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Air pollution in Europe 1990–2004

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Executive summary

Overall picture

This report analyses and presents changes in air pollutant emissions and their possible health or ecosystem impacts in Europe covering the period 1990–2004.

Emissions of all air pollutants fell substantially during the period 1990–2004 in the 32 EEA member countries (EEA-32), resulting in improved air quality over the region. However, ambient concentrations of particulate matter and ozone in the air have not shown any improvement since 1997, despite the decrease in emissions. This might be due to meteorological variability and growing long-distance transport of pollutants.

Fine particulate matter with a diameter size below 2.5 micrometer ($PM_{2.5}$) is now generally recognised to be the main threat to human health from air pollution. As sulphur emissions have fallen, ammonia emitted from agricultural activity and nitrogen oxides from combustion processes have become the predominant acidifying and eutrophying agents affecting ecosystems.

Air pollution issues in Europe

The major classical air pollutants emitted into the atmosphere in Europe are sulphur dioxide (SO_2), nitrogen oxides (NO_X), ammonia (NH_3), non-methane volatile organic compounds (NMVOC) and particulate matter (PM). Air pollutants have direct and indirect effects on human health (Figure 1).

Sulphur and nitrogen compounds emitted into the air are potentially acidifying and can cause harm when deposited into sensitive terrestrial or aquatic ecosystems. Nitrogen compounds are also potentially eutrophying, i.e. can cause an oversupply of nutrient in soils and water bodies (Figure 1).

Particulate matter emissions include primary PM and secondary particulates, formed from so-called PM precursor gases (SO_2, NO_X, NH_3, VOC and NMVOC). Primary PM is the fraction of PM that is directly emitted into the atmosphere, whereas secondary PM is the fraction of PM created in the atmosphere through oxidation of precursor gases, e.g. of SO_2, NO_X into sulphuric acid (liquid) and nitric acid (gaseous), respectively. Secondary organic PM can also be formed from the oxidation of volatile organic compounds (VOCs).

Ozone (O_3) is formed in the atmosphere by reaction between NO_X and NMVOC gases in the presence of heat and sunlight. Ozone pollution is thus a major concern during the summer months.

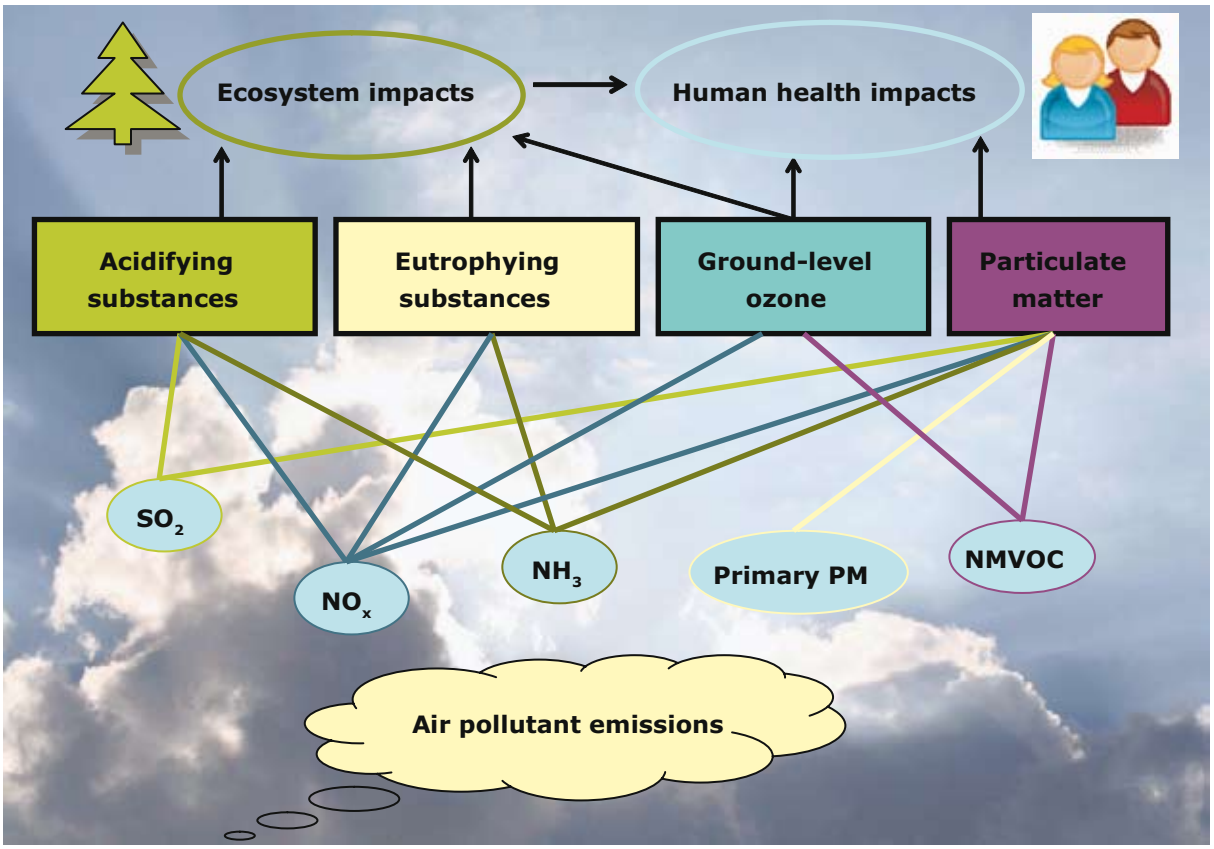
Presently, more than 2 300 air quality monitoring stations report air pollution data to the EEA. Widespread observations started to become available at the European level in 1996/1997. For 2004, 32 EEA member countries reported observations that could be used for the analyses presented in this report.

Particulate matter

- The significant emission reductions in PM precursors are not reflected in observed PM_{10} concentrations, which have shown no change between 1997 (when observations became widely available) and 2004. This can be (partly) explained by meteorological variability affecting concentrations by between 15–20 % in recent years.
- 20–30 % of the European urban population lives in cities where EU air quality limit values of particulate matter (PM_{10}) were exceeded at urban background monitoring stations between 1997 and 2004.

Small airborne particulate matter is inhaled by humans. It can shorten life expectancy and increase numbers of premature deaths, hospital admissions and emergency room visits (e.g. respiratory diseases, increased risk of heart attack). The coarse fraction of PM_{10} reaches the upper part of the airways and lung (PM_{10} = particles with a diameter

Figure 1 **Major air pollutants in Europe clustered according to human health and ecosystem impacts (1)**



Source: EEA (ETC/ACC).

up to 10 μm). The fine fraction of PM_{10} is more dangerous, as it penetrates more deeply into the lung ($PM_{2.5}$ = particles with a diameter up to 2.5 μm).

Adverse health effects occur after short-term exposure to concentration peaks, as well as long-term exposure to relatively low PM concentrations. However, the mechanism of how PM affects health still remains unclear.

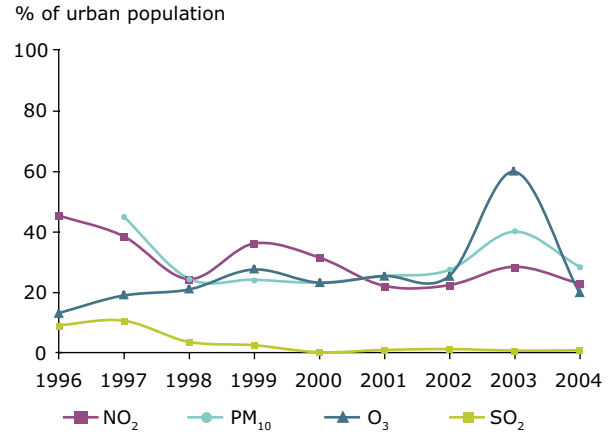
PM precursor and primary PM emissions fell by approximately 45 % over the period 1990–2004. For PM_{10}, however, between 23 % and 45 % of the urban population was exposed to ambient air concentrations in excess of the EU air quality limit value during 1997–2004. There was no discernible downward trend over the same period (Figure 2).

The highest urban PM_{10} concentrations were observed in Belgium, Bulgaria, the Czech Republic, Greece, Hungary, Italy, Luxembourg, the Netherlands, Poland, Portugal, Romania, Spain as well as in the cities of the western Balkan countries.

Some high PM_{10} and ozone concentrations, especially those observed in 2003, can partly be explained by meteorological variability. Reduced precipitation, high springtime temperatures and stable atmospheric conditions led to reduced airborne pollutant deposition and higher pollutant concentrations in the air. This factor will typically produce annual variations of 15–20 %, and is believed to have partly masked the effect of decreasing PM and ozone precursor emissions.

(1) Air pollutants can be grouped together in terms of their possible effects on human health and/or the environment. Emissions of acidifying substances can be aggregated by calculating the weighted sum of the emitted precursor gases SO_2, NO_x and NH_3. The weight factors account for the conversion from mass-units into acid equivalent units. Aggregated PM_{10} emissions represent the total primary PM_{10} emissions and a weighted sum total of the emitted precursor gasses SO_2, NO_x and NH_3. Parts of the precursor emissions are not converted into secondary aerosol (PM) but removed from the atmosphere by processes such as dry deposition of PM to plant surfaces. The weight factors account for the fraction that is converted into secondary PM. A similar approach is taken for the aggregated emissions of ozone forming gases. In this case, the weight factors account for the number of ozone molecules formed during the oxidation of a precursor molecule.

Figure 2 **Percentage of the urban population in EEA-32 potentially exposed to pollutant concentrations over selected limit/target values**



Source: EEA (ETC/ACC).

Exposure to PM_{10} has been estimated to cause an average loss of life expectancy of 9 months in EEA-32 countries (EU-25). The worst affected areas are BeNeLux, Poland, the Czech Republic and Hungary as well as in the Po Valley in Italy, and in southern Spain.

Ground-level ozone, nitrogen dioxide and other pollutants

- Human exposure to sulphur dioxide (SO_2), carbon monoxide and lead concentrations in the air decreased strongly due to the effectiveness of European air quality policies. This is particularly true for policies aimed at reducing emissions of SO_2 from power and heat generation as well as CO and lead emissions from passenger cars.
- The large emission reductions in ozone precursors have not yet shown up in O_3 concentrations, which indicated no change between 1996 (when observations became widely available) and 2004. An exception was reduced peak ozone levels in Sweden and Norway.
- 20–30 % of the European urban population lives in cities where EU air quality limit values of ozone and NO_2 were exceeded at urban background monitoring stations. Exposure of crops and forests to ozone exceeded limit/critical values for protection over very large areas of central and southern Europe.

For SO_2, lead and CO, the reported emissions reductions of up to 50 % since the mid-1990s were largely paralleled by the observations of air quality across the air pollutant monitoring networks in Europe. In general, current SO_2, CO, lead and benzene concentrations in the air do not pose significant problems for human health in Europe. However, specific local sources may still cause high levels of local exposure.

The effects of tropospheric or ground-level ozone (O_3) are different from stratospheric O_3 (ozone layer) which has the beneficial property of providing principal protection from the sun's harmful ultraviolet rays. In the lower atmosphere ground-level O_3 acts as a powerful oxidising agent that can cause adverse effects on human health (e.g. inflammation and irritation of the respiratory tract, increase of lung susceptibility to toxins and micro-organisms as well as premature deaths). High ozone concentrations can furthermore damage sensitive plants and thus reduce wild plant, crop and timber yields.

Although EEA-32 precursor gas emissions fell by 36 % from 1990 to 2004, exposure to ozone has not decreased since 1996. Peak concentrations recorded over Europe declined at the beginning of the 1990s. However, from 1996 onwards, when air quality measurements became widely available, 13–60 % of the urban population in Europe was exposed to ambient O_3 concentrations exceeding the EU target value set for the protection of human health (Figure 2). High rural ozone concentrations are most pronounced in the countries around the Mediterranean.

NO_2 concentrations in the air declined as NO_X emissions decreased. Traffic sites generally exhibit higher concentrations than urban sites, which in turn tend to be more affected than rural locations. Exceedances at hot spot locations (e.g. main roads) are observed all across Europe.

In the period 1996–2004, 22–45 % of the urban population lived in cities where ambient air NO_2 concentrations above the EU limit value set for the protection of human health were observed (Figure 2).

Sulphur and nitrogen deposition into ecosystems

- Across the EU-25, the proportion of (semi-)natural ecosystem areas subject to acid deposition beyond their critical load was approximately 15 % in 2004. A downward trend in deposition can be attributed to reductions in sulphur emissions, mainly

from large point sources (power and heat generation). As sulphur emissions have fallen, nitrogen compounds in the form of ammonia emitted from agricultural activity and NO_X from combustion sources have become the predominant acidifying agents.

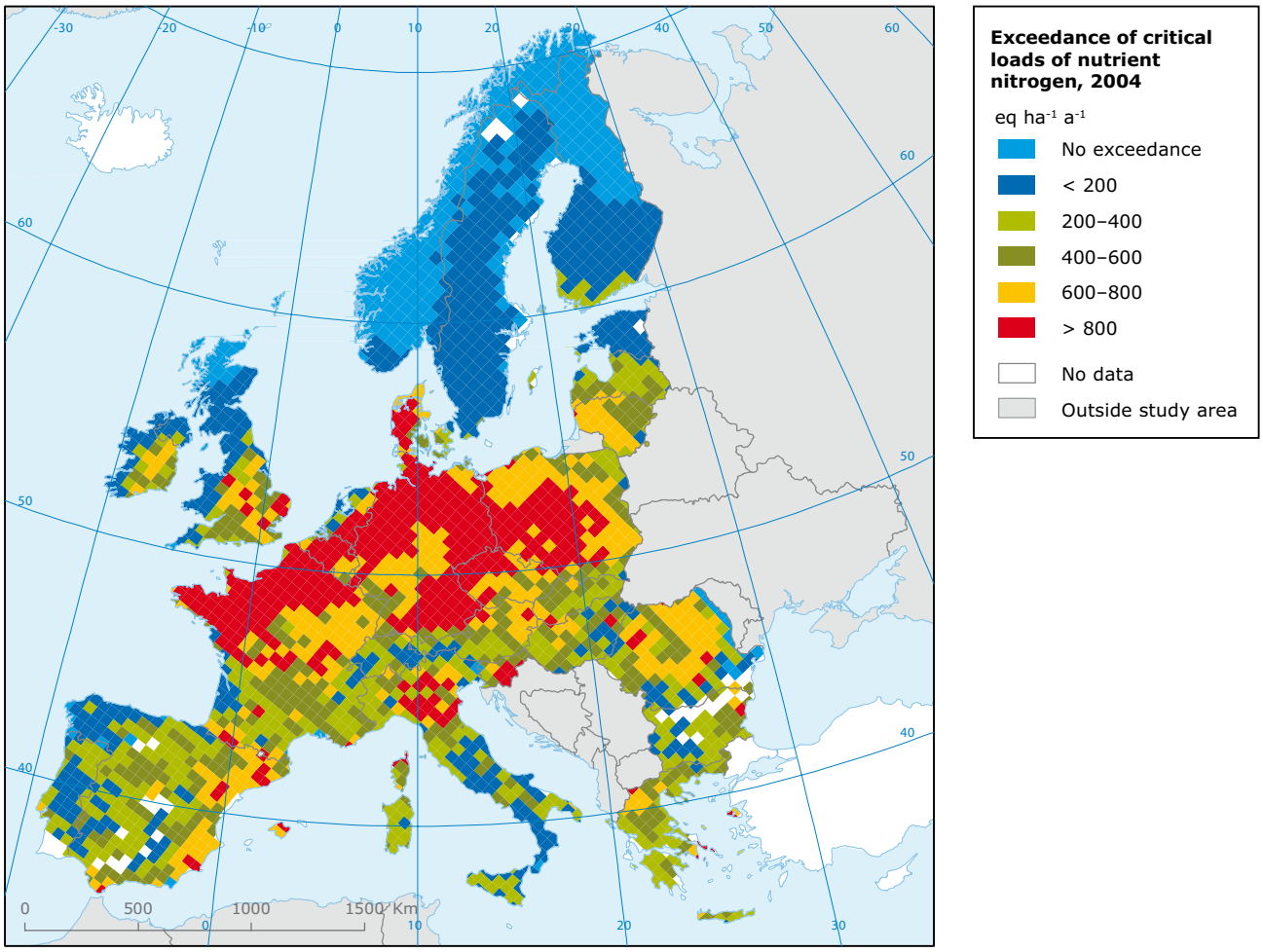
- Across the EU-25, the proportion of (semi-)natural ecosystem areas subject to nutrient nitrogen deposition beyond their critical load was approximately 47 % in 2004. Ammonia emissions from animal husbandry increasingly determine the magnitude and spatial pattern of exceedances of nutrient nitrogen critical loads.

