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Air quality in Europe — 2012 report

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Contents

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Executive summary

'Air pollution is bad for our health. It reduces human life expectancy by more than eight months on average and by more than two years in the most polluted cities and regions. Member States must comply with EU air quality standards quickly and reduce air pollutant emissions,' Janez Potočnik, EU Commissioner for the Environment (EU, 2010a).

Emissions of air pollutants derive from almost all economic and societal activities. In Europe, emissions of many air pollutants have decreased. Much progress has been made in tackling air pollutants such as sulphur dioxide (SO_2), carbon monoxide (CO) and benzene (C_6H_6) while other pollutants still present a serious threat to the health of Europeans and their environment.

Indeed air pollutant concentrations are still too high and harm our health and the ecosystems we depend on. A significant proportion of Europe's population lives in areas, especially cities, where exceedances of air quality standards occur. Particulate matter (PM) and ozone (O_3) pollution are particularly associated with serious health risks.

Air pollutants released in one European country may contribute to or result in poor air quality elsewhere. Moreover, important contributions from intercontinental transport influence the O_3 and PM concentrations in Europe.

Greater international cooperation, also focusing on links between climate and air pollution policies, is required more than ever to address air pollution. Reducing air pollution and improving air quality therefore remains a key priority.

Purpose and scope of this report

This report presents an overview and analysis of the status and trends of air quality in Europe based on concentration measurements in ambient air and data on anthropogenic emissions and trends from 2001 — when mandatory monitoring of ambient air concentrations of selected pollutants first produced reliable air quality information — to 2010.

This report has been published annually since 2011 and updates regularly the information given in the five yearly report 'the European environment — state and outlook' (SOER) of the European Environment Agency. The analysis covers up to 38 European countries (1), including the EU Member States and the EEA-32 member countries.

According to Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe, the Commission shall review in 2013 the provisions related to certain pollutants. This report aims to inform this review and the review of the European Commission's Thematic Strategy on Air Pollution.

Air pollution in Europe is a local, regional and transboundary problem caused by the emission of specific pollutants, which either directly or through chemical reactions lead to negative impacts. Each pollutant produces a range of effects from mild to severe as concentration or exposure increases. The main effects of air pollution are (see also Table 1.1):

- Damage to human health caused by exposure to air pollutants or intake of pollutants transported through the air, deposited and accumulated in the food chain;

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(1) The EEA-38 countries are the EEA-32 member countries (the EU Member States Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom, and the remaining five EEA member countries Iceland, Liechtenstein, Norway, Switzerland and Turkey), as well as six EEA cooperating countries (Albania, Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, Montenegro, and Serbia).

- Acidification of ecosystems, both terrestrial and aquatic, which leads to loss of flora and fauna;

- Eutrophication in ecosystems on land and in water, which can lead to changes in species diversity;

- Damage and yield losses affecting agricultural crops, forests and other plants due to exposure to ground-level O_3;

- Impacts of heavy metals and persistent organic pollutants on ecosystems, due to their environmental toxicity and due to bioaccumulation;

- Contribution to climate forcing;

- Reduction of atmospheric visibility;

- Damage to materials and cultural heritage due to soiling and exposure to acidifying pollutants and O_3.

Existing air quality legislation made simple

The Air Quality Directive 2008/50/EC, which replaced nearly all the previous EU air quality legislation — complemented by Directive 2004/107/EC — set legally binding limits for ground-level concentrations of outdoor air pollutants such as PM and nitrogen dioxide (NO_2).

Key elements of EU air quality legislation are:

- **EU limit values** are legally binding concentration thresholds that must not be exceeded. Limit values are set for individual pollutants and are made up of a concentration value. Limit values are accompanied by an averaging period, the number of exceedences allowed per year, if any, as well as a date by which the obligation should be met. Some pollutants have more than one limit value covering different endpoints or averaging times. Limit values are legally binding on EU Member States.

- **EU target values** — are to be attained where possible by taking all necessary measures not entailing disproportionate costs. Target values are not legally binding.

This report also refers to World Health Organization (WHO) air quality guidelines (AQG), which are often more stringent than current EU target and limit values.

The most problematic pollutants

At present, PM and O_3 are Europe's most problematic pollutants in terms of harm to human health. Domestic emissions are the most important contributors to O_3 and PM concentrations levels over Europe, but intercontinental transport of pollution also contributes to increased impacts on health, ecosystems and our economy (particularly crop productivity). Further studies are needed to attribute European air quality exceedance to non-European emissions of air pollutants.

Impacts on population

Table ES.1 gives an overview (²) 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 air quality guidelines WHO AQG in recent years (2008–2010).

Current pollution levels, especially of PM and O_3, clearly impact on large numbers of the urban population. This is particularly evident in the population exposure estimates based on the WHO AQG.

Impacts on European ecosystems

Air pollution's most important effects on European ecosystems are eutrophication, acidification and damage to vegetation resulting from exposure to O_3. As SO_2 emissions have fallen, ammonia (NH_3) emitted from agricultural activities and nitrogen oxides (NO_X) emitted from combustion processes have become the predominant acidifying and eutrophying air pollutants.

Impacts on climate

Several air pollutants are also climate forcers, having a potential impact on the planet's climate and global warming in the short term (decades).

(²) This estimate refers to a recent three-year period (2008–2010) and includes variations due to meteorology, as dispersion and atmospheric conditions differ from year to year.

Table ES.1 Percentage of the urban population in the EU exposed to air pollutant concentrations above the EU and WHO reference levels (2008–2010)

Pollutant	EU reference value	Exposure estimate (%)	WHO reference level	Exposure estimate (%)
$PM_{2.5}$	Year (20)	**16–30**	Year (10)	**90–95**
PM_{10}	Day (50)	**18–21**	Year (20)	**80–81**
O_3	8-hour (120)	**15–17**	8-hour (100)	**> 97**
NO_2	Year (40)	**6–12**	Year (40)	**6–12**
BaP	Year (1 ng/m^3)	**20–29**	Year (0.12 ng/m^3)	**93–94**
SO_2	Day (125)	**< 1**	Day (20)	**58–61**
CO	8-hour (10 mg/m^3)	**0–2**	8-hour (10 mg/m^3)	**0–2**
Pb	Year (0.5)	**< 1**	Year (0.5)	**< 1**
C_6H_6	Year (5)	**< 1**	Year (1.7)	**7–8**

Colour coding of exposure estimates fraction of urban population exposed to concentrations above the reference levels:

< 10 %	10–50 %	50–90 %	> 90 %

Note: The pollutants are ordered in terms of their relative risk for health damage — highest on top.

This estimate refers to a recent three year period (2008–2010) and includes variations due to meteorology, as dispersion and atmospheric conditions differ from year to year.

The reference levels included EU limit or target levels and WHO air quality guidelines (AQG).

The reference levels in brackets are in μg/m^3 except for CO which is in mg/m^3 and BaP in ng/m^3.

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

The comparison is made for the most stringent EU limit or target values set for the protection of human health. For PM_{10} the most stringent standard is for 24-hour mean concentration.

For $PM_{2.5}$ the most stringent EU standard is the 2020 indicative annual limit value (20 μg/m^3).

As the WHO has not set AQG for BaP and C_6H_6, the WHO reference level in the table was estimated assuming an additional lifetime risk of 1 x 10^{-5}.

Sources: EEA, 2012d (CSI 004); AirBase v. 6.

Ground-level O_3 and black carbon, a constituent of PM, contribute to global warming. Measures to cut black carbon and other pollutants, among them methane (CH_4 itself a greenhouse gas (GHG)), leading to O_3 formation will have double benefits, reducing both the health-and ecosystem damaging and the extent of global warming. Air quality and climate change can be tackled together by defining policies and measures developed through an integrated approach.

Figure ES.1 shows the major air pollutants in Europe and their potential impact on human health, ecosystems and the climate.

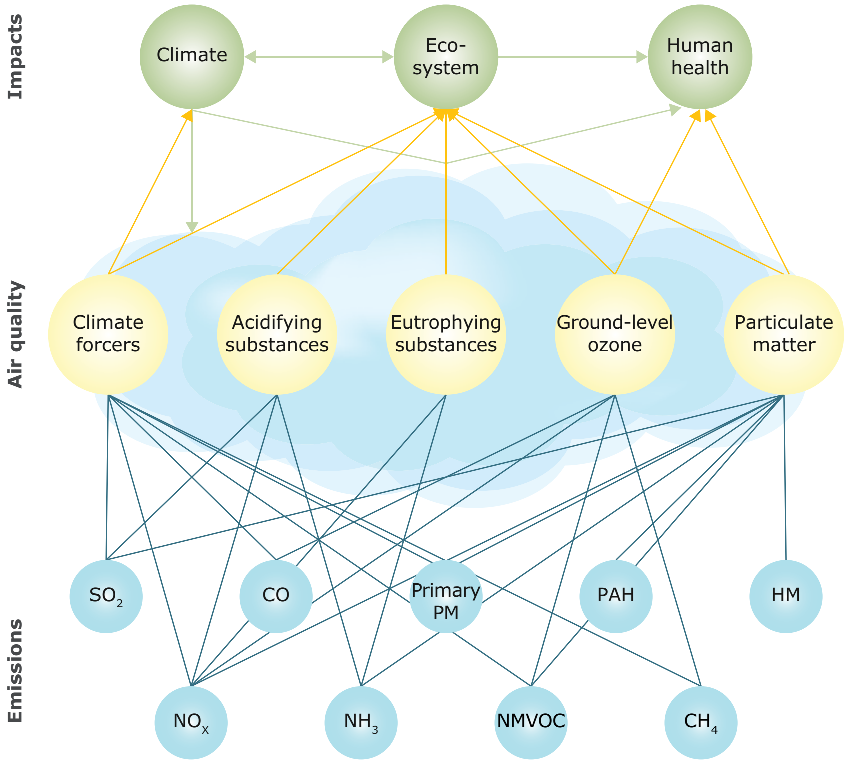
Key messages

Emissions of the main air pollutants in Europe declined in the period 2001–2010, resulting, for some of the pollutants, in improved air quality across the region. These results notwithstanding, many European countries still do not comply with one or more emission ceilings set under EU and United Nations (UN) agreements. For example, reported emission data for NO_X shows emissions higher than the respective ceilings in 12 EU Member States (EEA, 2012a).

Furthermore, due to the complex links between emissions and air quality, (explained later in this report) emission reductions do not always produce a corresponding drop in atmospheric concentrations, especially for PM and O_3. For example, while reductions of O_3 forming substances (O_3 precursor gases) have been substantial in Europe, O_3 concentrations in Europe have remained stable.

As a result, improving understanding of air pollution and developing and implementing effective policy to reduce it, remains a challenge and a priority.

Figure ES.1 Major air pollutants in Europe, clustered according to impacts on human health, ecosystems and the climate



Note: From left to right the pollutants shown are as follows: sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), ammonia (NH_3), particulate matter (PM), non-methane volatile organic compounds (NMVOC), polycyclic aromatic hydrocarbons (PAH), methane (CH_4), heavy metals (HM).

Key messages by pollutant

Particulate matter

In terms of potential to harm human health, PM is one of the most important pollutants as it penetrates into sensitive regions of the respiratory system and can lead to health problems and premature mortality. PM in the air has many sources and is a complex heterogeneous mixture whose size and chemical composition change in time and space, depending on emission sources and atmospheric and weather conditions.

PM in the atmosphere originates from:

- Primary particles emitted directly;
- Secondary particles produced as a result of chemical reactions involving so-called PM precursor gases: SO_2, NO_X, NH_3 and volatile organic compounds (VOC).

PM is measured in microns. The largest particles of concern are 10 microns in diameter or smaller (PM_{10}). The group of particles of most concern is 2.5 microns in diameter or smaller ($PM_{2.5}$). Some of these are small enough to pass from the lung into the bloodstream just like oxygen molecules. By comparison, the diameter of a human hair is 50–70 microns (Figure 2.1).

Emissions of primary PM

Emissions of primary PM_{10} and $PM_{2.5}$ decreased by 14 % and 15 % respectively in the EU and in the EEA-32 countries between 2001 and 2010.

Emissions of PM precursor gases

PM precursor emissions, except those of NH_3, decreased considerably between 2001 and 2010.

In the EU:

- Sulphur oxides (SO_X) emissions fell by 54 %;
- NO_X emissions fell by 26 %;
- NH_3 emissions fell by 10 %.

In the EEA-32 countries:

- SO_X emissions fell by 44 %;
- NO_X emissions fell by 23 %;
- NH_3 emissions fell by 8 % (2001–2009).

Despite these emission reductions, 18–41 % (3) of the EU urban population was exposed to concentrations of PM_{10} in excess of the EU air quality daily limit value in the period 2001–2010 and there was no discernible downward trend in this particular indicator (Figure ES.2). Between 23 % and 41 % (3) of the urban population in EEA-32 countries was exposed in the same period.

The EU limit and target values for PM were exceeded widely in Europe in 2010. The World Health Organization (WHO) guidelines for PM_{10} and $PM_{2.5}$ annual mean concentrations — which are stricter than the limit and target values set by EU legislation — were exceeded at the majority of monitoring stations across continental Europe.

Key observations relating to PM

- The small reductions observed in ambient PM concentrations over the period 2001–2010 reflect the slowly declining emissions of primary PM and NH_3.

- Twenty one per cent of the EU urban population lives in areas where the EU air quality 24-hour limit value for particulate matter (PM_{10}) was exceeded in 2010 (Figure ES.2). For EEA-32 countries the estimate is 41 %.

- EU urban population exposure to PM_{10} levels exceeding the WHO AQG is significantly higher, comprising 81 % of the total urban population in 2010 (Figure ES.2).

Ground-level ozone

Ozone is a secondary pollutant formed in the troposphere, the lower part of the atmosphere, from complex chemical reactions following emissions of precursor gases such as NO_X and non-methane VOC (NMVOC). At the continental scale, methane (CH_4) and CO also play a role in O_3 formation. Ozone is a powerful and aggressive oxidising agent, elevated levels of which cause respiratory health problems and lead to premature mortality. High levels of O_3 can also damage plants, leading to reduced agricultural crop yields and decreased forest growth.

Emissions of O_3 precursors

Ozone precursor gas emissions decreased considerably between 2001 and 2010.

In the EU:

- NO_X emissions decreased by 26 %;
- NMVOC emissions decreased by 27 %;
- CO emissions decreased by 33 %.

In the EEA-32:

- NO_X emissions decreased by 23 %;
- NMVOC emissions decreased by 28 %;
- CO emissions decreased by 35 %.

Ozone in Europe results also from precursor gases emitted elsewhere. For example, increased global emissions of CH_4 lead to higher concentrations of CH_4 in Europe which in turn contribute to the formation of O_3.

There is a discrepancy between the cuts in O_3 precursor gases emissions in Europe and the change in observed average O_3 concentrations in Europe. Reasons include increasing inter-continental transport of O_3 and its precursors in the northern hemisphere which are likely to mask the effects of European measures to reduce O_3 precursor emissions. Moreover, the relationship of O_3 concentrations in Europe to the emitted precursors in Europe is not linear.

Exposure to O_3 has not decreased since 2001. This excludes the estimated exposures in 2003 and 2006. Variations between years are influenced

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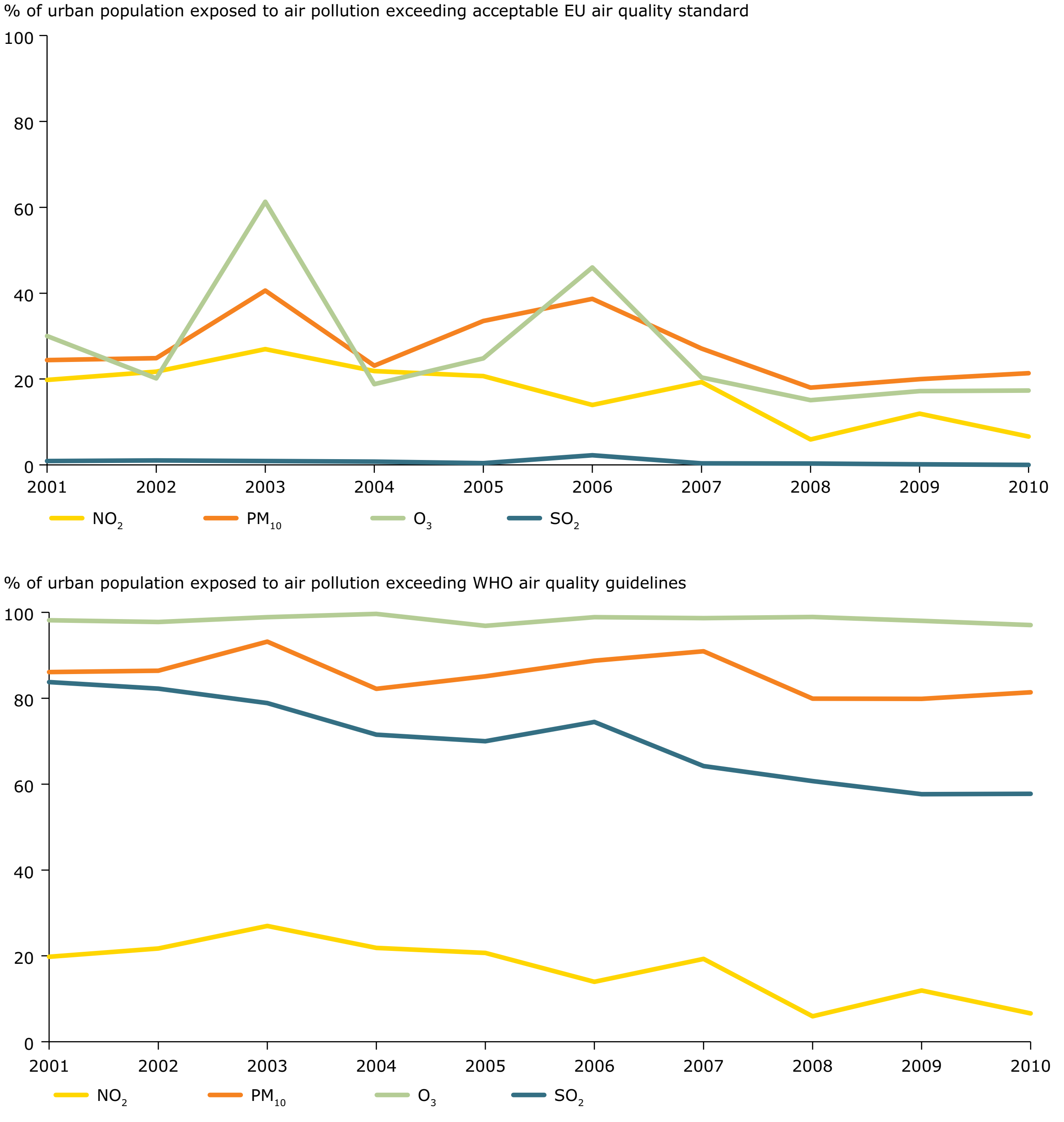
(3) The range partly reflects variations caused by meteorology, as dispersion and atmospheric conditions differ from year to year.

by meteorological factors. Summers in 2003 and 2006 had favourable meteorological conditions for O_3 formation resulting in exceptionally high concentrations. In other words, while emissions of gases that contribute to the formation of O_3 dropped in Europe, O_3 concentrations have not dropped. Larger emission reductions of O_3 precursor gases are necessary to achieve reductions in O_3 concentrations.

Between 15 % and 61 % ([3]) of the EU urban population was exposed to O_3 concentrations above the EU target value for protecting human health in the period 2001–2010 (Figure ES.2). Furthermore, between 22 % and 69 % ([3]) of agricultural crops in the EEA-32 were exposed to O_3 levels above the EU target value for protecting vegetation from 2001 to 2009. High O_3 concentrations are most pronounced in southern Europe.

Figure ES.2 Percentage of the EU urban population exposed to air pollution exceeding acceptable EU air quality standards (top) and WHO air quality guidelines (bottom)



Source: EEA, 2012d (CSI 004).

Key observations relating to O_3

- At aggregated EU level there is no clear trend for O_3 concentrations between 2001 and 2010, neither in the annual average nor in the indicator related to the target value set by legislation. Therefore, it can be concluded that concentrations in the period 2001–2010 do not reflect the European reductions in emissions of O_3 precursors in the same period.

- Seventeen per cent of the EU urban population lives in areas where the EU O_3 target value for protecting human health was exceeded in 2010 (Figure ES.2).

- The EU urban population exposed to O_3 levels exceeding the WHO AQG — which are stricter than EU target value, is significantly higher, comprising more than 97 % of the total urban population (Table ES.1, Figure ES.2).

- Europe's sustained ambient O_3 concentrations continue to cause considerable damage to vegetation growth and crop yields resulting in serious costs to Europe's economy.

Nitrogen oxides

Nitrogen oxides are emitted during fuel combustion, such as by road transport and industrial facilities. Of the chemical species that comprise NO_X it is NO_2 that is associated with adverse effects on health, as high concentrations cause inflammation of the airways and reduced lung function. NO_X also contributes to the formation of secondary inorganic PM and O_3 with associated effects on health and ecosystems.

Nitrogen (N) reactive compounds, emitted as NO_X and NH_3, are now the principal acidifying components in our air and cause eutrophication of ecosystems. The sensitive ecosystem area in Europe affected by eutrophication due to excessive atmospheric N has only diminished slightly over the last two decades. On the other hand, the area of sensitive ecosystems affected by excessive acidification from air pollution has fallen considerably in the past two decades (mainly due to the strong reduction in SO_2 emissions and partly due to reduction in NO_X emissions).

NO_X and NH_3 emissions continue to cause significant ecosystem impacts in Europe. Estimates calculated for 2010 show that 69 % of the total sensitive ecosystem area in the EU was at risk of eutrophication and 11 % was at risk of acidification (Hettelingh et al., 2008).

Key observations relating to NO_2

- Some cities in Europe show an increase in concentrations of NO_2 measured close to traffic. This reflects the increasing numbers of newer diesel vehicles. Exhaust emissions from such vehicles are lower for CO, NMVOC and PM but may be higher for NO_2.

- The decrease in NO_X transport emissions (27 % between 2001 and 2010 in the EU) is considerably greater than the fall in NO_2 annual mean concentrations (ca. 8 % measured at stations close to traffic, between 2001 and 2010). This is attributed primarily to the increase in NO_2 emitted directly into the air from diesel vehicles.

- Seven per cent of the EU urban population lives in areas where the annual EU limit value and the WHO AQG for NO_2 were exceeded in 2010 (Figure ES.2).

Sulphur dioxide

Sulphur dioxide is emitted when fuels containing sulphur are burned. It contributes to acidification, the impacts of which can be significant, including adverse effects on aquatic ecosystems in rivers and lakes, and damage to forests. Sulphur dioxide can affect the respiratory system and reduce lung function. It is also a major precursor to PM which is associated with significant health effects.

Key observations relating to SO_2

- SO_2 concentrations were halved in the EU, as EU Member States cut their SO_X emissions by 54 % in the period 2001–2010. The corresponding emission reduction in the EEA-32 countries was 44 %.

- Large sensitive ecosystem areas of Europe are no longer exposed to acidification, due mainly to reductions in sulphur emissions.

- 2010 is the first year for which the EU urban population has not been exposed to SO_2 concentrations above the EU 24-hour limit value (Figure ES.2). In the EEA-32 countries 1.6 % of the urban population has been exposed to SO_2 concentrations above the EU 24-hour limit value in 2010.

- The EU urban population exposed to SO_2 levels exceeding the WHO AQG is significantly higher, amounting to 58–61 % of the total urban population between 2008 and 2010 (Table ES.1).

Carbon monoxide

Carbon monoxide is emitted due to incomplete combustion of fossil fuels and biofuels and enters the body through the lungs. Exposure to CO can reduce blood's oxygen-carrying capacity, thereby reducing oxygen delivery to the body's organs and tissues.

The atmospheric lifetime of CO is about three months. The relatively long lifetime allows CO to slowly oxidise into carbon dioxide (CO_2), also forming O_3 during this process. CO therefore contributes to the atmospheric background concentration of O_3, with associated effects on health and ecosystems.

Key observations relating to CO

- The observed reduction in CO concentrations in the EU since 2001 reflect declining CO emissions of 33 % in the EU over the last decade.

- Exposure of the European population to CO concentrations above the EU limit value and WHO AQG is very localised and sporadic (Table ES.1).

Heavy metals

The heavy metals — arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg) and nickel (Ni) — are emitted mainly as a result of various combustion processes and industrial activities. Heavy metals can reside in or be attached to PM. As well as polluting the air, heavy metals can be deposited on terrestrial or water surfaces and subsequently build-up in soils or sediments. Heavy metals are persistent in the environment and may bio-accumulate in food-chains.

Emissions of heavy metals

In the period 2001–2010 emissions of heavy metals in the EU were reduced as follows:

- As reduced by 4 %;
- Cd by 30 %;
- Hg by 30 %;
- Ni by 41 %;
- Pb by 36 %.

Key observations relating to heavy metals

- The concentrations of As, Cd, Pb and Ni 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 heavy metal levels in soils, sediments and organisms.

- Despite cuts in estimated emissions of heavy metals since 2001 in the EU a significant share of the EU ecosystem area was still at risk of heavy metal contamination. Exceedances of Hg critical loads (4) were estimated to occur at 54 % of the sensitive ecosystem area in the EU in 2010, while for Pb the estimated area in exceedance is 12 % (Slootweg et al., 2010).

- A relatively small number of stations measure concentrations in air of As, Cd, Pb and Ni in Europe, since levels are often below the lower assessment threshold set by EU legislation. An even smaller number have been operating for five or more years. In the case of Hg, only a few stations report concentrations in air of different forms of Hg, making an analysis at the European level very difficult.

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(4) 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).

Benzene and benzo(a)pyrene

Benzene is released during incomplete combustion of fuels used by vehicles. Other sources are domestic heating, oil refining and petrol handling, distribution and storage. Inhalation is the dominant pathway for C_6H_6 exposure in humans. Benzene is a carcinogenic pollutant. The most significant adverse effects from prolonged exposure are damages to a cells' genetic material which can cause cancer.

Benzo(a)pyrene (BaP) is a polycyclic aromatic hydrocarbon (PAH), formed mainly from the burning of organic material such as wood, and from car exhaust fumes especially from diesel vehicles. It is a known cancer-causing agent and for this reason it is being used as an indicator of exposure to harmful PAH.

Emissions of C_6H_6 and BaP

- Benzene is not included as an individual pollutant in European emissions inventories covering VOC. However, the average C_6H_6 concentration in 2010 measured at traffic stations in the EU has declined to less than half since 2001, indicating significant emission reductions.
- Emissions of BaP in the EU have increased by 14 % between 2001 and 2010. In Europe, BaP pollution is a problem in areas where domestic coal and wood burning is common.

Key observations relating to C_6H_6 and BaP

- Exceedances of the limit value for C_6H_6 were limited to a few locations in Europe, primarily situated close to industrial sources in 2010.
- Exposure of the European population to BaP concentrations above the target value is significant and widespread in central and eastern Europe. Between 20 % and 29 % of the urban population in the EU was exposed to BaP concentrations above the target value (1 ng/m^3 to be met by 2013) in the period 2008 to 2010. The increase in BaP emissions in Europe over the last years is therefore a matter of concern, as it is aggravating the exposure of the European population to BaP concentrations.

1 Introduction

1.1 Report objectives and coverage

Background

Humans and the environment in Europe are exposed to a complex mixture of many air pollutants emitted from various sources and subject to atmospheric processes which can create new pollutants. Many of these pollutants can cause severe health problems and impact on ecosystems.

Despite successful legislation and some success in dealing with emissions to air, European populations are still breathing air containing dangerous substances. Understanding the 'state' of and key trends influencing air quality in Europe is a critical first step in dealing with the issue.

This is the background to *Air quality in Europe — 2012*, a European Environment Agency report, the second in a series of annual reports aiming to update information given in the five-yearly report 'The European environment — state and outlook' (SOER) of the European Environment Agency. The report is produced in support of European and national policy development and implementation in the field of air quality. It also supports air quality management and informs the general public on the current status and trends of air quality in Europe.

Objectives and coverage

This report presents an overview and analysis of air quality in Europe from 2001 — when mandatory monitoring of ambient air concentrations of selected pollutants first produced reliable air quality information — to 2010. The evaluation of the status and trends of air quality is based on ambient air measurements, in conjunction with anthropogenic emissions and their trends. An overview of policies and measures at European level is also given for each pollutant.

The links between emissions and ambient concentrations can only become evident and fully understood by means of air quality modelling. This report does not include analysis of reported modelled data, owing to the scarcity of such data officially made available by European countries through the current reporting and data exchange mechanism. Modelling studies reported elsewhere in the literature are presented, where relevant, to strengthen the analysis.

This report reviews progress towards meeting the requirements of the two air quality directives in force (EU, 2004b; EU, 2008c) and describes the policies and measures introduced at European level to improve air quality and minimise air pollution impacts on public health and ecosystems.

The report analyses each regulated pollutant in turn, following the single-pollutant approach currently adopted by EU air quality legislation and the World Health Organization (WHO) in its air quality guidelines. In reality, air pollution constitutes a complex mixture of pollutants which may interact in terms of their impacts on human health and vegetation. Therefore, exposure to air pollution is largely a multi-pollutant process.

Over the last decade European emission mitigation policies have followed a multi-pollutant approach and will continue to do so. The scientific air quality community still focuses on individual pollutants, although we are exposed to a complex mixture of pollutants. The move towards a multi-pollutant approach is described by this community as challenging. Additional research is needed to understand and quantify the possible additive, synergetic or antagonistic effects between pollutants which are encountered simultaneously in the ambient air.

New exposure-response functions for pollutant combinations are thus required to help us characterize more fully the complexity of the exposure and its impacts. That will be the first step towards resolving the relative impacts of air pollutants and achieving a holistic multi-pollutant approach to air quality decisions.

Table 1.1 Effects of air pollutants on human health, the environment and the climate

Pollutant	Health effects	Environmental effects	Climate effects
Particulate matter (PM)	Can cause or aggravate cardiovascular and lung diseases, heart attacks and arrhythmias, affect the central nervous system, the reproductive system and cause cancer. The outcome can be premature death.	Can affect animals in the same way as humans. Affects plant growth and ecosystem processes. Can cause damage to buildings. Reduced visibility.	Climate effect varies depending on particle size and composition: some lead to net cooling, while others lead to warming. Can lead to changed rainfall patterns. Deposition can lead to changes in surface albedo.
Ozone (O_3)	Can decrease lung function; aggravate asthma and other lung diseases. Can lead to premature mortality.	Damages vegetation, impairing plant reproduction and growth, and decreasing crop yields. Can alter ecosystem structure, reduce biodiversity and decrease plant uptake of CO_2.	Ozone is a greenhouse gas contributing to warming of the atmosphere.
Nitrogen oxides (NO_x)	NO_2 can affect the liver, lung, spleen and blood. Can aggravate lung diseases leading to respiratory symptoms and increased susceptibility to respiratory infection.	Contributes to the acidification and eutrophication of soil and water, leading to changes in species diversity. Acts as a precursor of O_3 and PM, with associated environmental effects. Can lead to damage in buildings.	Contributes to the formation of O_3 and PM, with associated climate effects.
Sulphur oxides (SO_x)	Aggravates asthma and can reduce lung function and inflame the respiratory tract. Can cause headache, general discomfort and anxiety.	Contributes to the acidification of soil and surface water. Causes injury to vegetation and local species losses in aquatic and terrestrial systems. Contributes to the formation of PM with associated environmental effects. Damages buildings.	Contributes to the formation of sulphate particles, cooling the atmosphere.
Carbon monoxide (CO)	Can lead to heart disease and damage to the nervous system and cause headaches, dizziness and fatigue.	May affect animals in the same way as humans.	Contributes to the formation of greenhouse gases such as CO_2 and O_3.
Arsenic (As)	Inorganic As is a human carcinogen. It can lead to damage in the blood, heart, liver and kidney. May also damage the peripheral nervous system.	Highly toxic to aquatic life, birds and land animals. Soil with high As content, reduces plant growth and crop yields. Organic As compounds are persistent in the environment and subject to bioaccumulation.	No specific effects.
Cadmium (Cd)	Cadmium, especially cadmium oxide is likely to be a carcinogen. It may cause damage to the reproductive and respiratory systems.	Toxic to aquatic life. Cadmium is highly persistent in the environment and bioaccumulates.	No specific effects.
Lead (Pb)	Can affect almost every organ and system, especially the nervous system. Can cause premature birth, impaired mental development and reduced growth.	Bioaccumulates and adversely impacts both terrestrial and aquatic systems. Effects on animal life include reproductive problems and changes in appearance or behaviour.	No specific effects.
Mercury (Hg)	Can damage the liver, the kidneys and the digestive and respiratory systems. It can also cause brain and neurological damage and impair growth.	Bioaccumulates and adversely impacts both terrestrial and aquatic systems. Can affect animals in the same way as humans. Very toxic to aquatic life.	No specific effects.
Nickel (Ni)	Several Ni compounds are classified as human carcinogens. It may cause allergic skin reactions, affect the respiratory, immune and defence systems.	Nickel and its compounds can have highly acute and chronic toxicity to aquatic life. Can affect animals in the same way as humans.	No specific effects.
Benzene (C_6H_6)	A human carcinogen, which can cause leukaemia and birth defects. Can affect the central nervous system and normal blood production, and can harm the immune system.	Has an acute toxic effect on aquatic life. It bioaccumulates, especially in invertebrates. Leads to reproductive problems and changes in appearance or behaviour. It can damage leaves of agricultural crops and cause death in plants.	Benzene is a greenhouse gas contributing to the warming of the atmosphere. It also contributes to the formation of O_3 and secondary organic aerosols, which can act as climate forcers.
Benzo-a-pyrene (BaP)	Carcinogenic. Other effects may be irritation of the eyes, nose, throat and bronchial tubes.	Is toxic to aquatic life and birds. Bioaccumulates, especially in invertebrates.	No specific effects.

1.2 Relevant policy instruments and legislation

Thematic strategy on air pollution

Within the European Union, the Sixth Environment Action Programme (EU, 2002) called for the development of a thematic strategy on air pollution with the objective of achieving levels of air quality that do not result in unacceptable impacts on, and risks to, human health and the environment. Formulated in 2005, the thematic strategy (EC, 2005b) sets specific long-term objectives for improvements in 2020 relative to the situation in 2000, specifically (EC, 2005c):

- a 47 % reduction in loss of life expectancy as a result of exposure to PM;
- a 10 % reduction in acute mortalities from exposure to O_3;
- a 74 % reduction in excess acid deposition in forest areas and a 39 % reduction in surface freshwater areas;
- a 43 % reduction in areas or ecosystems exposed to eutrophication.

To achieve these objectives, it was estimated that key emissions would have to fall significantly in the period 2000–2020, specifically:

- SO_2 emissions to decrease by 82 %;
- NO_X emissions by 60 %;
- VOC by 51 %;
- NH_3 by 27 %;
- Primary $PM_{2.5}$ (fine particles emitted directly into the air) by 59 %.

In the 'Roadmap to a Resource Efficient Europe' the European Commission has proposed the following milestone for the policy: 'By 2020, the EU's interim air quality standards will have been met, including in urban hot spots, and those standards will have been updated and additional measures defined to further close the gap to the ultimate goal of achieving levels of air quality that do not cause significant impacts on health and the environment' (EC, 2011a).

Legal instruments

In recent decades, the EU has introduced and implemented various legal instruments to improve air quality. The different legal mechanisms for air quality management comprise limits or targets for ambient concentrations; limits on total emissions (e.g. national totals); and regulating emissions from specific sources or sectors either by setting emission limits (for e.g. vehicle emissions) or by setting requirements on product quality (e.g. sulphur (S) and C_6H_6 in fuel). The European directives currently regulating ambient air concentrations of main pollutants are designed to avoid, prevent or reduce harmful effects of air pollutants on human health and the environment. They comprise:

- Directive 2008/50/EC on ambient air quality and cleaner air for Europe, which regulates ambient air concentrations of SO_2, NO_2 and NO_X, PM_{10} and $PM_{2.5}$, Pb, C_6H_6, CO and O_3 (EU, 2008c);
- Directive 2004/107/EC relating to As, Cd, Hg, Ni and PAH (including BaP) in ambient air (EU, 2004b).

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.

Several EU directives regulate anthropogenic emissions of pollutants to air, including precursors of key air pollutants such as O_3 and PM. The National Emission Ceilings Directive (EU, 2001b) and the Gothenburg Protocol (UNECE, 1999) to the UN Convention on Long-range Transboundary Air Pollution (LRTAP), which has been recently revised (UNECE, 2012), set national emission limits for SO_2, NO_X, NMVOC and NH_3 in order to abate acidification, eutrophication and ground-level O_3.

Likewise, several directives and international conventions regulate emissions of the main air pollutants from specific sources and sectors, either by setting emission limits, by requiring the use of the best available technology, or by setting requirements on fuel composition. These include:

- Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) (EU, 2010b), targets certain industrial, agriculture and waste treatment installations. The directive regulates emissions to air of SO_2 and other sulphur compounds, NO_X and other nitrogen compounds, CO, VOC, metals and their compounds, dust, asbestos, chlorine (Cl) and its compounds, fluoride (F) and its compounds, As and its compounds, cyanides, other carcinogenic and mutagenic compounds, and polychlorinated dibenzodioxins and polychlorinated dibenzofurans.

- The 'Euro standards' for road vehicle emissions set emission limits for NO_X, hydrocarbons (HC), CO and PM for most vehicle types. The Euro 4 limits are addressed in Directive 98/70/EC (EU, 1998a, 1998b) and Directive 2005/55/EC (EU, 2005). The Euro 5 and 6 limits are covered in Regulation (EC) No 692/2008 (EU, 2008a) and Regulation (EC) No 595/2009 (EU, 2009b).

- 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 VOC due to the use of organic solvents in certain activities and installations (EU, 1999a).

- Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources (EU, 1991).

- 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, 2003).

- The Marine Pollution Convention, MARPOL 73/78 (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 SO_X, NO_X, VOC and PM from ship exhausts and prohibits deliberate emissions of ozone-depleting substances.

Table 1.2 summarises the coverage of the European directives and international conventions regulating air pollutant emissions (either directly or indirectly by regulating precursors emissions). The list is not exhaustive. Annex 2 provides a more detailed description of the directives regulating emissions to air and fuel quality.

The 2004 and 2008 air quality directives do not specify an air quality objective for NH_3. The Gothenburg Protocol (UNECE, 1999) under the LRTAP convention and the National Emission Ceilings Directive (EU, 2001b) set emission reduction targets for NH_3 with the aim of reducing the acidification and eutrophication. Reporting of NH_3 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).

1.3 Air quality and climate change

1.3.1 Air quality and climate change — policy interactions

Human activity and natural processes lead to emissions of several gaseous and particulate compounds into the atmosphere affecting both air quality and climate. Carbon dioxide is the largest driver of global warming and climate change. In addition, non-CO_2 'climate forcers' (defined as any gaseous or particulate compound that contributes to climate change including O_3, CH_4, nitrous oxide, F-gases (gases containing fluorine) as well as PM) exert influence on the Earth's energy balance and on climate.

As many of the non-CO_2 climate forcers are common air pollutants, air pollution has an important influence on the regional and global climate. Suspended PM (aerosols) and its chemical constituents influence the Earth's energy balance directly, through reflection and absorption of solar and infrared radiation in the atmosphere. In general, absorption of radiation leads to a positive forcing (increase in temperature), whereas reflection leads to a negative forcing (cooling of the atmosphere).

Figure ES.1 illustrates the linkages between emitted pollutants and impacts on air quality and climate. Ground-level O_3 contributes to global warming. It is also one of the two major air pollutants that severely impact public health and ecosystems and is formed in the atmosphere from several precursor gases. Fine PM, the other major air pollutant, has also important climate impacts. One of the constituents of fine PM, black carbon has a warming effect, while other constituents, for instance sulphates and nitrates, may cool the climate.

Table 1.2 Legislation in Europe regulating emissions and ambient concentrations of air pollutants

	Pollutants Policies	PM	O_3	NO_2 NO_X NH_3	SO_2 SO_X S	CO	Heavy metals	BaP PAH	VOC
Directives regulating ambient air quality	2008/50/EC	PM	O_3	NO_2	SO_2	CO	Pb		C_6H_6
	2004/107/EC						As, Cd, Hg, Ni	BaP	
Directives regulating emissions of air pollutants	2001/81/EC	(a)	(b)	NO_X, NH_3	SO_2				NMVOC
	2010/75/EU	PM	(b)	NO_X, NH_3	SO_2	CO	Cd, Tl, Hg, Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V		VOC
	Euro limits on road vehicle emissions	PM	(b)	NO_X		CO			HC, NMHC
	94/63/EC	(a)	(b)						VOC
	2009/126/EC	(a)	(b)						VOC
	1999/13/EC	(a)	(b)						VOC
Directives regulating fuel quality	1999/32/EC	(a)			S				
	2003/17/EC	(a)	(b)		S		Pb	PAH	C_6H_6, HC, VOC
International conventions	MARPOL 73/78	PM	(b)	NO_X	SO_X				VOC
	LRTAP	PM (a)	(b)	NO_2, NH_3	SO_2	CO	Cd, Hg, Pb	BaP	NMVOC

Note: (a) Directives and conventions limiting emissions of PM precursors, such as SO_2, NO_X, NH_3 and VOC, indirectly aim to reduce PM ambient air concentrations.

(b) Directives and conventions limiting emissions of O_3 precursors, such as NO_X, VOC and CO, indirectly aim to reduce troposphere O_3 concentrations.

Particles can also cause climate forcing indirectly, through the changes they are causing in cloud properties, including cloud reflectivity and precipitation.

Measures to cut black carbon and O_3 precursor emissions will have double benefits, protecting both human health locally and the climate (Shindell et al., 2012). Methane is both a greenhouse gas and a contributor to the formation of ground-level O_3. Methane emissions (mainly from agriculture, energy and waste management) increased continuously during the 20th century, before growth slowed after 1990. Abatement of CH_4 will reduce health-and ecosystem-damaging O_3 levels and reduce the extent of climate change. There are therefore ways to tackle air quality and climate change together, defining policies and measures that reduce the impact of human activity on climate change and on air quality simultaneously (win-win or co-benefit measures).

On the other hand, there are also measures that reduce the impact on air quality but increase the impact on climate change or vice-versa (win-lose measures).

The European Union, governments, as well as regional and local authorities have developed policies to prevent air pollution in order to protect human health, ecosystems and materials, and are considering further policy measures (e.g. UNECE LRTAP, 2012 and the 2013 review of EU air policies). Similarly, policies are developed and implemented at international and (sub)national governance levels to minimise the negative effects of climate change. These policies grew up to a large extent independently, but there is increasing awareness amongst policymakers of the many linkages between air pollution and climate change. Legislation introduced to address air pollution as well as climate change has generally led to improved technology and subsequent pollution abatement by emission reductions. Examples of such technological improvements are the introduction of three-way catalysts to petrol vehicles, low nitrogen burners in power plants and efficiency improvements in energy and production processes, as well as in household products and vehicle engines. Nevertheless, more can be done to reduce emissions of both air pollutants and climate forcers, e.g. by reducing the combustion of fossil fuels and other resources, such as improving resource efficiency, switching energy sources, energy conservation and initiatives to induce behavioural change leading to lower environmental pressure.

1.3.2 *Impacts on European air quality from the adoption of European climate change policies*

In the EU roadmap for moving to a competitive low carbon economy in 2050 (EC, 2011b), the European Commission lays down the ambition to reduce domestic GHG emissions by 80 % in 2050 compared to 1990, thereby setting a long term perspective. In December 2011, the Commission also adopted an energy roadmap for 2050 (EC, 2011c), which is tightly linked to the low carbon economy roadmap, as GHG emissions result to a large extent from energy use.

Important elements of the transition to a low carbon economy include: reduction of final energy demand; increased use of bio-fuels to replace fossil fuels; application of carbon capture and storage (CCS) in industry and the power sector; and increase in share of wind, solar, hydro, geothermal, as well as nuclear energy in electricity production, together with an increased share of electricity in final energy consumption.

The effect of climate policies on air pollution depends on the nature and ambition level of climate measures being taken. It is widely recognized that measures to abate air pollution and GHG often target the same emission sources — combustion facilities, vehicle exhausts, and the management of manure and that control of one GHG can have co-benefits or trade-offs for air pollutant emissions and vice-versa (EEA, 2006; EEA, 2010a). However, several studies have highlighted potential co-benefits on air pollution from future climate policies with or without additional tailor-made air pollution abatement measures. For example, the European Commission's Joint Research Centre demonstrated substantial potential co-benefits in terms of reduced air pollutants emissions following an effective global climate policy by 2030 and 2050 that would keep global mean temperature increase less than two degrees compared to pre-industrial values (van Aardenne et al., 2010).

