregated EU level for all station types.

In urban streets and urban background the recent years reductions in NOx emissions from road traffic have led to slight increases in annual mean ozone concentrations, although these tendencies may not yet be statistically significant. Reducing NOx emissions in Europe can result in increased ozone concentrations in the highly urbanized areas of the central and north-western parts of Europe (the VOC sensitive areas), including e.g. Germany, The Netherlands, Belgium and the UK (Bach et al., 2014).

In the latest decade, there has been a decline in the number of episodic high O3 concentrations (also called 'peak concentrations') (EEA, 2010a). However, often the data does not paint a uniform and steady trend. For example, in the summer of 2012 the information threshold (a one-hour average O3 concentration of 180 μg/m3) was exceeded at approximately 28 % of all operational stations. This was a much higher percentage than in 2011, when 18 % of operational stations registered these exceedances, but it was still among the lowest percentages since 1997. The long‑term objective (LTO) for the protection of human health was exceeded in all EU Member States except Estonia during summer (April–September) 2012. The average number of exceedances in 2012 was comparable with 2009–2011 years (EEA, 2013d).

Table A1.5 (Annex 1) shows the trends of three month averages for winter (December, January and February) and summer (June, July and August) for Europe and by country. In average for Europe it is clear that O3 summer average concentrations have declined from 2003 to 2012, while winter concentrations have slightly increased. Twelve countries show a similar behaviour to the European average, but trends vary largely from country to country. For example Cyprus, Estonia and Latvia show the opposite behaviour, with an increase in summer ozone concentrations and a decrease in winter, while Bulgaria, Denmark and Hungary show an average increase in both summer and winter concentrations. Ten countries have decreasing trends in both seasons (Table A1.5). Recent studies indicate a change in the mean seasonal cycle of the baseline O3 with the seasonal maximum being shifted from summer to spring in recent years (Oltmans et al., 2013; Parrish et al., 2013).

***Relationship of O3 precursors emissions to ambient O3 concentrations***

The relationship of O3 concentration to the emitted precursors is not linear. There is a discrepancy between the cuts in O3 precursor gas emissions and the change in observed O3 concentrations in Europe. The reasons for this include increasing inter-continental transport of O3 and its precursors in the northern hemisphere (EEA, 2010a; EEA, 2013c). According to HTAP (2010), the transport of ozone from other source regions (North America, South Asia and East Asia) contributes together some 43% to ozone levels in Europe. The increase in ozone precursor emissions is strongest in Asia, compared to North America and Europe, and especially the increases in NOx emissions from Asia have potentially the strongest influence on the increasing ozone background levels in the Northern Hemisphere.

In addition, other factors are also likely to mask the effects of European measures to reduce O3 precursor emissions. These other factors include climate change/variability, NMVOC emissions from vegetation the magnitude of which is difficult to quantify, and fire plumes from forest and other biomass fires (EEA, 2010a). Formation of tropospheric O3 from increased concentrations of CH4 may also contribute to the sustained O3 levels in Europe. Methane concentrations increased continuously during the 20th century, before growth slowed after 1990. Then, between 1999 and 2007 CH4 concentrations levelled off. Since 2007, however, measurements suggest that concentrations of CH4 have started to rise again (Dlugokencky et al., 2009). Methane is a slowly-reacting pollutant that is well mixed across the world. Isolated local and regional abatement of CH4 emissions may therefore have limited impact on local O3 concentrations. Clearly, O3 concentrations are not only determined by precursor emissions but also by meteorological conditions. Sunlight and high temperatures favour O3 formation. Episodes of elevated O3 levels occur during periods of warm, sunny weather. However, independent of the episodic nature of O3 pollution that is strongly influenced by meteorological conditions, emissions of O3 precursor gases are sustaining a baseline of exceedances of legal concentration thresholds. The O3 pollution problem requires further mitigation efforts.

In conclusion, despite the fact that emission control legislation in Europe has achieved substantial reductions in ozone precursors emissions over the last decade, the issue of non-attainment of the target value for O3 in most EU Member States persists. The local / regional management of precursor emissions have resulted in a reduction in the magnitude and frequency of peak ozone episodes across Europe. However, the influence of baseline/background hemispheric ozone and the transboundary nature of ozone and its precursors has resulted in annual mean levels remaining constant or in some cases increasing across Europe, hence the continued exceedences of the target value (Bach et al., 2014).

### 4.3.3 Nitrogen dioxide (NO2)

***Exceedances of limit values for the protection of human heath***

The limit value for the annual mean NO2 concentration is set at 40 μg/m3 and EU Member States were obliged to meet this by 2010. In 2012, 20 MS recorded exceedances of the limit value at one or more stations (red and dark red spots in Map 4.4; Figure 4.8).

The lowest concentration levels and fewest exceedances occur at rural stations, and that the highest concentrations and most exceedances are at traffic stations. While secondary PM and O3 are formed regionally from precursor gases, chemical reactions are less likely to create NO2 on this geographical scale, as relatively limited fresh NO emissions are available, except near highways and near combustion plumes. For most NOX sources, the share of NO in NOX emissions is much greater than that of NO2, typically 10–20 times higher ([[12]](#footnote-12)). Reactions between NO and O3 then create more NO2, reducing the amount of NO. In traffic and urban areas with fresh inputs of NO, some of the O3 present is depleted while oxidising NO to NO2. The reaction between NO, NO2 and O3 leads to chemical equilibrium in the absence of VOCs. Guerreiro et al. (2010) provide a thorough discussion of NO2 concentrations at hotspots close to traffic and also in the urban background.

Although the annual limit value was exceeded in 2012 at only one rural background station and 2 % (17 stations) of all urban background stations, it was exceeded at 37 % of traffic stations, with a maximum observed concentration of 94 μg/m3 in 2012, i.e. 2.4 times the annual limit value for NO2.

Figure 4.8 shows the attainment of annual mean NO2 values for 2012 for all Member States. It clearly indicates that exceedance of the annual limit value (equal to the WHO AQG) value was observed in most Member States at one or more stations in 2012, with only Estonia, Ireland, Malta, Lithuania, Slovenia, Cyprus, and Luxembourg not registering any exceedance. The only countries, with complete NO2 data for the years 2001, 2005, 2010, 2011, and 2012 which did not register an exceedance of the NO2 annual limit value in any of the five years were Estonia and Ireland.

The hourly limit value threshold for NO2 is less stringent. Only two urban background stations and 4 % of traffic stations reported exceedances.

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.

***Trends in NO2 concentrations***

The average trends in NO2 concentrations over the period 2003–2012 are summarised in Figure 4.9 for different types of stations. A consistent set of stations was used to compile these figures ([[13]](#footnote-13)). Figure 4.9 shows that there is an average decreasing trend in NO2 concentrations at all types of stations.

Table A1.6 and Table A1.7 (Annex 1) show the calculated trends by country and by station type for NO2 annual mean and NO2 hourly concentrations, respectively, in the period 2003–2012. With the exception of Slovenia (where no exceedances have been measured in 2012), all countries had an average decreasing trend at (sub)urban background stations for the annual mean, and only Luxembourg and Norway had an increasing trend at traffic stations. These trends are mostly statistically non‑significant, but some stations registered statistically significant increasing trends in Portugal, Poland and Luxembourg. The trends of the peak NO2 concentrations (99.8 percentile of hourly concentrations, Table A1.7) are more variable, with more countries registering positive trends, but mostly non-significant. Six out of 25 countries had increasing peak concentrations at traffic stations.

***Relationship of NOX emissions and NO2 concentrations***

Nitrogen oxides emissions primarily comprise NO but also include some directly emitted NO2, which Member States are not currently required to report as a separate compound under the relevant EU legislation (EU, 2001). The concentrations of NO2 found in ambient air originate both from directly emitted NO2 and from chemical reactions forming NO2 in the atmosphere, predominantly between NO and O3. Figure 4.9 shows the average significant trends in NO2 concentrations measured at rural, urban and traffic stations. The average the trends have been decreasing in all types of stations, but some stations, especially traffic stations, register significant increasing trends. The main reason for this may be attributed to the increase in the share of NO2 in the NOX emissions from traffic and an increase in diesel vehicles share in some areas (Guerreiro et al., 2010).

### 4.3.4 Benzo(a)pyrene (BaP)

***Exceedances of the target value***

Benzo(a)pyrene measurements in 2012 were above the target value threshold (1 ng/m3 annual average to be met by 2013) at 45 % of monitoring stations in the EU28 (Map 4.5). This was the case mainly at urban and suburban background stations (65 % of stations in urban and suburban locations exceeded the target value) and, to a lesser extent, at rural, traffic and industrial stations. Exceedances are most predominant in central and eastern Europe (Poland, the Czech Republic, Bulgaria, Hungary, Lithuania, Italy (the Po Valley), Austria, and Slovenia) although there are also exceedances in Germany, France, Estonia, and the United Kingdom (the Midlands and Northern Ireland).

Figure 4.10 shows for all EU Member States the annual mean BaP values for 2012. It shows that average annual concentrations of BaP exceeded the target value in the twelve countries mentioned above. The average concentration measured at Polish stations is five times higher than the target value.

### 4.3.5 Other air pollutants

***Sulphur dioxide (SO2)***

The hourly limit value for the protection of human health was only exceeded in 2012 at one station in the EU, an urban station in Bulgaria out of a total of 1608 stations measuring SO2. The daily limit value was exceeded at three stations, two urban and one traffic station, in Bulgaria and Poland. SO2 concentrations are generally well below the limit values for health protection.