Critical loads for acidifying sulphur (S) and nitrogen (N) compounds can be defined as 'the highest deposition of acidifying compounds that will not cause chemical changes leading to long term harmful effects on ecosystem structure and function'.

Major effects of deposited S compounds are the loss of acid neutralisation capacity in soils and waters, loss of nutrients such as potassium or magnesium from soils and the release of toxic aluminium to the soil solution and waters. Depending on biogeochemical conditions, S can initially be stored in soils with subsequent slow release (postponed acidification). Positive effects of SO_2 emissions reduction measures can thus be delayed for decades.

N compounds have not only acidifying effects, but are also important nutrients. Excess atmospheric nitrogen deposition can lead to a surplus of nutrient N in such ecosystems, causing eutrophication (oversupply) in terrestrial ecosystems. Furthermore, subsequent nitrate (NO_3^-) leaching from soils into groundwater, rivers, lakes, coastal areas and the sea can cause eutrophication in water bodies. Excess nitrogen supply can lead to changes in unique terrestrial, aquatic or marine animal and plant communities, including biodiversity loss.

Figure 3 Pattern of critical loads exceedances of nutrient nitrogen



Note: This map shows areas in Europe where ecosystems are exposed to atmospheric loads of nitrogen (NO_3-N + NH_4-N) that are greater than the critical load for the most sensitive ecosystems in each 50 x 50 grid cell (2004 EMEP deposition data).

Source: CCE.

Large areas of Europe saw clear declines in acid deposition from 1990 to 2004. The downward trend is due to reductions in sulphur emissions, mainly from large point sources (heat and power generation). However, in 2004 still approximately 15 % of the EU-25 ecosystem area sensitive to acidification received deposition of acidifying compounds above critical loads.

As sulphur emissions fell, nitrogen became the predominant acidifying agent. In many areas of Europe eutrophication due to atmospheric N deposition is now a more serious problem than acidification (Figure 3).

Figure 3 highlights nutrient nitrogen pressures on the most sensitive ecosystems. More generally, in 2004, approximately 47 % of the EU-25 ecosystem area sensitive to an oversupply of nitrogen received excess nitrogen deposition leading to eutrophication in sensitive ecosystems, such as forests or waters. Ammonia emissions from animal husbandry increasingly determine the magnitude and spatial pattern of nutrient nitrogen critical loads exceedances.

Rural background, sub-urban, urban and hot spot concentrations

- Hemispheric transport of air pollutants may contribute to air pollution problems in the northern hemisphere and thus may mask the effects of air pollutant emissions reductions in Europe.

Long-range transport and pollutant dispersion together with meteorological (and topographical) conditions have a significant influence on local air pollution. Regional background contributions to urban background $PM_{2.5}$ and PM_{10} levels are typically in the range from 60–90 % ([2]). High rural background PM and also O_3 concentrations result from (fairly slow) reactions between the precursor gases emitted, making it difficult to control concentrations of those pollutants through local abatement alone. However, urban NO_2 and benzene concentrations are not dominated by regional pollutant levels. Concentrations increase typically as one moves from rural to urban to hot spot areas.

The relationship between ozone levels at rural, urban and hot spot locations is more complicated than for PM_{10} and NO_2. This is due to the chemical reactions involved in the build-up of ozone. On the one hand, long residence times and strong solar radiation in large urban areas especially in southern Europe may lead to substantial photochemical production of ozone in and downwind of such areas. Here, maximum urban background and suburban ozone concentrations sometimes exceed those in the nearby rural areas, while concentrations at hot spots, i.e. near roads, always remain lower (due to the reaction of NO with ozone). In general, O_3 levels at traffic hot spots are lower compared to urban background sites, where ozone concentrations are in turn lower than at rural locations.

In order to reach long term objectives with an air quality for ozone that does not give significant negative effects on human health and the environment, substantial emission reductions of both NO_X and VOCs would be needed at local, regional and hemispheric level. For PM, no safe level has been identified. Moreover, further substantial emission reductions of primary particulate matter and PM precursors such as NH_3, NO_X, and SO_2 are needed to bring down the present levels and so reduce damage to human health.

Emission control regulations in Europe

By setting interim environmental objectives, the European Union has committed itself to reducing the air pollution of four key pollutants — SO_2, NO_X, NMVOC and NH_3 by year 2010 below levels that have serious effects on human health and sensitive elements of the environment (National Emission Ceiling Directive, 2001/81/EC). Compared with the 1990 situation the area where critical loads of acidity are exceeded shall be reduced by at least 50 % by 2010 in each 50 x 50 km grid cell used for mapping. Ground-level ozone concentrations above the critical limit for human health shall be reduced by two thirds and the values above the critical level for crops and semi-natural vegetation by one third (in all grid cells; 2010 compared to 1990).

Furthermore, several emissions abatement measures have been introduced for the main emitting sectors since the 1990s (Table 1).

Another important strand to European air pollution reduction policy was the adoption of the Air Quality Framework Directive (1996) which, via daughter directives on air quality, sets limit or target values for the concentrations of designated contaminants in air. SO_2 and PM_{10} limit values for health protection had to be achieved in 2005. NO_2 and lead limit values will have to be reached by 2010.

([2]) Convention on Long-range Transboundary Air Pollution: Draft EMEP Particulate Matter Assessment Report, June 2007.

Table 1 Emission control regulations in Europe

EU directives, instruments	Type of measure	Pollutants covered
National Emission Ceiling (NEC) Directive (2001)	Binding emission ceilings, which EU Member States will have to meet by 2010	SO_2, NO_X, NMVOC, NH_3
Large Combustion Plant (LCP) Directive (1988, 2001)	Emission limit values	SO_2, NO_X , dust ([1])
Integrated Pollution Prevention and Control (IPPC) Directive (1996)	Integrated permit based on Best Available Technology (BAT)	Not specified: 'Overall environmental performance'
EURO standards (1992 …) for passenger cars and other light duty vehicles, heavy duty vehicles (e.g. lorries, busses) and motor cycles	Emission standards and testing Fuel regulations	NO_X, CO, HC ([2]), HC + NO_X and PM
Directive on the sulphur content of certain liquid fuels (1999)	Fuel regulations	SO_2
Directive on quality of petrol and diesel fuels (1999)	Ban on the marketing of leaded petrol Obligation to make sulphur-free fuels available within the EU	Not specified Lead; SO_2
Emissions limits for engines used in non-road mobile machinery (1997)	Emission standards and certification procedures with respect to these standards	NO_X and PM
Waste Incineration Directive (2000)	Stringent operating conditions Minimum technical requirements Emission limit values	Total dust ([1]), TOC ([3]), HCl ([4]), HF ([5]), NO_X, heavy metals (e.g. cadmium, lead mercury), dioxins and furans, SO_2, CO
VOC Stage I Directive (1994)	Technical measures to reduce emissions during storage of petrol at terminals and its subsequent distribution to service stations	VOC
Solvent Emissions Directive (1999)	Product-based limits for VOC emissions	VOC

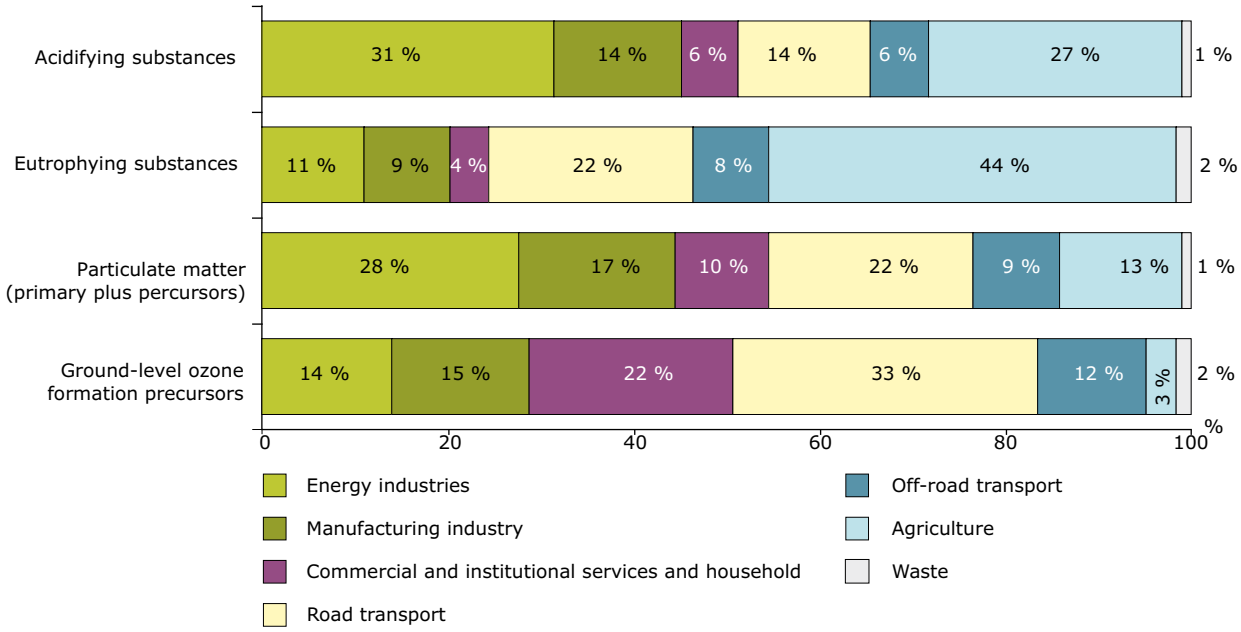
Note: ([1]) dust = total suspended particulate matter, including PM > PM_{10}; ([2]) HC = hydrocarbons; ([3]) TOC = total organic carbon; ([4]) HCl = hydrogen chloride; ([5]) HF = hydrogen fluoride.

Major emission sources and development of emissions in Europe

- EU Member States have committed themselves to achieving substantial reductions in national total emissions for four key pollutants (SO_2, NO_X, NMVOC and NH_3) by 2010. However, a number of EU Member States will have to implement further emission reduction measures to achieve the agreed emission ceilings and to avoid exceedances of air quality limit values.
- Various effective EU wide policies are aimed particularly at emission reductions in the power/heat generation, industry and road transport sectors. In the EEA-32 member countries primary particulate matter (PM) and secondary PM precursor emissions, ozone precursor emissions, and those of acidifying compounds fell by 45 %, 36 % and 50 %, respectively.
- PM emissions (from various sources), NO_X emissions (mainly from transport), ammonia emissions (mainly from agriculture) and NO_X and SO_2 emissions from shipping would need to be further abated to reduce harmful effects on human health and sensitive ecosystems.

The major sectors contributing to emissions of acidifying substances in 2004 were energy industries and agriculture (Figure 3). For eutrophying substances, i.e. mainly emissions of acidifying and nutrient NH_3, the agricultural sector was with 44 % by far the most important air pollutant source. Energy industries and road transport were the main contributing sectors to primary PM emissions and secondary PM_{10} formation in 2004. Road and off-road transport were the major sources of ozone formation precursors (approximately 45 %).

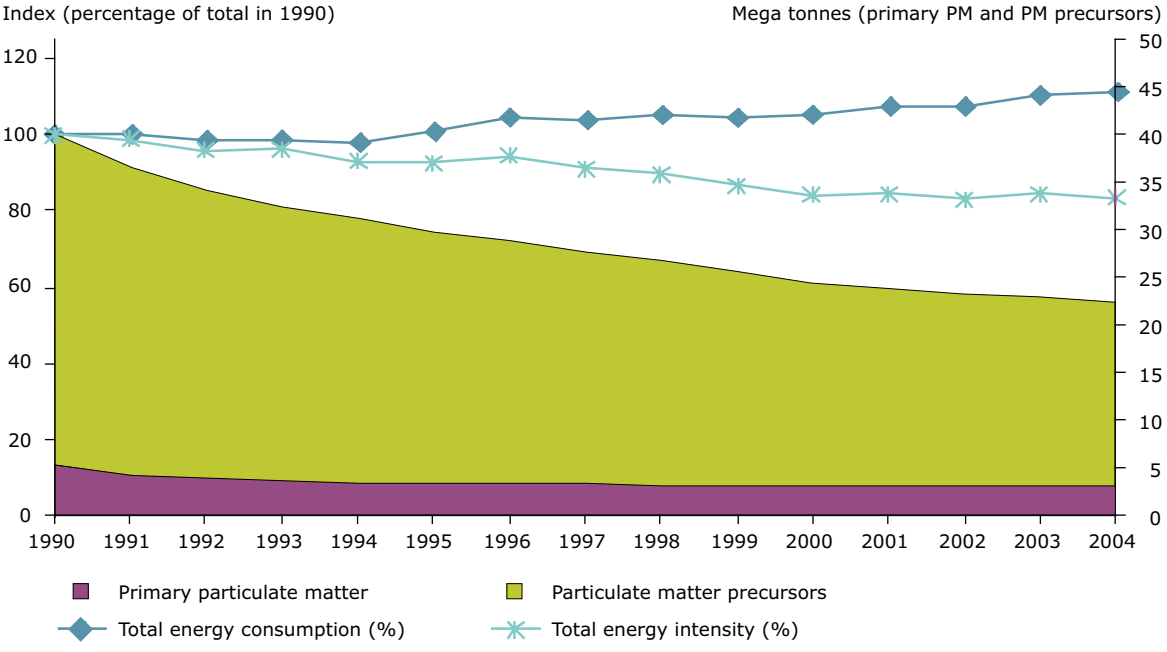
Figure 4 EEA-32 sector contributions to the main air pollution issues, 2004



Note: The first two bars (top-down) relate to ecosystem impacts, the third to human health impacts and the fourth to health and vegetation impacts. Energy industry: Emissions from public heat and electricity generation including fugitive emissions; Manufacturing industry: combustion and non-combustion processes; Commercial and institutional services and households: Combustion and non-combustion processes; Road transport: light and heavy duty vehicles, passenger cars and motorcycles; Off-road transport: railways, domestic shipping, certain aircraft movements, and non-road mobile machinery used in agriculture, forestry; Agriculture: manure management, fertiliser application; Waste: incineration, waste-water management.