A recent study by UNEP/WMO (2011) showed that fast implementation of existing emission controls on black carbon and methane will be a cost-effective way in reducing global warming and protection human health and ecosystems from climate change and air pollution. This is especially true for non-European regions, in particular Asia. To analyse the co-benefits in Europe, Colette et al. (2012) quantified co-benefits of climate mitigation scenarios on air pollutants using the GEA (Global Energy Assessment) and two of the IPCC (Intergovernmental Panel on Climate Change) RCPs (Representative Concentration Pathways) mitigation scenarios: RCP4.5 and RCP2.6. Two GEA scenarios (HIGH_CLE and LOW_CLE (5)) were applied in the atmospheric chemistry transport model CHIMERE to evaluate such potential impacts and co-benefits in 2030. The results indicate that surface NO_2 concentrations might decrease significantly by 2030 in Europe, so that in the most optimistic scenario the current hotspots of pollution would be barely above the background levels. Ozone formation would also decrease over most of Europe, although some increases would be observed in certain areas. For PM, the expected decrease by 2030 would make natural sources (mineral dust resuspension and sea salt) the dominating contributor to PM_{10} concentrations in Europe.

However, the effect of some climate policies on emissions of air pollutants depends on the technology used, and can be different for the various air pollutants. According to EEA (2011a), while some variants of CCS are clearly good for air pollutant emissions (implying low emissions), the application of other technologies might lead to increased air pollutant emissions (e.g. NH_3 and NO_X). Similarly, large scale introduction of biomass combustion as part of a climate change policy may lead to substantially higher emissions of $PM_{2.5}$ and carcinogenic substances — such as BaP unless abatement measures are taken. Consequently, depending on the climate measures taken, effects on air pollutant emissions can be either beneficial or detrimental.

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(5) HIGH_CLE: Full implementation of all current and planned air pollution legislation worldwide; no specific policies on climate change and energy access.
LOW_CLE: Full implementation of all current and planned air pollution legislation worldwide; stringent climate policy, complying approximately with the 2-degree global temperature increase limit by 2100.

The increased international recognition of the importance of addressing air pollution and climate change simultaneously is reflected for example in the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (http://www.unep.org/ccac) and the announcement of the Air Pollution & Climate Initiative from the International Geosphere-Biosphere Programme (IGBP) and the International Global Atmospheric Chemistry (IGAC) (IGBP/IGAC, 2012). The concept of air pollution and climate has been introduced in the long-term strategy of LRTAP which for example identified the assessment of 'the feasibility of incorporating short-lived climate forcers (SLCFs) into instruments such as the revised Gothenburg Protocol. Initial efforts should focus on measures targeting black carbon as a component of PM and on the development of guidelines for black carbon emission inventories (LRTAP EB Decision 2011/14, UNECE 2012).

However, many challenges remain in translating this knowledge to action and more studies are needed to better understand and quantify the impacts on European air quality following the adoption of European climate change policies.

1.3.3 *Particulate matter, both air pollutant and climate forcer*

As mentioned in Section 1.3.1, atmospheric particles are both an important air pollutant and a climate forcer. Particles may either increase or decrease global warming, depending on their characteristics and optical properties. 'White' particles with high capacity to reflect sunlight, act mainly as a cooling agent, while 'black' or 'brown' particles absorb sunlight and act as a warming agent. On the other hand, particles may also have indirect effects on the climate, as they play an important role in the formation, characteristics and duration of clouds, and influence the radiation properties of clouds and precipitation patterns. In addition, deposition of black carbon particles on snow and ice can contribute to raising temperatures locally, and an increased melting rate of the ice. The disappearance of snow or ice from the earth or sea surface will exacerbate global warming, as the property of reflecting sunlight (albedo) of the surface changes dramatically.

The complexity of particles characteristics and their uneven distribution and transformation in the atmosphere makes it very difficult to predict their direct and indirect role in the climate system. Current atmospheric models still lack a complete and detailed process description of the behaviour and effects of particles on the atmosphere, especially concerning aerosol-cloud interactions. Furthermore, and despite considerable advances since the IPCC's Third Assessment Report, the complex relations and feedback mechanisms between particles, climate and ecosystems (which also emit particles, depending on external conditions such as climate and atmospheric composition) are not fully understood nor fully described in the models (Solomon et al., 2007).

Particles mainly contribute to cooling the climate, even if some contribute to warming (such as black carbon and minerals containing specific copper and iron compounds). IPCC (Solomon et al., 2007) estimated the total direct effect of particles on climate to be – 0.5 ± 0.4 W/m^2, including both cooling effects and heating effects (the latter estimated to be 0.2 ± 0.15 W/m^2 for black carbon). The total indirect effect of particles on climate forcing was estimated to be between – 0.3 and – 1.8 W/m^2. Ramanathan and Carmichael (2008) estimated considerably higher heating effects, due to black carbon particles. As indicated by UNEP/WMO (2011) and other studies some win-win strategies have been identified where reduction of certain emissions like those of black carbon does not lead to increase of air pollution problems whereas the success of mitigation of climate change remains in the reduction of CO_2 emissions.

1.3.4 *Importance of intercontinental transport of air pollutants*

Although the influence of emission sources on atmospheric concentration is generally greatest near the sources, intercontinental transport of O_3 and PM and their precursors contribute to serious public health problems and damage to natural and agricultural ecosystems in many parts of the world (UN, 2010b).

Current and past observations provide a wealth of evidence that concentrations and deposition of O_3 and PM are influenced by atmospheric transport between continents and in some cases around the globe (UN, 2010b).

Concerning PM, long-term trends in observations of surface concentration and wet deposition (through precipitation) of PM at remote locations, as well as model simulation studies on source and receptor regions provide clear evidence of intercontinental transport. Further, measurements have also shown the importance of secondary particle formation from precursor gases transported from other regions. In-situ measurements and satellite observations have established the importance of intercontinental transport of PM from arid regions, forest fires, and anthropogenic sources. Studies have shown that due to atmospheric transport and chemistry processes, particle formation can take place at long distances from the sources of precursor gases. However, gaps remain in the knowledge and understanding of aerosol particle properties and fluxes (pollution, dust, biomass-burning emissions) between continents (UN, 2010a).

Concerning O_3, evidence of its intercontinental transport is provided by direct O_3 measurements, as well as measurements of precursor gases and model simulation studies on source and receptor regions. Plumes of O_3 have been observed in the free troposphere and at high altitude sites. Most importantly, an increasing trend in concentrations in air masses without the contribution from local anthropogenic emissions has been measured consistently at a number of remote sites across the Northern hemisphere (UN, 2010a). Measurements on the western coasts of Europe and North America show that trans-oceanic air flows can carry high enough O_3 concentrations that can contribute substantially to the exceedance of air quality targets for O_3 concentrations. Complex topography may enhance the mixing of O_3 transported at high altitudes with surface air.

Further, multi-model experiments done by the Task Force on Hemispheric Transport of Air Pollution (HTAP), evaluated the theoretical contribution of intercontinental transport to ground level O_3 and PM concentrations (UN, 2010a) by quantifying the relative importance of emissions changes outside a specific region (e.g. Europe) compared to emissions changes within region. The model runs assumed a 20 % reduction in emissions change and the analysis used the concept of RAIR (6). For ground level O_3, the study indicated that at least 30 % of the change in the modeled ground-level O_3 concentration changes could be attributed to intercontinental transport. The impact was largest for the case where North American emissions influence European surface O_3 levels, followed by the impact of European emissions on South and East Asia surface O_3 levels. For PM, the HTAP model study found lower contributions from intercontinental transport, with for example 5 % of the modeled European surface level PM concentration changes resulting from intercontinental transport. It is important to emphasize that these model studies are associated with significant uncertainties and should only be used as an indicator of the importance and impact of intercontinental transport on air quality. Further studies are needed to attribute European air quality exceedance to non-European emissions of air pollutants.

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(6) The Relative Annual Intercontinental Response metric is defined as the sum of changes in the annual regionally-averaged concentration within a region due to a 20 % decrease in emissions in other world regions divided by the sum of the changes in concentration within a region due to a 20 % decrease in both the receptor and other world regions. A value of 100 % indicates that air quality is 100 % dominated by emissions from other world regions. World regions are (North America, Europe, East Asia and South Asia).

2 Particulate matter (PM)

2.1 Sources and effects of PM

2.1.1 *Origins of PM in air*

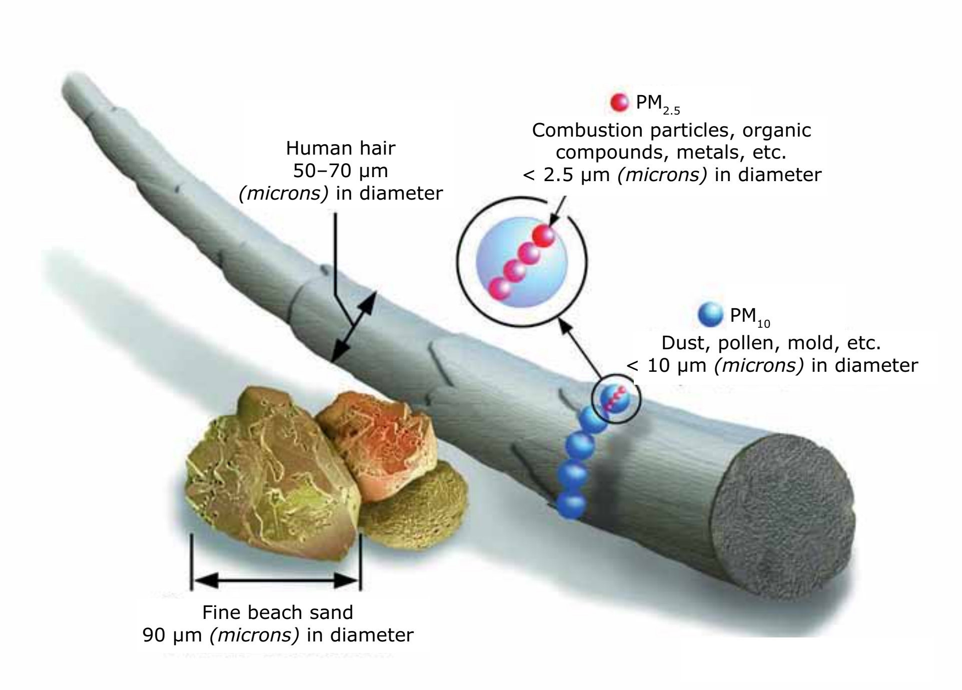
Particulate matter is the general term used for a mixture of particles (solid and liquid) suspended in air, collectively known as aerosols, with a wide range in size and chemical composition. $PM_{2.5}$ refers to 'fine particles' that have a diameter of 2.5 micrometres or less. PM_{10} refers to the particles with a diameter of 10 micrometres or less (see Figure 2.1). PM_{10} includes the 'coarse particles' fraction in addition to the $PM_{2.5}$ fraction.

Particulate matter is either primary because the particles enter the atmosphere directly (e.g. from smoke stacks) or formed in the atmosphere from oxidation and transformation of primary gaseous emissions. The latter are called secondary particles.

The most important precursors (gaseous pollutants contributing to particle formation) for secondary particles are SO_2, NO_X, NH_3 and VOC (which represent a class of chemical compounds whose molecules contain carbon). The main precursor gases SO_2, NO_X and NH_3 react in the atmosphere to form ammonium and other forms of sulphate and nitrate compounds that condense and form new particles in the air, called secondary inorganic aerosol (SIA). Certain VOC are oxidised to less volatile compounds, which form secondary organic aerosol (SOA).

When all main chemical components of the aerosol, including crustal material, sea salt, black carbon, dust, SIA and SOA are measured, they account for about 70 % or more of the PM_{10} and $PM_{2.5}$ mass. The rest is thought to be due to the presence of water or to the possible underestimation of the molecular mass ratio when estimating organic matter concentrations (Putaud et al., 2004).

Figure 2.1 Illustration of $PM_{2.5}$ and PM_{10} particle size



Source: EPA, 2010.

Particulate matter is either of natural origin, e.g. sea salt, naturally suspended dust, pollen, volcanic ash (see EEA, 2012e) or from anthropogenic sources, mainly from fuel combustion in thermal power generation, incineration, households for domestic heating and vehicles, amongst others. In cities vehicle exhaust, road dust re-suspension and burning of wood, fuel or coal for domestic heating are important local sources.

2.1.2 *Effects of PM*

Epidemiological studies attribute the most severe health effects from air pollution to PM and, to a lesser extent, O_3. Even at concentrations below current air quality guidelines PM are expected to pose a health risk. Scientific evidence does not suggest a threshold below which no adverse health effects would be anticipated when exposed to PM (WHO, 2006).

Health effects of fine PM ($PM_{2.5}$) are caused after their inhalation and penetration into the lungs. Both chemical and physical interactions with lung tissues can induce irritation or damage. The smaller the particles, the deeper they penetrate into the lungs. PM's mortality effects are clearly associated with the $PM_{2.5}$ fraction, which in Europe represents 40–80 % of the PM_{10} mass concentration in ambient air. However, the coarser 2.5–10 µm fraction of PM_{10} also has health impacts and affects mortality. Although evidence is growing that $PM_{2.5}$ is perhaps a greater health concern, ambient air quality measurements and emissions data are often only available for PM_{10} at present.

The current levels of PM exposure experienced by most urban and rural populations have harmful effects on human health. Chronic exposure to PM contributes to the risk of developing cardiovascular and respiratory diseases, as well as lung cancer. Mortality associated with air pollution is about 15–20 % higher in cities with high levels of pollution compared to relatively cleaner cities. In the European Union, average life expectancy is estimated to be 8.6 months lower due to exposure to $PM_{2.5}$ resulting from human activities (WHO, 2008).

In addition to effects on the human health, PM can also have adverse effects on climate change and ecosystems, as indicated in Table 1.1. PM also contributes to soiling and can have a corrosive effect on material and cultural heritage, depending on the PM composition.

2.2 European air quality standards for PM

The EU PM_{10} and $PM_{2.5}$ limit and target values for health protection are shown in Table 2.1. The deadline for EU Member States to meet the PM_{10} limit values was 1 January 2005. The deadline for meeting the target value for $PM_{2.5}$ (25 µg/m^3) was 1 January 2010, while the deadlines for meeting the other limit and 'obligation' values for $PM_{2.5}$ (20 µg/m^3) are 2015 or 2020.

Table 2.1 Air quality limit and target values for PM_{10} and $PM_{2.5}$ as given in the Air Quality Directive

Size fraction	Averaging period	Value	Comments
PM_{10}, limit value	One day	50 µg/m^3	Not to be exceeded on more than 35 days per year. To be met by 1 January 2005
PM_{10}, limit value	Calendar year	40 µg/m^3	To be met by 1 January 2005
$PM_{2.5}$, target value	Calendar year	25 µg/m^3	To be met by 1 January 2010
$PM_{2.5}$, limit value	Calendar year	25 µg/m^3	To be met by 1 January 2015
$PM_{2.5}$, limit value (^{a})	Calendar year	20 µg/m^3	To be met by 1 January 2020
$PM_{2.5}$, exposure concentration obligation (^{b})		20 µg/m^3	2015
$PM_{2.5}$ exposure reduction target (^{b})	0–20 % reduction in exposure (depending on the average exposure indicator in the reference year) to be met by 2020		

Note: (^{a}) Indicative limit value (Stage 2) to be reviewed by the Commission in 2013 in the light of further information on health and environmental effects, technical feasibility and experience of the target value in EU Member States.

(^{b}) Based on a three-year average of concentration measurements in urban background locations in zones and agglomerations throughout the territory of a Member State.

Source: EU, 2008c.

For PM_{10} there are limit values for short-term (24 hour) and long-term (annual) exposure, while for $PM_{2.5}$ there are only values for long-term (annual) exposure. In Europe the short-term limit value for PM_{10} (i.e. not more than 35 days per year with a daily average concentration exceeding 50 µg/m^3) is the limit value most often exceeded in European cities and urban areas.

The World Health Organization (WHO) air quality guidelines (AQG), shown in Table 2.2, are stricter than the EU air quality standards. The WHO (2008) explains the reasoning behind its limit values as follows:

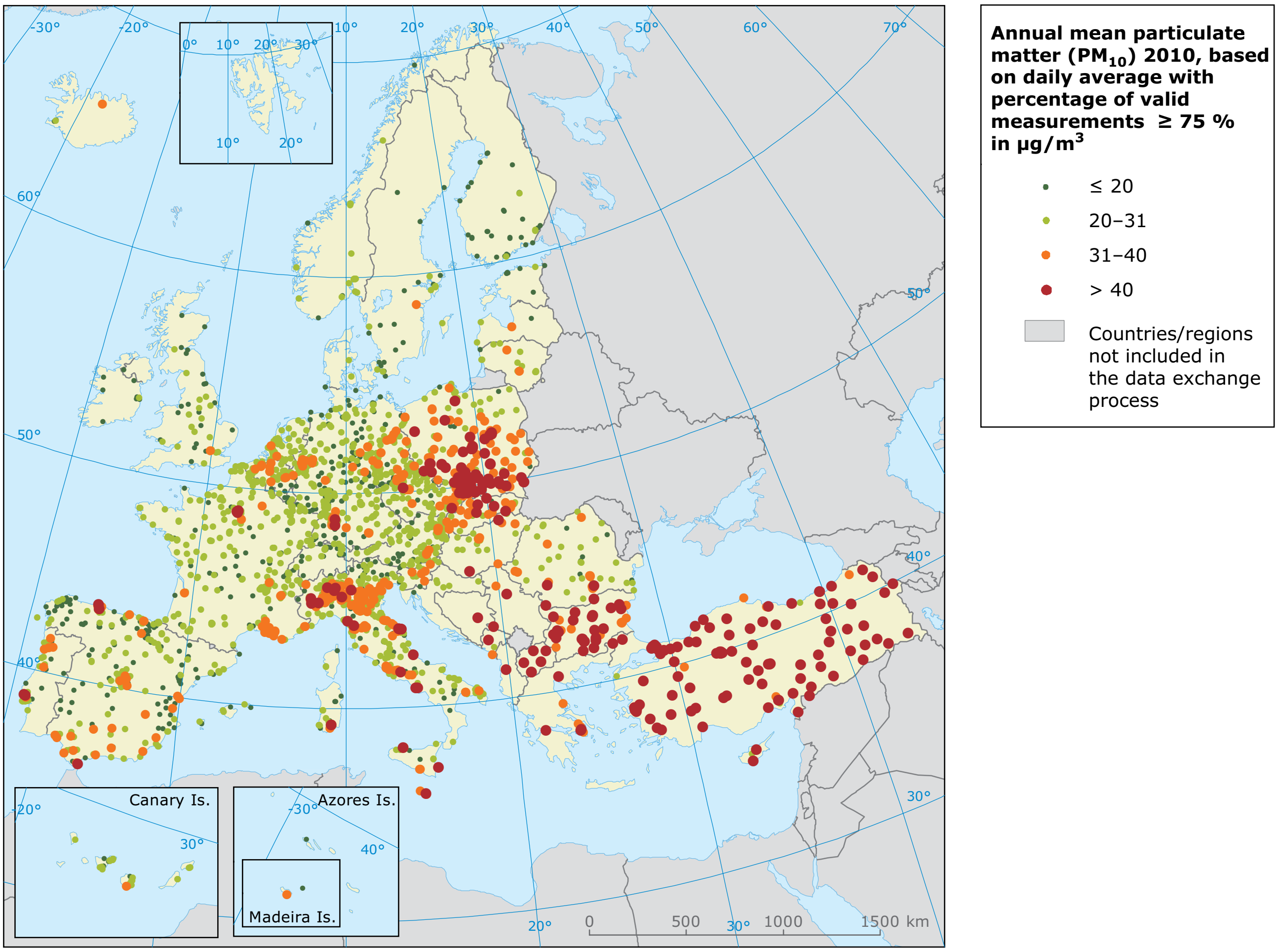
Table 2.2 WHO air quality guidelines

µg/m³	24-hour mean	Annual mean
$PM_{2.5}$	25	10
PM_{10}	50	20

Source: WHO, 2006.

'The 2005 AQG set for the first time a guideline value for PM. 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, the recommended value

Map 2.1 Annual mean concentrations of PM_{10} in 2010



Note: The red dots indicate stations reporting exceedances of the 2005 annual limit value (40 µg/m^3), as set out in the Air Quality Directive (EU, 2008c).

The orange dots indicate stations reporting exceedances of a statistically derived level (31 µg/m^3) corresponding to the 24-hour limit value, as set out in the Air Quality Directive (EU, 2008c).

The pale green dots indicate stations reporting exceedances of the WHO air quality guideline for PM_{10} of less than 20 µg/m^3 but not in exceedance of limit values as set out in the Air Quality Directive (EU, 2008c)

The dark green dots indicate stations reporting concentrations below the WHO air quality guideline for PM10 and implicitly below the limit values as set out in the Air Quality Directive (EU, 2008c).

Source: AirBase v. 6.

should represent an acceptable and achievable objective to minimise health effects in the context of local constraints, capabilities and public health priorities.'

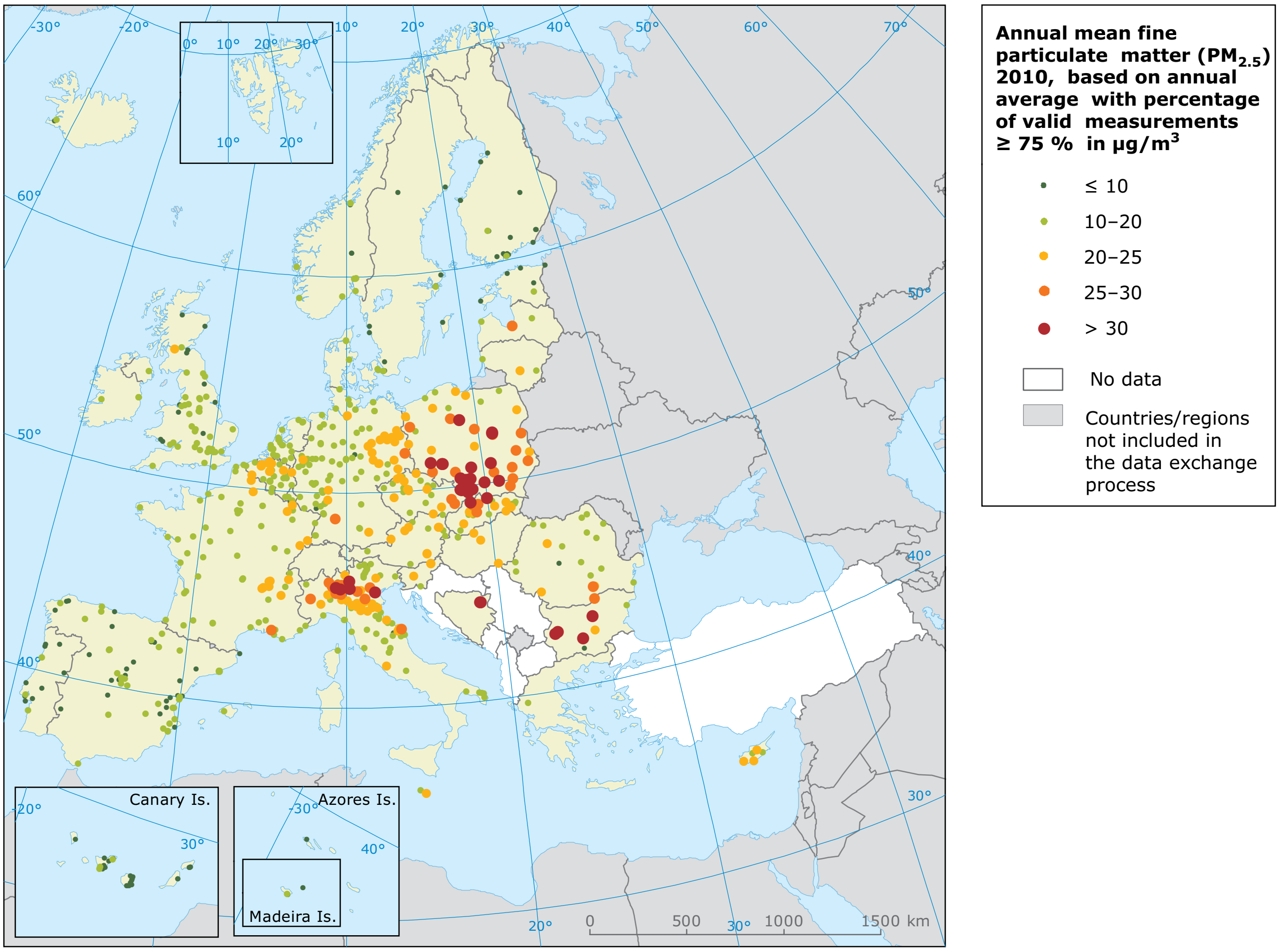
2.3 Europe-wide survey of PM

2.3.1 *Exceedances of limit and target values*

The EU limit values (applying from 2005) and target value (applying from 2010) for PM were exceeded widely in Europe in 2010, as the data of the European air quality database, AirBase (see Annex 1), and Map 2.1, Map 2.2 and Figure 2.2 show.

The annual limit value for PM$_{10}$ (applying from 2005) was exceeded most often (red dots in Map 2.1) in Poland, Italy, Slovakia, the Balkan region, Turkey and several other urban regions. The daily limit value (also applying from 2005) was exceeded (orange dots in Map 2.1) in other cities in those countries, as well as in many other countries in central and western Europe. Cities in Latvia, Lithuania and Sweden also exceeded the daily limit value. In the United Kingdom, exceedances of the daily limit value were recorded but only in London.

Map 2.2 Annual mean concentrations of PM$_{2.5}$ in 2010



Note: The red dots indicate stations reporting exceedances of the 2010 annual target value (25 μg/m³) plus at least 5 μg/m³.

The dark orange dots indicate stations reporting exceedances of the 2010 annual target value (25 μg/m³), as set out in the Air Quality Directive (EU, 2008c).

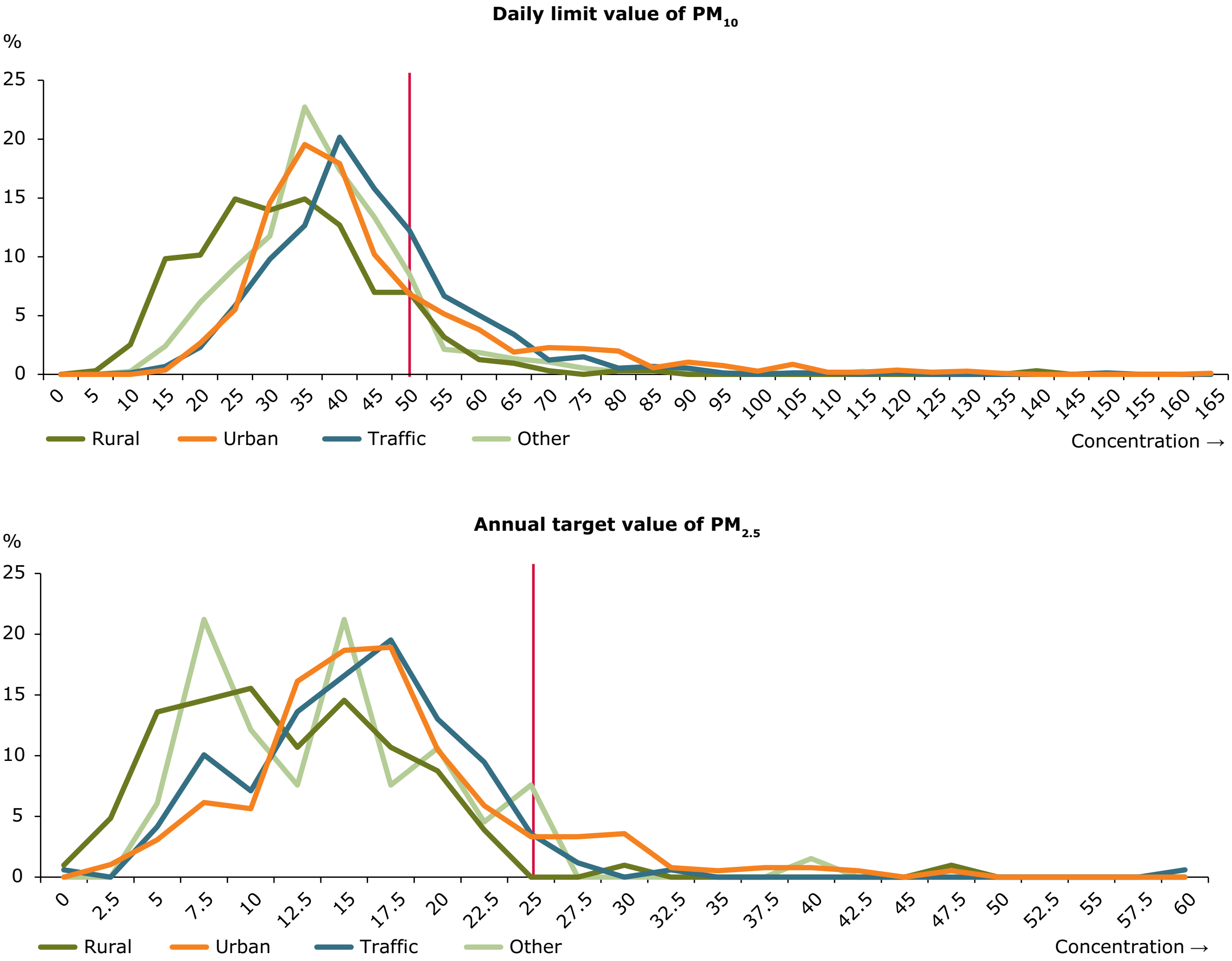
The orange dots indicate stations reporting exceedances of the 2020 indicative annual limit value (20 μg/m³), as set out in the Air Quality Directive (EU, 2008c).

The pale green dots indicate stations reporting exceedances of the WHO air quality guideline for PM$_{2.5}$ of less than 10 μg/m³ but not in exceedance of target or limit values for PM$_{2.5}$ as set out in the Air Quality Directive (EU, 2008c).

The dark green dots indicate stations reporting concentrations below the WHO air quality guideline for PM$_{2.5}$ and implicitly below the target and limit values for PM$_{2.5}$ as set out in the Air Quality Directive (EU, 2008c).

Source: AirBase v. 6.

Figure 2.2 **Distance-to-target graphs for daily limit value of PM_{10} (top) and for annual target value of $PM_{2.5}$ (bottom), 2010**



Note: The graphs show the percentage frequency distribution of stations (on y-the axis) in the EU Member States versus the various concentration classes (on the x-axis, in µg/m³).

Vertical lines correspond to limit or target values set by the EU legislation.

Source: AirBase v. 6.

More monitoring stations measure PM_{10} than $PM_{2.5}$. For $PM_{2.5}$ in 2010 there were 754 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). Compared to 2009 150 additional stations measured $PM_{2.5}$ in 2010. The $PM_{2.5}$ concentrations were higher than the annual target value to be met by 2010 (red and orange dots in Map 2.2) at several stations in Bulgaria, the Czech Republic, Italy, Poland and Slovakia and at several stations in other countries. The stricter value of the WHO guidelines for annual mean PM were exceeded (pale green, yellow, orange and red dots in Map 2.1 and Map 2.2) at most of the monitoring stations across continental Europe but less commonly in Nordic countries.

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

The rural background concentration of PM represents the concentration of PM in rural areas. Contributions from urban emissions build on the rural background level to produce the concentrations occurring in urban areas (more generally called urban background concentrations). Local control efforts can reduce urban additions but will have limited effects on the rural background level.

Particulate matter is partly directly emitted into the atmosphere and partly formed in the atmosphere.

The formation depends on a variety of chemical and physical factors:

1) the concentrations of the main precursors;
2) the reactivity of the atmosphere (see Box 2.1) which depends on the concentrations of highly reactive substances such as O_3 and the hydroxyl radical (called radical because it contains an unpaired electron);
3) meteorological conditions, like solar radiation, relative humidity and cloud cover.

Due to the interplay and variability of the above factors, it is difficult to relate ambient concentrations of formed substances, present in ambient PM, to the emissions of precursor gases.

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 by the EMEP (7) network in 2009 were in the Netherlands, Hungary and Italy with the lowest in the Nordic countries and the United Kingdom (EMEP, 2011). In addition to primary PM emissions (natural and anthropogenic), rural PM concentrations are determined by contributions from secondary particles, both secondary inorganic aerosols (SIA) and secondary organic aerosols (SOA). 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 with 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.

2.3.3 *Distance to target*

To indicate the 'distance to target' to meeting the EU limit values and target value for PM, Figure 2.2 shows the extent of the exceedances in 2010 of the 24-hour limit value for PM_{10} (to be met by 2005)

Box 2.1 The chemistry of PM formation

Inorganic PM
In Europe, about one third of the PM_{10} concentration and half of the $PM_{2.5}$ concentration in the regional background consist of inorganic chemical substances, such as ammonium (NH_4^+), nitrate (NO_3^-) and sulphate (SO_4^{2-}). These substances are the result of chemical reactions in the atmosphere involving the PM precursor gases: NH_3, NO_x and SO_x.

Sulphate forming reactions involve the gas phase conversion of SO_2 to sulphuric acid and aqueous phase chemical reactions which may occur in cloud and fog droplets or in liquid films on atmospheric particles. The rate of some of these reactions is enhanced by the presence of metals, e.g. Fe and Mn.

The NO_2 portion of NO_x can be converted to nitric acid during the day. At night NO_x is mainly oxidized to nitric acid by a sequence of reactions initiated by O_3.

Both sulphuric and nitric acids thus formed react with NH_3 and form ammonium nitrate (NH_4NO_3) and ammonium sulphate $(NH_4)_2SO_4$. In addition, nitric acid may react with chemical substances in coarse particles and provide additional nitrate to the coarse particle fraction.

Organic PM
Organic substances contribute in average about 30 % to the $PM_{2.5}$ concentrations and 20 % to the PM_{10} concentrations in the European regional background. Organic PM is composed of hundreds of individual chemical substances. Some of the organic substances are semi volatile, such that their presence can be both as gases and as condensed material in the PM. Their presence complicates the sampling process. Consequently, it is difficult to obtain complete chemical information of the organic substances.

Atmospheric reactions in the gas phase, fog and cloud droplets as well as aqueous particulates involve a variety of VOC such as alkanes, olefins, aromatics, and organic compounds such as isoprene and terpenes released by vegetation, leading to the formation of organic end products.

Volatile organic compounds react with hydroxyl radicals, O_3 and other substances in numerous interlinked chemical reactions to form a large suite of organic compounds. There is a clear link between O_3 episodes and formation of organic PM.

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(7) The EMEP (European Monitoring and Evaluation Programme) station network provides parties in the LRTAP convention with information on concentration and deposition rates of air pollutants transported across Europe and reaching rural background monitoring sites.

and of the target value for $PM_{2.5}$ (to be met by 2010) within the EU. The analysis here is based on measurements at fixed sampling points and does not account for the fact that the Air Quality Directive (EU, 2008c) provides the EU Member States with the possibility to subtract the contribution of natural sources (8) and winter road sanding/salting when limits are exceeded (EEA, 2012d).

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);
- rural background sites.

In 2010, the PM_{10} 24-hour limit value to be met by 2005 was exceeded at 33 % of traffic sites, 29 % of urban background sites, 17 % of 'other' sites (mostly industrial) and even at 14 % of rural sites within the EU. The percentage of stations in exceedance at rural background sites has more than doubled from 2009 to 2010. Increased PM concentrations due to the eruption of the volcano Eyjafjallajökull in Iceland in April and May 2010 have been noted; in a number of cases this might have contributed to exceedances. The highest PM_{10} concentrations reported in 2010 were exceptionally high — above 2 000 $\mu g/m^3$ in Iceland.

The PM_{10} daily limit value to be met by 2005 is more stringent than the annual limit value and more frequently exceeded. Figure 2.3 shows for all EU Member States the exceedances of the PM_{10} daily limit value in 2010, 2005 and 2001. It clearly indicates that exceedance of the daily limit value was observed in 23 EU Member States at one or more stations in 2010, with only Denmark, Finland, Ireland and Luxembourg recording no exceedance. The only country, with PM_{10} concentration data for 2001, 2005 and 2010, which did not register an exceedance of the PM_{10} daily limit value in any of the years, was Ireland. The figure also shows that there has been an improvement in the number of exceedances of the PM_{10} daily limit value over the years in United Kingdom, Sweden, Spain, Portugal, the Netherlands, Belgium, Italy and Greece, and a clear increase in Poland and Bulgaria, from 2001 to 2005 and further to 2010.

Figure 2.4 shows similar plots of the annual mean $PM_{2.5}$ values for 2010, 2005 and 2001 in the EU Member States. It shows that exceedance of the target value for $PM_{2.5}$ (25 $\mu g/m^3$) to be met by 2010 was observed in nine EU Member States at one or more stations in 2010. The only country with $PM_{2.5}$ data for 2001, 2005 and 2010 that did not register an exceedance of the target value for $PM_{2.5}$ in any of the three years was Finland.

The $PM_{2.5}$ target value was exceeded at 6 % of traffic sites, 14 % of urban background sites, 9 % of 'other' (mostly industrial) sites and at 2 % of rural sites. Particular sites in the Czech Republic and Poland registered annual mean concentrations of $PM_{2.5}$ concentrations close to or above double the target value. A rural background station in Iceland registered an annual mean concentration about four times higher than the target value — attributed to the eruption of the Eyjafjallajökull volcano.

These findings demonstrate that PM concentrations must be reduced substantially in large areas of Europe (focusing on traffic and urban locations) for the limit and target values to be met.

Concerning the reporting on the occurrence of natural events that would have caused exceedances of PM limit values, EEA presented an evaluation of EU Member States reporting on natural air pollution under the Air Quality Directive (EEA, 2012d). Ten EU Member States reported exceedances of the PM_{10} annual and daily limit values due to natural events in 2008, and eight EU Member States did so in 2009. The dominant natural event responsible for exceedances of the PM_{10} daily limit value was the movement of natural particles from dry regions outside the Member State. The mean annual contributions of natural sources to PM_{10} levels ranged from 1–3 $\mu g/m^3$ in Italy, France, Greece and Portugal , to 4–5 $\mu g/m^3$ in Spain and the United Kingdom, and 13 $\mu g/m^3$ in Cyprus in 2008. In 2009, the mean contributions were lower in Spain (1 $\mu g/m^3$), higher in Greece (8 $\mu g/m^3$), and similar in Cyprus. The analysis of 2010 data was not completed before publication of this report.

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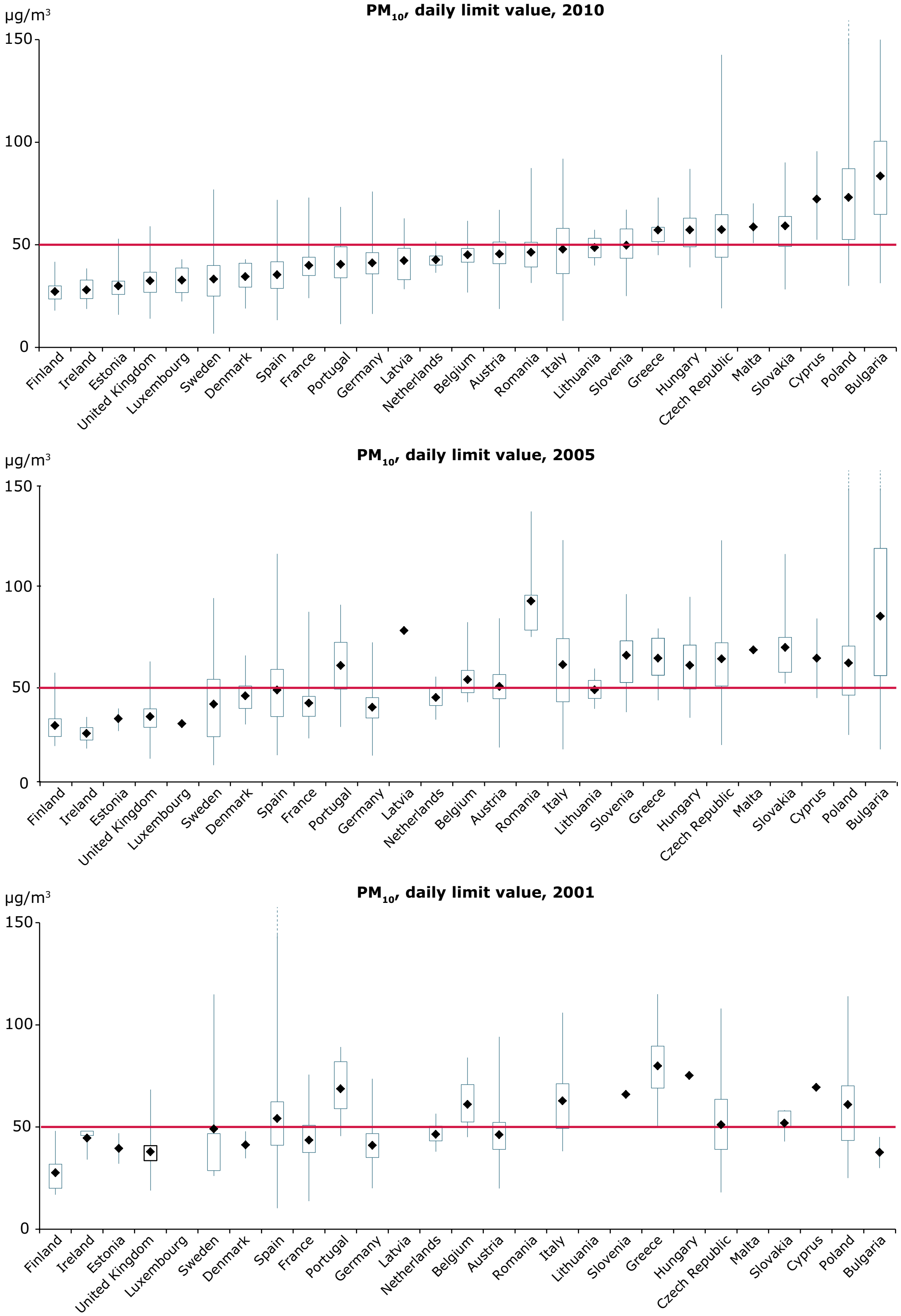
(8) Examples of natural sources the directive allow to subtract are: volcanic eruptions, seismic activities, geothermal activities, wild-land fires, high-wind events or the atmospheric resuspension or transport of natural particles from dry regions and sea spray.

Figure 2.3 Attainment situation for PM_{10}, reference years 2010, 2005, 2001

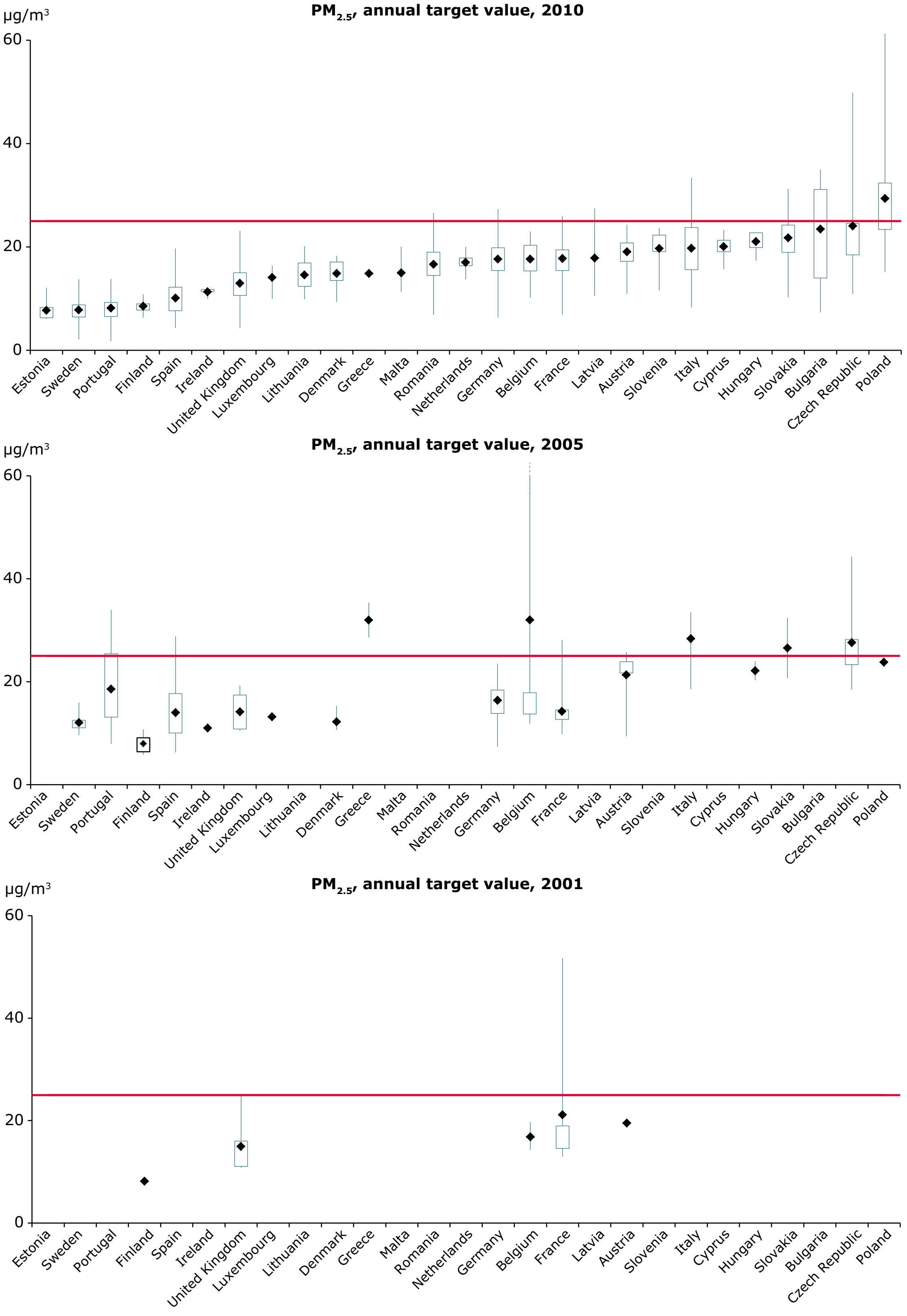


Note: The graphs are based on the 90.4 percentile of daily mean concentration values corresponding to the 36th highest daily mean; they present the range of concentrations at all station types (in µg/m³) officially reported by the EU Member States and how the concentrations relate to the limit value set by EU legislation (marked by the red line).

