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Air quality in Europe — 2011 report

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Executive summary

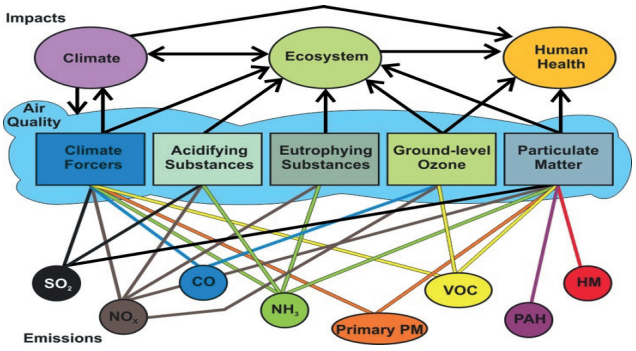
The present report provides an overview and analysis of air quality in Europe. The analysis covers up to 38 European countries (EEA-38) ([1]) and spans the two decades of data that countries have made officially available up to 2009. The evaluation of the status and trends of air quality is based on ambient air measurements and data on anthropogenic emissions and trends.

Emissions of the main air pollutants in Europe declined significantly in the period 1990–2009, in particular sulphur dioxide (SO_2) and lead (Pb), resulting in improved air quality across the region. These results notwithstanding, many European countries do not expect to comply with one or more pollutant-specific ([2]) emission ceilings set under EU and United Nations (UN) agreements for 2010. Furthermore, due to complex links between emissions and ambient air quality, as well as a number of uncertainties associated with estimating emission data, emission reductions have not always produced a corresponding drop in atmospheric concentrations, especially for particulate matter (PM) and groundlevel ozone (O_3).

At present, PM ([3]) and O_3 are Europe's most problematic pollutants in terms of harm to health. Air pollution's most important effects on European ecosystems are eutrophication, acidification and vegetation damage resulting from exposure to O_3. As sulphur emissions have fallen, ammonia (NH_3) emitted from agricultural activity and nitrogen oxides (NO_X) from combustion processes have become the predominant acidifying and eutrophying air pollutants. Several air pollutants are also climate forcers, having a potential impact on the planet's climate. Figure ES.1 shows the major air pollutants in Europe and their potential impact on human health, ecosystems and the climate.

Table ES.1 gives an overview ([4]) of the proportion of the EU urban population exposed to pollutant concentration levels above the limit and target

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 as follows: sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), ammonia (NH_3), particulate matter (PM), volatile organic compounds (VOC), polycyclic aromatic hydrocarbons (PAH), heavy metals (HM).

([1]) The EEA-38 countries are the EEA-32 member countries (the EU Member States: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom; and the remaining five EEA member countries: Iceland, Liechtenstein, Norway, Switzerland and Turkey), as well as EEA-6 cooperating countries (Albania, Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, Montenegro, and Serbia).

([2]) These pollutant emission ceilings address sulphur dioxide (SO_2), nitrogen oxides (NO_X), volatile organic compounds (VOC), ammonia (NH_3).

([3]) Particulate matter (PM) is the general term used for particles with a wide range of sizes and chemical compositions. $PM_{2.5}$ refers to 'fine particles' with a diameter of 2.5 micrometres or less. PM_{10} refers to the particles with a diameter of 10 micrometres or less.

([4]) This estimate refers to a recent three-year period (2006–2008) and includes variations due to meteorology, as dispersion and atmospheric conditions differ from year to year.

values ([5]) set in the EU legislation and the air quality guidelines (AQG) set by the World Health Organization (WHO) (de Leeuw and Ruyssenaars, 2011). Current pollution levels clearly impact on large parts of the urban population. This is particularly evident in the population exposure estimates based on the WHO air quality guidelines, which in some cases are more stringent than corresponding standards in the EU legislation.

Particulate matter

- Significant reductions in emissions of some PM precursors in the period 1999–2009 are only partly reflected in observed PM_{10} concentrations, which only fell slightly.

- Twenty 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 2009 (Figure ES.2). For EEA-32 countries the estimate is 39 %.

- EU urban exposure to PM_{10} levels exceeding the WHO AQG is significantly higher, comprising 80–90 % of the total urban population (Table ES.1).

Epidemiological studies indicate that the most severe health effects from exposure to air pollution are associated with particulate matter and, to a lesser extent, ozone.

Particulate matter in the atmosphere originates both from direct emissions (primary particles) and as a product of oxidation (secondary particles) of so-called PM precursor gases: sulphur dioxide (SO_2), nitrogen oxides (NO_X), ammonia (NH_3) and volatile organic compounds (VOC). PM precursor emissions decreased considerably between 1999 and 2009 in the EU; SO_X emissions fell by 56 % and NO_X by 28 %. NH_3 fell less, by 11 %. Emissions of primary PM_{10} and $PM_{2.5}$ decreased by 16 % and 21 % respectively in the same period. The corresponding emission reductions in the EEA-32 countries were as follows: SO_X 54 %, NO_X 27 %, NH_3 11 %, primary PM_{10} 16 %, primary $PM_{2.5}$ 21 %.

Despite these emission reductions, 18–49 % ([6]) of the EU urban population was exposed to ambient air concentrations of PM_{10} in excess of the EU air quality daily limit value in the period 1997–2009 and there was no discernible downward trend (Figure ES.2). Between 21 % and 50 % of the urban population in EEA-32 countries was exposed in this period.

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

Pollutant	EU reference value	Exposure estimate (%)	WHO AQG	Exposure estimate (%)
SO_2	Day (125)	0.3–2.3	Day (20)	68–85
NO_2	Year (40)	7–19	Year (40)	7–19
PM_{10}	Day (50)	18–40	Year (20)	80–90
Pb	Year (0.5)	< 1	Year (0.5)	< 1
CO	8-hour (10)	0–2	8-hour (10)	0–2
O_3	8-hour (120)	16–50	8-hour (100)	> 95

Colour coding of exposure estimates, fraction of urban population exposed to concentrations above the reference level:				
	< 10 %	10–50 %	50–90 %	> 90 %

Note: The reference levels included comprise EU limit or target levels and WHO air quality guidelines (AQG). The averaging period is shown and the reference levels in brackets are in µg/m³ except for CO which is in mg/m³.

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

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

This estimate refers to a recent three-year period (2006–2008) and includes variations due to meteorology, as dispersion and atmospheric conditions differ from year to year.

([5]) A 'limit value' is a level to be attained within a given period and not to be exceeded once attained; a 'target value' is a level to be attained where possible over a given period.

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

The EU limit and target values for PM were exceeded widely in Europe in 2009. The World Health Organization (WHO) guidelines for PM_{10} and $PM_{2.5}$ annual mean concentrations were likewise exceeded at a large number of monitoring stations across continental Europe, although to a lesser extent in the Nordic countries.

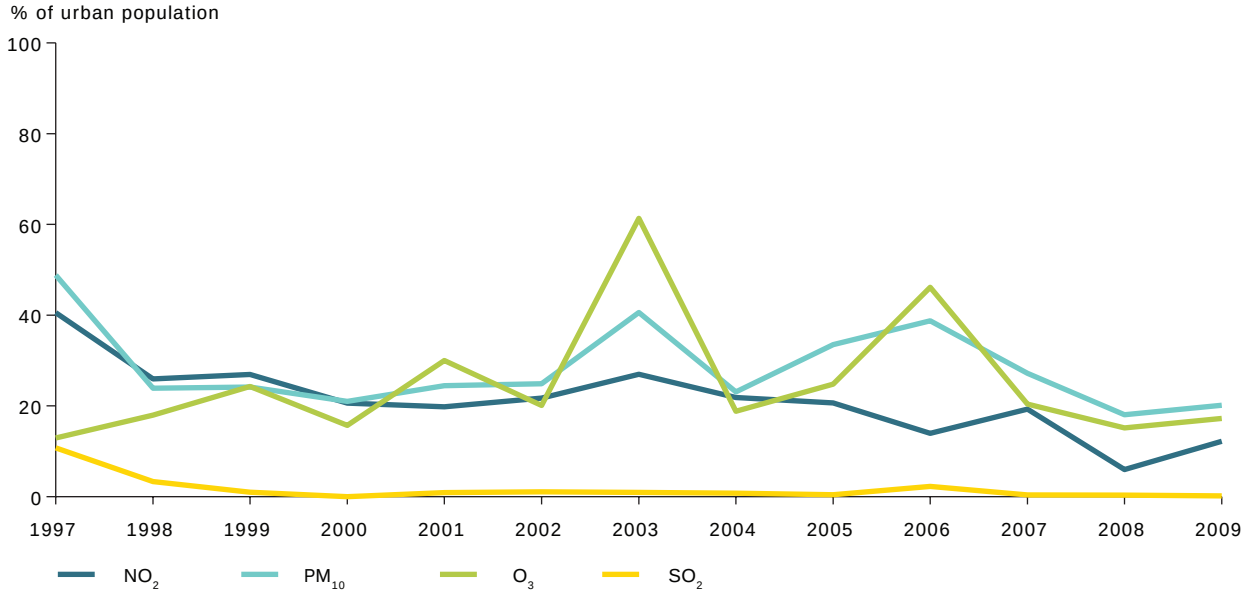
Ozone

- Substantial reductions in emission of most anthropogenic ozone precursors are not reflected in observed annual average ozone concentrations, which do not show a downward trend in Europe between 1999 and 2009.
- The number of exceedances of the 120 µg/m^3 target value ([7]) threshold (daily maximum 8-hour mean values) has gone down since 1992 but has remained at sustained levels in recent years.
- Seventeen per cent of the EU urban population lives in areas where the EU ozone target value ([7]) for protecting human health was exceeded in 2009 (Figure ES.2). For EEA-32 countries the estimate is also 17 %.
- The EU urban population exposed to O_3 levels exceeding the WHO AQG is significantly higher, comprising more than 95 % of the total urban population (Table ES.1).
- Europe's sustained ambient O_3 concentrations continue to cause considerable damage to vegetation growth and crop yields.

Ozone is a strong oxidising agent and a greenhouse gas. In Europe it is currently one of the air pollutants posing greatest threats to human health and vegetation.

Ozone is not directly emitted into the atmosphere but formed from a chain of photochemical reactions following emissions of precursor gases: nitrogen oxides (NO_X), carbon monoxide (CO) and volatile organic compounds (VOC). Although ozone precursor gas emissions decreased considerably

Figure ES.2 Percentage of the EU urban population potentially exposed to air pollution exceeding acceptable EU air quality standards



Source: EEA, 2011c (CSI 004).

([7]) Directive 2008/50/EC on ambient air quality and cleaner air for Europe sets out the target value for the protection of human health from ozone. Specifically, the maximum daily 8-hour mean concentration of ozone should not exceed 120 µg/m^3 on more than 25 days per calendar year averaged over three years. It further specifies that the target value will first be calculated using validated data from 2010 and following years. As such, it will not be possible to assess exceedance of the target value fully until data for 2010, 2011 and 2012 have been compiled.

between 1999 and 2009 in the EU (NO_X by 28 %, NMVOC by 34 % and CO by 44 %) and in the EEA-32 (NO_X by 27 %, NMVOC by 31 %, CO by 44 %), exposure to ozone has not decreased since measurements commenced in around 1997.

Between 13 % and 61 % ([6]) of the EU and EEA-32 urban population was exposed to ozone concentrations in excess of the EU target value for protecting human health in the period 1997–2009 (Figure ES.2). Furthermore, between 30 % and 69 % ([6]) of agricultural crops in the EEA-32 were exposed to ozone levels in excess of the EU target value for protecting vegetation from 1996 to 2008. High ground-level ozone concentrations are most pronounced in southern Europe.

Nitrogen dioxide

- NO_2 ambient air concentrations have generally declined as NO_X emissions decreased. However, the decrease in NO_X emissions (28 % between 1999 and 2009) is considerably greater than the fall in NO_2 concentrations, which was about 15 % during the same period.
- Some cities show an increase in roadside concentrations of NO_2. This reflects the increased fraction of NO_2 in NO_X emissions from traffic resulting from increasing market penetration of newer diesel vehicles. Exhaust after-treatment systems in such vehicles reduce emissions of carbon monoxide, hydrocarbons and particulate matter but may increase NO_2 emissions.
- Twelve 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 2009 (Figure ES.2). For EEA-32 countries the estimate is also 12 %.
- Exceedances at hot-spot locations (e.g. main roads) are observed all over Europe.
- NO_X and NH_3 emissions continue to cause significant impacts in European ecosystems. Projections 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).

Nitrogen (N) 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 affected by eutrophication due to excessive atmospheric N has only diminished slightly over the last two decades. On the other hand, the sensitive ecosystem area affected by excessive acidification from air pollution has fallen considerably since 1990 (mainly due to the strong reduction in SO_2 emissions).

Sulphur dioxide

- Ambient SO_2 concentrations in Europe have declined, as EU Member States cut their SO_X emissions by 56 % in the period 1999–2009. The corresponding emission reduction in the EEA-32 countries was 54 %.
- Large areas of Europe have seen clear declines in acid deposition from 1990 to 2009, due mainly to reductions in sulphur emissions.
- The percentage of the EU urban population exposed to SO_2 concentrations above the EU 24-hour limit value has been reduced from 11 % in 1997 to 0.1 % in 2009 (Figure ES.2). The corresponding reduction in the EEA-32 countries is from 11 % of the urban population in 1997 to 2.4 % in 2009.
- The EU urban population exposed to SO_2 levels exceeding the WHO AQG is significantly higher, amounting to 68–85 % of the total urban population (Table ES.1).

Carbon monoxide

- The observed reduction in CO concentrations since 1999 (50 % at traffic stations, 35 % at urban stations and 25 % at rural stations) is in line with the reported 44 % reduction in total EU and EEA-32 emissions of CO over the same period.
- Exposure of the European population to CO ambient concentrations above the EU limit value and WHO AQG is very localised and sporadic, limited to very few restricted areas (Table ES.1).

Heavy metals

- The atmospheric levels of arsenic (As), cadmium (Cd), lead (Pb) and nickel (Ni) 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 considerable cuts in emissions of heavy metals since 1990 in the EU (As reduced by 64 %, Cd by 70 %, Hg (mercury) by 67 %, Ni by 57 % and Pb by 91 %), a significant share of the EU ecosystem area was still at risk of heavy metal contamination. Exceedances of Hg critical loads ([8]) were projected to occur at 54 % of sensitive ecosystems areas in 2010 under current legislation, while for Pb the projected exceedance area is 12 % of sensitive ecosystem areas.

A relatively small number of stations measure atmospheric concentrations 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 of different forms of Hg, making an analysis of airborne concentrations at the European level very difficult.

Benzene and benzo(a)pyrene

- Exceedances of the benzene limit value were limited to a few locations in Europe, primarily situated close to traffic.

- The average benzene concentration measured at traffic stations in 2009 has declined to less than half of the 2001 level.

- Exposure of the European population to benzo(a) pyrene (BaP) concentrations above the target value is quite significant and widespread in central and eastern Europe.

No trends in BaP concentrations can be seen in the few (45) stations in operation since 2005. However, measurements clearly show that exceedances of the target value are persistent in central Europe.

([8]) 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).

1 Introduction

1.1 European air pollution today

Emissions of the main air pollutants in Europe have declined significantly in recent decades, in particular sulphur dioxide (SO_2) and lead (Pb) emissions. Despite these changes, many European countries do not expect to comply with one or more pollutant-specific emission ceilings set under EU and UN agreements for 2010. Furthermore, due to complex links between emissions and ambient air quality, emission reductions have not always produced a corresponding drop in atmospheric concentrations.

Many EU Member States do not comply with legally binding air quality limit and target concentration values, especially for particulate matter (PM), groundlevel ozone (O_3) and nitrogen dioxide (NO_2). PM and O_3 are Europe's most problematic pollutants in terms of harm to health, with effects ranging from minor respiratory irritation to cardiovascular diseases and premature death.

The ecosystem area affected by excess acidification from air pollution shrank considerably between 1990 and today. Whereas sulphur oxides previously dominated, nitrogen (N) compounds, emitted as nitrogen oxides (NO_X) and ammonia (NH_3), are now the principal acidifying components in our air. In addition to its acidifying effects, N also contributes to eutrophication of ecosystems, and the area of sensitive ecosystems affected by excessive atmospheric nitrogen has only diminished slightly over the last two decades. Europe's sustained ambient O_3 concentrations continue to cause considerable damage to vegetation growth and crop yields.

1.2 Report objectives and coverage

The present report provides an overview and analysis of air quality in Europe. This analysis spans the two decades of data that have been made officially available by European countries up to 2009. 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 modelled data, owing to the scarcity of such data officially made available by European countries through the current reporting and data exchange mechanism.

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.

This 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.

1.3 Effects of 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. As explained in more detail below, these include:

- effects on human health caused by exposure to air pollutants or intake of pollutants transported through the air, deposited and accumulated in the food chain;
- 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 ozone;
- impacts of heavy metals and persistent organic pollutants on ecosystems, due to their environmental toxicity and due to bioaccumulation;
- effects on climate forcing;
- reduction of atmospheric visibility;
- damage to materials and cultural heritage due to soiling and exposure to acidifying pollutants and ozone.

Health impacts

Air pollution is a major environmental risk to health. Numerous scientific studies have linked air pollution to health effects including:

- harm to the respiratory system, leading to the development or aggravation of respiratory diseases, decreased lung function, increased frequency and severity of respiratory symptoms such as coughing and difficulty breathing, or increased susceptibility to respiratory infections;
- harm to the cardiovascular system;
- harm to the nervous system, affecting learning, memory and behaviour;
- harm to the reproductive system;
- cancer.

Some of these impacts may result in premature death. Sensitive individuals, such as older adults and children and people with pre-existing heart and lung diseases or diabetes, appear to be at greater risk of air pollution-related health effects. In 2005, an estimated 5 million years of lost life were caused by fine particulate matter pollution ($PM_{2.5}$) alone in the EEA-32 countries (EEA, 2010a). The status and trends of the European population's exposure to the different air pollutants is presented and discussed in the following chapters.

Ecosystem impacts

Air pollution also damages the environment. For example, ozone can damage crops and other vegetation, impairing growth. These impacts can reduce the ability of plants to take up CO_2 from the atmosphere and indirectly affect entire ecosystems and the planet's climate. The atmospheric deposition of sulphur and nitrogen compounds has acidifying effects on soils and freshwaters. Acidification causes disturbances in the function and structure of ecosystems with harmful ecological effects, including biodiversity loss. Likewise, deposition of nitrogen compounds can lead to eutrophication, which constitutes an oversupply of nutrient nitrogen in terrestrial and aquatic ecosystems. Consequences include changes in species diversity, invasions of new species and leaching of nitrate to groundwater.

The impacts on the environment depend not only on the air pollutant emission rates but also on the location and conditions of the emission and the location of the receptor point. Factors determining the transport, chemical transformation and deposition of air pollutants, including meteorology and topography, are also important. Further, the environmental impacts of air pollution also depend on the sensitivity of ecosystems to acidification, eutrophication, heavy metal deposition and direct ecosystem exposure to pollutant concentrations.

Climate impacts

Air pollution may also impact the Earth's climate. Some air pollutants interfere with the Earth's energy balance and are therefore known as 'climate forcers'. These can either be gases (e.g. ozone) or airborne particulate matter (aerosols). Some climate forcers reflect solar radiation (e.g. sulphate aerosols) leading to net cooling, while others (e.g. black carbon aerosols) absorb solar radiation, thereby warming the atmosphere. In addition, aerosols influence the formation, microphysics and optical properties of clouds, resulting in indirect climatological effects. Deposition of certain aerosols (e.g. black carbon) may also change the Earth's surface reflectivity (albedo), especially on ice- and snowcovered surfaces, thereby accelerating melting.

Material impacts

Air pollution damages materials. It is generally recognised that air pollutants have greatly accelerated the degradation of buildings and physical cultural heritage, such as historic buildings, works of art and archaeological treasures. The two main forms of damage are corrosion or erosion (caused by acidifying and oxidising compounds) and soiling (caused by particulate matter).

Table 1.1 summarises the main effects of different air pollutants on human health, the environment and the climate. Each pollutant produces a range of effects, ranging from mild to severe as concentration or exposure increases.

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 (e.g. reduced lung function, asthma attacks, chronic bronchitis, susceptibility to respiratory infections), heart attacks and arrhythmias. Can 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 damages and soiling of buildings, including monuments and objects of cultural heritage. Reduced visibility.	Climate effect varies depending on particle size and composition: some are reflective and lead to net cooling, while others absorb solar radiation leading to warming. Can lead to changed rainfall patterns. Deposition can lead to changes in surface albedo.
Ozone (O_3)	Irritates eyes, nose, throat and lungs. Can destroy throat and lung tissues, leading to decrease in lung function; respiratory symptoms, such as coughing and shortness of breath; aggravated asthma and other lung diseases. Can lead to premature mortality.	Damages vegetation by injuring leaves, reducing photosynthesis, impairing plant reproduction and growth, and decreasing crop yields. Ozone damage to plants 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. Enhances sensitivity to secondary stress (such as drought) on vegetation. Acts as a precursor of ozone and, particulate matter, with associated environmental effects. Can form nitric acid and damage buildings by surface recession.	Contributes to the formation of ozone and particulate matter, 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. Contributes indirectly to the transformation of mercury to the bioaccumulative methyl-mercury, which is toxic. Causes injury to vegetation and local species losses in aquatic and terrestrial systems. Contributes to the formation of inorganic particulate matter with associated environmental effects. Damages building materials.	Contributes to the formation of sulphate particles, cooling the atmosphere.
Carbon monoxide (CO)	Can lead to heart disease and damage to the nervous system (e.g. personality and memory changes, mental confusion and loss of vision). Can cause headache, dizziness and fatigue.	May affect animals in the same way as humans, although concentrations capable of causing these effects are unlikely to occur in the natural environment, except in extreme events such as forest fires.	Contributes to the formation of greenhouse gases such as CO_2 and ozone.
Arsenic	Inorganic arsenic is a human carcinogen. May cause decreased production of red and white blood cells, damage to blood vessels, abnormal heart rhythms, and liver and kidney damage. May damage the peripheral nervous system.	Highly toxic to aquatic life, birds and land animals. Where soil has high arsenic content, plant growth and crop yields may be reduced. Organic arsenic compounds are very persistent in the environment and subject to bioaccumulation.	No specific effects.

Table 1.1 Effects of air pollutants on human health, the environment and the climate (cont.)

Pollutant	Health effects	Environmental effects	Climate effects
Cadmium	Cadmium, especially cadmium oxide is likely to be a carcinogen. It may also cause reproductive damage and is toxic to the respiratory system. Exposure can cause permanent kidney damage, anaemia, fatigue and loss of the sense of smell. It can also cause lung damage, shortness of breath, chest pain and accumulation of fluid in the lungs.	Toxic to aquatic life, as it is absorbed by organisms directly in water. It interacts with cytoplasmatic components such as enzymes, causing toxic effects in cells. Cadmium is highly persistent in the environment and bioaccumulates.	No specific effects.
Lead	Can affect almost every organ and system, especially the nervous system. Can cause premature birth, impaired mental development and reduced growth. It can also have cardiovascular and renal effects in adults and effects related to anaemia.	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	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	Several nickel compounds are classified as human carcinogens. Non-cancer effects include allergic skin reactions, effects on the respiratory tract, the immune and defence system and on endocrine regulation.	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	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 ozone 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.

1.4 Air quality as a European environmental issue

Despite significant progress made across Europe in reducing anthropogenic emissions of the main air pollutants, human health and the environment are still affected by poor air quality. As noted above, air pollution has adverse impacts on health and on ecosystems, influences atmospheric visibility and contributes to climate change and to the degradation and soiling of materials and cultural heritage.

The need to improve air quality in Europe has been long recognised. In modern times the disaster in the Meuse Valley in 1930 and London's deadly smog in 1952 prompted the adoption of air quality legislation. In more recent decades a variety of laws have been enacted and action has been taken at the local, regional, national and EU levels, as well as through international conventions, such as the Convention on Long-range Transboundary Air Pollution (UNECE, 1979).

In recent years decision-makers have increasingly recognised the links between air pollution and climate change and the benefits in making policy responses more integrated and coherent. Air pollutants can affect climate change, just as climate change can influence air pollution's dispersion, chemical and physical formation and transformation in the atmosphere, and deposition. The energy, transport and agricultural sectors are major emitters of greenhouse gases and air pollutants. The transport sector is largely responsible for noise pollution.

Policies combating climate change or noise may contribute substantially to reducing air pollution but some measures combating climate change can worsen air quality. Likewise, air quality policies and measures can have both positive and negative climate change impacts. European policies and measures increasingly seek to maximise co-benefits, managing air pollutant and greenhouse gas emissions at the lowest cost to society. Integrated models are emerging, which explore the effects of policies by coupling economics with our understanding of atmospheric transport and chemistry, climate and ecosystems.

Air pollution impacts occur at all scales, meaning that policies and air quality management must be implemented and coordinated across the local, regional, national, European and intercontinental levels. Within the European Union, the concept of subsidiarity is applied in the area of air quality management, meaning that decisions are taken at the most appropriate level of governance. Actions should aim to minimise exposure and impacts of air pollution as effectively and efficiently as possible, using three main types of measures:

- reducing emissions at source;
- structural measures, for example urban planning, which can both reduce emissions and minimise exposure;
- behavioural measures, including minimising pressures by changes to life style and energy use, and steps to reduce exposure such as staying at home on highly polluted days.

Policies and management programmes at all levels should aim to minimise risks and impacts by progressively adopting a multi-pollutant or multi-risk and multi-effect approach, integrating air quality, climate change and noise reduction management as far as possible.

1.5 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 particulate matter;
- a 10 % reduction in acute mortalities from exposure to ozone;
- 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 SO_2 emissions need to decrease by 82 %, NO_X emissions by 60 %, volatile organic compounds (VOC) by 51 %, ammonia by 27 % and primary $PM_{2.5}$ (fine particles emitted directly into the air) by 59 % in the period 2000–2020.

In the 'Roadmap to a Resource Efficient Europe' the European Commission has recently 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, 2011).

Legal instruments

Over 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 standards (for e.g. vehicle emissions) or by setting requirements on product quality (e.g. sulphur and benzene 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 sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and oxides of nitrogen (NO_X), particulate matter (PM_{10} and $PM_{2,5}$), lead, benzene, carbon monoxide and ozone (EU, 2008c);

- Directive 2004/107/EC relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons (PAH), (including benzo(a)pyrene, BaP) in ambient air (EU, 2004b).

In the case of non-compliance with the air quality limit and target values stipulated in Directive 2008/50/EC, local and regional administrations must develop and implement air quality management plans 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 ozone and particulate matter. The National Emission Ceilings Directive (EU, 2001b) and the Gothenburg Protocol (UNECE, 1999) to the UN Convention on Long-range Transboundary Air Pollution (LRTAP) set national emission limits for SO_2, NO_X, NMVOC and NH_3 in order to abate acidification, eutrophication and ground-level ozone.