Reported SO2 concentrations decreased steadily in the last decade, falling on average by about one third in the EU. This development corresponds well with the reported emission reductions.

***Carbon monoxide (CO)***

Nine out of 951 operational stations with more than 75 % data coverage (i.e. each station produced valid data at least 75 % of the time) in the EEA-33 countries reported exceedances of the CO limit value and the WHO AQG value: 6 traffic stations, 2 industrial stations and one rural background station, all of them in Italy . In contrast to the situation for the NO2 annual limit value, high concentration levels of CO are few and not widespread. This is illustrated in Map 4.6.

Average CO concentrations have decreased at all station types and in average the CO daily 8-hour maxima concentrations decreased by about one third in the EU over the last decade. These reductions in concentrations are in line with the reported reduction in total emissions.

***Toxic metals***

The number of monitoring stations measuring toxic metals has increased over the last years, but monitoring data for parts of Europe is still missing. This is probably due to the fact that concentrations are generally low and bellow the lower assessment threshold, allowing assessment to be made by modelling or objective estimates. In 2012 between 650 and 700 stations reported measurement data for each toxic metal (As, Cd, Pb and Ni) with minimum data coverage of 14 % (i.e. at least 14 % 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.

Map 4.7 a to d present annual mean ambient concentrations of As, Cd, Pb and Ni reported across Europe for 2012. The maps show that the air pollution problem of these toxic metals is highly localised: problems are related to specific industrial plants. The results from the reported 2012 data can be summarised as follows:

**• Arsenic** concentrations below the lower assessment threshold (2.4 ng/m3) were reported at nearly 75 % of the stations in 2012. At six stations (out of 657 operational stations) the reported concentrations exceeded the target value set for 2013 (6 ng/m3). Exceedances of the target value were observed in Belgium and Poland.

**• Cadmium** concentrations exceeded the target value at 1 % of the stations in Europe in 2012, i.e. at 6 out of 688 stations. Exceedances beyond the 5 ng/m3 target value were observed in three countries (Belgium, the Czech Republic and Bulgaria). At the majority of the other stations (96 %), Cd concentrations were below the lower assessment threshold (2 ng/m3).

**• Lead** concentrations exceeded the 500 ng/m3 limit value at two stations in 2012 in France. 99 % of the stations reported Pb concentrations below the lower assessment threshold of 0.25 μg/m3.

**• Nickel** concentrations exceeded the target value of 20 ng/m3 at six out of the 684 operational stations. These stations are located in Germany, Italy, United Kingdom, Norway and Spain. Most of the exceedances are related to industry.

**• Mercury** concentrations recorded in AirBase are very few, despite the fact that Directive 2004/107/EC (EU, 2004) requests EU Member States to perform (indicative) measurements of Hg at least at one background station. Background concentrations of Hg in air in 2011 ranged from bellow the detection limit to 3.7 ng/m3 (stations in Belgium, Cyprus, Germany, Finland, Ireland, Italy, Latvia, Poland, Sweden, Slovenia and the United Kingdom). One urban industrial station in the United Kingdom registered a concentration of 23.5 ng/m3 Hg in air, and industrial stations in Belgium measured concentrations between 4.4 and 9.7 ng/m3.

***Benzene***

Benzene is measured at a relatively small number of stations, 502 in 2012. At 78 % of the locations, annual mean concentrations of benzene is below the lower assessment threshold of 2 μg/m3. When concentrations are below the lower assessment threshold, air quality can be assessed by means of indicative or discontinuous measurements or by modelling or objective estimates.

Map 4.8 presents the annual average of benzene concentrations at stations with at least 50 % data coverage. The 2008 Air Quality Directive (EU, 2008c) sets an annual average concentration limit value of 5 μg/m3 for benzenein ambient air, to be met by 2010. The limit value was exceeded at five stations within EU28, in the Czech Republic, Italy and Poland, in addition to one station in Serbia. The exceedances were observed in urban (2) and industrial (3) stations, with no exceedances of the limit value observed at rural background stations.

## 4.4 Population exposure and impacts on health

### 4.4.1 Human exposure to PM pollution in Europe

The PM10 monitoring data in AirBase provide the basis for estimating the exposure of the urban European population to exceedances of the PM10 daily limit value (50 µg/m3 not to be exceeded on more than 35 days a calendar year). The exposure is estimated based upon PM10 measured at all urban and suburban background monitoring stations for most of the urban population and at traffic stations for the part of the population living within 100 m from major roads. The methodology is described in EEA (2014a).

In 2012 about 21 % of the urban population in the EU28 was exposed to PM10 above the daily limit value. The extent of exposure above the daily limit value has varied between 21 % and 41 % between 2003 and 2012 and there is no apparent trend in this exposure indicator over the period. For EEA‑33 countries the estimate of the urban population exposed to PM10 above the daily limit value is 38 % in 2012 and the variation was between 25 % and 46 % during the period 2003–2012. The range partly reflects variations caused by meteorology and changes in the subset of cities and stations included in the year-to-year estimates.

For PM2.5, the 2008 Air Quality Directive (EU, 2008c) introduced a target value, to be attained by 2010, which will become a limit value starting in 2015 (Table 4.2). In 2012 about 11 % of the urban population in the EU28 and EEA-33 was exposed to PM2.5 above the target value threshold. The percentage of the population exposed to annual levels above the target value has varied between 10 % and 14 % in the period 2010–2012. The same directive also established the national exposure reduction target for human exposure to PM2.5 based on the average exposure indicator (AEI) set at the national level. The AEI is an averaged level of concentrations (in space — per country and time – over a three-year period), measured at urban background monitoring stations (representative of general population exposure). Figure 4.5 indicates that in at least eight EU Member States the average urban concentrations in the period 2010–2012 were above 20 μg/m3. This is the legally binding level for this exposure concentration obligation to be met in the EU by 2015. The presented levels are not based on a stable set of stations. For a number of countries results are based on data for less than three years.

Table ES.1 shows the percentage of the EU urban population exposed to concentrations above the EU28 limit or target values and the WHO AQG levels between 2010 and 2012. Between 21 % and 30 % of the urban population were exposed to PM10 concentrations exceeding the EU daily limit value in this time, while up to 89 % (in 2011) of the same urban population was exposed to concentrations exceeding the stricter WHO AQG value for PM10. The percentage of the EU28 urban population exposed to levels above the PM2.5 target value (25 μg/m3) and above the PM2.5 exposure concentration obligation of 20 μg/m3 was in the range of 10 % - 14 % and 19 % - 31 % in the period 2010–2012, respectively. In terms of urban population exposure to levels above the more stringent WHO AQG (10 μg/m3) for PM2.5, it has varied between 94 % and 96 % in 2010-2012 Here too the range in the percentage of the population affected partly reflects variations caused by meteorology.

***Impacts on health***

The recent Global Burden of Disease study indicates that worldwide, 3.1 million deaths and almost 3 % of all DALYs (Disability Adjusted Life Years) could be attributed to exposure to ambient PM2.5. In western, central and eastern Europe the study estimated 430 000 premature deaths, and over 7 million DALYs (Lim et al., 2012). The latest WHO and EC estimates indicate that more than 400 000 premature deaths were attributable to ambient air pollution in Europe (WHO, 2014a; EC, 2013). Heart disease and stroke are the most common reasons of premature death due to air pollution, responsible for 80% of the cases, followed by lung diseases and lung cancer (WHO, 2014a). In addition to causing premature death, air pollution increases the incidence of a wide range of diseases, such as respiratory, cardiovascular and cancer, with both long- and short-term health effects.

An ETC/ACM systematic estimate of the health impacts attributable to the exposure to PM shows that the effect of PM2.5 concentrations on total mortality leads to about 458 000 premature deaths per year in Europe (over 40 countries ([[14]](#footnote-14))) and around 430 000 in the EU28. The estimate is based on 2011 concentrations ([[15]](#footnote-15)) and population data from the UN Population Prospects (UN, 2012). The relative risk from Krewski et al (2009) was used. i.e. a 10 μg/m3 increase in PM2.5 annual meanconcentration is associated with 6 % increase[[16]](#footnote-16) in total (non-violent) mortality.

Table 4.4 shows the estimated total mortality due to exposure to PM2.5 per country, for all the European countries included in the analysis. Germany, with the largest population in Europe, is the country with the highest estimate of premature deaths due to PM2.5 pollution, in total over 79 000 per year. It is followed by Italy and Poland, with almost 57 000 and 46 700 premature deaths per year, respectively. These three countries, with 34 % of the European population, account for 39 % of the total mortality in Europe, due to PM2.5 exposure.

The twelve countries ([[17]](#footnote-17)) with average PM2.5 annual concentrations above 20 µg/m3, mostly in Eastern Europe, account for 28% of the total mortality in Europe due to exposure to PM2.5, even if their population amount to 20% of the European population.

### 4.4.2 Human exposure to O3 pollution in Europe

Ozone concentrations measured at all urban monitoring stations provide the basis for estimating the urban exposure of the European population to exceedances of the EU's O3 target value (applicable from 2010) for the protection of human health, following the EEA methodology (described in EEA, 2014a).

It is noteworthy that people in rural areas are exposed to higher O3 levels than people in cities. In urban areas with fresh inputs of NO from traffic emissions, some of the O3 is depleted while oxidising NO to NO2. In 2012 about 14 % of the EU28 and EEA33 population in urban areas was exposed to O3 concentrations above the EU target value threshold. The percentage of the urban population exposed to ozone levels above the target value threshold has varied between 14 % and 58 % since 2003. The same exposure levels were estimated for the urban population of the EEA-33.There is no apparent trend in this indicator over the period. The range partly reflects variations caused by meteorology.