The diagram indicates the lowest and highest observations, the means and the lower and upper quartiles. The lower quartile splits the lowest 25 % of the data and the upper quartile splits the highest 25 % of the data.

Source: ETC/ACM.

Figure 2.4 Attainment situation for $PM_{2.5}$, reference years 2010, 2005, 2001



$PM_{2.5}$, annual target value, 2010

$PM_{2.5}$, annual target value, 2005

$PM_{2.5}$, annual target value, 2001

Note: The graphs are based on the annual mean concentration values; they present the range of concentrations at all station types (in µg/m³) officially reported by the EU Member States and how the concentrations relate to the target value set by EU legislation (marked by the red line).

The diagram indicates the lowest and highest observations, the means and the lower and upper quartiles. The lower quartile splits the lowest 25 % of the data and the upper quartile splits the highest 25 % of the data.

Source: ETC/ACM.

2.3.4 *Trends in PM concentrations*

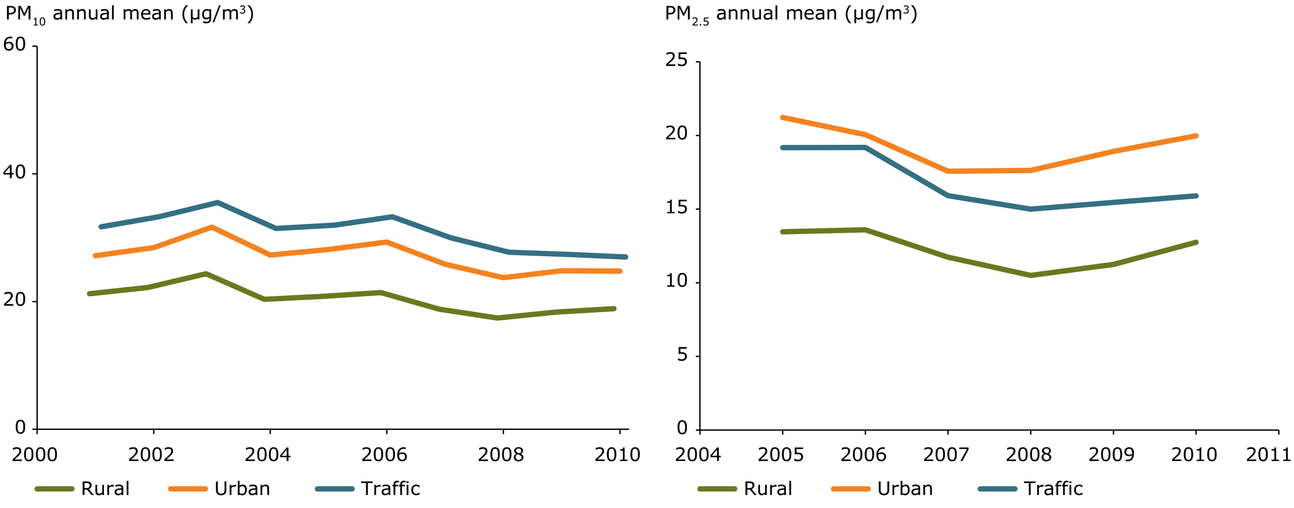
The average change in PM_{10} annual mean concentrations since 2001 is presented in Figure 2.5, for traffic, urban background and rural stations. Traffic stations recorded a steady decrease of average levels since 2006, while urban non-traffic stations registered an increase in 2009, stabilising in 2010. Rural stations recorded an average increase in 2009 and 2010. Map 2.3 shows the average changes in PM_{10} annual mean concentrations between 2001 and 2010 (de Leeuw, 2012) (9). Most of the stations registering a trend (10) recorded decreasing annual mean concentrations of PM_{10} by more than 1 $\mu g/m^3$ per year during this period. Only 2 % of the stations registered a positive trend (meaning increasing concentrations) from 2001 to 2010 (11). The number of $PM_{2.5}$ stations operational throughout the last six years is still limited. Concentrations, on average, tended to decrease during the first four years (2005–2008). A small increase was apparent in 2009 and 2010 for all station types (Figure 2.5). The available data for $PM_{2.5}$ are too limited to draw firm conclusions about the observed trends.

In contrast to the PM_{10} data and expectations, Figure 2.5 suggests that the overall average $PM_{2.5}$ concentrations at urban nontraffic sites exceed those at traffic sites. Differences in the spatial distribution of urban and traffic stations over Europe have influenced the aggregated trends. This is a further indication that the $PM_{2.5}$ station set is not sufficiently representative at present to underpin a trend analysis.

Emissions of primary PM and precursor gases

When explaining trends in PM concentrations in air, emission trends in both primary PM and precursor gases must be considered. In addition to emissions, meteorology plays an important role. A certain fraction of the emitted precursor gases forms particles in the air, depending on atmospheric conditions (temperature, sunlight, humidity, reaction rate). Dispersion and atmospheric conditions differ from year to year. This has not been adjusted in the present analysis.

Figure 2.5 Trend in PM_{10} (left graph, 2001–2010) and $PM_{2.5}$ (right graph, 2005–2010) concentrations per station type



Note: All stations in EU Member States, with at least 75 % data coverage for at least eight years (PM_{10}) or six years ($PM_{2.5}$), were included in the analysis. Concentrations per station type are given in $\mu g/m^3$. In the diagrams a geographical bias exists towards central Europe where there is a higher density of stations.

In 2006, France introduced a nation-wide system to correct PM_{10} measurements. French PM_{10} data prior to 2007 have been corrected using station-type dependent factors (de Leeuw and Fiala, 2009).

Source: ETC/ACM.

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(9) A consistent set of 858 stations with data for 2001 to 2010 was used in the trend analysis. Of these, 449 stations registered a trend (i.e. a significant trend, using the Mann-Kendall test). The remaining 409 stations had no significant trend.

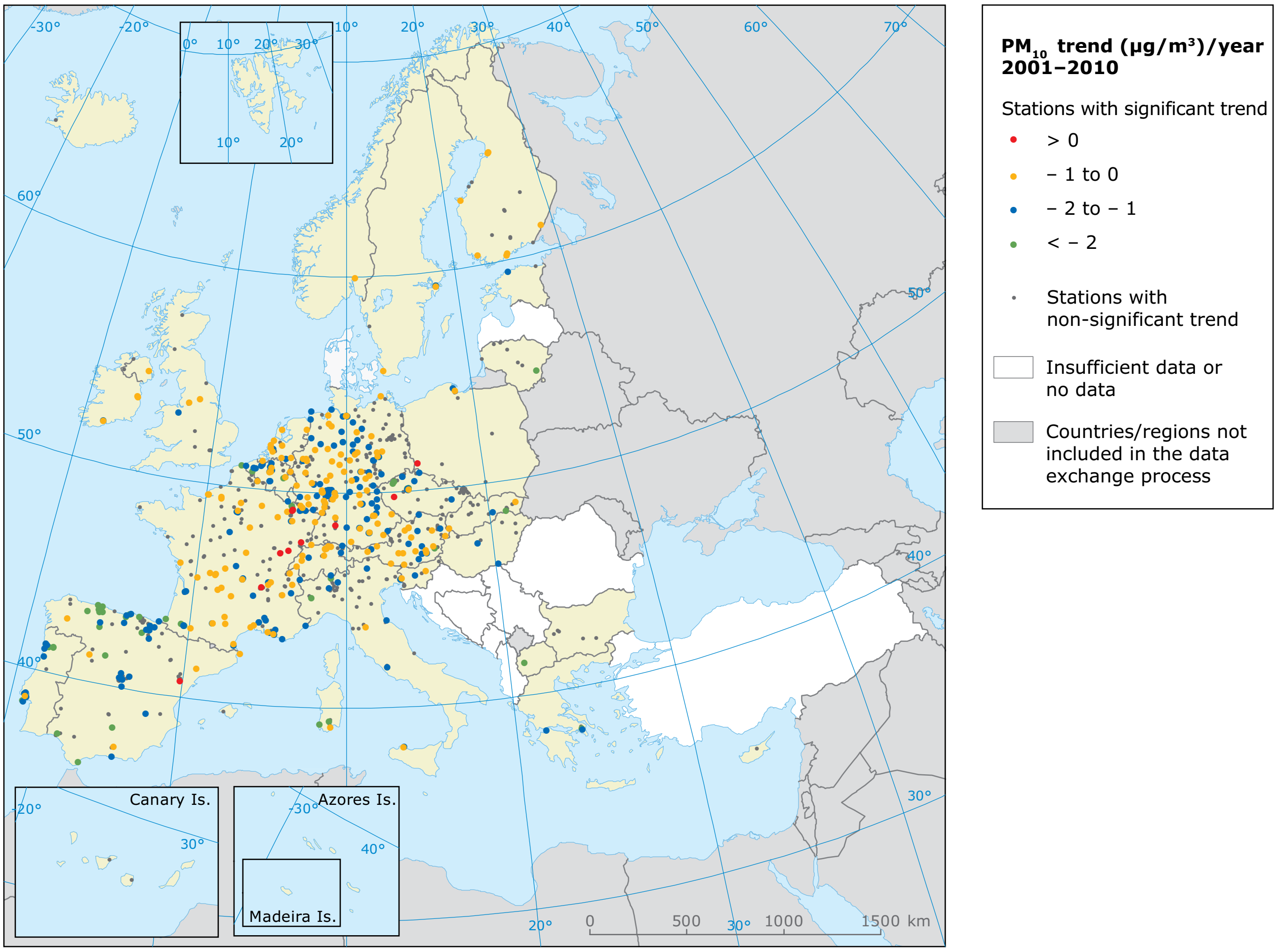
(10) 244 stations which is the equivalent of 54 % of the stations with a trend.

(11) 2 % is equivalent to ten stations.

The European emissions inventory 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 1990–2010 was published by the EEA (2012a).

Emissions of primary PM fell in the EU by 14 % for PM$_{10}$ and 15 % for PM$_{2.5}$ between 2001 and 2010 (Figure 2.6). The reductions in the same period for the EEA-32 member countries were similar to those in the EU for PM$_{10}$ and for PM$_{2.5}$. Emissions of the precursor gases SO$_X$ and NO$_X$ declined by 54 % and 26 % respectively in the period 2001 to 2010 in the EU, and by 44 % and 23 % in the EEA-32 countries. EU emissions of NH$_3$, another precursor gas, have fallen less: only about 10 % between 2001 and 2010.

Map 2.3 Annual changes in concentrations of PM$_{10}$ in the period 2001–2010

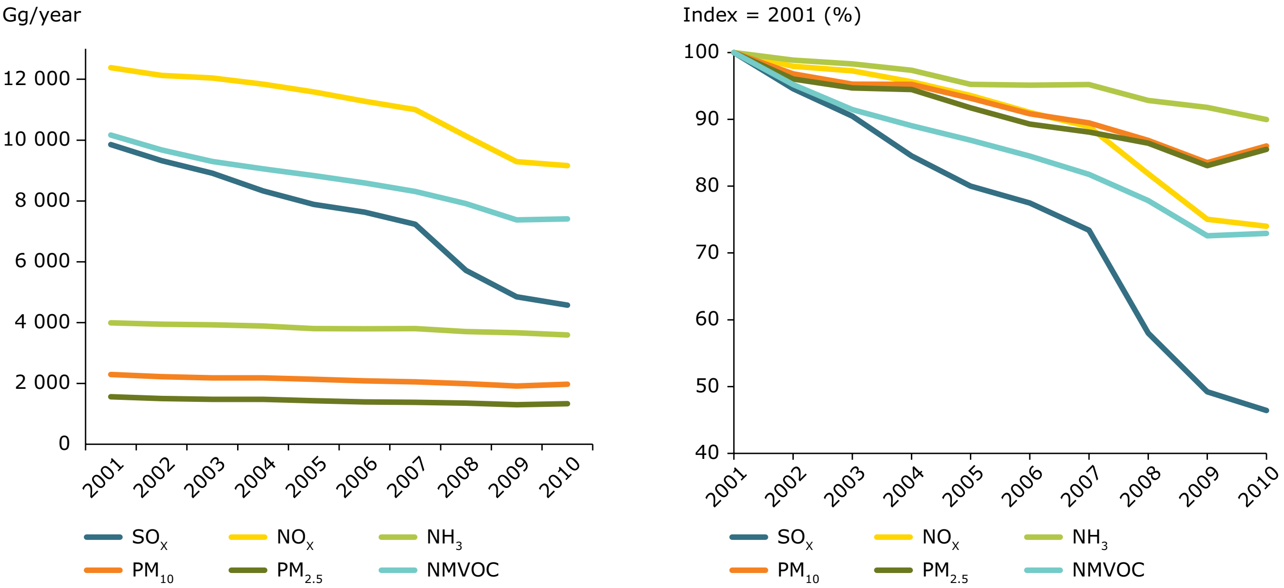


Note: The data presented were derived from a consistent set of stations in all years. In 2006, France introduced a nation-wide system to correct PM$_{10}$ measurements. French PM$_{10}$ data prior to 2007 have been corrected using station-type dependent factors (de Leeuw and Fiala, 2009).

Statistically significant trends (level of significance 0.1) are calculated by applying the Mann-Kendall test. The trend slopes are indicated with coloured dots when statistically significant. Red dots indicate increasing concentrations. The applied method is described in de Leeuw, 2012.

Source: de Leeuw, 2012.

Figure 2.6 **EU emissions of primary PM and of PM and O_3 precursor gases not including carbon monoxide ([a]), 2001–2010**



Note: ([a]) Emissions of CO, a precursor for O_3, are shown in Figure 6.4.

Source: EEA — Air pollutant emissions data viewer (LRTAP Convention).

The emission data submitted under the NEC Directive (EEA, 2012a) by the EU Member States indicate that 12 EU Member States ([12]) have exceeded their NO_X emission ceiling. The same data also indicates that Germany and Spain have exceeded their NMVOC emission ceilings, and Finland and Spain have exceeded the NH_3 emission ceiling, as set by the NEC Directive to be met in 2010. On the other hand, all countries have achieved their SO_2 emission ceilings.

Organic precursor gases of secondary organic aerosol (SOA) are dominated by natural organic emissions but also include an anthropogenic component. Natural VOC emissions are not included in the present emission inventories.

Depending partly on the atmospheric conditions, SIA contributes on average about one third of the PM_{10} mass in rural air in central Europe (EMEP, 2011). They account for a lower percentage of PM in urban air because local emissions of primary particles add to the rural PM mass concentrations.

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[12] Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Malta, the Netherlands, Spain and Sweden.

Sectoral output of primary PM and precursor gases

Various source sectors contribute to the primary anthropogenic PM and precursor gases (Figure 2.7). Commercial, institutional and household fuel combustion dominates emissions of primary PM_{10} and $PM_{2.5}$ and has increased since 2001.

The second largest emission sector of primary PM_{10} is industry, followed by transport. For $PM_{2.5}$ both sectors have had similar emissions, but since 2009 the transport sector has surpassed the industrial sector emission. Non-exhaust emissions from road traffic, which are not included in Figure 2.7, add to the total road traffic emission contribution. Non-exhaust emissions are estimated to equal about 50 % of exhaust emissions of primary PM_{10} and about 22 % of exhaust emissions of primary $PM_{2.5}$ (Hak et al., 2009). The transport sector is clearly the largest contributor to NO_X emissions, while the energy production and industry sectors dominate the SO_X emissions. The agricultural sector was responsible for 94 % of the total NH_3 emissions in the EU in 2010 and has only decreased its NH_3 emissions by 10 % between 2001 and 2010. European policies have cut certain PM precursor gas emissions significantly. It is estimated that current European policies cut NO_X emissions from road vehicles by 55 % and from industrial plants by 68 % in the period 1990–2005, compared to a hypothetical situation with no directives in force. The policy-induced reduction in SO_X emissions from the industrial plant sector is estimated at 70 % in the same period (EEA, 2010b). These sources also dominate the total emissions of NO_X and SO_X (Figure 2.7).

Relationship of emissions to ambient PM concentrations

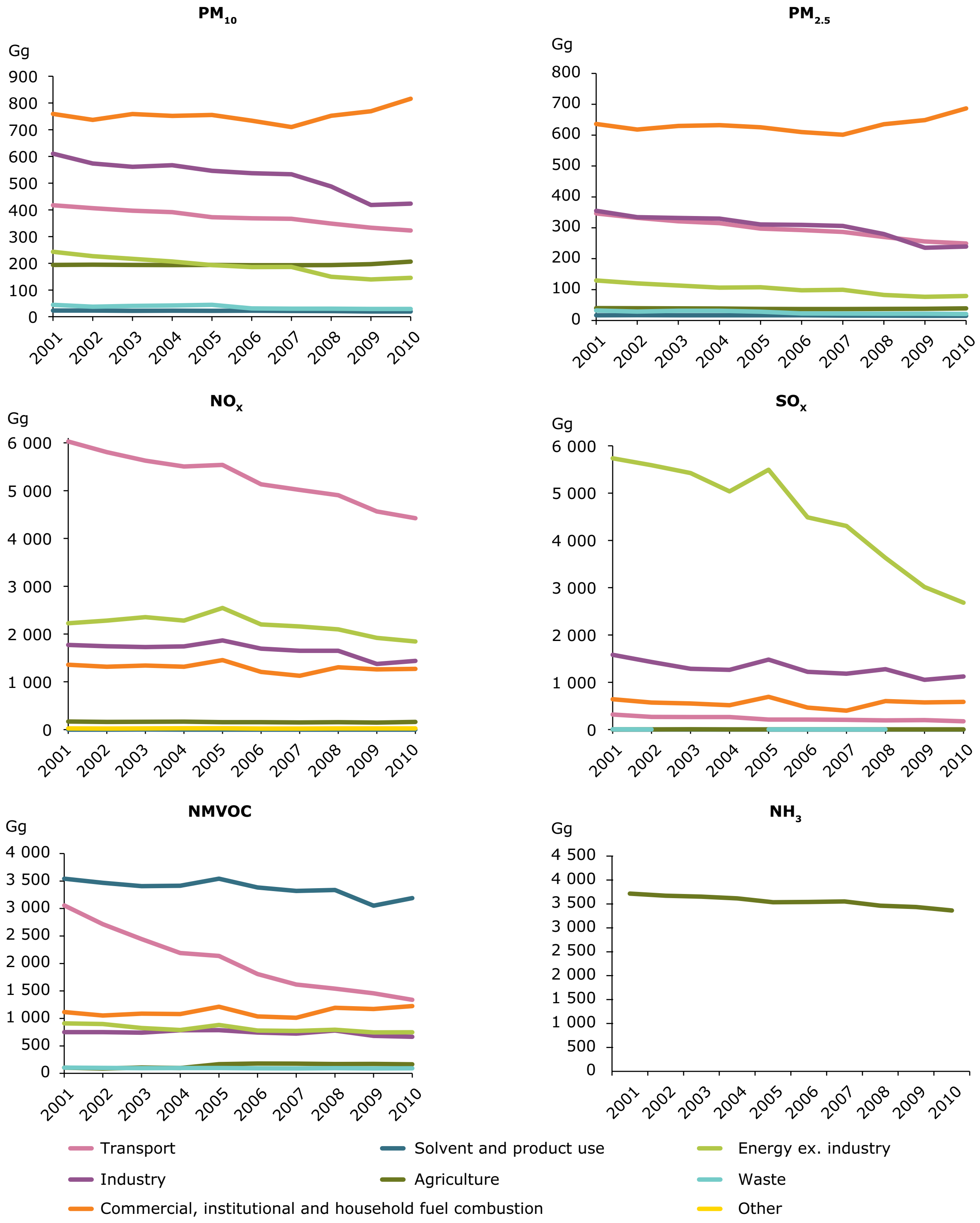
Emissions of primary PM from commercial, institutional and households fuel combustion have increased since 2007 (Figure 2.7), meaning that the sector continues to sustain PM concentrations in both rural and urban areas, despite emission reductions in other sectors. Contrastingly, diminishing primary PM emissions from transport tends to compensate for that increase, especially in urban areas.

The reductions in emissions of the PM precursors NO_X and SO_X were much larger than the primary PM reductions from 2001 to 2010. Meanwhile the reduction of NH_3 emissions was small (about 10 %) between 2001 and 2010 in the EU. According to Erisman and Schaap (2004) SIA concentrations (which make up about half of the $PM_{2.5}$ mass) can only be reduced effectively if all three precursor gases NO_X, SO_X and NH_3 are reduced to the same extent. According to the emission information presented above, this has not been the case in Europe in the past decade.

The small reductions observed in ambient PM_{10} concentrations over the period 2001–2010 (Figure 2.5) only partly reflect the declining emissions of primary PM and precursor gases. Slowly decreasing primary PM and agricultural NH_3 emissions are expected to contribute to a baseline PM_{10} concentration that is only declining slowly. In addition and as discussed in Section 1.3.4, intercontinental transport of PM and its precursor gases may also influence European ambient levels.

A number of studies have identified and quantified the contributions of various sources to ambient PM concentrations by using modelling techniques (see EEA, 2011c). An EEA analysis of source apportionment reported in the notifications submitted by twenty EU Member States for time extension of PM_{10} limit values shows that the combined urban and local traffic contribution to PM_{10} concentration levels measured at 29 urban traffic sites ranges from 13 % (Duisburg) to 61 % (Glasgow) with an average of 34 %. The contribution of traffic to PM_{10} concentration levels measured at five urban background sites is estimated at 15 %, ranging from 6 % (Yorkshire) to 22 % (Brno). These finding indicate that traffic contributions to urban PM concentrations should be addressed when applying measures to reduce ambient PM concentrations.

Figure 2.7 **Contributions to EU emissions from main source sectors (Gg/year = 1 000 tonnes/year) of primary PM, NO_x, SO_x, NMVOC and NH_3, 2001–2010**



Source: EEA — Air pollutant emissions data viewer (LRTAP Convention).

2.4 Exposure to PM pollution in Europe

The PM_{10} monitoring data in AirBase provide the basis for estimating the exposure of the European population to exceedances of the PM_{10} daily limit value (50 µg/m^3 not to be exceeded on more than 35 days a calendar year). This estimate is shown in Figure 2.8 for the period 2001–2010. The exposure is estimated based upon PM_{10} measured at all urban background (non-traffic) monitoring stations. For each city an average concentration is calculated. It is considered that the entire population in cities is exposed to these concentrations, since people move freely within the city.

In 2010 about 21 % of the urban population in the EU was exposed to PM_{10} above the limit value. The extent of exposure above the limit value has varied between 18 % and 41 % since 2001 and there is no apparent trend over this period. For EEA-32 countries the estimate is 41 % in 2010 and the variation was between 23 % and 41 % during the period 2001–2010. The range partly reflects variations caused by meteorology.

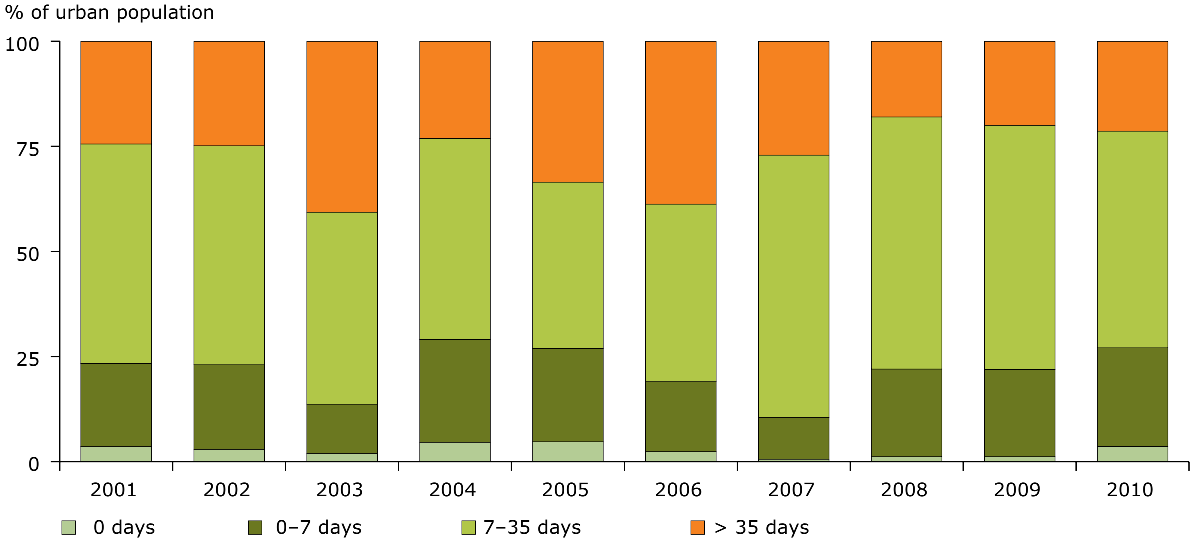
For $PM_{2.5}$, the 2008 Air Quality Directive (EU, 2008c) introduced a target value, to be attained by 2010, which will become a limit value starting in 2015 (Table 2.1). Moreover, the same directive established the national exposure reduction target for human exposure based on the average exposure indicator (AEI) set at the national level. The AEI is the averaged level measured at urban background (non-traffic and non-industrial) monitoring stations over a three year period. Figure 2.9 indicates that in at least seven EU Member States the average urban concentrations in the period 2008–2010 were above 20 µg/m^3. 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 fraction of EU urban population exposed to concentrations above the EU limit value and the AQG level between 2008 and 2010. Between 18 and 21 % of the urban population is exposed to PM_{10} concentrations exceeding the EU daily limit value while up to 81 % of the same urban population is exposed to concentrations exceeding the stricter WHO AQG value for PM_{10} (Table ES.1). Also here, the range partly reflects variations caused by meteorology.

2.5 Responses

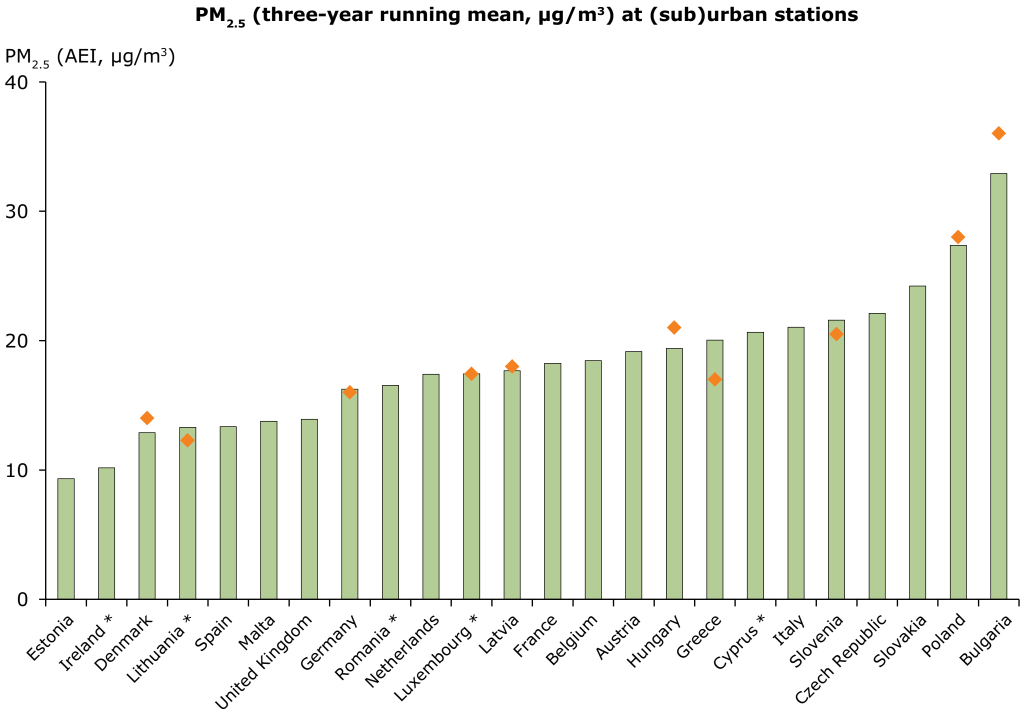
As both primary and secondary PM make up significant parts of PM concentrations, European efforts to reduce rural and urban concentrations must address emissions of both primary PM and also precursor gases. The key anthropogenic sources of these compounds are road vehicles, industrial installations and commercial, institutional and household fuel combustion. Annex 2 contains more information on each of the policy instruments discussed below.

Figure 2.8 Percentage of population resident in EU urban areas exposed to PM_{10} concentration levels exceeding the daily limit value, 2001–2010



Source: EEA, 2012d (CSI 004).

Figure 2.9 **Urban $PM_{2.5}$ concentrations presented as multi-annual average in the EU, 2008–2010**



Note: The three-year running mean of $PM_{2.5}$ concentrations (2008–2010) is similar to the method used to calculate the average exposure indicator. Compiled data reflects background (non-traffic and non-industrial) urban and suburban stations.

Results for countries marked with an asterisk are based on less than three years of data.

The orange dots correspond to figures provided by the EU Member States in the air quality questionnaire.

Source: de Leeuw, 2012.

2.5.1 *Road transport sector*

For the road transport sector, the Euro standards regulate exhaust emissions of CO, NO_X, NMVOC and primary PM. NO_X and PM emissions are directly relevant for PM concentrations in air.

The 'Euro standards' emission limits for type approval of new cars are as follows:

- for PM, the Euro 4 emission limits (in force since 2005) are 75 % lower than the 1996 Euro 2 emission limits for light duty diesel (passenger) vehicles and for heavy duty diesel vehicles the Euro IV 2005 PM emission limit is 92 % lower than Euro II (from 1996);
- for NO_X, the 2005 Euro 4 emission limits are 50 % lower than the 1996 Euro 3 emission limits for diesel passenger cars and 58 % lower for heavy duty diesel vehicles;
- Euro 5 (from 2009) requires a further substantial drop in emission limits, in particular for PM (80 % reduction compared to Euro 4 for diesel cars).

These reductions in permissible emission limits have resulted in substantial reported declines in NO_X and PM emissions from vehicles over the last decade despite the large increase in the number of vehicles and total traffic activity over the same period.

The decrease in transport emissions in the period 2001–2010 was 39 % for NO_X, 28 % for PM_{10} and 40 % for $PM_{2.5}$ in the EU. Under real-world driving conditions, emissions from vehicles often exceed the test cycle limits specified in the Euro emission standards (EEA, 2011d). Reported emissions data from countries are based on the best knowledge available concerning real-world emissions. However, the lack of vehicle exhaust measurements, especially for newer vehicle technology types, often means the reported emission estimates are of relatively high uncertainty, and may not always reflect the actual, potentially higher, on-road driving emissions.

Non-exhaust vehicle emissions, such as tyre and brake wear, and road abrasion, are currently not regulated. They equal approximately 60 % of the exhaust emissions of PM_{10} and about 30 % of exhaust emissions of $PM_{2.5}$ in the EU (EEA, 2010b).

2.5.2 *Large combustion plants*

The industry-related directives — the Large Combustion Plant (LCP) Directive (EU, 2001a) and the IPPC Directive (EU, 2008b), have resulted in a substantial reduction in emissions from large combustion and industrial plants. Both directives, together with several other sectoral directives, have been replaced by the Industrial Emissions Directive (EU, 2010b) but will remain in force for several years. Although the effects of the directives on PM emissions have not been fully assessed, EEA (2010b) estimated that they delivered reductions in NO_X and SO_X emissions (PM precursor gases) of about 50 % and 75 % respectively in the period 1990–2005.

2.5.3 *NEC Directive on total emissions*

The NEC Directive (EU, 2001b) includes limits on total national emissions of the acidifying or eutrophying gases SO_2, NO_X and NH_3, which are also PM precursors. The ceilings were to be met by 2010, and the 2010 emission data provided by the EU Member States estimate that NO_X emissions exceeded the ceiling by 10 % while SO_X emissions were 42 % beneath the ceiling (Annex II emission ceilings in the NEC Directive) and NH_3 were 17 % below (Annex I emission ceiling in the NEC Directive) (EEA, 2012a).

2.5.4 *Air quality plans*

The air quality directives in force require that air quality plans are developed as an additional policy instrument and implemented in air quality management zones and agglomerations where ambient concentrations of pollutants exceed the relevant air quality limit or target values. To ensure coherence between different policies, the air quality plans should, where feasible, be consistent 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, including children.

3 Ozone (O_3)

3.1 Sources and effects of O_3

3.1.1 Origins of O_3 *in air*

Ground-level (tropospheric) O_3 is not directly emitted into the atmosphere but formed from a chain of chemical reactions following emissions of the precursor gases NO_X, VOC and CO. Nitrogen oxides are emitted during fuel combustion, for example by industrial facilities and road transport. Nitrogen oxides play a complex role in O_3 chemistry: close to its source NO_X will deplete O_3 due to the reaction between the freshly emitted NO and O_3. Areas downwind of major sources of VOC and NO_X may experience O_3 peaks after wind has carried O_3 and its precursors far from their sources. Thus, high O_3 concentrations can occur in remote areas (see Box 3.1).

Volatile organic compounds are emitted from a large number of sources including paint, road transport, refineries, dry-cleaning and other solvent uses. Volatile organic compounds are also emitted by vegetation, with amounts dependent on temperature. Methane (CH_4), also a VOC, is released from coal mining, natural gas extraction and distribution, landfills, wastewater, ruminants, rice cultivation and biomass burning.

Fire plumes from wild forest and other biomass fires contain CO and can contribute to O_3 formation. There is also a global background concentration of O_3 in air, partly resulting from photochemical O_3 formation globally and partly from the downward transport of stratospheric O_3 to the troposphere.

3.1.2 Effects of O_3

Excessive O_3 in the air can have a marked effect on human health. It can cause breathing problems, trigger asthma, reduce lung function and cause lung diseases (WHO, 2008). Short-term studies show that current O_3 concentrations in Europe have adverse health effects, especially in the summer, on pulmonary function, lung inflammation, lung permeability, respiratory symptoms, increased medication usage, morbidity and mortality. Several European studies have reported that daily mortality rises with increases in O_3 exposure (WHO, 2008).

Epidemiological health evidence of chronic effects from exposure to O_3 is less conclusive, owing mostly to an absence of studies designed specifically to address the issue. The studies with the most detailed analysis linking exposure to impacts provide new evidence of O_3's chronic effects in terms of reduced

Box 3.1 Ozone: a photochemically formed pollutant

Ozone is not emitted directly into the air. Virtually all of it is formed by chemical reactions involving primarily NO and NO_2 and VOC.

The chemistry of O_3 formation and its decay are complex and are also driven by energy from the sun. Therefore, O_3 is labelled as photochemical pollutant. The main features of this can be summarized as follows: NO_2 can efficiently absorb sunlight and dissociate, producing atomic oxygen (O) and NO. The atomic oxygen in turn reacts rapidly with molecular oxygen (O_2) to form O_3 (provided a third molecule such as molecular oxygen or nitrogen absorbs the excess energy released in this reaction). On the other hand, NO, typically emitted by combustion processes, reacts rapidly in the air with O_3 to form NO_2 and O_2 and therefore contributing to the decay of O_3 concentrations. The latter is known as the titration reaction.

The chemical mechanism outlined above describes the equilibrium state in the atmosphere, in the absence of other gaseous substances, a situation in which the amount of O_3 would be controlled by the relative amounts of NO_2 and NO as well as the intensity of sunlight. By this equilibrium the observed high O_3 levels could not be explained. Polluted air however contains also VOC. Nitrogen oxides and VOC are taking part in hundreds of chemical reactions. Through the action of the hydroxyl radical formed by the action of sunlight, VOC are degraded to produce substances that react with NO to produce NO_2 without consuming O_3. The net result of these reactions is that more than one O_3 molecule is formed for each VOC molecule degraded.

lung capacity and possibly causing asthma (WHO, 2006).

High levels of O_3 can also damage plants, impairing reproduction and growth, leading to reduced agricultural crop yields, decreased forest growth and reduced biodiversity. Ozone decreases photosynthesis, thereby reducing also plant uptake of CO_2 (EEA, 2010a). Ozone also increases the rate of degradation of buildings and physical cultural heritage.

In addition to effects on human health, plants and crops, O_3 is a GHG contributing to the warming of the atmosphere.

3.2 European air quality standards for O_3

European air quality objectives for O_3 are shown in Table 3.1. The 2008 Air Quality Directive (EU, 2008c) sets out values for the protection of human health and for the protection of vegetation.

For health protection a daily maximum eight hour average threshold is specified (120 μg/m^3). The target value, to be applied by EU Member States from 1 January 2010, is that the threshold should not be exceeded at a monitoring station on more than 25 days per year, 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 public information and alert thresholds. When the alert threshold is exceeded, the EU Member State affected is requested to draw up a short-term action plan according to specific provisions defined in the 2008 Air Quality Directive.

The EU has the objective of protecting vegetation from high O_3 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 O_3 values over 40 micrograms per cubic metre (μg/m^3) during the daylight period of the most intense growing season (May to July). The target value for 2010 is 18 000 (μg/m^3).hour. The long term objective is 6 000 (μg/m^3).hour, as shown in Table 3.1. In addition to the EU target value, within the UNECE Convention on Long-range Transboundary Air Pollution (UNECE, 1979) defines a critical level for the protection of forest. This critical level related to the accumulated exposure over threshold (AOT40) during the full summer (April-September) and is set to 10 000 (μg/m^3).h. The updated WHO air quality guideline for O_3 is an 8-hour mean concentration of 100 μg/m^3 (WHO, 2006). WHO (2008) explains the rationale for the guideline as follows:

> 'The previously recommended limit, which was fixed at 120 μg/m^3 8-hour mean, has been reduced to 100 μg/m^3 based on recent conclusive associations between daily mortality and O_3 levels occurring at O_3 concentrations below 120 μg/m^3.'

Table 3.1 Air quality standards for O_3 as defined in the Air Quality Directive

Objective	Period	Target or threshold value	Number of allowed exceedances
Human health	Daily maximum 8-hour mean	120 μg/m^3 (^{b})	25 days per year averaged over three years
Vegetation	AOT40 accumulated over May–July	18 000 (μg/m^3).h averaged over five years	
LTO health	Daily maximum 8-hour mean	120 μg/m^3	
LTO vegetation	AOT40 accumulated over May–July	6 000 (μg/m^3).h	
Information	One hour	180 μg/m^3	
Alert (^{a})	One hour	240 μg/m^3	

Note: (^{a}) To be measured over three consecutive hours.

(^{b}) Target value to be met by 1 January 2010.

Source: EU, 2008c.

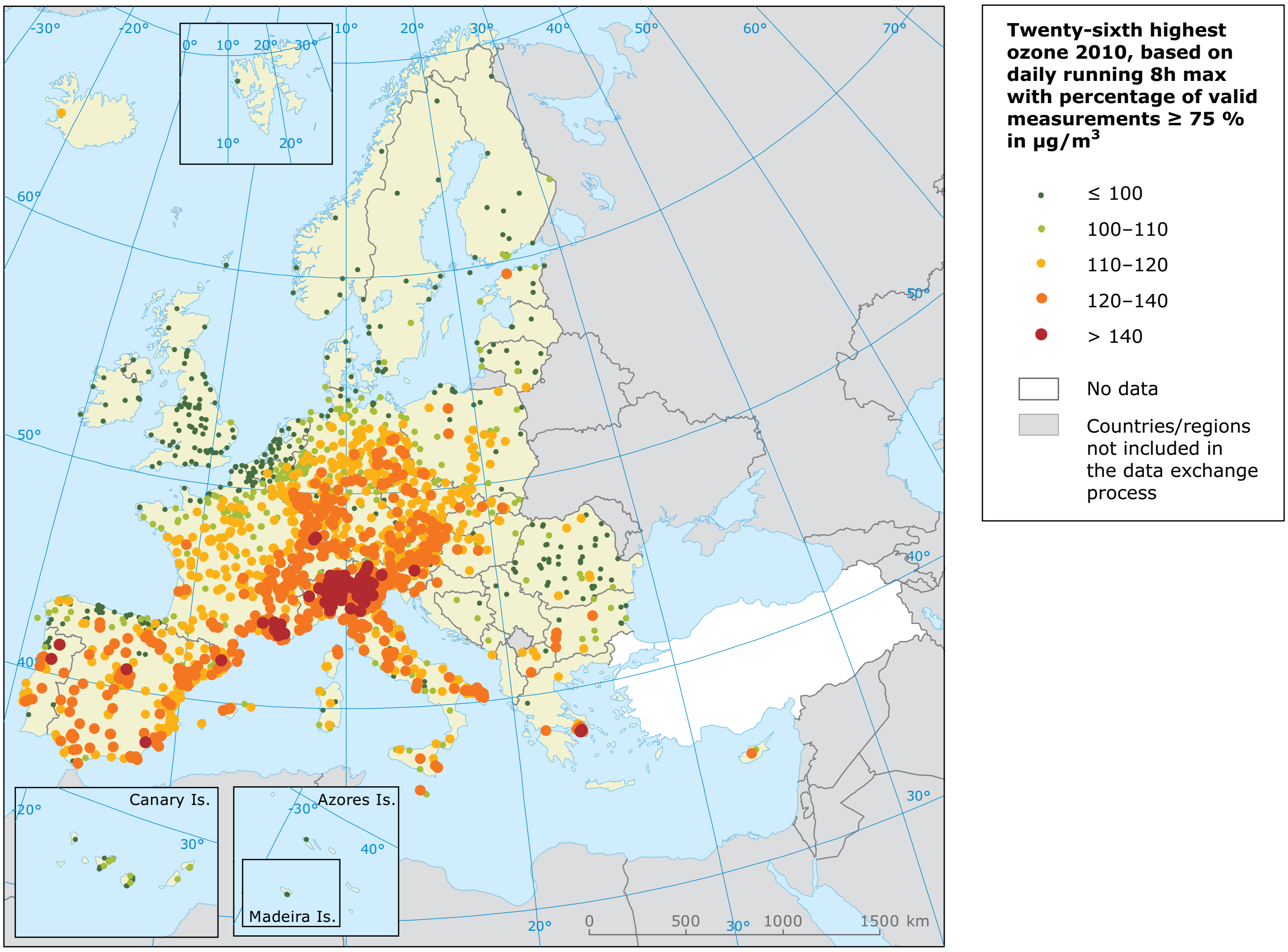
3.3 Europe-wide survey of O_3

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

The target value threshold for O_3 of 120 µg/m³ (daily maximum of running 8-hour mean values) was exceeded on more than 25 days per year at a large number of stations across Europe in 2010 (the dark orange and red dots in Map 3.1).

Since the formation of O_3 requires sunlight, O_3 concentrations show a clear increase from the northern parts to the southern parts of the continent, with the highest concentrations in the Mediterranean countries. The O_3 concentration typically increases with altitude in the first kilometres of the troposphere. Close to the ground O_3 is depleted due to surface deposition and the titration reaction (see Box 3.1). Higher concentrations of O_3 can therefore be observed at high altitude stations.

Map 3.1 **Twenty-sixth highest daily maximum 8-hour average O_3 concentration recorded at each monitoring station in 2010**



Note: The map shows the proximity of recorded O_3 concentrations to the target value. At sites marked with dark orange and red dots, the twenty-sixth highest daily O_3 concentration exceeded the 120 µg/m³ threshold and the number of allowed exceedances by the target value.