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

- Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control) (EU, 2010), 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 and its compounds, fluoride and its compounds, arsenic and its compounds, cyanides, other carcinogenic and mutagenic compounds, and polychlorinated dibenzodioxins and polychlorinated dibenzofurans.

- The Euro Directives for road vehicle emissions set standards for emissions of NO_X, hydrocarbons (HC), non-methane hydrocarbons (NMHC), CO and PM for most vehicle types. The Euro 4 standards are addressed in Directive 98/70/EC (EU, 1998a, 1998b) and Directive 2005/55/EC (EU, 2005). The Euro 5 and 6 standards 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 emissions of precursor gases). 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 ammonia (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. Abatement 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).

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

Policies \ Pollutants		PM	O_3	NO_2 NO_X NH_3	SO_2 SO_X	CO	Heavy metals	BaP PAH	VOC
Directives regulating ambient air quality	2008/50/EC	PM	O_3	NO_2	SO_2	CO	Pb		Benzene
	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 standards 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
	91/676/EEC			NH_3					
Directives regulating fuel quality	1999/32/EC	[a]			S				
	2003/17/EC	[a]	[b]		S		Pb	PAH	Benzene, hydro-carbons, 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 particulate matter precursors, such as SO_2, NO_X, NH_3 and VOC, indirectly aim to reduce particulate matter ambient air concentrations.

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

Methane (CH_4), which is not listed explicitly in Table 1.2, is an important ozone precursor. Methane is a well-mixed pollutant globally, with the consequence that isolated local and regional abatement of emissions has a limited impact on ambient concentrations. European countries have legally binding emission reduction commitments for CH_4 under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC).

2 Particulate matter, PM

2.1 Sources and effects of PM

2.1.1 Origins of PM in air

Particulate matter (PM) is the general term used for a mixture of aerosol particles (solid and liquid) 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. PM_{10} includes the 'coarse particles' fraction in addition to the $PM_{2.5}$ fraction.

PM is either directly emitted as primary particles or formed in the atmosphere from oxidation and transformation of primary gaseous emissions. The latter, formed from condensed material, are called secondary particles. The most important precursors for secondary particles are sulphur dioxide, nitrogen oxides, ammonia and volatile organic compounds (VOC). 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 particles in the air, called secondary inorganic aerosol (SIA). VOC are oxidised to less volatile products, which form secondary organic aerosol (SOA).

PM is either of natural origin (e.g. sea salt, naturally suspended dust, pollen, volcanic ash) or from anthropogenic sources, mainly from fuel combustion in e.g. thermal power generation, incineration, households for domestic heating and vehicles. 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, ozone. For both pollutants, no safe level has been identified. Even at concentrations below current air quality guidelines they pose a health risk (WHO, 2006).

Health effects of fine particulate matter ($PM_{2.5}$) 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 further 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 particulate matter 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 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 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 $\mu g/m^3$) was 1 January 2010, while the deadlines for meeting the other limit and 'obligation' values for $PM_{2.5}$ (20 $\mu g/m^3$) 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/m³	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/m³	To be met by 1 January 2005
$PM_{2.5}$, target value	Calendar year	25 µg/m³	To be met by 1 January 2010
$PM_{2.5}$, limit value	Calendar year	25 µg/m³	To be met by 1 January 2015
$PM_{2.5}$, limit value ([a])	Calendar year	20 µg/m³	To be met by 1 January 2020
$PM_{2.5}$, exposure concentration obligation ([b])		20 µg/m³	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 Member States.

([b]) Based on a three-year average.

Source: EU, 2008c.

Table 2.2 WHO air quality guidelines

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

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/m³) 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:

> 'The 2005 AQG set for the first time a guideline value for particulate matter (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 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 and target values for PM were exceeded widely in Europe in 2009, as evidenced by the monitored data reported to the European air quality database, Airbase (see Annex 1), and shown in Map 2.1, Map 2.2 and Figure 2.2.

The annual limit value for PM_{10} was exceeded most often (dark orange dots in Map 2.1) in Poland, Italy, Slovakia, several Balkan states and Turkey. The daily limit value was exceeded (light 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 Sweden and Latvia also exceeded the daily limit value. In the United Kingdom, exceedances of the daily limit value were recorded only in London.

Monitoring station spread is less comprehensive for $PM_{2.5}$ than for PM_{10}. For 2009 there were 595 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). That was an increase of more than 250 stations compared to the preceding year and the number of stations is still increasing. The 2009 $PM_{2.5}$ concentrations were higher than the annual target value to be met by 2010 (dark and light orange dots in Map 2.2) at several stations in Poland and Italy, and at a few stations in other countries.

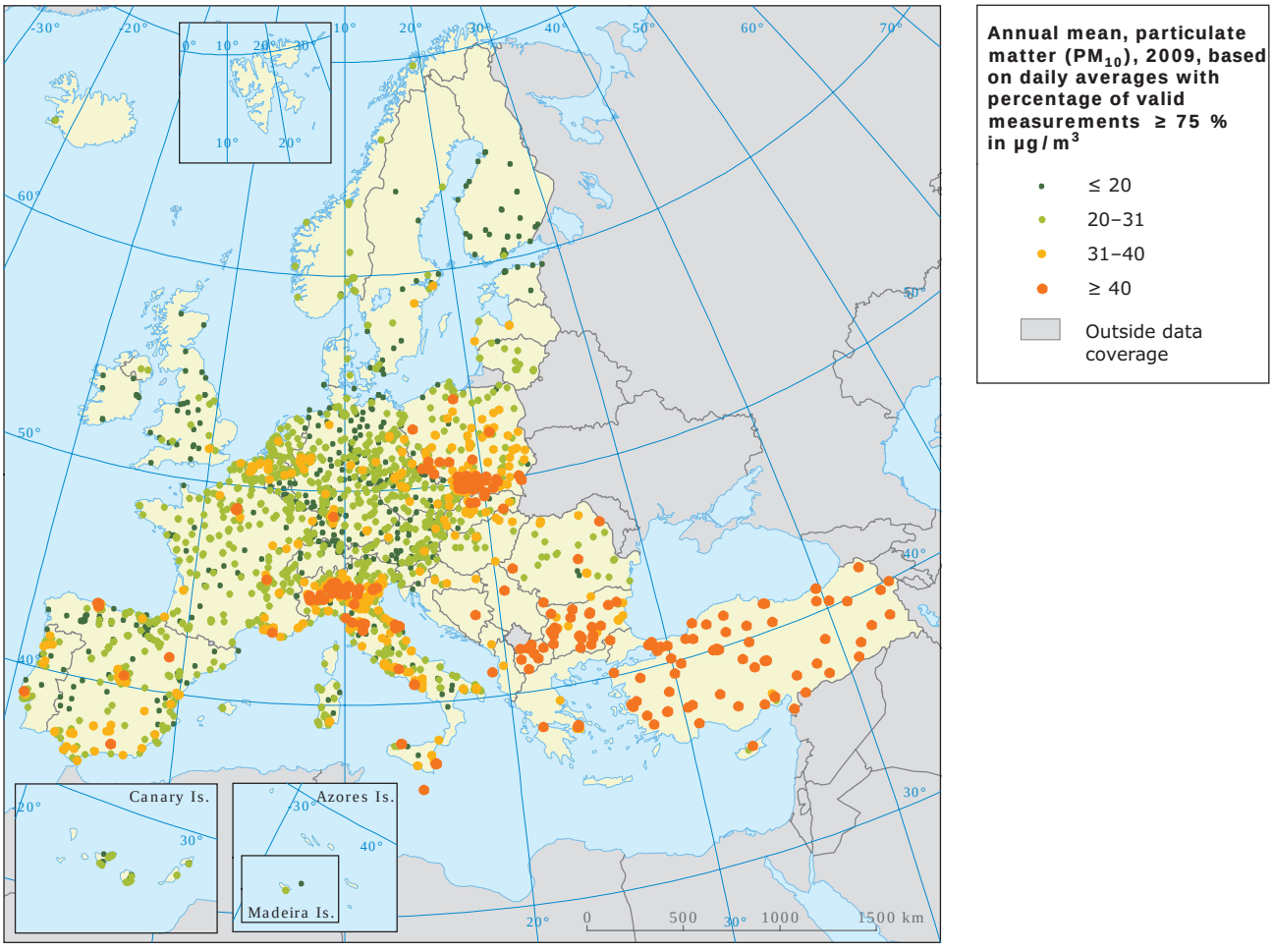
The WHO guidelines for annual mean PM were exceeded (pale green, light and dark orange dots in Map 2.1 and Map 2.2) at most of the AirBase monitoring stations across continental Europe but less commonly in Nordic countries.

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

The concentration of PM in rural areas represents the rural background PM concentration. 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 the urban addition but will have limited effects on the rural background level.

The rural background concentration level of PM constitutes a substantial part of the PM concentrations measured in the cities. Rural concentrations vary across Europe (Figure 2.1), decreasing from eastern and southern Europe towards western and northern Europe. It is also high at coastal sites for PM_{10} due to the contribution of sea salt (EMEP, 2010).

Map 2.1 Annual mean concentrations of PM_{10} in 2009



Note: The dark orange dots indicate stations reporting exceedances of the 2005 annual limit value (40 µg/m³), as set out in the Air Quality Directive (EU, 2008c).

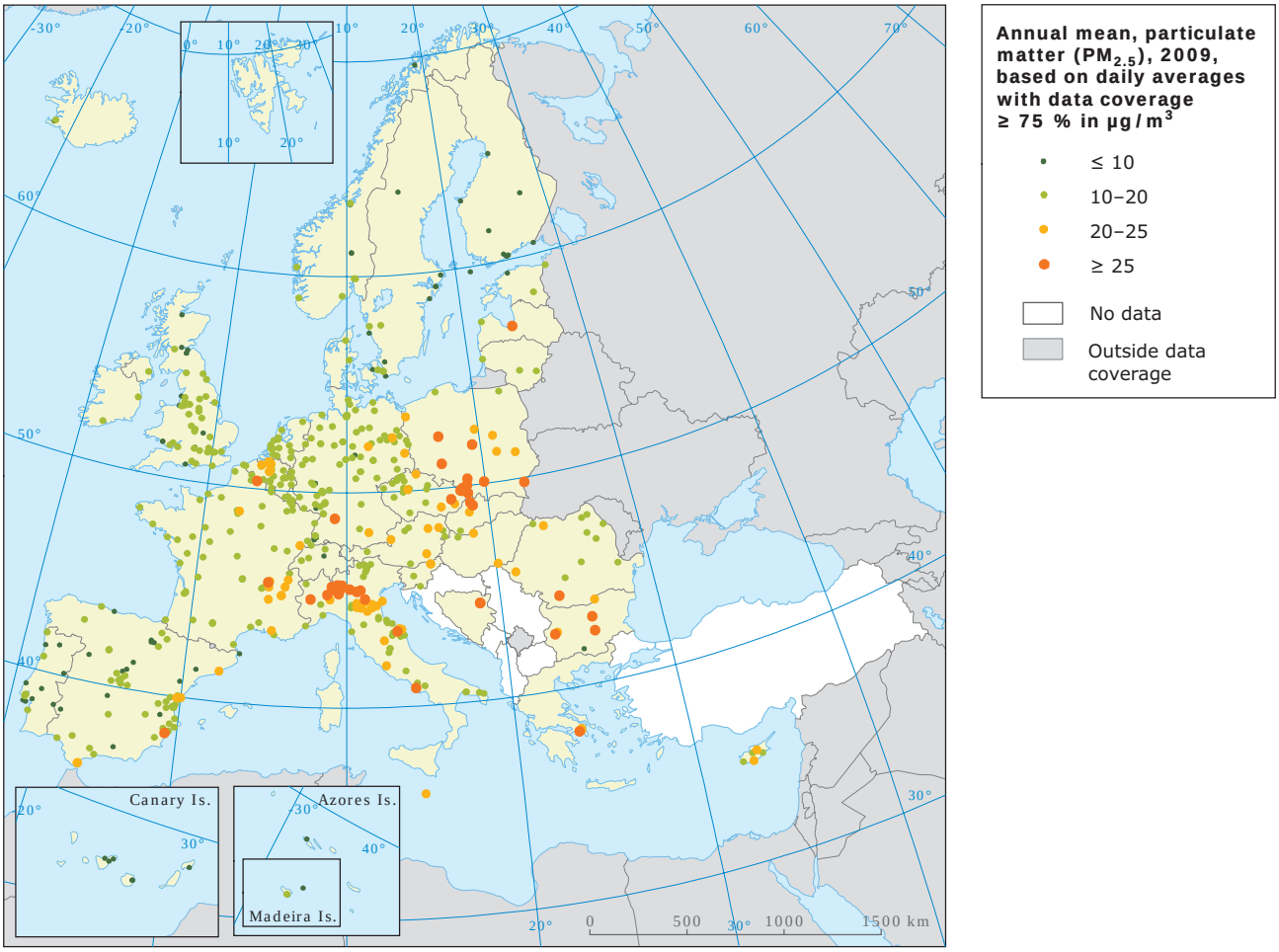
The light orange dots indicate stations reporting exceedances of a statistically derived level (31 µg/m³) corresponding to the 24-hour limit value.

The pale green dots indicate stations reporting exceedances of the WHO air quality guideline for PM_{10} of less than 20 µg/m³.

The dark green dots indicate stations reporting concentrations below the WHO air quality guideline for PM_{10}.

Source: Mol et al., 2011.

Map 2.2 Annual mean concentrations of $PM_{2.5}$ in 2009



Note: 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 light 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.

The dark green dots indicate stations reporting concentrations below the WHO air quality guideline for $PM_{2.5}$.

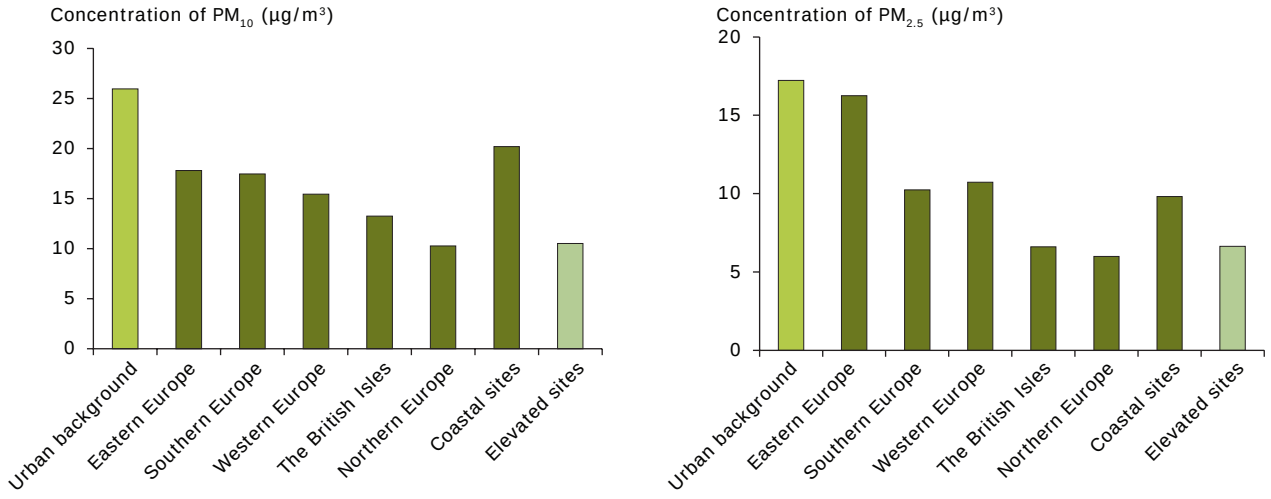
Source: Mol et al., 2011.

In addition to primary PM emissions, 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 to terrestrial vegetation and marine biota.

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 SOA is generally higher in summer, when biogenic emissions are larger, with an increasing north-south gradient. Based upon the chemical speciation measurements of PM within the EMEP station network ([9]), it

([9]) 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.

Figure 2.1 Annual mean concentrations of PM_{10} (left) and $PM_{2.5}$ (right) for various regions of the EMEP domain in 2008 (µg/m³)



Note: Annual mean concentrations of PM_{10} and $PM_{2.5}$ for all European urban background sites (from AirBase) are included for comparison.

Source: EMEP, 2010. Data from 2008.

can be inferred that on average SIA currently contributes about 30 % to annual average rural PM_{10} concentrations in Europe. The contribution to $PM_{2.5}$ is larger than 30 % but not as precisely determined as for PM_{10} due to less data being available (EMEP, 2010).

2.3.3 Distance to target

To indicate the 'distance to target' to meeting the EU limit value (LV) and target value (TV) for PM, Figure 2.2 shows the extent of the exceedances in 2009 of the 24-hour limit value for PM_{10} (to be met by 2005) and of the annual 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.

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 2009, the PM_{10} 24-hour LV was exceeded at 30 % of traffic sites, 31 % of urban background sites, 18 % of 'other' sites (mostly industrial) and even at 6 % of rural sites. The highest concentration measured in the EU was almost three times the LV, and in EEA-32 countries almost four times the LV.

The $PM_{2.5}$ annual TV was exceeded at 7 % of traffic sites, 9 % of urban background sites, 6 % of 'other' (mostly industrial) sites and at 3 % of rural sites. The limit value plus a margin of tolerance (29 µg/m³ for 2009) was exceeded at 3 % of all stations. For $PM_{2.5}$ there were sites where the concentration was close to double the target value.

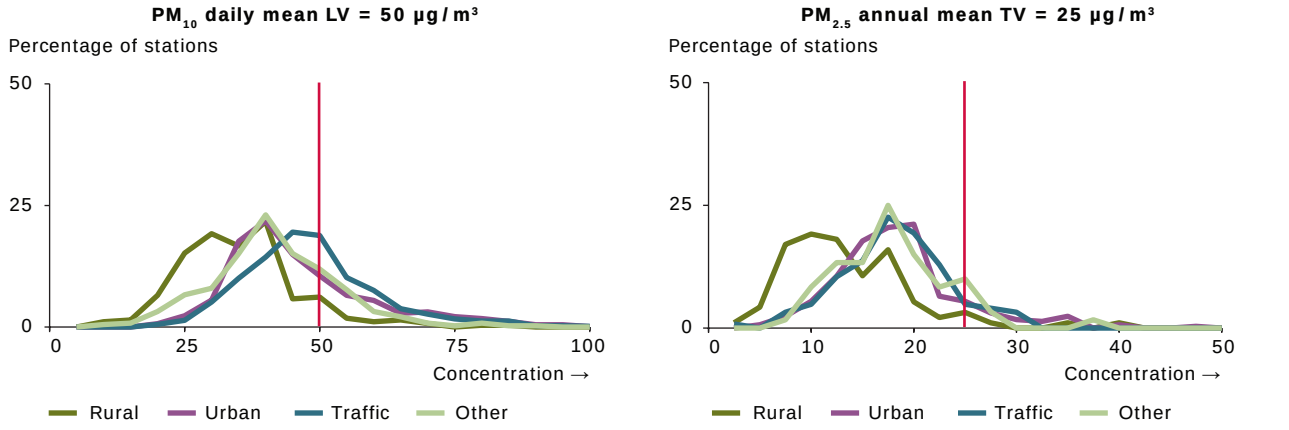
These findings demonstrate that PM concentrations must be reduced substantially in large areas of Europe (focusing on traffic and urban locations) for the limit and target values to be met.

2.3.4 Trends in PM concentrations

The average change in PM_{10} concentrations since 1999 is presented in Figure 2.3, for traffic, urban background and rural stations. In total 459 stations were operational for at least nine years between 1999 and 2009 and were included in this analysis.

At 83 % of the stations a small negative trend of less than 1 µg/m³ per year is apparent. The trend is estimated to be statistically significant at 42 %

Figure 2.2 Distance-to-target graphs for daily limit value of PM_{10} and for annual target value of $PM_{2.5}$, 2009



Note: The graphs show the percentage frequency distribution of stations in various concentration classes (µg/m³) The vertical red line designates the PM_{10} daily mean LV (50 µg/m³) in the left graph and the $PM_{2.5}$ annual mean TV (25 µg/m³) in the right graph.

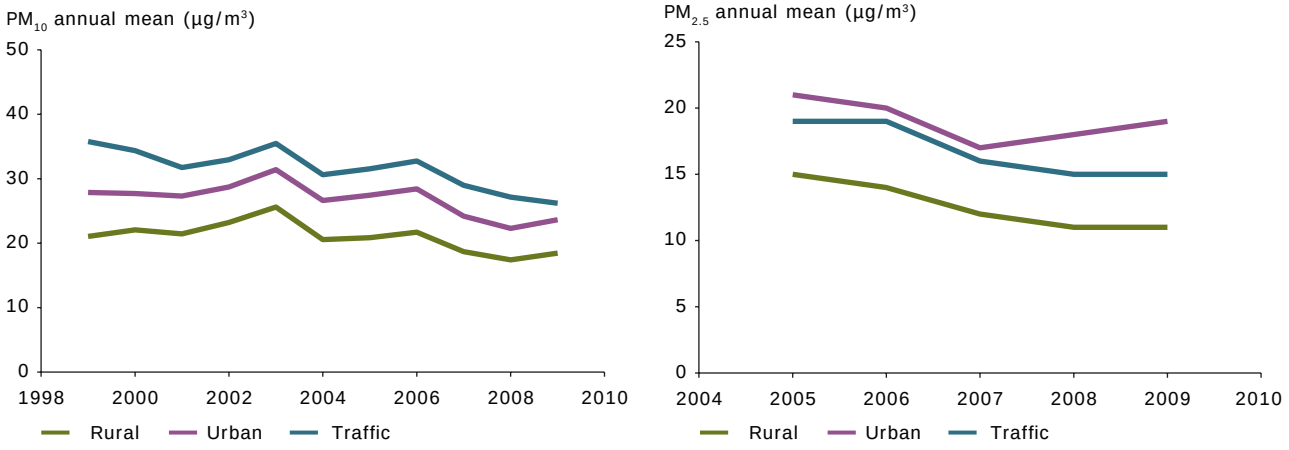
Source: de Leeuw and Ruyssenaars, 2011.

of these stations. Traffic stations recorded a steady decrease of average levels since 2006, while at rural and urban non-traffic stations an increase is observed in 2009 (Mol et al., 2011).

The number of $PM_{2.5}$ stations operational throughout the last five years is still limited (151 stations). Concentrations tended to decrease during the first four years (2005–2008) and a small increase is seen in 2009 for all station types (Figure 2.3). The available data are too limited to draw firm conclusions about trends (Mol et al., 2011).

In contrast to the PM_{10} data and expectations, the overall average $PM_{2.5}$ concentrations at urban non-traffic sites exceed those at traffic sites. Differences in the spatial distribution of urban and traffic stations over Europe may 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.

Figure 2.3 Trend in PM_{10} (left, 1999–2009) and $PM_{2.5}$ (right, 2005–2009) concentrations per station type



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 measurements. As a result, the time series data from France used in this aggregation are not homogeneous.

Secondary inorganic PM

The 20–35 EMEP rural stations measuring secondary inorganic PM (SIA), located mostly within the EU area, recorded a downward trend in concentrations. The stations reported the following changes in the period 1990–2008 (Larssen, 2011):

- sulphate aerosol concentrations fell by 58 % (based on data from 31 sites, all reporting a decrease);
- nitrate aerosol concentrations fell by 14 % (based on data from 20 sites, 35 % of which reported a decrease);
- ammonium aerosol concentrations fell by 7 % (based on data from 20 sites, 70 % of which reported a decrease).

The SIA mass concentration in 1990 was approximately 10 μg/m^3 as an average across these sites. The measured reductions noted above correspond to a reduction in SIA mass of about 3 μg/m^3 by 2008. This finding is supported by the slight downward trend in the PM_{10} mass concentration at rural stations shown in the AirBase data (Figure 2.3).

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). As dispersion and atmospheric conditions differ from year to year, the trend includes a year-to-year variability. This is not adjusted for in the present analysis.

The inventory of European emissions of primary PM has been fairly complete since 2000, although non-exhaust emissions (tyre and road wear) are not 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 inventory of the EU emissions in 1990–2009 is reported by EEA (2011b).

Emissions of primary PM fell in the EU between 1999 and 2009, by 16 % for PM_{10} and 21 % for $PM_{2.5}$ (Figure 2.4). The reductions from 1990 to 2009 were 27 % for PM_{10} and 34 % for $PM_{2.5}$ Emissions of the precursor gases SO_X and NO_X declined by 80 % and 44 % respectively in the period 1990–2009, and by 56 % and 28 % in the period 1999–2009. Emissions of ammonia (NH_3), another precursor gas, have fallen less: only about 11 % between 1999 and 2009 ([10]).

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, SIAs contribute on average about 30 % of the PM_{10} mass in rural air in central Europe (EMEP, 2010). They account for a lower percentage of PM in urban air because local emissions of primary particles add to the urban PM mass concentrations.

Sectoral output of primary PM and precursor gases

Various source sectors contribute to the primary anthropogenic PM and precursor gases (Figure 2.5). Commercial, institutional and household fuel combustion dominates emissions of primary PM_{10} and $PM_{2.5}$, and has reduced very little since 1990, especially for PM_{10}.

The second largest emission sector of primary PM_{10} and $PM_{2.5}$ is industry, followed by transport. Non-exhaust emissions from road traffic, which are not included in Figure 2.5, 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). With that contribution added, the transport sector becomes the second largest $PM_{2.5}$ emitter.

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 2009 and has decreased its NH_3 emissions by 27 % between 1990 and 2009. In EEA-32 the decrease was 26 %.

([10]) EEA-32 countries registered the following emission reductions between 1999 and 2009: 16 % for primary PM_{10}, 21 % for primary $PM_{2.5}$, 54 % for SO_X, 27 % for NO_X, 11 % for NH_3.

European policies have cut 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 % (EEA, 2010b). These sources also dominate the total emissions of NO_X and SO_X (Figure 2.5).