Source: EEA (ETC/ACC).

Figure 5 EEA-32 primary and secondary particulate matter emissions (PM_{10}), 1990–2004



Note: Total energy consumption is what Eurostat refers to as Gross Inland Energy Consumption (in million tonnes oil equivalents). The gross domestic product (GDP) in the EU-25 Member States grew at an average annual rate of 2.1 % during 1990–2004 (EEA, fact sheet EN17).

Source: EEA (ETC/ACC).

Primary and secondary PM_{10} emissions were reduced by 45 % between 1990 and 2004 in the EEA-32 member countries (Figure 5). SO_2 and NO_X were the most important pollutants contributing to secondary PM_{10} formation.

The residential sector (mainly wood-burning), road transport and public electricity and heat production are the main sources of primary PM emissions. Re-suspension of road dust or natural sources (Saharan dust, sea salt, biogenic particulate organic carbon) can contribute considerably to primary PM emissions in some European regions.

Emission reductions between 1990 and 2004 were mainly achieved through a combination of use of fuels with lower sulphur content, fuel switching from coal and oil to natural gas, the implementation of emission abatement technologies in the energy supply and industry sectors, and an increased market penetration of road vehicles with catalytic converters.

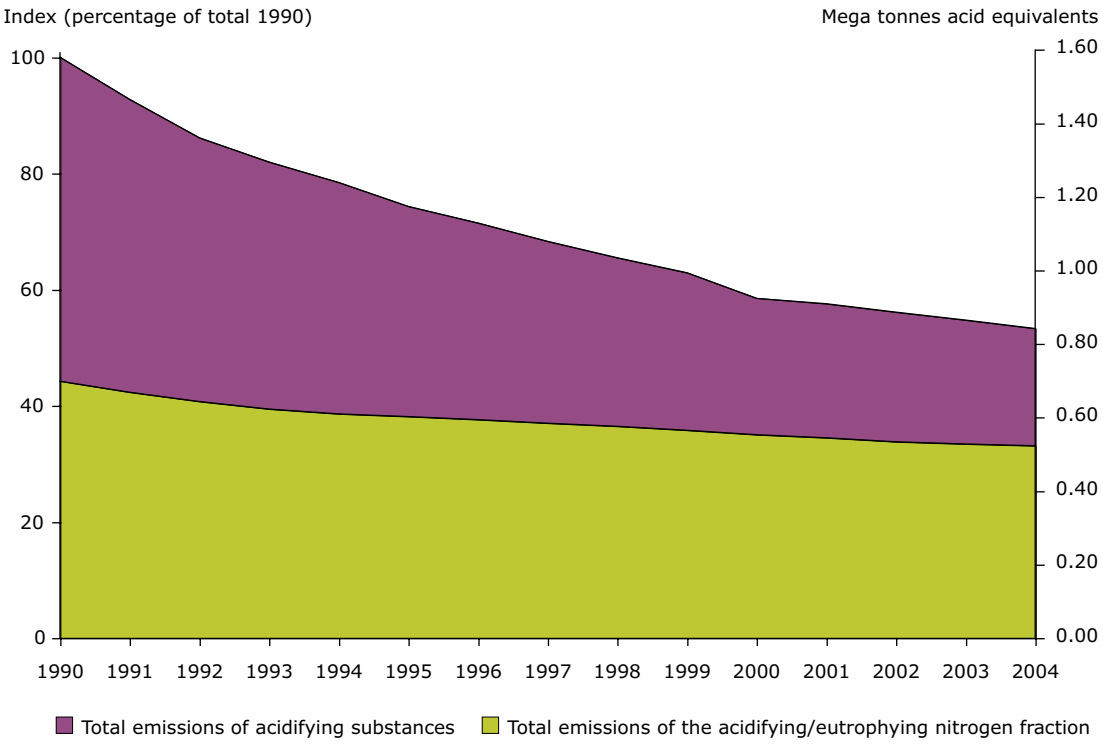
Main options to abate ozone-forming gases have been the introduction of catalytic converters in new cars and the increased penetration of diesel cars. Emissions of ground-level ozone precursors were reduced by 36 % across the EEA-32 member countries between 1990 and 2004. The ozone precursor gases non-methane volatile organic compounds (NMVOC) and NO_X are covered by the NEC Directive. Emission reductions were also achieved due to the implementation of the Solvent Emissions Directive in industrial processes and reductions of fuel consumption.

Between 1990 and 2004 emissions of potentially acidifying substances decreased by approximately 50 % due to substantial reductions in SO_2 emissions (Figure 6). However, the acidifying and eutrophying nitrogen fraction (NH_3 plus NO_X) stayed almost unchanged (Figure 6). The energy industries sector contributed approximately 50 % to the total reduction in emissions of acidifying substances.

Although EU Member States agreed to achieve substantial reductions of national total emissions for four key pollutants (SO_2, NO_X, NMVOC and NH_3) by 2010, in 2004 a number of countries still had to take further steps to reach their national total emissions ceilings (Figure 7).

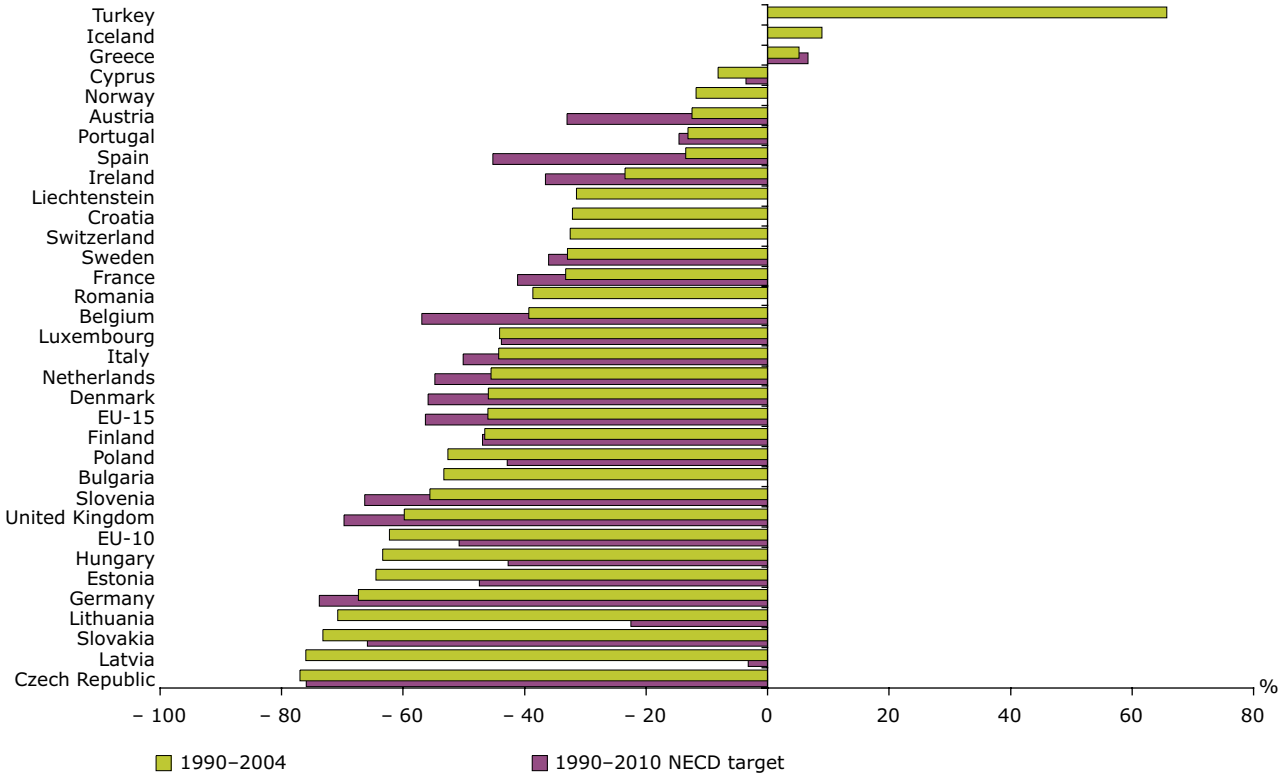
Emissions of all air pollutants fell due to various effective EU wide policies aimed particularly

Figure 6 Total emissions of acidifying substances (sulphur plus nitrogen) and of eutrophying nitrogen in the EEA-32 for 1990 to 2004



Source: EEA (ETC/ACC).

Figure 7 **EEA-32 national emission changes from 1990 to 2004 for acidifying pollutants, and remaining reduction targets under the National Emission Ceiling Directive (NECD) for EU Member States**



Source: EEA (ETC/ACC).

at power/heat generation, industry and road transport. However, further measures will be necessary in these and other source sectors to achieve the agreed national emission ceilings and to avoid exceedances of air quality limit values (by 2010).

Only partly covered by official international emissions inventories, the share of emissions from international shipping as well as air transport is steadily increasing in Europe. This is both due to considerable reductions of emissions from land-based sources and increasing growth in global trade.

1 Introduction

1.1 Objectives and coverage

This report provides an overview and analysis of air pollution in Europe for the period 1990–2004. Air quality and pollutant deposition changes are assessed through indicators of impact upon human health and upon ecosystems. A management context is provided through evaluation of underlying sector-wise driving forces, pollutant emissions, and the effectiveness of policies and measures.

The main policy questions addressed in the report are:

- What are the trends in emissions from the main socio-economic sectors causing air pollution?
- What progress is being made towards meeting the targets of the EU National Emission Ceiling (NEC) Directive and the Gothenburg Protocol (UNECE, 1999), emission targets?
- What progress is being made towards meeting the requirements of the EU Air Quality Directives (AQD)?
- How effective have policies and measures for reducing air pollution been?

This report aims to support policy development and review at EU and national level, but is also expected to be of relevance to local air pollution management as well as the general public.

Both local scale and wider regional scale air pollution issues across European urban and rural areas are examined. Local scale sources may make such a major contribution to human exposure to air pollution that local or national measures to abate emissions may be more suitable. However, a pan-European approach is needed not only because of the long-range transport of many of the pollutants but also because many of the economic and political measures that have real implications for air pollution are taken at European level. The most important policies and measures for air pollution management are the EU Framework and Daughter Directives on Air Quality (AQDD; EC 1996b), the National Emission Ceilings Directive (NECD; EC, 2001c), and the UNECE CLRTAP Protocols for multi-pollutant emissions (Gothenburg) and for heavy metals and persistent organic pollutants (Århus).

The report covers the 32 EEA member countries (EEA-32) and Croatia:

- EU-15 (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom);
- EU-10 (Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia);
- EFTA-4 (Iceland, Liechtenstein, Norway and Switzerland);
- Bulgaria, Romania (EU Member States since January 2007), Turkey and Croatia.

A distinction was made between those country groupings in order to show developments in air pollutant emissions (and in air quality) for EU and non-EU Member States with different economic backgrounds.

1.2 Air pollution as a European environmental issue

The main air pollution issues in Europe are presently:

a) human health impact of exposure to particulate matter and ozone (and to a lesser extent NO_2, SO_2, CO, lead and benzene);
b) acidification and eutrophication of ecosystems;
c) damage to ecosystems and crops through exposure to ozone;
d) damage to materials and cultural heritage due to exposure to acidification and ozone;
e) impacts of heavy metals and persistent organic pollutants on human health and ecosystems.

The main sectors emitting air pollutants are road transport, power and heat production sectors, industry and agriculture. Widespread exposure of the human population as well as ecosystems and materials to adverse air quality and deposition is the result.

The household sector (e.g. home heating by wood and coal burning) can be an important source of air pollutants, especially PM, in some European areas (e.g. Nordic countries, Sternhufvud *et al.*, 2004).

While air pollutant emissions from most other sectors have decreased, marine, inland water and air transport are becoming more and more significant SO_2, NO_X and PM emission sources in Europe.

Pollutant emissions are dispersed in air and are removed from the atmosphere by chemical reaction and deposition. The resulting pollutant concentrations vary strongly by pollutant, location and time. The pollutants principally having high concentrations close to their emission sources include sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_X and NO_2) and benzene from streets and industrial plants. Other pollutants generally occur on a broader scale as a consequence of their formation and transformation under atmospheric transport. Ozone and the deposition of acidifying compounds fall into this category. These are observed typically as 'regional background' pollution levels, subject only to limited local modification. Indeed, they may be influenced by hemispheric scale pollutant transport, e.g. ozone and PM formed from precursor pollutants emitted across the northern hemisphere (TFHTAP, 2007). A third category are pollutants such as particulate matter (PM monitored as $PM_{2.5}$ and PM_{10}), which both show high regional background levels, but to which local (urban) emissions can add significant concentrations.

The European Union has stated that the long-term climate objective should limit global mean temperature increase to 2 °C above pre-industrial levels. The resulting policies combating climate change will contribute substantially to reducing air pollution. The ancillary benefits would be a drop in the potential harm to public health and ecosystems caused by air pollutants and lower overall costs of controlling air pollutant emissions (EEA, 2006).

1.3 Data and indicators

The emission data used in this report are based on those officially submitted under the UNECE CLRTAP Protocols. The observed air quality data utilised are those officially reported by EEA-32 according to the Exchange of Information Decision (EoI; EC, 1997). Computer model estimates of pollutant deposition and some additional air quality data have been obtained from EMEP.

The EEA European Topic Centre on Air and Climate Change (ETC/ACC) has developed a set of air pollution indicators, and this report uses most of those selected for the core set. To a large extent, this report is based on these indicators and the underlying data (EEA, 2005a).

1.4 Driving forces of air pollution

The driving forces behind air pollution are directly associated with human activity, for which one priority measure is the gross domestic product (GDP). Energy consumption, industrial activities, transport demand and agriculture husbandry are the specific forces most directly linked to air emissions. The development of these driving forces determines the potential scale of air pollutant emissions. Actual levels of pollutant emissions, however, will also vary depending on technical and social changes developed in response to air quality and emission abatement legislation. The development in the driving forces for air pollution since 1990 is further described in Appendix A.

While population growth in Europe has been minimal since 1990 (small increase in EU-15 and small decrease in EU-10), the number of households grew rapidly by approximately 11 % between 1990 and 2000 whilst GDP grew by approximately 33 % at constant price index. In contrast, total energy consumption increased by about 12 % to 2004, which along with the GDP increase, represents a substantial improvement in energy efficiency in the production of goods and services. Another important development which has led to decreasing emissions is the shift from coal and oil to lighter oil use and gas.

The transport sector has grown to become the largest energy consuming sector, accounting for approximately 31 % of final European energy consumption in 2004. In comparison, the industrial sector used 28 % and households 27 %. Road transport activity (passenger-kilometres and tonne-kilometres travelled on European roads) has increased faster than GDP growth. The potential for transport-related air pollution caused by road vehicles has, therefore, increased and has to be compared to the effects of emission reduction regulation.

SO_X emissions from shipping due to combustion of fuels with high sulphur content contribute considerably to air pollution. PM and NO_X emissions from shipping are also important pollutant sources. Ships are fast becoming the biggest source of air

pollution in the EU. Unless more action is taken, they are set to emit more than all land sources combined by 2020 (CAFE, 2005). Harmful effects on the environment (acidification, eutrophication) and human health can be expected particularly around coastal areas and ports. However, due to long-range pollutant transport other European regions can also be affected. Furthermore, the rise in demand for air travel is becoming a serious environmental threat, not only in terms of carbon dioxide (CO_2), but also air pollutant emissions.