Source: AirBase v. 6.

3.3.2 Ozone in rural, urban and traffic locations

In contrast to other pollutants, O_3 levels are generally highest at rural locations. This is because at short distances from NO_X sources, as is the case at urban and traffic stations, O_3 is depleted through titration by the freshly emitted NO (see Box 3.1). Figure 3.1 (top), for the short-term indicator, and Figure 3.3 (left), for the annual average, show this gradient from higher concentrations at rural sites towards lower concentrations at urban sites and lower still at traffic locations. The high O_3 concentrations occurring at a few urban stations shown in Map 3.1 are due to the O_3 formation that occurs at times in large urban areas during episodes of high solar radiation and temperatures. The maximum concentration of this local O_3 formation often occurs downwind of the urbanised area.

Differences in the distribution and magnitude of O_3 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 O_3 concentrations. Year-to-year differences in the O_3 levels are also induced by meteorological variations. Hot, dry summers with long-lasting periods of high air pressure over large parts of Europe lead to elevated O_3 concentrations.

3.3.3 Distance to target

The health-related threshold of the O_3 target value (applicable from 2010) was exceeded more than 25 times in 2010 at 40 % of the rural stations, 27 % of urban background stations, 27 % of industrial sites (labelled as 'other' in Figure 3.1 (top)) and 12 % of traffic sites.

Figure 3.1 (middle) shows that the threshold used for the target value (applicable from 2010) set for protection of vegetation was exceeded to a substantial degree (42 % of the rural stations). The highest measured values (in Italy) exceeded 45 000 µg/m^3.h, which is more than twice the target threshold.

Figure 3.1 (bottom) shows that the UNECE-CLRTAP (13) critical level of 10 000 (µg/m^3).h set for protection of forests was exceeded at nearly all rural stations. The few stations which do not show exceedance of the critical level are mostly located in North-western Europe. For this indicator there is substantially higher numbers of exceedances, than for protection of vegetation.

Conformity with the WHO AQG value for O_3 (8-hour mean of 100 µg/m^3) set for the protection of human health was observed only at two out of 510 rural background stations in 2010. Only 3 % and 7 % of (sub)urban background and traffic stations respectively measured concentrations which did not exceed the WHO AQG in 2010.

Although the EU target value (120 µg/m^3, 25 exceedances allowed) is less ambitious than the WHO AQG, non-attainment situations (i.e. not having achieved the air quality standard) are widely found in most of the EU Member States as shown in Figure 3.2. In (sub)urban areas the observed levels in 2010 indicate attainment of the target value at about 75% of the background stations (de Leeuw, 2012).

3.3.4 Trends in O_3 concentrations

Changes in O_3 concentrations may be different for the different station types and for different indicators (Mol et al., 2011). A negative trend (implying fewer occurences) has been observed among episodic high O_3 concentrations (called peak concentrations) (EEA, 2010a). Lately, in summer 2011 the information threshold (a one-hour average O_3 concentration of 180 µg/m^3) was exceeded at approximately 18 % of all operational stations — the lowest share since comprehensive summer O_3 reporting started in Europe in 1997 (EEA, 2012b).

Map 3.2 shows the average changes in O_3 annual mean of the maximum daily 8-hour mean values for stations that registered a trend over the period 2001 to 2010 (de Leeuw, 2012) (14). At 66 % of the stations registering a trend, a slight negative trend

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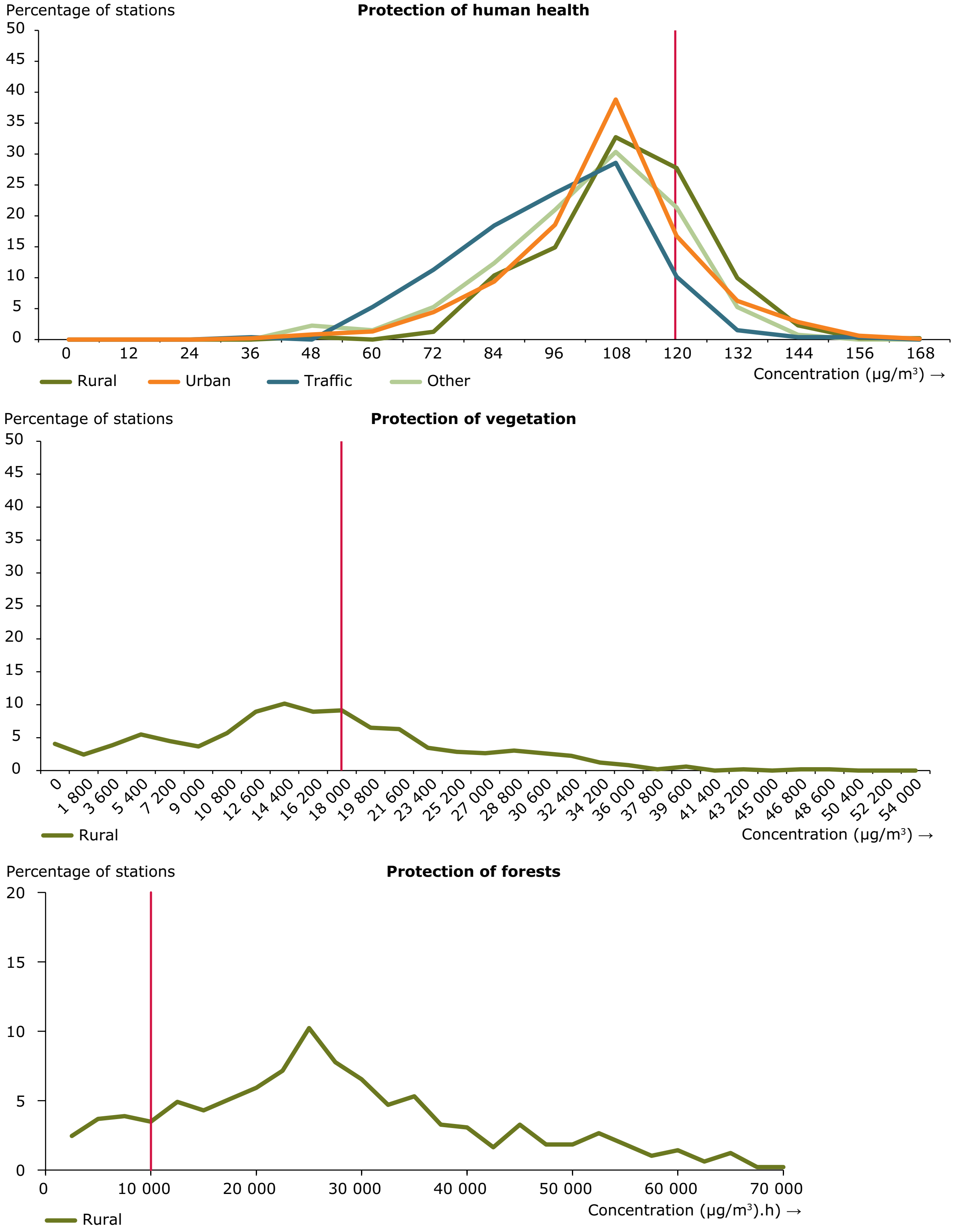
(13) UNECE-CLRTAP: United Nations Economic Commission for Europe — Convention on Long-range Transboundary Air Pollution.

(14) A consistent set of 1 241 stations with data for 2001 to 2010 was used in the trend analysis. Of these, only 253 stations registered a trend (a significant trend, using the Mann-Kendall test). The remaining 988 stations had no significant trend.

Figure 3.1 Distance-to-target graphs for the O_3 target threshold for protection of human health (top), protection of crops (middle) and forests (bottom), in 2010



Protection of human health

Protection of vegetation

Protection of forests

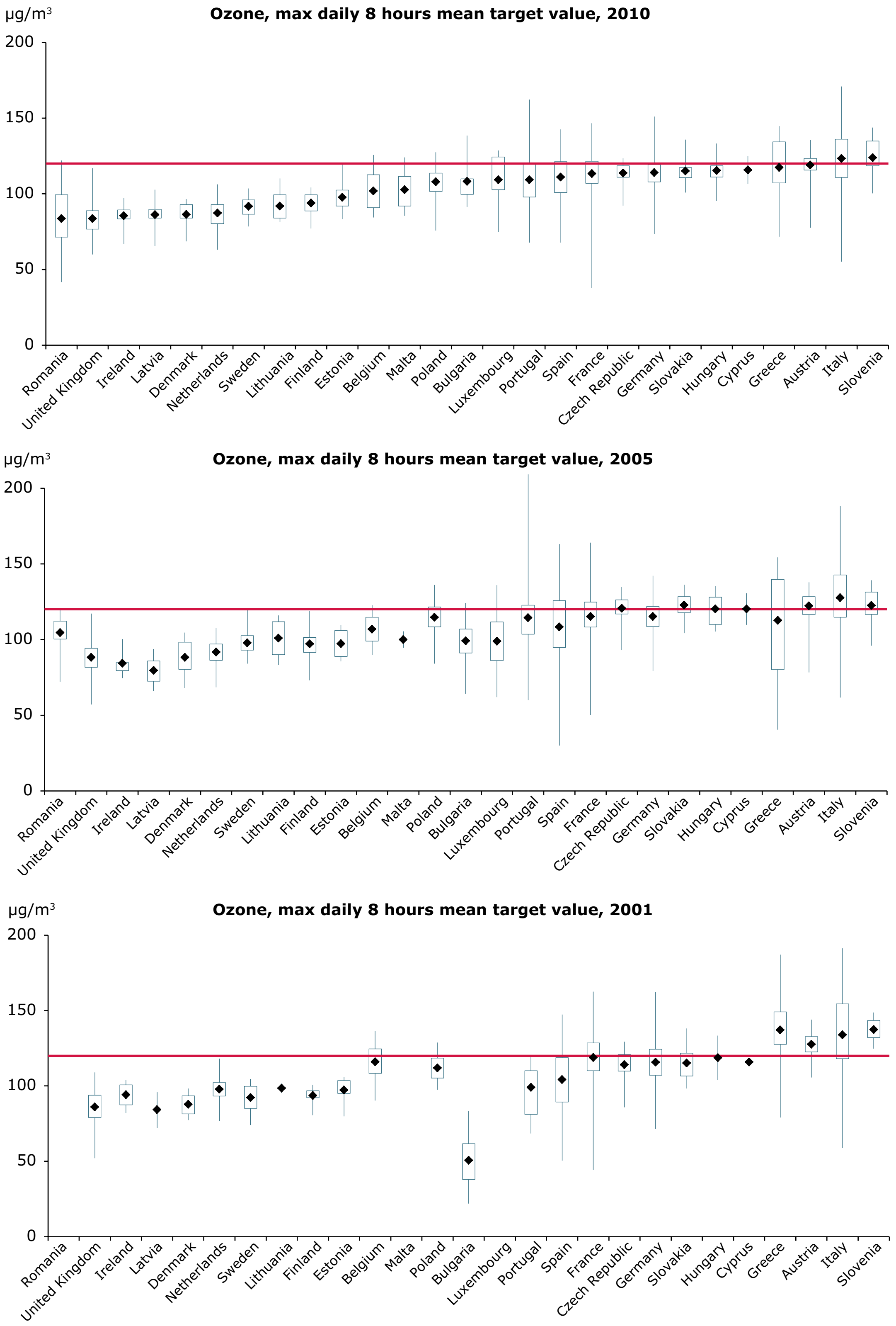
Note: The graphs show the percentage frequency distribution of stations (on the y-axis) in the EU Member States versus the various concentration classes (on the x-axis, in µg/m³ except for AOT40 which is in (µg/m³).h).

The graphs show the percentage frequency distribution for the 26th highest daily maximum of the running 8h-mean O_3 concentrations for the various types of stations (top); AOT40 concentrations measured in rural stations in the EU for the protection of vegetation (accumulated over May to July) (middle) and for the protection of forests (accumulated over April to September) (bottom).

Vertical lines correspond to target or threshold values set by EU legislation. The red vertical bar (bottom) corresponds to the CLRTAP critical level: AOT40 (the accumulated dose of O_3 over a threshold of 40 ppb, equivalent to 80 µg/m³, from 1 April to 30 September) set at 10 000 (µg/m³).h.

Source: AirBase v. 6 (top and middle); de Leeuw (2012) (bottom).

Figure 3.2 Attainment situation for O_3, reference years 2010, 2005 and 2001

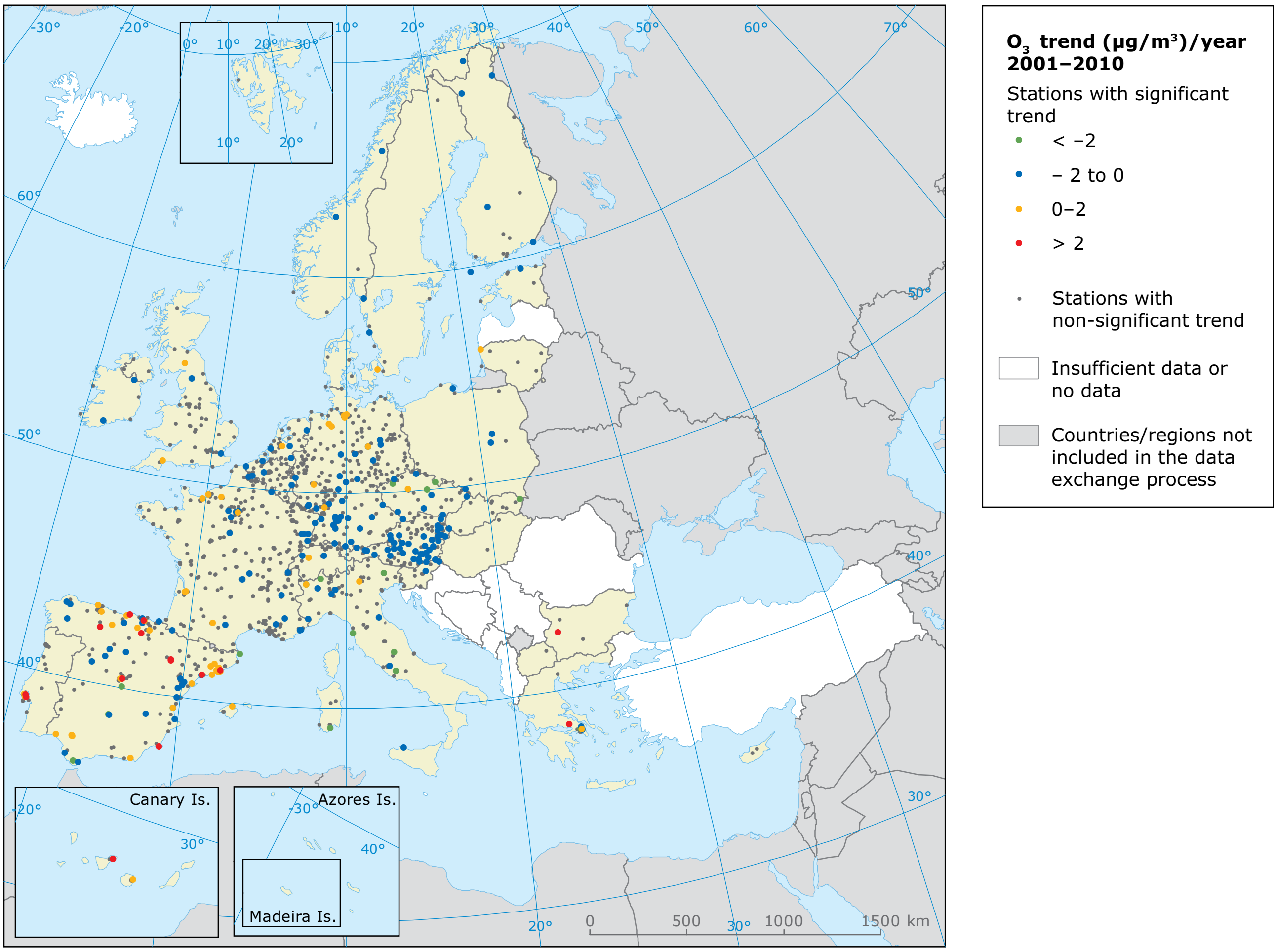


Note: The graphs are based on the 93.2 percentile of maximum daily 8 hours mean concentration values corresponding to the 26th highest daily maximum of the running 8h-mean; they present the range of concentrations at all station types (in μg/m³) officially reported by the EU Member States and how the concentrations relate to the target value set by EU legislation (marked by the red line).

The diagram indicates the lowest and highest observations, the means and the lower and upper quartiles. The lower quartile splits the lowest 25 % of the data and the upper quartile splits the highest 25 % of the data.

Source: ETC/ACM.

Map 3.2 **Annual changes in annual mean of the maximum daily 8-hour O_3 concentrations in the period 2001–2010**



Note: Statistically significant trends (level of significance 0.1) are calculated by applying the Mann-Kendall test. The trend slopes are indicated with coloured dots when statistically significant. Red dots indicate increasing concentrations. The applied method is described in de Leeuw, 2012.

Source: de Leeuw, 2012.

(of less than 2 µg/m³ per year) is apparent, while 7 % of the stations had a more pronounced negative trend (equal to or above 2 µg/m³ per year) (15). 28 % of the stations registered a positive trend from 2001 to 2010 (16). Most of the stations having a large positive trend are located in the Iberian Peninsula (17). Nine out of those fourteen stations are classified as being traffic stations, the others are urban or industrial stations. The increasing O_3 levels at traffic locations are mainly attributed to a reduced depletion of O_3 by NO as a result of the decrease in traffic NO_x emissions (de Leeuw, 2012).

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(15) 66 % is equivalent to 167 stations.

(16) 28 % is equivalent to 70 stations

(17) Sixteen stations registered a trend with an increase of 2 ug/m³ per year or more, 14 of which located in the Iberian Peninsula.

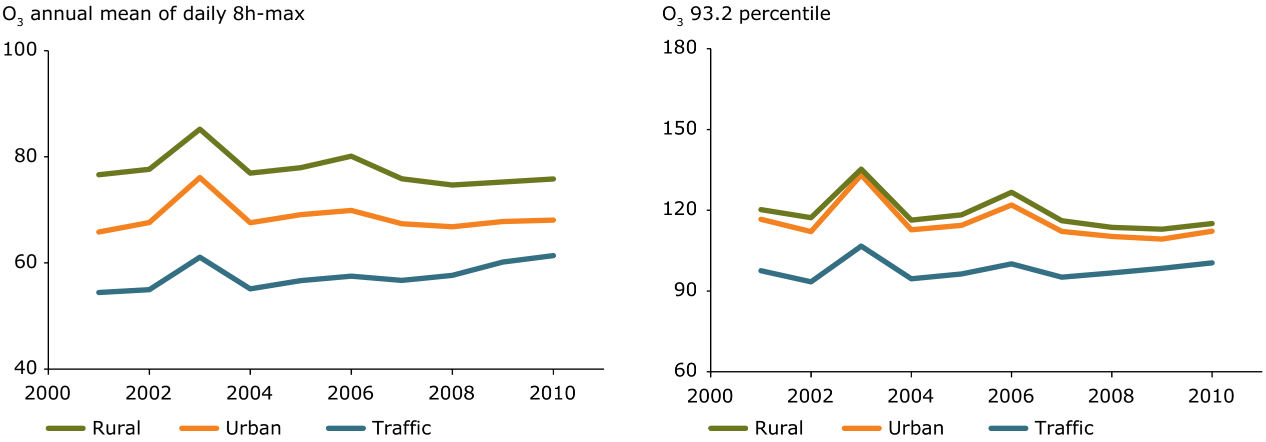
Figure 3.3 shows the trends in annual mean of daily max 8-hour mean O_3 concentrations (left) and its 93.2 percentile (right) at different station types over the period 2001–2010. The latter indicator is directly related to the target value for O_3, as 25 days per year are allowed to have exceedances of the target value threshold of 120 µg/m³. The varying concentrations reported at the different station types illustrate the effects of depletion of O_3 by locally emitted NO, with traffic stations reporting the lowest concentrations and rural stations the highest. Figure 3.3 does not show a clear trend at the aggregated EU level, neither in the annual mean nor in the indicator related to the target value, at urban and rural sites.

Emissions of O_3 precursors

The EU emissions of the air pollutants primarily responsible for the formation of harmful groundlevel O_3 fell significantly in the period 2001–2010. Carbon monoxide emissions were cut by 33 % (Figure 6.4), NMVOC by 27 % and NO_X by 26 % (Figure 2.6) ([18]). Nevertheless, in 2010 NO_X emissions remained 12 % above the NEC Directive ceiling (Annex II) to be attained by 2010, mainly due to road transport emissions. For NMVOC, emissions in 2010 were marginally below the ceiling (EEA, 2012a), but these decreased emissions did not manifest in significantly diminished ground-level O_3 concentrations.

The transport and the energy sectors are the main sectors responsible for emissions of NO_X, followed by industry (Figure 2.7). The transport sector reduced its NO_X emissions by 27 % between 2001 and 2010 and the energy and industry sectors by 17 % and 19 %, respectively. As Figure 2.7 shows, several sectors have cut their NMVOC emissions in the last decade, with the exception of the sector 'Commercial, institutional and household fuel combustion', which increased its emissions by 10 % and the agriculture sectors with an increase of 56 %. The transport sector, which was the second largest emitter in 2001, secured the largest reduction with a 56 % cut in the period 2001–2010. The solvent and product use sector has been the largest source of NMVOC emissions and has reduced its emissions by 10 % from 2001 to 2010. Non-methane VOC emissions from the waste and industry sectors were reduced by 11 % and emissions from the energy sector fell by 14 %.

Figure 3.3 Trend in annual mean of daily max 8 h-mean O_3 concentrations (left) and trend in 93.2 percentile of daily 8 max h-mean O_3 concentrations (right) (in µg/m³) for 2001–2010 per station type



Note: All stations in EU Member States, with at least 75 % data coverage for at least eight years were included in the analysis. Concentrations per station type are given in µg/m³. In the diagrams a geographical bias exists towards central Europe where there is a higher density of stations.

The 93.2 percentile of daily max 8-h mean values is directly related to the target value for O_3, as 25 days per year are allowed to have exceedances of the target value threshold of 120 µg/m³.

Source: ETC/ACM.

([18]) EEA-32 countries registered emission reductions as follows between 2001 and 2010: 35 % for CO, 28 % for NMVOC, 23 % for NO_X.

Relationship of O_3 precursors to ambient O_3 concentrations

The relationship of O_3 concentration to the emitted precursors is not linear. There is a discrepancy between the cuts in O_3 precursor gas emissions and the change in observed annual average O_3 concentrations in Europe (Figure 3.3). Reasons include increasing inter-continental transport of O_3 and its precursors in the northern hemisphere (EEA, 2010a; UN, 2010a) (see Section 1.3.4 of this report) and other factors which are likely to mask the effects of European measures to reduce O_3 precursor emissions. These include climate change/variability, NMVOC emissions from vegetation, whose magnitude is difficult to quantify, and fire plumes from forest and other biomass fires (EEA, 2010a). Formation of tropospheric O_3 from increased concentrations of CH_4 may also contribute to the sustained O_3 levels in Europe. Methane concentrations increased continuously during the 20th century, before growth slowed after 1990 and eventually stabilised between 1999 and 2007. Since 2007, however, measurements suggest that concentrations have started to rise again (Dlugokencky et al., 2009). Methane is a slowly reacting, globally well-mixed pollutant. Isolated local and regional abatement of CH_4 emissions may therefore have limited impact on local O_3 concentrations.

Clearly, O_3 concentrations are not only determined by precursor emissions but also by meteorological conditions. Sunlight and high temperatures favour O_3 formation. Episodes of elevated O_3 levels occur during periods of warm, sunny weather. However, independent of the episodic nature of O_3 pollution strongly influenced by meteorological conditions, emissions of O_3 precursor gases are sustaining a baseline of exceedances of legal concentration thresholds. Decreased anthropogenic emissions of some O_3 precursors (NO_X, CO and some NMVOC) in the past decade has nevertheless reduced the number of peak concentration values. The O_3 pollution problem requires further mitigation efforts.

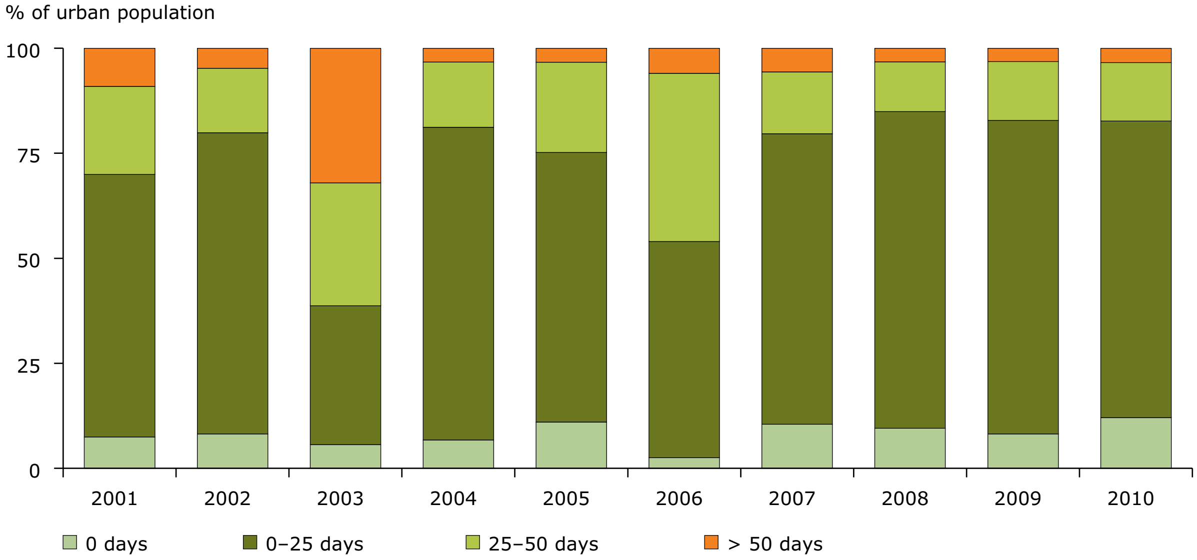
3.4 Exposure to O_3 pollution in Europe

3.4.1 Human exposure

The O_3 monitoring data in AirBase provide the basis for estimating the urban exposure of the European population to exceedances of the O_3 target value (applicable from 2010) for the protection of human health. This estimation is shown in Figure 3.4 for the period 2001–2010. The exposure is estimated based on O_3 measured at all urban background monitoring stations. For each city an average concentration is calculated. It is considered that the entire population of a city is exposed to this average concentration.

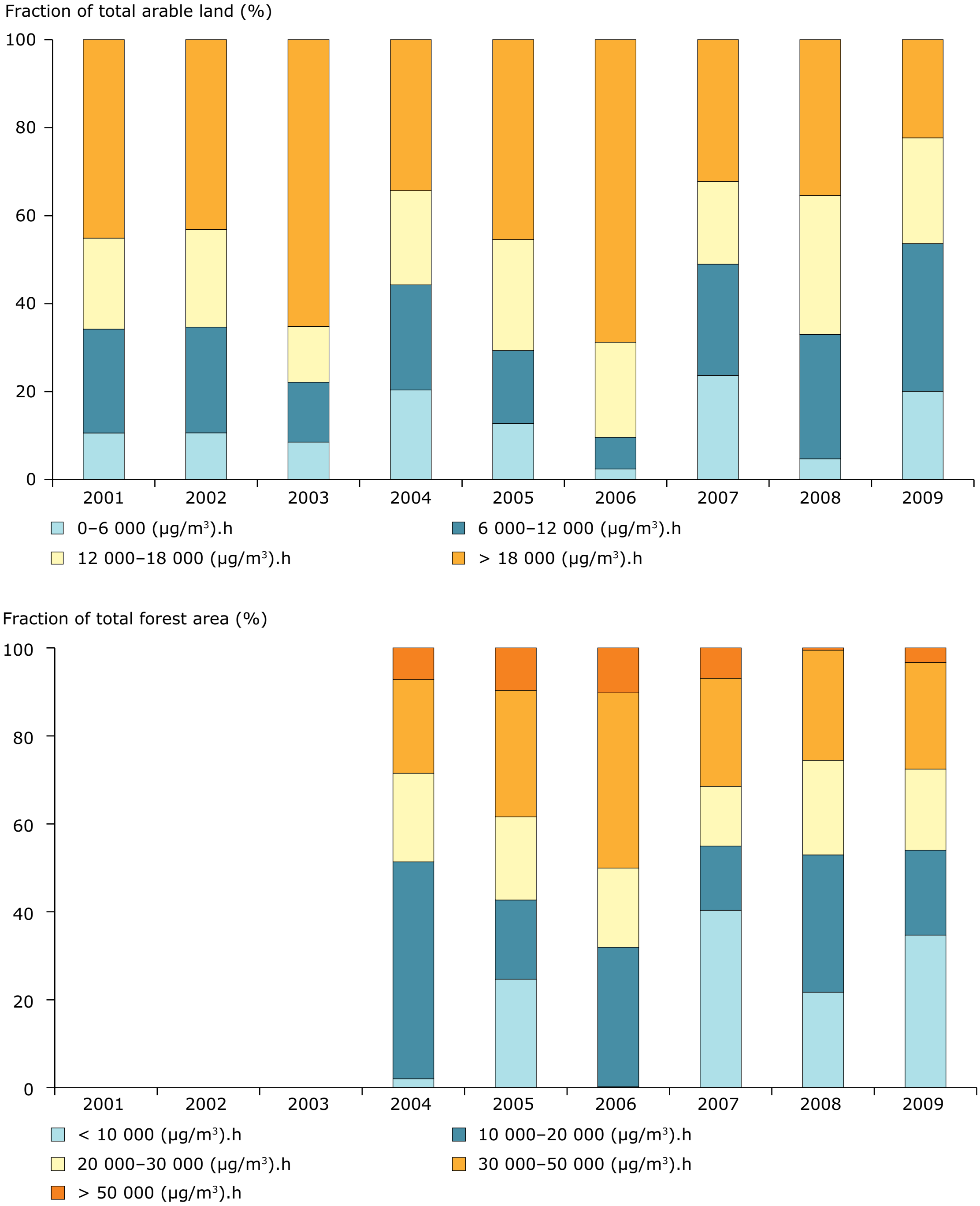
It is noteworthy that people in rural areas are exposed to higher O_3 levels than people in cities. In urban areas with fresh inputs of NO from

Figure 3.4 **Percentage of the EU urban population exposed to O_3 concentrations over the target value threshold set for protection of human health, 2001–2010**



Source: EEA, 2012d (CSI 004).

Figure 3.5 **Exposure of agricultural area (top) and exposure of forest area (bottom) to O_3 (AOT40 in µg/m³.h)**



Note: The assessment is made for EEA-32 member countries.

Top figure: In the Air Quality Directive (2008/50/EC) the target value for protection of vegetation is set to 18 000 (µg/m³).h while the long-term objective is set to 6 000 (µg/m³).h. Due to lack of detailed land cover data and/or rural O_3 data Iceland and Norway were not included until 2006. Switzerland has not been included in the analysis for the entire period 2001–2007 due to the same reasons. Turkey is not included in the analysis 2001–2008.

Bottom figure: UNECE has set a critical level for protection of forest to 10 000 (µg/m³).h. Since 2004 a growing number of EEA member countries have been included. In 2004 Bulgaria, Greece, Iceland, Norway, Romania, Switzerland and Turkey have not been included. In 2005-2006 Iceland, Norway, Switzerland and Turkey are still excluded in the analyses due to lack of detailed land cover data and/or rural O_3 data. In 2007 Switzerland and Turkey are not included. Since 2008 only Turkey is not included. Calculations of forest exposure are not available for years prior to 2004.

Source: EEA, 2012c (CSI 005).

traffic emissions, some of the O_3 is depleted while oxidising NO to NO_2. In 2010 about 17 % of the EU population in urban areas was exposed to O_3 concentrations above the target value. The extent of exposure above the target value has varied between 15 % and 61 % since 2001. The same percentages were estimated for the EEA-32. There is no apparent trend over this period. The range partly reflects variations caused by meteorology.

The EU urban population exposed to O_3 levels exceeding the WHO AQG value is significantly higher, representing more than 97 % of the total urban population in 2010 (Table ES.1).

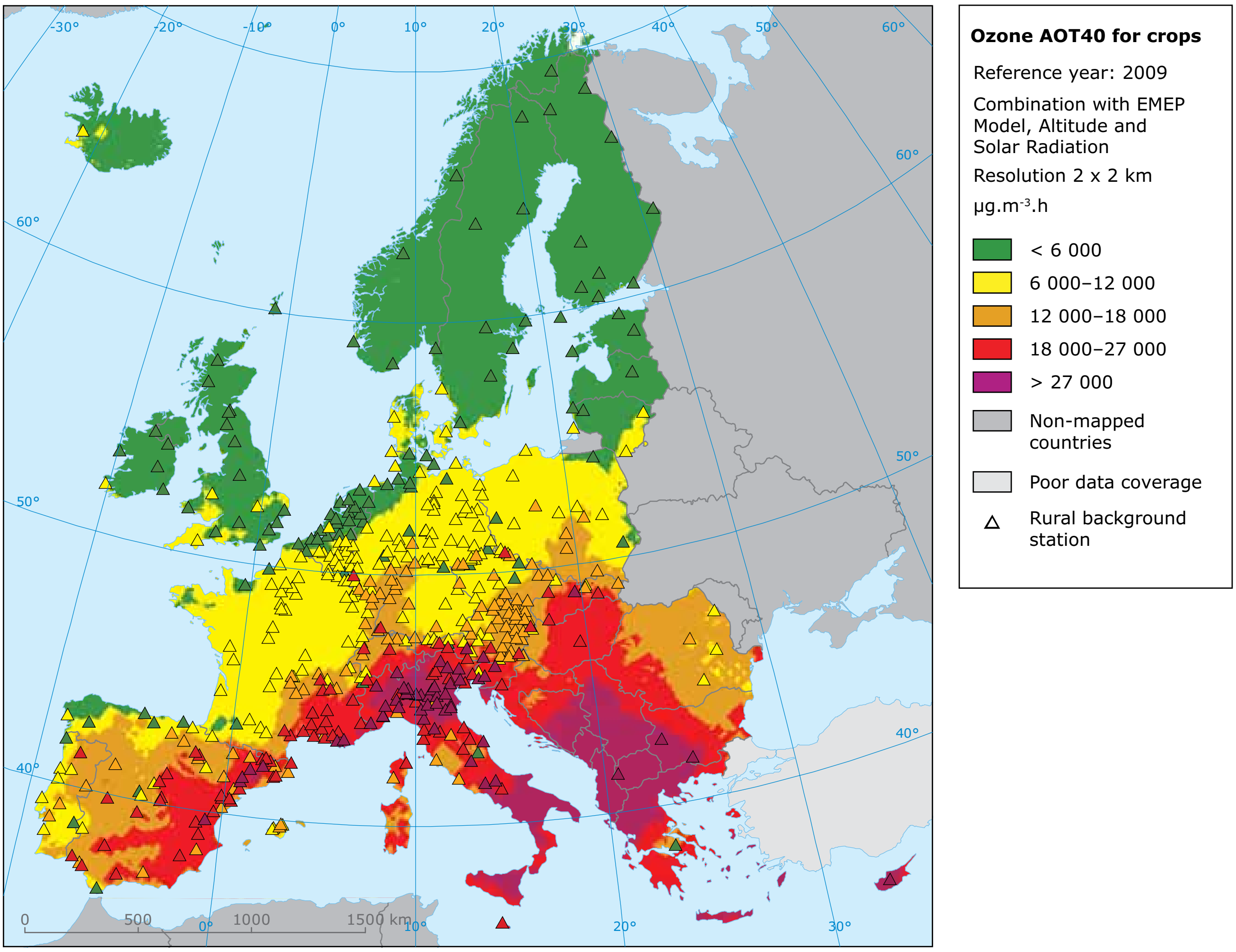
3.4.2 *Exposure of ecosystems*

The target value for protecting vegetation from high O_3 concentrations, the AOT40 (accumulated exposure above 40 µg/m^3 for the summer months May–July), to be met by 2010 is 18 000 µg/m^3.hour, averaged over five years. The long-term objective is AOT40 of 6 000 µg/m^3.hour.

Since 2001, the target value threshold has been exceeded in a substantial part of the agricultural area in the EEA-32 countries. For example, in 2009 the threshold was exceeded in about 22 % of this area (Figure 3.5 and Map 3.3). Exceedances of the target value have notably been observed in southern, central and eastern Europe (Map 3.3). The long-term objective was met in 20 % of the total agricultural area in 2009, mainly in the United Kingdom, Ireland and the Nordic countries.

The variations between years (Figure 3.5) are influenced by meteorological factors. Summers in 2003 and 2006 had favourable meteorological conditions for O_3 formation resulting in

Map 3.3 **Exposure of European agricultural areas to O_3 (AOT40)**



Source: EEA, 2012c (CSI 005).

exceptionally high concentrations. In fact, average O_3 concentrations in 2006 were only slightly higher than in 2005 but June and July 2006 were characterised by a large number of O_3 episodes resulting in a much higher AOT40 value compared to 2005 (EEA, 2011b).

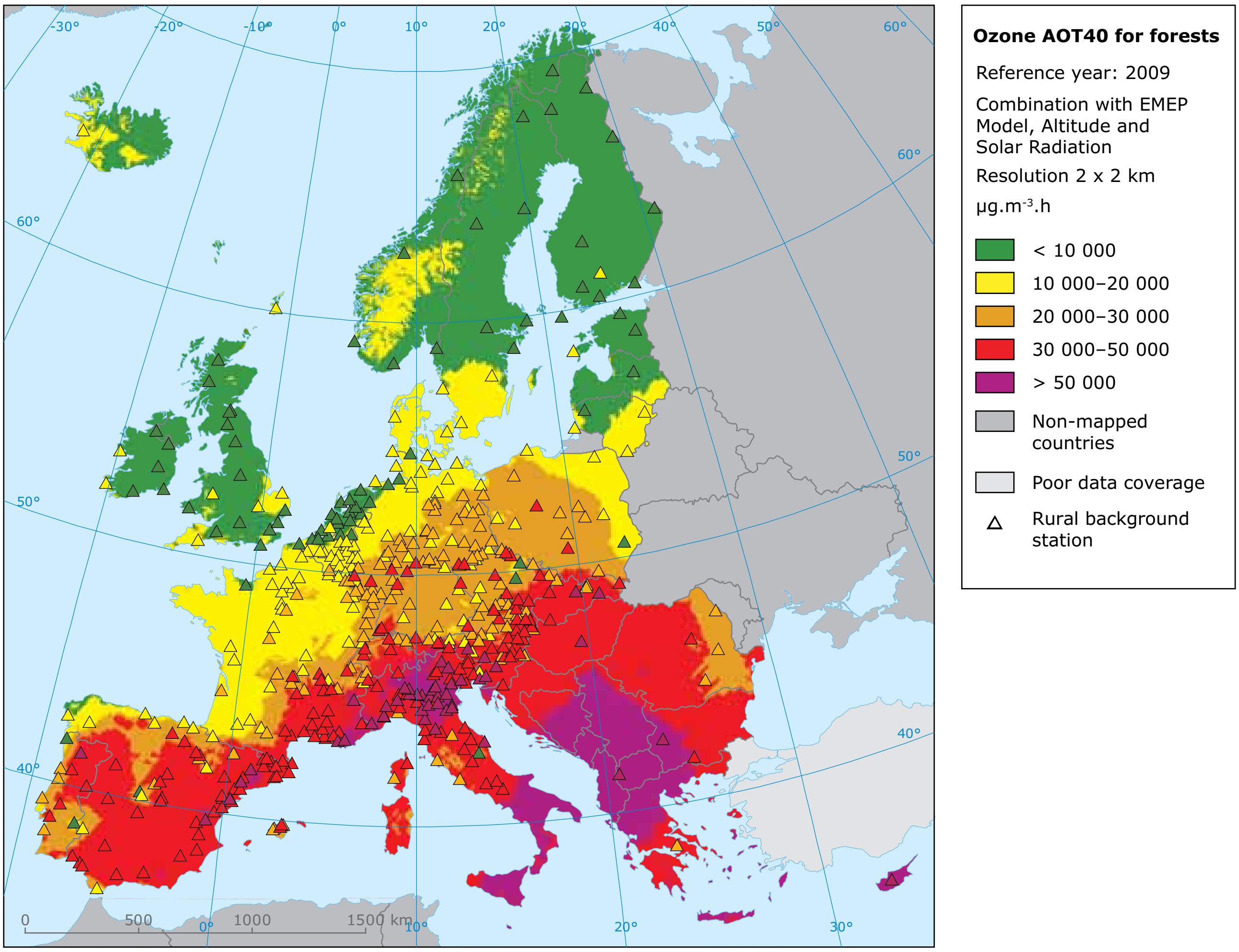
Regarding the UNECE–CLRTAP critical level for the protection of forest (10 000 $(\mu g/m^3)$.h), Figure 3.5 (bottom) shows that this critical level was exceeded in 65 % of the total forest area in the EEA-32 member countries in 2009. Map 3.4 shows clearly that the attainment areas in 2009 were in the Northern part of Europe, while the highest exceedances occurred in the South-east and Italy.

3.5 Responses

Current policy measures to reduce O_3 concentrations mainly target emissions of the precursors NO_X and NMVOC.

The relevant NO_X-reducing measures are described in Section 2.5 (since NO_X is also a precursor of PM). As noted in Section 2.5, the directives for road vehicle emissions and the LCP and IPPC directives for industrial sources and power plants are estimated to have reduced NO_X emissions from road vehicles by 55 % and from power plants and large industrial plants by 68 % in the period 1990–2005, compared to a hypothetical situation with no directives implemented (EEA, 2010b).

Map 3.4 **Exposure of European forest areas to O_3 (AOT40)**



Source: EEA, 2012c (CSI 005).

The Euro emission standards also limit NMVOC emissions from road vehicles. Specifically, the introduction of the three-way catalyst has led to considerable NMVOC emission reductions.

Volatile organic compounds vapour emissions from motor fuel service stations are regulated and limited by the Vapour Recovery Directives (EU, 1994 and 2009a, discussed in Annex 2). The Stage I Vapour Recovery Directive (EU, 1994) has reduced the total VOC emissions from storage of petrol at terminals and its subsequent distribution to service stations.

Directives limiting emissions of NMVOC from industrial sectors include the Paints Directive (EU, 2004a), the Solvents Directive (EU, 1999a) and the IPPC Directive (EU, 2008b) — the latter two replaced by Directive 2010/75/EU on industrial emissions (EU, 2010b) remaining in force for several additional years. Each is described in Annex 2. The Solvents Directive limits emissions of VOC from a number of activities and installations, including coating, dry cleaning, varnish and adhesives manufacturing, pharmaceutical manufacturing, printing, surface cleaning, vehicle refinishing and others. The Paints Directive regulates the maximum VOC contents in paints and varnishes and in vehicle-refinishing products. The Directive on industrial emissions (EU, 2010b) regulates emission permits and requires the use of best available techniques (BAT) in production facilities and cleaning equipment. The UNFCCC (United Nations Framework Convention on Climate Change) Kyoto Protocol addresses emissions of CH_4, as one of the six main GHG.

Implementing air quality plans can determine the extent of progress towards the air quality targets and long-term objectives for O_3 (EU, 2008c).

4 Nitrogen dioxide (NO_2)

4.1 Sources and effects of NO_2

4.1.1 *Origins of NO_2 in air*

Nitrogen dioxide is a reactive gas that is mainly formed by oxidation of NO. High temperature combustion processes (e.g. those occurring in car engines and power plants) are the major sources of NO_X, the term used to describe the sum of NO and NO_2. Nitrogen monoxide makes up the majority of NO_X emissions. A small part is directly emitted as NO_2, typically 5–10 % for most combustion sources, with the exception of diesel vehicles. There are clear indications that for traffic emissions the direct NO_2 fraction is increasing significantly due to increased penetration of diesel vehicles, especially newer diesel vehicles (Euro 4 and 5). Such vehicles can emit up to 70 % of their NO_X as NO_2 (e.g. Grice et al., 2009) because their exhaust aftertreatment systems increase the direct NO_2 emissions (see Section 4.3.2). This may lead to more frequent breaching of the NO_2 limit values in traffic hotspots.

4.1.2 *Effects of NO_2*

Health effects can result from short-term exposure to NO_2 (e.g. changes in lung function in sensitive population groups) and long-term exposure (e.g. increased susceptibility to respiratory infection). Epidemiological studies have shown that symptoms of bronchitis in asthmatic children increase in association with long-term exposure to NO_2. Reduced lung function is also linked to NO_2 at concentrations currently found in cities of Europe and North America (WHO, 2008). It should be noted that as NO_2 is highly correlated with other pollutants (in particular PM) it is difficult to differentiate the effects of NO_2 from those of other pollutants in epidemiological studies.