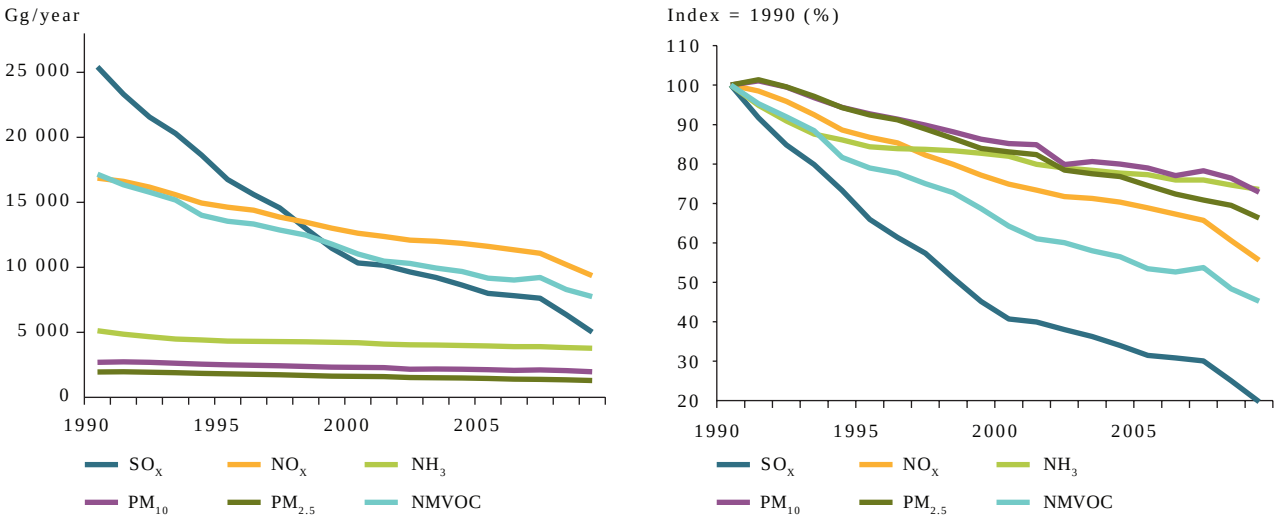
Relationship of emissions to ambient PM concentrations

Emissions of primary PM from commercial, institutional and households fuel combustion are not declining (Figure 2.5), meaning that the sector will continue to sustain PM concentrations in both rural and urban areas. Contrastingly, diminishing primary PM emissions from transport will tend to reduce the urban PM concentrations.

The reductions in emissions of the PM precursors NO_X and SO_X were much larger than the primary PM reductions. Meanwhile the reduction of NH_3 emissions was small (about 11 % between 1999 and 2009 in the EU and EEA-32). The combined effect was a reduction of the SIA contribution to total concentrations. As noted above, the 20–35 EMEP stations recording SIA mass concentration data reported a fall of about 3 µg/m^3 between 1990 and 2008. The slight downward trend observed in PM_{10} concentrations at rural sites (Figure 2.3) is in line with such a reduction in SIA, which is an integral part of PM_{10}. According to Erisman and Schaap (2004) SIA concentrations can only be reduced effectively if all three precursor gases NO_X, SO_X and NH_3 are reduced to the same extent.

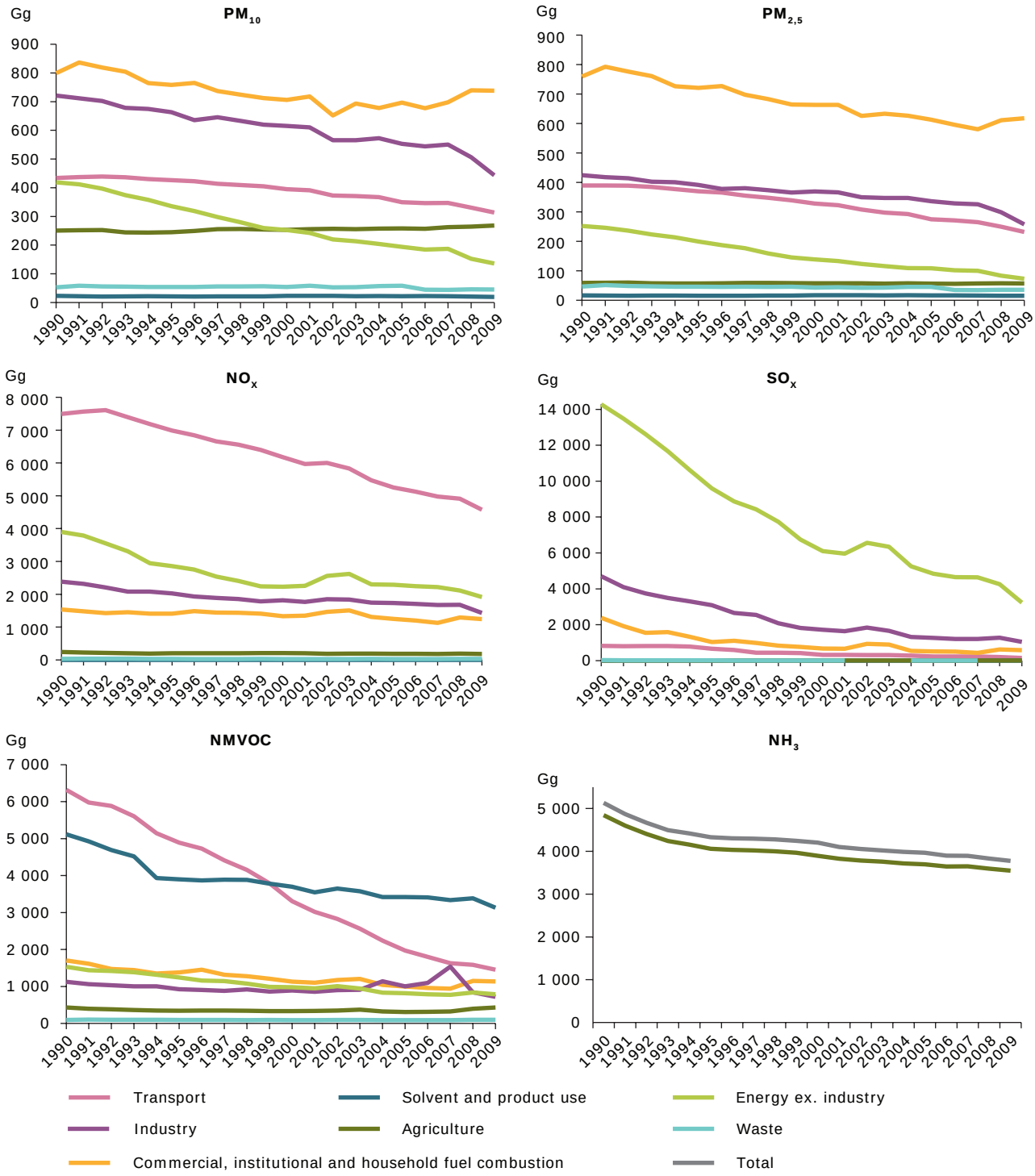
The small reductions observed in ambient PM concentrations over the period 1999–2009 (Figure 2.3) partly reflect the declining emissions of primary PM and precursor gases. Slowly decreasing primary PM and agricultural NH_3 emissions are expected to contribute to a baseline PM_{10} concentration that is only declining slowly.

Figure 2.4 EU emissions of primary PM and of PM and ozone precursor gases not including carbon monoxide ([a]), 1990–2009



Note: ([a]) Emissions of CO, a precursor for ozone, are shown in Figure 6.3.

Figure 2.5 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, 1990–2009



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 estimation is shown in Figure 2.6 for the period 1997–2009. 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 whole population in cities is potentially exposed to these concentrations, since people move freely within the city.

In 2009 about 20 % of the urban population in the EU was exposed to PM_{10} above the limit value. The extent of exposure above the LV has varied between 18 % and 49 % since 1997 and there is no apparent trend over this period. For EEA-32 countries the estimate is 39 % in 2009 and the variation was between 21 % and 50 % during the period 1997–2009. The range partly reflects variations caused by meteorology.

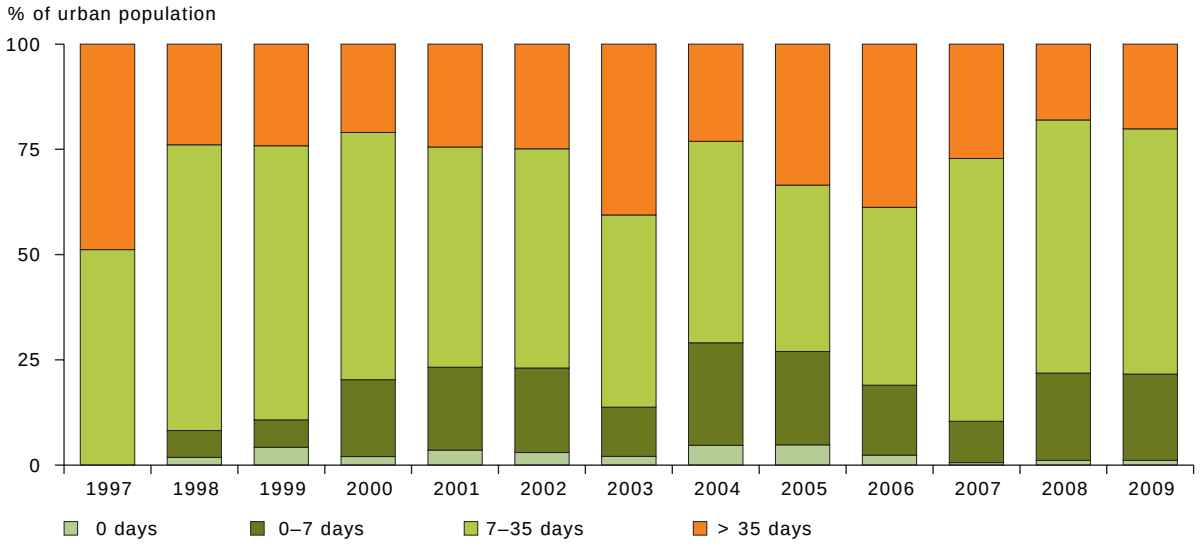
For $PM_{2.5}$, the 2008 Air Quality Directive (EU, 2008c) has introduced a target value for human exposure based on the average exposure indicator (AEI) set at the national level. The AEI is the averaged level measured at urban background (non-traffic and non-industrial) monitoring stations over a three-year period. Figure 2.7 indicates that in at least seven member states the average urban concentrations in 2007–2009 were above 20 μg/m^3, the legally binding level in the EU in 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.

De Leeuw and Ruyssenaars (2011) present an overview of the most stringent EU limit or target values set for the protection of human health, including those for PM, in comparison with the air quality guidelines (AQG) set by the WHO. The study, referring to the situation in the period 2006–2008, gives a rough estimate of the fraction of EU urban population currently exposed to concentrations above the EU limit value and the AQG level. Between 18 and 40 % of the urban population is exposed to PM_{10} concentrations exceeding the EU daily limit value while up to 80–90 % of the same urban population is exposed to concentrations exceeding the WHO AQG for PM_{10} (Table ES.1). Also here, the range partly reflects variations caused by meteorology.

2.5 Responses

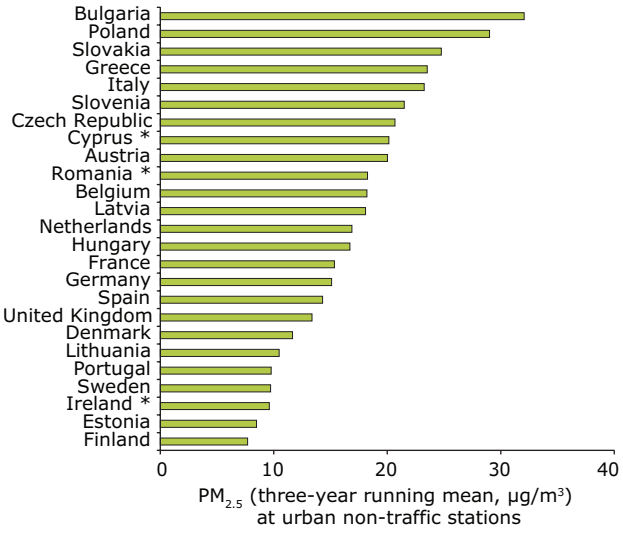
As both primary and secondary PM make up significant parts of PM concentrations, European efforts to reduce rural and urban concentrations

Figure 2.6 Percentage of population resident in EU urban areas potentially exposed to PM_{10} concentration levels exceeding the daily limit value, 1997–2009



Source: EEA, 2011c (CSI 004).

Figure 2.7 Urban $PM_{2.5}$ concentrations presented as multi-annual average in selected European countries, 2007–2009



Note: The three-year running mean (2007–2009) resembles the average exposure indicator. The compilation considers the background (non-traffic and non-industrial) urban stations.

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

must address emissions of both primary PM and also precursor gases. The key anthropogenic sources of these compounds are road vehicles and industrial installations. Annex 2 contains more information on each of the policy instruments discussed below.

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 impacts of the Euro standards on the average emission factors of the vehicle fleet on the roads are as follows:

- for PM, the Euro 4 emission factors (in force since 2005) are 69 % lower than the Euro 2 emission factors (from 1996) for light duty (passenger) vehicles and 92 % lower for heavy duty diesel vehicles;
- for NO_X, the Euro 4 emission factors are about 50 % lower than the Euro 2 emission factors for passenger cars and 70 % lower for heavy duty diesel vehicles;
- Euro 5 (from 2009) requires a further substantial drop in emission factors.

These reductions in permissible emission limits have resulted in substantial declines in NO_X and PM emissions from vehicles over the last decade (Figure 2.5) despite the large increase in the number of vehicles and total traffic activity over the same period. The actual decrease in transport emissions in the period 1990–2009 was about 39 % for NO_X, 28 % for PM_{10} and 40 % for $PM_{2.5}$ in the EU.

The decrease is even larger when compared to the projected emissions if the Euro regulations had not been introduced. In 2005 compared to 1990, total road traffic NO_X emissions were about 55 % lower than they would have been in the absence of Euro standards, while PM emissions were 63 % lower (EEA, 2010b).

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 Integrated Pollution Prevention and Control (IPPC) Directive (EU, 2008b), now replaced by the Industrial Emissions Directive (EU, 2010) — have resulted in a substantial reduction in emissions from large combustion and industrial plants. 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 are to be met by 2010, and the projections for emissions in 2010 (based upon the 2009 reporting by the Member States) estimate that NO_X emissions will exceed the ceiling by 12 % but SO_X emissions will be 36 % beneath the ceiling and NH_3 will be 3 % below.

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 ([11]) 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.

([11]) A zone is a part of the territory of an EU member state, delimited for the purpose of air quality management. Agglomeration is a type of zone that is a conurbation with high population density or a population in excess of 250 000 inhabitants.

3 Ozone, O_3

3.1 Sources and effects of ozone

3.1.1 Origins of ozone in air

Ground-level (tropospheric) ozone is not directly emitted into the atmosphere but formed from a chain of chemical reactions following emissions of precursor gases: NO_X, carbon monoxide (CO) and VOC. NO_X are emitted during fuel combustion, for example by industrial facilities and road transport. NO_X plays a complex role in ozone chemistry: close to its source NO_X will actually deplete ozone due to the scavenging reaction between the freshly emitted nitrogen monoxide (NO) and ozone.

VOC are emitted from a large number of sources including paint, road transport, refineries, dry-cleaning and other solvent uses. Biogenic VOC are 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 ozone formation. There is also a global background concentration of ozone in air, partly resulting from photochemical ozone formation globally and partly from the downward transport of stratospheric ozone to the troposphere.

3.1.2 Effects of ozone

Ozone is a strong oxidising agent. Excessive ozone 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 ozone exposure (WHO, 2008).

Epidemiological health evidence of chronic effects from exposure to ozone 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 ozone's chronic effects in terms of reduced 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 carbon dioxide (EEA, 2010a).

In addition to effects on human health, plants and crops, ozone is a greenhouse gas contributing to the warming of the atmosphere. Ozone also increases the rate of degradation of buildings and physical cultural heritage.

3.2 European air quality standards for ozone

European air quality objectives for ozone 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 8-hour average threshold is specified (120 μg/m^3). The target value, to be applied by Member States from 1 January 2010, is that the threshold should not be exceeded at a monitoring station on more than 25 days per year, 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 country affected is requested to draw up a short-term action plan according to specific provisions defined in the 2008 Air Quality Directive.

The vegetation protection value is specified as 'accumulated exposure over threshold', AOT40. This

Table 3.1 Air quality standards for ozone 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/m³ (b)	25 days per year averaged over three years
Vegetation	AOT40 accumulated over May–July	18 000 (µg/m³).h averaged over five years	
LTO health	Daily maximum 8-hour mean	120 µg/m³	
LTO vegetation	AOT40 accumulated over May–July	6 000 (µg/m³).h	
Information	One hour	180 µg/m³	
Alert (a)	One hour	240 µg/m³	

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

(b) Target value to be met by 1 January 2010, determined from a three-year average.

Source: EU, 2008c.

is calculated as the sum of all hourly ozone values over 40 µg/m³ during the most intense growing season, which is May to July.

The updated WHO air quality guideline for ozone is an 8-hour mean concentration of 100 µg/m³ (WHO, 2006). WHO (2008) explains the rationale for the guideline as follows:

> 'The previously recommended limit, which was fixed at 120 µg/m³ 8-hour mean, has been reduced to 100 µg/m³ based on recent conclusive associations between daily mortality and ozone levels occurring at ozone concentrations below 120 µg/m³.'

3.3 Europe-wide survey of ozone

3.3.1 Exceedance of the target values for protection of health

The target value threshold for ozone 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 2009 (the dark orange dots in Map 3.1).

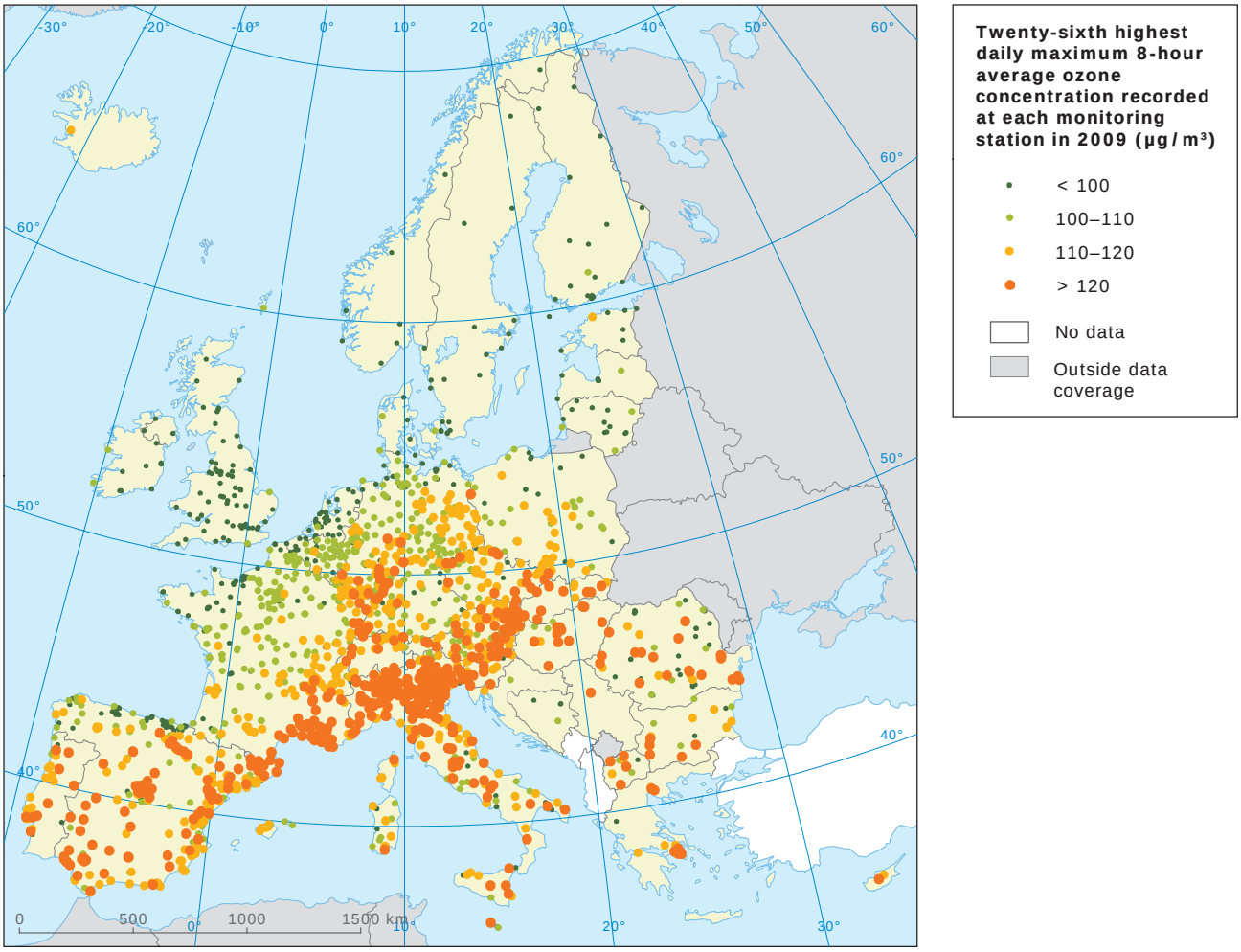
Since the formation of ozone requires sunlight, ozone concentrations show a clear north–south gradient with the highest concentrations in the Mediterranean countries. High levels are also observed at high altitude stations.

3.3.2 Ozone in rural, urban and traffic locations

In contrast to other pollutants, ozone 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, ozone is chemically quenched by the freshly emitted NO. Figure 3.1, for the short-term indicator, and Figure 3.2, 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 ozone concentrations occurring at a few urban stations shown in Map 3.1 are due to the ozone formation that occurs at times in large urban areas during episodes of high solar radiation and temperatures. The maximum concentration of this local ozone formation often occurs downwind of the urbanised area.

Differences in the distribution and magnitude of ozone 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 ozone concentrations. Year-to-year differences in the ozone 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 ozone concentrations.

Map 3.1 **Twenty-sixth highest daily maximum 8-hour average ozone concentration recorded at each monitoring station in 2009**



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

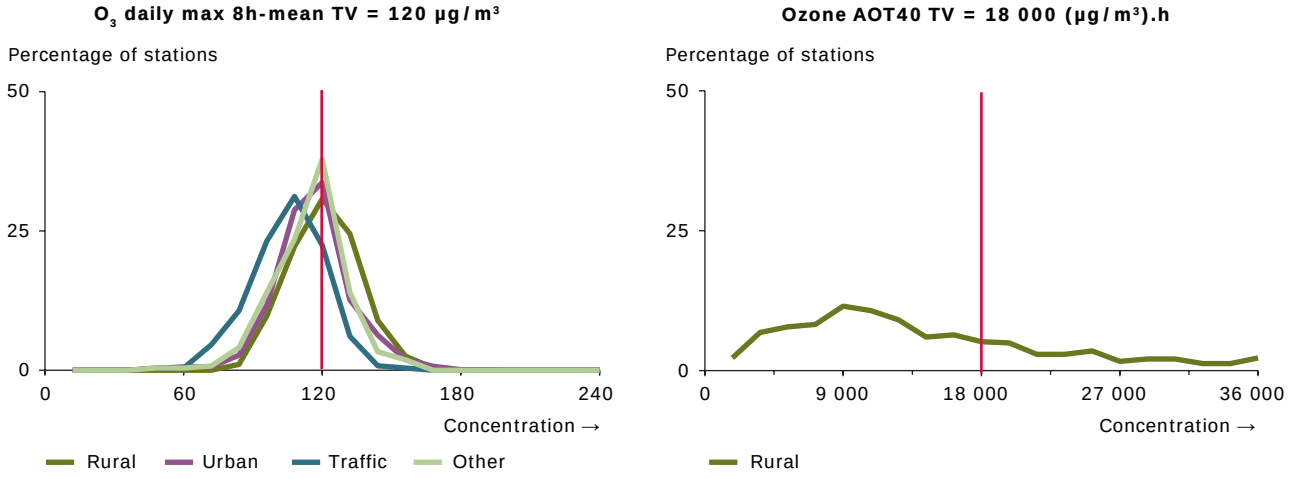
3.3.3 Distance to target

The health-related threshold of the target value (applicable from 2010) was exceeded more than 25 times in 2009 at 36 % of the rural stations, 22 % of urban background stations, 22 % of industrial sites (labelled as 'other' in Figure 3.1) and 8 % of traffic sites.

The 26th highest daily maximum of the running 8-hour mean values encountered in 2009 was slightly above 180 µg/m³. In contrast to other pollutants, whose concentrations can reach very low levels on unpolluted days and in unpolluted areas, the level of this indicator never falls below 50 µg/m³ at any site, corresponding to the current European background level.

Figure 3.1 shows that the threshold used for the target value (applicable from 2010) set for protection of vegetation was exceeded to a substantial degree at many stations, including many rural stations. The highest measured values exceeded 36 000 µg/m³.h, which is more than twice the target threshold.

Figure 3.1 Distance-to-target graphs for the target threshold for protection of human health (left) and protection of crops (right), 2009



Note: The graphs show the percentage frequency distribution of the 26th highest daily maximum of the running 8h-mean O_3 concentrations (left) and AOT40 concentrations (right) for the various types of stations.

Source: Left: de Leeuw and Ruyssenaars, 2011; right: Mol et al., 2011.

3.3.4 Trends in ozone concentrations

Map 3.2 (left) shows the change in the average number of exceedance days of the 120 µg/m^3 threshold (daily maximum 8-hour mean values) between the three-year periods 1992–1994 and 2007–2009. At nearly all stations this number decreased by more than four days although at some stations an increase is apparent. For this long time series, data are available for a very limited number of countries and stations. The findings are consistent with the ones reported in the latest ozone trend assessment (EEA, 2009).

When comparing the three-year periods 1998–2000 and 2007–2009, data from many more stations are available, covering a larger part of Europe (Map 3.2, right). Most stations reported fewer exceedances of the daily threshold, although some recorded an increase, mainly in southern and central Europe. Generally, the number of exceedances of the 120 µg/m^3 target value threshold has gone down since the 1990s but has remained at sustained levels in recent years (EEA, 2011a).

Figure 3.2 shows the trend in annual mean concentration recorded at different station types over the period 1999–2009. The varying concentrations reported at the different station types illustrate the effects of quenching by local NO sources, with traffic stations reporting the lowest concentrations and rural stations the highest. Ozone levels are typically lower at rural stations at altitudes below 500 m (rural — low) than at mountainous stations at higher altitudes (rural — high). Figure 3.2 does not show a clear trend in the mean annual average at any of the station types, although at both sets of rural stations there is a slight decreasing tendency since 2006.