The agricultural sector contributes significantly to airborne ammonia (NH_3) pollution, and thus particularly to the deposition of acidifying and eutrophying compounds. Animal husbandry is a key sub-sector. Poultry numbers in the EU-25 have increased since 1995; the number of pigs has been stable, whereas cattle numbers have decreased by approximately 10 % since 1995. Altogether, agricultural emissions remained largely unchanged in the decade to 2000.

Against this backdrop of the economic and social driving forces, the following chapters describe levels of air pollution and their environmental impact in Europe.

1.5 Summary of relevant policy instruments and legislation

The aim of European air quality legislature in recent years has been to coordinate an EU strategy through the twin-track approach of long-term air quality objectives together with air pollutant emission abatement measures.

In 1996, the Framework Directive (EC, 1996b) on ambient air quality assessment and management was adopted (AQFD). The AQFD is supported by four daughter directives. These have set air quality target and limit values for sulphur dioxide, nitrogen dioxide, particulate matter, ozone, benzene, carbon monoxide, arsenic, lead, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons. They also seek to harmonise monitoring, measuring and quality assessment methods to achieve comparability and ensure good public information.

The 1999 UNECE Gothenburg protocol for the Convention on Long-range Transboundary Air pollution (CLRTAP; UNECE, 1999) sets emission ceilings for 2010 for the air pollutants sulphur dioxide (SO_2), nitrogen oxide (NO_X), volatile organic compounds (VOCs) and ammonia (NH_3). Two further specific emission control protocols were agreed under this Convention at Århus in 1998: one for the heavy metals cadmium, lead and mercury, and another for persistent organic pollutants (POPs), including dioxins, furans, PCB, PAHs, HCB and a number of older pesticides. These latter protocols require emission reductions to below 1990 ([3]) levels.

The NEC Directive (EC, 2001c) also set emission targets (2010) for the four main pollutants responsible for acidification, eutrophication and ground-level ozone (SO_2, NO_X, NMVOCs and NH_3). The ceilings are in general slightly stricter than those negotiated under the Gothenburg Protocol and are designed to meet objectives for acidification, eutrophication and ozone, in the most cost-effective way for the Community. The NEC Directive is supported by sector-specific legislation, such as that aimed at large combustion plants (EC, 2001a), industrial activities (EC, 1996a), restrictions on the level of sulphur in fuels (EC, 1993), and reduction of non-methane volatile organic compounds from solvent use (EC, 1999a). During 2007, the Commission will review the NEC Directive and will propose revised emission ceilings based on the level of ambition set out in the Thematic Strategy (see below).

The EU's Sixth Environment Action Programme (6EAP) calls on the Commission to develop seven thematic strategies, including one on air pollution. The 6EAP established the objective of achieving levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment. For ecosystems, this includes the requirement that critical loads and levels shall not be exceeded.

In 2001 the European Commission launched the Clean Air for Europe (CAFE) programme. The aim of the programme was to review current air quality policies and assess progress towards attainment of EU's long-term air quality objectives, as laid down in the 6EAP. CAFE has dealt with health and environmental problems related to particulate matter, ground-level ozone, acidification, and eutrophication.

Following the CAFE analysis of the various scenarios, the Commission adopted in September 2005 its Thematic Strategy on Air Pollution (EC, 2005). By establishing interim environmental

([3]) Or an alternative year between 1985 and 1995 in the case of the 1998 Århus Protocol for POPs.

objectives for 2020 in the strategy, the Commission set the level of ambition regarding air quality in the EU up to year 2020.

As regards specific legislative initiatives, the Thematic Strategy is accompanied by a proposal to merge the Air Quality Framework Directive and three daughter directives containing minimum requirements for air quality. The merged directive introduces new provisions for fine particulate matter ($PM_{2.5}$).

Appendix B lists the current air quality and emission limits and targets.

1.6 Outline of the report

The issues covered by this report are:

- health-related: PM_{10}, ground-level ozone, NO_2;
- ecosystems-related: acidifying and eutrophying deposition, ground-level ozone;
- toxic compounds: heavy metals and organic compounds.

Health and ecosystem issues are evaluated in the body of the report using the DPSIR framework ([4]), whilst toxic compounds are discussed in two topic-specific boxes (for arctic pollution and for marine pollution; Boxes 3.2 and 4.1). Driving forces leading to air pollution problems have been summarised above and a more detailed account can be found in Appendix A. The pressures on the environment are the emissions of air pollutants which result from the driving forces; these are evaluated in Chapter 2 together with the progress towards meeting emission targets. The impacts of individual air pollutants components with reference to relevant limit and target values, and state in terms of pollutant concentrations/depositions in 2004 are described in each of Chapters 3 (health-related pollutants) and 4 (ecosystems-related pollutants). Finally, responses are considered through assessment of effectiveness of policies employed.

([4]) DPSIR; the chain from Driving force, Pressure, State, Impact to Response.

2 Development of air pollution emissions; progress towards targets

Key messages

- Emissions of primary and secondary particulate matter, ozone precursors and acidifying compounds fell by over a third in the EEA-32 between 1990 and 2004.
- Whilst most countries have made good progress, substantial reductions are still needed if emission targets are to be met. This is true for ozone precursor emissions from most EU-15 Member States and of potentially acidifying emissions from several EU-15 countries.
- There are no overall PM emission reduction targets at the present time.

2.1 Overview

This chapter looks at changes and current status in emissions related to the separate air pollution problems. Some individual pollutants contribute to more than one problem (e.g. SO_2, which contributes to both particulate matter (PM) formation and acidification problems, or NO_X which contributes to NO_2, ozone and eutrophication problems).

The NECD and the UNECE Gothenburg Protocol prescribe emissions target ceilings by country for each separate pollutant. The CAFE programme (see Section 1.5) deals with human health and environmental problems related to particulate matter, ground-level ozone, acidification and eutrophication. For ecosystems, this includes the requirement that critical loads of acidity and eutrophication as well as critical levels of ozone shall not be exceeded. In this chapter combined emission changes for pollutant groups related to each problem and the associated combined reduction targets have been calculated with a view to evaluating changing emission pressures relevant specifically to the four pollution problems mentioned above.

Subsections a) to d) describe these pollutant issues with the contributions from the main economic sectors to these four issues summarised (Table 2.1 and Figure 2.1). Energy industries (energy production), road transport and agriculture contribute to several of the air pollution issues. Emissions of SO_2 and NO_X from many sectors and NH_3 from agriculture are still the main contributors to European air pollution problems.

a) Primary particles and PM precursor gases (SO_2, NO_X and NH_3)

Particulate matter is emitted both as primary particulate matter (PPM) and as precursor gases, which react in the atmosphere to produce secondary inorganic (SI) fine particles. Together these constitute PM in the atmosphere. Secondary particles lie predominantly within the PM_{10} size range (diameter 10 μm), with most in the $PM_{2.5}$ (diameter 2.5 μm) range. They can be inhaled and are potentially damaging to health. The respective contributions to particulate formation from inorganic precursor gas emissions may be combined according to their relative particulate formation factors SO_2 = 0.54, NO_X = 0.88, NH_3 = 0.64 (de Leeuw, 2002) and are added to PPM emissions to represent the combined occurrence of PM_{10} in the atmosphere.

Secondary organic particles are also produced in the atmosphere from reactions between nitrous gases and VOC, under radiation from sunlight. In terms of mass, the organic secondary particles are less abundant than the inorganic ones, but in terms of health impact, recognition of their importance is growing. Due to the complex chemistry behind organic particle production, inclusion of their precursor gases in total PM_{10} estimates using ratios such as those above has not been attempted.

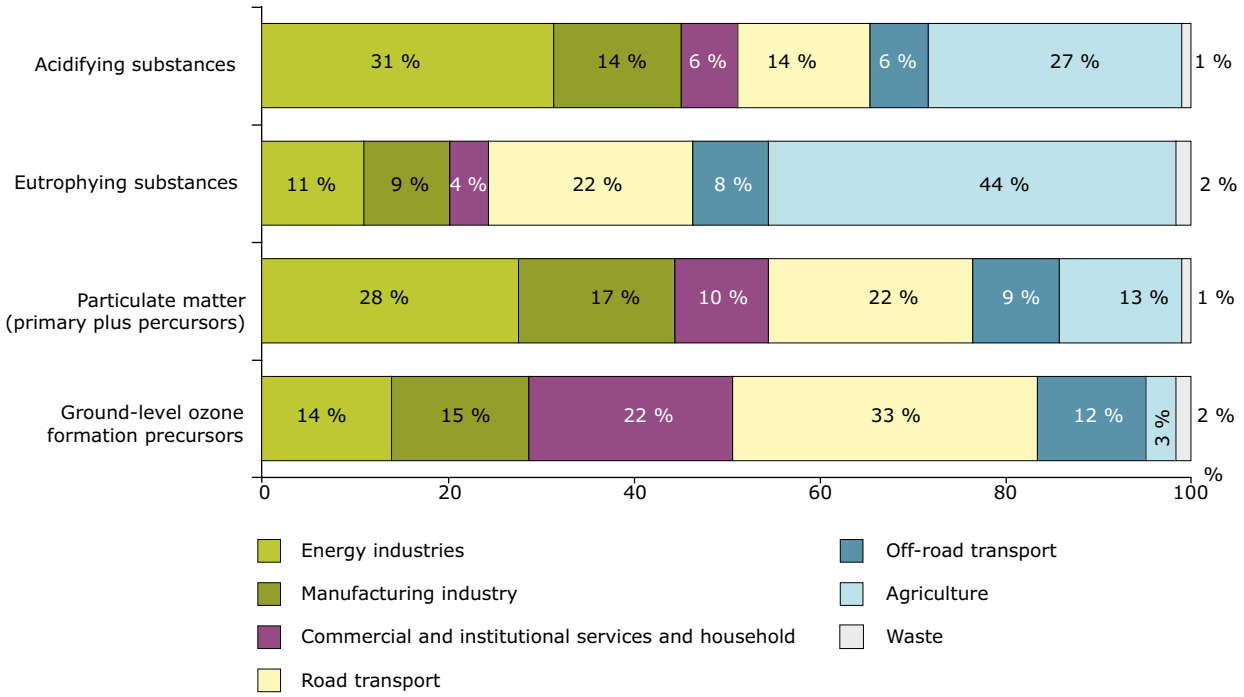
b) Ozone precursor gases

Ozone is a powerful oxidant, and as such can have deleterious impacts on both human health and the environment. Emissions of NO_X, methane (CH_4), other non-methane volatile organic compounds (NMVOC), and CO all contribute to the formation of ground level (tropospheric) ozone. These pollutants are known as ozone precursors, and the relative impact of their combined contribution to ozone formation has been assessed based on their tropospheric ozone forming potential (TOFP): NO_X = 1.22, NMVOC = 1.0, CO = 0.11, CH_4 = 0.014 (de Leeuw, 2002).

Table 2.1 Summary of impacts by sector upon acidification, eutrophication, particulate matter and ground level ozone production

Economic sector	Issue contributed to	Pollutants of concern
Energy industries	All four issues, but largest contributions to acidifying substances and particulate matter (PM)	Mainly SO_2, but also NO_x and PM
Road transport	All four issues, largest contribution to ozone formation precursors	Mainly NO_x and PM, but also NMVOC and CO (to ozone formation)
Agriculture	Eutrophication and acidifying substances as well as to ozone formation	Mainly NH_3, but also PM
Industrial energy and processes	Smaller contributions to all four issues	Mainly SO_2 and NO_x
Residential	All four issues	Mainly SO_2, NO_x and PM
Other energy	Mainly to ozone formation	NO_x and CO

Figure 2.1 EEA-32 sector contributions to the main air pollution issues, 2004



Note: The first two bars (top-down) refer to ecosystem impacts, the third to human health impacts, and the fourth to health and vegetation impacts Energy industry: Emissions from public heat and electricity generation including fugitive emissions; Manufacturing industry: combustion and non-combustion processes; Commercial and institutional services and household: Combustion and non-combustion processes; Road transport: light and heavy duty vehicles, passenger cars and motorcycles; Off-road transport: railways, domestic shipping, certain aircraft movements, and non-road mobile machinery used in agriculture, forestry; Agriculture: manure management, fertiliser application; Waste: incineration, waste-water management.

Source: EEA (ETC/ACC).

c) Acidifying, and d) Eutrophying precursors

The acidifying potential of the emitted compounds SO_2, NO_X and NH_3 is estimated by converting each to units of acid equivalent. This is related to the electrical charge of the compound and to its molecular weight, such that the factors are: $SO_2 = 2/64$, $NO_X = 1/46$, and $NH_3 = 1/17$ acid equivalents per gram (de Leeuw, 2002).

The eutrophying potential is related to the fertilising effect of nitrogen, and hence to emissions of ammonia and nitrogen oxides. These are treated equally, i.e. that 1 unit of nitrogen as NO_X is equal to one unit of nitrogen as NH_3.

2.2 Primary particulate matter (PM) and PM precursor emissions

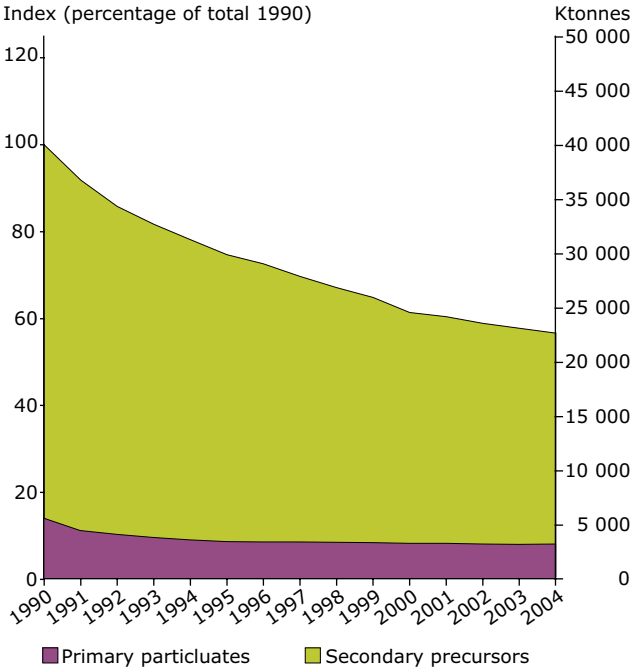
Key messages

- Total EEA-32 emissions of PM_{10} fell by 44 % between 1990 and 2004, mainly due to reductions in emissions of the secondary particulate precursors SO_2 and NO_X, but also due to reductions of primary PM_{10} from energy industries.
- Most EEA-32 countries have made good progress in particulate emission reduction since 1990, only four countries (Greece, Portugal, Iceland, Turkey) have seen increases.