Nitrogen compounds have acidifying effects but are also important nutrients. Excess deposition of reactive nitrogen can lead to a surplus of nutrient nitrogen in ecosystems, causing eutrophication (nutrient oversupply) in terrestrial and aquatic ecosystems. Excess nitrogen supply can lead to changes in unique terrestrial, aquatic or marine animal and plant communities, including biodiversity loss (EEA, 2010a).

Nitrogen oxides play a major role in the formation of O_3. They also contribute to the formation of secondary inorganic aerosols (SIA), through nitrate formation, contributing to PM_{10} and $PM_{2.5}$ concentrations.

4.2 European air quality standards for NO_2 and NO_X

European air quality standards for NO_2 and NO_X as set by the 2008 Air Quality Directive (EU, 2008c) are shown in Table 4.1. For NO_2 two limit values and an alert threshold are defined for the protection of human health. The limit values are specified for shortterm (one-hour) and long-term (annual) exposure and EU Member States were obliged to meet them by 1 January 2010. The one-hour value can be exceeded up to 18 times per year before the limit value is breached. A critical level is set for the annual mean of NO_X for the protection of vegetation, defined as the sum of NO and NO_2 expressed in units of mass concentration of NO_2.

The 2008 Air Quality Directive (EU, 2008c) also defines an alert threshold value of 400 μg/m³. When 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 limiting motor-vehicle traffic, construction works, ships at berth, and the use of industrial plants or products and domestic heating. Specific actions aiming at the protection of sensitive population groups, including children, by reducing their exposure to high NO_2 levels may also be considered in the framework of those plans.

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 NO_2, shown in Table 4.2 (WHO, 2006).

Table 4.1 Limit and threshold values for NO_2 and NO_X as set out in the 2008 Air Quality Directive

Objective	Averaging period	Limit or threshold value	Number of allowed exceedances
Human health	One hour	200 µg/m^3	18 hours per year
Human health	Calendar year	40 µg/m^3	
Alert (a)	One hour	400 µg/m^3	
Vegetation (b)	Calendar year	30 µg/m^3	

Note: (a) To be measured over three consecutive hours at locations representative of air quality over at least 100 km^2 or an entire zone or agglomeration, whichever is smaller.

(b) As NO_X, expressed as µg NO_2/m^3.

Source: EU, 2008c.

Table 4.2 WHO air quality guideline for NO_2

µg/m^3	1-hour mean	Annual mean
NO_2	200	40

Source: WHO, 2006.

4.3 Europe-wide survey of NO_2 and NO_X

4.3.1 *Exceedances of limit values*

The limit value of the annual mean NO_2 concentration is set at 40 µg/m^3 and countries were obliged to meet this by 2010. In 2010, 22 of the 27 EU Member States recorded exceedances of the limit value at one or more stations (orange and red spots in Map 4.1; Figure 4.2). The distance-to-target plots show that the lowest concentration levels and fewest exceedances occur at rural stations and the highest concentrations and exceedances are at traffic stations (Figure 4.1). Guerreiro et al. (2010) provide a thorough discussion of NO_2 concentrations at hotspots close to traffic and also in the urban background.

4.3.2 *NO_2 in rural, urban and traffic locations*

Nitrogen dioxide concentrations vary between rural, urban and traffic sites in a different manner from PM and O_3. Nitrogen dioxide concentrations are higher close to the sources and at traffic stations, decreasing in quantity in urban background areas. The lowest concentrations are found in rural areas (Figure 4.1 and Figure 4.3). While secondary PM and O_3 are formed regionally from precursor gases, chemical reactions are less likely to create NO_2 on this geographical scale. For most NO_X sources, the share of NO in NO_X emissions is much greater than that of NO_2, typically 10–20 times higher ([19]). The NO_2 concentration is then increased at the expense of NO, due to reactions with O_3. In traffic and urban areas with fresh inputs of NO, some of the O_3 present is depleted while oxidising NO to NO_2. In rural areas relatively limited fresh NO emissions are available, except near highways and near combustion plumes. The reaction between NO, NO_2 and O_3 leads to chemical equilibrium (Box 3.1 on O_3 in Section 3.1.1).

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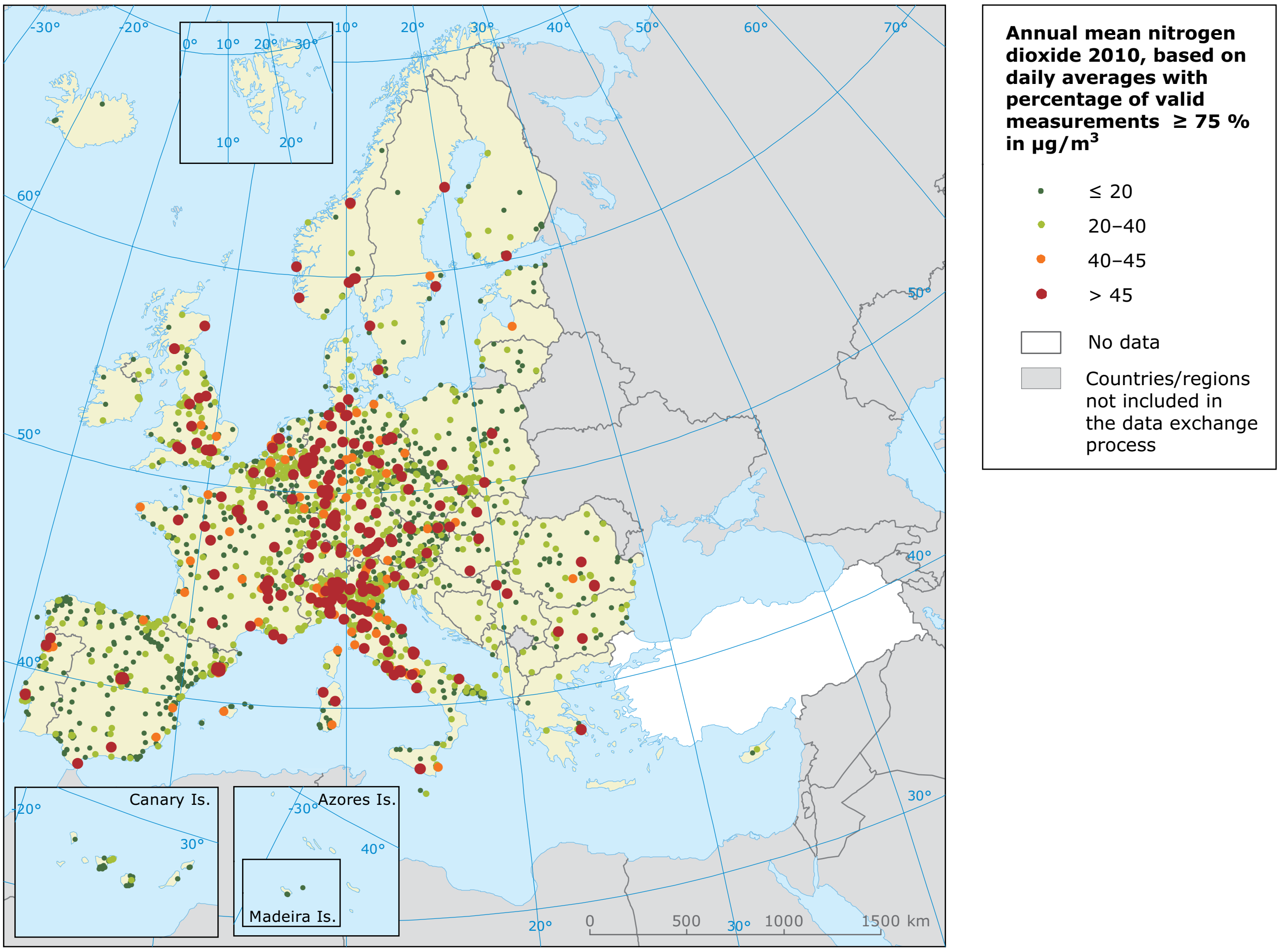
[19] An exception is emissions from motor vehicles produced after 1990 (i.e. complying with Euro emission standards). Due to the effect of catalytic converters on gasoline-powered vehicles and particle filters on diesel vehicles, the NO_2 fraction in emissions is much higher, making up 20–70 % of NO_X depending upon the technology (e.g. Grice et al., 2009).

Map 4.1 Annual mean concentration of NO_2 in 2010

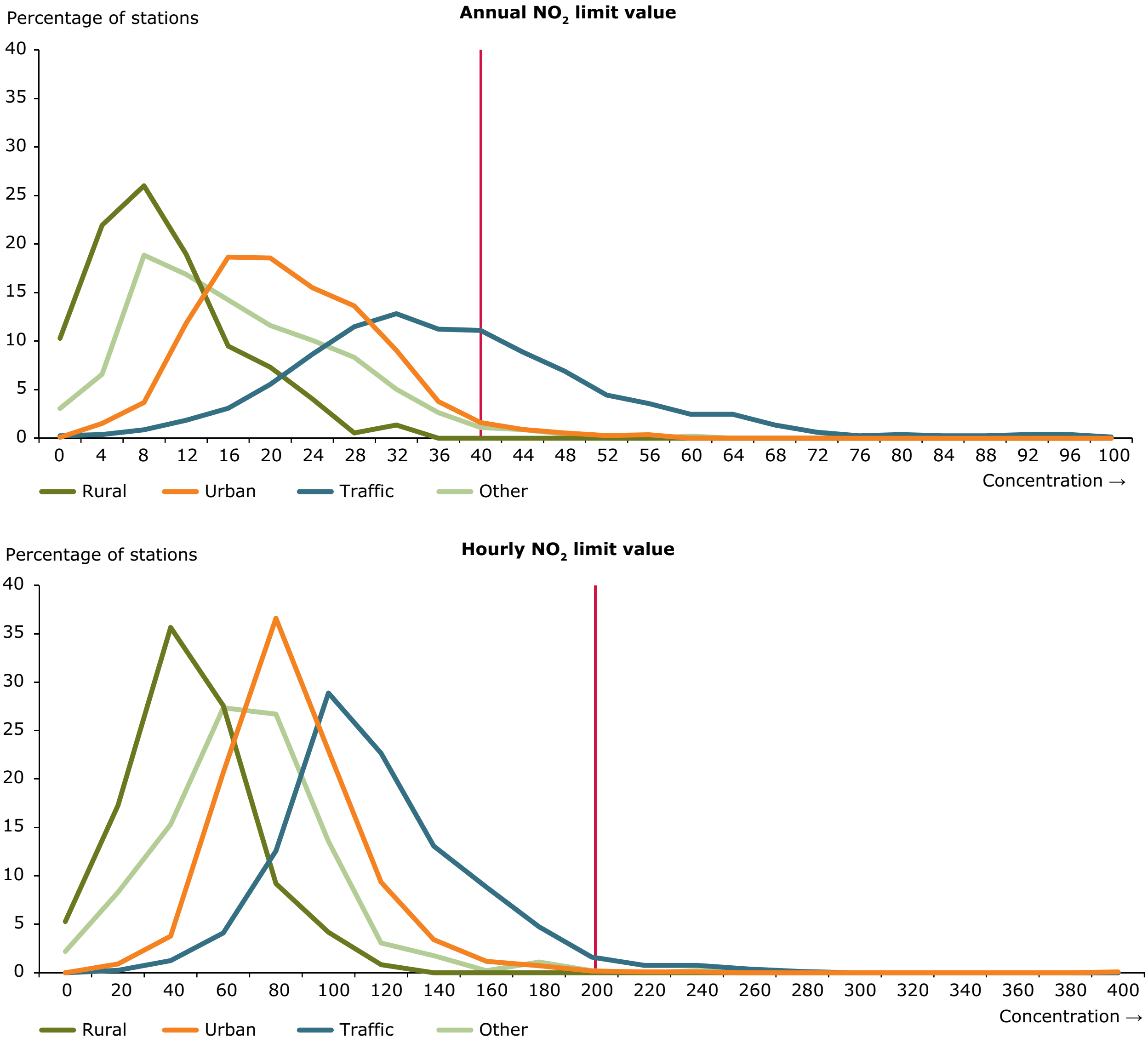


Note: Orange and red dots correspond to exceedances of the annual limit value (40 µg/m³).

Red dots correspond to exceedances of the annual limit value + 5 µg/m³.

Source: AirBase v. 6.

Figure 4.1 Distance-to-target graphs for the annual (top) and hourly (bottom) NO_2 limit value, for different station types, 2010

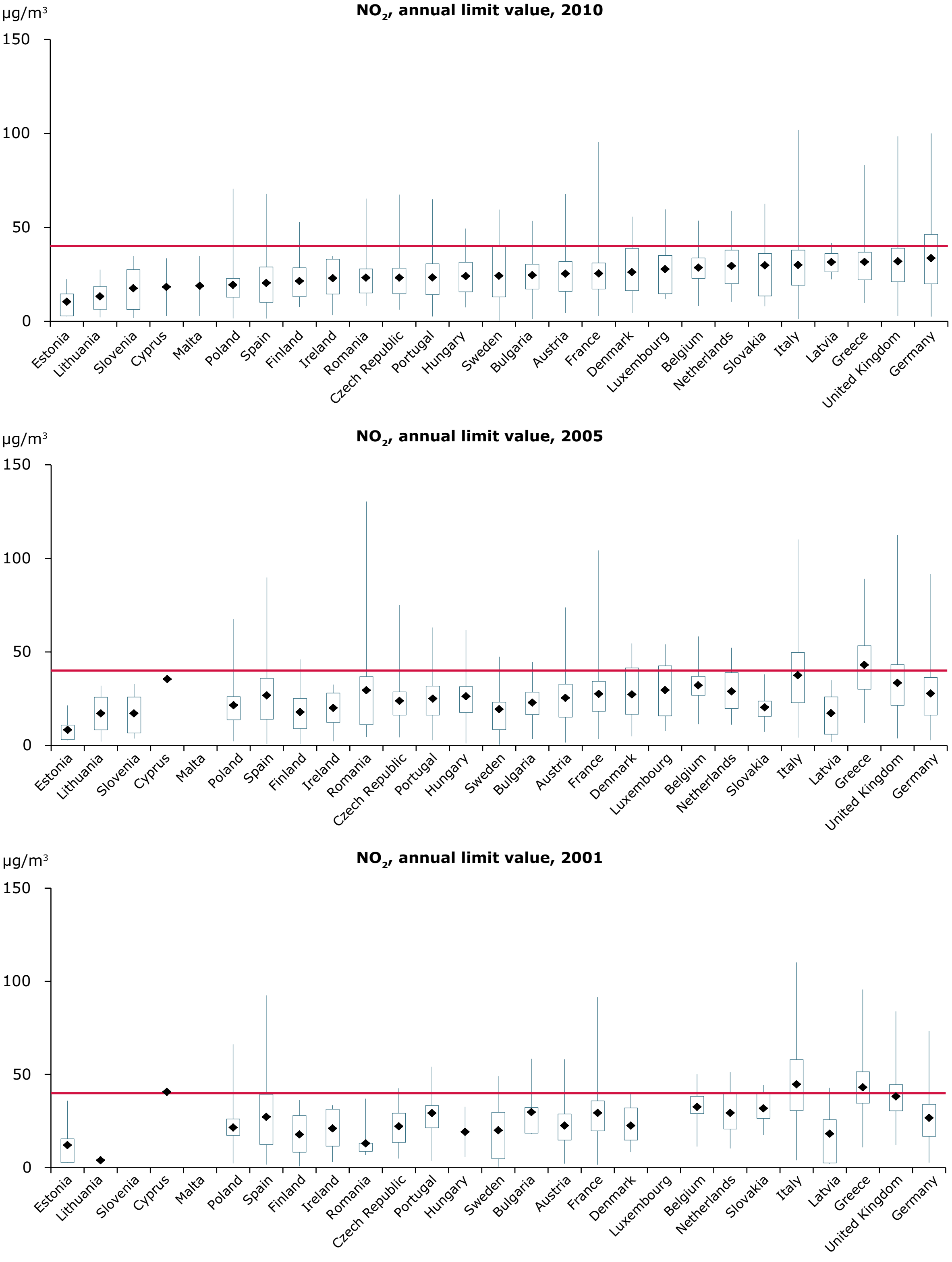


Note: The graphs show the percentage frequency distribution of stations (on the y-axis) in the EU Member States versus the various concentration classes (on the x-axis, in µg/m³).

Vertical lines correspond to limit values set by the EU legislation.

Source: AirBase v. 6.

Figure 4.2 Attainment situation for NO_2, reference years 2010, 2005, 2001



Note: The graphs are based on the annual mean concentration values; they present the range of concentrations at all station types (in µg/m³) officially reported by the EU Member States and how the concentrations relate to the limit value set by EU legislation (marked by the red line).

The diagram indicates the lowest and highest observations, the means and the lower and upper quartiles. The lower quartile splits the lowest 25 % of the data and the upper quartile splits the highest 25 % of the data.

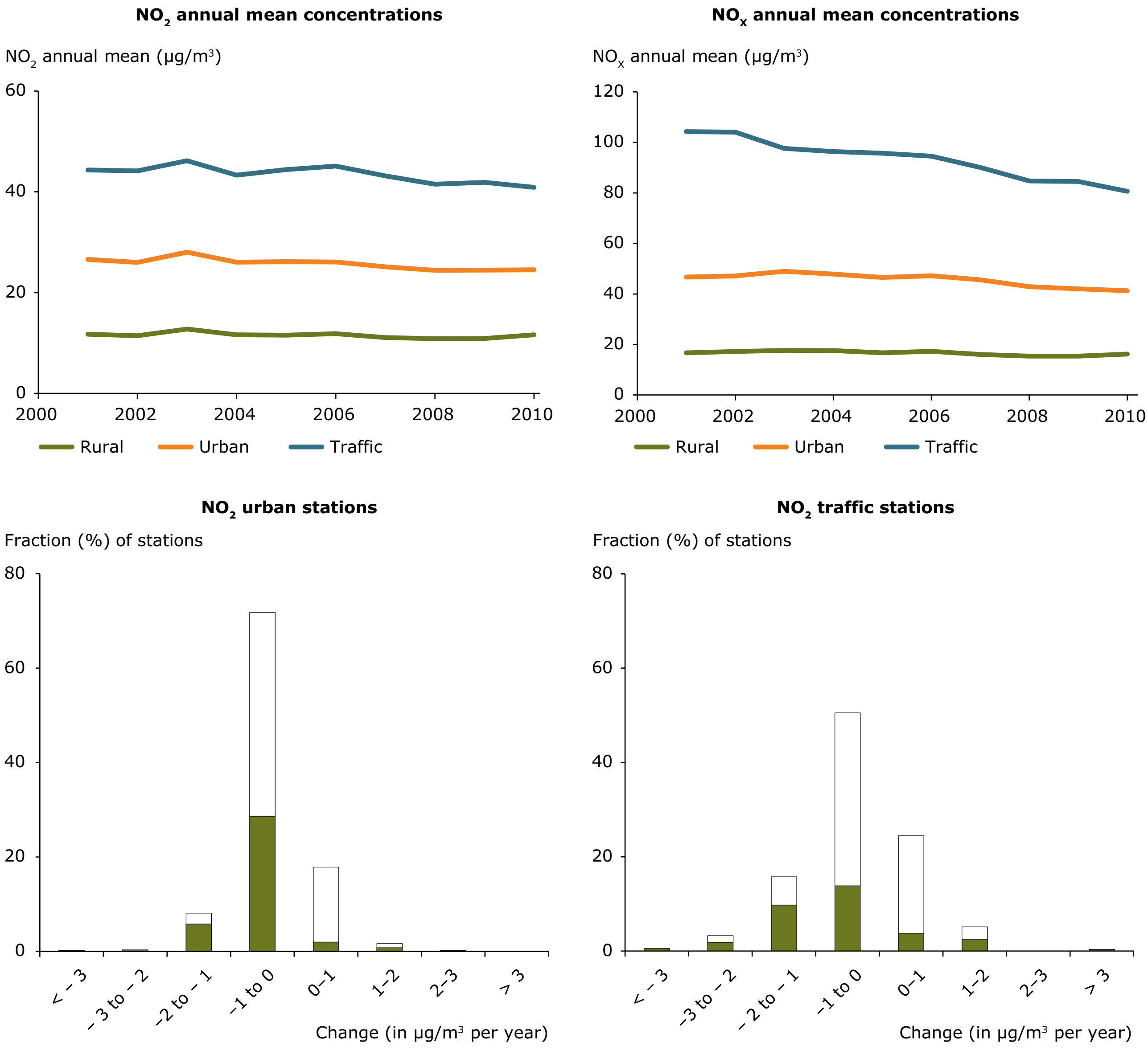
Source: ETC/ACM.

4.3.3 *Distance to target*

While the annual limit value is exceeded at only a very few rural background stations, it is exceeded at 4 % of all urban background stations. The annual limit value is identical to the WHO AQG value. Exceedance of the limit value was reported at 44 % of traffic stations, with a maximum observed concentration of 102 µg/m³ in 2010, i.e. 2.5 times the threshold.

Figure 4.2 shows the annual mean NO_2 values for 2010, 2005 and 2001 for all EU Member States. It clearly indicates that exceedance of the annual limit

Figure 4.3 Trend in NO_2 and NO_x annual mean concentrations (2001–2010) per station type (top); percentage frequency distribution of estimated annual change of NO_2 annual mean concentrations at urban stations and at traffic stations (bottom)



Note: All stations in EU Member States, with at least 75 % data coverage for at least eight years were included in the analysis. Concentrations per station type are given in µg/m³. In the top two diagrams a geographical bias exists towards central Europe where there is a higher density of stations.

In the percentage frequency distribution graphs, closed bars denote stations showing a statistically significant trend, open bars denote stations with a non-significant trend. Statistically significant trends (level of significance 0.1) are calculated by applying the Mann-Kendall test. The applied method is described in de Leeuw, 2012.

Source: ETC/ACM.

value and the WHO AQG value was observed in most EU Member States at one or more stations in 2010, with only Cyprus, Estonia, Ireland, Latvia, Malta, and Slovenia, in attainment. The only countries, with complete NO_2 data for the years 2001, 2005 and 2010, which did not register an exceedance of the NO_2 annual limit value in any of the three years were Estonia, Ireland and Latvia.

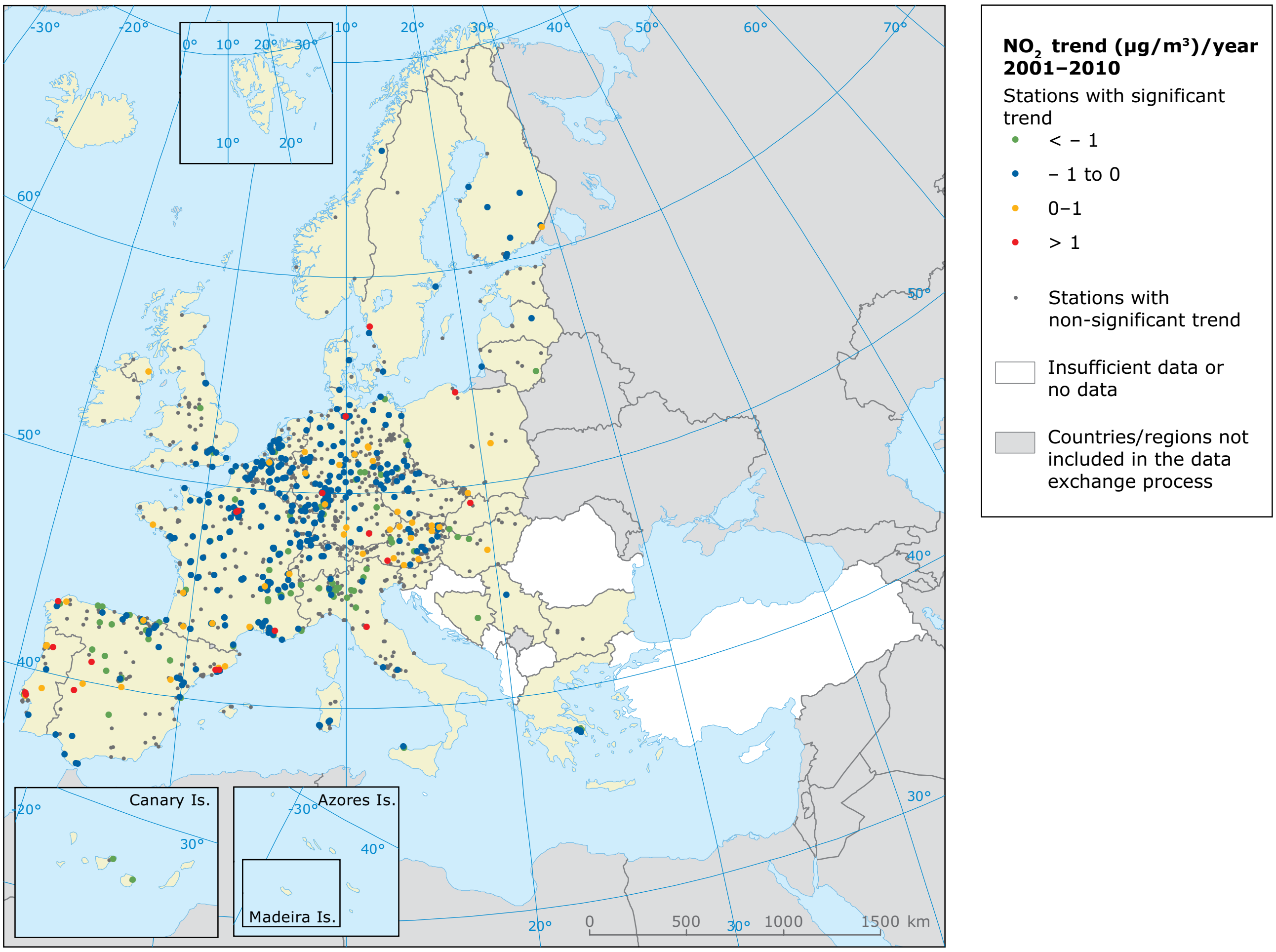
The hourly limit value threshold for NO_2 is less stringent. About 0.4 % of urban background stations reported exceedances and 4 % of traffic stations.

These findings demonstrate that NO_2 concentrations must be reduced substantially in large areas of Europe (focusing on traffic and urban locations) for the annual limit value to be met. Exceedances of this objective are rather persistent: 12 % of the stations operational in the period 2006–2010 in the EU showed exceedances each year. Similar figures were found in the period 2005–2009. The long-lasting exceedances are mostly observed at traffic stations (de Leeuw, 2012).

4.3.4 *Trends in NO_2 and NO_x concentrations*

The trends in NO_2 and NO_x concentrations over the period 2001–2010 are summarised in Figure 4.3 and Map 4.2. A consistent set of stations is used for both NO_2 and NO_x but the distribution of the stations differs, therefore influencing the comparison. The concentration time series in Figure 4.3 show slightly decreasing NO_2 annual mean concentrations at all station types, with the exception of NO_2 concentrations at rural sites. The proportional fall in

Map 4.2 Changes in annual mean concentrations of NO_2 in the period 2001–2010



Note: Statistically significant trends (level of significance 0.1) are calculated by applying the Mann-Kendall test. The trend slopes are indicated with coloured dots when statistically significant. Red dots indicate increasing concentrations. The applied method is described in de Leeuw, 2012.

Source: de Leeuw, 2012.

NO_X is larger than the reduction in NO_2, attributed to the increase in primary NO_2 emissions from diesel vehicles and the shift in the photostationary state (Guerreiro et al., 2010).

NO_X emissions

As shown in Figure 2.6, EU emissions of NO_X fell by 26 % in the period 2001–2010 and by 1.4 % from 2009 to 2010. Nevertheless, total NO_X emissions in 2010 were about 10 % higher than the emissions ceiling for the EU as a whole set in the NEC Directive (EU, 2001b) for 2010.

Transport is the dominant sector for NO_X emissions, accounting for 48 % of the total in 2010, followed by the energy sector, which contributed 20 % of the total (Figure 2.7). These two sectors have substantially reduced emissions since 2001. Over the period 2001–2010 emissions from transport decreased by 27 % and from industry by 19 %, while emissions from the energy sector decreased by 17 %. The commercial, institutional and households' fuel combustion sector as well as the agriculture sector have decreased their NO_X emissions by only 6 % in the same period.

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 NO_X emissions from light-duty diesel vehicles. EU Member States regularly update the emission factors used in their emission inventories and their previously reported emissions. Reported developments in emissions should therefore include 'real world' emission factors.

Relationship of NO_X emissions and NO_2 concentrations

Nitrogen oxides emissions primarily comprise NO but also include some directly emitted NO_2, which countries are not currently required to report as a separate compound under the relevant EU legislation (EU, 2001b). The concentrations of NO_2 found in air originate both from directly emitted NO_2 and from chemical reactions forming NO_2 in the atmosphere, predominantly between NO and O_3 (see Box 3.1).

An EEA analysis of source apportionment in the notifications submitted by sixteen EU Member States for time extension of NO_2 limit values shows that the urban and local traffic contribution to NO_2 levels measured at 74 urban traffic sites averages at 64 %, ranging from 33 % (Essen) to 91 % (Catania). The higher fraction of NO_2 in NO_X emissions from diesel vehicles could lead to increased NO_2 concentrations in traffic exposed areas and possibly also in urban areas in general.

The time series and frequency distributions in Figure 4.3 show the differing trends in NO_2 concentrations recorded at rural, urban and traffic stations (²⁰). At urban background locations the situation is relatively clear: the NO_2 levels are decreasing at 92 % of the stations registering a trend. At traffic locations, NO_2 concentrations are decreasing at fewer stations (80 % of traffic stations registering a trend). These trends reflect the increase in the share of NO_2 in the NO_X emissions from traffic and the shift in the photostationary state in favour of NO_2 that results from a decrease in NO_X, without an equivalent decrease in O_3 concentrations (Guerreiro et al., 2010). These are probably also the main reasons for the much lower average decrease in NO_2 concentrations measured over Europe (8 % decrease measured at stations closed to traffic) (see Figure 4.3) than the decrease in NO_X transport emissions (27 % decrease in the EU) between 2001 and 2010.

Map 4.2 shows the spatial distribution of NO_2 trends at station locations between 2001 and 2010, based on the same data and trend analysis as presented in Figure 4.3. Although some countries have clusters of stations reporting an upward trend (e.g. Austria), most regions have stations with both upward and downward trends with the latter dominating. It is important to note that the number of stations with data covering the period 2001 to 2010 is very low in some parts of Europe, notably in parts of Eastern Europe and Scandinavia.

(²⁰) A consistent set of 1 467 stations with data for 2001 to 2010 was used in the trend analysis. Of these, 529 stations registered a trend (a significant trend, using the Mann-Kendall test). Of the 529 stations with a trend, 248 were urban background stations and 121 were traffic stations.

4.4 Exposure to NO_2 pollution in Europe

4.4.1 *Human exposure*

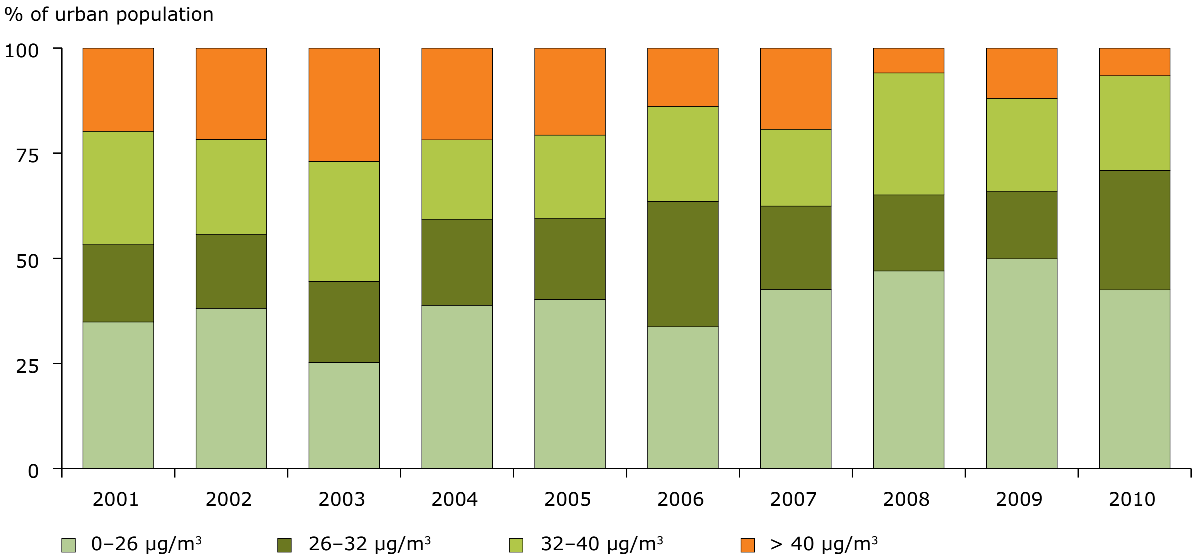
The NO_2 monitoring data in AirBase provide the basis for estimating the exposure of the European population to exceedances of the NO_2 annual mean limit value of 40 μg/m³. Figure 4.4 presents the data for the period 2001–2010, based on NO_2 measured at urban background monitoring stations. For each city an average concentration is calculated. It is considered that the whole population is exposed to these concentrations, since people move freely within the city. Close to traffic people are in reality exposed to higher NO_2 concentrations than in the urban background. This renders an underestimation of the estimated impact of exposure. According to this method, about 7 % of the EU and EEA-32 urban population was exposed to NO_2 above the annual limit value and the WHO AQG for NO_2 in 2010. Exposure above the limit value varied between 6 % and 27 % since 2001, with same percentages estimated for the EEA-32. There is a decreasing trend over this period with a decrease also observed between 2009 and 2010. The range partly reflects variations caused by meteorology.

4.4.2 *Exposure of ecosystems*

Nitrogen compounds emitted as NO_X and NH_3 are now the principal acidifying components and also cause eutrophication in sensitive ecosystems. Eutrophication is enrichment with nutrients, here by airborne reactive nitrogen, which creates damage to the ecosystems. Acidification of ecosystems is in addition to NO_X and NH_3 caused by the SO_X emissions.

The acidification and eutrophication effects are estimated using the concept of 'critical load': the ecosystem's ability to absorb deposited atmospheric acidifying and eutrophying

Figure 4.4 **Percentage of the EU urban population exposed to NO_2 concentration over the limit value set for protection of human health, 2001–2010**



Source: EEA, 2012d (CSI 004).

pollutants without negative effects on the natural environment. Exceedance of spatially determined 'critical loads' present a risk of damage. Such exceedances are calculated based upon measurement data and model calculations ([21]). EEA (2010a) showed calculated exceedances of critical loads for acidity and nutrient nitrogen in 2010 ([22]). High exceedances of critical loads of acidity were evidenced in Belgium, at the north-west coast of France, the Netherlands and Poland. In the case of acidification, the situation has considerably improved and it is predicted to improve further. The area of sensitive ecosystems in Europe where the critical load of acidity is exceeded is estimated to have declined by more than 80 % compared with the 1990 base year. This improvement is primarily attributed to heavily decreased SO_X emissions in the past two decades.

Concerning eutrophication, calculated exceedances for 2010 cover most of continental Europe as well as Ireland and southern areas of the United Kingdom and Sweden (EEA, 2010a). The risk of ecosystem eutrophication and its geographical coverage have diminished only slightly over the last decade and is still widespread over Europe. This conflicts with the EU's long-term objective of not exceeding critical loads of airborne acidifying and eutrophying substances in European ecosystem areas (EU, 2001b; EU, 2002; EC, 2005b).

4.5 Responses

The most relevant EU legislative instruments addressing NO_X emissions and concentrations of NO_X and NO_2 relate to motor vehicle emissions (Euro emission standards) and emissions from combustion of fuel in industry and power production (the LCP and IPPC Directives). As described in the preceding sections, the legislation has resulted in an overall reduction of NO_X emissions. However, 'real-world emissions' of NO_X from diesel passenger cars have decreased very little over the last decade (both per-vehicle emissions and total emissions) and are considered to be the main driver of the exceedances of the NO_2 limit value found across the EU. The upcoming Euro 6 standard will focus on real-world emissions.

As explained above, concentrations of NO_2 in the atmosphere and at rural, urban and traffic locations originate partly from direct NO_2 emissions, and partly from NO emissions transformed into NO_2. A negative effect of some technologies used in diesel vehicles to meet the Euro emission limits is that the fraction of direct NO_2 emissions in total NO_X emissions is increasing.

The policy responses for NO_X mitigation are presented in Section 2.5. The use of air quality plans is described in Section 2.5.4.

([21]) The results were computed using the 2008 Critical Loads database hosted by the Coordination Centre for Effects (CCE). Deposition data were made available by the Centre for Integrated Assessment Modelling under the LRTAP Convention at the International Institute for Applied Systems Analysis (IIASA).

([22]) Turkey was not included in the analysis because it lacks sufficient data for calculating critical loads. For Malta no data were available. The territories of Serbia and Montenegro are treated as one critical loads/exceedance area in the CCE dataset.

5 Sulphur dioxide (SO_2)

5.1 Sources and effects of SO_2

5.1.1 Origins of SO_2 in air

Sulphur dioxide is emitted when fuels containing sulphur are burned. The key manmade contributions to ambient SO_2 derive from sulphurcontaining fossil fuels and biofuels used for domestic heating, stationary power generation and transport. Volcanoes are the most important natural source.

5.1.2 Effects of SO_2

Epidemiological studies suggest that SO_2 can affect the respiratory system and lung functions, and causes irritation of the eyes. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma and chronic bronchitis and makes people more prone to infections of the respiratory tract. Mortality and hospital admissions for cardiac disease increase on days with higher SO_2 levels (WHO, 2008).

Sulphur dioxide is a major precursor to $PM_{2.5}$, which is associated with significant health effects, as described in Section 2.1.

Sulphur dioxide and its oxidation products contribute to acidic deposition, causing adverse effects on aquatic ecosystems in rivers and lakes, damage to forests and acidification of soils. The major effects of deposited S compounds are the loss of acid neutralisation capacity in soils and waters, loss of nutrients such as potassium or magnesium from soils and the release of toxic aluminium to the soil and waters. Depending on biogeochemical conditions, S can initially be stored in soils with subsequent slow release (postponed acidification). Effects of SO_2 emissions reduction measures can thus be delayed for decades.

5.2 European air quality standards for SO_2

Table 5.1 presents the European air quality limit values for SO_2 defined in the 2008 Air Quality Directive (EU, 2008c). Values are given for health protection and vegetation protection. Health protection limit values are specified for short-term exposure, for 1-hour and 24-hour averages. Countries were obliged to meet them by 2005. There is also an alert threshold value of 500 µg/m³. When exceeded over three consecutive hours, authorities have to implement action plans. As shown in Table 5.2 (WHO, 2006), the WHO air quality guidelines for SO_2 are significantly more stringent than the limit values set by the 2008 Air Quality Directive.

Table 5.1 Air quality standards for SO_2 as given in the 2008 Air Quality Directive

Objective	Averaging period	Limit or threshold value	Number of allowed exceedances
Human health	One hour	350 µg/m³	24 hours per year
Human health	One day	125 µg/m³	3 days per year
Alert ([a])	One hour	500 µg/m³	
Vegetation	Calendar year	20 µg/m³	
Vegetation	Winter (1 October–31 March)	20 µg/m³	

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

Source: EU, 2008c.

Table 5.2 WHO air quality guidelines for SO_2

AQG (µg/m^3)	10-minute mean	24-hour mean
SO_2	500	20

Source: WHO, 2006.

5.3 Europe-wide survey of SO_2

5.3.1 *Exceedances of limit values*

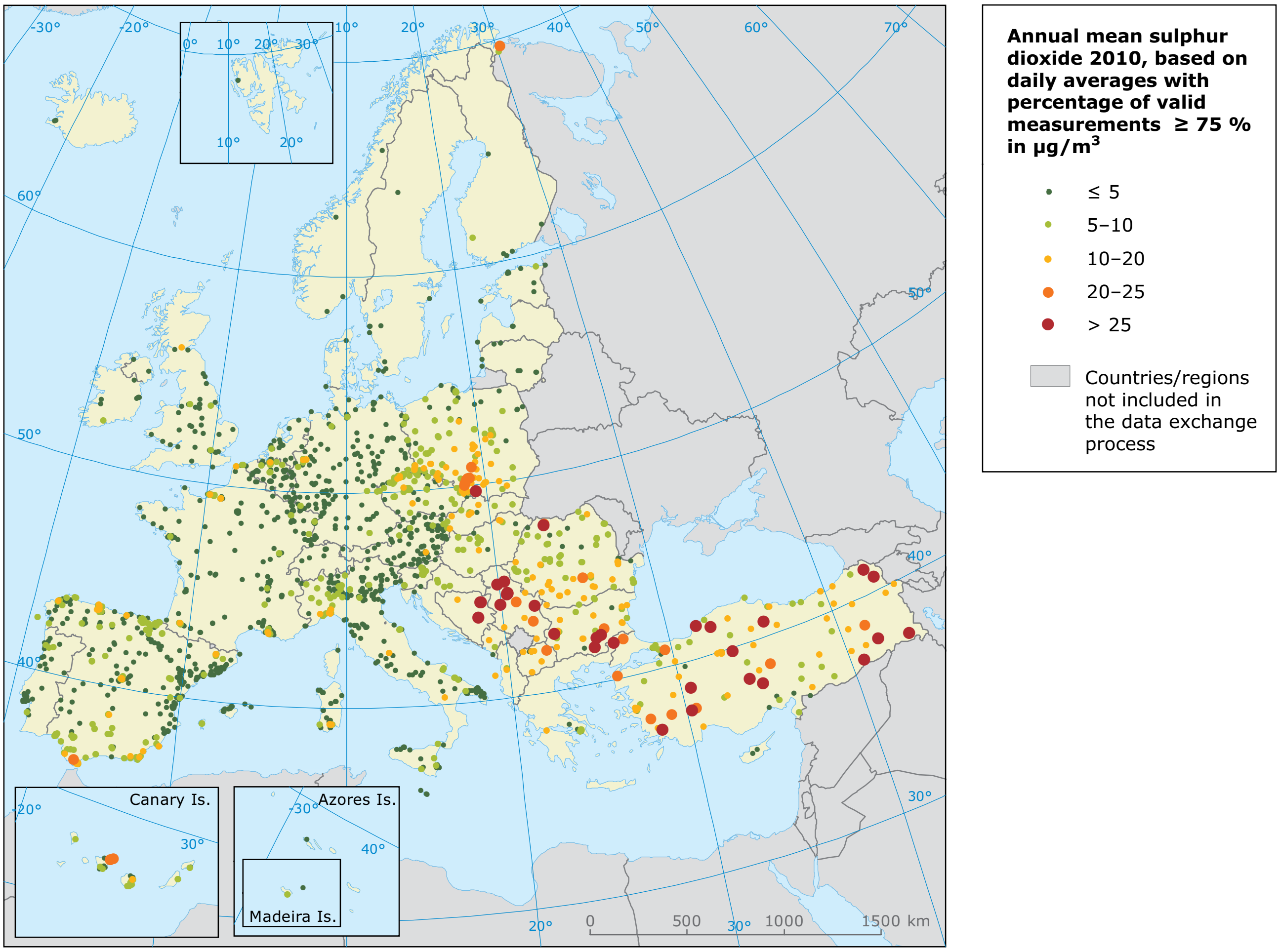
The hourly limit value for the protection of human health was only exceeded in 2010 at three stations (all urban), two in Bulgaria and one in Romania. The daily limit value was exceeded also at three urban stations, in Bulgaria, Poland and Romania (Figure 5.2).

Map 5.1 shows annual mean SO_2 concentrations in 2010. As in previous years, the highest concentrations and exceedances of the annual limit value for protection of vegetation occurred in the western Balkan countries and Turkey, and at some stations in Silesia in south Poland.

5.3.2 *Distance to target*

Figure 5.1 is the distance-to-target graph for the daily and hourly limit values of SO_2 for health protection. SO_2 concentrations are well below the limit values, except for three urban stations.