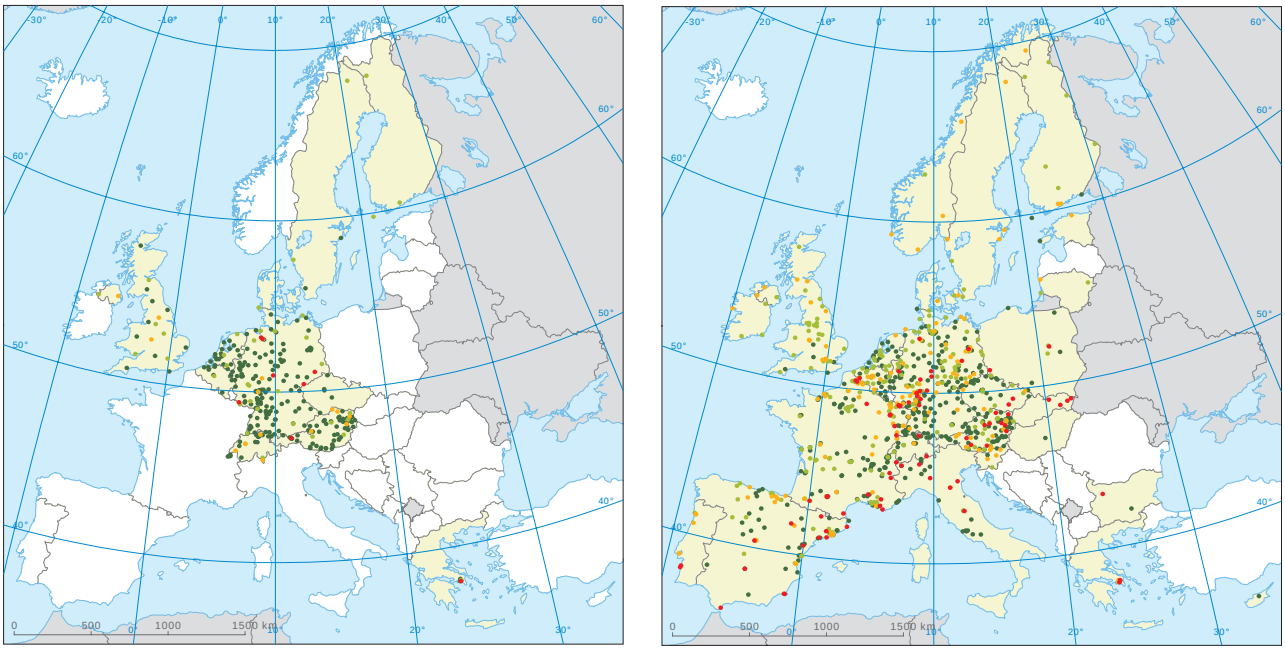
Emissions of ozone precursors

The EU emissions of the air pollutants primarily responsible for the formation of harmful ground-level ozone fell significantly in the period 1990–2009. CO emissions were cut by 62 % (Figure 6.3), NMVOC by 55 % and NO_X by 44 % (Figure 2.4) ([12]). Nevertheless, in 2009 NO_X emissions remained 12 % above the NEC Directive ceiling to be attained by 2010, mainly due to road transport emissions. For NMVOC, emissions in 2009 were below the pollutant ceilings (EEA, 2011b) but these decreased emissions did not manifest in significantly diminished ground-level ozone concentrations.

The transport and the energy sectors are the main sectors responsible for emissions of NO_X, followed by industry (Figure 2.5). The transport sector reduced its NO_X emissions by 39 % between 1990 and 2009 and the energy and industry sectors by 51 % and 40 %, respectively.

([12]) EEA-32 countries registered emission reductions as follows between 1990 and 2009: 61 % for CO, 51 % for NMVOC, 41 % for NO_X.

Map 3.2 **Change in the number of days on which the 120 µg/m³ threshold was exceeded, comparing the averages in 1992–1994 and 2007–2009 (left) and the averages in 1998–2000 and 2007–2009 (right)**



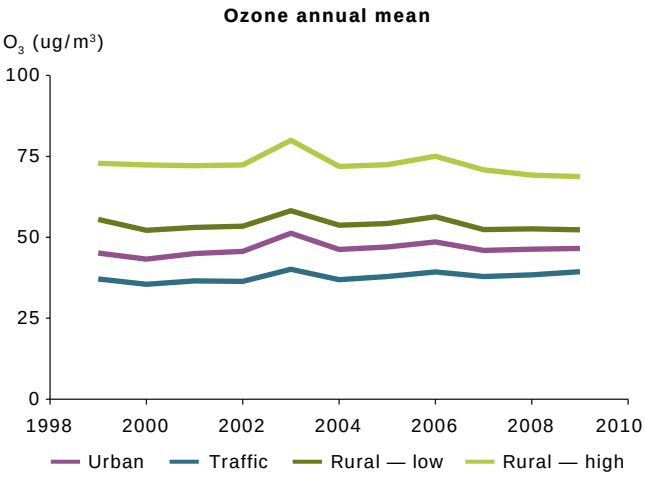
Note: Stations of all types operating for at least two years in each of the three-year periods have been included. Green dots refer to stations reporting a decrease in the number of exceedances of more than 4 days; red dots denote an increase in the number of exceedances of more than 4 days from period one (either 1992–1994 or 1998–2000) to period two (2007–2009).

As Figure 2.5 shows, several sectors have significantly cut their NMVOC emissions in the last two decades. The transport sector, which was the largest emitter in the 1990s, secured the largest reduction with a 77 % cut in the period 1990–2009. The solvent and product use sector has been the largest source of NMVOC emissions since 1999, despite reducing its emissions by 39 % from 1990 to 2009. NMVOC emissions from other sectors have changed little, with the exception of those from the energy sector, which fell by 48 %.

Relationship of ozone precursors to ambient ozone concentrations

There is an obvious discrepancy between the substantial cuts in ozone precursor gas emissions and the stagnation in observed annual average ozone concentrations in Europe (Figure 3.2). Reasons include increasing inter-continental transport of O_3 and its precursors in the northern hemisphere (EEA, 2010a). In addition to the long-range transport of pollution, other factors are likely to mask the

Figure 3.2 **Annual mean ozone concentrations (1999–2009) per station type**



Note: The results presented are from stations with data for all years.

effects of European measures to reduce O_3 precursor emissions. These include climate change/variability, biogenic NMVOC emissions, whose magnitude is difficult to quantify, and fire plumes from forest and other biomass fires (EEA, 2010a).

Formation of tropospheric ozone from increased concentrations of methane (CH_4) may contribute to the sustained ozone 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 well-mixed pollutant globally. Isolated local and regional abatement of methane emissions may therefore have limited impact on local ozone concentrations.

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

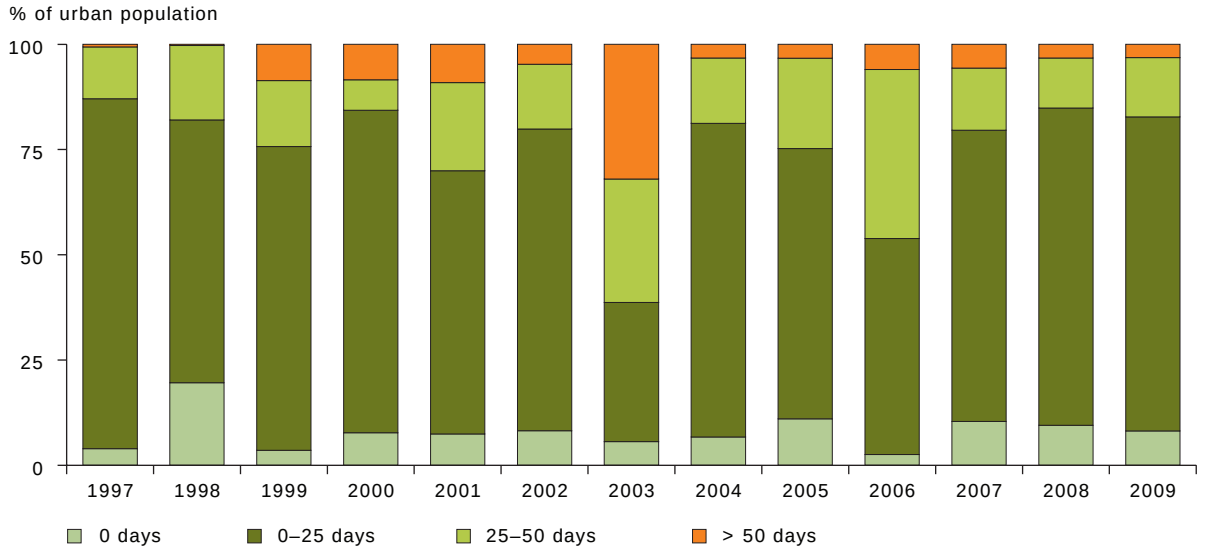
3.4 Exposure to ozone pollution in Europe

3.4.1 Human exposure

The ozone monitoring data in AirBase provide the basis for estimating the urban exposure of the European population to exceedances of the ozone target value (applicable from 2010) for the protection of human health (a daily maximum 8-hour mean concentration of 120 µg/m³, not to be exceeded on more than 25 days per calendar year, averaged over three years). This estimation is shown in Figure 3.3 for the period 1997–2009. The exposure is estimated based on ozone measured at all urban monitoring stations. For each city an average concentration is calculated. It is considered that the whole population is potentially exposed to this average concentration.

It is noteworthy that people in rural areas are potentially exposed to higher ozone levels than people in cities. In urban areas with fresh inputs of NO from traffic emissions, some of the ozone is quenched while oxidising NO to NO_2. The indicator in Figure 3.3 presents the exposure of the urban population.

Figure 3.3 Percentage of the EU and EEA-32 urban population potentially exposed to ozone concentrations over the target value threshold set for protection of human health, 1997–2009



Source: EEA, 2011c (CSI 004).

In 2009 about 17 % of the EU population in urban areas was exposed to ozone concentrations above the target value (TV). The extent of exposure above the TV has varied between 13 % and 61 % since 1997. 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 is significantly higher, representing more than 95 % of the total urban population (Table ES.1).

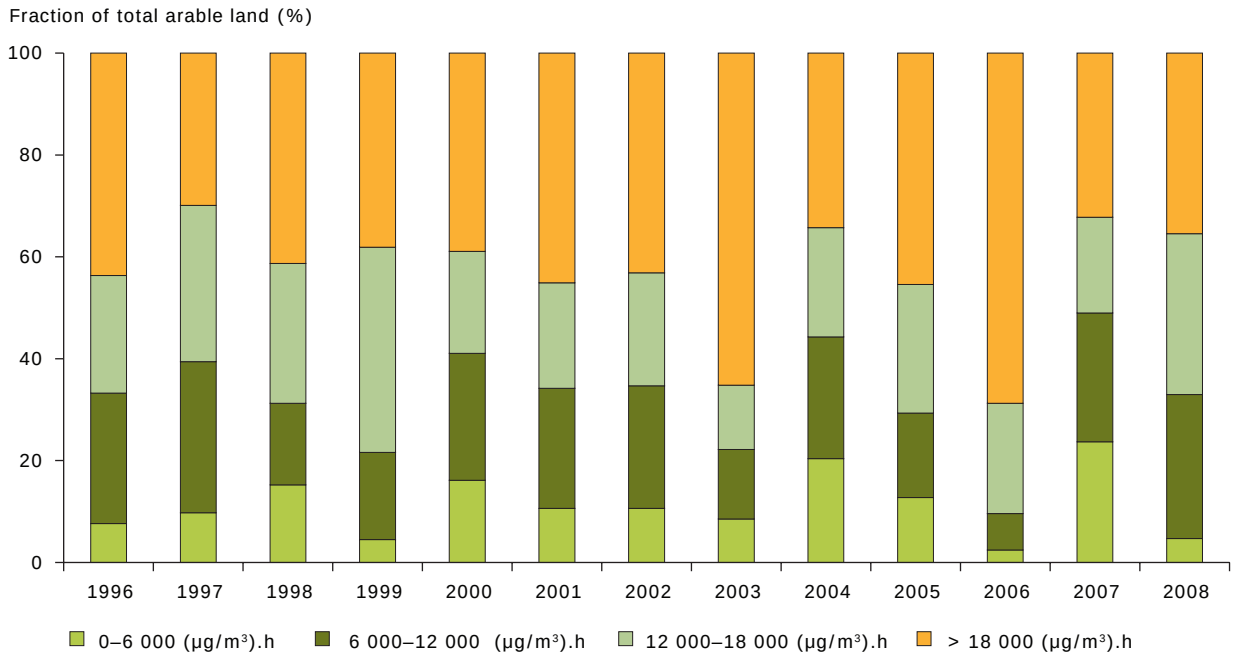
3.4.2 Exposure of ecosystems

The target value for protecting vegetation from high ozone concentrations, the AOT40 (accumulated exposure above 40 µg/m³ for the summer months May–July), to be met by 2010 is 18 000 µg/m³.hour, averaged over five years. The long-term objective is AOT40 of 6 000 µg/m³.hour.

Since 1996, the target value threshold has been exceeded in a substantial fraction of the agricultural area in EEA-32 member countries. For example, in 2008 the threshold was exceeded in about 35 % of this area (Figure 3.4 and Map 3.3). Exceedances of the target values have notably been observed in southern, central and eastern Europe (Map 3.3). The long-term objective was met in 5 % of the total agricultural area in 2008, mainly in Ireland and northern Scandinavia.

The variations between years (Figure 3.4) are influenced by meteorological factors. Summers in 2003 and 2006 had favourable meteorological conditions for ozone formation resulting in exceptionally high concentrations. In fact, average ozone concentrations in 2006 were only slightly higher than in 2005 but June and July 2006 were characterised by a large number of ozone episodes resulting in a much higher AOT40 value compared to 2005 (EEA, 2011a).

Figure 3.4 Exposure of agricultural area to ozone (AOT40 in µg/m³.h) in EEA-32 member countries

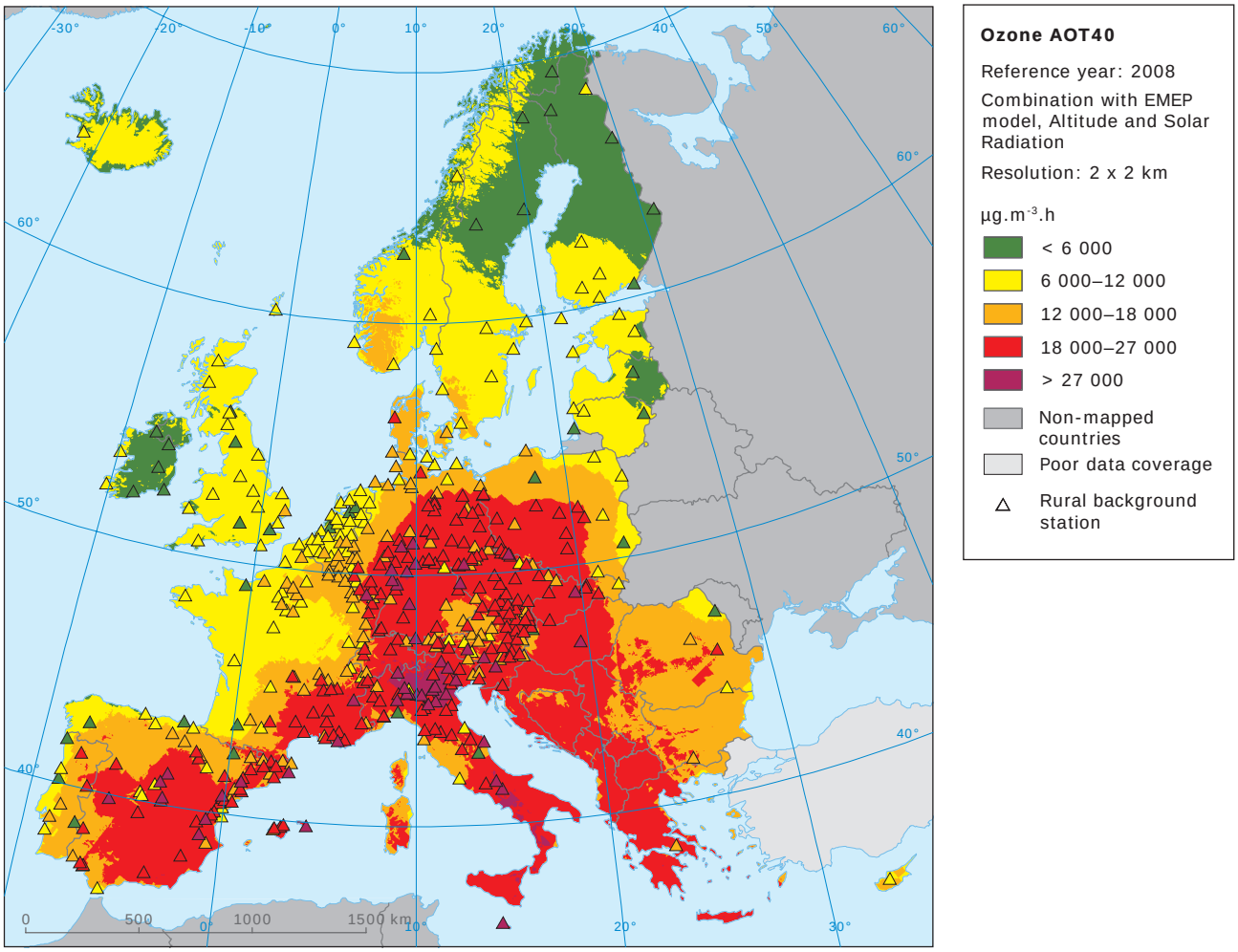


Note: Until 2006, Iceland, Norway, Switzerland and Turkey were excluded due to lack of detailed land-cover data and/or rural ozone data. In 2007, Switzerland and Turkey were excluded. In 2008, only Turkey was excluded.

The 2008 Air Quality Directive (EU, 2008c) sets the target value for protection of vegetation at 18 000 µg/m³.h and the long-term objective at 6 000 µg/m³.h.

Source: EEA, 2011d (CSI 005).

Map 3.3 Exposure of European land areas to ozone (AOT40)



Source: EEA, 2011d (CSI 005).

3.5 Responses

Current policy measures to reduce ozone concentrations target mainly emissions of the precursors NO_X and NMVOC. The relationship of ozone to its precursors is not linear.

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 Euro 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 %, compared to a hypothetical situation with no directives implemented. (EEA, 2010b).

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.

VOC 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 Solvents Directive (EU, 1999a), the Paints Directive (EU, 2004a) and the IPPC Directive (EU, 2008b) now replaced by

Directive 2010/75/EU on industrial emissions (EU, 2010). 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, 2010) regulates emission permits and requires the use of best available techniques (BAT) in production facilities and cleaning equipment.

The UNFCCC Kyoto Protocol requires limitation and/or reduction of emissions of methane, as one of the six main greenhouse gases.

Implementing air quality plans can determine the extent of progress towards the air quality targets and long-term objectives for ozone (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 nitrogen monoxide (NO). High temperature combustion processes (e.g. those occurring in car engines and power plants) are the major sources of nitrogen oxides, NO_X, the term used to describe the sum of NO and NO_2. NO 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 50 % of their NO_X as NO_2 (e.g. Grice et al., 2009) because their exhaust after-treatment systems increase the direct NO_2 emissions (see Section 4.3). 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 nitrogen dioxide from those of other pollutants in epidemiological studies.

Nitrogen compounds have acidifying effects but are also important nutrients. Excess deposition of atmospheric nitrogen can lead to a surplus of nutrient N 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 ozone. They also contribute to the formation of secondary inorganic aerosols (SIAs), 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 short-term (one-hour) and long-term (annual) exposure and countries 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. For the protection of vegetation a critical level is set for the annual mean of nitrogen oxides (NO_X), 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 $\mu g/m^3$. When exceeded over three consecutive hours at locations representative of air quality over at least 100 km^2 or an entire air quality management zone or agglomeration, authorities have to implement short-term action plans. Those action plans may include measures in relation to motor-vehicle traffic, construction works, ships at berth, and the use of industrial plants or products and domestic heating. Specific actions aiming at the protection of sensitive population groups, including children, 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/m³	18 hours per year
Human health	Calendar year	40 µg/m³	
Alert ([a])	One hour	400 µg/m³	
Vegetation ([b])	Calendar year	30 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 is smaller.

([b]) As oxides of nitrogen (NO_X), expressed as µg NO_2/m³.

Source: EU, 2008c.

Table 4.2 WHO air quality guideline for NO_2

µg/m³	1-hour mean	Annual mean
NO_2	200	40

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 40 µg/m³ and countries were obliged to meet it by 2010. The limit value plus a margin of tolerance (MT, specified by the 2008 Air Quality Directive) was 42 µg/m³ in 2009. In 2009, nearly all countries recorded exceedances of the LV and the LV+MT at one or more stations (Map 4.1). 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

NO_2 concentrations vary between rural, urban and traffic sites in a different manner from PM and ozone. While secondary PM and ozone are formed regionally from precursor gases, NO_2 is less formed by such chemical reactions. For most NO_X sources, the concentration of NO in emissions is much greater than that of NO_2, typically 10–20 times higher ([13]). The NO_2 concentration is then increased at the expense of NO, due to reactions with ozone.

In traffic and urban areas with fresh inputs of NO and NO_2 emissions, some of the ozone present is quenched while oxidising NO to NO_2. Indeed, ozone is normally the limiting factor in these reactions. In rural areas relatively limited fresh NO emissions are available, except near highways and near combustion plumes. The reaction between NO, NO_2 and ozone continues towards photochemical equilibrium. The result is an NO_2 gradient with rural and urban areas revealing the lowest concentrations and traffic areas the highest.

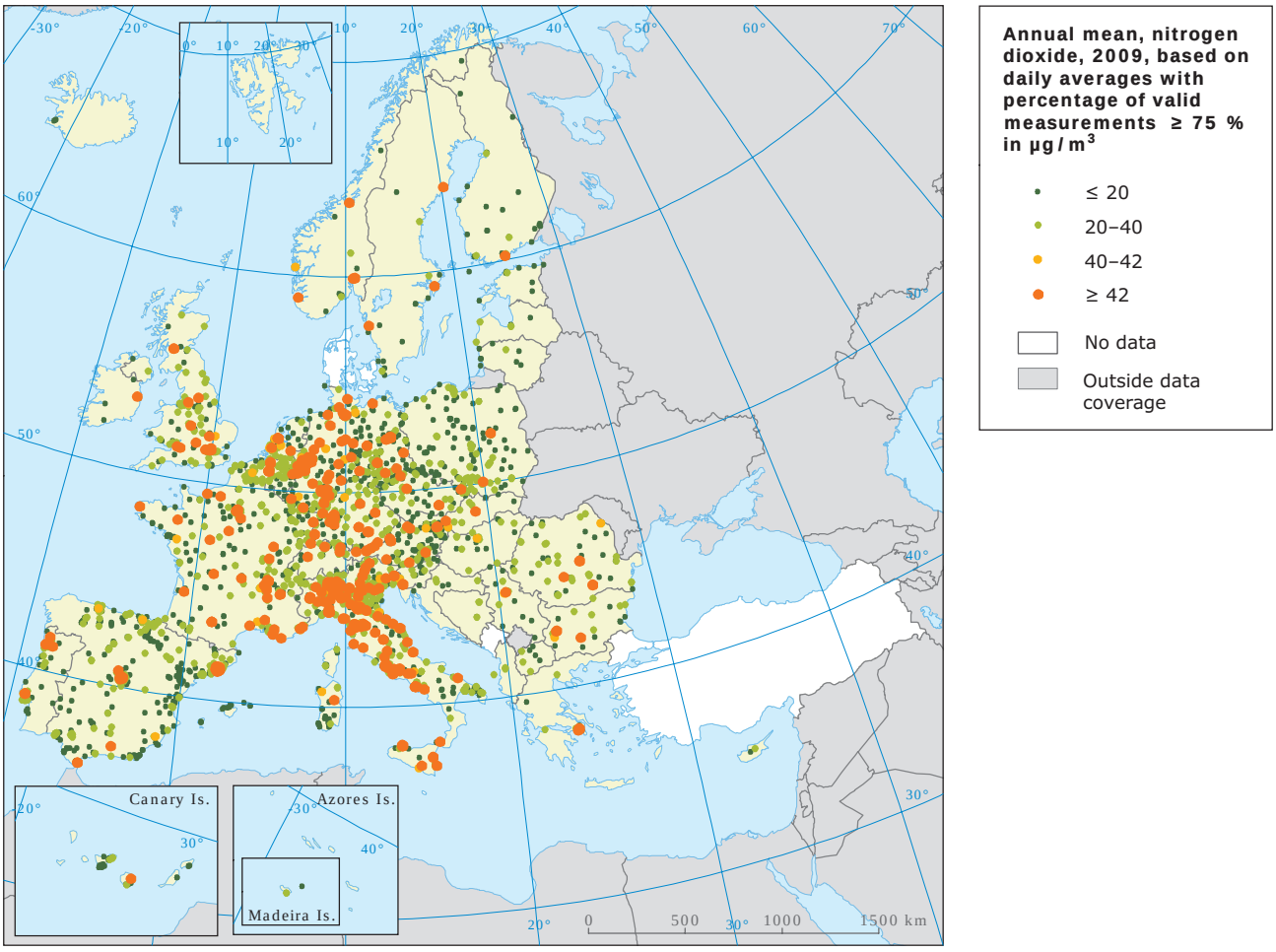
4.3.3 Distance to target

While the annual LV threshold is exceeded at only very few rural background stations, it is exceeded at 5 % of the 57 urban background stations. Exceedance of the LV threshold was reported at 47 % of traffic stations, with a maximum observed concentration of 112 µg/m³ in 2009, i.e. 2.8 times the threshold. In 2009 the NO_2 annual limit value plus margin of tolerance was exceeded at 41 % of traffic stations (Mol et al., 2011).

The hourly limit value threshold for NO_2 is less stringent. About 1 % of urban background stations reported exceedances and 8 % of traffic stations (Mol et al., 2011).

([13]) An exception is emissions from motor vehicles produced after 1990 (i.e. complying with Euro standards). Due to the effect of catalytic converters on gasoline-powered vehicles and particle filters on diesel vehicles, the 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

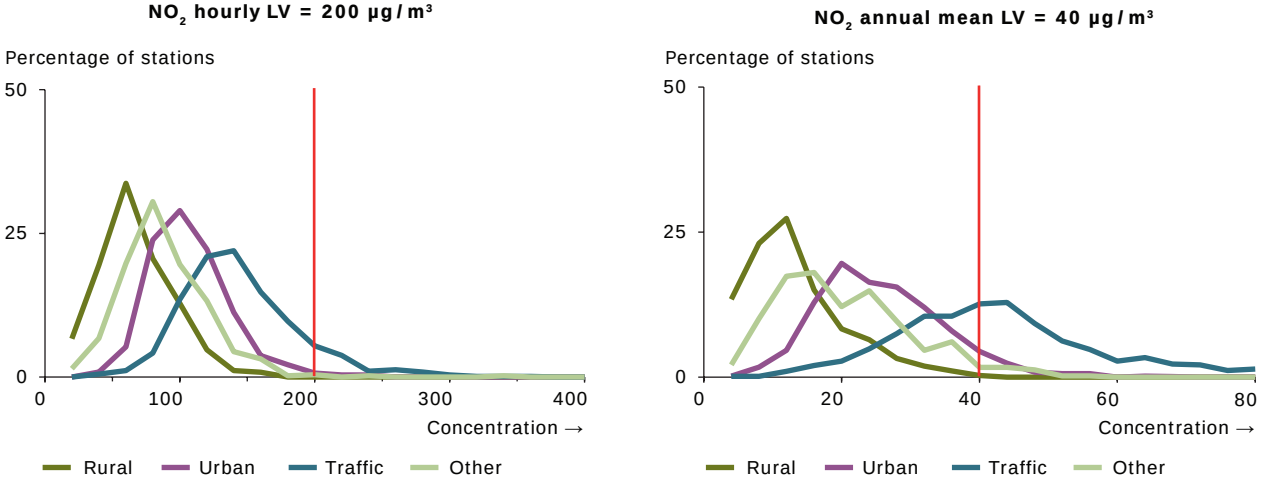


Note: Light orange dots correspond to exceedances of the annual limit value (40 µg/m³).