The EU urban population exposed to O3 levels exceeding the WHO AQG value (which is stricter than the EU's target value) is significantly higher, representing about 99 % of the total urban population in 2012 and varying between 97 % and 99 % in 2010-2012 (Table ES.1).

***Impacts on health***

An ETC/ACM systematic estimate of the health impacts attributable to exposure to O3 concentrations ([[18]](#footnote-18)) shows that the effect of O3 concentrations on total mortality leads to 17 400 premature deaths per year as a total for 40 countries (Table 4.4), and about 16 160 in the EU28. The estimate is based on 2011 concentrations ([[19]](#footnote-19)) and population data from the UN Population Prospects (UN, 2012).

Table 4.4 shows the estimated total mortality due to exposure to ozone per country, for all the European countries included in the analysis. Italy, with the fourth largest population in Europe, is the country with the highest estimate of premature deaths due to ozone pollution, in total almost 3400 per year. It is followed by Germany, France and Spain with over 2300, 1800 and 1700 premature deaths per year, respectively. These four countries, with 46 % of the European population, account for 54 % of the total mortality in Europe, due to exposure to ozone. Poland, Greece, United Kingdom, Romania and Hungary also have more than 500 premature deaths a year due to ozone exposure.

### 4.4.3 Human exposure to NO2 pollution in Europe

The NO2 monitoring data in AirBase provide the basis for estimating the exposure of the urban European population to exceedances of the NO2 annual limit value (40 µg/m3).The exposure is estimated based upon NO2 measured at all urban and suburban background monitoring stations for most of the urban population and at traffic stations for the part of the population living within 100 m from major roads. The methodology is described in EEA (2014a). According to this method, about 8 % of the EU28 and EEA-33 urban population was exposed to NO2 above the EU annual limit value and the WHO AQG for NO2 in 2012. The fraction of urban population exposed to concentration above the annual limit value varied between 8 % and 27 % between 2003 and 2012, with the same percentages estimated for the EEA-33. There is a trend of decreasing NO2 exposure to exceedances over this period with a continuous decrease between 2009 and 2012. The range partly reflects variations caused by meteorology.

### 4.4.3 Human exposure to BaP pollution in Europe

Exposure to BaP pollution is quite significant and widespread. As Map 4.5 shows, people across Europe, and especially in central and eastern Europe, are exposed to ambient BaP concentrations above the target value of 1 ng/m3 (to be met by 2013). Between 24 % and 28 % of the urban population in the EU28 was exposed to BaP concentrations above the target value in the period 2010 to 2012, while 77 % to 88 % of the EU28 urban population was exposed to BaP concentrations above the WHO reference level over the same period. Of the countries that reported BaP measurement data in 2012, only Sweden did not report levels above the WHO reference level (2 stations).

The increase in BaP emissions and concentrations in Europe over the last six years is therefore a matter of concern, as it is aggravating the exposure of the European population to BaP concentrations, especially in urban areas.

### 4.4.4 Human exposure to other pollutants in Europe

***SO2***

In 2012 a very small fraction of the EU28 urban population was exposed to SO2 above the 24-hour average limit value, as exceedance was only measured in one urban station in Bulgaria. There has been a trend of decreasing exposure to SO2 over the last decade and since 2007 the exposure of urban population to concentrations above the limit value has been under 0.5 %.

The EU28 urban population exposed to SO2 levels exceeding the WHO AQG in 2012 was significantly higher, amounting to 37 % of the total urban population, and varying between 37 % and 42 % in 2010-2012 (Table ES.1). However, here too a declining trend can be observed: this percentage has declined from 77 % to 37 % between 2003 and 2012.

***CO***

Based on the available measurements, it can be concluded that the European population's exposure to CO ambient concentrations above the limit value (8-hour maximum) is very localised and infrequent, and is limited to very few areas near traffic and industry.

***Toxic metals***

Human exposure to Pb, As, Cd, 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. On the other hand, atmospheric deposition of toxic metals contributes to the exposure of ecosystems and organisms to toxic metals and bioaccumulation in the food chain, thus affecting human health.

***Benzene***

As measurement data shows, exposure to benzene in Europe is limited to a few local areas, often close to traffic or industrial sources.

# 5. Vulnerability of ecosystems to air pollution

5.1 Description of the adverse effects of air pollution on ecosystems

Air pollution also damages the environment and it is estimated that two-thirds of the protected sites in the EU Natura 2000 network ([[20]](#footnote-20)) are currently under severe threat from air pollution (EC, 2013). For example, ozone can damage crops and other vegetation, impairing their growth. The atmospheric deposition of sulphur and nitrogen compounds has acidifying effects on soils and freshwaters. Table 5.1 summarizes the main effects of air pollutants on the environment.

The deposition of nitrogen compounds can also lead to eutrophication, an oversupply of nutrients that may lead to changes in species diversity and invasions of new species. In addition, toxic metals and persistent organic pollutants may lead to 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. Also aerosols impact ecosystems through radiation changes in different ways. On one hand, they reduce total solar radiation reaching the surface, but on the other hand, they increase the fraction of diffuse radiation relative to the direct fraction. Increase in the diffuse fraction may enhance the land carbon sink.

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 ozone exposure, acidification, eutrophication, and toxic metals.

***Vegetation damage by ground-level ozone***

Ground-level ozone is an air pollutant that is harmful to vegetation, but it is also harmful to the respiratory systems of humans and animals, and causes corrosion of materials and buildings. Ozone is formed near the ground due to the emissions of precursor gases which can come from both human activity and natural processes. Downward transport of ozone that exists in the stratosphere or intercontinental transport of ozone may also contribute to higher background ozone concentrations at ground level. The most important mechanism for removing ozone 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, a phenomenon known as 'necrosis'. In some sensitive plants, ozone can cause the leaves to exhibit what appear to be burn marks.

By impairing plants' reproduction and growth, high levels of ozone can thus lead to reduced agricultural crop yields, decreased forest growth, and reduced biodiversity.

***Eutrophication***

Eutrophication refers to an excess of nutrients in water or soil. It threatens biodiversity through the excessive growth of a few species, which thrive in the presence of the added nutrients, to the detriment of a larger number of species, which have long been part of the ecosystems 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 this excess of nutrient nitrogen, as the nitrogen emitted to the air, mostly from NOX emissions (mainly from combustion of fuels) and NH3 emissions (mostly from agricultural fertiliser ), deposits on soils and waters.

In water, eutrophication often leads to algae 'blooms', the rapid growth of algae, forming dense patches near the surface of the water and preventing 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. This high biological oxygen demand due to the increased bacterial activity may lead to a severe reduction in oxygen available to other forms of life, and in severe cases causes fish to suffocate. As more fish die, the number of these bacteria increases even more, intensifying the problem in a vicious cycle.

***Acidification***

Acidification damages plant and animal life both on land and in water, and it damages materials and buildings by corrosion.

The process of soil acidification works as follows: nitrogen and sulphur emissions into the atmosphere create nitric acid and sulphuric acid. This nitric acid and sulphuric acid falls to the earth as acid rain, and in so doing leads to a build-up of hydrogen ions in the soil. Build-up of hydrogen ions leads to reduction in the soil's pH level, a sign that the soil is becoming more acidic. Acidification also occurs when positively charged ions (also known as 'cations') of calcium, magnesium, potassium and sodium are leached and lost from the soil through the action of acid rain. Nitrogen compounds, often added as fertiliser, contribute further to the acidification of the soil through the production of ammonium. Soils and waters with poor buffering (neutralising) capacity are the most sensitive to acid rain.

***Environmental impacts of toxic metals***

Although the atmospheric concentrations of arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg) and nickel (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 health risk.

Arsenic is highly toxic to aquatic life and also very toxic to animals in general. Plant growth and crop yields may be reduced where soil As content is high. Organic As compounds are very persistent in the environment (they are not broken down over time by environmental processes) and bioaccumulate in the food chain.

Cadmium is highly persistent in the environment and bioaccumulates. Cadmium is toxic to aquatic life as it is directly absorbed by organisms in water. It interacts with cellular components, causing toxic effects in the cells of all organisms.

Lead bioaccumulates and adversely impacts both terrestrial and aquatic systems. As with humans, the effects on animal life include reproductive problems and changes in appearance or behaviour. Air pollution may contribute significantly to the Pb content of crops, through direct deposition. Although uptake via plant roots is relatively limited, rising Pb levels in soils over the long term are a matter for concern and should be addressed because of the possible health risks of low-level exposure to Pb.

Mercury bioaccumulates and adversely impacts both terrestrial and aquatic systems. It can affect animals in the same way as humans and is very toxic to aquatic life.

As is the case for humans, Ni is an essential element for animals in small amounts, but in high concentrations, Ni and its compounds can be acutely and chronically toxic to aquatic life and may affect animals in the same way as humans. High Ni concentrations in sandy soils can damage plants, and that high concentrations in surface waters can diminish the growth rates of algae. Microorganisms can also suffer from growth decline. Nickel is not known to accumulate in plants or animals.