Map 5.1 Annual mean SO_2 concentrations (µg/m^3), 2010

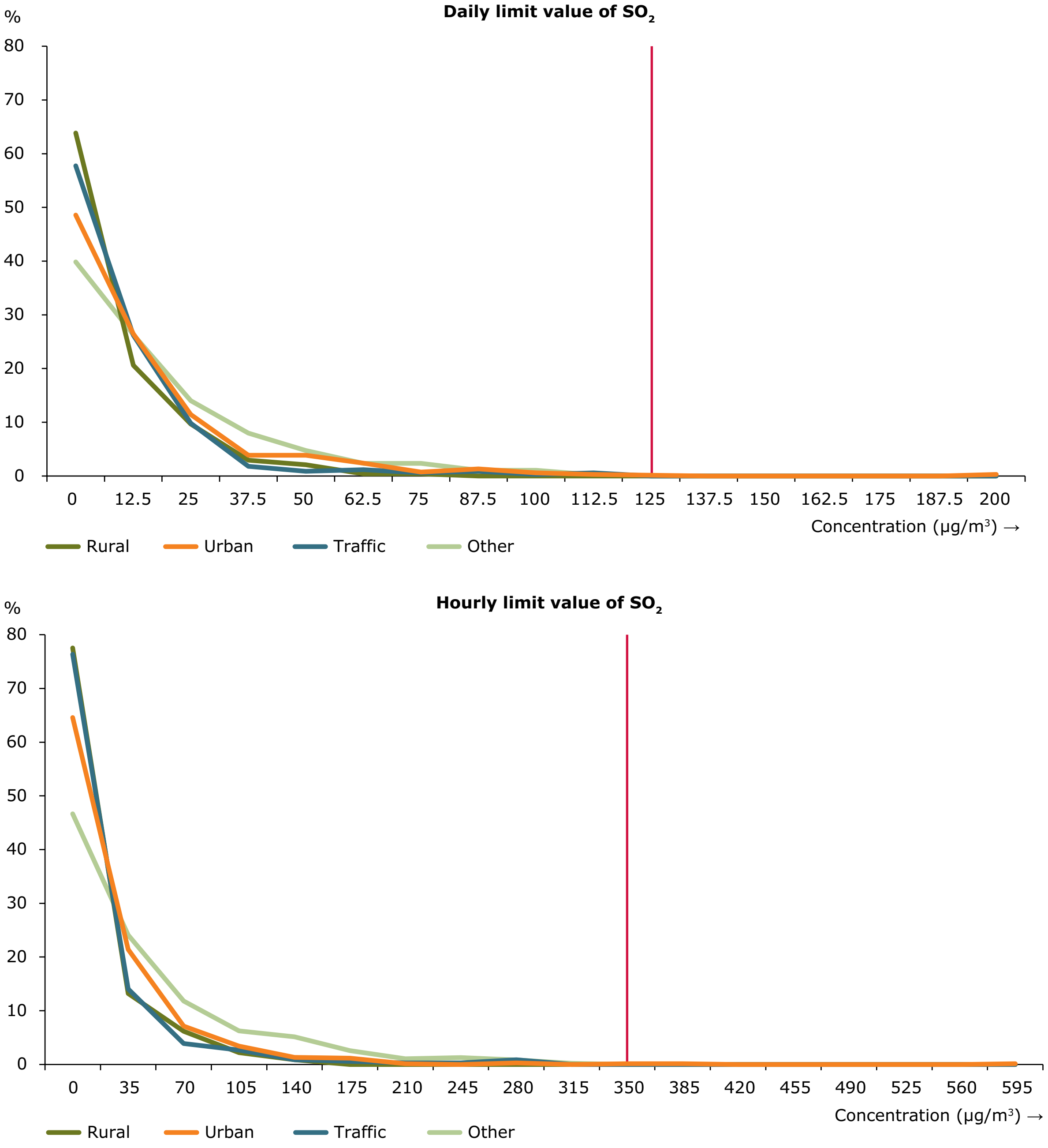


Note: The dark orange and red dots correspond to exceedances of the limit value (20 µg/m^3) for the protection of vegetation.

Source: AirBase v. 6.

The limit value set for the protection of vegetation (20 µg/m^3 annual mean) was exceeded at 1.1 % of stations in the EU in 2010. None of those exceedances occurred at rural locations where relatively more vegetation needs to be protected than in urban areas. The limit value for the protection of vegetation set for the winter period (20 µg/m^3) was not exceeded at rural stations, but at urban (23), traffic (6) and industrial (8) stations.

Figure 5.1 Distance-to-target graph for the daily (top) and hourly (bottom) limit values of SO_2 for health protection, 2010

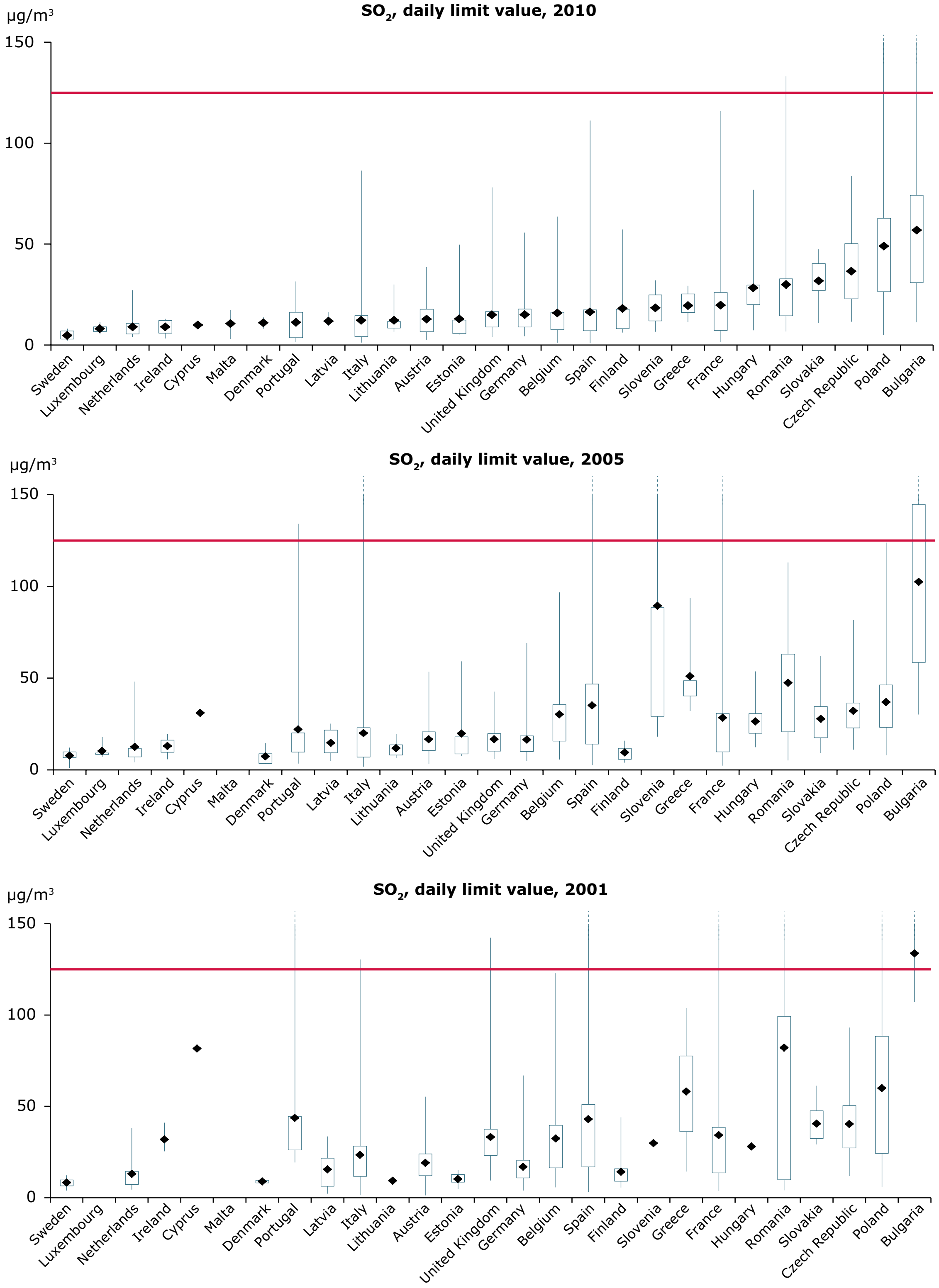


Note: The graphs show the percentage frequency distribution of stations (on the y-axis) in the EU Member States versus the various concentration classes (on the x-axis, in µg/m^3).

Vertical lines correspond to the limit values set by the EU legislation.

Source: AirBase v. 6.

Figure 5.2 Attainment situation for SO_2, reference years 2010, 2005, 2001



Note: The graphs are based on the 99.2 percentile of daily mean concentration values corresponding to the 4th highest daily mean; they present the range of concentrations at all station types (in µg/m³) officially reported by the EU Member States and how the concentrations relate to the limit value set by EU legislation (marked by the red line).

The diagram indicates the lowest and highest observations, the means and the lower and upper quartiles. The lower quartile splits the lowest 25 % of the data and the upper quartile splits the highest 25 % of the data.

Source: ETC/ACM.

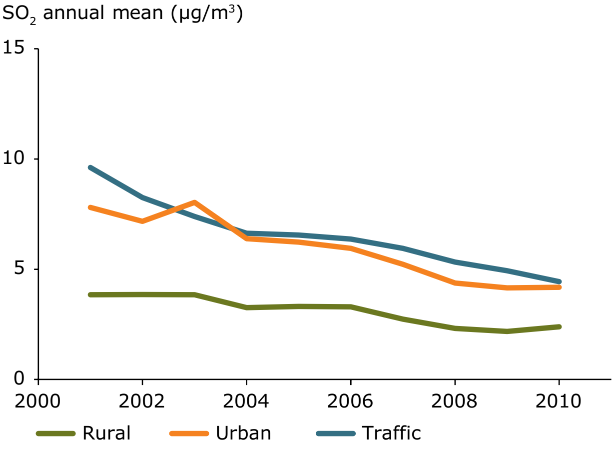
Figure 5.2 shows for all EU Member States the exceedance of the daily limit value for SO_2 in 2010, 2005 and 2001. It shows that exceedance of the daily limit value has been decreasing in total number and especially in Belgium, Bulgaria, France, Greece, Portugal, Romania and Spain. The only country, with SO_2 data for 2001, 2005 and 2010, which registered an exceedance of the daily limit value for SO_2 in all of the three years was Bulgaria.

5.3.3 *Trends in SO_2 concentrations and emissions*

Reported SO_2 concentrations decreased steadily in the period 2001–2010 (Figure 5.3), falling on average by about half. At nearly all urban background and traffic stations a significant trend is observed (de Leeuw, 2012). During this period, the average concentration at traffic stations was about 1 μg/m^3 higher than at urban background stations, falling to 0.3 μg/m^3 in 2010, suggesting that the contribution to SO_2 emissions from road traffic is small and decreasing.

EU emissions of SO_2 have fallen substantially since 2001 (Figure 2.6). Total EU emissions in 2010 were 54 % less than in 2001. The reduction of EEA-32 emissions of SO_2 in the same period was 44 %. Sulphur dioxide emissions in 2010 were approximately 40 % lower than the aggregated emissions ceiling for EU set for 2010 in the NEC Directive. Observed SO_2 concentrations fell by 54 % at traffic stations during the period 2001–2010, and by 46 % and 38 % at urban and rural stations, respectively (Figure 5.3). These data correspond well with the reported emissions reductions.

Figure 5.3 Trend in average annual SO_2 concentrations (2001–2010) per station type



Note: All stations in EU Member States, with at least 75 % data coverage for at least eight years were included in the analysis. Concentrations per station type are given in μg/m^3. In the diagram a geographical bias exists towards central Europe where there is a higher density of stations.

Source: ETC/ACM.

The energy sector is still the dominant emissions source for SO_x, accounting for 59 % of EU emissions in 2010 (Figure 2.7), although its emissions have been cut by 53 % since 2001. The next largest sector is industry, with 25 % of EU emissions in 2010, with a reduction of 29% of its emissions between 2001 and 2010.

5.4 Exposure to SO_2 pollution in Europe

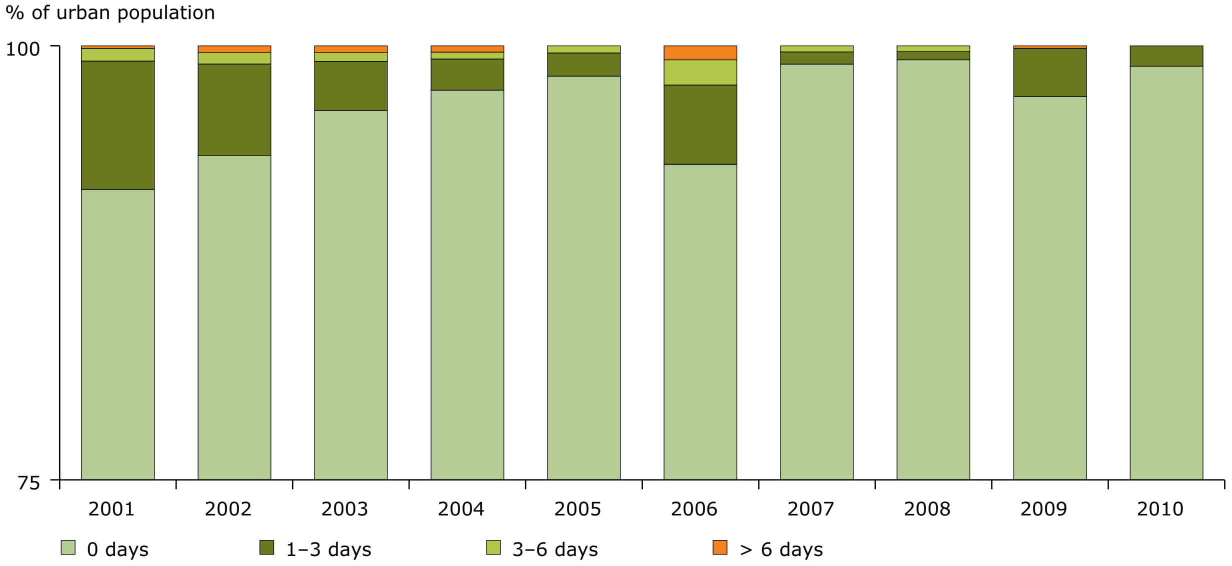
5.4.1 *Human exposure*

AirBase SO_2 monitoring data provide the basis for estimating the European population's exposure to exceedances of the SO_2 limit value of 125 μg/m^3 as a daily average, not to be exceeded more than three days in a year and to be met by 2005. This analysis is shown in Figure 5.4 for the EU in the period 2001–2010. The exposure is estimated based on SO_2 measured in urban background locations. It is considered that the entire population is exposed to these concentrations, since people move freely within the city. For each city an average concentration is calculated.

In 2010 none of the EU urban population (and 1.6 % of the EEA-32 urban population) was exposed to SO_2 above the 24-hour average limit value, which includes a derogation of 3 days of allowed exceedances per year (Figure 5.4). The extent of exposure above this limit value has varied in the EU and EEA-32 between zero and 4 % since 2001. There is a decreasing trend over this period. The range partly reflects variations caused by meteorology. The stations measuring SO_2 concentrations above the limit values are mostly industrial stations.

The EU urban population exposed to SO_2 levels exceeding the WHO AQG was significantly higher in 2010, comprising 58 % of the total urban population. This percentage has declined from 84 to 58 % between 2001 and 2010 (Figure ES.2).

Figure 5.4 **Percentage of the EU urban population exposed to SO_2 concentrations over the daily average limit value for protection of human health, 2001–2010**



Source: EEA, 2012d (CSI 004).

5.4.2 *Exposure of ecosystems*

Sulphur dioxide emissions and subsequent deposition of S (via wet or dry deposition) contribute to acidification of the natural environment. The exposure of European ecosystems to acidifying compounds is described in Section 4.4.2, where also estimated exceedance of critical loads for acidity is discussed.

5.5 Responses

The directives most relevant for the reduction of SO_2 in air are those relating to emissions from combustion of fuels in power plants and industry, i.e. the LCP and IPPC Directives (EU, 2001a and EU, 2008b). The directives led to significantly reduced SO_X emissions from these sources.

The Sulphur Contents of Liquid Fuels Directive (EU, 1999b) has limited the sulphur contents of heavy fuel oil and gas oils since 2003, contributing to SO_2 emission reductions and subsequent concentration reductions.

The Fuels Quality Directive (EU, 2003) cut the sulphur contents of fuels from 150 mg/kg for petrol and 350 mg/kg for diesel before 2005 to 50 mg/kg for each by 2005 and to 10 mg/kg by 2009. Air quality plans, as described in Section 2.5.4 are additional policy instruments to reduce exposure to SO_2.

6 Carbon monoxide (CO)

6.1 Sources and effects of CO

6.1.1 Origins of CO in air

Carbon monoxide is a gas emitted due to incomplete combustion of fossil fuels and biofuels. Road transport used to emit significant amounts of CO 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.

6.1.2 Health effects of CO

Carbon monoxide enters the body through the lungs. In the blood it is strongly bound to haemoglobin. Exposure to CO can reduce blood's oxygen-carrying capacity, thereby reducing oxygen delivery to the body's organs and tissues. Those suffering from cardiovascular disease are the most sensitive towards CO exposure. Such people already have a reduced capacity for pumping oxygenated blood to the heart, which can cause them to experience myocardial ischemia (reduced oxygen to the heart), often accompanied by angina (chest pain), when exercising or under increased stress. Short-term CO exposure further affects their body's already compromised ability to respond to the increased oxygen demands of exercise or exertion. At extremely high levels, CO can cause death.

Table 6.1 Air quality limit value set by the Air Quality Directive and the WHO air quality guidelines for CO

CO mg/m³	Hourly	8-hour average
EU	–	10
WHO	30	10

Source: EU, 2008c; WHO, 2006.

The atmospheric lifetime of CO is about three months. It slowly oxidises into CO_2, also forming O_3 during this oxidation process. CO therefore contributes to the atmospheric background concentration of O_3, with associated effects on health and ecosystems.

6.2 European air quality standards for CO

Table 6.1 sets out the European air quality limit value and the WHO air quality guideline for CO. The European limit value for health protection is the maximum allowable eight-hour average, to be met by 2005.

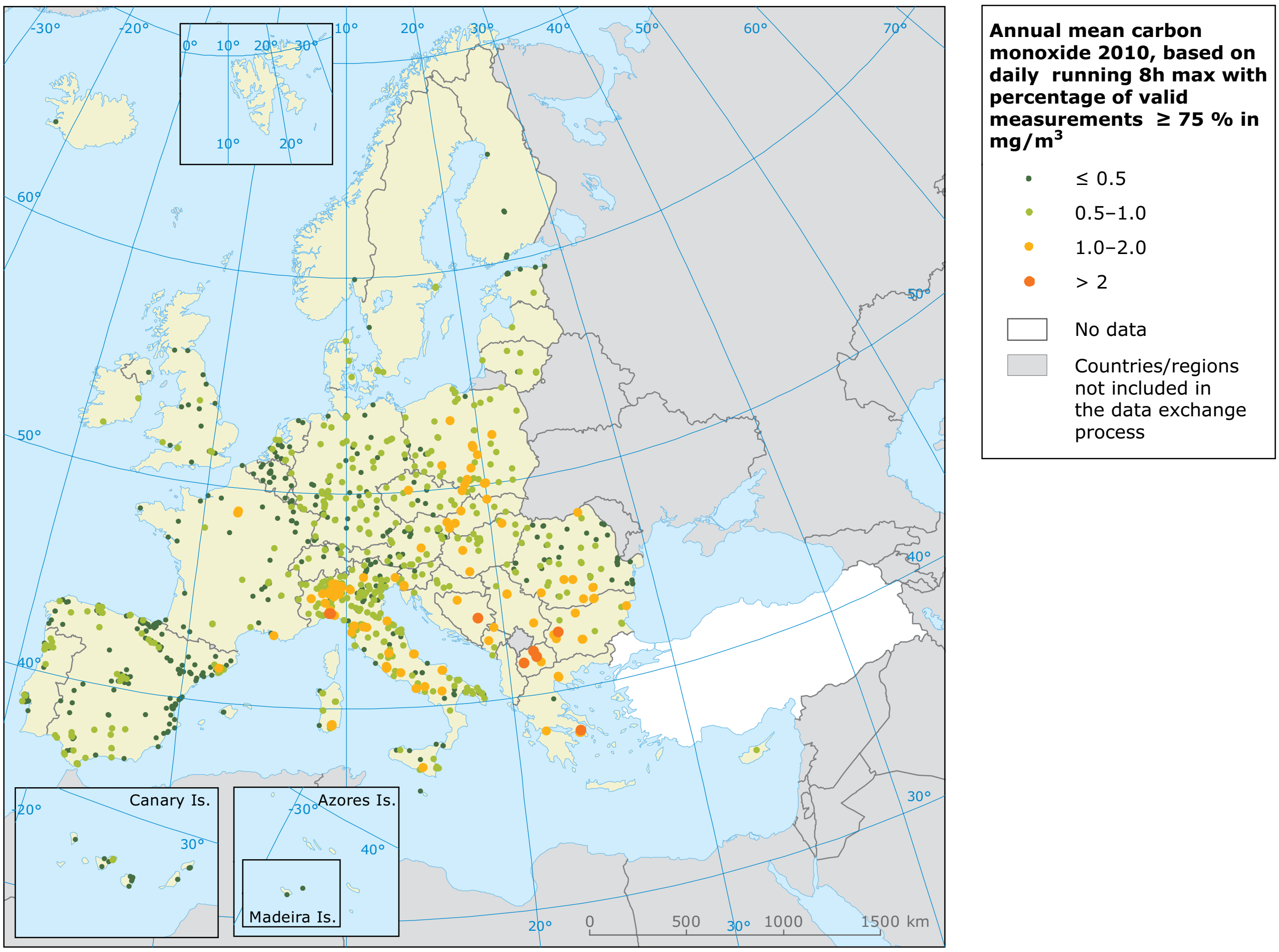
6.3 Europe-wide survey of CO

6.3.1 Exceedances of limit values

Eleven out of 1 159 operational stations with more than 75 % data coverage in the EEA-32 countries reported exceedances of the CO limit value: three traffic stations, six urban background stations and two industrial stations, located in Austria, Bulgaria, Bosnia and Herzegovina, Germany, Italy, Montenegro, Serbia and Sweden. The exceedance example in Sweden took place due to a classic car event in Stockholm over a weekend.

The annual averages of the daily 8-hour maxima (Map 6.1) show elevated levels in some of those countries.

Map 6.1 **Annual mean of maximum daily 8-hour mean CO concentrations (mg/m³), 2010**



Source: AirBase v. 6.

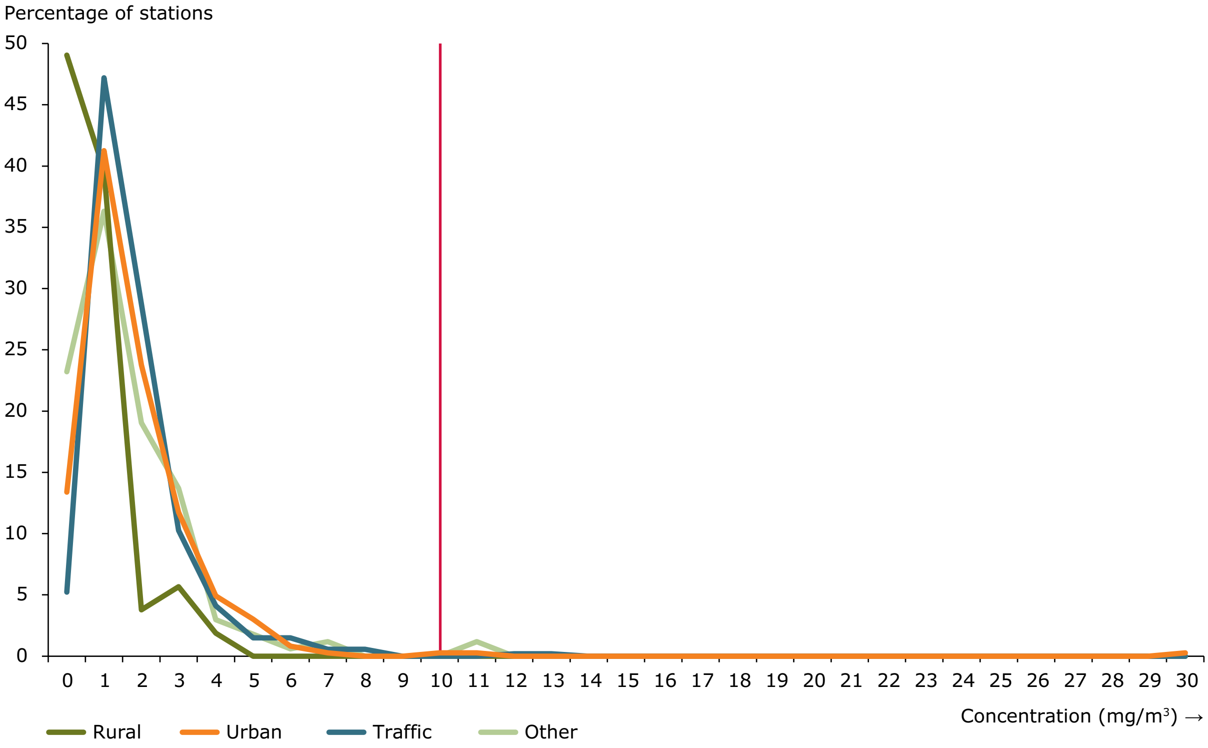
6.3.2 *Distance to target*

Figure 6.1 shows that, except at very few stations, measured CO concentrations in Europe are well below the limit value.

Figure 6.2 shows for all EU Member States the status of the maximum daily 8-hour mean value of CO for 2010, 2005 and 2001. It shows that exceedance of the EU limit value and WHO AQG value occurred in five EU member countries in 2010. The only country, with CO data for 2001, 2005 and 2010, which registered an exceedance of the limit value in the three years was Italy.

In contrast to the situation for the NO_2 annual limit value, CO exceedance situations are sporadic. In the last five years, the limit value was exceeded in three years at two stations; at six additional stations the exceedance occurred during two years (de Leeuw, 2012).

Figure 6.1 Distance-to-target graph for the CO limit value, 2010

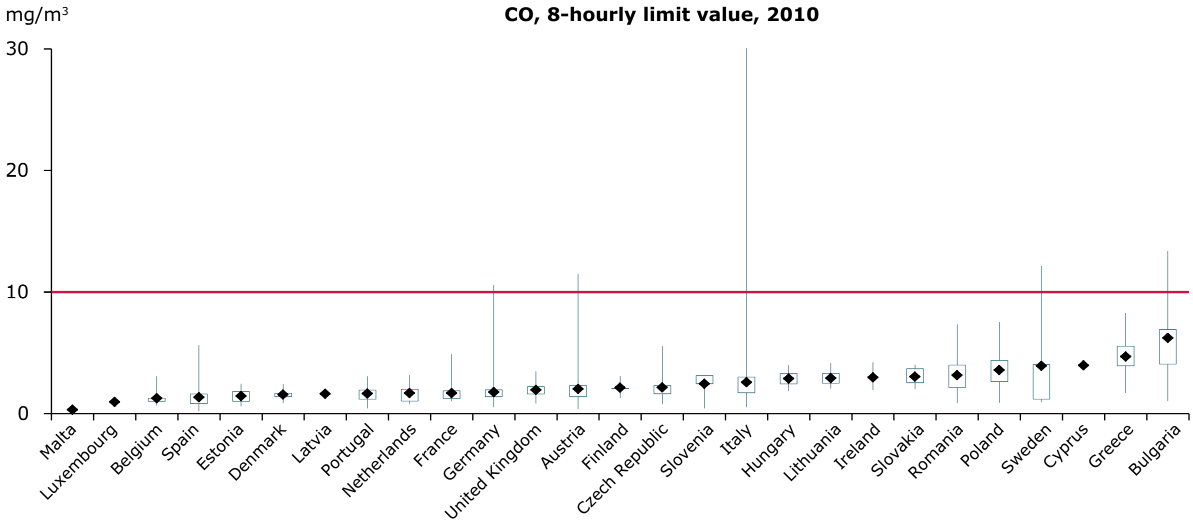


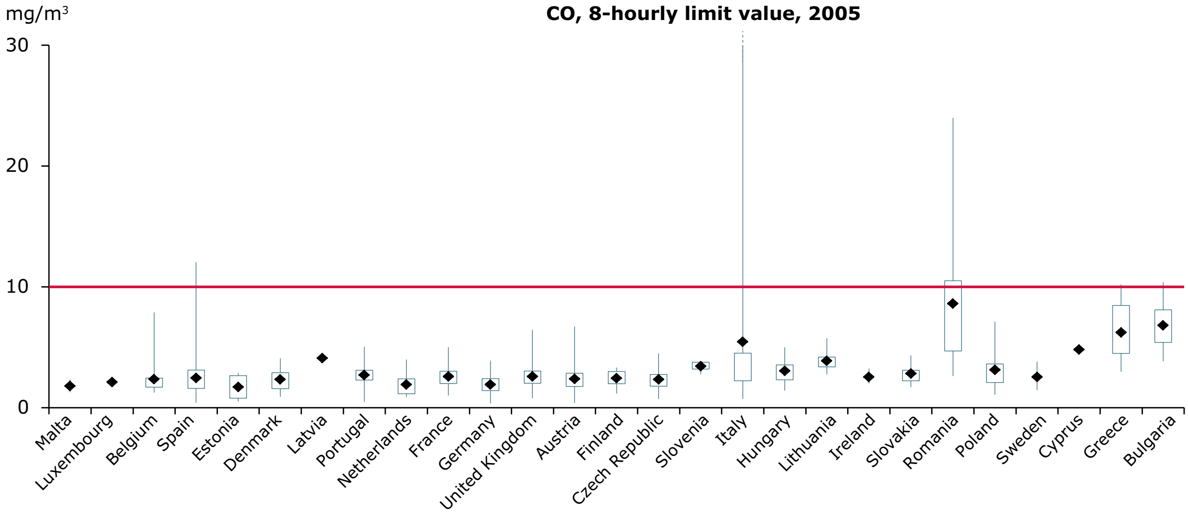
Note: The graph shows the percentage frequency distribution of stations (on the y-axis) in the EU Member States versus the various concentration classes (on the x-axis, in mg/m^3).

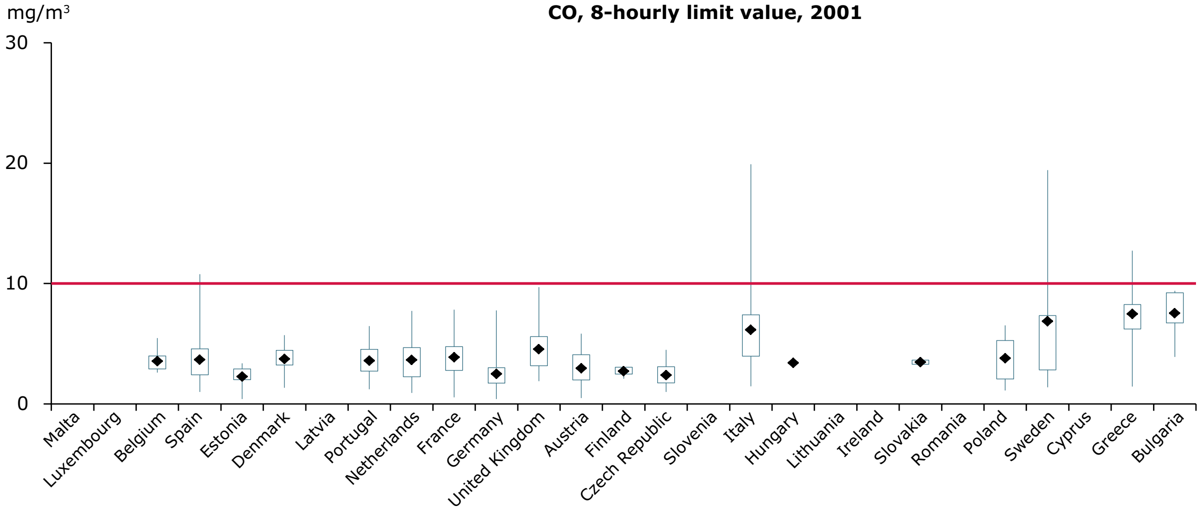
The vertical line corresponds to the limit value set by EU legislation.

Source: AirBase v. 6.

Figure 6.2 Attainment situation for CO, reference years 2010, 2005, 2001





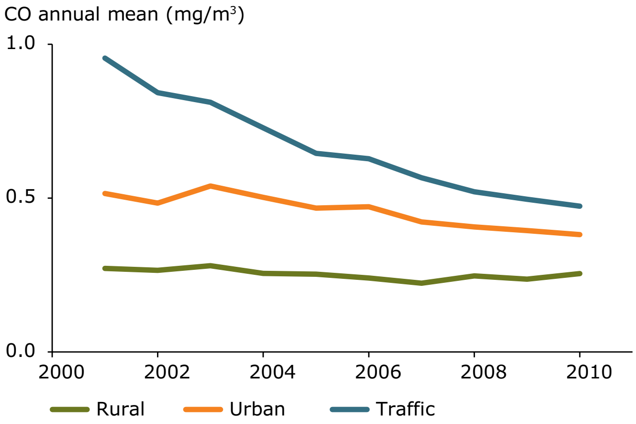


Note: The graphs are based on the 8-hourly mean concentration values; they present the range of concentrations at all station types (in mg/m³) officially reported by the EU Member States and how the concentrations relate to the limit value set by EU legislation (marked by the red line).

The diagram indicates the lowest and highest observations, the means and the lower and upper quartiles. The lower quartile splits the lowest 25 % of the data and the upper quartile splits the highest 25 % of the data.

Source: ETC/ACM.

Figure 6.3 **Trend in annual mean CO concentrations (2001–2010) per station type**



Note: All stations in EU Member States, with at least 75 % data coverage for at least eight years were included in the analysis. Concentrations per station type are given in mg/m³. In the diagram a geographical bias exists towards central Europe where there is a higher density of stations.

Source: ETC/ACM.

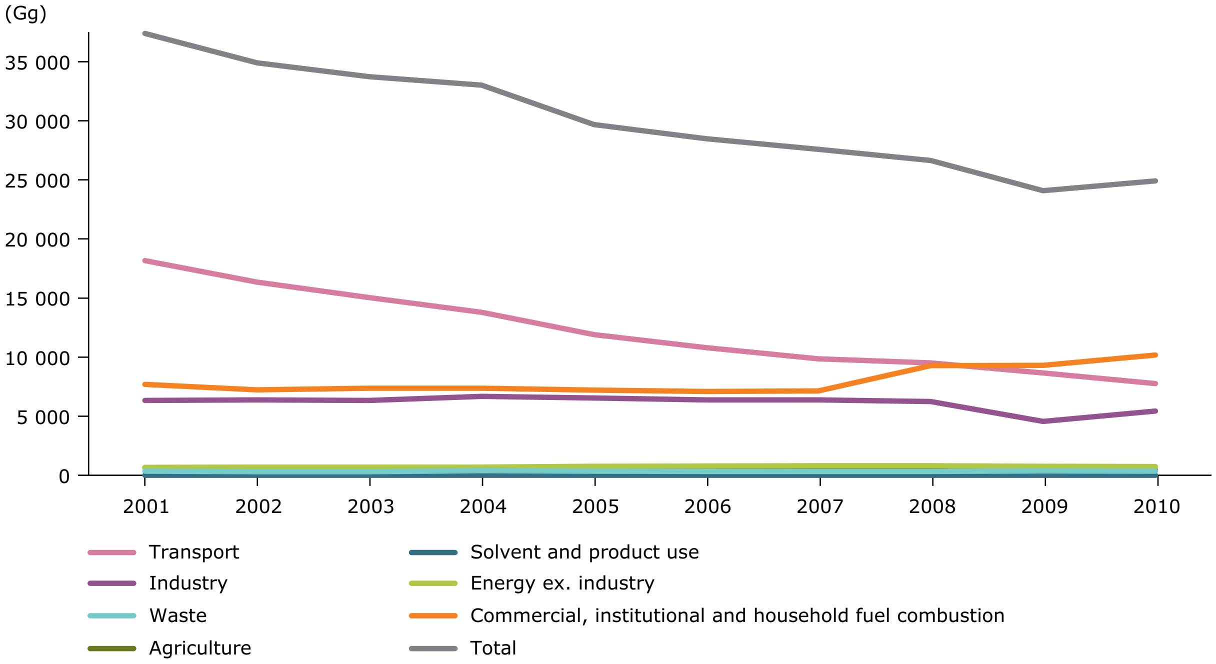
6.3.3 *Trends in CO concentrations*

More than 80 % of urban background and traffic stations show a downward trend. At a limited number of rural stations (18 in total) trends are less clear (de Leeuw, 2012).

Figure 6.3 shows the trend in the annual average CO concentration at each station type from 2001 to 2010. It should be noted that CO — more than any of the other pollutants — is typically measured at traffic stations (more than 50 % of the stations are traffic stations), as traffic is its main cause of exceedance. Figure 6.3 confirms that CO concentrations are in average higher at traffic stations, compared to urban background stations. It also shows a clear decreasing trend in average CO concentrations measured at both traffic and urban stations. The average reduction in annual average CO concentrations measured at traffic stations was 50 % from 2001 to 2010, and 26 % at urban stations.

The concentration at rural stations is very low — close to the detection limit. At these stations there is a large contribution from the hemispheric background of CO. The CO emission reduction in

Figure 6.4 **Total CO emissions (Gg/year = 1 000 tonnes/year) and contributions of the main sources in the EU**



Source: EEA — Air pollutant emissions data viewer (LRTAP Convention).

the period 2001–2010 was 33 % in the EU and 35 % in EEA-32 (Figure 6.4). Commercial, institutional and household fuel combustion was Europe's largest CO source in 2010, following the very significant reduction in transport sector emissions that have resulted from applying the Euro emission standards.

The observed reductions in CO concentrations in the period 2001–2010 (with a 50 % average decrease at traffic stations, 26 % at urban background stations and 6 % at rural stations) is in line with the reported reduction in total emissions of about 33 % over the same period. CO concentrations are now very low most of the time and instrument measurement uncertainties at these levels affect the accuracy of the measured concentrations and therefore also the accuracy of trend estimates.

6.4 Exposure to CO pollution in Europe

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, limited to very few areas, near traffic and industry.

6.5 Responses

Carbon monoxide emissions are mainly regulated by the IPPC Directive (EU, 2008b) — now replaced by the Industrial Emissions Directive (EU, 2010b) and the Euro emission standards for motor vehicles, which set CO emission limits for gasoline and diesel vehicles (see Annex 2). The emission limits have been more than halved since the early 1990s. Over the same period the CO emissions from transport have been reduced by more than 75 %. The largest CO emission sector is now residential heating, which is currently unregulated with respect to CO emissions and increasing since 2007 (Figure 6.4).

7 Heavy metals

Arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg) and nickel (Ni) are common air pollutants, mainly emitted as a result of various industrial activities and combustion of coal. Although the atmospheric levels are low, they contribute to the deposition and build-up of heavy metal contents in soils, sediments and organisms. Heavy metals are persistent in the environment and some bioaccumulate, i.e. accumulate in organisms, in the food chains.

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 exposures have developmental and neuro-behavioural effects on foetuses, infants and children, and elevate blood pressure in adults. Mercury is toxic in the elemental and inorganic forms but the main concern is associated with its organic compounds, especially methylmercury. It 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 heavy metals affect even the most remote regions (WHO, 2007).

7.1 Sources and effects of heavy metals

7.1.1 As

Origins of As in air

Arsenic is released into the atmosphere from both natural and anthropogenic sources. Most man-made emissions are released from metal smelters and the combustion of fuels. Pesticides used to be an important source but their importance declined as a result of restrictions in various countries. Tobacco smoke may contain As, thereby being a source of exposure in ambient air.

Arsenic in air is usually a mixture of As and arsenate, with organic varieties of negligible importance except in areas where there is substantial application of methylated As pesticides.

Effects of As

The oral uptake of As, through food and drinking water, is generally the most important route of exposure. Inhalation normally contributes less than 1 % to the total dose. The non-cancerous effects of inhaling air with high As levels include increased mortality from cardiovascular diseases, neuropathy and gangrene of the extremities. There is evidence that inorganic As compounds are skin and lung carcinogens in humans. Lung cancer is the critical effect following exposure by inhalation.

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 and bioaccumulate in the food chain.

7.1.2 Cd

Origins of Cd in air

Cadmium is released into the atmosphere from natural and anthropogenic sources. Volcanoes, windborne particles and biogenic emissions are considered the main natural sources of Cd in the atmosphere. The anthropogenic sources of Cd include non-ferrous metal production, stationary fossil fuel combustion, waste incineration, iron and steel production and cement production.

Effects of Cd

Food is the main source of Cd exposure in the general population, representing more than 90 %

of the total intake in non-smokers. In heavily contaminated areas, resuspended dust can constitute a substantial part of the exposure for the local population.

In Europe, air pollution and mineral and organic fertilisers contribute almost equally to annual exposure. They increase the relatively large accumulations of Cd in topsoil, thereby increasing the risk of future exposure through food. The levels of Cd in non-smokers have not decreased over the last decade.

The kidneys and bones are the critical organs affected by chronic environmental exposure to Cd. Main effects include impaired kidney function and increased risk of osteoporosis. An increased risk of lung cancer has also been reported following inhalation exposure in occupational settings.

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. It can also produce lung cancer in humans and animals via inhalation. Cadmium is highly persistent in the environment and bioaccumulates.

7.1.3 Pb

Origins of Pb in air

Lead is released into the atmosphere from natural and anthropogenic sources. Natural emissions typically include soil dust and sea spray containing Pb, as well as particles found in ashes from volcanoes and forest fires. These emissions are not entirely natural but contain some deposits of anthropogenic Pb. Major anthropogenic emission sources of Pb on a global scale include the combustion of fossil fuels from, for example, traffic, waste disposal and production of non-ferrous metals, iron, steel and cement. The contribution to emissions from Pb in gasoline has been eliminated in Europe. This followed a complete phase-out through legislation and complete take-up of un-leaded gasoline.

Effects of Pb

Lead is a neurotoxic metal that also accumulates in the body and damages organs, such as the kidneys, liver, brain, and nerves. Exposure to high levels causes serious brain damage, including mental retardation, behavioural disorders, memory problems and mood changes. Impairment of neurodevelopment in children is the most critical effect. Exposure in utero, during breastfeeding or in early childhood may lead to such health problems. Lead accumulates in the skeleton which is potentially dangerous during pregnancy. Hence, previous exposure to a woman before pregnancy is important.

Inhalation exposure may be significant when Pb levels in the air are high. Elevated exposures are generally due to local sources rather than being the result of long-range transport. Most often, food is the predominant source of Pb uptake in the general population. However, 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.

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.

7.1.4 Hg

Origins of Hg in air

The largest anthropogenic source of 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. The main natural sources of Hg emissions are diffusion from the Earth's mantle though the lithosphere, evaporation from the sea surface and geothermal activity. Mercury emitted in inorganic forms is converted biologically to methylmercury in soil and water.

Effects of Hg

Mercury can damage the liver, the kidneys and the digestive and respiratory systems. It can also cause brain and neurological damage and impair growth. Methylmercury is a potent neurotoxin. Unborn children are the most vulnerable population group.

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.

7.1.5 Ni

Origins of Ni in air

Nickel is a trace metal which occurs in soil, water, air and in the biosphere. Nickel emissions to the atmosphere may occur from natural sources such as wind-blown dust, volcanoes and vegetation. The main anthropogenic sources of Ni emissions into the air are combustion of oil for heat, shipping or power generation, Ni mining and primary production, incineration of waste and sewage sludge, steel manufacture, electroplating and coal combustion.

Effects of Ni

Food is the major source of exposure to Ni but exposure can also result from breathing ambient air, drinking water or inhaling tobacco smoke containing Ni. Skin contact with soil, bath or shower water, or metals containing Ni, as well as metals plated with Ni can also result in exposure.

In very small quantities Ni is essential to humans. However, a large uptake can be a danger for human health as several Ni compounds are carcinogenic, increasing the risk of developing, for example, lung, nose, larynx or prostate cancers. Non-cancerous effects on health are allergic skin reactions (generally not caused by inhalation) and effects on the respiratory tract, the immune and defence systems and on endocrine regulation. The most common harmful health effect of Ni in humans is an allergic reaction. Approximately 10–20 % of the population is sensitive to Ni.

As is the case for humans, Ni is an essential element for animals in small amounts. 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. It is known that high Ni concentrations in sandy soils can damage plants and 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.

7.2 European air quality standards for heavy metals

Table 7.1 shows the European air quality target values for As, Cd and Ni and the limit value for Pb. The values specified are maximum annual averages, which countries are required to meet by 2013, except for the limit value for Pb which was to be met by 2005. Table 7.1 also shows the WHO air quality guidelines as annual mean concentrations.

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.