Dark orange dots correspond to exceedance of the annual limit value + margin of tolerance in 2009 (42 µg/m³).

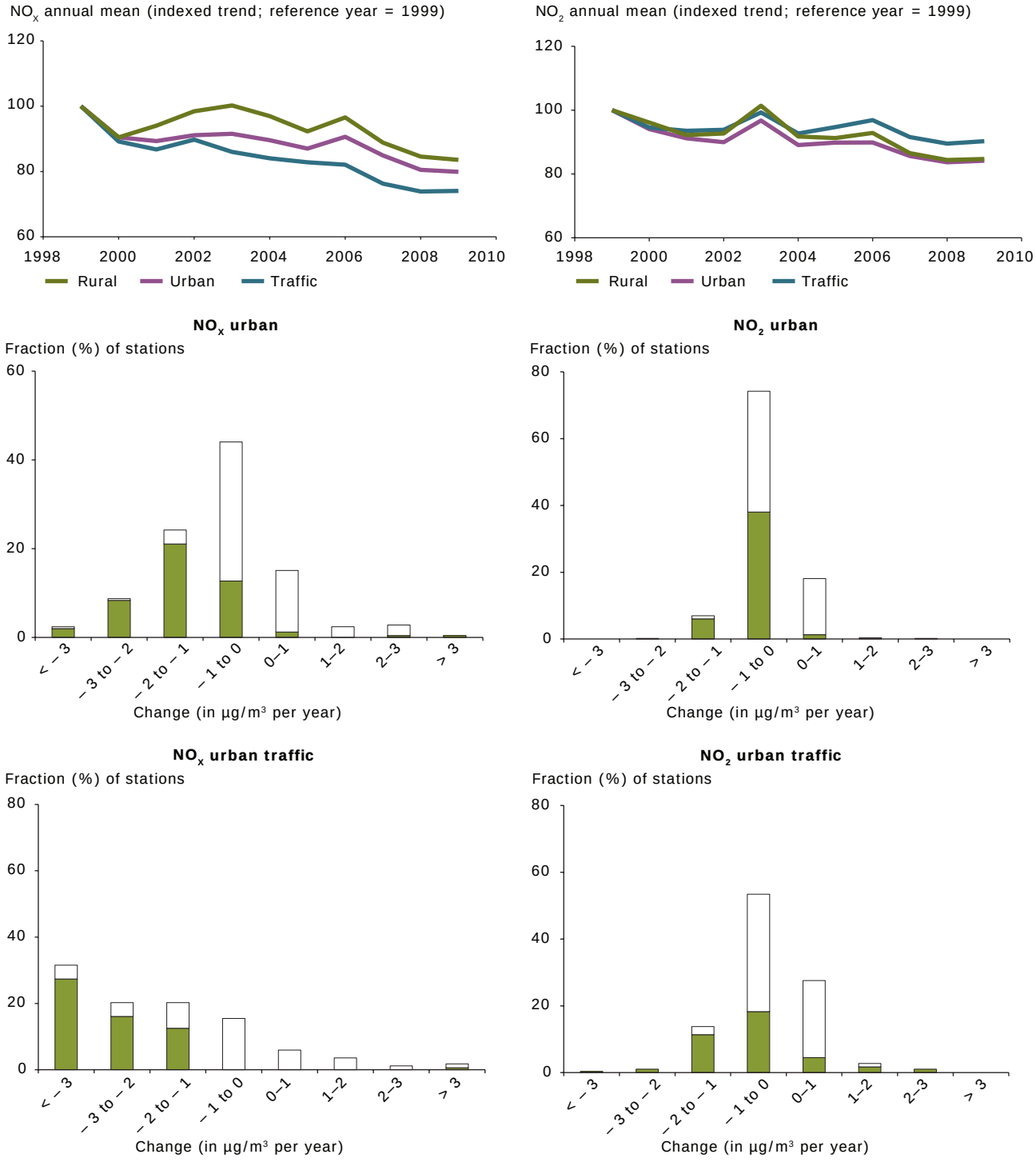
Source: Mol et al., 2011.

Figure 4.1 Distance-to-target graphs for the annual (left) and hourly (right) NO_2 limit value, for different station types in the EU, 2009



Source: de Leeuw and Ruyssenaars, 2011.

Figure 4.2 Overview NO_2 and NO_x concentrations trends, period 1999–2009
Top: indexed trend (1999 = 100) at rural, urban and traffic stations
Middle: percentage frequency distribution of estimated annual change at urban stations
Bottom: percentage frequency distribution of estimated annual change at traffic stations



Note: In the percentage frequency distribution graphs, closed bars denote stations showing a statistically significant trend, open bars denote stations with a non-significant trend. In the top diagrams a geographical bias exists towards central Europe where there is a higher density of stations.

4.3.4 *Trends in NO_2 and NO_X concentrations*

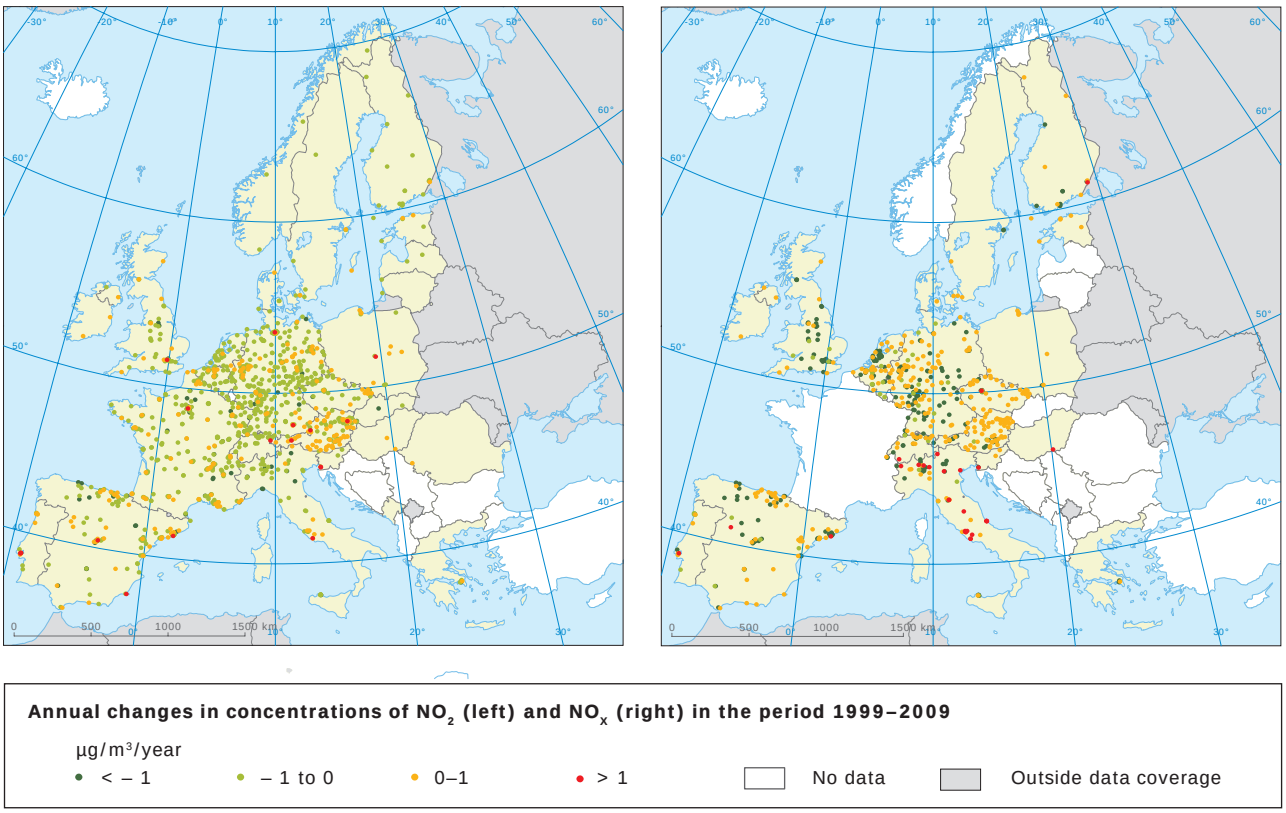
The trends in NO_2 and NO_X concentrations over the period 1999–2009 are summarised in Figure 4.2 and Map 4.2. A consistent set of stations is used for both NO_2 and NO_X but the distribution of the stations differs, therefore influencing the comparison. The concentration time series in Figure 4.2 shows decreasing NO_2 and NO_X concentrations at all station types but the proportional fall in NO_X is larger than the reduction in NO_2. In the NO_X case, the relative size of the reductions at rural, urban and traffic sites reflects the proximity of the sources, particularly traffic. In the NO_2 case, the reduction at traffic stations is clearly less than at rural and urban stations. The trends in concentrations are linked to changes in emission sources.

As shown in Figure 2.4, EU emissions of NO_X fell 44 % in the period 1990–2009 and 8 % from 2008 to 2009. Nevertheless, total NO_X emissions in 2009 were about 12 % higher than the aggregated emissions ceiling set in the NEC Directive (EU, 2001b) for 2010.

Transport is the dominant sector for NO_X emissions, accounting for 49 % of the total in 2009, followed by the energy sector, which contributed 20 % of the total (Figure 2.5). These two sectors have substantially reduced emissions since 1990. Over the period 1999–2009 emissions from transport decreased by 28 % and from industry by 20 %, while emissions from the energy sector only decreased 15 %. The commercial, institutional and households fuel combustion sector as well as the agriculture sector have decreased their NO_X emissions by 12 % in the same period.

Actual emissions from vehicles (often termed 'real world emissions') may exceed the allowed 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.

Map 4.2 Annual changes in concentrations of NO_2 (left) and NO_X (right) in the period 1999–2009



Note: NO_X concentrations are expressed in µg NO_2/m^3.

Source: Mol et al., 2011.

Impacts of the growing primary NO_2 fraction in NO_X

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

The increasing primary NO_2 fraction (f-NO_2) in emission from diesel vehicles could lead to increased NO_2 concentrations in traffic exposed areas and possibly also in urban areas in general. This process has not been fully analysed but Grice et al. (2009) have projected future NO_2 concentrations based on emission inventory calculations, f-NO_2 data and projections of ambient air quality. In the mentioned study, modelled NO_2 ambient concentrations decreased since 2005, in accordance with many empirical results. Looking ahead, the model projected a further decrease in most countries studied. In some countries, however, NO_2 concentrations were projected to increase until 2010 and decline thereafter.

The time series and frequency distributions in Figure 4.2 show the differing trends in NO_2 and NO_X concentrations recorded at urban and traffic stations. At urban background locations the situation is relatively clear: the NO_2 levels are decreasing at 81 % of stations (at 44 % the trend is statistically significant). Similar numbers are estimated for the NO_X stations although annual changes are larger than in the case of NO_2. At traffic locations, NO_X concentrations are decreasing at 88 % of the stations, reflecting the changes in emissions from road traffic, but NO_2 trends are less statistically significant and less downward. These trends reflect both the increase in the f-NO_2 in the NO_X emissions from traffic and the shift in the photostationary state that results from a decrease in NO_X, without an equivalent decrease in ozone concentrations.

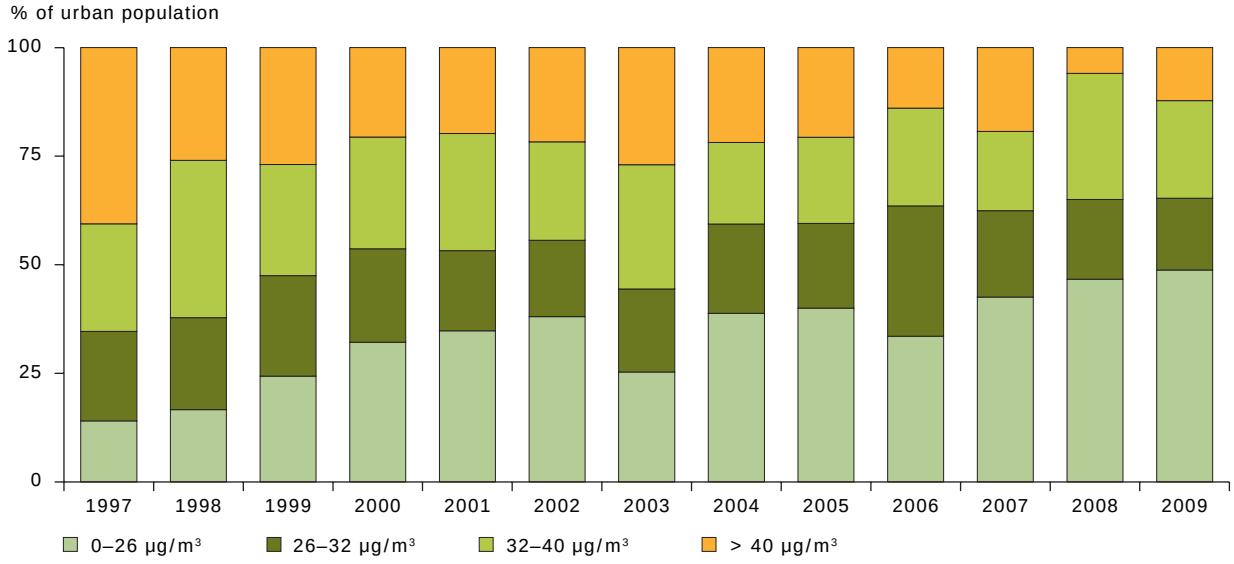
Map 4.2 shows the spatial distribution of NO_2 and NO_X trends. Although some regions have clusters of stations reporting an upward trend (e.g. Austria, Italy), most regions have stations with both upward and downward trends. It is important to note, however, that the coverage of stations with time series stretching from 1999 to 2009 is very low in some parts of Europe, notably in Eastern Europe and in Scandinavian countries.

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 4.3 presents the data for the period 1997–2009, based on NO_2 measured

Figure 4.3 Percentage of the EU urban population potentially exposed to NO_2 concentration over the limit value set for protection of human health, 1997–2009



Source: EEA, 2011c (CSI 004).

at urban background monitoring stations. For each city an average concentration is calculated. It is considered that the whole population is potentially exposed to these concentrations, since people move freely within the city.

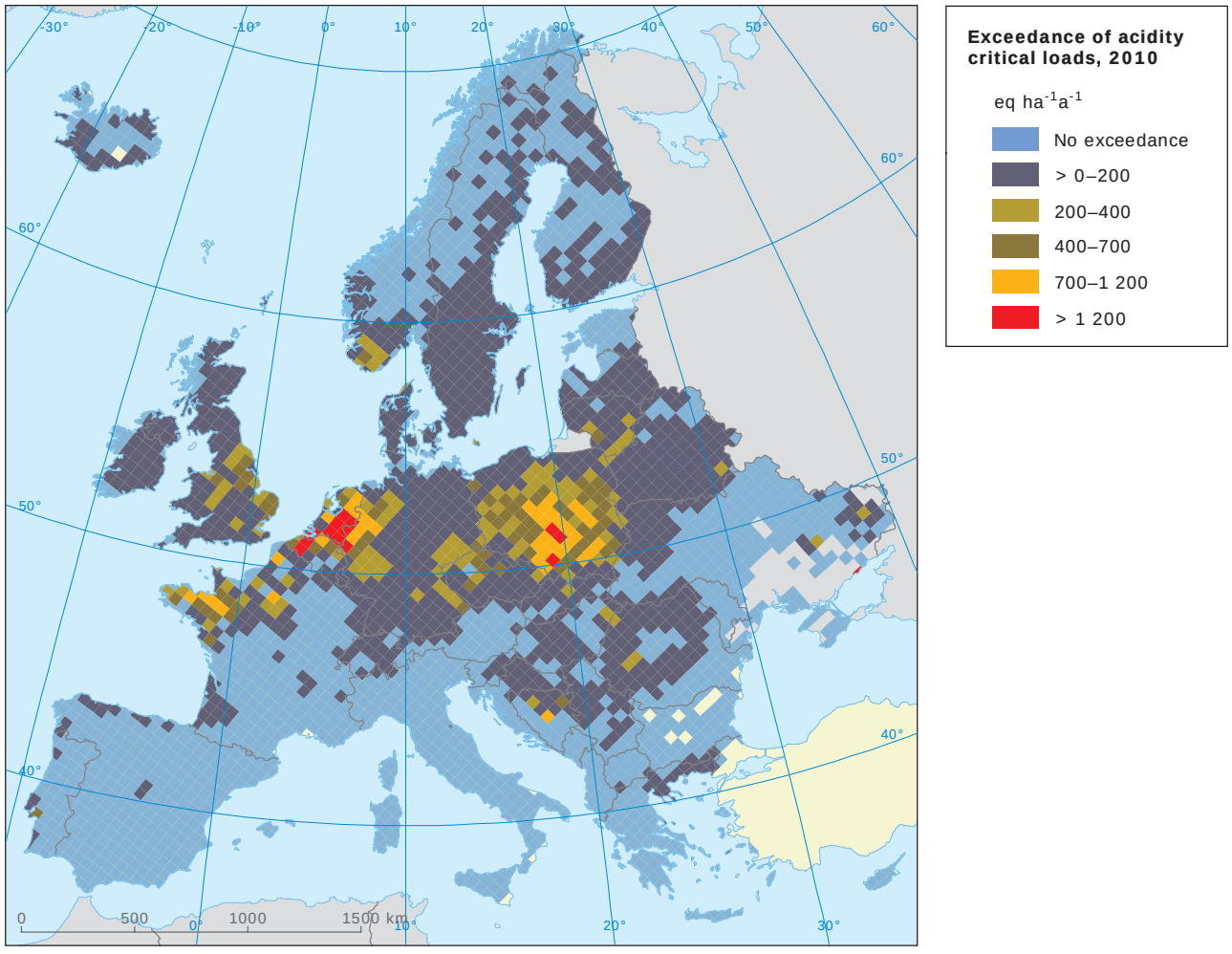
According to this method, about 12 % of the EU and EEA-32 urban population was exposed to NO_2 above the annual limit value and the WHO AQG for NO_2 in 2009. Exposure above the limit value varied between 6 % and 41 % since 1997, with same percentages estimated for the EEA-32. There is a decreasing trend over this period but an increase between 2008 and 2009. 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 of ecosystems. The assessment here is combined for both types of nitrogen inputs. In the case of acidification it also includes the effect of SO_X emissions.

The acidification and eutrophication effects are estimated using the concept of 'critical load': the ecosystem's ability to absorb deposited atmospheric nitrogen without negative effects on the natural environment. Exceedance of this spatially determined 'critical load' presents a risk of damage. Such exceedances are calculated based upon measurement data and model calculations ([14]).

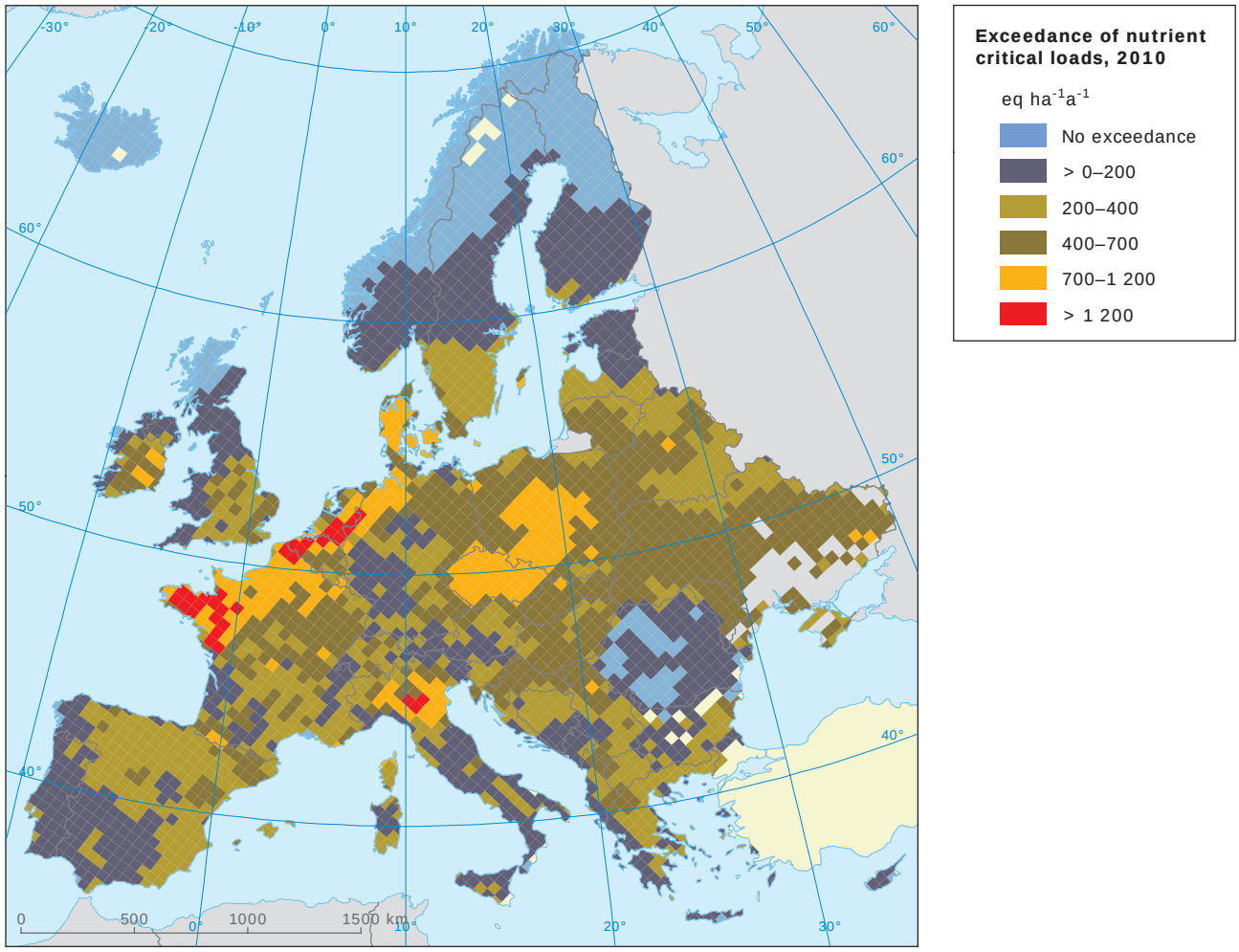
Map 4.3 Projected exceedance of critical loads for acidification by deposition of nitrogen and sulphur compounds in 2010



Source: Coordination Centre for Effects (CCE), European Critical Loads Database 2008.

([14]) The results were computed using the 2008 Critical Loads database developed by the Coordination Centre for Effects (CCE) in collaboration with the National Focal Centres under the LRTAP Convention (see Hettelingh et al., 2008). 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).

Map 4.4 **Projected exceedance of critical loads for eutrophication due to the deposition of nutrient nitrogen in 2010**



Source: Coordination Centre for Effects (CCE), European Critical Loads Database, 2008; Hettelingh et al., 2008.

Map 4.3 and Map 4.4 show the projected exceedances of critical loads for acidity and nutrients in 2010, based on a current legislation scenario for precursor emissions (EEA, 2010a) ([15]). Exceedances of critical loads for acidity are projected in large parts of northern Europe in 2010 with particularly large exceedances in Belgium and the Netherlands, the north-west coast of France and Poland.

In the case of acidification, the situation has considerably improved and it is predicted to improve further. The European ecosystem areas where the critical load for acidity will be exceeded are projected to have declined by more than 80 % in 2010 compared with the 1990 base year.

Concerning eutrophication (Map 4.4), projected exceedances for 2010 cover most of continental Europe as well as Ireland and southern areas of the United Kingdom and Sweden. Exceedances in Romania are relatively low due to a submission in 2008 by Romania of high critical loads for eutrophication (Hettelingh et al., 2008).

The risk of ecosystem eutrophication and its geographical coverage have diminished only slightly

([15]) 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.

over the last decade. Projections for 2010 indicate that the risk 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 strong reductions of NO_X 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. An unintended effect of some technologies used in diesel vehicles to meet the Euro emission standards 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.

5 Sulphur dioxide, SO_2

5.1 Sources and effects of SO_2

5.1.1 Origins of SO_2 in air

Sulphur dioxide (SO_2) is emitted when fuels containing sulphur are burned. The key man-made contributions to ambient SO_2 derive from sulphur-containing 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 sulphur dioxide 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).

SO_2 is a major precursor to particulate matter ($PM_{2.5}$), 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 sulphur 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, sulphur 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 and 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.

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 is the smaller.

Source: EU, 2008c.

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.

5.3 Europe-wide survey of SO_2

5.3.1 *Exceedances of limit values*

The hourly and daily limit values for the protection of human health were only exceeded in Bulgaria and Romania in 2009. The hourly limit value were exceeded at 0.35 % of the operational urban stations (with more than 75 % data coverage) in the two countries and the daily limit value was exceeded at 0.28 % of urban stations there (Mol et al., 2011).

Map 5.1 shows annual mean SO_2 concentrations in 2009. As in 2008, 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.