2.2.1 *Overall trends in total emissions by region, and by country*

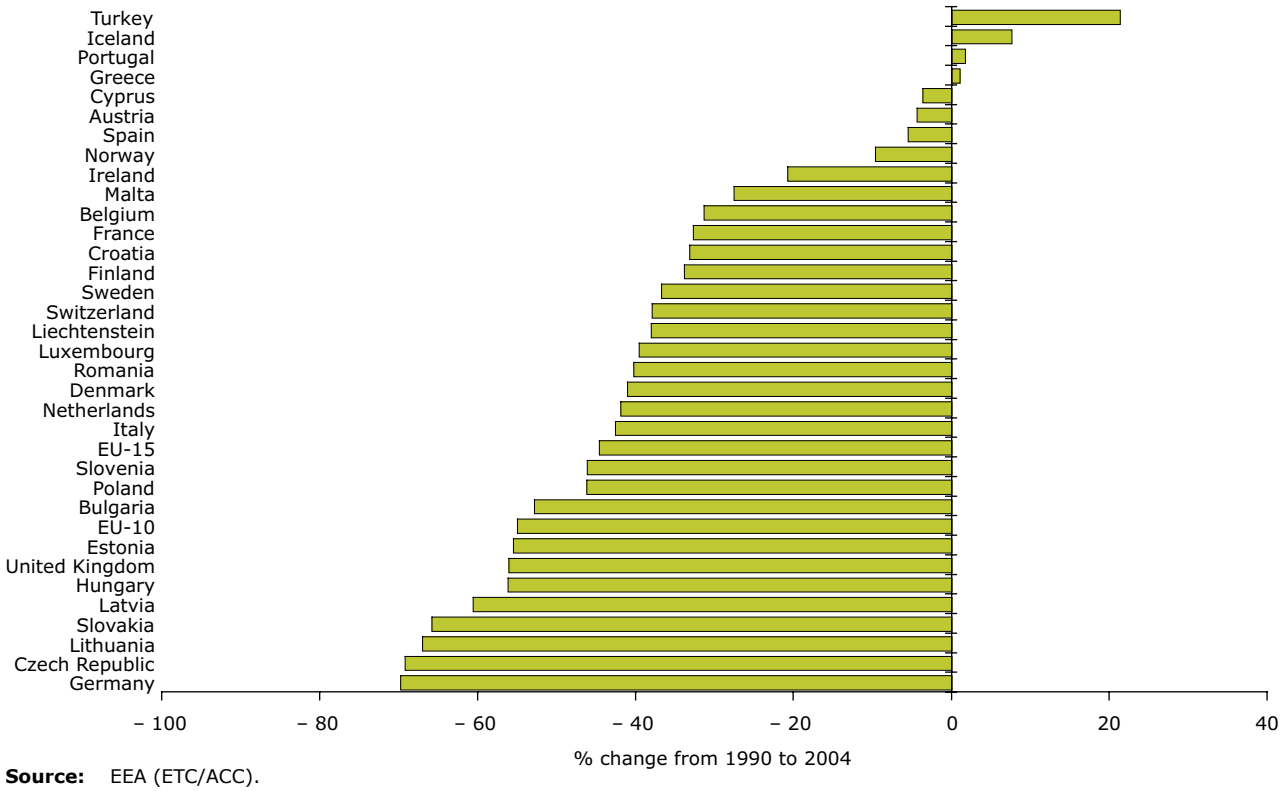
Primary PM_{10} and secondary PM_{10} precursor emissions (= total PM emissions) in the EEA-32 fell by 44 % from 1990–2004 (Figure 2.2). The reduction rate slowed dramatically between 2000 and 2004, reaching only 2 % between 2003 and 2004. The United Kingdom and Germany reduced emissions by more than 50 %. Reductions in eight other EU-15 Member States exceeded more than 30 %. Good progress has also been made by the EU-10, with four countries (Lithuania, Czech Republic, Latvia and Slovakia) having reduced emissions by more than 60 % (Figure 2.3).

Figure 2.2 EEA-32 primary and secondary particulate emissions, 1990–2004



Source: EEA (ETC/ACC).

Figure 2.3 Changes (%) in primary and secondary PM emissions from 1990 to 2004



Source: EEA (ETC/ACC).

2.2.2 *Sectoral emissions, and their contributions to total reductions*

The most important sources of PM emissions in 2004 were the energy industry (27 %) and road transport (22 %) sectors. The most important emitted pollutants were NO_X (50 %) and SO_2 (24 %).

Overall, reductions in energy-related particulate emissions since 1990 were achieved mainly through a combination of the use of lower sulphur content fuels, fuel switching from coal and oil to natural gas, deployment of abatement technologies in energy supply (– 59 %) and industry sectors (– 52 %), and increased market penetration of catalytic converters on road transport vehicles (– 6 %). Emissions of primary PM_{10} and secondary PM_{10} precursors are expected to decrease in the future with further improved vehicle engine technologies, vehicle particle filters, abatement of stationary fuel combustion emissions, and the further use of low sulphur fuels.

2.3 Ozone precursors

Key messages

- Emissions of ozone precursor gases were reduced by 36 % across the EEA-32 between 1990 and 2004. Emission reductions were mainly due to the introduction of catalytic converters on new cars.
- Nine of the EU-15 Member States have achieved less than linear progress towards 2010 NECD targets since 1990. Increased emissions have occurred in Spain and Portugal despite the fact that these two countries were required to reduce overall emissions of the two ozone precursor gases (NMVOC and NO_X) for which emission ceilings were set in the NEC Directive (EC, 2001c).
- Seven EU-10 Member States have already met or surpassed their NO_X and NMVOC emission targets for 2010, Hungary and the Czech Republic are close to the target, and only Slovenia achieved less than linear progress between 1990 and 2004.

2.3.1 *Overall trends in total emissions by region and country*

Total ozone precursor emissions in the EEA-32 were reduced by 36 % from 1990 to 2004. The reduction was 39 % for EU-15, 40 % for EU-10, with a decrease in NO_X and NMVOC emissions of 29 % and 40 %, respectively.

Whilst the EU-15 as a whole nears two-thirds of the distance to its aggregated 2010 NECD target for NMVOCs and NO_X, (and is well on track to meet targets), a few large country-specific emission reductions dominate, e.g. Germany (55 %), United Kingdom (50 %), Netherlands (44 %), Sweden (39 %) and France (39 %). In contrast, some country emissions have increased since 1990, namely in Spain (13 %), Greece (11 %) and Portugal (8 %). Most EU-15 Member States still need to make substantial emission reductions to meet their respective NECD targets.

In contrast, EU-10 Member States have made substantial progress, with seven of ten already having met or exceeded their respective NECD targets. Hungary and the Czech Republic are more than 90 % of the way to their targets, and only Slovenia lies markedly under the line of linear progress. Largest emission reductions have taken place in Lithuania (– 55 %), Slovakia (– 50 %), Estonia (– 47 %), Czech Republic (– 45 %) and Latvia (– 39 %). Malta did not report in 2004.

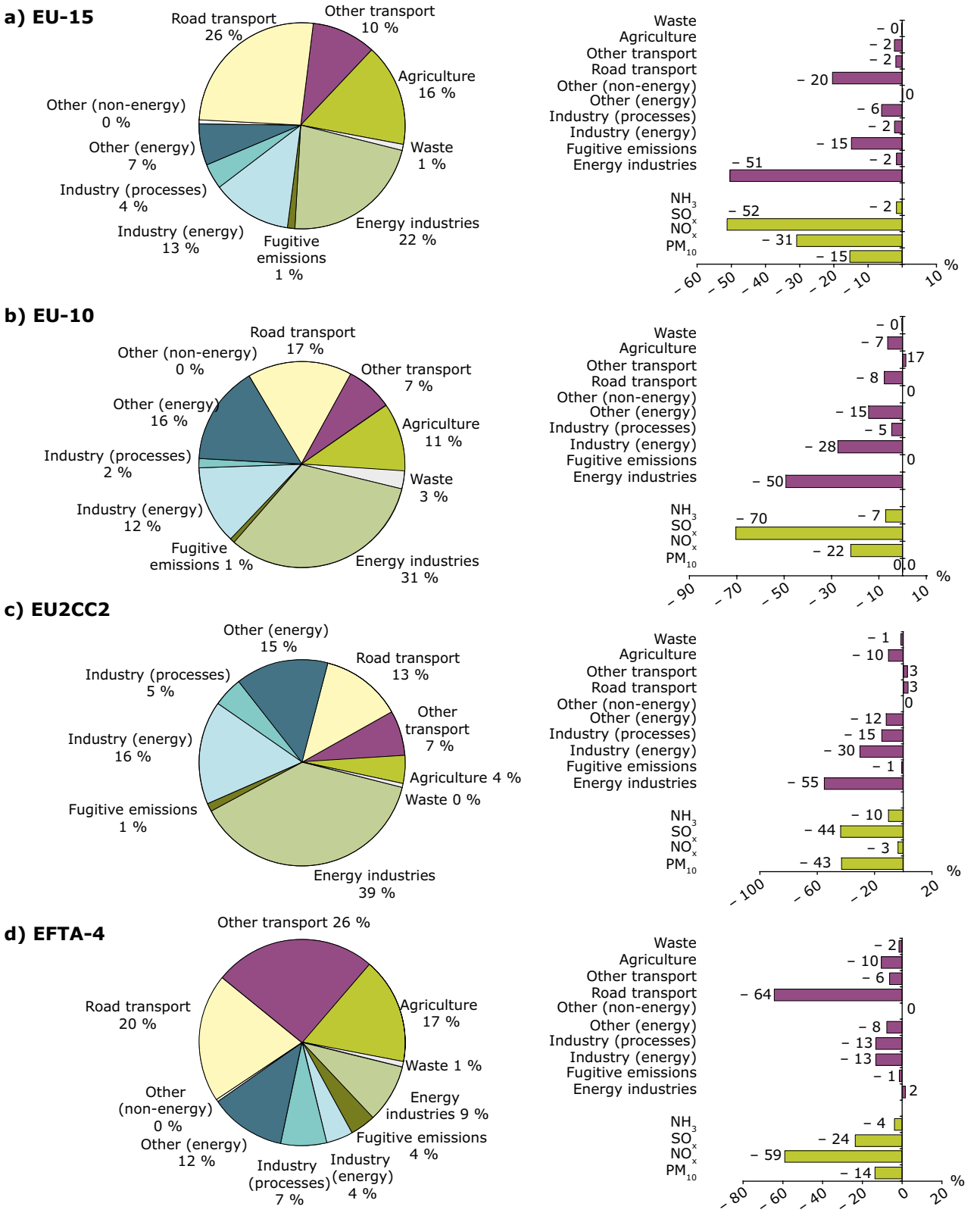
Of EU2CC2 countries, Bulgaria, Croatia and Romania have already met emission targets set in the Gothenburg Protocol. Turkish emissions have increased substantially 1990–2004 (+ 51 %). Turkey is not a signatory to the Gothenburg Protocol and hence has no emission targets set.

2.3.2 *Sectoral emissions and their contributions to total reductions*

Transport was the dominant source of ozone precursors, contributing 44 % of total EEA-32 emissions in 2004. Other important sources included commercial and domestic combustion and use of solvents in paint, glue and printing. Amongst the individual pollutants contributing most in 2004 were nitrogen oxides (51 %), NMVOCs (35 %), CO (13 %) and methane (1 %).

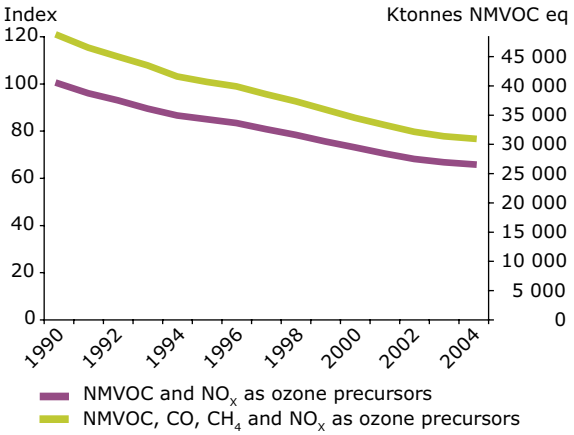
Reductions achieved since 1990 occurred mainly in the road transport sector (49 %) due to further introduction of catalytic converters for cars and increased penetration of diesel, and in the energy industries sector (37 %). Further improvements resulted from implementation of the Solvents Directive in industrial processes. Large reductions have occurred in EU-10 in industrial processes (– 76 %) and energy-related sectors (– 53 to – 68 %).

Figure 2.4 Total particulate emissions by economic sector for EEA country groupings in 2004, and contributions from each sector and pollutant to total change since 1990



Source: EEA (ETC/ACC).

Figure 2.5 EEA-32 emissions of total ozone precursors, and of precursors subject to targets (NMVOC and NO_x), 1990–2004



Source: EEA (ETC/ACC).

2.4 Acidifying and eutrophying pollutants

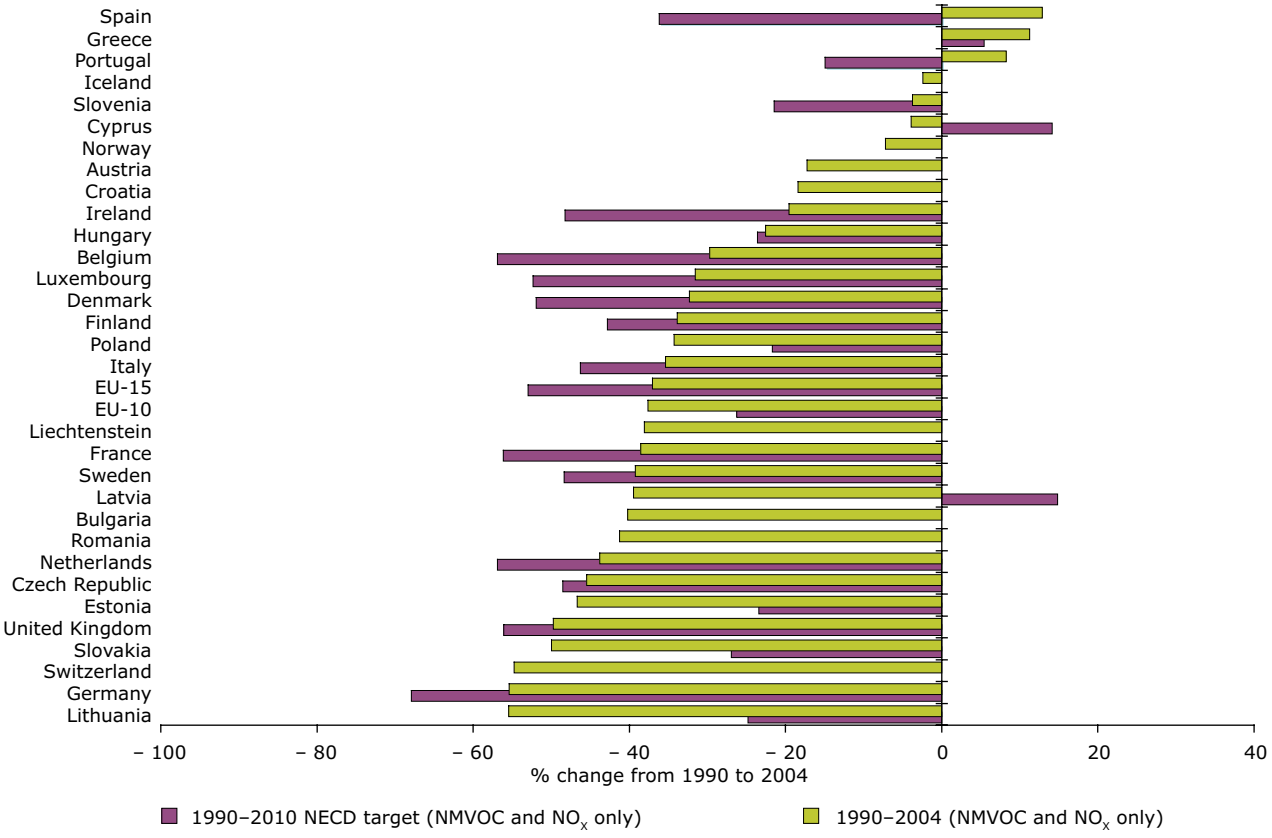
Key messages

- Emissions of acidifying gases have decreased significantly in most EEA-32 countries. Between 1990 and 2004, emissions decreased by 46 % in the EU-15 and by 62 % in the EU-10 despite increased economic activity (GDP) in both regions.
- The EU-15 as a whole has made good progress towards the 2010 targets of the NECD, but still requires additional efforts. EU-10 has made excellent progress, with eight countries already having met their respective targets.