## 5.2 European air quality standards for the protection of ecosystems/vegetation

The 2008 Air Quality Directive (EU, 2008c) sets out values for the protection of vegetation. Table 5.2 presents a summary of the critical levels, target values and long-term objectives for the protection of vegetation

The EU has the objective of protecting vegetation from high O3 concentrations accumulated over the growing season (defined as the summer months May to July). The vegetation protection value is specified as 'accumulated exposure over threshold', AOT40. This is calculated as the sum of all hourly O3 values over 40 micrograms per cubic metre (µg/m3). The vegetation protection value is calculated as the sum of all the hourly O3values that exceed 40 micrograms per cubic metre (µg/m3) during the daylight period of the most intense growing season. The target value for 2010 is 18 000 (μg/m3).hour. The long-term objective is 6 000 (μg/m3).hour, as shown in Table 5.2.

In addition to the EU target value, the UNECE Convention on Long-range Transboundary Air Pollution (UNECE, 1979) defines a ‘critical’ level for the protection of forest. This critical level is a function of the accumulated exposure over threshold AOT40 during the full summer (April-September) and is set to 10 000 (μg/m3).h (UNECE, 2011).

A critical level is set by the air quality directive (EU, 2008c) for NOX annual mean of 30 µg/m3 for the protection of vegetation, defined as the sum of NO and NO2 expressed in units of mass concentration of NO2.

Table 5.2 also presents the European air quality limit values for SO2 (EU, 2008c) for vegetation protection, i.e. as the annual and winter means not to exceed 20 µg/m3. Member States were obliged to meet the vegetation protection limits by 2005.

## 5.3 Status and trends in ecosystems relevant air pollutants

***Ozone***

The threshold used for the AOT40 target value (applicable from 2010) set for protection of vegetation (18 000 µg/m3.hour of accumulated exposure to AOT40, see Table 5.2) 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.

Since 2003, the target value threshold has been exceeded in a substantial part of the agricultural area in the EEA member countries. For example, in 2011 the threshold was exceeded in about 19 % of this area (Figure 5.1). Exceedances of the target values have notably been observed in southern and central Europe (Map 5.1). The long-term objective was met in only 12 % of the total agricultural area in 2011, mainly in the United Kingdom, Ireland and the Nordic countries. This is lower than in 2010 (15 %) and 2009 (19%). On the other hand, comparing Map 5.1 to the one for 2010 there was in general a slight decrease in the extent of areas with the highest AOT40 levels (red and purple), specifically in the central and south-western regions of Europe. Some increase occurred in southern Italy, the Balkan regions and Greece (Horálek et al, 2013). The variations between years (Figure 5.1) are influenced by meteorological factors. Summers in 2003 and 2006 had favourable meteorological conditions for O3 formation resulting in exceptionally high concentrations.

The UNECE — CLRTAP critical level of 10 000 (μg/m3).h set for protection of forests (UNECE, 2011) was exceeded at 85 % of the rural stations in 2012. For this forest‑protection objective, there is a substantially higher number of exceedances, than for the target value for protection of vegetation.

***NOx***

The NOx annual limit value for the protection of vegetation (30 µg/m3, expressed as µg NO2/m3) was exceeded at 18 rural background stations, mainly in Italy (12 stations), but also in Austria, Belgium, Germany and Switzerland in 2012

***SO2***

As in previous years, in 2012 the highest concentrations and exceedances of the annual limit value for protection of vegetation from SO2 occurred in the Balkan countries and Turkey, and at some stations in Silesia in southern Poland. In the EU the exceedances were recorded at urban and suburban stations (16 in total) in Bulgaria, Romania, Poland, Italy and Spain. None of those exceedances occurred at rural locations where there is more vegetation that needs to be protected than in urban areas. The limit value for the protection of vegetation set for the winter period (20 μg/m3) was not exceeded at rural stations within the EU28 or EE-33 during the winter 2011/2012. On the other hand, within the EU28, it was exceeded at 17 urban, 8 traffic and 4 industrial stations. In total 80 stations exceeded this limit value in the EEA-33 countries at urban, traffic and industrial stations.

## 5.4 Exposure and impacts on ecosystems

### 5.4.1 Extent of ecosystems exposure to O3 concentrations

The target value for protecting vegetation from high O3 concentrations was exceeded in about 19 % (413 550 km2) of the agricultural area in the EEA-33 in 2011, mostly in southern and central Europe (Map 5.1). 60 % of the total agricultural area in exceedance was in Italy (126270 km2) and Spain (121651 km2). The long-term objective was exceeded in 88 % of the total agricultural area. Twenty seven EEA member countries had practically all their agricultural area exceeding the long term objective in 2011 (Horálek et al., 2013).

The UNECE–CLRTAP critical level for the protection of forest was exceeded in 69 % (1 043 740 km2) of the total forest area in the EEA-33 member countries in 2011, increasing from 63 % in 2010 (Figure 5.1 bottom). Map 5.2 shows clearly that the attainment areas in 2011 were in the Northern part of Europe, while the highest exceedances occurred in southern France and north Italy. Twenty eight EEA member states had all the forest area in their territories in exceedance (Horálek et al., 2013). Furthermore, 84 % of the Natura 2000 areas were exposed to O3 concentrations above the critical level for the protection of forest in 2011.

***Estimated impacts of ozone on vegetation***

Ozone is considered to be more damaging to vegetation than any other air pollutant (Ainsworth et al., 2012), with significant effects on the growth of trees, vegetation in general, and important crops, such as wheat, soybean and rice (Ainsworth et al., 2012; Mills et al., 2011; Wilkinson et al., 2012).

Harmens and Mills (2012) concluded that today's levels of ozone exposure in northern and central Europe have the potential to reduce the rate of increase in forest living biomass by roughly 10 %, as compared to pre-industrial ozone exposure levels. Trees are an important carbon sink and many studies have shown that ozone reduces tree growth. Harmens and Mills (2012) estimated that between 1990 and 2000 the reduction in carbon stored in vegetation that can be accounted for by ozone concentrations was 6.2 % globally and almost 4 % in Europe.

Ozone impacts on vegetation and hence nitrogen (N) and carbon (C) storage by vegetation are still difficult to quantify, especially for forest ecosystems. There is a need to better understand how ozone acts within the mix of climate, other pollutants, and biotic stresses (e.g. insect pests, fungal diseases) that occur presently and are more likely in the future in the context of a changing climate.

Mills and Harmens (2011) calculated that assuming soil moisture is not limiting to production, ozone impacts on wheat resulted in European losses in production of 27 million tonnes of grain in 2000. The study showed that effects would be greatest in parts of central Europe (e.g. Germany, France and Poland), as well as in some Mediterranean countries (e.g. Italy, Spain). Ozone-induced growth reductions also result in an economic loss for the forest owners. For example the annual economic loss for owners of Swedish forests has been estimated to be approximately EUR 40 m (Karlsson et al., 2005).

### 5.4.2 Extent of ecosystems exposure to NOx concentrations

Map 5.3 shows the exposure of European ecosystems and Natura 2000 areas to NOx concentrations in 2011. The concentration map is based on rural background measurements (at 393 stations) and EMEP MSC-W modelled NOx annual mean concentration field in 2011, as documented in Horálek et al. (2013). The concentration map was then overlaid with the Natura 2000 areas to determine exceedances over these sensitive areas. The map shows that exceedance of the limit value for the protection of vegetation (red and purple colour) occurred mostly in the Po Valley in Italy and also areas in central Europe, specially the Netherlands. Most of the exceedance area is not Natura 2000 area, and only 0.6 % of the total Natural 2000 area was exposed to NOx concentrations exceeding this limit value. 70 % of the Natural 2000 area was exposed to NOx annual mean concentrations bellow 10 µg/m3, and 27 % to concentrations from 10 to 20 µg/m3.

Nitrogen oxide emissions and subsequent deposition of nitrogen contribute to both eutrophication and acidification of ecosystems, which is a bigger problem than the exposure to NOx ambient concentrations. The exposure of European ecosystems to eutrophying and acidifying compounds is discussed in Sections 5.4.3 and 5.4.5, respectively.

### 5.4.3 Extent of eutrophication

Emissions of NOX and NH3 are the main causes of eutrophication in European ecosystems.

Eutrophication effects are estimated using the concept of 'critical load', a term that describes the ecosystem's ability to absorb eutrophying pollutants that have been deposited from the atmosphere without negative effects on the natural environment. Exceedance of these spatially determined critical loads present a risk of damage or change in the existent ecosystem. Such exceedances are estimated based upon measurement data and model calculations.

EEA (2014e) estimates that 63 % of the total EU28 ecosystem area and 73 % of Natura 2000 area was at risk of eutrophication in 2010 due to excessive atmospheric nitrogen, covering most of continental Europe as well as Ireland and southern areas of the United Kingdom and Sweden. The average accumulated exceedance of critical loads was 221 eq ha–1a–1 of EU28 ecosystems and 257 eq ha–1a–1 for Natura 2000 areas. The reduction of ecosystem area at risk of eutrophication has been only moderate. For 2005, EEA (2014e) estimates that 67 % of EU28 ecosystem area and 78 % of Natura 2000 area was at risk of eutrophication, and the average accumulated exceedance of critical loads was 280 (337) eq ha–1a–1. The risk of ecosystem eutrophication and its geographical coverage have thereby diminished only slightly over the last decade and is still widespread over Europe. This conflicts with EU long-term objective of not exceeding critical loads of airborne acidifying and eutrophying substances in European ecosystem areas (EU, 2001; EU, 2002; EC, 2005).