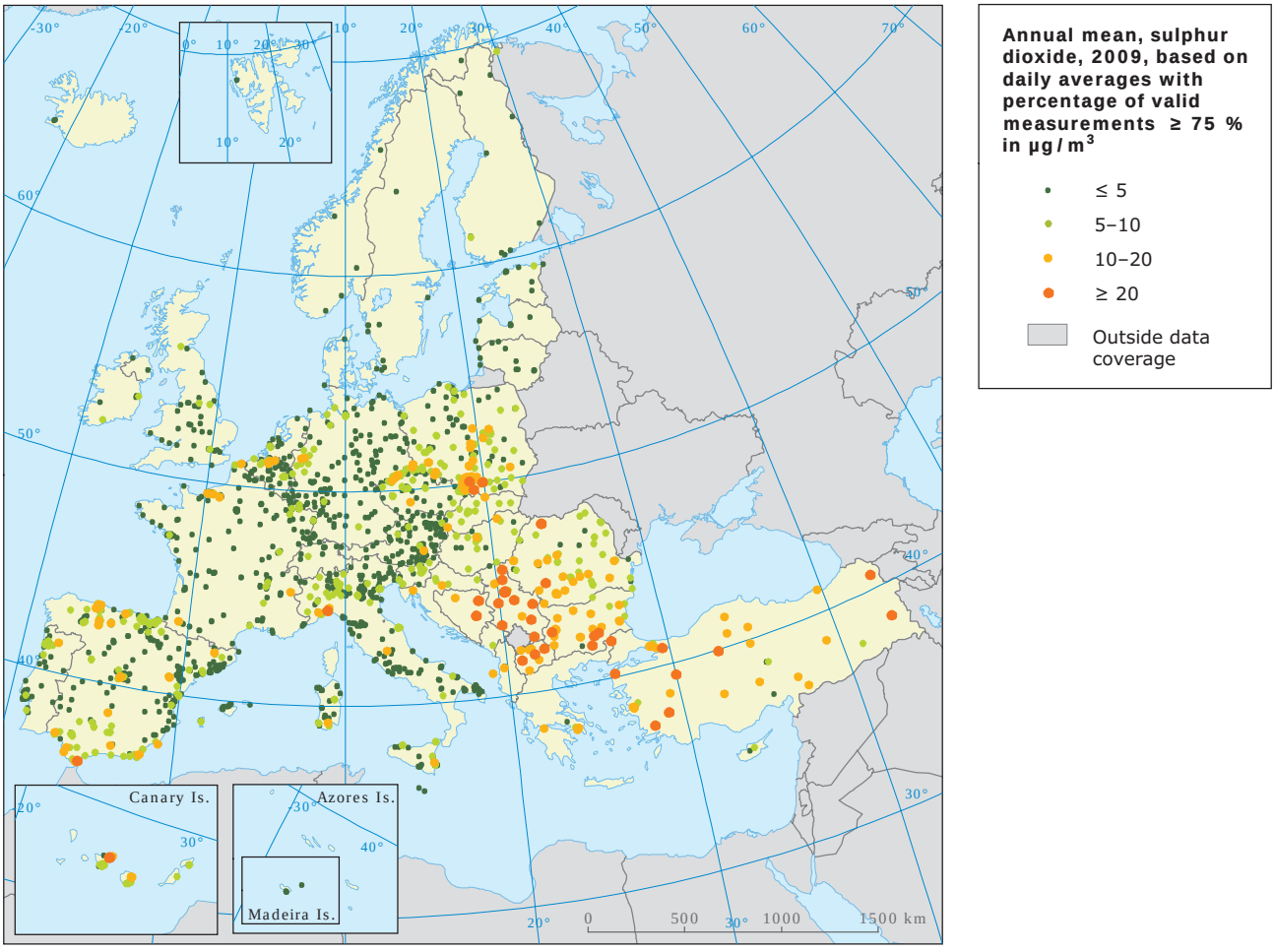
5.3.2 *Distance to target*

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 at a few industrial stations for the daily LV and at several industrial and urban stations for the hourly LV.

Table 5.2 WHO air quality guideline for SO_2

AQG (µg/m³)	10-minute mean	24-hour mean
SO_2	500	20

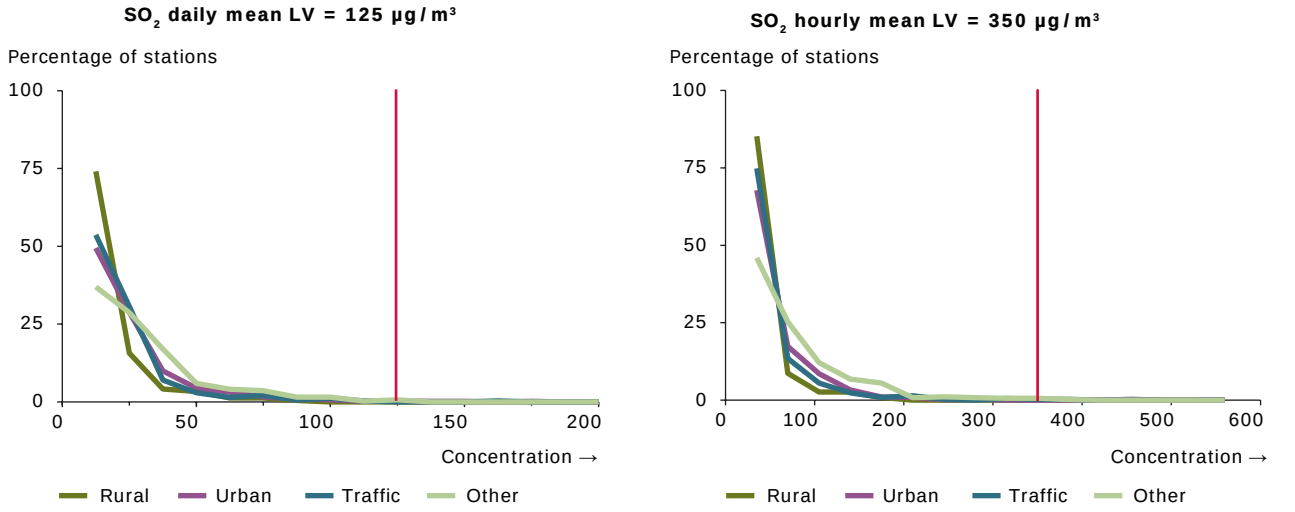
Map 5.1 Annual mean SO_2 concentrations (µg/m³), 2009



Note: The dark orange dots correspond to exceedances of the limit value (20 µg/m³) for the protection of vegetation.

Source: Mol et al., 2011.

Figure 5.1 Distance-to-target graph for the daily (left) and hourly (right) limit values of SO_2 for health protection, EU, 2009



Source: de Leeuw and Ruyssenaars, 2011.

The limit value set for the protection of vegetation (20 µg/m³ annual mean) was exceeded at 0.8 % of stations in the EU in 2009. None of those exceedances occurred at rural locations where relatively more vegetation needs to be protected than in urban areas.

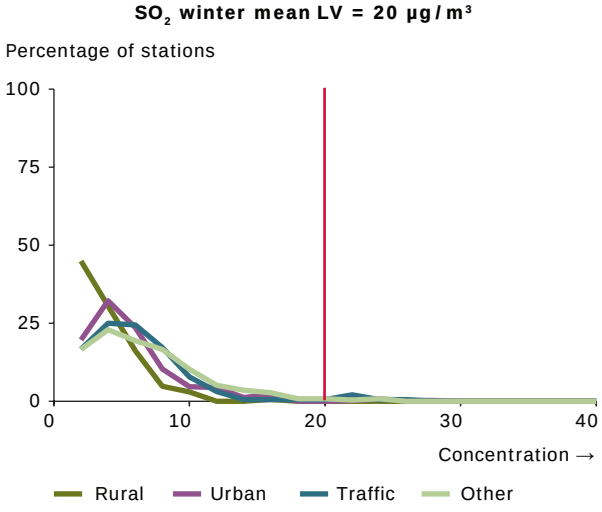
As emissions tend to be higher and dispersion conditions are worse during winter periods, the concentrations during the winter 2008–2009 are slightly higher on average than those recorded for the whole year 2009. The distance-to-target graph for the winter mean limit value is shown in Figure 5.2. The limit value for the protection of vegetation set for the winter period (20 µg/m³) was exceeded at one rural station.

5.3.3 Trends in SO_2 concentrations

Reported SO_2 concentrations decreased steadily in the period 1999–2009 (Figure 5.3), falling by more than half at all station types. During the second half of this period, the average concentration at traffic stations was about 1µg/m³ higher than at urban background stations, a difference that might be explained by the sulphur in motor fuel. Although the sulphur content is low, the traffic stations are very close to the traffic flows and emissions.

EU emissions of SO_2 have fallen substantially since 1990 (Figure 2.4). Total EU emissions in 2009 were 80 % less than in 1990 and 56 % less than in 1999. EEA-32 emissions in 2009 were 76 % less than in 1990 and 54 % less than in 1999. The reduction in the period 2008–2009 was 21 % in the EU and 17 % in EEA-32. SO_2 emissions in 2009 were approximately 36 % lower than the aggregated emissions ceiling for EU set for 2010 in the NEC Directive.

Figure 5.2 Distance-to-target graph for the winter mean limit value of SO_2 for vegetation protection, 2009



Observed SO_2 concentrations fell by 52 % at urban and traffic stations during the period 2000–2009 and 46 % at rural stations (Figure 5.3). These data correspond well with the reported emissions reductions.

The energy sector is still the dominant emissions source for SO_X, accounting for 64 % of EU emissions in 2009 (Figure 2.5), although its emissions have been cut by 77 % since 1990 and 52 % since 1999. The next largest sector is industry, with 21 % of EU emissions in 2009.

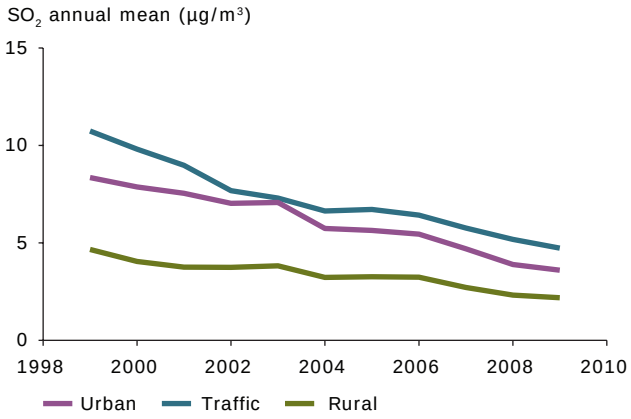
5.4 Exposure to SO_2 pollution in Europe

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/m³ 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 1997–2009. The exposure is estimated based on SO_2 measured in urban background locations. For each city an average concentration is calculated. It is considered that the whole population is potentially exposed to these concentrations, since people move freely within the city.

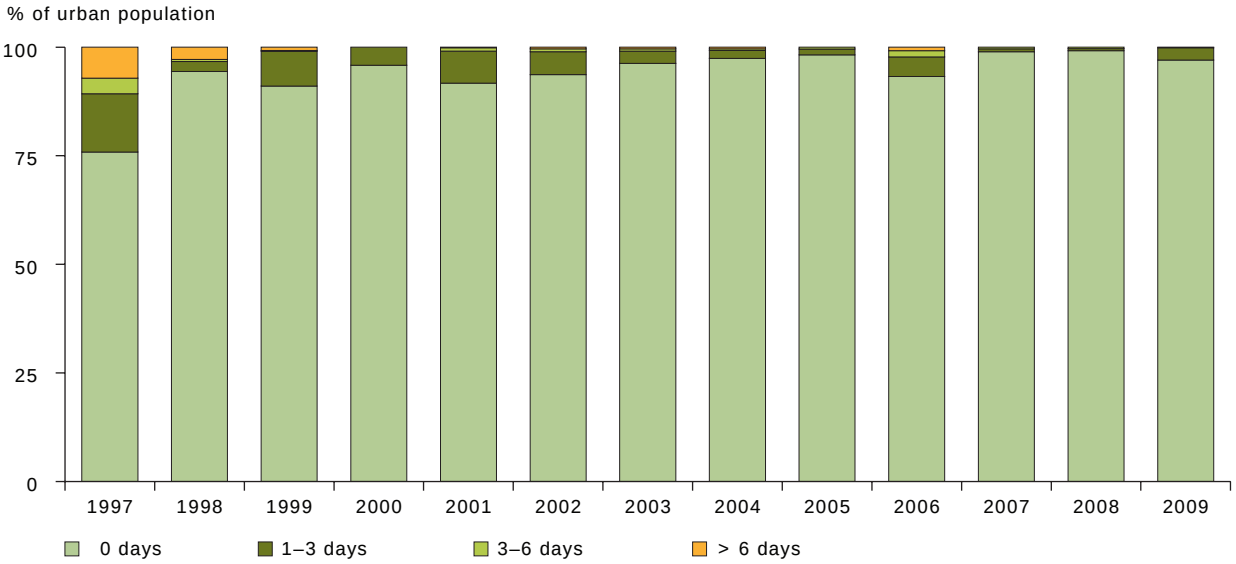
In 2009 only about 0.1 % of the EU urban population (and 2.4 % of the EEA-32 urban population) was exposed to SO_2 above the 24-hour average limit value. The extent of exposure above the limit value has varied in EU and EEA-32 between zero and

Figure 5.3 Average annual SO_2 concentrations per station type, 1999–2009



Note: Only stations operational for at least nine of the 11 years in the period 1999–2009 were included.

Figure 5.4 Percentage of the EU urban population potentially exposed to SO_2 concentrations over the daily average limit value for protection of human health, 1997–2009



Source: EEA, 2011c (CSI 004).

11 % since 1997. There is a clear 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 is significantly higher, comprising 68–85 % of the total urban population (Table ES.1).

5.4.2 Exposure of ecosystems

SO_2 emissions and subsequent deposition of sulphur (via precipitation 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, and the projected exceedance of critical loads for acidity is also shown there.

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). Together with fuel switching, 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 (CO) 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.

The atmospheric lifetime of CO is about three months. It slowly oxidises into carbon dioxide, also forming ozone during this oxidation process. CO therefore contributes to the atmospheric background concentration of ozone, 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

Six out of 1 171 operational stations in EEA-32 reported exceedances of the CO limit value: four traffic stations, one urban background station and one industrial station, located in Italy, Bulgaria and Bosnia and Herzegovina (Mol et al., 2011).

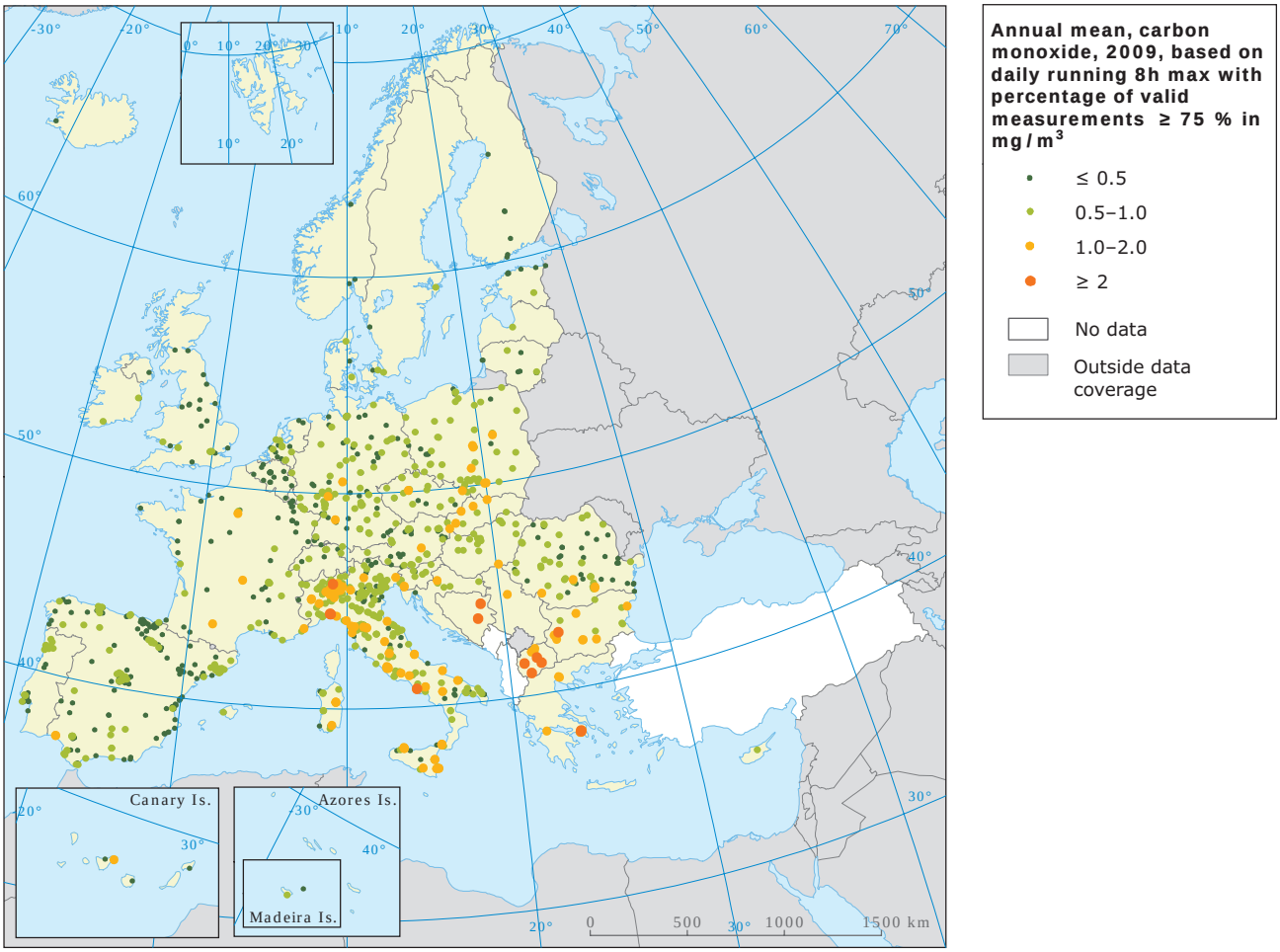
The annual averages of the daily 8-hour maxima (Map 6.1) show elevated levels in the same regions. Note that instead of the maximum 8-hour values, the annual means of daily maximum 8-hour mean values are plotted because they are less sensitive to meteorological fluctuations.

Table 6.1 Air quality limit values set by the Air Quality Directive and the WHO air quality guideline for CO

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

Source: EU, 2008c; WHO, 2006.

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

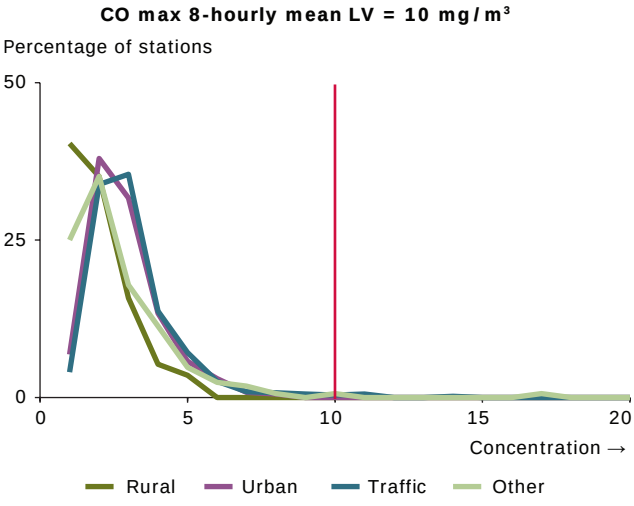


Source: Mol et al., 2011.

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.

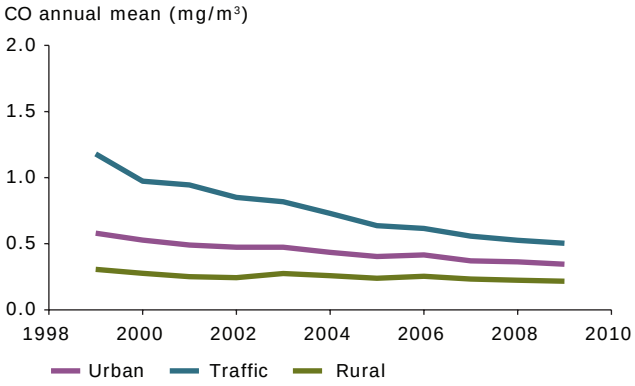
Figure 6.1 Distance-to-target graph for the CO limit value, 2009



6.3.3 *Trends in CO concentrations*

Figure 6.2 shows the trend in the annual average CO concentration at each station type. A consistent set of stations (135 urban; 219 traffic and 14 rural) is used. At more than 90 % of urban and traffic stations a downward trend is apparent (statistically significant at 90 % of traffic stations and 72 % of 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.

Figure 6.2 Annual mean CO concentrations, 1999–2009



Source: Mol et al., 2011.

The CO emission reduction in the period 1990–2009 was substantial, totalling 62 % in the EU and 61 % in EEA-32 (Figure 6.4). From 1999 to 2009 the EU and EEA-32 emissions were reduced by 44 %, and the reduction from 2008 to 2009 was 11 % in the EU (10 % in EEA-32). Commercial, institutional and household fuel combustion was Europe's largest CO source in 2009, following the very significant reduction in transport sector emissions that have resulted from applying the Euro standards.

The observed reductions in CO concentrations in the period 1999–2009 (a 50 % average fall at traffic stations, 35 % at urban background stations and 25 % at rural stations) is in line with the reported reduction in total emissions of about 44 % 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 therewith also the accuracy of trend estimates.

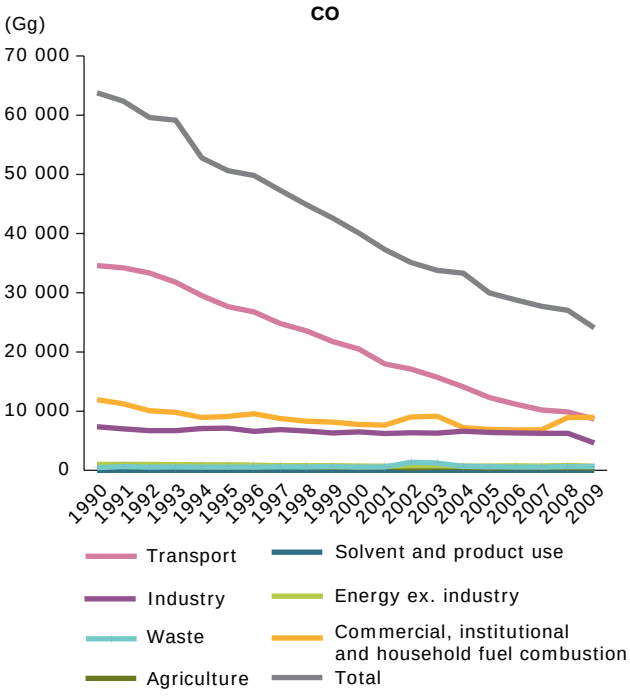
6.4 Exposure to CO pollution in Europe

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

CO emissions are mainly regulated by the IPPC Directive (EU, 2008b) – now replaced by the Industrial Emissions Directive (EU, 2010) and the Euro 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 % (Figure 6.3). The largest CO emission sector is now residential heating, which is currently unregulated with respect to CO emissions.

Figure 6.3 Total CO emissions (Gg/year = 1 000 tonnes/year) and contributions of the main sources in the EU



7 Heavy metals

The 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 in 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 the organic compounds, especially methylmercury. It accumulates in the food chain, for example in predatory fish in lakes and seas and reaches humans. Nickel is a known carcinogen and also has other non-cancerous effects, e.g. 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 Arsenic

Origins of arsenic 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 arsenic, thereby being a source of exposure in ambient air.

Arsenic in air is usually a mixture of arsenite and arsenate, with organic varieties of negligible importance except in areas of where there is substantial application of methylated arsenic pesticides. Most As in the air is found in the fine particle fraction.

Effects of arsenic

The oral uptake of arsenic, through food and drinking water, is generally the most important route of exposure, whereas inhalation normally contributes less than 1 % to the total dose. The non-cancerous effects of inhaling air with high arsenic levels are increased mortality from cardiovascular diseases, neuropathy and gangrene of the extremities. There is evidence that inorganic arsenic 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 arsenic content is high. Organic arsenic compounds are very persistent in the environment and bioaccumulate in the food chain.

7.1.2 Cadmium

Origins of cadmium 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 cadmium in the atmosphere. The anthropogenic sources of cadmium include non-ferrous metal production, stationary fossil fuel combustion, waste incineration, iron and steel production and cement production.

Effects of cadmium

Food is the main source of cadmium exposure in the general population, representing more than 90 % of the total intake in non-smokers. In heavily contaminated areas, dust resuspension can constitute a substantial part of the exposure for the local population.

In Europe, air pollution and mineral and organic fertilisers contribute roughly equally to annual exposure. Each continues to augment the relatively large accumulations of cadmium in topsoil, increasing the risk of future exposure through food. The levels of cadmium in non-smokers have not decreased over the last decade.

Kidney and bones are the critical organs affected by chronic environmental exposure to cadmium. The main effects include an increased excretion of low-molecular-weight proteins in urine 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 cytoplasmatic components such as enzymes, causing toxic effects in the cells. It can also produce lung cancers in humans and animals exposed via inhalation. Cadmium is highly persistent in the environment and bioaccumulates.

7.1.3 Lead

Origins of lead in air

Lead is released into the atmosphere from natural and anthropogenic sources. Natural emissions are soil suspension by wind, sea salt, volcanoes, forest fires and biogenic sources. These emissions are not entirely natural but contain some contributions from past depositions of anthropogenic lead. Major anthropogenic emission sources of lead 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 lead in gasoline has been eliminated in Europe after the complete penetration of non-leaded gasoline.

The lead inputs through atmospheric deposition and the application of mineral and organic fertilisers to top-soils are of roughly the same magnitude. Those inputs are relatively small in comparison to lead stores that have already accumulated and inputs from natural sources.

Effects of lead

Lead is a neurotoxic metal that also accumulates in the body and damages organs (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 all be responsible for these effects. Lead accumulates in the skeleton and its mobilisation from the bones during pregnancy and lactation exposes the foetus or the breastfed infant. Hence, the lifetime exposure of a woman before pregnancy is important.

Inhalation exposure may be significant when lead 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 lead uptake in the general population. However, air pollution may contribute significantly to the lead content of crops, through direct deposition. Although uptake via plant roots is relatively limited, rising lead 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 lead.

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 Mercury

Origins of mercury in air

The largest anthropogenic source of mercury 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 emissions of mercury. The main natural sources of mercury are diffusion from the Earth's mantle though the lithosphere, evaporation from the sea surface and geothermal activity. Natural sources of mercury contribute about one-third of total global emissions, with anthropogenic emissions accounting for about two-thirds. Mercury emitted in inorganic forms is converted biologically to methylmercury in soil and water.

Effects of mercury

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 susceptible 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. In several species of (mainly large predatory) fish and mammals the mercury guideline level (0.5 mg/kg) is often exceeded in many countries.

7.1.5 Nickel

Origins of nickel in air

Nickel is a ubiquitous 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 nickel emissions into the air are combustion of oil for heat or power generation, nickel mining and primary production, incineration of waste and sewage sludge, steel manufacture, electroplating and coal combustion.

Effects of nickel

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

In very small quantities nickel is essential to humans. However, a large uptake can be a danger for human health as several nickel 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 nickel in humans is an allergic reaction. Approximately 10–20 % of the population is sensitive to nickel.

As is the case for humans, nickel is an essential element for animals in small amounts. In high concentrations, nickel 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 nickel 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. As a result nickel will not biomagnify at higher levels in the food chain.

7.2 European air quality standards for heavy metals

Table 7.1 shows the European air quality target values for the heavy metals arsenic, cadmium and nickel and the limit value for lead. The values specified are maximum annual averages, which countries are obliged to meet by 2013, except for the limit value for lead 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 mercury.

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 cadmium in agricultural soil, likely to increase the dietary intake of future generations.