2.4.1 Overall trends in total emissions, by region

EU-15 emissions decreased by 46 % from 1990 to 2004 despite increasing GDP; this decrease slowed to 2.1 % between 2003 and 2004. The

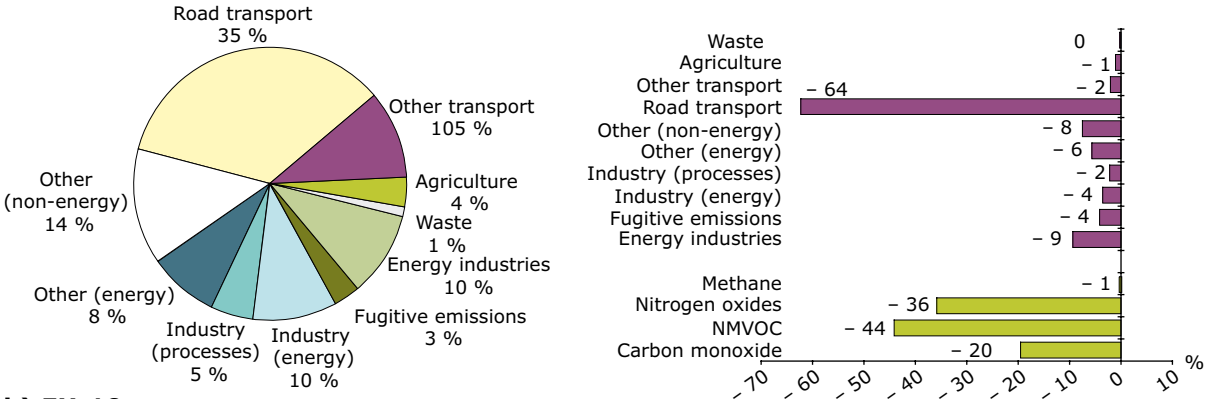
Figure 2.6 EEA-32 National emission reductions for ozone precursors (green), and remaining distance to reduction targets for EU Member States (purple)



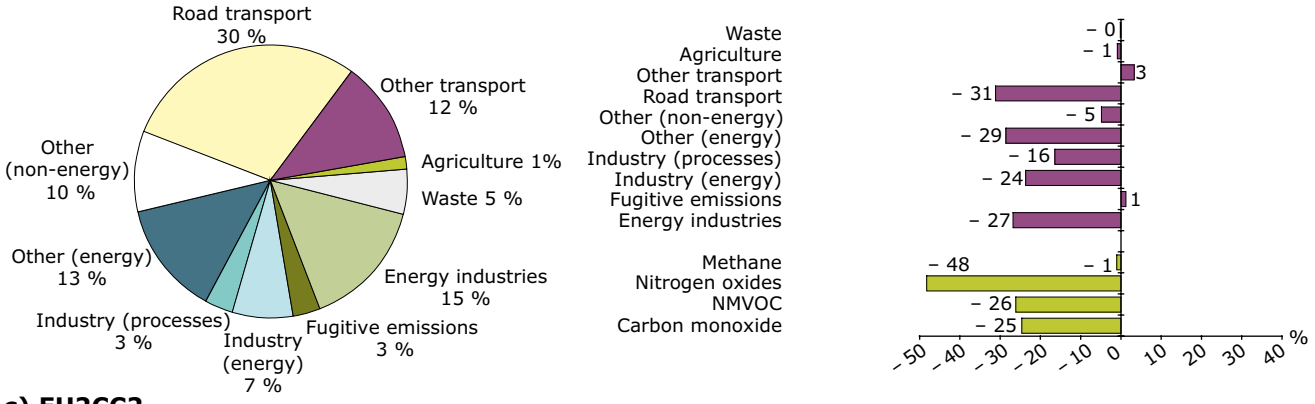
Source: EEA (ETC/ACC).

Figure 2.7 Total TOFP emissions by economic sector for EEA country groupings, 2004, and contributions of each sector and pollutant to total change 1990–2004

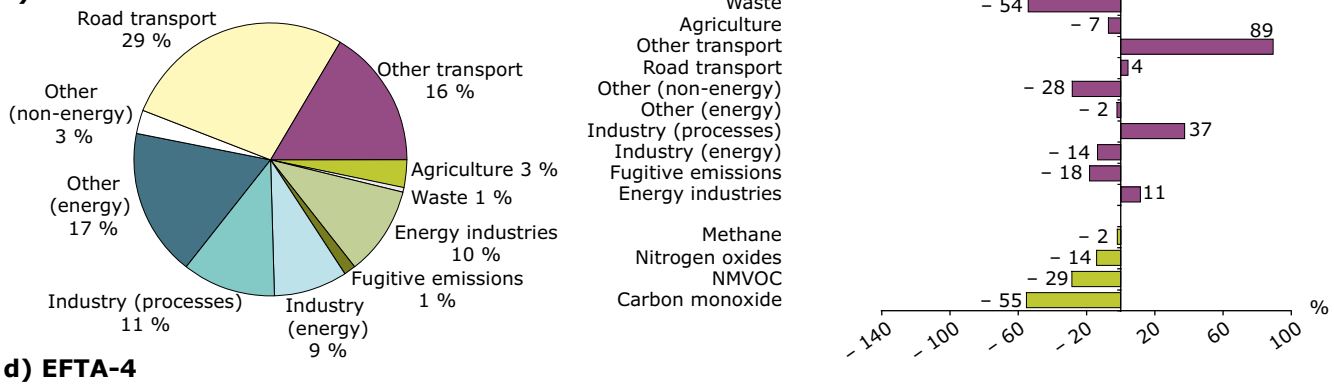
a) EU-15



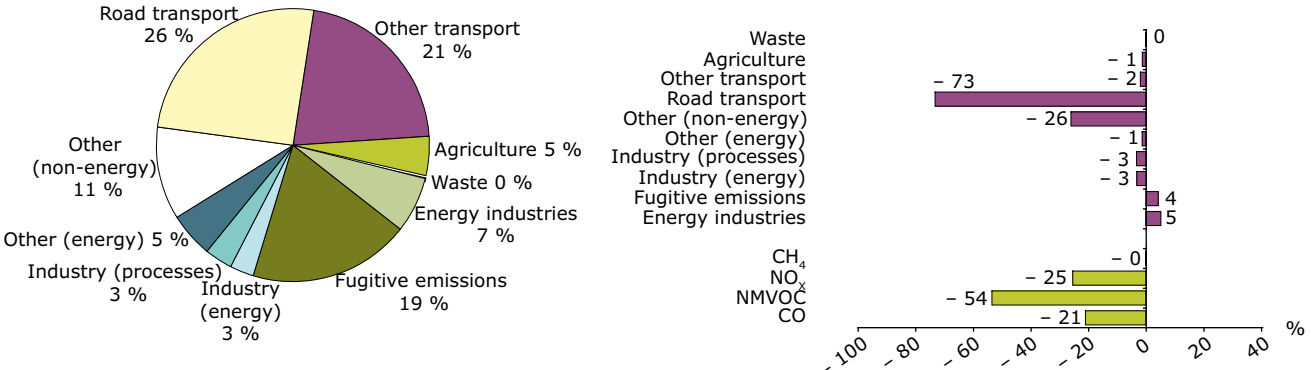
b) EU-10



c) EU2CC2

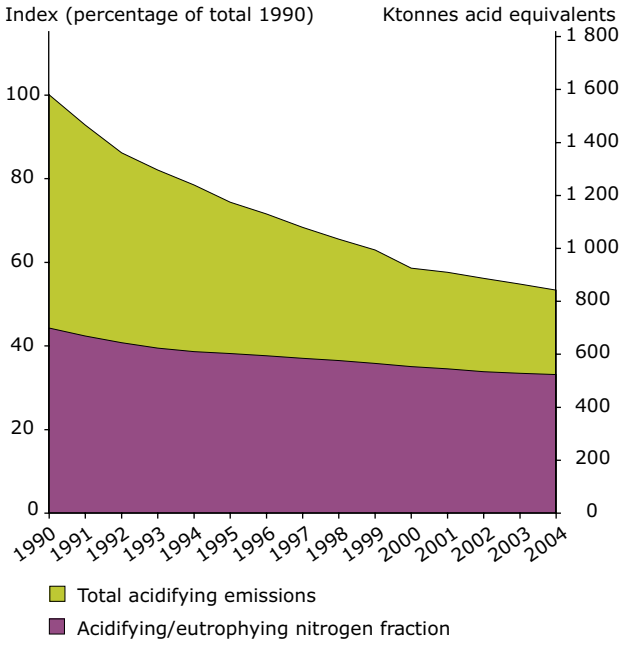


d) EFTA-4



Source: EEA (ETC/ACC).

Figure 2.8 Total emissions of acidifying substances (sulphur, nitrogen) and of eutrophying nitrogen in the EEA-32 for 1990 to 2004

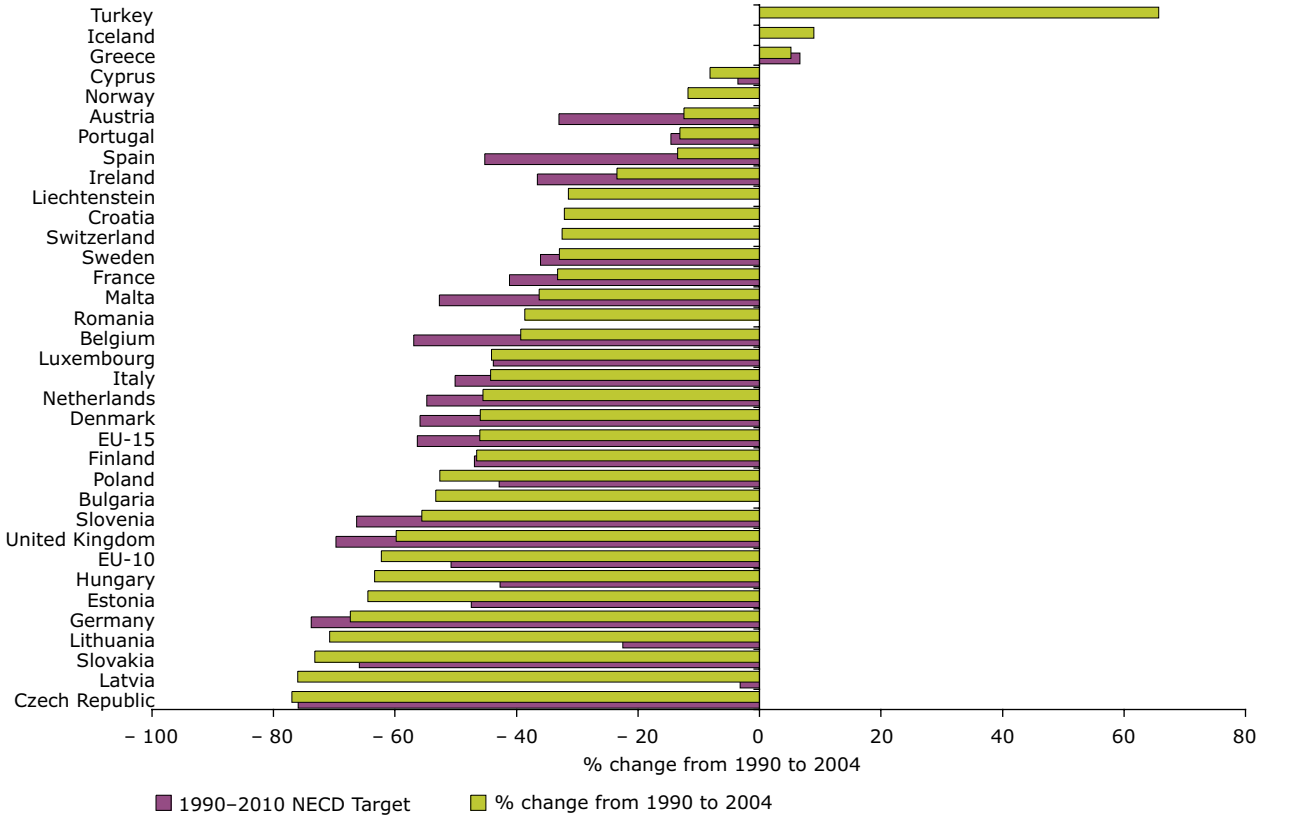


Source: EEA (ETC/ACC).

substantial decrease in total acidifying emissions has been mainly due to the switch from high sulphur solid and liquid fuels to natural gas, economic restructuring of the new *Länder* (counties) in Germany, and the introduction of flue gas desulphurisation at many industrial plants and power stations. The result has been a 70 % reduction in emissions of sulphur dioxide since 1990. Conversely, abatement of nitrogen oxides emissions has to some extent been offset by increased road traffic. Ammonia emissions are stabilising, although agricultural emissions (the major emissions source) are difficult to control and emission estimates themselves are subject to high uncertainty. Nitrogen is now the principal component in total EEA-32 acidifying emissions, with total eutrophying emissions having seen a lesser decline.