### 5.4.4 Extent of ecosystems exposure to SO2 concentrations

The exposure of European ecosystems and Natura 2000 areas to SO2 concentrations in 2011 (annual mean) and in winter 2010/2011 were calculated using the same methodology as described for exposure to NOx concentrations in chapter 5.4.2. For SO2, 232 rural background stations were used for the annual mean, and 214 rural background stations for the winter average (1 October 2010 to 31 March 2011) concentration fields. Exceedance of the limit values for the protection of vegetation occurred mostly in Bulgaria and Bosnia- Herzegovina. Most of the exceedance area is not Natura 2000 area, and only 0.1 % of the total Natural 2000 area was exposed to SO2 concentrations exceeding the annual mean and the winter mean limit values. 91 % and 86 % of the Natural 2000 area was exposed to respectively annual mean and winter mean SO2 concentrations bellow 5 µg/m3. SO2 emissions and subsequent deposition of sulphur (via wet or dry deposition) contribute to the acidification of ecosystems, which is a bigger problem than the exposure of ecosystems to SO2 ambient concentrations. The exposure of European ecosystems to acidifying compounds is discussed in Section 5.4.5.

### 5.4.5 Extent of acidification

In addition to causing eutrophication, emissions of NOX and NH3 are also the main cause of acidification in Europe. Due to the considerable SOx emission reductions over the last decades, nitrogen compounds emitted as NOX and NH3 have become the principal acidifying components in ecosystems, both terrestrial and aquatic. However, emissions of SOX, which have a higher acidifying potential than NOX and NH3, still contribute to acidification.

Similar to eutrophication effects, acidification effects are estimated using the concept of 'critical load', describing the 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 present a risk of damage. Such exceedances are also estimated based upon measurement data and model calculations.

It is estimated that 9 % of Europe's forest area and 25 % of the European lakes were exposed to air pollution levels that exceeded EU limits for acidification in 2010 (EC, 2013).

EEA (2014e) estimates that 7 % of the total EU28 ecosystem area and 5 % of Natura 2000 area were at risk of acidification in 2010 and the average accumulated exceedance of critical loads was 26 eq ha–1a–1 and 16 eq ha–1a–1, respectively. This represents a considerable reduction from 2005 levels estimated to be respectively 10 % and 39 eq ha–1a–1 for the total EU28 ecosystem area, and 8 % and 32 eq ha–1a–1 for Natura 2000 areas. Compared to 1990, the area of sensitive ecosystems in the EU28 where the critical load of acidity was exceeded had declined by 94 % in 2010. This improvement is primarily attributed to sharp reductions in SOX emissions in the past two decades. The analysis doesn’t address the fact that even though ecosystems will in the future receive deposition of acidifying substances not exceeding critical loads, it may still take decades before a full recovery from past acidification occurs in the ecosystems.

### 5.4.6 Extent of exposure of ecosystems to toxic metals

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

The share of national ecosystem area in Europe, exceeding critical loads for Cd is below 1 % in most countries, except countries which have set lower critical loads than other countries (e.g. Bulgaria) (Slootweg et al., 2010).

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

The largest exceedances of toxic metal critical loads involve Hg. More than half of all EEA-33 countries ([[21]](#footnote-21)) have exceedances of critical loads for Hg across nearly 90 % or more of their ecosystem area. In total, atmospheric deposition of Hg exceeds the critical loads across 54 % of the EU ecosystem area (Slootweg et al., 2010).

# 6. Air pollution effects on climate change

Atmospheric pollution and climate change are distinct problems, but they are linked in several important ways. Greenhouse gases (GHGs), which cause global warming, generally have long lifetimes in the atmosphere, carbon dioxide (CO2) lasting about 100 years. Methane (CH4) is lasting about 12 years. Traditional air pollutants, like SO2, PM, O3 and NOx are short-lived, having lifetimes of a few days to weeks. Ground-level O3, black carbon (BC) – a constituent of PM and CH4 have a warming effect on climate and have relatively short life times. They are therefore called Short-Lived Climate Pollutants (SLCP). Table 6.1 summarizes the main effects of air pollutants on climate. The table includes only pollutants regulated by the 2008 Air Quality Directive.

Ground-level O3 contributes to global warming as it absorbs some of the infrared energy emitted by the earth and creates warming effects in its immediate surroundings. Emissions of precursors to O3 formation (CH4, NMVOC, NOx, CO) are therefore important in the context. In addition, ozone's effects on vegetation decrease photosynthesis, thereby also reducing plant uptake of CO2 which further enhances warming. Of the ozone precursors, CH4 has the largest impact on climate change. This due to its direct radiative forcing effect (RF), its oxidation to CO2, the contribution to tropospheric O3 formation and the contribution to stratospheric H2O formation. See Box 6.1 explaining the concept of radiative forcing, RF. As an ozone precursor NOx contributes with positive RF, leading to warming but as a PM precursor (see below) it contributes to negative RF, leading to cooling. Also the impact of NOx on CH4 lifetime contributes to negative RF. Carbon monoxide emissions contribute to positive RF due to its oxidation in the atmosphere to CO2, by increasing the lifetime of CH4 and due its role in O3 formation. Among the ground-level O3 precursors, the smallest climate effect is caused by NMVOC emissions.

Fine PM also has important climate impacts. Black carbon (BC) is one of the constituents of fine PM and has a warming effect, while other PM constituents (for instance sulphates and nitrates) may cool the climate. The role of direct dust emissions and aerosol precursor emissions is presented in Box 6.1. The largest contribution is formed by the emissions of BC with a combination of BC having a positive RF effect due to its presence in the atmosphere and a positive indirect RF due to its deposition on snow and ice. BC is a product of incomplete combustion of organic carbon and is emitted from traffic, biomass burning and industry. The second largest impact is by SO2 emissions, that due to their role in sulphate aerosol formation contribute to negative RF. The emissions of organic carbon and mineral dust have both a negative RF. Due to their role in nitrate aerosol formation, NOx and NH3 contribute to negative RF. Fine PM can also cause RF indirectly, by changing the properties of clouds, such as cloud reflectivity, cloud distribution, cloud formation, and precipitation.

When addressing air pollution and climate change at the same time, the information provided above makes a clear case for CH4, CO and NMVOC emissions reductions and that for NOx emission reduction, the effect could be different. At the global level, when taking all direct and indirect effects into account, the emissions of CH4, CO and NMVOC lead to a net positive radiative forcing (and thereby warming) and that SO2, NOX and NH3 emissions lead to a net negative radiative forcing (and thereby cooling). The resulting quantification of the climate impact is presented in Box 6.1.

***­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­­***

***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_***

***Box 6.1 Greenhouse gases and air pollutants impact on climate change***

The main pathways where greenhouse gases and air pollutants are impacting the climate system are direct and indirect radiative forcing, RF (IPCC, 2013).

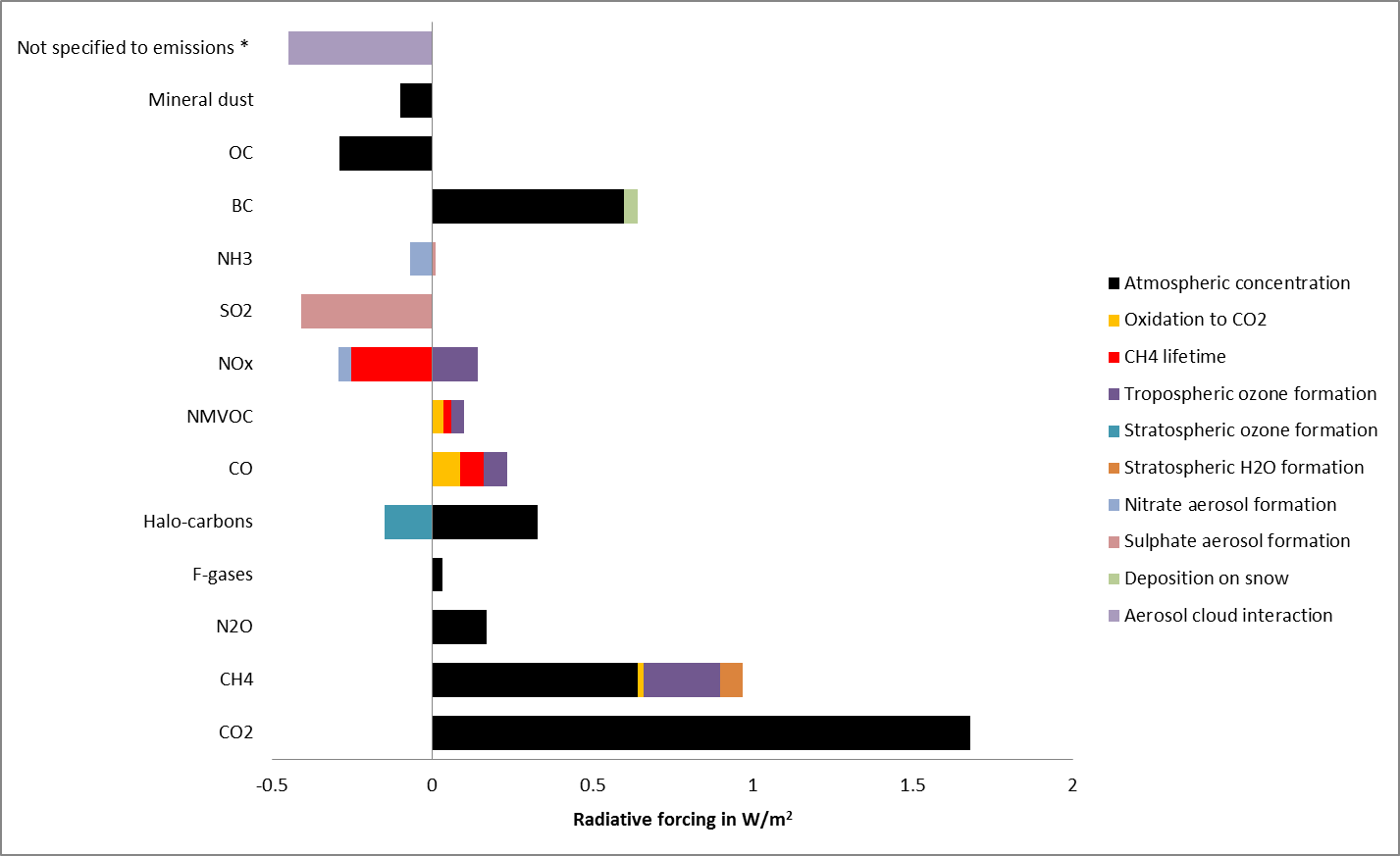
Direct RF refers to the change of fraction of radiant energy received from the sun being either absorbed (by e.g. the well-mixed greenhouse gases, tropospheric ozone and stratospheric water vapour) or scattered by e.g. sulphate aerosols.