7.3 Europe-wide survey of heavy metals

Barrett et al. (2008) reviewed the concentrations of lead and the pollutants covered by the Fourth Daughter Directive 2004/107/EC (EU, 2004b), i.e. arsenic, cadmium, nickel and benzo(a)pyrene and pointed to the little availability of concentration measurements. Compared to 2008, the number of reporting stations increased in 2009 by between 120 and 170, depending on the heavy metal pollutant (Mol et al., 2011).

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}-fraction or on another (undefined) size fraction.

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.

Mol et al. (2011) summarised the results from the reported 2009 data as follows:

- **Arsenic** concentrations below the lower assessment threshold were reported at about 90 % of the stations in 2009. At 11 stations (out of 534 operational stations) the reported concentrations exceeded the target value set for 2013.
- **Cadmium** concentrations in air exceeded the target value at 4 % of all reporting stations in Europe.
- **Lead** concentrations exceeded the limit value at two locations — an urban industrial station in Romania and an urban background station in Bulgaria. No monitoring data were received from Greece, Hungary, Norway and Portugal. According to the EU reporting questionnaire for the air quality directives, the concentrations in Greece and Hungary were below the lower assessment threshold and methods other than monitoring could be used for assessment.
- **Nickel** concentrations exceeded the target value at eight out of the 561 operational stations. These stations are located in eastern Belgium, the German Ruhr area, France and southern Norway. Most of the exceedances are related to industry.
- **Mercury** concentrations in air reported to AirBase are very few. As a consequence, this survey does not include Hg.

7.4 Trends in concentrations and emissions of heavy metals

7.4.1 Arsenic

The number of stations reporting As concentrations in air to AirBase has increased rapidly in recent years, to more than 500 in 2009, including background, traffic and industrial stations. For the five-year period 2005–2009, data from 137 stations are available for analysis (Mol et al., 2011).

The majority of stations recorded a slight reduction in As concentrations in the period 2005–2009, although it is worth stressing that the sampling and measurement method was not reported for some stations and the methods might have 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 in this group (Figure 7.1) decreased their country average concentrations between 2005 and 2009. Bulgaria increased its emissions of As between 2007 and 2009 by 7 %, which may explain the increase in concentrations. Contrastingly, Slovakia reduced its As emissions by 26 % between 2005 and 2009, and these adjustments are likewise reflected in lower ambient concentrations.

Figure 7.2 shows the development in arsenic (and other heavy metal) emissions reported by the EU Member States between 1990 and 2009 as a percentage of 1990 emissions. Arsenic emissions were reduced by about 64 % during this period in EU and EEA-32. Eighteen countries ([16]) reported emissions for all the years.

([16]) Belgium, Cyprus, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom.

Map 7.1 Annual mean concentrations of heavy metals (arsenic, cadmium, lead and nickel), 2009

Annual mean concentrations of arsenic, 2009

ng/m³
- < 2.4
- 2.4–3.6
- 3.6–6
- > 6

No data | Outside data coverage

Annual mean concentrations of cadmium, 2009

ng/m³
- < 2
- 2–3
- 3–5
- > 5

No data | Outside data coverage

Annual mean concentrations of lead, 2009

µg/m³
- < 0.1
- 0.1–0.25
- 0.25–0.5
- > 0.5

No data | Outside data coverage

Annual mean concentrations of nickel, 2009

ng/m³
- < 10
- 10–14
- 14–20
- > 20

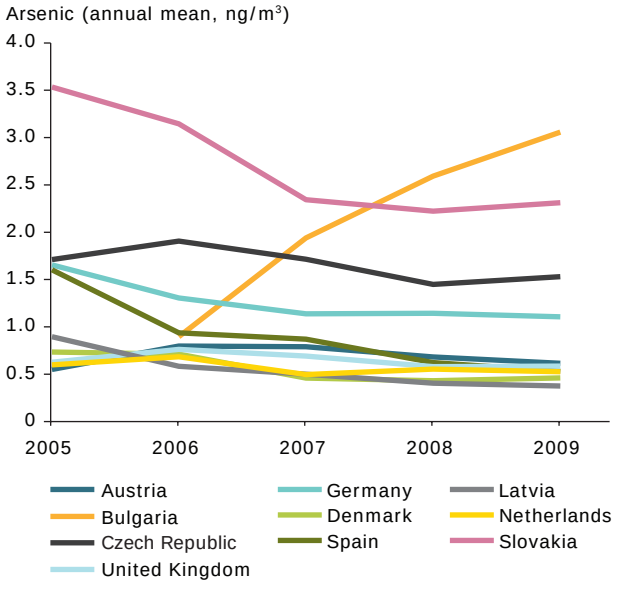
No data | Outside data coverage

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 Cadmium

As is the case for arsenic, the number of stations reporting cadmium concentrations in air has increased significantly over recent years, reaching almost 600 in 2009. For the 10-year period 2000–2009, concentration data from 54 stations (eight traffic, 15 industrial and 31 rural or urban background stations) in seven European countries could be used to assess the recent development in Austria, Belgium, Bulgaria, Switzerland, Denmark, the Netherlands and Romania. A consistent set of stations with data for at least eight years was used, with the exception of the station in Romania, which had data for seven years.

Figure 7.1 Average of the annual mean concentrations of As reported by monitoring stations in various countries, 2005–2009



Note: A consistent set of stations with data for at least four years was used.

Concentrations are decreasing at all stations in Switzerland (based on data from 14 stations) and Denmark (six stations) (Figure 7.3), as well as at the one station in Romania. In the remaining four countries (Austria, Belgium, Bulgaria and the Netherlands) the stations recorded a mixture of increasing and decreasing concentrations.

Cadmium emissions in the EU decreased by 70 % between 1990 and 2009 (Figure 7.2). Twenty countries ([17]) reported Cd emissions for all the years.

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 Lead

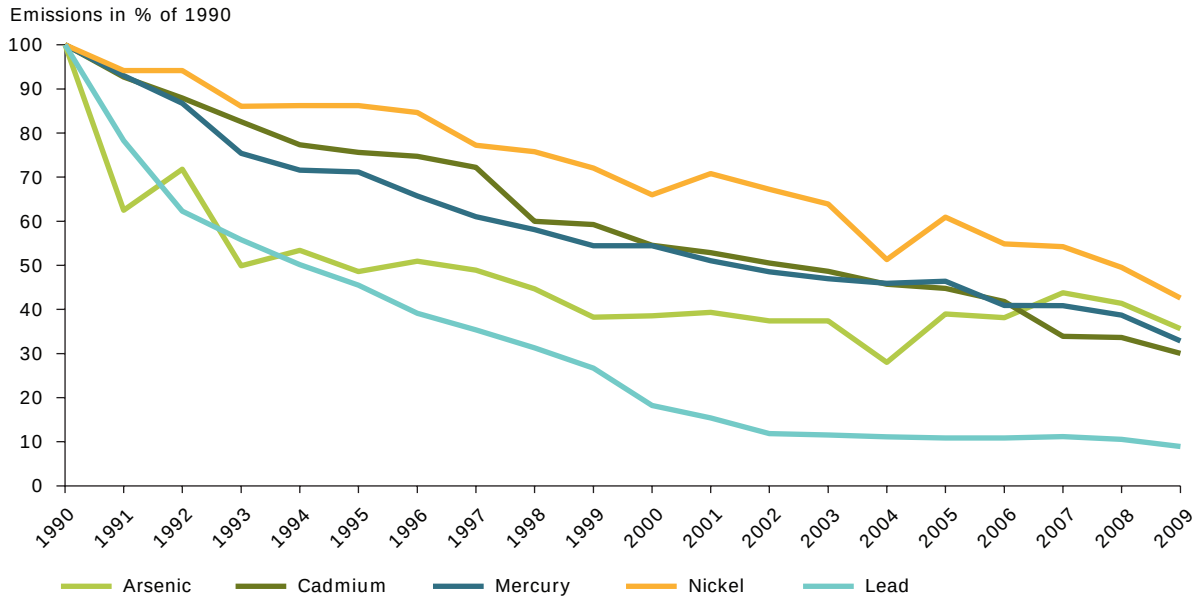
For the period 1999–2009, lead concentration data in AirBase from up to 58 stations in eight countries ([18]) were available for analysis: 15–18 urban stations, 6–10 traffic stations, 10–12 rural stations and 14–18 other (mostly industrial) stations, depending on the number of stations operational each year. While concentrations have remained almost constant at traffic and rural stations since 2001 (Figure 7.4), there is a clear reduction in measured concentrations at industrial stations (designated as 'other') since 2002.

Lead emissions decreased in the EU and EEA-32 by 91 % between 1990 and 2009 (Figure 7.2). Twenty-three countries ([19]) reported lead emissions for all these years.

The Pb concentration time series are limited to eight countries. The low geographical coverage does not support a Europe-wide comparison with emission changes.

([17]) Austria, Belgium, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, the Netherlands, Poland, Portugal, Slovenia, Spain, Sweden, and the United Kingdom.
([18]) Austria, Belgium, Bulgaria, Denmark, Ireland, Netherlands, Romania and Switzerland.
([19]) Austria, Belgium, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Figure 7.2 EU emissions of As, Cd, Hg, Ni and Pb, 1990–2009, as a percentage of 1990 emissions



Source: CEIP (2011) for As and Ni, and EEA (2011b) for Cd, Hg and Pb.

7.4.4 Mercury

Various compounds of mercury 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 mercury concentrations in air in Europe are not evaluated here.

Mercury emissions in the EU decreased by 67 % between 1990 and 2009 (Figure 7.2). The same 23 countries that reported lead emissions also reported mercury emissions for all years. The fall in EEA-32 emissions was 68 %.

Figure 7.3 Average of the annual mean concentrations of Cd reported by monitoring stations in four selected European countries, 2000–2009

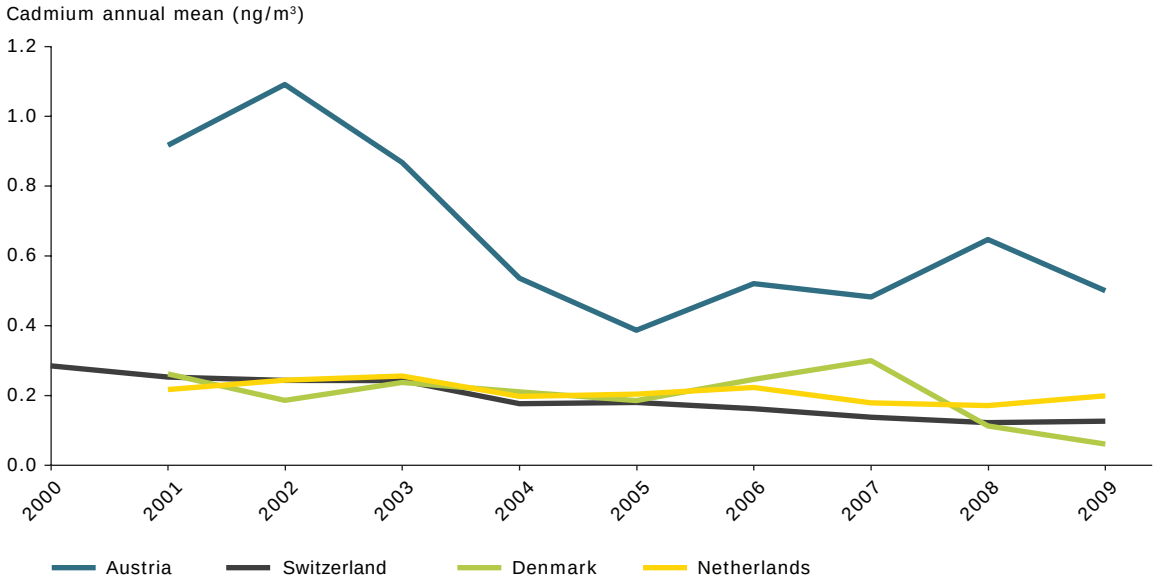
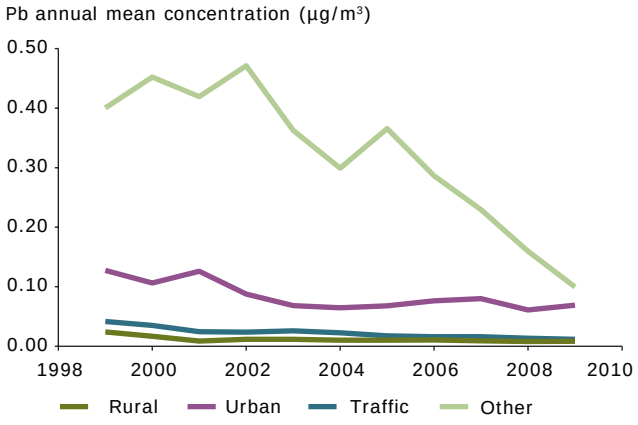


Figure 7.4 Average of the annual mean concentrations of Pb reported by monitoring stations in eight European countries, 1999–2009



7.4.5 *Nickel*

Nickel concentrations were reported for the period 2000–2009 by Belgium and Denmark. There is a general decrease in concentrations reported at the 30 stations available for analysis. In Belgium the average annual decrease in nickel concentrations was 1 ng/m³, while in Denmark, which has considerably lower concentrations, the annual reduction was 0.1 ng/m³ (Figure 7.5). In the period 2000–2009 Belgium has reduced its Ni emissions by 69 % and Denmark by 39 %.

Nickel emissions decreased in the EU by 57 % between 1990 and 2009 (Figure 7.2). Only 16 countries ([20]), all in the EU, reported nickel emissions for all years.

As outlined above, Ni concentration time series are limited to two countries. The geographical coverage is too low to support a Europe-wide comparison with emission changes.

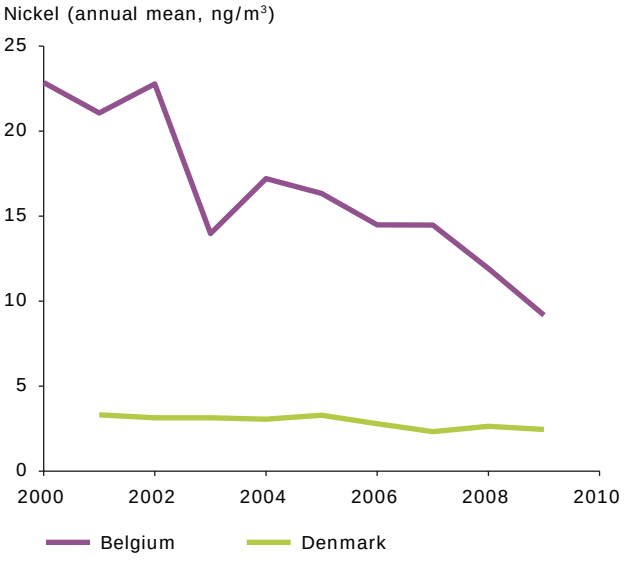
7.5 Exposure to heavy metal pollution in Europe

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. In some European countries, a significant percentage of national ecosystem areas are 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).

Figure 7.5 Average of the annual mean concentrations of Ni reported by monitoring stations in Belgium and Denmark, 2000–2009



([20]) Belgium, Cyprus, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, the Netherlands, Portugal, Spain, Sweden and the United Kingdom.

For Pb the area and extent of the exceedances 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 EEA-32 member countries ([21]) have exceedances of critical loads for Hg across nearly 90 % or more of their ecosystem area. In total, atmospheric deposition of Hg exceeds the critical loads across 54 % of the EU ecosystem area (Slootweg et al., 2010).

7.6 Responses

The former IPPC Directive (EU, 2008b) and the Waste Incineration Directive (EU, 2000), now replaced by the Industrial Emissions Directive (EU, 2010), 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 lead free. This has eliminated the contribution from road traffic to lead concentrations in air.

The European Commission's Strategy on Mercury (EC, 2005a) set restrictions on the sale of measuring devices containing mercury, a ban on exports of mercury from the EU that will come into force in 2011 and new rules on safe storage. The Strategy on Mercury is a comprehensive plan addressing mercury pollution both in the EU and globally. It contains 20 measures to reduce mercury emissions, cut supply and demand, and protect against exposure, especially to methylmercury in fish.

([21]) 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.

8 Benzene and benzo(a)pyrene

8.1 Emissions and effects

8.1.1 Benzene

Origins of benzene in air

Incomplete combustion of fuels is the largest source of benzene. Benzene is an additive to petrol and 80–85 % of benzene emissions are due to vehicular 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 benzene where wood burning can account for more than half of the domestic energy needs (Hellén et al., 2008).

Removal of benzene from the atmosphere mainly occurs through the reaction of benzene with the hydroxyl (OH) radical. Photo-oxidation contributes to ozone formation, although benzene reactivity is relatively low. A lifetime of several days is sufficient for benzene to be transported over long distances.

Health effects of benzene

Inhalation is the dominant pathway for benzene 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 haematotoxicity, genotoxicity and carcinogenicity. Chronic exposure to benzene can depress bone marrow and cause haematological effects such as decreased red and white blood cell counts.

8.1.2 Benzo(a)pyrene (BaP)

Origins of BaP in air

Benzo(a)pyrene (BaP) is a five-ring polycyclic aromatic hydrocarbon (PAH) and is found in fine particulate matter originating from combustion. A main source of BaP in Europe is domestic home heating, in particular wood burning. Other sources include road traffic, outdoor burning and rubber tyre wear.

Health effects of BaP

The International Agency for Research on Cancer (IARC) considers BaP a known animal carcinogen and probable human 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 PAHs, 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 ozone to produce strong mutagens such as benzo(a)pyrene-4,5 oxide.

8.2 European air quality standards for benzene and benzo(a)pyrene

The limit value for benzene and the target value for benzo(a)pyrene 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 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.

8.3 Europe-wide survey of benzene and benzo(a)pyrene

8.3.1 Benzene

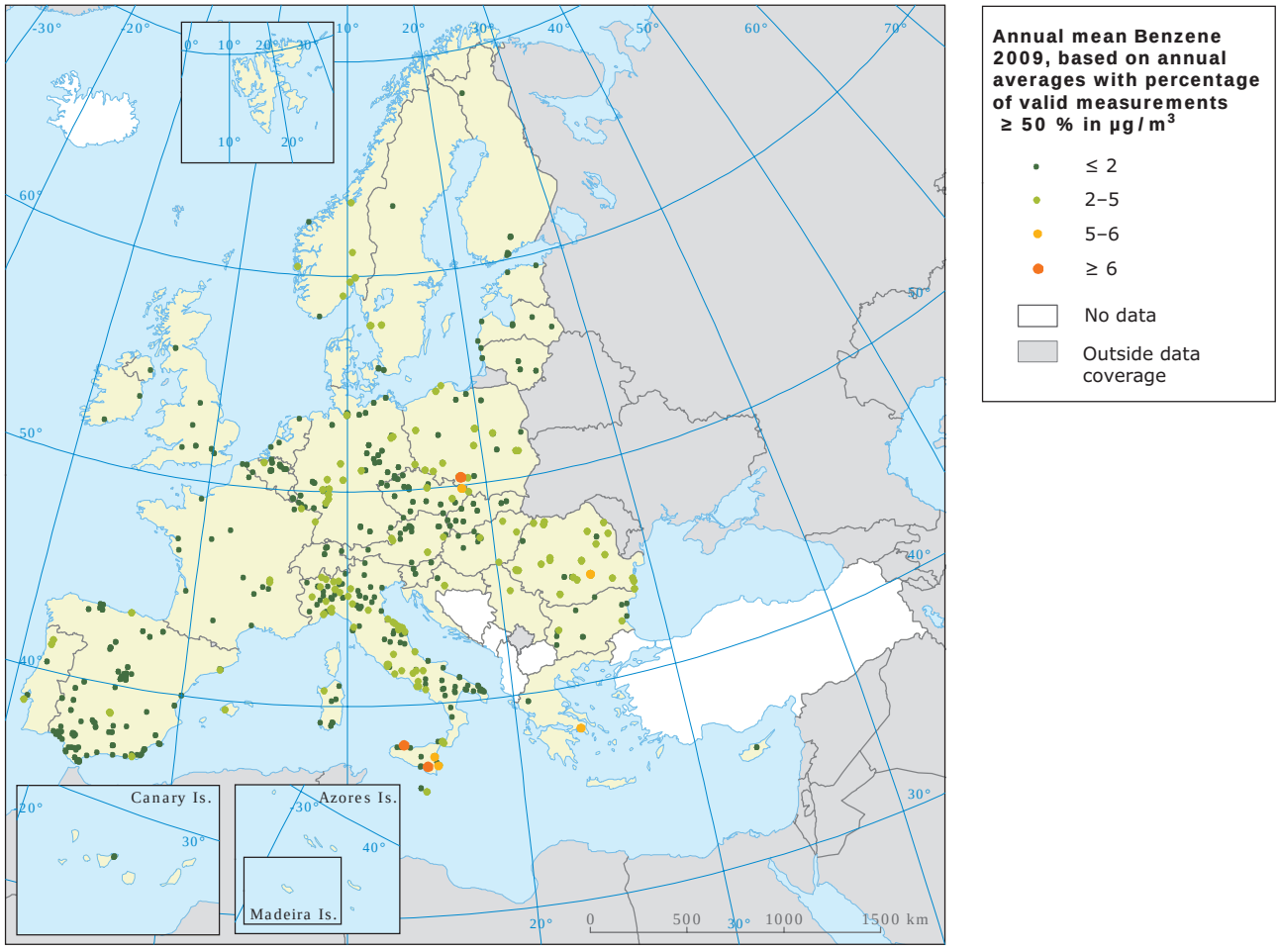
Exceedances of limit value

At many locations, annual mean concentrations of benzene are below the lower assessment threshold of 2 µg/m³ (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 µg/m³ for benzene in ambient air, to be met by 2010. Including the margin of tolerance, annual mean concentrations may not exceed 6 µg/m³ in 2009.

Map 8.1 presents the annual average benzene concentrations at stations with at least 50 % data coverage. The limit value plus margin of tolerance was exceeded at three stations, in Italy and Poland. Concentrations above the limit value were observed at six additional stations (in the Czech Republic, Greece, Italy, and Romania). The exceedances were observed in urban areas at traffic and industrial stations, with no exceedances of the limit value observed at rural background stations.

Map 8.1 Annual mean benzene concentrations, 2009



Note: Pale green dots correspond to exceedances of the lower assesment threshold (2 µg/m³)
Light orange dots correspond to exceedances of the limit value (5 µg/m³)
Dark orange dots correspond to exceedanes of the limit value plus margin of tolerance (6 µg/m³)
The data coverage criterion has been set to 50 % by the Working group on benzene.

Source: Mol et al., 2011.

Distance to target

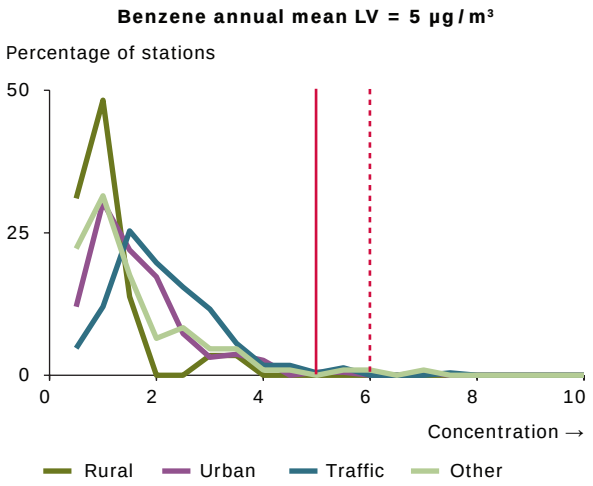
Figure 8.1 shows that, except at a small number of stations, measured benzene concentrations in Europe are well below the limit value.

Trends in benzene concentrations

Time series of benzene annual mean concentrations, averaged for each station type, are shown in Figure 8.2. In total data from 35 urban background, 78 traffic, six rural and 15 other stations in 13 countries ([22]) were available. Concentrations were highest at traffic stations but 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 benzene emissions recorded a similar stabilisation after 2007 is unclear because benzene is not included as an individual VOC pollutant in European emissions inventories.

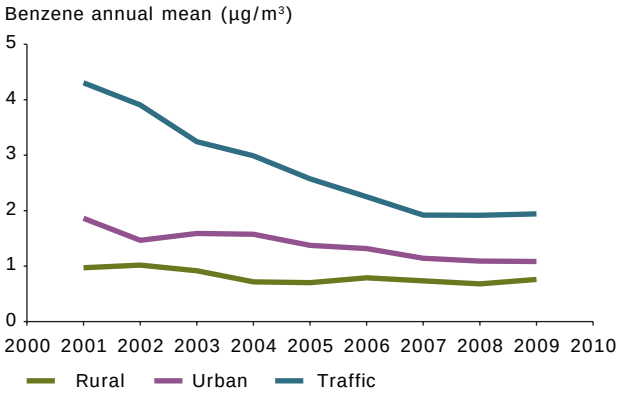
Figure 8.1 Distance-to-target graph for the benzene limit value, 2009



Note: The red line corresponds to the limit value, LV (5 µg/m³); the dashed red line corresponds to the LV plus margin of tolerance (6 µg/m³).

Source: Mol et al., 2011.

Figure 8.2 Average annual mean benzene concentrations (1999–2009) at each station type



Note: A consistent set of stations was used for all years.