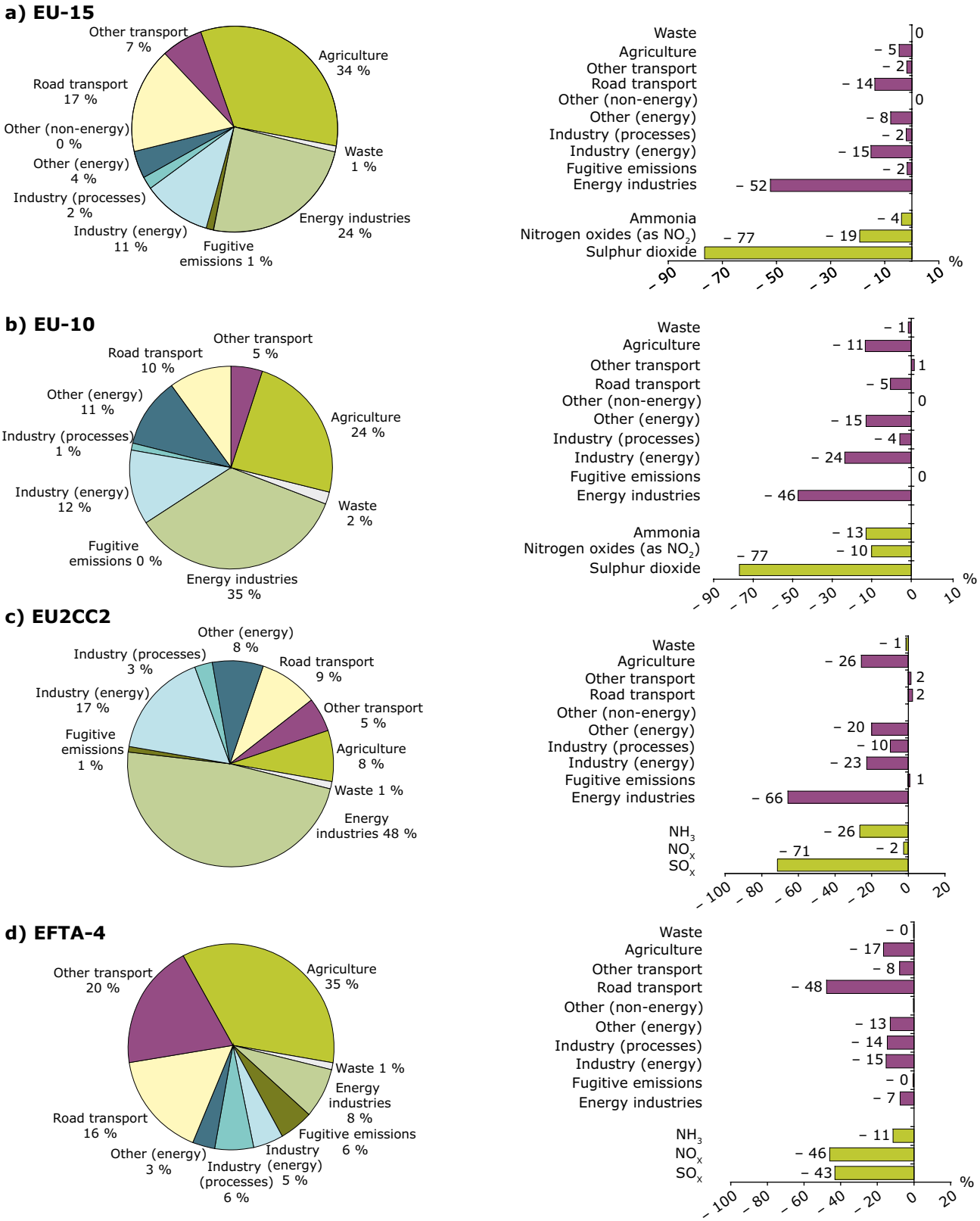
Acidifying emissions also decreased significantly in EU-10 by 62 % over the whole period 1990–2004 and by 24 % in EU2CC2 countries, despite an increase in GDP. The emissions decrease from 2003 to 2004 was 7 % for the EU-10. Despite the fact that substantial SO_2 emission reductions (72 %) led to significant decreases in total

Figure 2.9 EEA-32 national emission reductions for acidifying pollutants (green) and remaining distance to emission reduction targets for EU Member States (purple)



Source: EEA (ETC/ACC).

Figure 2.10 Total acidifying emissions by economic sector for EEA country groupings, 2004, and contributions from each sector and pollutant to total change 1990–2004



Source: EEA (ETC/ACC).

acidifying emissions, sulphur dioxide remained the principal contributor to total acidifying gas discharge (48 %); being twice as significant as NO_X (27 %) and NH_3 emissions (25 %). A switch from high sulphur solid and liquid fuels to natural gas, economic restructuring, and the introduction of flue gas desulphurisation were also key factors behind changes in the EU-10. Nitrogen oxides emissions were reduced due to both lower energy consumption and abatement.

2.4.2 Sectoral emissions and their contributions to total reductions

By 2004 the most significant sources of acidifying emissions in the EU-15 were agriculture (34 %, up from 20 % in 1990), energy industries (24 %), road transport (17 %) and energy use in industry (10 %). The largest decreases were in the energy industries sector (– 65 %). By pollutant, in 2004 NO_X contributed 37 %, NH_3 35 %, and SO_2 28 % to total acidifying emissions.

Similarly, in the EU-10 the largest reductions were seen in the energy industries (68 %), in energy production within industry (77 %), in industry (Processes) (85 %) and in agriculture (44 %). By 2004 the most significant source was still energy industries (36 %) followed by agriculture (24 %), transport (15 %) and industrial energy use (12 %).

Additional effort is required to meet emission reduction targets by 2010 in the EU-15. Large emission reductions have occurred in some countries, e.g. Germany and the United Kingdom contributing 39 % and 26 % respectively to total EU-15 reductions. Finland, Denmark, Luxembourg, Italy and the Netherlands have also achieved more than a 40 % emission reduction, but five countries (Spain, Portugal, Ireland, Greece and Belgium) remain above a linear path reduction for 1990–2010. Greece is the only Member State to have increased emissions (+ 5 %), although this increase still lies within the agreed NEC Directive target of 7 %. All EU-10 Member States have already met their respective targets with the exception of Slovenia and Malta.

3 Health-related air pollution assessment

Key messages

- Overall exposure of Europe's population to pollutants with a health impact has not improved since the late 1990s. However, there have been some pollutant-specific exceptions. Indeed, as a consequence in part of adverse meteorological conditions, some recent years have seen worse exposure than before the late 1990s, despite the reported precursor gas emission decrease.
- Whilst exposure to high levels of NO_2 has steadily decreased, up to 30 % of Europe's urban population may still be exposed to concentrations in excess of limit values. Thus, determined effort is still required if ambient air concentration and exposure targets.
- Emissions of particulates and precursors are reported to have declined. In 2003, adverse meteorological conditions produced such abnormally high concentrations that most urban areas exceeded limit values. Despite the reductions in emissions, a quarter of urban areas remain in exceedance.
- The situation for **NO_2** is improving, although approximately 25 % of the urban population lives in areas with concentrations above the limit value.
- For **ozone** there was considerable variation between years. Usually, a maximum of 25 % of the urban population was exposed to concentrations above limit values; in 2003 — a year with extremely high ozone concentrations — this fraction increased to approximately 60 %.
- For **PM_{10}** the urban population potentially exposed to ambient air concentrations in excess of the EU limit value (50 μg/m³ daily mean to be exceeded a maximum 35 days p.a.) varied between 23 % and 45 % between 1997 and 2004. There was no discernible trend over the period.

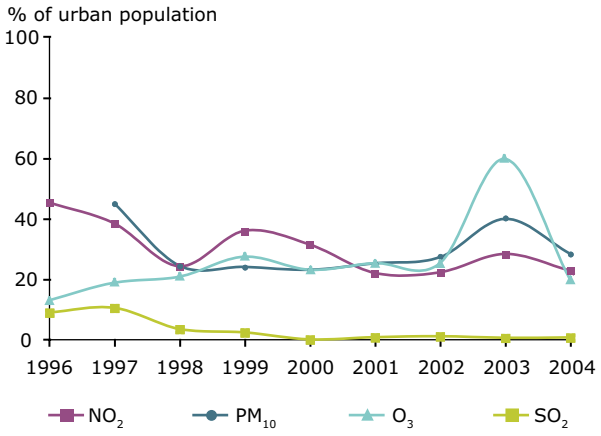
3.1 Overview

Across Europe, population exposure to air pollution exceeds standards set by the EU and by the World Health Organization (WHO). Urban/suburban areas are predominantly impacted upon, although for PM_{10} and ozone this also takes place in rural areas. Long-term exposure to air pollution — especially to particulate matter — increases mortality, risk of chronic respiratory illness and the risk of developing cancer.

Urban exposure to SO_2, NO_2, O_3 and PM_{10} in 1996–2004 can be summarised as follows (Figure 3.1):

The assessment in subsequent sections is based to a large extent on the air pollutant concentration data reported by EEA member countries and contained in AirBase. These observations are heavily dependent upon monitoring station location relative to sources. Moreover, they are classified as rural, suburban,

Figure 3.1 Percentage of the urban population potentially exposed to pollutant concentrations over selected limit/target values



Source: EEA (ETC/ACC).

Box 3.1 Classification and availability of air quality monitoring data

The classification of measurement stations may be grouped into 'rural background', 'urban background' or 'hot spot' to indicate their spatial representativity. These classifications may be interpreted as follows:

- *Rural background* stations — The measured concentration of air pollutants here is mainly influenced by long distance transport of air pollutants and from emissions in the region in which the station is located. The distance to large pollutant sources (e.g. cities, power plants, major motorways) is so great (at least 10 km) that the pollution plume is massively dispersed. Consequently, the plume cannot be distinguished from background pollution. Typical geographical representativity for these stations is more than ten kilometres.
- *Urban background* stations — They are not directly influenced by specific local urban sources, but are placed so that they provide a general picture of ambient air pollutant concentrations arising in urban populated and industrialized areas. Typical spatial scales are those of urban areas and will be in the order of a few kilometres.
- *'Hot spot'* stations are placed in the proximity of major emission sources such as main roads or industries. A typical geographical scale for this type of stations is 10 metres for traffic hot spots and less than a kilometre for industrial hot spots. In this report traffic hot spot stations have been labelled as 'street' or 'traffic' stations.

urban, and hot spot stations; the latter being traffic or industrial hot spots (see Box 3.1 for a description) in accordance with the Exchange of Information Decision (EoI, 1997) on exchange of air pollution data between countries.

3.2 Ground level ozone

Key messages

- Ozone concentrations were exceptionally high during 2003, with meteorological conditions that year being largely to blame. Although concentrations were 'back to normal' during 2004, approximately 20 % of Europe's population across large parts of the continent was exposed to concentrations above the target value. Both rural and urban locations were affected.
- Current estimates of premature deaths due to ozone exposure are placed at approximately 21 400 premature deaths annually. Current air pollution control legislation would bring only small improvements by 2030.

3.2.1 Health impact of ground level ozone

Short-term studies show that O_3 has adverse health effects on pulmonary function, lung inflammation, lung permeability, respiratory symptoms, increased medication usage, morbidity and mortality.

Long-term effects are less clear; the spatial and seasonal patterns of health effects being less extensively studied than for other pollutants. The margins between background O_3 concentrations in remote areas and levels which are considered potentially harmful to human health and ecosystems are slight; in fact they are smaller than for any other pollutant discussed in this report.

WHO recommends a daily maximum 8-hour mean concentration as the principal benchmark for assessing impact on mortality, with assessment over a full year (WHO, 2006). Current evidence is insufficient to derive a level for this 8-hour mean below which ozone has no effect on mortality, although current practice adds up the sum of the excess of daily maximum 8-h mean concentrations over a cut-off point of 70 $\mu g/m^3$ (35 ppb) for every day in a year. This parameter, the SOMO35 (sum of means over 35 ppb), is a measure of accumulated high exposure.

The ultimate measure is impact upon mortality, and the average estimate for premature deaths in year 2000 due to elevated ozone was approximately 21 400 premature deaths in 2000 (CAFE Steering Group, 2005) . Possible positive effects of further reductions in European precursor emissions are being obscured to a certain degree by an ageing European population who are at greater risk to ozone exposure. Concomitantly, there is an increasing death rate.

3.2.2 *Ozone concentrations in Europe, 2004*

Ozone concentrations in 2004 were reported by 1886 stations across 32 countries. Station density was thinner across much of eastern and southern Europe. Whilst parts of northern Europe also have low monitoring density, ozone concentrations are generally lower and threshold/target values less frequently exceeded.

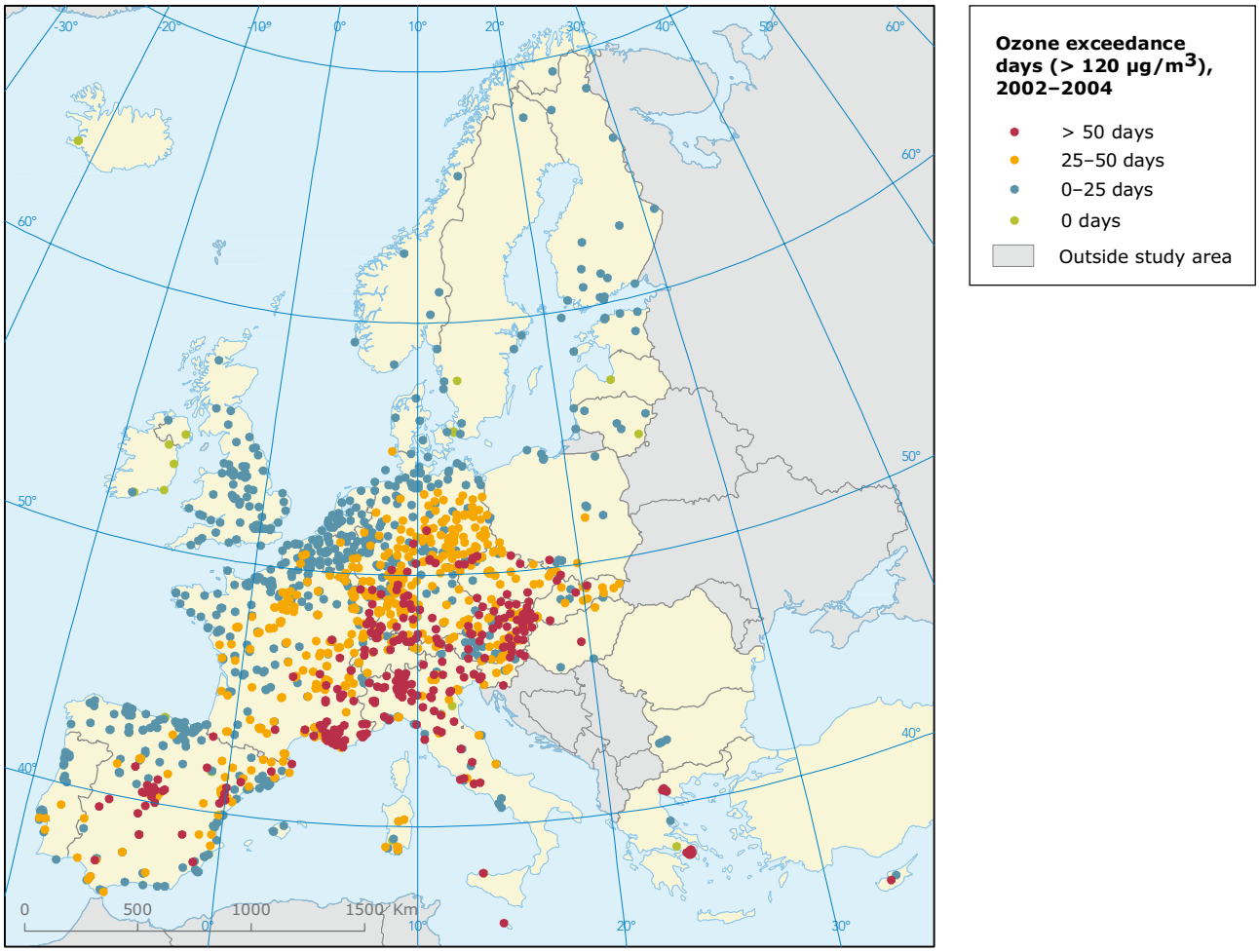
Concentrations in 2004 were lower than the extraordinarily high values seen in 2003 when concentrations across most of Europe exceeded permitted levels. Nevertheless, when, in accordance with the ozone directive, concentrations were averaged over a 3-year period, the target value was not met in continental Europe (see Figure 3.2).