Indirect RF refers primarily to aerosols altering cloud properties and precipitation patterns and efficiency. Other indirect effects are deposition of black carbon aerosol on ice and snow, resulting in less solar radiation being reflected by these surfaces, resulting in heat retention with as consequence a faster melting of snow and ice masses.

In previous IPCC assessments the atmospheric concentration was used to calculate the impact on radiative forcing (IPCC, 2001; 2007) but with advances in atmospheric modelling the combined impact from emissions, chemical transformation, aerosol-cloud interactions and distribution over the atmosphere can be taken into account (IPCC, 2013).

Figure 6.1 presents the radiative forcing in 2011 compared to pre-industrial time, 1750, resulting from greenhouse gases and air pollutants emissions over this period. The figure shows that some emissions have had either a warming or a cooling effect while other emissions resulted in a mixed effect resulting either in net warming or net cooling at the global scale. Emissions of CO2, CH4, N2O, F-gases, BC, CO and NMVOC all resulted in a warming of the atmosphere. Emissions of SO2, organic carbon and mineral dust all contributed to a cooling of the atmosphere. Emissions of halocarbons had both a warming and cooling effect with net warming result. Also the emissions of NOx and NH3 have both had a warming and cooling effect but the net result in their case was cooling. Figure 6.1 further highlights that aerosol-cloud interactions resulted in a cooling of the atmosphere although the contribution of individual emitted compounds to this RF effect are unknown.

Figure 6.1 Contribution of emitted compounds to radiative forcing for the period 1750-2011. In W/m2.



Source: EEA (based on IPCC (2013))

***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_***

# References

Aguilera, I., Garcia-Esteban, R., Iñiguez, C., Nieuwenhuijsen, M., Rodríguez, A., Paez, M., Ballester, F. and Sunyer, J., 2010, 'Prenatal exposure to traffic-related air pollution and ultrasound measures of fetal growth in the INMA Sabadell cohort', *Environmental Health Perspectives* (118/5), 705–711.

Ainsworth, E.A., Yendrek, C.R., Sitch, S., Collins, W.J., Emberson, L.D., 2012. *The effects of tropospheric ozone on net primary productivity and implications for climate change*. In: Merchant, SS, editor. Ann. Rev. Plant Biol; vol. 63 of Annual Review of Plant Biology. p. 637– 661. doi:{10.1146/annurev-arplant-042110-103829}.

AIRPARIF, 2014, *Bilan de l’épisode de pollution de mars 2014 et de la circulation alternée du 17 mars 2014*. <http://www.airparif.asso.fr/_pdf/publications/bilan-episodemars14-circulation-alternee-2014-140514.pdf>

Bach, H., Brandt, J., Christensen, J.H., Ellermann, T., Geels, C., Hertel, O., Massling, A., Nielsen, H.Ø., Nielsen, O.-K., Nordstrøm, C., Nøjgaard, J.K., Skov, H., Chatterton, T., Hayes, E., Laxen, D., Irwin, J., Longhurst, J., Pelsy, F., Zamparutti, T., 2014. Services to assess the reasons for non-compliance of ozone target value set by Directive 2008/50/EC and potential for air quality improvements in relation to ozone pollution: Final report. ECORYS, Rotterdam.

Baïz, N., Slama, R., Béné, M.-C., Charles, M.-A., Kolopp-Sarda, M.-N., Magnan, A., Thiebaugeorges, O., Faure, G. and Annesi-Maesano, I., 2011, 'Maternal exposure to air pollution before and during pregnancy related to changes in newborn's cord blood lymphocyte subpopulations. The EDEN study cohort', *BMC Pregnancy and Childbirth* (11/1), 87.

Bessagnet, B., Beauchamp, M., Guerreiro, C., de Leeuw, F., Tsyro, S., Colette, A., Meleux, F., Rouïl, L., Ruyssenaars, P., Sauter, F., Velders, G. J. M., Foltescue, V. L., van Aardennee, J., 2014. Can further mitigation of ammonia emissions reduce exceedances of particulate matter air quality standards? Environmental Science & Policy. In press.

Bond TC, Doherty SJ, Fahey DW, Forster PM, Berntsen T, et al. 2013. Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres 118: 5380-552).

Chiusolo, M., Cadum, E., Stafoggia, M., Galassi, C., Berti, G., Faustini, A., Bisanti, L., Vigotti, M.A., Dessì, M.P., Cernigliaro, A., Mallone, S., Pacelli, B., Minerba, S., Simonato, L. and Forastiere, F., 2011, 'Short-Term Effects of Nitrogen Dioxide on Mortality and Susceptibility Factors in 10 Italian Cities: The EpiAir Study', *Environmental Health Perspectives* (119/9), 1 233–1 238.

Choi, H., Jedrychowski, W., Spengler, J., Camann, D. E., Whyatt, R.M., Rauh, V., Tsai, W.-Y. and Perera, F.P., 2006, 'International Studies of Prenatal Exposure to Polycyclic Aromatic Hydrocarbons and Fetal Growth', E*nvironmental Health Perspectives* (114/11), 1 744–1 750.

Dahl, A., Gharibi, A., Swietlicki, E., Gudmundsson, A., Bohgard, M., Ljungman, A., Blomqvist, G. and Gustafsson, M., 2006, *Traffic-generated emissions of ultrafine particles from pavement–tire interface*. Atmospheric Environment, 40(7), 1314-1323.

De Leeuw, F., 2012, *AirBase: a valuable tool in air quality assessments at a European and local level*, ETC/ACM Technical Paper 2012/4.

Dlugokencky, E. J. and Bruhwiler, L., 2009, Observational constraints on recent increases in the atmospheric CH4 burden, *Geophysical Research Letters*, 36, L18803.

EC, 1992, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206, 22.7.1992, p. 7–50) (<http://eur-lex.europa.eu/LexUriServ/LexUriServ>. do?uri=CELEX:31992L0043:EN:NOT) accessed 17 June 2014.

EC, 2005, Communication from the Commission to the Council and the European Parliament ‘Thematic Strategy on air pollution’ (COM(2005) 0446 final 21.9.2005) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52005DC0446:EN:NOT) accessed 15 July 2014.

EC, 2012, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. 'CARS 2020: Action Plan for a competitive and sustainable automotive industry in Europe' (COM(2012) 636 final) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0636:FIN:EN:PDF) accessed 15 July 2014.

EC, 2013, *Commission Staff Working Document Accompanying the Communication on a revised EU Strategy on Air Pollution Proposal for a revision of Directive 2001/81/EC on national emission ceilings for certain atmospheric pollutants. Proposal for a legislative instrument on control of emissions from Medium Combustion Plants. - Impact Assessment*, SWD (2013) 531, European Commission, Brussels, 2013 (http://ec.europa.eu/environment/air/pdf/clean\_air/Impact\_assessment\_en.pdf) accessed 15 July 2014.

Edwards, S.C., Jedrychowski, W., Butscher, M., Camann, D., Kieltyka, A., Mroz, E., Flak, E., Li, Z., Wang, S., Rauh, V. and Perera, F., 2010, 'Prenatal Exposure to Airborne Polycyclic Aromatic Hydrocarbons and Children's Intelligence at 5 Years of Age in a Prospective Cohort Study in Poland', *Environmental Health Perspectives* 118(9), 1 326–1 331.

EEA, 2010a, *The European environment state and outlook 2010*, European Environment Agency (http://www.eea.europa.eu/soer) accessed 09 July 2014.

EEA, 2012a. NATURA 2000. Version 2012 rev. 1. <https://sdi.eea.europa.eu/internal-catalogue/srv/eng/search?uuid=c773f1a8-16ed-4f7a-91aa-f7475105f805>

EEA, 2012b, *Particulate matter from natural sources and related reporting under the EU Air Quality Directive in 2008 and 2009*,EEA Technical Report No 10/2012, European Environment Agency.

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

EEA, 2013b, *Environment and human health*, EEA Report No 5/2013, European Environment Agency.

EEA, 2013c, Air Quality in Europe - 2013 report. EEA Report No 9/2013, European Environment Agency.

EEA, 2013d, *Air pollution by ozone across Europe during summer 2012- Overview of exceedances of EC ozone threshold values for April–September 2012*,EEA Technical Report No 3/2013, European Environment Agency.

EEA, 2013g, *Air Implementation Pilot — Lessons learnt from the implementation of air quality legislation at urban level*, EEA Report No 7/2013, European Environment Agency.

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

EEA, 2014a, Exceedance of air quality limit values in urban areas (Indicator CSI 004), European Environment Agency.