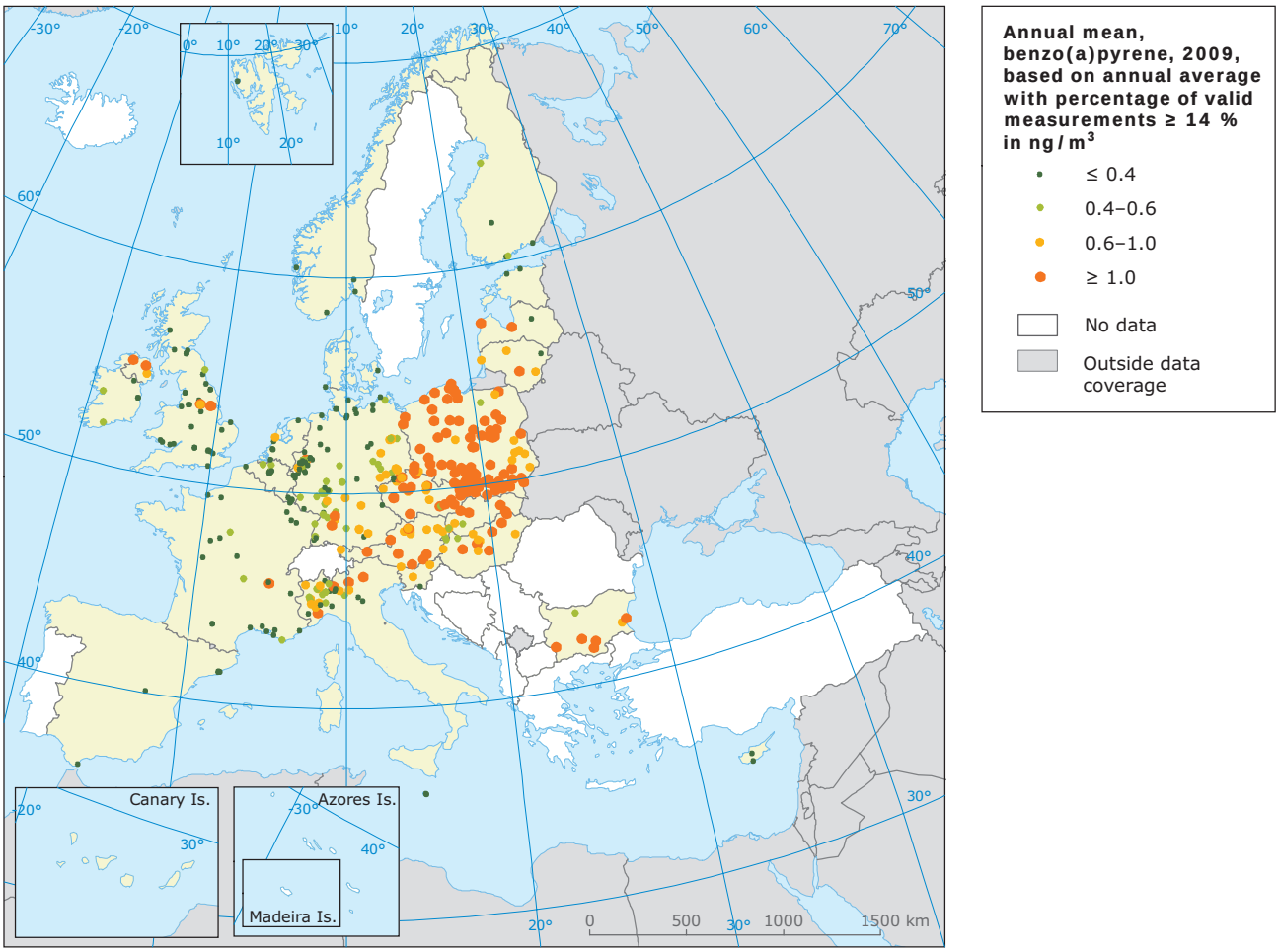
8.3.2 Benzo(a)pyrene

Exceedances of target value

Benzo(a)pyrene (BaP) measurements in 2009 were above the target value threshold (1 ng/m³ annual average to be met by 2013) at 37 % 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 (the Baltic states, Poland, the Czech Republic, Slovakia, Hungary, Austria and the Po Valley) although they are also observed in the United Kingdom (the Midlands and Northern Ireland), the German Ruhr-area and Bulgaria. In addition to the countries mentioned above, Finland and Greece also report exceedances of the target value in one or more zones, without providing measured data.

([22]) Austria (17 stations), Belgium (10 stations), Czech Republic (five stations), Denmark (one station), France (two stations), Germany (44 stations), Italy (29 stations), Lithuania (one station), the Netherlands (one station), Slovakia (one station), Spain (13 stations), Switzerland (two stations) and the United Kingdom (eight stations).

Map 8.2 Annual mean concentrations of benzo(a)pyrene (ng/m³), 2009

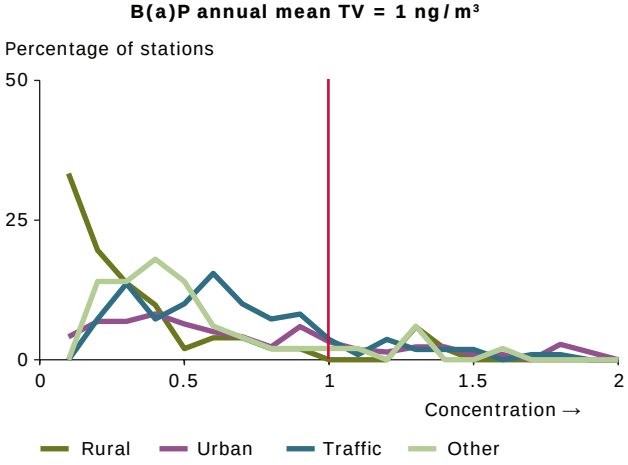


Source: Mol et al., 2011.

Distance to target

Figure 8.3 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 8.3 Distance-to-target graph for the benzo(a)pyrene target value

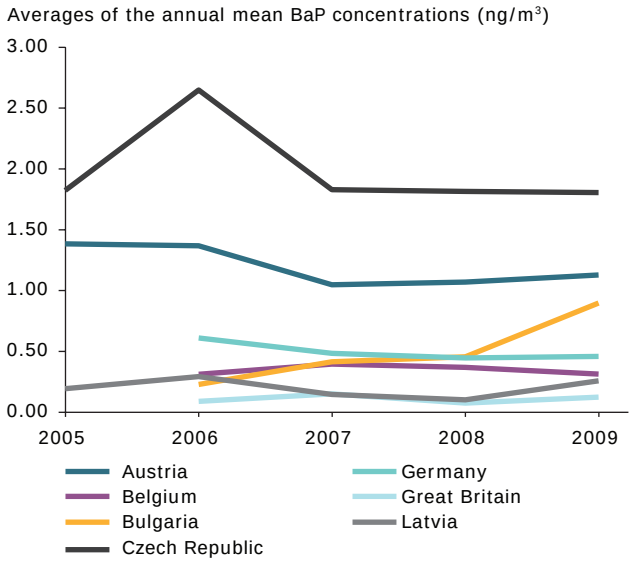


Source: Mol et al., 2011.

Trends in benzo(a)pyrene concentrations

BaP concentrations are available for a limited number of stations: 45 stations in seven countries reported data for at least four years since 2005. The annual concentrations at monitoring stations averaged per country ([23]) show that exceedances of the target value are persistent in all these countries (Figure 8.4).

Figure 8.4 Averages of the annual mean BaP concentrations (ng/m³) reported by monitoring stations in various countries, 2005–2009



Note: A consistent set of stations was used for all years.

8.4 Exposure to benzene and benzo(a)pyrene pollution in Europe

While exposure to benzene in Europe is limited to a few local areas close to traffic or industrial sources, exposure to benzo(a)pyrene pollution is quite significant and widespread. Populations living in central and eastern Europe (i.e. the Baltic states, Poland, the Czech Republic, Slovakia, Hungary, Austria and the Po Valley) and some regions in the United Kingdom (the Midlands and Northern Ireland), the German Ruhr area and Bulgaria are exposed to ambient B(a)P concentrations above the target value. Some 94 million persons lived in zones reporting an exceedance and were therefore potentially exposed to BaP concentrations above the target value in 2009 (de Leeuw and Ruyssenaars, 2011).

8.5 Responses

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

Regarding BaP (which is a PAH), the Industrial Emissions Directive (EU, 2010) 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'. BaP, 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 PAHs to below their levels in 1990 (or an alternative year between 1985 and 1995). For the incineration of municipal, hazardous and medical waste, it lays down specific limit values.

([23]) Austria , Belgium, Bulgaria, Czech Republic, Germany, Latvia and the United Kingdom.

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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 multi-annual time series of air quality measurement data and statistics for a number of pollutants. It also contains meta-information on the involved monitoring networks, 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 2008 to 2009 for $PM_{2.5}$ and VOC in particular, following the requirements in the air quality directives. The number of stations where heavy metals and PAH (including BaP) are measured also increased markedly.

Table A1.1 Number of stations that provided data on different substances in 2009, specified per station type

	SO_2	NO_2	NO_x or / and NO	PM_{10}	$PM_{2.5}$	Pb	CO	C_6H_6	O_3	VOC	HM	PAH
Reporting EU Member States	27	26	25	27	27	24	27	27	27	15	25	23
Total number of stations	2 015	3 147	2 272	2 809	798	661	1 304	757	2 176	402	727	540
of which												
• Traffic	387	894	721	823	180	146	631	297	298	178	147	135
• Urban background	825	1 322	823	1171	403	270	416	274	1 072	108	307	252
• Industrial	525	506	393	471	82	142	187	130	265	89	148	71
• Rural background	264	399	328	319	123	98	62	53	507	25	120	78
• Other	14	26	7	25	10	5	8	3	34	2	5	4
Reporting non-EU countries	10	10	7	11	4	1	8	5	10	2	2	1
Total number of stations	169	121	82	206	28	14	51	18	70	6	18	5
of which												
• Traffic	31	50	37	50	18	2	29	13	20	1	2	1
• Urban background	104	39	25	129	8	5	9	3	22	4	5	2
• Industrial	19	14	9	17	0	0	11	1	8	0	2	0
• Rural background	14	17	11	9	2	7	2	1	20	1	9	2
• Other	1	1	0	1	0	0	0	0	0	0	0	0
Total reporting countries	37	36	32	38	31	25	35	32	37	17	27	24
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
Increase stations 2008/2009 data	– 96	35	– 64	173	267	51	7	56	19	112	108	61
Percentage Increase stations 2008/2009 data	– 4 %	1 %	– 3 %	6 %	48 %	8 %	1 %	8 %	1 %	38 %	17 %	13 %

Table A1.2 Number of stations that provided data on different substances in 2009, specified per country

	SO_2	NO_2	NO_x or / and NO	PM_{10}	$PM_{2.5}$	Pb	CO	C_6H_6	O_3	VOC	HM	PAH
EU Member States:												
Austria	108	155	134	143	13	18	41	22	113	0	18	19
Belgium	56	69	69	62	34	51	21	39	40	0	53	23
Bulgaria	27	23	16	41	7	8	16	17	19	7	12	13
Cyprus	2	2	2	3	5	2	1	1	2	0	2	2
Czech Republic	73	89	89	124	33	67	29	29	60	0	67	34
Denmark	2	0	0	7	7	8	7	3	9	3	8	1
Estonia	9	9	9	7	6	2	7	2	9	0	2	2
Finland	10	30	28	31	10	1	6	8	19	8	7	6
France	271	495	0	384	81	35	91	28	446	0	33	24
Germany	162	438	387	450	111	132	134	65	284	64	182	119
Greece	14	27	19	17	4	0	13	2	24	2	0	0
Hungary	24	24	23	25	3	0	21	12	17	12	6	16
Ireland	12	14	14	17	5	5	6	3	11	1	8	5
Italy	316	631	622	501	107	38	393	197	355	160	38	36
Latvia	7	9	1	9	7	5	1	7	9	0	5	3
Lithuania	13	10	13	14	7	5	9	5	14	1	5	5
Luxembourg	6	6	6	6	3	5	3	2	6	0	5	5
Malta	4	3	2	4	3	4	4	3	4	3	4	3
Netherlands	20	59	44	43	29	6	21	8	37	8	8	6
Poland	211	248	121	222	31	98	67	61	65	1	85	92
Portugal	54	65	65	56	23	0	40	5	48	0	0	0
Romania	69	67	67	54	24	29	78	33	66	0	35	0
Slovakia	12	16	16	31	4	6	10	9	14	0	6	8
Slovenia	22	11	10	12	4	4	5	2	12	2	6	3
Spain	458	497	387	438	150	92	249	143	394	124	93	80
Sweden	9	33	11	37	15	4	4	11	18	0	4	0
United Kingdom	44	117	117	71	72	36	27	40	81	6	35	35
Total in EU Member States	2 015	3 147	2 272	2 809	798	661	1 304	757	2 176	402	727	540
Non-EU countries:												
Albania	3	3	0	2	0	0	0	0	2	0	0	0
Bosnia and Herzegovina	8	4	2	1	2	0	3	0	5	0	0	0
Croatia	8	8	0	8	0	0	8	4	2	0	0	0
former Yugoslav Republic of Macedonia, the	28	15	15	15	0	0	14	0	13	0	0	0
Iceland	5	7	6	8	6	0	1	1	1	1	0	0
Liechtenstein	0	1	1	1	0	0	0	0	1	0	0	0
Montenegro	3	4	4	4	0	0	4	0	3	0	0	0
Norway	9	29	23	29	15	0	8	9	11	0	4	5
Serbia	20	18	0	1	0	0	1	1	1	0	0	0
Switzerland	11	32	31	27	5	14	12	3	31	5	14	0
Turkey	74	0	0	110	0	0	0	0	0	0	0	0
Total in non-EU countries	169	121	82	206	28	14	51	18	70	6	18	5
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
Increase stations 2008/2009 data	– 96	35	– 64	173	267	51	7	56	19	112	108	61
Percentage increase stations 2008/2009 data	– 4 %	1 %	– 3 %	6 %	48 %	8 %	1 %	8 %	1 %	38 %	17 %	13 %

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

Country	Air quality reporting start / end year	Number of stations for which data have been delivered for at least one year in the whole period	Number of stations for which 2008 data have been delivered	Number of stations for which 2009 data have been delivered
EU Member States:				
Austria	1981–2009	255	195	193
Belgium	1985–2009	341	233	226
Bulgaria	1998–2009	41	32	41
Cyprus	1993–2009	7	2	6
Czech Republic	1992–2009	188	171	174
Denmark	1976–2009	40	14	14
Estonia	1997–2009	11	9	9
Finland	1990–2009	92	51	56
France	1976–2009	1 064	725	700
Germany	1976–2009	1 149	550	545
Greece	1983–2009	37	29	29
Hungary	1996–2009	45	32	32
Ireland	1973–2009	102	26	29
Italy	1976–2009	1 075	708	707
Latvia	1997–2009	19	12	12
Lithuania	1997–2009	25	17	18
Luxembourg	1976–2009	14	8	8
Malta	2002–2009	7	3	4
Netherlands	1976–2009	92	68	78
Poland	1997–2009	474	418	389
Portugal	1986–2009	101	62	67
Romania	1999–2009	154	103	107
Slovakia	1995–2009	56	36	37
Slovenia	1996–2009	32	29	30
Spain	1986–2009	785	582	601
Sweden	1985–2009	77	51	55
United Kingdom	1969–2009	644	265	270
Total		6 927	4 431	4 437
Non-EU countries:				
Albania	2009–2009	3	0	3
Bosnia and Herzegovina	1985–2009	21	4	8
Croatia	2004–2009	8	8	8
former Yugoslav Republic of Macedonia, the	1997–2009	46	34	30
Iceland	1993–2009	12	4	9
Liechtenstein	2004–2009	2	1	1
Montenegro	2009–2009	4	0	4
Norway	1994–2009	57	34	46
Serbia	2002–2009	26	22	20
Switzerland	1991–2009	47	34	32
Turkey	2007–2009	116	98	113
Total		342	239	274
Total EU + non-EU countries		**7 269**	**4 670**	**4 711**

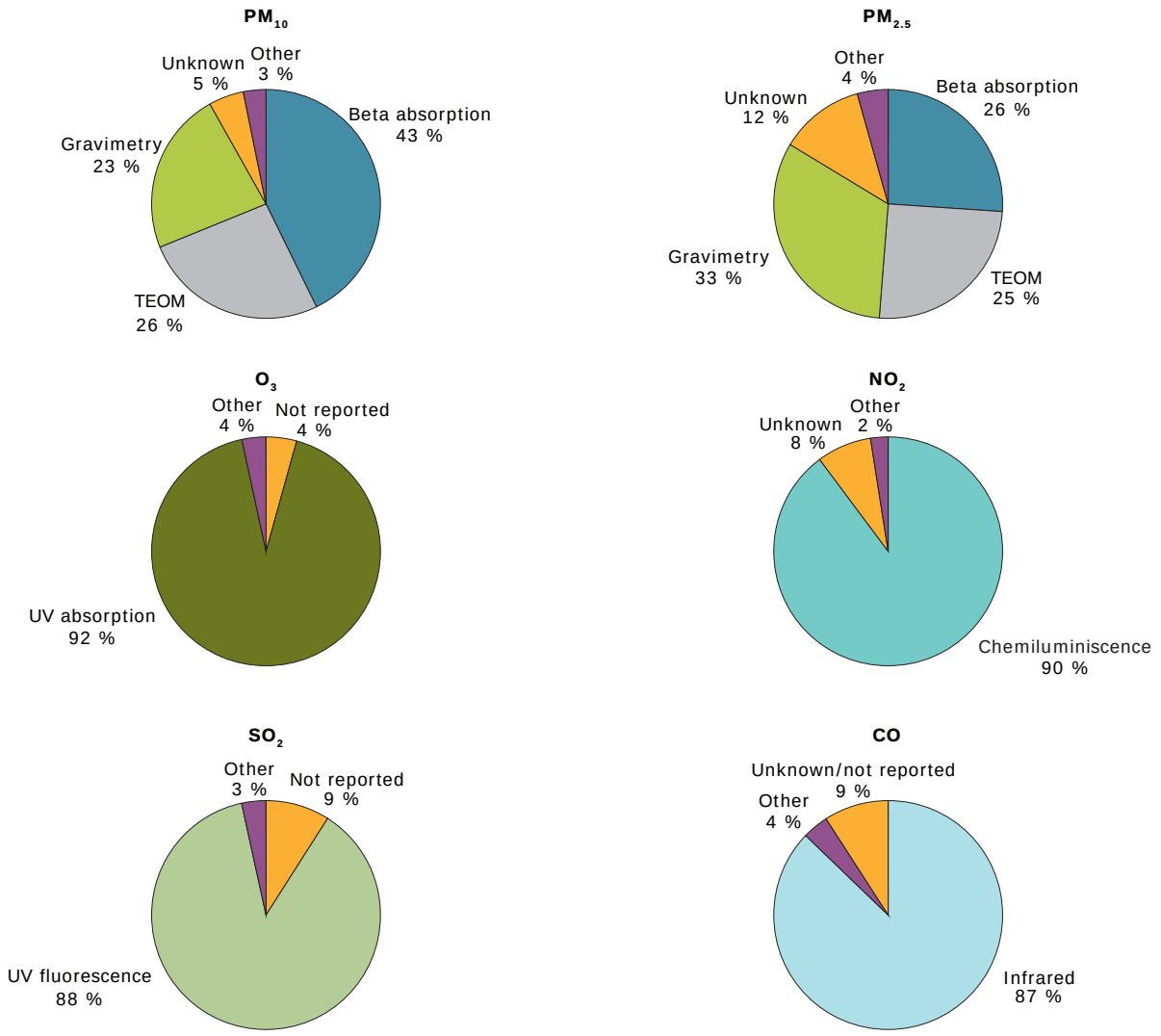
Air monitoring methods

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 ozone (UV absorption, 92 %), NO_2 (chemiluminescence, 90 %), SO_2 (UV fluorescence, 88 %) and CO (infrared absorption, 87 %).

For PM_{10} and $PM_{2.5}$ gravimetric methods are used at 23 % 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.

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

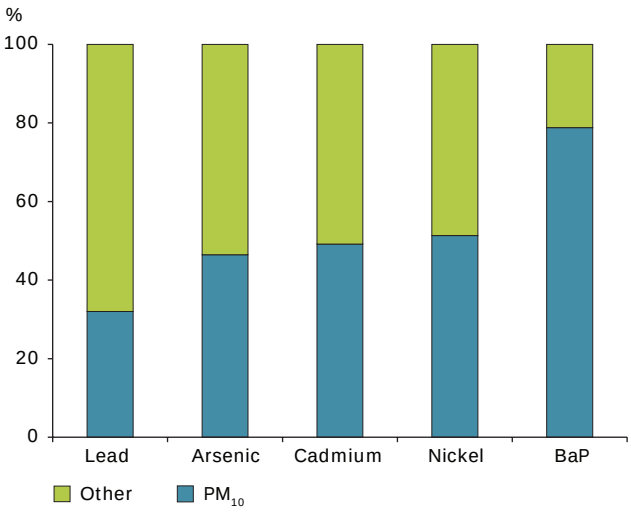


For benzene, most stations do not report the method used. Those that do report a method use (gas) chromatography without further specification, or followed by mass spectroscopy or flame ionisation for quantification.

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 station 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 10 microns.

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



Data reporting and processing, 2009

Thirty-eight countries, including the EU-27 Member States, provided air quality data for the reporting year 2009.

The delivery of data was facilitated by the AQ Data Exchange Module (AQ-DEM) ([24]), which was used by most countries. Some countries provided their data in files in the EoI specified formats (DEM and ISO-7168-1: 1999 (extended) format). All data delivered for the reporting year 2009 was loaded into AirBase. All statistics and exceedances relevant in the Air Quality Directive have been calculated and were also uploaded into AirBase.

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 are 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.

Data suppliers were given extensive feedback. The country feedback sent to the Member States requested one or more updates of their original reports, for example:

- 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 et al. (2011).

([24]) http://air-climate.eionet.europa.eu/country_tools/aq/aq-dem/index_html.

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

Country	Date 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
Albania	30.09.10	19.10.10	20.10.10	26.10.10	03.12.10
Austria	03.09.10	17.09.10	17.09.10	29.09.10	03.12.10
Bosnia and Herzegovina	05.10.10	19.10.10	22.10.10	02.12.10	21.02.11
Belgium	29.09.10	01.10.10	07.10.10	04.11.10	03.12.10
Bulgaria	15.09.10	17.09.10	17.09.10	12.10.10	03.12.10
Switzerland	03.08.10	24.08.10	24.08.10	26.08.10	03.12.10
Cyprus	06.10.10	20.10.10	21.10.10	14.12.10	03.12.10
Czech Republic	30.09.10	04.10.10	07.10.10	02.11.10	03.12.10
Germany	29.09.10	09.11.10	12.11.10	10.12.10	21.02.11
Denmark	29.09.10	01.10.10	08.10.10	26.11.10	21.02.11
Estonia	06.09.10	08.09.10	17.09.10	23.09.10	03.12.10
Spain	29.09.10	04.10.10	07.10.10	05.11.10	03.12.10
Finland	12.11.10	12.11.10	16.11.10	25.11.10	03.12.10
former Yugoslav Republic of Macedonia, the	27.09.10	28.09.10	28.09.10	25.10.10	03.12.10
France	25.09.10	25.10.10	28.10.10	21.12.10	21.02.11
United Kingdom	30.09.10	11.10.10	19.10.10	26.11.10	03.12.10
Greece	06.09.10	14.09.10	20.09.10	15.11.10	21.02.11
Croatia	29.09.10	29.09.10	06.10.10	12.10.10	03.12.10
Hungary	30.09.10	11.10.10	18.10.10	28.10.10	03.12.10
Ireland	01.10.10	19.10.10	22.10.10	19.11.10	21.02.11
Iceland	29.09.10	01.10.10	07.10.10	23.11.10	03.12.10
Italy	30.09.10	11.10.10	19.10.10	17.12.10	21.02.11
Liechtenstein	01.10.10	19.10.10	21.10.10	–	03.12.10
Lithuania	27.09.10	28.09.10	06.10.10	05.11.10	03.12.10
Luxembourg	13.09.10	17.09.10	20.09.10	29.09.10	03.12.10
Latvia	27.09.10	28.09.10	28.09.10	20.10.10	03.12.10
Montenegro	30.09.10	26.10.10	27.10.10	-	03.12.10
Malta	25.01.11	25.01.11	–	–	21.02.11
Netherlands	27.09.10	27.09.10	29.09.10	30.11.10	21.02.11
Norway	28.06.10	30.06.10	19.07.10	21.07.10	03.12.10
Poland	29.09.10	04.10.10	08.10.10	18.11.10	03.12.10
Portugal	28.09.10	29.09.10	06.10.10	09.11.10	03.12.10
Romania	27.08.10	27.08.10	31.08.10	22.09.10	21.02.11
Serbia	30.09.10	12.10.10	18.10.10	01.11.10	03.12.10
Sweden	30.09.10	12.10.10	18.10.10	19.11.10	03.12.10
Slovenia	29.09.10	29.09.10	06.10.10	18.10.10	03.12.10
Slovak Republic	23.09.10	24.09.10	27.09.10	02.12.10	21.02.11
Turkey	05.10.10	20.10.10	22.10.10	03.12.10	21.02.11

Annex 2 European policies and measures on air pollutant emissions

Background

In the period addressed in this report, 1990–2009, 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) ([25]), starting in 1973. The 5th EAP (1993–2000) and 6th EAP (2002–2012) are the ones most relevant for the period addressed here, while the 6th EAP also looks ahead towards 2020. 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 are:

- improving monitoring and assessment of air quality, including the deposition of pollutants, and the providing 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 ozone 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** ([26]), setting e.g. 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 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** ([27]), 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** ([28]) was formulated as the final result of the CAFE Programme. It considers the complex interaction between pollutants, impacts and pollutant receptors (both humans and nature).

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

It deals with particulate matter in air, acidification, eutrophication and ground-level ozone, 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

The **Euro standards** have regulated emissions from motor vehicles since about 1970, through the so-called ECE R15/01-15/04 regulations for gasoline powered passenger cars. Since roughly 1990 the work was continued under the EU umbrella, using the so-called Euro 1–4 regulations for light-duty vehicles (gasoline and diesel powered) and the similar Euro I–IV regulations for heavy-duty diesel engines in trucks and buses, during the period 1992–2005. The further Euro 5/V and Euro 6/VI regulations took effect in 2009, a period not affecting the analysis in this report ([29]).

Petrol vapour recovery directives ([30])

The **Stage I Petrol Vapour Recovery Directive** (1994/63/EC) aims to prevent emissions to the atmosphere of volatile organic compounds (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 three, six or nine years delay depending upon the size of existing service stations, with shorter times for larger stations. This means that the Directive has influenced VOC emissions since about 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. 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 any effect on VOC emissions in Europe.

Directives on fuel quality

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

- In heavy fuel oil, the maximum sulphur 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 sulphur 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 sulphur, lead and benzene in motor fuels, as well as other fuel quality parameters. The limit set in this Directive are:

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

([29]) http://ec.europa.eu/environment/air/transport/road.htm.
([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 sulphur 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 above legal instruments are briefly described below in chronological order:

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 ozone 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 co-incineration 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, nitrogen oxides (NO_X), sulphur dioxide (SO_2), hydrogen chloride (HCl), hydrogen fluoride (HF), heavy metals, dioxins and furans. For heavy metals (HM), 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, particulate matter and ozone precursors (e.g. SO_2, NO_X and particulate matter ('dust')) from large combustion plants for heat end energy production. The Directive sets emission limit values (ELVs) ([36]) for sulphur dioxide (SO_2), nitrogen oxides (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).

([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, 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 volatile organic compounds, 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 adapted four times, until the present version, adopted on 21 December 2007 (2008/1/EC) ([38]). 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, chlorine, fluoride, arsenic, 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' or 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 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 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.

([37]) http://ec.europa.eu/environment/air/pollutants/paints_legis.htm.
([38]) http://ec.europa.eu/environment/air/pollutants/stationary/ippc/index.htm.

Directive on national total emissions

The National Emissions Ceiling Directive (**NEC Directive**) ([39]), 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 ozone pollution (sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia). It leaves it largely to the Member States to decide which measures — on top of 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. 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 to reduce and prevent 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.

([39]) http://ec.europa.eu/environment/air/pollutants/ceilings.htm.

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