7.3 Europe-wide survey of heavy metals

Barrett et al. (2008) reviewed the concentrations of Pb and the pollutants covered by the Fourth Daughter Directive (4DD) 2004/107/EC (EU, 2004b), i.e. As, Cd, Ni and BaP and pointed to the little

Table 7.1 Air quality limit and target values for As, Cd, Ni and Pb regulated by EU, and WHO air quality guidelines

Pollutant	EU target or limit value (a)	WHO AQG
Arsenic	6 ng/m^3 (b)	–
Cadmium	5 ng/m^3 (b)	5 ng/m^3 (d)
Nickel	20 ng/m^3 (b)	–
Lead	500 ng/m^3 (c)	500 ng/m^3

Note: (a) Annual mean, measured as contents in PM_{10}.

(b) Target value, entering into force on 31 December 2012.

(c) Limit value to be met by 1 January 2005. The limit value to be met only by 1 January 2010 in the immediate vicinity of specific industrial sources situated on sites contaminated by decades of industrial activities. In such cases, the limit value until 1 January 2010 is 1.0 µg/m^3.

(d) AQG set to prevent any further increase of Cd in agricultural soil.

Source: EU, 2004b; and WHO, 2000.

availability of concentration measurements. Compared to 2006, the period reviewed by Barrett et al. (2008), the number of monitoring stations has increased in 2010 but monitoring data for parts of Europe is still missing in AirBase.

As concentrations of these pollutants are frequently below the lower assessment threshold (LAT), techniques other than monitoring can be used for assessing air quality. This might be the reason why these pollutants are reported for a relatively small number of stations. Following the data quality objectives set in EU legislation, for indicative measurements a criterion on data coverage of 14 % is applied here on the heavy metal data. 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 heavy metals have been measured on the PM_{10}-particle size fraction (as required by the directive) or on another (undefined) size fraction, e.g. particles of all sizes.

Map 7.1 presents annual mean ambient concentrations of As, Cd, Pb and Ni reported across Europe. The maps show that the air pollution problem of these heavy metals is highly localised: problems are related to specific industrial plants or areas covered by monitoring stations.

De Leeuw (2012) summarised the results from the reported 2010 data as follows:

- **Arsenic** concentrations below the lower assessment threshold (2.4 ng/m^3) were reported at nearly 90 % of the stations in 2010. At twelve stations (out of 542 operational stations) the reported concentrations exceeded the target value set for 2013. A relatively large number of exceedances is observed in Belgium (five stations of which four are located close to one industrial plant in Hoboken, near Antwerp). The remaining five exceedances are seen in the Czech Republic, Germany, Poland and Slovakia. In two exceedance situations As has been reported as belonging to 'aerosol', i.e. an undefined size fraction.
- **Cadmium** concentrations in air exceeded the target value at 1.7 % of the stations in Europe in 2010. Exceedances are observed in three countries (Belgium, Bulgaria, Spain) mainly at industrial, traffic and urban stations. At the majority of the other stations, concentrations are below the lower assessment threshold (2 ng/m^3).
- **Lead** concentrations exceeded the limit value at two stations (in Bulgaria and in Romania) in 2010. 99 % of the stations reported Pb concentrations below the lower assessment threshold of 0.25 µg/m^3.
- **Nickel** concentrations exceeded the target value at eight out of the 551 operational stations (1.5 %). These stations are located in Belgium, Germany and Italy. Most of the exceedances are related to industry.
- **Mercury** concentrations recorded in AirBase are very few, despite the fact that the 4DD (EU, 2004b) requests EU Member States to perform (indicative) measurements of Hg, at — at least — one background station. Background concentrations of Hg in air in 2010 ranged from 1.3 to 2.0 ng/m^3 over large parts of Europe (17 stations in Finland, Germany, Lithuania, Poland, Slovenia and Sweden). Deposition measurements are reported at 20 stations (of which 18 are located in Germany and the United Kingdom). Averaged over all stations, the annual deposition flux is 0.10 g/ha/year.

7.4 Trends in concentrations and emissions of heavy metals

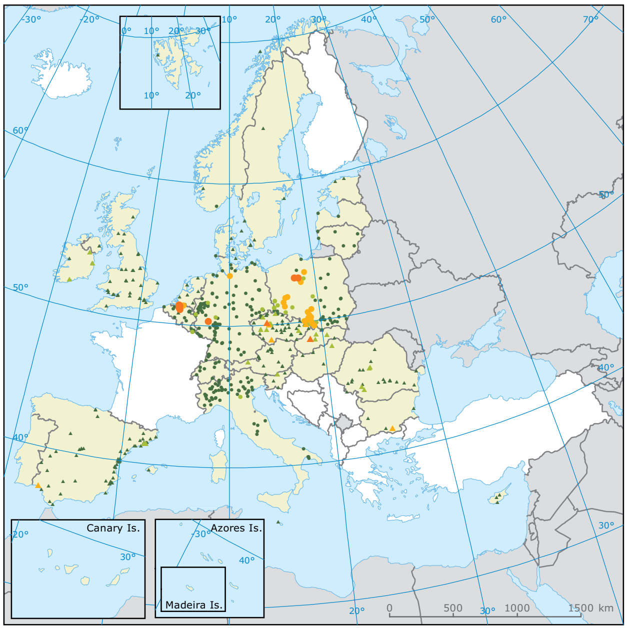
There is no requirement in EU legislation that EU Member States report emissions for different heavy metals. Nevertheless, a number of EU Member States have signed and ratified the 'Heavy Metals Protocol' under the UNECE LRTAP Convention under which the reporting of certain information is required. Meanwhile, others report emission data to the convention voluntarily for these species. Nevertheless, the reported estimates of heavy metal emissions are of relatively high uncertainty compared to the main air pollutants, as the data is not always complete and emissions estimates are sometimes based on relatively few measurement data.

7.4.1 As

The number of As monitoring stations has increased rapidly in recent years, to more than 500 stations in 2009 and 2010, including background, traffic and industrial stations.

The majority of stations recorded a slight reduction in As concentrations in the period 2006–2010, although it is worth stressing that the sampling and measurement method was not reported for some stations and the methods might have

Map 7.1 Annual mean concentrations of heavy metals (arsenic, cadmium, lead and nickel), 2010

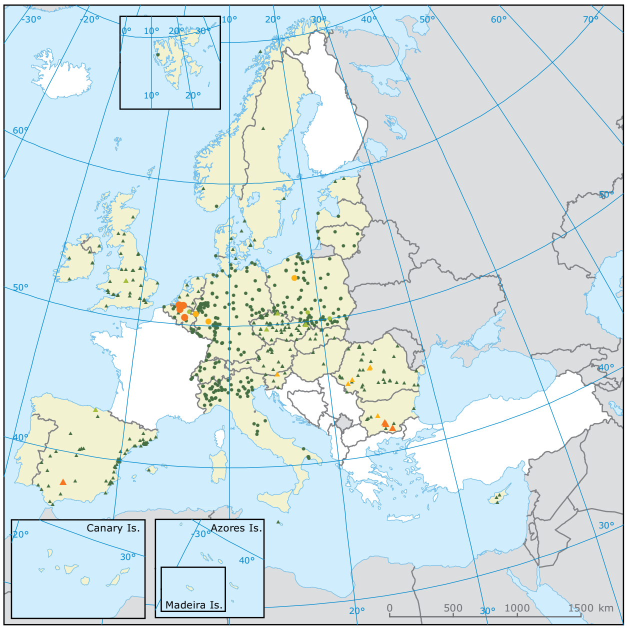


Annual mean arsenic 2010, based on annual average with percentage of valid measurements ≥ 14 % in ng/m^3

○ Reported in PM_{10} fraction △ No indication of PM_{10} fraction

▲ ● ≤ 2 ▲ ● 2–4 ▲ ● 4–6 ▲ ● > 6

☐ No data ▨ Countries/regions not included in the data exchange process

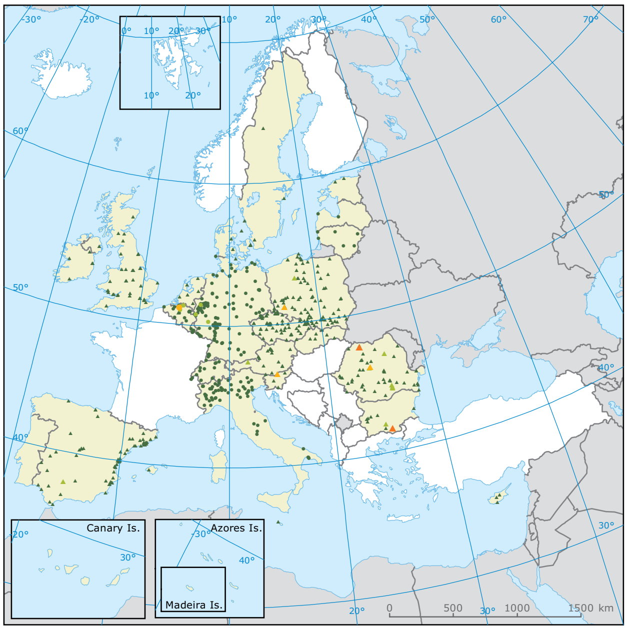


Annual mean cadmium 2010, based on annual average with percentage of valid measurements ≥ 14 % in ng/m^3

○ Reported in PM_{10} fraction △ No indication of PM_{10} fraction

▲ ● ≤ 2 ▲ ● 2–3 ▲ ● 3–5 ▲ ● > 5

☐ No data ▨ Countries/regions not included in the data exchange process

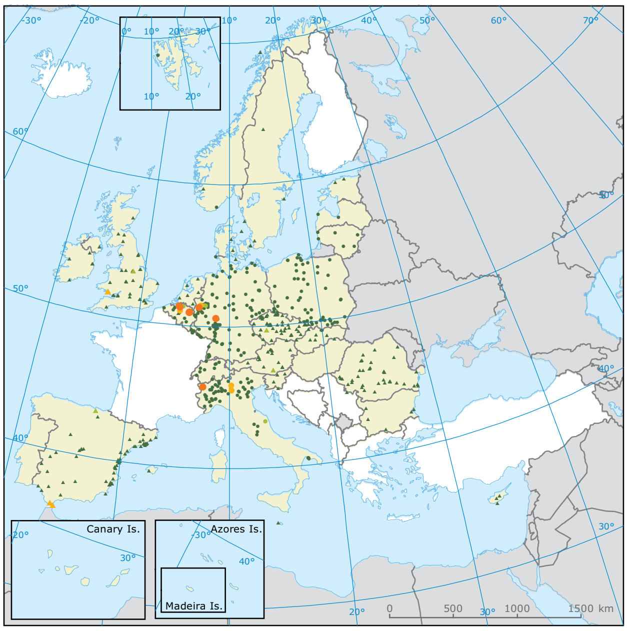


Annual mean lead 2010, based on annual average with percentage of valid measurements ≥ 14 % in µg/m^3

○ Reported in PM_{10} fraction △ No indication of PM_{10} fraction

▲ ● ≤ 0.1 ▲ ● 0.1–0.25 ▲ ● 0.25–0.5 ▲ ● > 0.5

☐ No data ▨ Countries/regions not included in the data exchange process



Annual mean nickel 2010, based on annual average with percentage of valid measurements ≥ 14 % in ng/m^3

○ Reported in PM_{10} fraction △ No indication of PM_{10} fraction

▲ ● ≤ 10 ▲ ● 10–15 ▲ ● 15–20 ▲ ● > 20

☐ No data ▨ Countries/regions not included in the data exchange process

Source: AirBase v. 6.

changed during the period. The short period of the assessment makes it impossible to undertake a statistical analysis of the concentration trend and its statistical significance.

Most countries decreased their country average concentrations between 2006 and 2010. Bulgaria decreased its total As emissions between 2006 and 2010 by 25 %. Arsenic concentration at one station in Bulgaria increased however significantly between 2006 and 2009, while at another station a decrease could be observed from 2006 to 2010. Slovakia reduced its As emissions by 18 % between 2006 and 2010 (registering an increase between 2009 and 2010). These changes in Slovak emissions are reflected in generally decreasing As concentrations between 2006 and 2010 and an increase between 2009 and 2010 at three stations.

Figure 7.1 shows the development in As (and other heavy metals) emissions reported by the EU Member States between 2001 and 2010 as a percentage of 2001 emissions. Arsenic emissions were reduced in average by about 4 % from 2001 to 2010 in EU (by 5 % in the EEA-32 countries), registering both increases and decreases in the period.

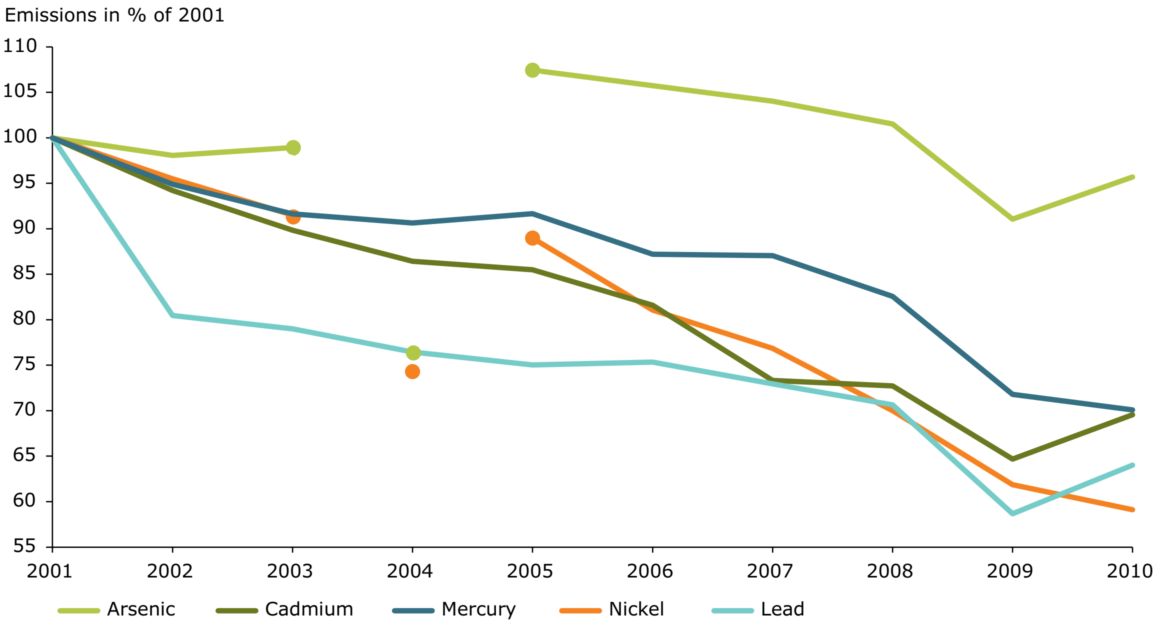
Twenty-two countries reported emissions for whole period. Poland did not report emissions of As in 2004, which is the reason for the decrease in reported total emissions in 2004. Poland was responsible for 15–20 % of EU emissions of As in 2001–2010. The time series of As concentration changes are at present too short and the geographical coverage too limited to support a Europe-wide comparison with emission trends.

7.4.2 *Cd*

As is the case for As, the majority of stations recorded a reduction in concentrations during the last five years. The number of stations measuring Cd concentrations in air has increased significantly over recent years, reaching almost 600 in 2010 and covering 23 EU Member States.

Concentrations are decreasing at all (14) stations in Switzerland over the last ten years (2001–2010), albeit two of them registered an increase from 2009 to 2010. United Kingdom (with 21 stations recording data from 2006 to 2010) registered a decrease in concentrations between 2006 and 2010 and a

Figure 7.1 EU emissions of As, Cd, Hg, Ni and Pb, 2001–2010, as a percentage of 2001 emissions



Note: Poland did not report emissions of As nor Ni in 2004 which explains the decrease in reported emissions in 2004. Poland was responsible for 15–20 % of EU emissions of As and 13–18 % of EU emissions of Ni in 2001–2010.

Source: CEIP, 2012 for As and Ni, and EEA for Cd, Hg and Pb.

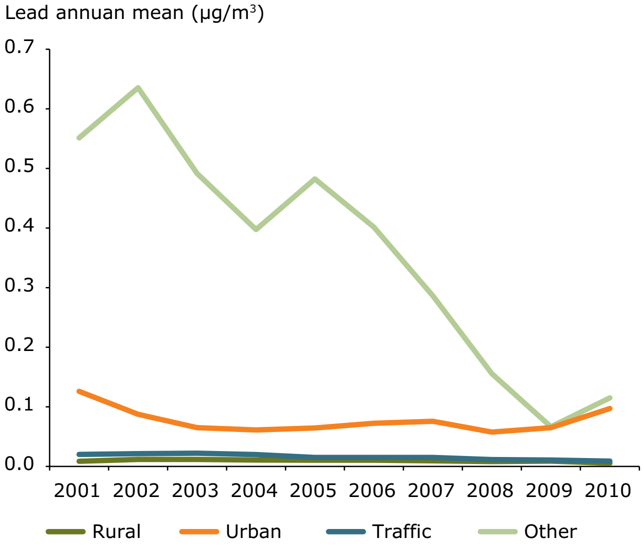
slight increase at three stations between 2009 and 2010. Spain registered a clear general decrease in concentrations between 2006 and 2010. In Austria, Belgium, Bulgaria, the Czech Republic and Germany the stations recorded both increasing and decreasing concentrations since 2006.

Cadmium emissions in the EU and EEA-32 decreased by 30 % between 2001 and 2010 (Figure 7.1). The Cd concentration time series are limited to several countries. The limited geographical coverage in Europe does not support a Europe-wide comparison with emission changes.

7.4.3 Pb

For the period 2001–2010, Pb concentration data in AirBase were available for eight countries (23). While concentrations have remained almost constant at traffic and rural stations since 2001 (Figure 7.2), there is a clear reduction in measured concentrations at industrial stations (designated as 'other') since 2002 and until 2009, with some increase between 2009 to 2010.

Figure 7.2 Average of the annual mean concentrations of Pb reported by monitoring stations in eight countries (23), 2001–2010



Source: ETC/ACM.

Lead emissions decreased in the EU and EEA-32 by 36 % between 2001 and 2010 (Figure 7.1). The Pb concentration time series are limited to eight countries. The low geographical coverage does not support a Europe-wide comparison with emission changes.

7.4.4 Hg

Various compounds of Hg are measured at a number of stations in the EMEP network, using a variety of methods. Pending an EMEP analysis of those measurements, and in view of the limited data available in AirBase, trends in Hg concentrations in air in Europe are not evaluated here.

Mercury emissions in the EU and EEA-32 decreased by 30 % between 2001 and 2010 (Figure 7.1).

7.4.5 Ni

Nickel concentrations were reported for the period 2001–2010 by Belgium. There is a general decrease in concentrations. In Belgium the average annual decrease in Ni concentrations was about 1 ng/m^3. In the period 2001–2010 Belgium has reduced its Ni emissions by 85 %.

From 2006 to 2010 thirteen countries reported concentrations of Ni: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Germany, Italy, Latvia, the Netherlands, Slovakia, Spain, Switzerland and the United Kingdom. The average concentrations measured between 2006 and 2010 have continuously decreased in Austria, Belgium, Bulgaria, the Czech Republic and Spain.

Nickel emissions decreased in the EU and EEA-32 countries by 41 % between 2001 and 2010 (Figure 7.1). As outlined above, Ni concentration time series is limited to one country for the period 2001–2010. The geographical coverage is too low to support a Europe-wide comparison with emission changes.

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(23) Austria, Belgium, Bulgaria, Denmark, Ireland, the Netherlands, Romania and Switzerland.

7.5 Exposure to heavy metal pollution in Europe

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 typically related to specific industrial plants.

On the other hand, atmospheric deposition of heavy metals into the environment contributes to the exposure of ecosystems and organisms to heavy metals and bioaccumulation in the food chain, also affecting human health. A part of the ecosystem area is at risk due to atmospheric deposition of Cd, Pb or 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 or 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 heavy metal critical loads involve Hg. More than half of all EEA-32 countries (24) 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).

7.6 Responses

The former IPPC Directive (EU, 2008b) and the Waste Incineration Directive (EU, 2000), now replaced by the Industrial Emissions Directive (EU, 2010b), as well as the Fuels Quality Directive (EU, 2003) regulate heavy metals emissions.

The Industrial Emissions Directive includes metals and their compounds in its list of polluting substances to be regulated. It obliges industries to use best available techniques to limit the emissions of heavy metals as much as possible.

The Fuels Quality Directive (2003/17/EC) requires that all motor fuel sold in the EU after 1 January 2002 be Pb free. This has eliminated the contribution from road traffic to Pb concentrations in air.

The European Commission's Strategy on Mercury (EC, 2005a), launched in 2005 and reviewed in 2010, addresses most aspects of the Hg life cycle. Its key aim is to reduce Hg levels both in relation to human exposure and the environment. It identifies twenty priority actions undertaken, both within the EU and internationally, to reduce Hg emissions, cut supply and demand and protect against exposure, especially to methylmercury in fish. As a result, restrictions were set on the sale of measuring devices containing Hg, a ban on exports of Hg from the EU came into effect in March 2011 and new rules on safe storage were adopted.

Further, international conventions control emissions and transport of Hg: Examples are: 1) the UNECE Convention on Long-Range Transboundary Air Pollution aiming to cut emissions of Hg and other heavy metals from industry, combustion and waste and lower emissions from products; 2) the Basel Convention (25) on the Control of Transboundary Movements of hazardous Wastes and their Disposal aiming to protect health and environment from use/movement of waste to developing countries/eastern Europe and stating that Hg contaminated waste may not be exported from the EU for disposal, recovery or recycling in other countries.

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

(25) http://www.basel.int.

8 Benzene (C_6H_6) and benzo(a)pyrene (BaP)

8.1 Sources and effects

8.1.1 C_6H_6

Origins of C_6H_6 in air

Incomplete combustion of fuels is the largest source of C_6H_6. Benzene is an additive to petrol and 80–85 % of C_6H_6 emissions are due to vehicle traffic in Europe. Other sources are domestic heating, oil refining and petrol handling, distribution and storage. In general the contributions from domestic heating are small (about 5 %) but with sharp geographic patterns. Wood combustion can be an important local source of C_6H_6 where wood burning can account for more than half of the domestic energy needs (Hellén et al., 2008).

Removal of C_6H_6 from the atmosphere mainly occurs through the photochemical degradation of C_6H_6 which also contributes to O_3 formation, although the chemical reactivity of C_6H_6 is relatively low. An atmospheric lifetime of several days is sufficient for C_6H_6 to be transported over long distances.

Health effects of C_6H_6

Inhalation is the dominant pathway for C_6H_6 exposure in humans, with smoking representing a large source of personal exposure. Food and water consumption is only a minor source.

Benzene is a carcinogenic pollutant. The most significant adverse effects from prolonged exposure are damages to a cells' genetic material which can cause cancer. Chronic exposure to C_6H_6 can depress bone marrow and cause haematological effects such as decreased red and white blood cell counts.

8.1.2 BaP

Origins of BaP in air

Benzo(a)pyrene is a five-ring PAH and is found in fine PM originating from incomplete combustion. A main source of BaP in Europe is domestic home heating, in particular wood burning, waste burning, coke and steel production and mobile sources. Other sources include outdoor burning and rubber tyre wear.

Health effects of BaP

The International Agency for Research on Cancer (IARC) considers BaP a known carcinogen. While laboratory studies show that BaP is a known carcinogen in animals, epidemiological studies have only been able to assess the effect of a mixture of PAH, including BaP found in soot, tars and oils. Benzo(a)pyrene is a promutagen, which means it needs to be metabolised before it can induce mutation. Benzo(a)pyrene can also react with O_3 to produce strong mutagens such as BaP-4,5 oxide.

8.2 European air quality standards for C_6H_6 and BaP

The limit value for C_6H_6 and the target value for BaP for the protection of human health set by EU legislation are shown in Table 8.1.

Table 8.1 **Air quality limit and target values for C_6H_6 and BaP annual mean concentration as set out in EU legislation**

	EU
Benzene µg/m³	5 (^{a})
Benzo(a)pyrene ng/m³	1 (^{b})

Note: (^{a}) Limit value to be met by 2010.

(^{b}) Target value to be met by 2013.

Source: EU, 2004b; EU, 2008c.

8.3 Europe-wide survey of C_6H_6 and BaP

8.3.1 C_6H_6

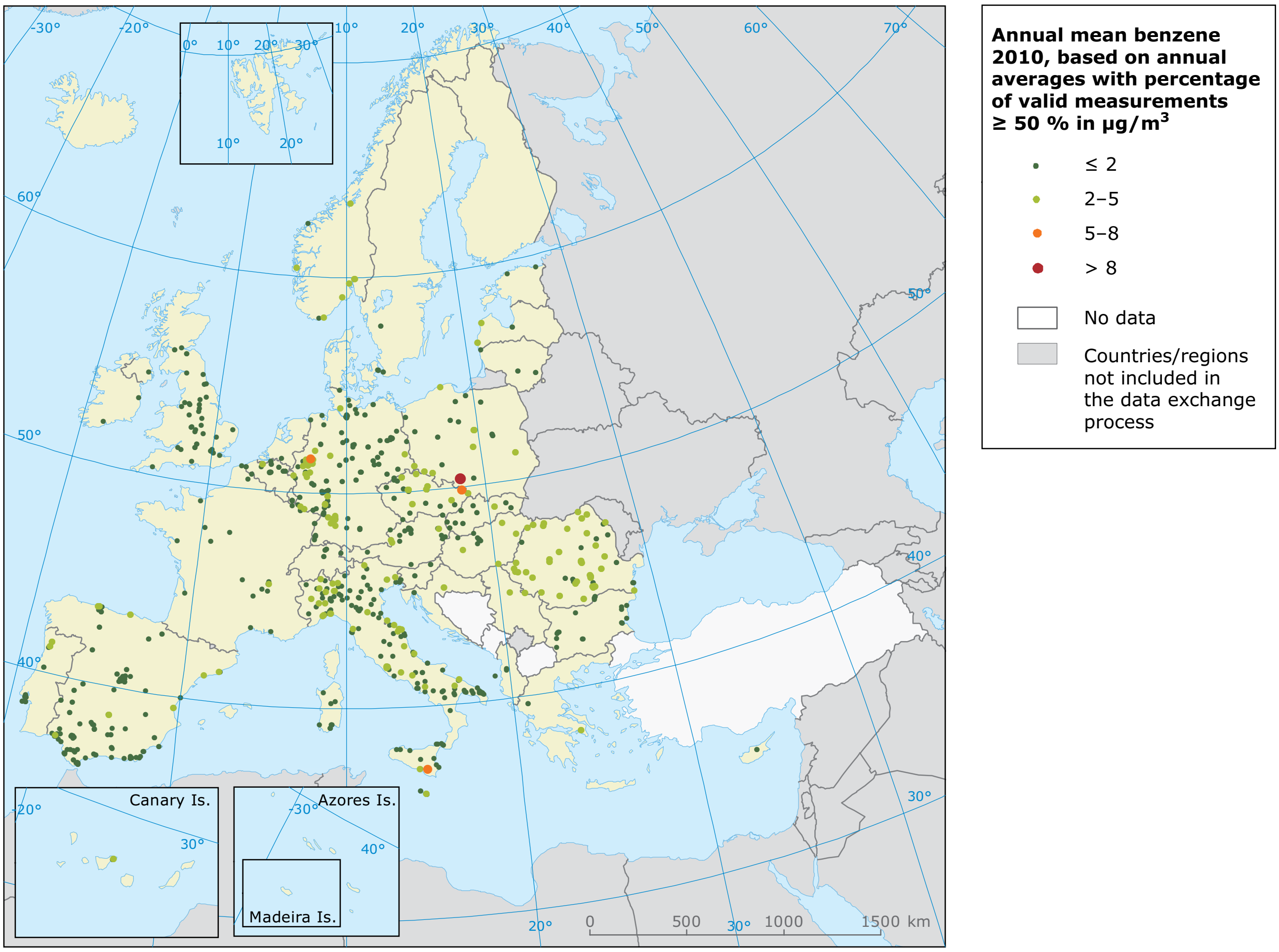
Exceedances of limit value

Benzene is measured at a relatively small number of stations. At many locations, annual mean concentrations of C_6H_6 are below the lower assessment threshold of 2 $\mu g/m^3$ (Barrett et al., 2008). When concentrations are below the lower assessment threshold air quality can be assessed by means of indicative or discontinuous measurements.

The 2008 Air Quality Directive (EU, 2008c) sets an annual average concentration limit value of 5 $\mu g/m^3$ for C_6H_6 in ambient air, to be met by 2010.

Map 8.1 presents the annual average C_6H_6 concentrations at stations with at least 50 % data coverage. The limit value was exceeded at four stations, in the Czech Republic, Germany, Italy and Poland. The exceedances were observed in urban (1) and industrial (3) stations, with no exceedances of the limit value observed at rural background stations.

Map 8.1 Annual mean C_6H_6 concentrations, 2010



Note: Pale green dots correspond to exceedances of the lower assesment threshold (2 $\mu g/m^3$).
Orange and red dots correspond to exceedances of the limit value (5 $\mu g/m^3$).
Red dots correspond to exceedances of the limit value plus 3 $\mu g/m^3$.
The data coverage criterion has been set to 50 % by an European Commission working group on benzene (Mol et al., 2011).

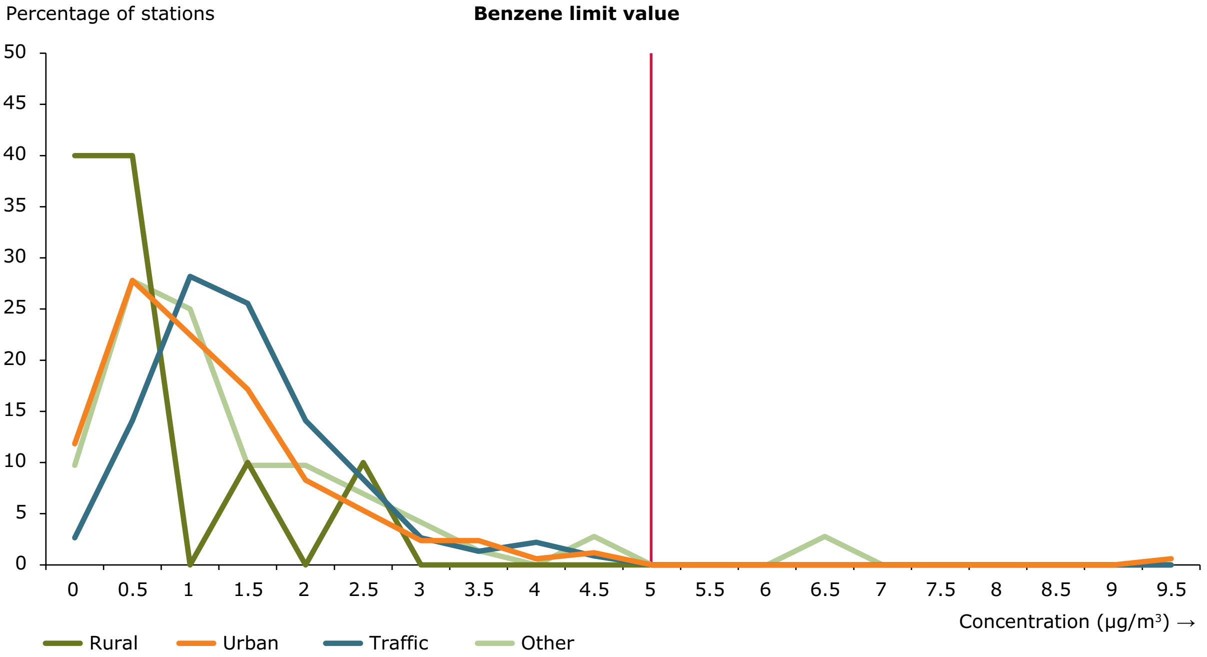
Source: AirBase v. 6.

Distance to target

Figure 8.1 shows that, except at four stations, measured C_6H_6 concentrations in Europe are well below the limit value.

Figure 8.2 shows for all EU Member States the status of the annual mean C_6H_6 values for 2010, 2005 and 2001. It shows that in 2010 C_6H_6 annual concentrations were, on average, well below the limit value.

Figure 8.1 Distance-to-target graph for the C_6H_6 limit value, 2010

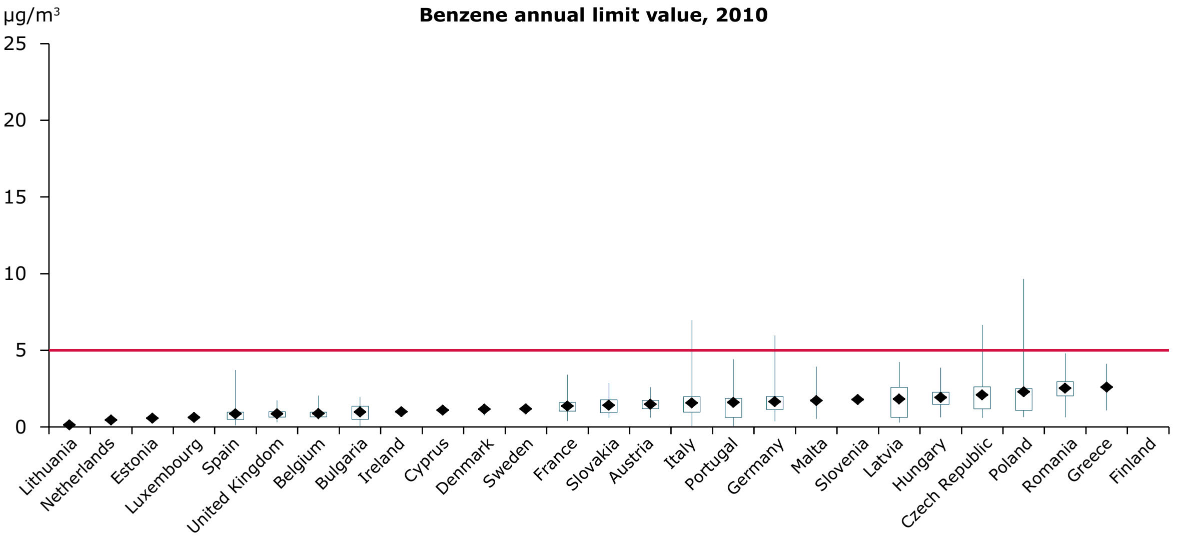


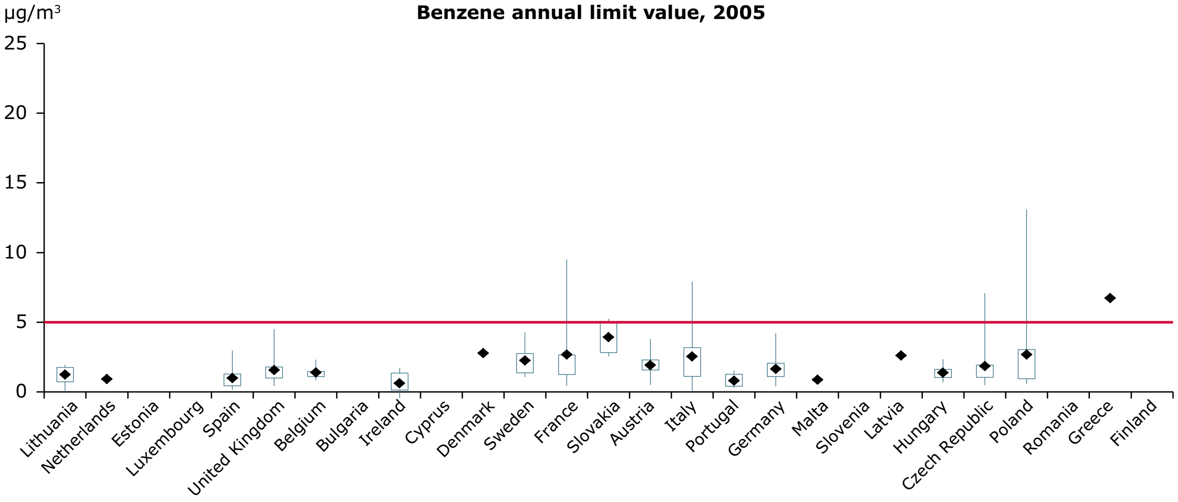
Note: The graph shows the percentage frequency distribution of stations (on the y-axis) in the EU Member States versus the various concentration classes (on the x-axis, in µg/m³).

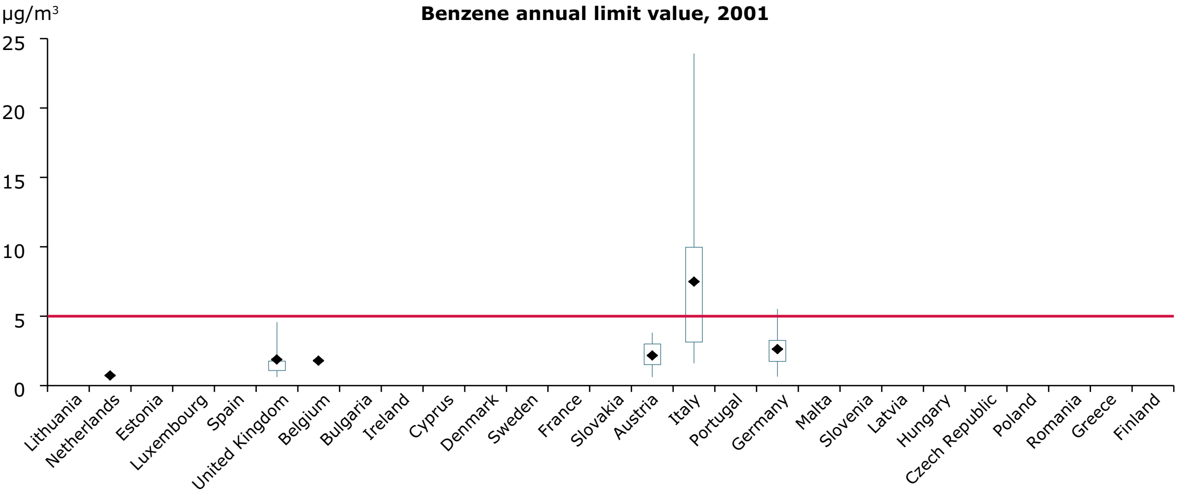
The vertical line corresponds to the limit value set by the EU legislation.

Source: AirBase v. 6.

Figure 8.2 Attainment situation for C_6H_6, reference years 2010, 2005, 2001





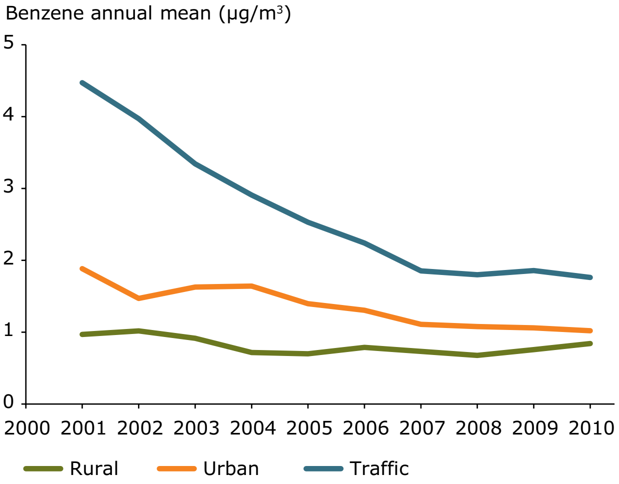


Note: The graphs are based on the annual mean concentration values; they present the range of concentrations at all station types (in µg/m³) officially reported by the EU Member States and how the concentrations relate to the limit value set by EU legislation (marked by the red line).

The diagram indicates the lowest and highest observations, the means and the lower and upper quartiles. The lower quartile splits the lowest 25 % of the data and the upper quartile splits the highest 25 % of the data.

Source: ETC/ACM.

Figure 8.3 **Trend in average annual mean C_6H_6 concentrations (2001–2010) per station type**



Note: All stations in EU Member States, with at least 75 % data coverage for at least eight years were included in the analysis. Concentrations per station type are given in µg/m³. In the diagram a geographical bias exists towards central Europe where there is a higher density of stations.

Source: ETC/ACM.

Trends in C_6H_6 concentrations

Annual mean concentrations of C_6H_6 averaged for each station type are shown in Figure 8.3. Concentrations were highest at traffic stations, as gasoline is still one of the most important sources of C_6H_6. Concentrations measured at traffic stations decreased steadily until 2007, after which they stabilised. Benzene concentrations at urban and rural stations show a much lower decrease during the same period.

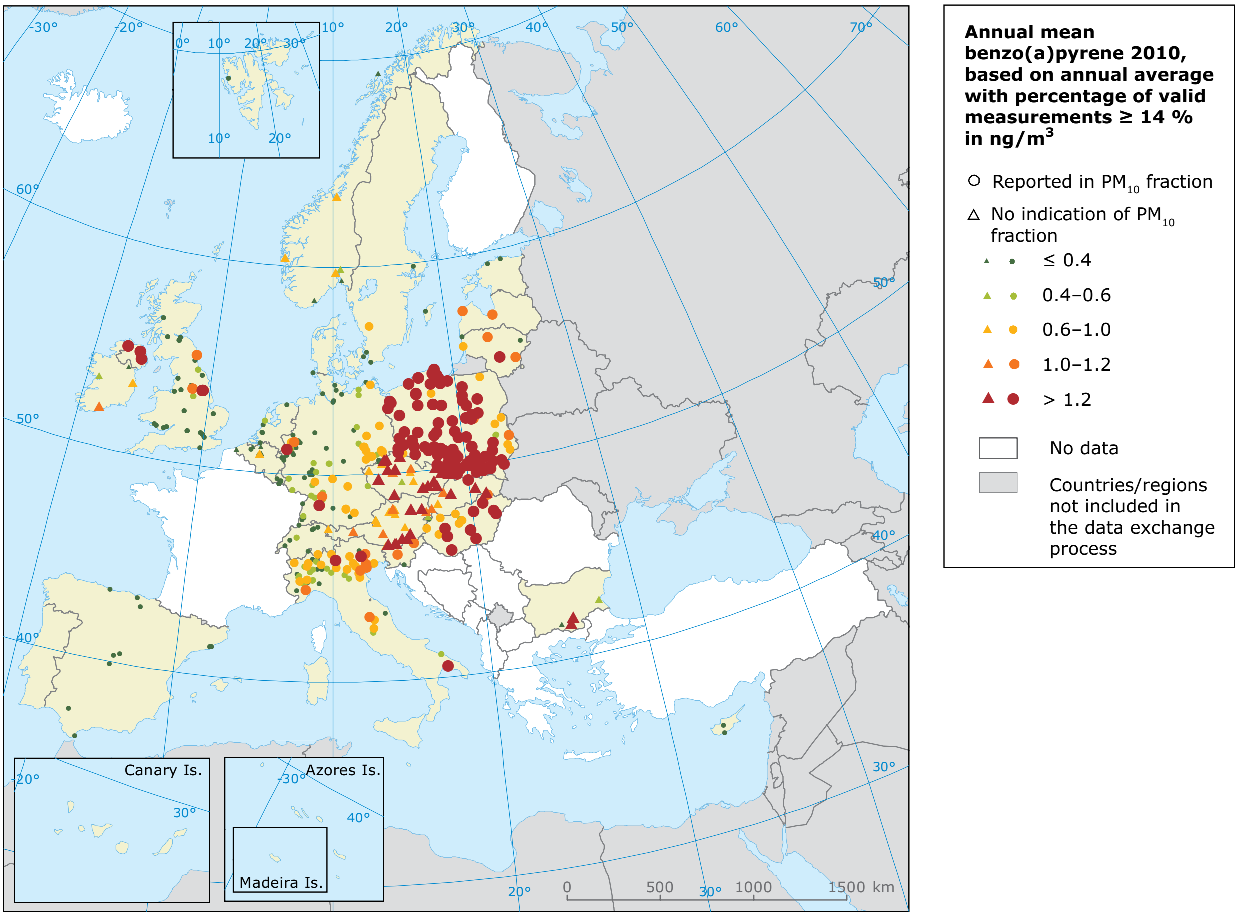
Whether C_6H_6 emissions recorded a similar stabilisation after 2007 is unclear because C_6H_6 is not included as an individual pollutant in European emissions inventories covering VOC.

8.3.2 BaP

Exceedances of target value

Benzo(a)pyrene measurements in 2010 were above the target value threshold (1 ng/m³ annual average

Map 8.2 **Annual mean concentrations of BaP (ng/m³), 2010**



Source: AirBase v. 6.

to be met by 2013) at 38 % of the monitoring stations (Map 8.2). This was the case mainly at urban background stations and, to a lesser extent, at rural, traffic and industrial stations. Exceedances are most predominant in central and eastern Europe (Austria, the Baltic states, the Czech Republic, Hungary, Italy (the Po Valley), Poland and Slovakia although they are also observed in Bulgaria, Germany (the Ruhr area), Ireland, and the United Kingdom (the Midlands and Northern Ireland). In addition France and Greece also report exceedances of the target value in one or more air quality management zones. The assessment for Greece is based on modelling. The exceedances in France are based on monitoring data; these data are, however, not available in AirBase (de Leeuw, 2012).