EEA, 2014b, Exposure of ecosystems to acidification, eutrophication and ozone (Indicator CSI 005), European Environment Agency.

EEA, 2014c, *European Union emission inventory report 1990–2012 under the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP)*, EEA Technical Report No 12/2014, European Environment Agency.

EEA, 2014d , http://www.eea.europa.eu/data-and-maps/data/data-viewers/air-emissions-viewer-lrtap

EEA, 2014e – Technical report No 11/2014 Past and future exposure of European freshwater and terrestrial habitats to acidifying and eutrophying air pollutants

EMEP, 2011, *Transboundary Particulate Matter in Europe,: EMEP Status Report 2011*, edited by: Yttri, K. E. et al, European Monitoring and Evaluation Programme Status Report 4/2011.

EU, 1991, Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (OJ L 375, 31.12.1991, p. 1–8). (http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:31991L0676) accessed 15 July 2014.

EU, 1994, European Parliament and Council Directive 94/63/EC of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations( OJ L 365, 31.12.1994, p. 24–33) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31994L0063:EN:NOT) accessed 16 July 2014.

EU, 1999a, Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations (OJ L 85, 29.3.1999, p. 1–22). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31999L0013:EN:NOT) accessed 16 July 2014.

EU, 1999b, Council Directive 1999/32/EC of 26 April 1999 relating to a reduction in the sulphur content of certain liquid fuels and amending Directive 93/12/EEC (OJ L 121, 11.5.1999, p. 13–18). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31999L0032:EN:NOT) accessed 16 July 2014

EU, 2001, Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants (OJ L 309, 27.11.2001, p. 22-30). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:309:0022:0030:EN:PDF) accessed 15 July 2014.

EU, 2002, Decision No 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme (OJ L 242, 10.9.2002, p. 1-15). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002D1600:EN:NOT) accessed 15 July 2014.

EU, 2003a, Directive 2003/17/EC of the European Parliament and of the Council of 3 March 2003 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels (OJ L 76, 22.3.2003, p. 10–19). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32003L0017:EN:NOT) accessed 15 July 2014.

EU, 2003b, Directive 2003/96/EC of the European Parliament and of the Council of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity (OJL 283, 31.10.2003, p. 51–70). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:283:0051:0070:EN:PDF) accessed 15 July 2014.

EU, 2004, Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (OJ L 23, 26.1.2005, p. 3-16) (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:023:0003:0016:EN:PDF) accessed 15 July 2014.

EU, 2008a, Commission Regulation (EC) No 692/2008 of 18 July 2008 implementing and amending Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information (OJ L 199, 28.7.2008, p. 1–136). (http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32008R0692) accessed 15 July 2014.

EU, 2008b, Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control (Codified version) (OJ L 24, 29.1.2008, p. 8–29). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:024:0008:0029:EN:PDF) accessed 15 July 2014.

EU, 2008c, Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (OJ L 152, 11.6.2008, p. 1-44). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:152:0001:0044:EN:PDF) accessed 15 July 2014.

EU, 2009a, Directive 2009/126/EC of the European Parliament and of the Council of 21 October 2009 on Stage II petrol vapour recovery during refuelling of motor vehicles at service stations (OJ L 285, 31.10.2009, p. 36–39). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0036:0039:EN:PDF) accessed 15 July 2014.

EU, 2009b, Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC (OJ L 188, 18.7.2009, p. 1–13). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:188:0001:0013:EN:PDF) accessed 15 July 2014.

EU, 2010, Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (OJ L 334, 17.12.2010, p. 17–119). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:334:0017:0119:en:PDF) accessed 15 July 2014.

Faustini, A., Rapp, R., and Forastiere, F., 2014, *Nitrogen dioxide and mortality: review and meta-analysis of long-term studies*, European Respiratory Journal, erj01147-2013 , doi: 10.1183/09031936.00114713

Genc, S., Zadeoglulari, Z., Fuss, S.H. and Genc, K., 2012, *'The Adverse Effects of Air Pollution on the Nervous System*', Journal of Toxicology 2012, pp. 1–23.

Grice, S., Stedman , J., Kent, A., Hobson, M., Norris, J., Abbott, J., Cooke, S., 2009, 'Recent trends and projections of primary NO2 emissions in Europe', *Atmospheric Environment,* (43) 2154–2167.

Guerreiro, C., Horálek, J., de Leeuw, F., Hak, C., Nagl, C., Kurfürst, P. and Ostatnicka, J., 2010, *Status and trends of NO2 ambient concentrations in Europe,* ETC/ACC Technical Paper 19/2010.

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

Harmens, H. and Mills, G. (eds), 2012, *Ozone Pollution: Impacts on carbon sequestration in Europe*. ICP Vegetation Programme Coordination Centre, Centre for Ecology and Hydrology, Environment Centre Wales.

Hellén, H., Hakolaa, H., Haaparantaa, S., Pietarilaa, H. and Kauhaniemia, M., 2008, 'Influence of residential wood combustion on local air quality', *Science of The Total Environment*, (393) 283–290.

Horálek, J., de Smet, P., Kurfürst, P., de Leeuw, F., Benešová, N., 2013*, European air quality maps of PM and ozone for 2011 and their uncertainty*, ETC/ACM Technical Paper 2013/13.

IMO, 1973, *International Convention for the Prevention of Pollution from Ships (MARPOL)* (<http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx>) accessed 16 July 2014.

IPCC, 2001: *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC, 2013*: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Jedrychowski, W.A., Perera, F.P., Maugeri, U., Mrozek-Budzyn, D., Mroz, E., Klimaszewska- Rembiasz, M., Flak, E., Edwards, S., Spengler, J., Jacek, R. and Sowa, A., 2010, 'Intrauterine exposure to polycyclic aromatic hydrocarbons, fine particulate matter and early wheeze. Prospective birth cohort study in 4-year olds', *Pediatric Allergy and Immunology* (21/4p2), e723–e732.

Karlsson, P.E., 2005*, Economic assessment of the negative impacts of ozone on the crop yield and forest production. A case study of the Estate Östads Säteri in southwestern Sweden*.Ambio 34: 32-40.

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

Krewski, D., Jerrett, M., Burnett, R.T., Ma, R., Hughes, E., Shi, Y., et al., 2009,*Extended Follow-up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality*. Health Effects Institute, Research Report 140.

Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H., et al, 2012, A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet, 38039, 2224-2260, doi:10.1016/S0140-6736(12)61766-8.

Mills, G. and Harmens, H. (eds), 2011, *Ozone pollution: A hidden threat to food security.* ICP Vegetation Programme Coordination Centre, CEH Bangor, UK. ISBN: 978-1-906698-27-0.

Mills, G., Hayes, F., Simpson, D., Emberson, L., Norris, D., Harmens, H., et al., 2011. *Evidence of widespread effects of ozone on crops and (semi-)natural vegetation in Europe (1990-2006) in relation to AOT40- and flux-based risk maps*. Global Change Biology; 17(1):592–613. doi:10.1111/j.1365-2486.2010.02217.x. http://dx.doi.org/10.1111/j.1365-2486.2010.02217.x.

Mol, W. and van Hooydonk, P.R., 2013, *The European exchange of information in 2012*, ETC/ACM Technical Paper 1/2013.

OECD/IEA, 2013, *Nordic Energy Technology Perspectives: Pathways to a Carbon Neutral Energy Future*, International Energy Agency, Paris.

Oltmans, S., Lefohn, A., Shadwick, D., Harris, J., Schee,l H., Galbally, I., et al., 2013, *Recent tropospheric ozone changes – a pattern dominated by slow or no growth.* Atmospheric Environment 2013; 67(0):331 –51. doi: http://dx.doi.org/10.1016/j.atmosenv.2012.10.057.

Parrish DD, Law KS, Staehelin J, Derwent R, Cooper OR, Tanimoto H, et al, 2013, *Lower tropospheric ozone at northern midlatitudes: Changing seasonal cycle*. Geophys Res Lett 2013; 40(8):1631–1636. doi:{10.1002/grl.50303}.

Pearce, M.S., Glinianaia, S.V., Ghosh, R., Rankin, J., Rushton, S., Charlton, M., Parker, L. and Pless‑Mulloli, T., 2012, 'Particulate matter exposure during pregnancy is associated with birth weight, but not gestational age, 1962–1992: a cohort study', *Environmental Health* (11/1), 13.

Pereira, G., Haggar, F., Shand, A.W., Bower, C., Cook, A. and Nassar, N., 2012, 'Association between pre-eclampsia and locally derived traffic-related air pollution: a retrospective cohort study', *Journal of epidemiology and community health*.

Pey, J., Querol, X., Alastuey, A., Forastiere, F. and Stafoggia, M., 2013*, African dust outbreaks over the Mediterranean Basin during 2001–2011: PM10 concentrations, phenomenology and trends, and its relation with synoptic and mesoscale meteorology.* Atmos. Chem. Phys., 13, 1395-1410, 2013.

Putaud, J.-P., Van Dingenen, R., Alastuey, A., Bauer, H., Birmili,W., Cyrys, J., Flentje, H., Fuzzi, S., Gehrig, R., Hansson, H.C., Harrison, R. M., Herrmann, H., Hitzenberger, R., H¨uglin, C.,Jones, A. M., Kasper-Giebl, A., Kiss, G., Kousa, A., Kuhlbusch,T. A. J., L¨oschau, G., Maenhaut, W., Molnar, A., Moreno, T.,Pekkanen, J., Perrino, C., Pitz, M., Puxbaum, H., Querol, X.,Rodriguez, S., Salma, I., Schwarz, J., Smolik, J., Schneider, J.,Spindler, G., ten Brink, H., Tursic, J., Viana, M., Wiedensohler,A., and Raes, F., 2010, A European aerosol phenomenology – 3: Physical and chemical characteristics of particulate matter from 60 rural, urban, and kerbside sites across Europe, Atmos. Environ. 44, 1308–1320, 2010.