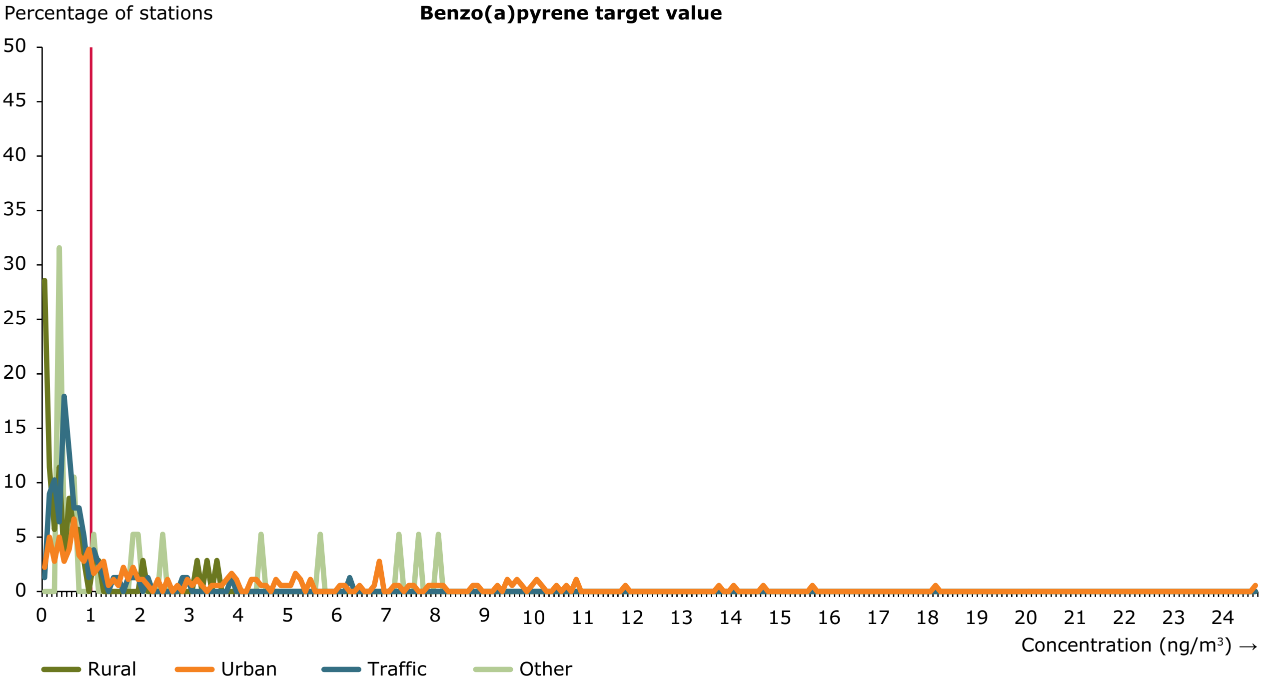
Distance to target

Figure 8.4 shows that many stations are approaching and exceeding the target value for BaP for rural, urban, traffic and other (including industrial) station types. As the figure shows, exceedances occurred at all station types and the lowest concentrations are predominantly measured at rural stations. Figure 8.5 shows for all EU Member States a box plot of the annual mean BaP values for 2010. It shows that in average annual concentrations of BaP exceeded the target value in six countries (Austria, Bulgaria, the Czech Republic, Hungary, Poland, and Slovakia. The average concentration measured at Polish stations is six times higher than the target value.

Trends in BaP concentrations and emissions

Benzo(a)pyrene concentrations can be sourced from a limited number of stations. Since commencing in 2005, 22 stations in three countries have reported data for at least five years. For the three year period leading up to 2010, 17 countries (285 stations) reported BaP measurements, allowing an analysis of persistent exceedances over this period. The exceedances of the EU target value are persistent: at 30 % of the stations measuring an exceedance in 2010, the non-attainment situation continued during the period 2008–2010 (de Leeuw, 2012).

Figure 8.4 Distance-to-target graph for the BaP target value, 2010

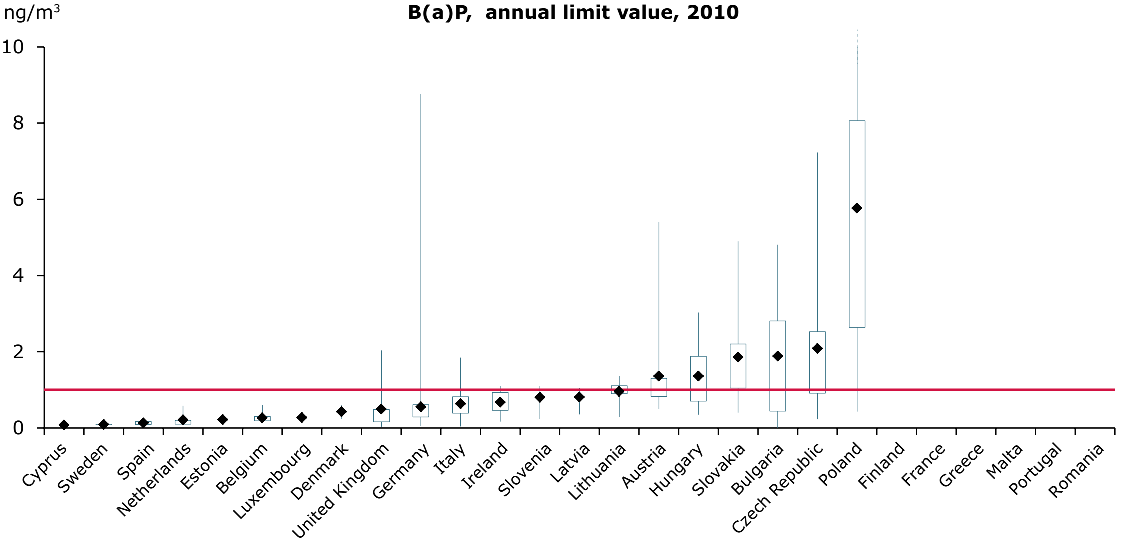


Note: The graph shows the percentage frequency distribution of stations (on the y-axis) in the EU Member States versus the various concentration classes (on the x-axis, in ng/m^3).

The vertical line corresponds to the target value set by the EU legislation.

Source: AirBase v. 6.

Figure 8.5 Attainment situation for BaP, 2010



Note: The graphs are based on the annual mean concentration values. They present the range of concentrations at all station types (in ng/m³) officially reported by the EU Member States and how the concentrations relate to the target value set by EU legislation (marked by the red line).

The diagram indicates the lowest and highest observations, the means and the lower and upper quartiles. The lower quartile splits the lowest 25 % of the data and the upper quartile splits the highest 25 % of the data.

Based on a minimum of 15 % data coverage.

Source: ETC/ACM.

Emissions of BaP in the EU have increased by 14 % between 2001 and 2010. The main emission sector is the 'Commercial, institutional and household fuel combustion' sector, responsible for 84 % of the total emissions of BaP in 2010 in the EU. Emissions from this sector have steadily increased since 2006 (16 % from 2006 to 2010).

8.4 Exposure to C_6H_6 and BaP pollution in Europe

While exposure to C_6H_6 in Europe is limited to a few local areas close to traffic or industrial sources, exposure to BaP pollution is quite significant and widespread. Populations living in central and eastern Europe are exposed to ambient BaP concentrations above the target value (to be met by 2013), as evidenced on Map 8.2. Between 20 % and 29 % of the urban population in the EU was exposed to BaP concentrations above the target value (1 ng/m³) in the period 2008 to 2010. As much as 94 % of the urban population was exposed to BaP concentrations above the calculated WHO reference level (Table ES.1). The increase in BaP emissions in Europe over the last years is therefore a matter of concern, as it is aggravating the exposure of the European population to BaP concentrations.

8.5 Responses

The Fuels Quality Directive (EU, 2003) limits the C_6H_6 content in petrol to below 1 %.

Regarding BaP, the Industrial Emissions Directive (EU, 2010b) regulates emissions from a large range of industrial sources. The list of regulated compounds includes 'Substances and preparations which have been proved to possess carcinogenic or mutagenic properties'. Benzo(a)pyrene as a proven carcinogen, is thus included in the list of compounds regulated by this directive.

The UNECE Protocol on Persistent Organic Pollutants (POPs) obliges parties to reduce their emissions of PAH 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.

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Annex 1 AirBase

AirBase is the EEA's public air quality database system. It contains air quality monitoring data and information submitted by participating countries throughout Europe.

The air quality database consists of a multi-annual time series of air quality measurement data and statistics for a number of pollutants. It also contains meta-information on those monitoring networks involved, their stations and their measurements.

The database covers geographically all EU Member States, the EEA member countries and some EEA candidate countries. The EU Member States are bound under Decision 97/101/EC to engage in a reciprocal exchange of information (EoI) on ambient air quality.

The number of stations increased significantly from 2009 to 2010 for $PM_{2.5}$, C_6H_6 and VOC in particular, following the requirements in the air quality directives.

Table A1.1 Number of stations that provided data on different substances, specified per station type

	SO_2	NO_2	NO_X / NO	PM_{10}	$PM_{2.5}$	Pb	CO	C_6H_6	O_3	VOC	$PM_{2.5}$ _spec	HM	PAH
Reporting EU Member States	27	27	26	27	27	23	27	27	27	17	5	24	23
Total number of stations in 2010 of which	1 897	3 155	2 333	2 817	965	644	1 265	841	2 200	459	15	744	550
• Traffic	365	994	725	837	220	151	600	343	288	193	3	155	141
• Urban background	745	1 229	861	1159	506	259	410	299	1 078	126		311	261
• Industrial	510	494	402	449	96	134	189	137	277	100		144	64
• Rural background	265	411	343	346	136	100	63	60	519	38	12	134	84
• Other	12	27	2	26	7		3	2	38	2			
Reporting non-EU countries	10	10	9	11	4	1	9	6	10	2		2	2
Total number of stations in 2010 of which	201	123	98	223	32	14	49	19	70	7		18	17
• Traffic	24	48	43	50	17	2	25	12	20	2		2	4
• Urban background	144	43	29	140	11	5	11	5	24	4		5	7
• Industrial	20	14	13	17			11	1	7			1	
• Rural background	12	18	13	16	4	7	2	1	19	1		9	5
• Other	1											1	1
Total reporting countries	37	37	35	38	31	24	36	33	37	19	5	26	25
Total number of stations 2010 data	2 098	3 278	2 431	3 040	997	658	1 314	860	2 270	466	15	762	567
Total number of stations 2009 data	2 184	3 268	2 354	3 015	826	675	1 355	775	2 246	408		745	545
Total number of stations 2008 data	2 280	3 233	2 418	2 842	559	624	1 348	719	2 227	296		637	484
Total number of stations 2007 data	2 013	2 629	1 906	2 357	307	431	1 069	505	1 823	211		363	212
Total number of stations 2006 data	2 165	2 870	2 095	2 423	320	247	1 209	569	2 074	218		340	112
Total number of stations 2005 data	2 236	2 753	1 937	2 289	269	257	1 251	582	2 004	155		263	49
Total number of stations 2004 data	2 008	2 435	2 146	1 884	160	139	1 076	387	1 892				
Total number of stations 2003 data	1 987	2 316		1 678	91	160	1 063	289	1 796				
Total number of stations 2002 data	1 927	2 046		1 306	42	112	914	184	1 671				
Total number of stations 2001 data	1 959	2 043		1 067	23	84	921	119	1 569				
Change stations 2009/2010 data	– 86	10	77	25	171	– 17	– 41	85	24	58		17	22
Percentage change stations 2009/2010 data	– 4 %	0 %	3 %	1 %	21 %	– 3 %	– 3 %	11 %	1 %	14 %		2 %	4 %

Source: Mol and van Hooydonk, 2012.

Table A1.2 Number of stations that provided data on different substances in 2010, specified per country

	SO_2	NO_2	NO_X/NO	PM_{10}	$PM_{2.5}$	Pb	CO	C_6H_6	O_3	VOC	$PM_{2.5}$_spec	HM	PAH
EU Member States													
Austria	101	156	136	144	15	17	44	21	114			18	26
Belgium	62	85	85	61	38	42	22	40	41	40		47	23
Bulgaria	28	24	18	42	9	9	16	17	19	6		12	11
Cyprus	2	2	2	3	5	3	1	1	2		1	3	2
Czech Republic	73	88	88	126	35	62	27	30	61			62	33
Denmark	2	13	8	8	9	7	8	3	10	3		7	2
Estonia	9	9	9	7	7	2	7	2	9			2	2
Finland	7	25	25	38	19		5	4	16	4			
France	260	476		373	88		74	24	427				
Germany	159	553	390	451	128	125	126	143	288	116	9	201	107
Greece	13	25	18	19	4		14	2	23	2			
Hungary	24	24	23	25	7		21	12	17	12		7	20
Ireland	12	14	14	17	5	5	6	3	12	1		8	5
Italy	306	643	632	522	130	60	366	198	368	141		60	60
Latvia	4	5	1	8	5	3	2	4	7	2	2	3	4
Lithuania	10	14	11	14	7	5	7	3	12	1		5	5
Luxembourg	6	6	6	6	3	5	3	2	6			5	5
Malta	4	3	3	4	3	3	4	3	5	3	1	3	2
Netherlands	20	59	44	48	30	6	22	2	37	2		8	6
Poland	130	139	125	206	67	91	71	54	64	1		91	107
Portugal	53	61	61	59	23	1	38	13	49			2	1
Romania	91	79	79	59	25	53	87	56	81			44	
Slovakia	12	15	14	32	27	5	10	10	15			5	7
Slovenia	19	11	10	16	4	4	5	2	12	2		4	3
Spain	435	476	401	424	179	95	251	142	409	117		104	82
Sweden	10	32	12	39	16	4	4	7	16			4	4
United Kingdom	45	118	118	66	77	37	24	43	80	6	2	39	33
Total EU Member States	**1 897**	**3 155**	**2 333**	**2 817**	**965**	**644**	**1 265**	**841**	**2 200**	**459**	**15**	**744**	**550**
Non-EU countries:													
Albania	3	3		2			3	3	2				
Bosnia and Herzegovina	7	4	2	1	2		2		4				
Croatia	8	8	8	7			8	2	2				
former Yugoslav Republic of Macedonia	21	15	15	15			13		12				
Iceland	4	8	7	12	6		1	1	1	1			
Liechtenstein		1	1	1					1				
Montenegro	3	4	4	4			4		2				
Norway	10	30	24	31	19		2	9	11			4	8
Serbia	18	17	5	3			4	1	3				
Switzerland	10	33	32	30	5	14	12	3	32	6		14	9
Turkey	117			117									
Total non-EU countries	**201**	**123**	**98**	**223**	**32**	**14**	**49**	**19**	**70**	**7**		**18**	**17**
Total all countries	**2 098**	**3 278**	**2 431**	**3 040**	**997**	**658**	**1 314**	**860**	**2 270**	**466**	**15**	**762**	**567**

Source: Mol and van Hooydonk, 2012.

Table A1.3 Summary of periods and number of stations that provided data

Country	Air quality reporting Start/end year ([a])	Number of stations for which data have been delivered for at least one year in the whole period ([a])	Number of stations for which 2009 data have been delivered in the EoI2010 ([a])	Number of stations for which 2010 data have been delivered in the EoI2011 ([a])
EU-27 Member States				
Austria	1981–2010	262	193	195
Belgium	1985–2010	380	226	243
Bulgaria	1998–2010	42	41	42
Cyprus	1993–2010	9	6	6
Czech Republic	1992–2010	192	174	172
Denmark	1976–2010	42	14	15
Estonia	1997–2010	11	9	9
Finland	1990–2010	102	56	59
France	1976–2010	1 084	700	678
Germany	1976–2010	1 235	545	660
Greece	1983–2010	37	29	28
Hungary	1996–2010	49	32	36
Ireland	1973–2010	106	29	28
Italy	1976–2010	1 103	707	705
Latvia	1997–2010	20	12	11
Lithuania	1997–2010	25	18	18
Luxembourg	1976–2010	14	8	8
Malta	2002–2010	8	4	5
Netherlands	1976–2010	98	78	80
Poland	1997–2010	521	389	274
Portugal	1986–2010	105	67	72
Romania	1999–2010	176	107	132
Slovakia	1995–2010	59	37	38
Slovenia	1996–2010	34	30	30
Spain	1986–2010	831	601	600
Sweden	1985–2010	83	55	57
United Kingdom	1969–2010	573	270	183
Total		**7 201**	**4 437**	**4384**
Non-EU countries				
Albania	2008–2010	3	3	3
Bosnia and Herzegovina	1985–2010	21	8	8
Croatia	2004–2010	8	8	8
former Yugoslav Republic of Macedonia	1997–2010	46	30	24
Iceland	1993–2010	18	9	13
Liechtenstein	2004–2010	2	1	1
Montenegro	2008–2010	4	4	4
Norway	1994–2010	62	46	49
Serbia	2002–2010	29	20	20
Switzerland	1991–2010	47	32	33
Turkey	2007–2010	117	113	117
Total		**357**	**274**	**280**
Total EU-27 + Non-EU countries		**7 558**	**4 711**	**4 664**

Note: ([a]) Irrespective of the component(s) measured.

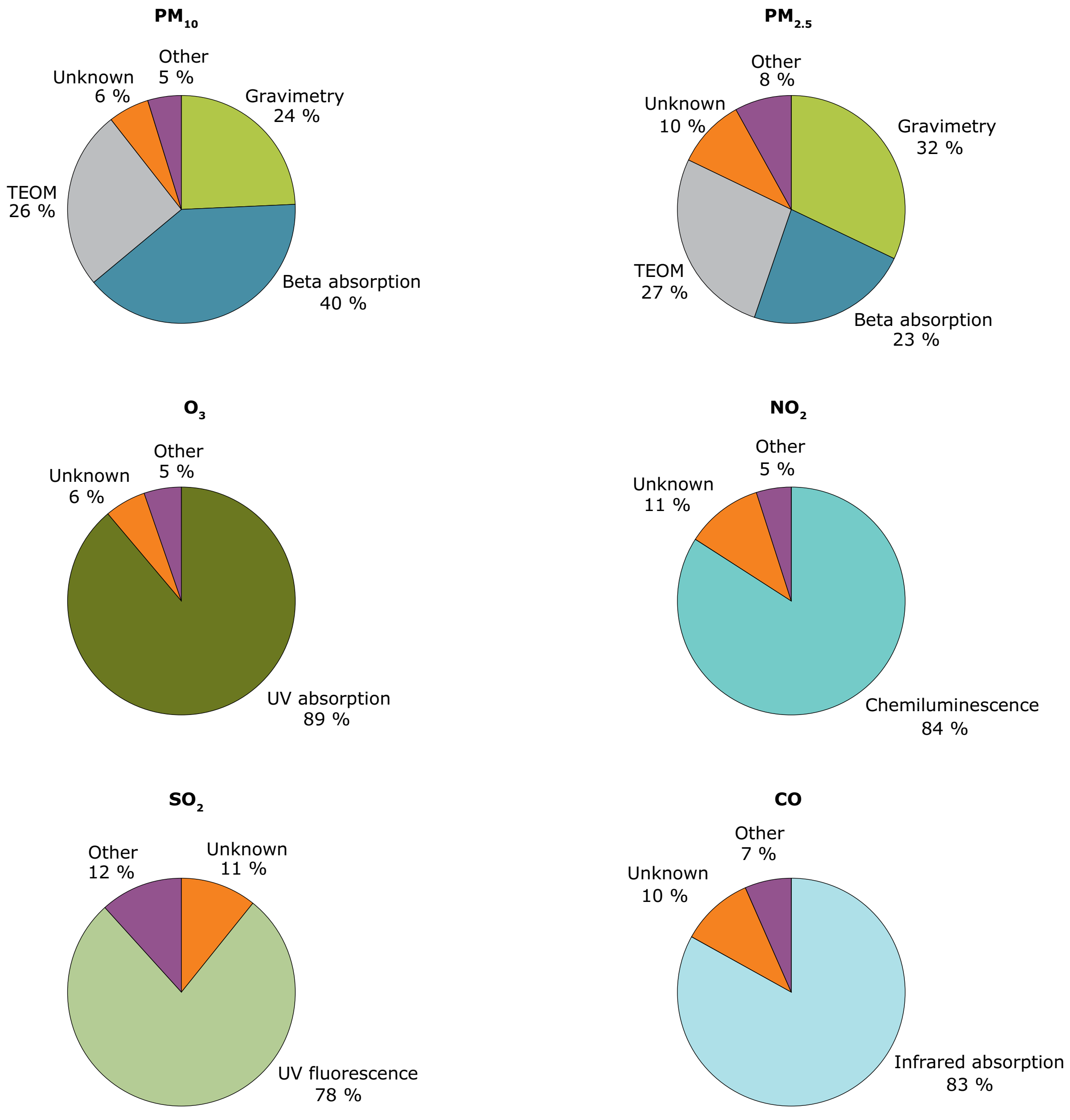
Source: Mol and van Hooydonk, 2012.

Air monitoring methods

Figure A1.1 shows the relative use of different measurement and monitoring methods for the various compounds. The figure shows that reference methods are used to a very large extent for the compounds O_3 (UV absorption, 93 %), NO_2 (chemiluminescence, 88 %), SO_2 (UV fluorescence, 89 %) and CO (infrared absorption, 86 %).

For PM_{10} and $PM_{2.5}$ gravimetric methods are used at 22 % and 33 % of stations, respectively. It is assumed that the gravimetric methods used conform to the reference method prescribed in the 2008 Air Quality Directive. The commonly used automatic instrumental methods 'TEOM' and 'beta absorption' are used extensively, providing hourly data, while the gravimetric methods give typically only 24-hour averages. These methods should have been compared with the reference method at each station/type of area, and a correction factor used on the data. Unknown/other methods and not reported methods used to some extent should be specified, and their equivalence demonstrated. For C_6H_6 most stations do not report the method used. Those that do report a method use (gas) chromatography without further specification, or followed by mass spectroscopy or flame ionisation for quantification.

Figure A1.1 Measurement methods used for PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2 and CO



Source: Mol and van Hooydonk, 2012.

With respect to the heavy metals (HM) and BaP, the reference methods are mostly used for analysis. The largest problem when comparing the results of different stations is that the fraction of particle sizes sampled is generally not known. The 2008 Air Quality Directive prescribes PM_{10}.

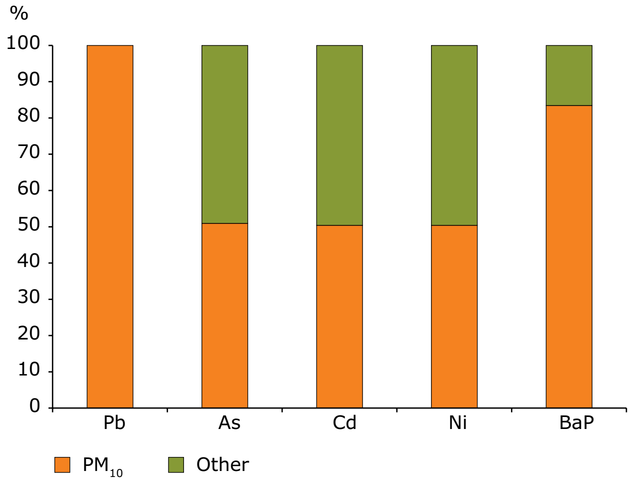
Figure A1.2 shows the proportion the stations reporting that HM and BaP are determined using a PM_{10} sample. For the other stations the size fraction is unknown. It could be larger or smaller than ten microns.

2010-data reporting and processing

A total of 38 countries, including all 27 EU Member States, have provided air quality data for 2010. Measurement data from a total of 4 664 stations have been delivered. This is a small decrease in comparison with the previous year. One of the reasons is that the United Kingdom has reorganised its networks in AirBase, so that many multiply defined stations have been removed.

Small increases are seen in the number of stations reporting $PM_{2.5}$ and VOC (21 % and 14 % respectively). Some countries have started to deliver $PM_{2.5}$ speciation concentrations.

Figure A1.2 Proportion (%) of HM and BaP measuring stations where the sample uses the PM_{10} particle size fraction in the EU Member States



Note: All operational stations (defined as having data coverage of more than 0 %).

'Other' may include aerosol (undefined size), TSP, $PM_{2.5}$.

Source: AirBase v. 6.

In the letter sent to all the data suppliers, accompanying the request sent to the EU Member States in 2011 for submitting 2010 air quality data, the EU Member States were requested to submit at least two of the three oxidised nitrogen components (NO_2, NO, NO_X). In spite of this request there is still a difference of almost 800 stations (from which about 500 stations of France) between the number of stations for which NO_2 has been reported and the number of stations for which NO (or NO_X) has been reported. In AirBase NO_X values have been derived for stations where NO and NO_2 values have been reported, but no NO_X values.

The number of stations for the 4DD components has increased slightly: the number of stations where one or more heavy metals listed in the 4DD have been reported, has increased by 2 % while the number of stations where BaP or other PAH have been reported has increased by 4 %.

The quality of the meta information, measurement data but also the derived information (statistics, exceedances) in AirBase has been further improved.

Nearly all countries delivered the 2010 data in time i.e. before 1 October 2011. The time line of the data reporting and processing process is shown in Table A1.4.

QA/QC feedback actions

Several quality checks were performed on delivered data and the already available information in AirBase. The yearly QA/QC checks on the delivered EoI data include checks on outliers, missing essential metadata, missing data, possible overwriting of data already stored in AirBase and possible deletion of stations and measurement configurations with data. In addition to these standard checks, QA/QC checks are also performed on questionable station coordinates and overlapping stations.

Intensive feedback took place with all reporting countries on these items. The country feedbacks sent to the MS resulted in one or more updates for 31 original EoI reports including:

- revalidation of suspicious data, originally reported as valid;
- resubmission of time series in which suspicious data were detected;
- updating (essential) meta-information;
- submission of missing time series.

More detailed information on the country feedback can be found in Mol and van Hooydonk (2012).

Table A1.4 Overview of the exchange of information (EoI) reporting cycle for 2010 data

Status since: 31.01.2012

Country	Date EoI data arrived at ETC/ACM	Initial upload to AirBase for QA/QC checking	Date QA/QC report sent to country	Date country reply to QA/QC report	End date processing data and statistics into AirBase	Remark
Albania	22.09.2011	11.11.2011	11.11.2011		30.01.2012	
Austria *	30.08.2011	30.08.2011	01.09.2011	07.09.2011	30.01.2012	
Bosnia and Herzegovina	14.09.2011	14.09.2011	20.09.2011	02.12.2011	30.01.2012	
Belgium *	30.09.2011	12.10.2011	02.11.2011	30.11.2011	30.01.2012	
Bulgaria *	28.09.2011	11.10.2011	02.11.2011	22.11.2011	30.01.2012	DEM-reply (01.12.2011)
Switzerland **	15.08.2011	16.08.2011	29.08.2011	01.09.2011	30.01.2012	
Cyprus *	30.09.2011	12.10.2011	02.11.2011	14.12.2011	30.01.2012	
Czech Republic *	30.09.2011	12.10.2011	02.11.2011	01.12.2011	30.01.2012	
Germany *	29.09.2011	25.11.2011	01.12.2011	28.12.2011	30.01.2012	Add. reply end january
Denmark *	30.09.2011	12.10.2011	02.11.2011	26.11.2011	30.01.2012	
Estonia *	29.09.2011	11.10.2011	02.11.2011		30.01.2012	No response expected
Spain *	30.09.2011	12.10.2011	02.11.2011	02.12.2011	30.01.2012	
Finland *	30.11.2011	12.12.2011	13.12.2011		30.01.2012	
France *	23.05.2011	15.08.2011	30.08.2011		30.01.2012	Reminder 01.12.2011
United Kingdom *	30.09.2011	17.10.2011	02.11.2011	07.12.2011	30.01.2012	
Greece *	31.05.2011	15.08.2011	29.08.2011	13.12.2011	30.01.2012	
Croatia	29.09.2011	13.10.2011	02.11.2011	28.11.2011	30.01.2012	
Hungary *	23.09.2011	28.09.2011	16.10.2011	15.11.2011	30.01.2012	
Ireland *	29.09.2011	11.10.2011	02.11.2011	22.11.2011	30.01.2012	
Iceland **	21.12.2011	22.12.2011	22.12.2011		30.01.2012	
Italy *	30.09.2011	13.10.2011	02.11.2011	19.12.2011	30.01.2012	
Liechtenstein **	13.09.2011	14.09.2011	19.09.2011		30.01.2012	No response expected
Lithuania *	26.09.2011	30.09.2011	16.10.2011	15.11.2011	30.01.2012	
Luxembourg *	22.09.2011	28.09.2011	16.10.2011	20.10.2011	30.01.2012	
Latvia *	27.09.2011	04.10.2011	16.10.2011	27.10.2011	30.01.2012	
Montenegro	31.10.2011	09.11.2011	11.11.2011	16.11.2011	30.01.2012	
former Yugoslav Republic of Macedonia	16.09.2011	16.09.2011	19.09.2011	21.10.2011	30.01.2012	
Malta *	27.01.2012	30.01.2012	30.01.2012		30.01.2012	
Netherlands *	27.09.2011	11.10.2011	02.11.2011	01.12.2011	30.01.2012	
Norway **	27.06.2011	16.08.2011	30.08.2011	19.09.2011	30.01.2012	
Poland *	28.09.2011	11.10.2011	03.11.2011	02.12.2011	30.01.2012	
Portugal *	30.09.2011	13.10.2011	03.11.2011	07.12.2011	30.01.2012	
Romania *	30.09.2011	13.10.2011	03.11.2011	06.12.2011	30.01.2012	
Serbia	30.09.2011	13.10.2011	03.11.2011	02.12.2011	30.01.2012	
Sweden *	30.09.2011	13.10.2011	03.11.2011	01.12.2011	30.01.2012	
Slovenia *	21.09.2011	28.09.2011	16.10.2011	08.11.2011	30.01.2012	
Slovak Republic *	29.09.2011	11.10.2011	03.11.2011	07.12.2011	30.01.2012	
Turkey **	03.10.2011	14.10.2011	03.11.2011	01.12.2011	30.01.2012	

Note: * EU Member State.
** Non EU-country, EEA-32 country.

Source: http://acm.eionet.europa.eu/country_tools/aq/eoi_to_airbase_status/index_html.

Annex 2 European policies and measures on air pollutant emissions

Background

During the period addressed in this report, 2001–2010, environmental policies and measures at the European level have affected the development of air pollutants emissions and the occurrence of air pollution.

The EU has developed a series of six Environment Action Programmes (EAPs) ([26]), starting in 1973. The 5th (1993–2000) and 6th EAP (2002–2012) are most relevant for the period addressed here. The 5th EAP, under the theme of 'air pollution' concentrated on acidification and air quality, with particular attention given to:

- a strategy to ensure that critical loads of acidifying, eutrophying and photochemical air pollutants are not exceeded;
- establishing or amending air quality objectives for specific pollutants;
- developing common procedures for assessing and monitoring of air quality.

The 6th EAP, under the theme 'environment and health and quality of life', in particular its Article 7 (f) on air quality, states that: 'development and implementation of the measures in Article 5 in the transport, industry and energy sectors should be compatible with and contribute to improvement of quality of air'. Further measures envisaged include:

- improving monitoring and assessment of air quality, including the deposition of pollutants, and the providing of information to the public, including the development and use of indicators;
- a thematic strategy to strengthen a coherent and integrated policy on air pollution to cover priorities for further actions, the review and updating where appropriate of air quality standards and national emission ceilings with a view to reaching the long-term objective of no-exceedence of critical loads and levels, and the development of better systems for gathering information, modelling and forecasting;
- adopting appropriate measures concerning ground-level O_3 and particulates;
- considering indoor air quality and the impacts on health, with recommendations for future measures where appropriate.

Thus, the 5th EAP and 6th EAP set the scene for developing specific policies and directives to control air pollution and improve air quality in the last two decades.

During the 1990s, the EU developed and adopted a series of directives on air quality management and assessment ([27]), setting, for example, the air quality limit and target values, and methods to monitor and assess air quality. These directives have paved the way for the effective exchange of data on air quality and station networks that has enabled the overview of European air quality as presented in this report.

The setting of health-related air quality limit and target values specified in the air quality directives benefited from the work and studies carried out under the Clean Air for Europe (CAFE) Programme ([28]), in cooperation with the World Health Organization (WHO), on the health effects of air pollutants.

The 6th EAP specified that the Commission should develop thematic strategies on a series of themes, including air pollution. The Thematic Strategy on Air Pollution ([29]) was formulated as the final result of the CAFE Programme. It considers the complex interaction between pollutants, impacts

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([26]) http://ec.europa.eu/environment/archives/env-act5/envirpr.htm.
([27]) http://ec.europa.eu/environment/air/quality/legislation/existing_leg.htm.
([28]) http://ec.europa.eu/environment/archives/cafe/general/keydocs.htm.
([29]) http://ec.europa.eu/environment/archives/cafe/pdf/strat_com_en.pdf.

and pollutant receptors (both humans and nature). It deals with PM in air, acidification, eutrophication and ground-level O_3, and impacts on human health, nature and biodiversity, materials and crops. The Strategy sets goals for reduced impacts on human health and the natural environment in 2020.

Current European policies and measures

In the context of this report, the interest is in policies and measures that have affected the changes, i.e. improvements, in the air quality and impact situation during the period of this overview.

Overview of directives

Regulations of emissions from the road traffic sector

Standards set in Europe have been used to limit emissions from motor vehicles since about 1970, through the so-called ECE R15/01-15/04 regulations for gasoline powered passenger cars. Since 1992 regulation of emissions continued under the so-called Euro 1–6 emission standards for light-duty vehicles (gasoline and diesel powered) and the Euro I–VI regulations for heavy-duty diesel engines in trucks and buses.

Petrol vapour recovery directives (30)

The **Stage I Petrol Vapour Recovery Directive** (1994/63/EC) aims to prevent emissions to the atmosphere of VOC during the storage of petrol at terminals and subsequent distribution to service stations. It entered into force on 20 December 1994. The directive contains measures that terminals should employ such as floating roofs and reflective coatings to reduce evaporative losses from storage tanks. In addition when petrol is loaded onto tankers and transported to service stations the directive ensures that any vapours are recovered and returned to the tanker or terminal. Implementation was obligatory from 31 December 1995 for new service stations and with a delay of three, six or nine years depending upon the size of existing service stations, with shorter times for larger stations. This means that the directive has influenced VOC emissions since 2000.

The **Stage II Petrol Vapour Recovery Directive** (2009/126/EC) aims to ensure the recovery of petrol vapour that would otherwise be emitted to the air during the refuelling of vehicles at service stations. EU Member States have until 31 December 2011 to transpose the directive into national law.

The minimum level of recovery of the systems employed should be 85 %. New service stations should comply with the directive from 2012, while existing stations have a longer timeline. All stations with a throughput greater than 3 000 m^3/year must comply by end-2018 at the latest. The directive has not yet had an effect on VOC emissions in Europe.

Directives on fuel quality

The **Sulphur Contents of Liquid Fuels Directive**, 1999/32/EC (31) regulates the S in fuel oils, establishing the following limits for S:

- In heavy fuel oil, the maximum S content is 1 % by weight, to be implemented by 1 January 2003. Derogation is provided for installations that come under the IPPC Directive requiring emission reduction technology.
- In gas oil the maximum S content is:
  - 0.20 % by weight, to be implemented by July 2000. Derogation is provided for certain external waterways;
  - 0.10 % by weight, to be implemented by 1 January 2008.

The **Fuels Quality Directive** (2003/17/EC) (32), amends the previous fuels directive (98/70/EC). It regulates the contents of S, Pb and C_6H_6 in motor fuels, as well as other fuel quality parameters. The limits set in this directive are:

- for S, 10 mg/kg for petrol and diesel from 1 January 2009;
- for Pb in petrol, 0.005 g/l (in practice lead-free gasoline);
- for C_6H_6 in petrol, 1 % v/v;
- for PAH in diesel fuel, 11 % m/m.

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(30) http://ec.europa.eu/environment/air/transport/petrol.htm.
(31) http://ec.europa.eu/environment/air/transport/sulphur.htm.
(32) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:076:0010:0019:EN:PDF.

Since 1 January 2002 all petrol sold in the EU is unleaded. Between 1 January 2005 and 1 January 2009 the limit on the S content of petrol and diesel was 50 mg/kg.

Regulation of industrial emissions

Directive 2010/75/EU aims to recast the seven existing directives related to industrial emissions into a single clear and coherent legislative instrument. This includes the IPPC Directive, the LCP Directive, the Waste Incineration Directive, the Solvents Emissions Directive and three directives on titanium dioxide. The Commission proposed that minimum emission limit values in certain industrial sectors should be tightened — particularly for large combustion plants where progress to reduce pollution is considered insufficient.

The aforementioned legal instruments are briefly described below:

The **Solvents Directive** (33) (1999/13/EC) regulates the use of solvents and sets limits on emissions of VOC due to the use of organic solvents in certain activities and installations. The expressed objective of the directive is to limit the formation of O_3 in air. The list of activities and uses of solvents regulated by the directive includes adhesive coating and other coating activities, dry cleaning, manufacturing of varnishes, adhesives, inks, pharmaceuticals, printing, surface cleaning, vehicle refinishing, wood impregnation and other. The directive sets emission limit values for waste gases or per volume of product, and requires a solvent management scheme for each activity. The general compliance date for existing installations is 31 October 2007, while new installations shall comply when commencing operations.

The **Waste Incineration Directive** (2000/76/EC) (34) repealed former directives on the incineration of hazardous waste (Directive 94/67/EC) and household waste (Directives 89/369/EEC and 89/429/EEC) and replaced them with a single text. The aim of the Waste Incineration Directive is to prevent or reduce as far as possible negative effects on the environment caused by the incineration and coincineration of waste. In particular, it should reduce pollution caused by emissions into the air, soil, surface water and groundwater, and thus lessen the risks that these pose to human health. This is to be achieved through the application of operational conditions, technical requirements, and emission limit values for incineration and co-incineration plants within the EU.

The Waste Incineration Directive sets emission limit values and monitoring requirements for pollutants to air such as dust, NO_X, SO_2, hydrogen chloride (HCl), hydrogen fluoride (HF), heavy metals, dioxins and furans. For heavy metals, emission limits are set for groups of HM: Cd+Tl, Hg, Sb+As+Pb+Cr+Co+Mn+Ni+V.

Most types of waste incineration plants fall within the scope of the Waste Incineration Directive, with some exceptions, such as those treating only biomass (e.g. vegetable waste from agriculture and forestry).

The Waste Incineration Directive makes a distinction between:

- incineration plants, which are dedicated to the thermal treatment of waste and may or may not recover heat generated by combustion;
- co-incineration plants, such as cement or lime kilns, steel plants or power plants whose main purpose is energy generation or the production of material products and in which waste is used as a fuel or is thermally treated for the purpose of disposal.

The deadline to bring existing plants into compliance was 28 December 2005.

The **Large Combustion Plants (LCP) Directive** (35) (2001/80/EC) regulates emissions of acidifying pollutants, PM and O_3 precursors (e.g. SO_2, NO_X and PM ('dust')) from large combustion plants for heat end energy production. The directive sets emission limit values (ELVs) (36) for SO_2, NO_X and dust (Total Suspended Particles, TSP), which vary according to the age of the plant, the fuel used and the plant capacity (see EEA Technical report No 8/2010).

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(33) http://ec.europa.eu/environment/air/pollutants/stationary/solvents.htm.

(34) http://ec.europa.eu/environment/air/pollutants/stationary/wid.htm.

(35) http://ec.europa.eu/environment/air/pollutants/stationary/lcp.htm.

(36) Under the LCP Directive, EU Member States have certain opt-out provisions (Article 4(4)) and may define and implement national emission reduction plans (NERPs) (Article 4(6)).

Regarding deadlines for implementation, the LCP Directive contains the following provisions:

- plants licensed after 27 November 2002 have to comply with the (stricter) emission limit values for SO_2, NO_X and dust fixed in part B of Annexes III to VII to the directive;
- plants licensed after 1 July 1987 and before 27 November 2002, have to comply with the (less strict) emission limit values fixed in part A of Annexes III to VII to the LCP Directive;
- significant emission reductions are required from 'existing plants' (licensed before 1 July 1987) to be achieved by 1 January 2008, either:
  - by individual compliance with the emission limit values established for new plants referred to in bullet 2 above (1987–2002); or
  - through a national emission reduction plan (NERP) that achieves overall reductions calculated using the emission limit values.

The **Paints Directive** (37) (2004/42/CE) establishes limit values for the maximum VOC contents of decorative paints and vehicle-refinishing products, to limit the emissions of VOC, amending also the Solvents Directive concerning vehicle-refinishing products. It has two phases for the implementation of stricter limits on VOC contents in products, Phase I to be implemented by 1 January 2007 and Phase II by 1 January 2010.

The original **Integrated Pollution Prevention and Control (IPPC) Directive** was adopted on 24 September 1996, and has since been amended four times. It regulates basically all industrial plants, including energy production, metals production, mineral industries, chemical industries, waste management and other sectors. The air pollutants addressed are SO_2, NO_X, CO, VOC, metals, dust, asbestos, Cl, F, As, cyanides and other carcinogenic and mutagenic compounds and some specific dioxins. New installations and existing installations that are subject to 'substantial changes' have been required to meet the requirements of the IPPC Directive since 30 October 1999. Other existing installations had to be brought into compliance by **30 October 2007**. This was the key deadline for full implementation of the directive.

In the directive, the concept of 'best available techniques' (BAT) plays a central role. In this context:

- 'techniques' include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- 'available' techniques are those developed on a scale that allows application in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the EU Member State in question, and as long as they are reasonably accessible to the operator;
- 'best' means most effective in achieving a high general level of protection of the environment as a whole.

Operators of relevant industrial installations must apply BAT to prevent and control pollution. Authorities are also obliged to set up a system of issuing integrated permits that will lead to the implementation of BAT in new and existing plants.

Conclusions as to what are considered to be BAT at the EU level for the activities covered by the directive are given in BAT reference documents (BREFs), which are developed under the coordination of the European Commission (EU IPPC Bureau, Joint Research Centre), through an exchange of information by expert groups comprised of representatives of the EU Member States, industry, NGOs and other stakeholders.

The definition of industrial combustion facilities used in this study goes beyond that in the LCP BREF. The LCP BREF covers, in general, combustion installations with a rated thermal input exceeding 50 MW. This includes the power generation industry and those industries where 'conventional' (commercially available and specified) fuels are used and where the combustion units are not covered within another sector BREF. In this context, industrial combustion facilities comprise power plants, refineries and those in the manufacturing sector, regardless of capacity.

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(37) http://ec.europa.eu/environment/air/pollutants/paints_legis.htm.

Directive on national total emissions

The National Emissions Ceiling Directive (**NEC Directive**) (38), adopted on 23 October 2001, sets upper limits for each Member State for the total emissions in 2010 of the four main pollutants responsible for acidification, eutrophication and ground-level O_3 pollution (SO_2, NO_X, VOC and NH_3). It leaves it largely to the EU Member States to decide which measures — in addition to Community legislation for specific source categories — to take in order to comply.

Directive concerning the protection of waters against pollution caused by nitrates from agricultural sources

Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources has the aim of providing for all waters a general level of protection against pollution. EU Member States shall:

- establish a code or codes of good agricultural practice, to be implemented by farmers on a voluntary basis;
- set up where necessary a programme, including the provision of training and information for farmers, promoting the application of the code(s) of good agricultural practice.

Moreover there is a requirement for the establishment of fertiliser plans on a farm-by-farm basis and the keeping of records on fertiliser use.

LRTAP Convention

The long-range transport of air pollution is an important factor affecting ecosystems and the human population. The United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) aims at reducing and preventing air pollution. In addition to the EU legislation listed above the LRTAP Convention has a number of legally binding protocols, covering specific categories of air pollutants. The Convention was ratified by the European Community in 1982. Article 2 of the Convention states that 'the Contracting Parties, taking due account of the facts and problems involved, are determined to protect man and his environment against air pollution and shall endeavour to limit and, as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution'.

The Convention has set up a process for negotiating concrete measures to control specific pollutants through legally binding protocols. Since 1984, eight protocols have come into force. The most recent, the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, came into force on 17 May 2005.

In 2012, Parties were requested to report 2010 emissions data for NO_X, NMVOC, SO_X, NH_3, CO, heavy metals, persistent organic pollutants and PM, and also associated activity data. The information was copied by EU Member States to the EEA Eionet Reportnet Central Data Repository.

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(38) http://ec.europa.eu/environment/air/pollutants/ceilings.htm.

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