Rafaj, P., Amann, M., Cofala, J., Sander, R., 2012. Factors determining recent changes of emissions of air pollutants in Europe - TSAP Report #2, International Institute for Applied Systems Analysis (IIASA). (http://ec.europa.eu/environment/air/pdf/review/TSAP-DISTANCE-20120612[1].pdf)

Rexeis, M. and Hausberger, S., 2009, *Tend of vehicle emission levels until 2020 - Prognosis based on current vehicle measurements and future emission legislation*. Atmospheric Environment, 43, 4689-4698.

Sitch S. et al, 2007, *Indirect radiative forcing of climate change through ozone effects on the land-carbon sink*. Nature 448: 791-794.

Slootweg, J., Maximilian, P., Hettelingh, J., 2010, *Progress in the Modelling of Critical Thresholds and Dynamic Modelling, including Impacts on Vegetation in Europe*, CCE Status Report 2010. Report No. 680359001. ISBN No. 978-90-6960-249-3.

Tørseth, K., Aas, W., Breivik, K., Fjæraa, A. M., Fiebig, M., Hjellbrekke, Lund Myhre, A. G., C., Solberg, S., and Yttri, K. E., 2012, *Introduction to the European Monitoring and Evaluation Programme (EMEP) and observed atmospheric composition change during 1972–2009.* Atmos. Chem. Phys., 12, 5447–5481, 2012

UN, 2012, *World Population Prospects: The 2010 Revision*. United Nations, Department of Economic and Social Affairs, Population Division.

UNECE, 1979, *Convention on Long-range Transboundary Air Pollution,* United Nations Economic Commission for Europe, Geneva. (http://live.unece.org/fileadmin/DAM/env/lrtap/full%20text/1979.CLRTAP.e.pdf) accessed 15 July 2014.

UNECE, 1999, *Convention on Long-range Transboundary Air Pollution — Protocol to Abate Acidification, Eutrophication and Ground-level Ozone,* United Nations Economic Commission for Europe, Geneva. (http://live.unece.org/env/lrtap/multi\_h1.html) accessed 15 July 2014.

UNECE, 2011, *Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads & Levels and Air Pollution Effects, Risks and Trends - Chapter 3: Mapping Critical Levels for Vegetation*, United Nations Economic Commission for Europe, Geneva. (http://icpvegetation.ceh.ac.uk/manuals/mapping\_manual.html*)* accessed 15 July 2014.

Van Kempen, E., Fischer, P., Janssen, N., Houthuijs, D., Van Kamp, I., Stansfeld, S. and Cassee, F., 2012, 'Neurobehavioral effects of exposure to traffic‑related air pollution and transportation noise in primary schoolchildren', *Environmental Research* (115), 18–25.

WHO, 2000, *Air quality guidelines for Europe*,World Health Organization Regional Office for Europe, Copenhagen. (<http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf>). Accessed 14 July 2014.

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

WHO, 2006a*, Air quality guidelines.Global update 2005. Particulate matter, ozone, nitrogen dioxide and sulfur dioxide*, World Health Organization, Regional Office for Europe, Copenhagen, Denmark.

WHO, 2006b, Health risks of particulate matter from long-range transboundary air pollution, World Health Organization, Regional Office for Europe, Copenhagen, Denmark.

WHO, 2007, Health risks of heavy metals from long-range transboundary air pollution. Joint WHO/ Convention Task Force on the Health Aspects of Air Pollution, World Health Organization, Regional Office for Europe, Copenhagen, Denmark.

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

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

WHO, 2014a, Burden of disease from Ambient Air Pollution for 2012 - Summary of results (<http://www.who.int/phe/health_topics/outdoorair/databases/AAP_BoD_results_March2014.pdf>)

WHO, 2014b, Ambient (outdoor) air quality and health, Fact sheet N°313, Updated March 2014 (<http://www.who.int/mediacentre/factsheets/fs313/en/>)

WHO, 2014c, ‘Air quality and health — Fact sheet no 313 — Updated March 2014’ (http://www.who.int/mediacentre/factsheets/fs313/en/) accessed 30 June 2014.

Wilkinson, S., Mills, G., Illidge, R., Davies, W.J., 2012. *How is ozone pollution reducing our food supply?* J Exp Bot;63(2):527–536. doi:{10.1093/jxb/err317}.

Yttri, K. E., Aas, W., Bjerke, A., Cape, J. N., Cavalli, F., Ceburnis, D., Dye, C., Emblico, L., Facchini, M. C., Forster, C., Hanssen,J. E., Hansson, H. C., Jennings, S. G., Maenhaut, W., Putaud,J. P., and Tørseth, K, 2007, *Elemental and organic carbon in PM10: a one year measurement campaign within the European Monitoring and Evaluation Programme EMEP*, Atmos. Chem. Phys., 7, 5711–5725, doi:10.5194/acp-7-5711-2007, 2007.

# Annex 1 Trends in PM10, PM2.5, O3 and NO2 by country and station type

1. ETC/ACM stands for the European Topic Centre on Air pollution and Climate change Mitigation. [↑](#footnote-ref-1)
2. The EEA-38 countries are the EEA-33 member countries (the EU Member States Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom, and the remaining five EEA member countries, Iceland, Liechtenstein, Norway, Switzerland and Turkey), as well as EEA cooperating countries (Albania, Bosnia-Herzegovina, the former Yugoslav Republic of Macedonia, Montenegro, and Serbia). [↑](#footnote-ref-2)
3. This estimate refers to a recent three-year period (2010–2012) and includes variations due to meteorology, as dispersion and atmospheric conditions differ from year to year. [↑](#footnote-ref-3)
4. The average concentrations are calculated based on a population weighted average, using the same methodology as the for the calculation of the Structural Indicator (de Leeuw and Fiala, 2009) [↑](#footnote-ref-4)
5. The 40 countries covered in the estimate are listed in Table 4.4. [↑](#footnote-ref-5)
6. Based on SOMO35, which is the accumulated O3 concentration (daily maximum 8-hour) in excess of 35 ppb (70 μg/m3). It is used as an indicator of health hazards for overall long-term ozone levels. [↑](#footnote-ref-6)
7. The general definition of a critical load is ‘a quantitative estimate of an exposure to pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge’ (UNECE, 2004) [↑](#footnote-ref-7)
8. EEA-33 countries registered emission reductions as follows between 2003 and 2012: 27 % for CO, 26 % for NMVOC, 26 % for NOX, and 12 % for CH4. [↑](#footnote-ref-8)
9. Fixed sampling points in Europe are situated at four types of sites: traffic-related locations; urban and sub-urban background (non-traffic) locations; industrial locations (or other less defined locations); and rural background sites. [↑](#footnote-ref-9)
10. A consistent set of 1231 stations with data for 2003 to 2012 was used in the trend analysis. Of these, only 447 stations registered a trend (a significant trend, using the Mann-Kendall test). The remaining 784 stations had no significant trend. [↑](#footnote-ref-10)
11. Including only significant trends. [↑](#footnote-ref-11)
12. An exception is emissions from motor vehicles produced after 1990 (i.e. complying with Euro standards). Due to the effect of catalytic converters on gasoline-powered vehicles and particle filters on diesel vehicles, the NO2 fraction in emissions is much higher, making up 20–70 % of NOx depending upon the technology (e.g. Grice et al., 2009). [↑](#footnote-ref-12)
13. A consistent set of 1443 stations with data for 2003 to 2012,with a minimum data coverage of 75% of valid data per year for at least 8 years out of the 10 years period, was used. [↑](#footnote-ref-13)
14. The 40 countries covered in the estimate are listed in Table 4.4. [↑](#footnote-ref-14)
15. Based on 1x1 km2 resolution European map of annual mean PM2.5 concentrations in 2011, from a combination of measured and modelled data (Horálek et al, 2013). Table 4.4 gives an overview over all the countries included in the estimate. [↑](#footnote-ref-15)
16. 95% Confidence Interval (CI) 4-8%. [↑](#footnote-ref-16)
17. The Former Yugoslav Republic of Macedonia, Poland, Albania, Monte Negro, Bulgaria, Serbia, Bosnia and Herzegovina, Cyprus, the Czech Republic, Slovakia, Hungary, and Greece. [↑](#footnote-ref-17)
18. Based on SOMO35, which is the accumulated O3 concentration (daily maximum 8-hour) in excess of 35 ppb (70 μg/m3). It is used as an indicator of health hazards for overall long-term ozone levels. [↑](#footnote-ref-18)
19. Based on 1x1 km2 resolution European map of SOMO35concentrations in 2011, from a combination of measured and modelled data (Horálek et al, 2014). Table 4.4 gives an overview over all the countries included in the estimate. [↑](#footnote-ref-19)
20. Natura 2000 is an EU‑wide network of nature protection areas (EEA, 2012a) established under the 1992 Habitats Directive (EC, 1992). The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats. [↑](#footnote-ref-20)
21. Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Denmark, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, the former Yugoslav Republic of Macedonia, the Netherlands, Poland, Romania, Slovenia and Spain. [↑](#footnote-ref-21)