Peak concentrations during summer smog frequently exceed 140 µg/m^3, reaching 200 µg/m^3. The limit value is 120 µg/m^3 (8-hourly mean). Ozone is a regional scale pollutant, so that high concentrations occur across large areas. However, rural concentrations have generally been higher than urban/suburban, with the lowest values observed in trafficked sites. This is related to the reaction of O_3 with local NO emissions, leading to NO_2 formation and thus elevated NO_2 concentrations in the air. Figure 3.3 shows a clear example of an urban and a rural station in the United Kingdom in 2003.

3.2.3 *Changes 1996–2004 and remaining distance-to-target*

Between 1996 and 2004 there was a year-on-year increase in daily 8-hour maximum concentrations at most stations, shown in Figure 3.4. An upward trend was observed at 371 of the 629 stations, whilst a downward trend was found at only 29. Sub/urban

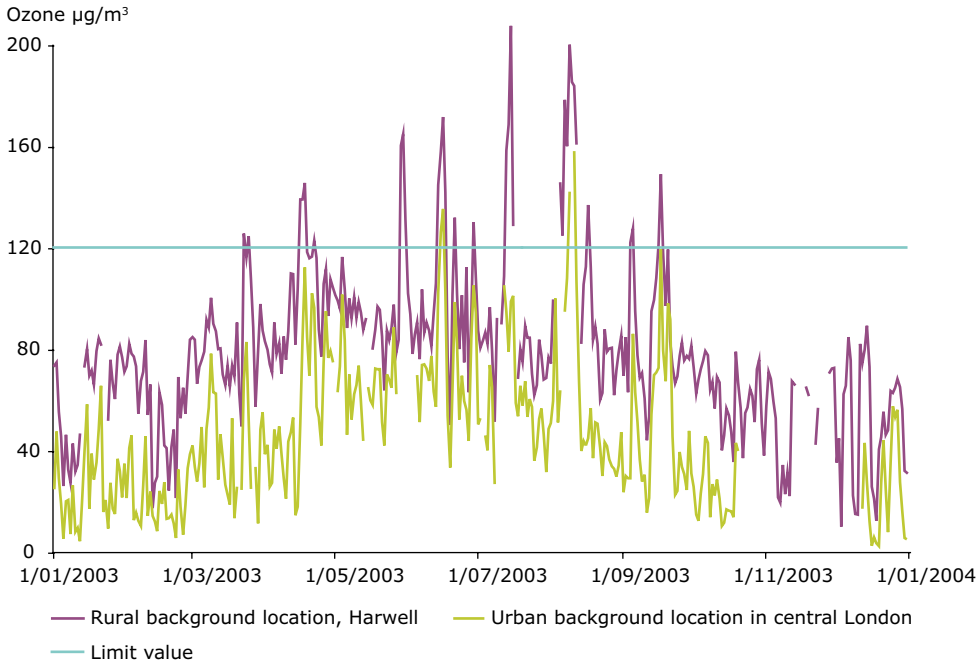
Figure 3.2 Days exceeding the target value as 3-year average 2002–2004



Note: In 2004 urban/suburban background areas provided 44 % of stations, rural background areas 24 %, traffic sites 18 %, industrial 9 %, and 5 % not properly classified.

Source: EEA (ETC/ACC).

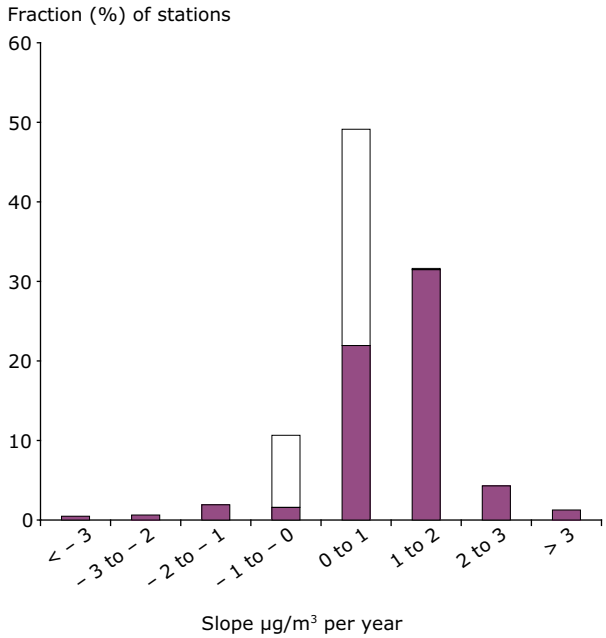
Figure 3.3 Daily maximum 8-hourly mean ozone concentrations at an urban background location in central London and a rural background location, 2003



Note: Urban background location in central London = Bloomsbury (blue line). Separation distance is about 80 km.

Source: EEA (ETC/ACC).

Figure 3.4 Frequency distribution of trends in 8h-daily maximum values, 1996–2004



Note: 629 stations with 75 % data coverage p.a. Closed bars are stations with significant trends, open bars are stations with non-significant trend.

Source: EEA (ETC/ACC).

background and traffic stations showed the greatest upward trends, 40–45 % of which had an annual increase of > 1 µg/m³.

When concentrations at stations are converted to estimated population exposure, not only do large regions fail to meet environmental objectives but a notable fraction of the urban population, typically around 25 %, is exposed to elevated ozone (Figure 3.5). Extreme conditions in 2003 pushed this to approximately 60 %. In Figure 3.5, this appears as a gentle increase in occurrence of high concentrations. Nevertheless, the picture remains unclear. Changes in the SOMO35, often used as a guide to accumulated exposure to elevated ozone, are slight.

The extent of compliance with the ozone target value of no more than 25 days with maximum 8-hour average concentrations above 120 µg/m³ during 2004 is displayed in Figure 3.6. For each station type — rural, sub/urban background and traffic hotspot stations — the figure shows:

- average concentrations at all stations of each type on the 26th highest day;
- the average concentrations only at stations exceeding the target value; and

- the stations with the maximum observed concentrations.

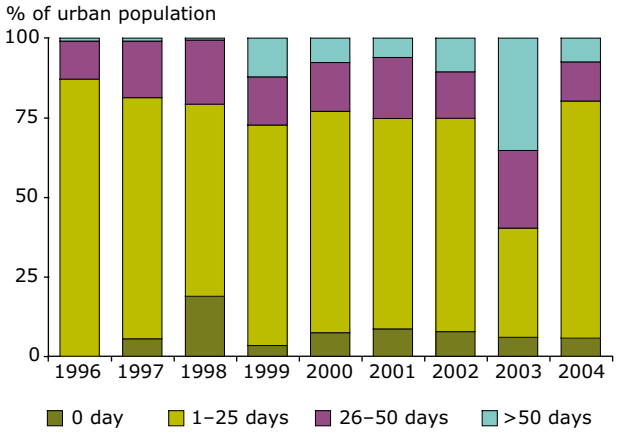
Whilst overall average concentrations did not actually exceed the target value at any station type, average concentrations across all rural locations were virtually equal to the target value. There are also a large number of locations which still have some distance to cover before complying with the target value. Exceedances were observed at 39 % of rural, 26 % of sub/urban background, and 10 % of traffic stations. Maximum observed concentrations approached 50 % over target value.

3.2.4 Differences between locations

At sub-national level, elevated rural concentrations compared to adjacent urban locations have been observed (Section 3.2.2). Meanwhile, trafficked stations see the lowest concentrations. The difference between location types is clearly visible for levels of exposure relevant to health impact. Figure 3.7 displays the average rates of exposure in traffic, urban background and rural sites since 1996. Very little change is observable.

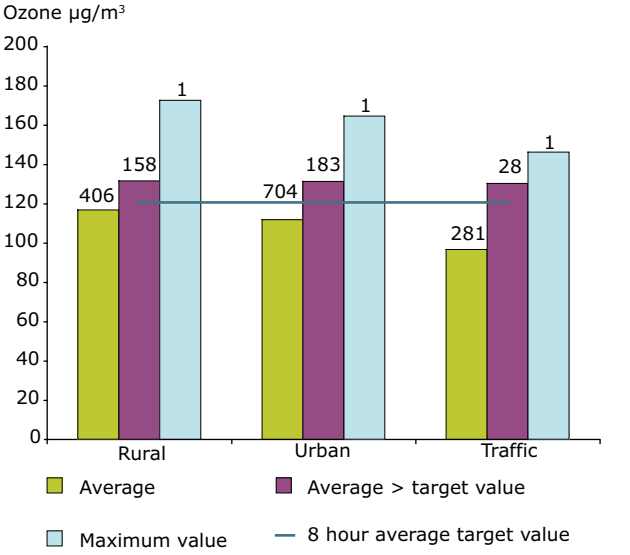
In heavily populated areas, freshly emitted NO_X (predominantly as NO) will rapidly react with O_3 to form NO_2 during the night when photochemical activity is low. During the day it is mainly the interaction between the hydroxyl radical (·OH) and NO_2 which reduces the production of ozone.

Figure 3.5 Exposure of urban population in EEA-32 countries to maximum ozone concentration above the 8h-daily mean target value of 120 µg/m³



Source: EEA (ETC/ACC).

Figure 3.6 Ozone distance to target, 2004



Note: 26th highest 8-hour daily maximum concentrations (µg/m³) at all stations, at stations exceeding the target value (indicated by the thick line), and the maximum concentrations (Directive permits 25 exceedances per year).

Source: EEA (ETC/ACC).

Under high NO_2 concentrations and low VOC/NO_X ratios, the (·OH) radical in the atmosphere, may become depleted which also inhibits ozone formation. At this point any decrease in NO_X through emission abatement may ease the availability of the hydroxyl radical and actually increase ozone. A VOC-limited regime is said to exist, in which control of organic compound emissions is more efficient in reducing ozone than NO_X control.

Conversely, in an ageing air mass, as in background areas, NO_X concentrations decrease faster than those of VOC, and VOC/NO_X ratios increase. As NO_X concentrations become low, hydroxyl radical regeneration becomes extremely inefficient and ozone formation is again inhibited. Availability of NO_X now limits ozone creation (NO_X-limitation), so that reducing NO_X emissions is considered more effective at bringing ozone levels down than reducing organic compound emissions.

Moreover, in years like 2003 summer meteorological conditions (e.g. number, length and intensity of high-pressure periods) have significantly increased ambient concentrations.

On a European scale, most stations in north-western and central-eastern Europe showed up to a 2 µg/m³ increase of the 8h-daily maximum values per

year, whilst stations in southern Europe were very diverse, ranging from major negative to insignificant to major positive trends. The complexity of ozone chemistry confounds simple explanation, with ozone increasing despite the fact that emissions of the precursors (mainly NMVOC and NO_X) have been falling steadily by 36 % since 1990. Pollutant balance in the atmosphere involved in the breakdown of ozone is critical, and is further discussed in the context of policy actions in Section 3.2.5.

In summary, a number of processes determined the geographical and inter-annual variations in ozone concentrations observed:

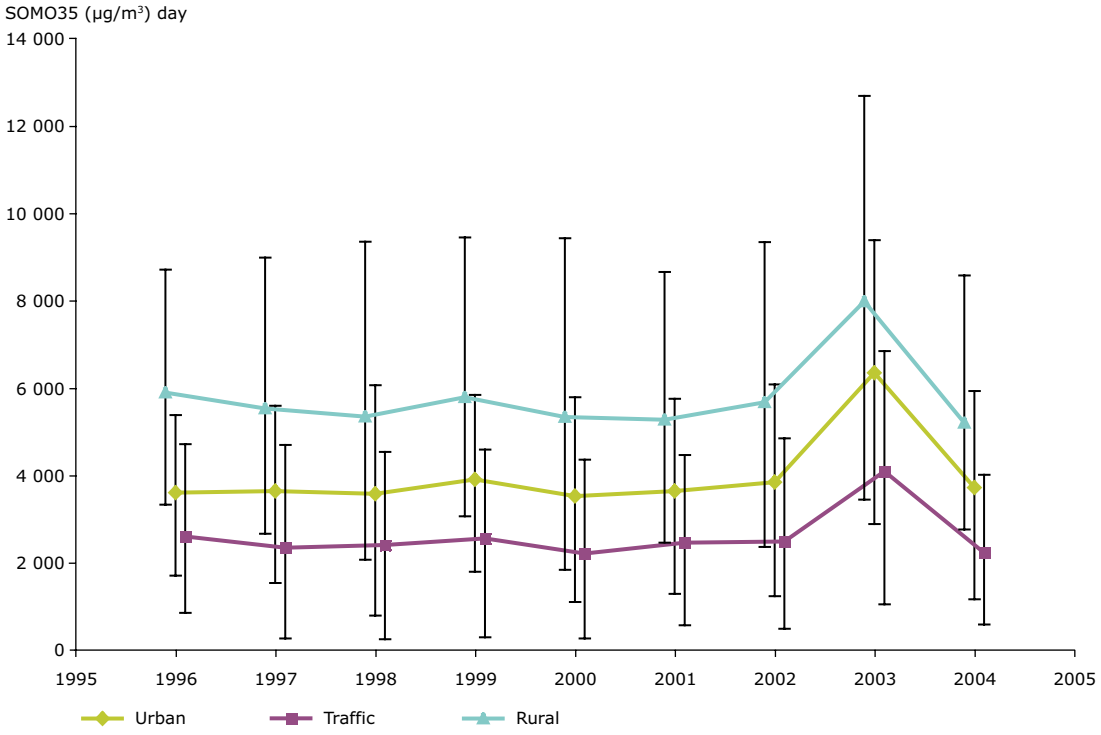
1) Long-range generation of ozone from precursor emissions across the northern hemisphere during transport over several hundred to thousands of kilometres.
2) Local generation of O_3 downwind of precursor emission sources in sunny weather.
3) Local destruction of O_3 by NO_X where emissions are high, i.e. in urban areas; if less NO_X is emitted less urban ozone will be destroyed and concentrations may rise. In remote areas without significant traffic emissions, this effect does not occur.
4) Deposition of O_3 to the surface. Under dry conditions plant stomata close (Note: Stomata are tiny openings in plant leaves whose function is to primarily assimilate CO_2). However, pollutant gases such as ozone can also diffuse through those openings. Dry conditions reduce O_3 deposition to vegetation. Low summer precipitation may thus increase ozone concentrations in the air.

3.2.5 Policy effectiveness

Road traffic is a major emission source of ozone forming precursors within the EU. Between 1990 and 2003 total ozone forming precursor (TOFP) emissions from traffic decreased by 53 % from 17 million to 8 million tonnes within EU-15 (Note: transport statistics are available only for the EU-15). The following points can be made:

- In the absence of other changes, population increase would have meant a rise in emissions of 1 million tonnes.
- Traffic intensity increasing more rapidly than population would have meant an additional emissions increase of 5 million

Figure 3.7 Ozone inter-annual variations, SOMO35, 1996–2004



Note: Urban, traffic, and rural background stations vertical bars represent 10th and 90th percentiles.

Source: EEA (ETC/ACC).

tonnes (approximately 2 million tonnes from passenger transport, over 3 million tonnes from freight transport).
- Improved energy efficiency in the road transport system led to a reduction of approximately 2 million tonnes.
- The introduction of catalytic converters in passenger cars reduced emissions by approximately 13 million tonnes; broken down as follows:
  - 5 million tonnes from NMVOC emission reduction;
  - 5 million tonnes from NO_X emission reduction;
  - 3 million tonnes from CO emission reduction.

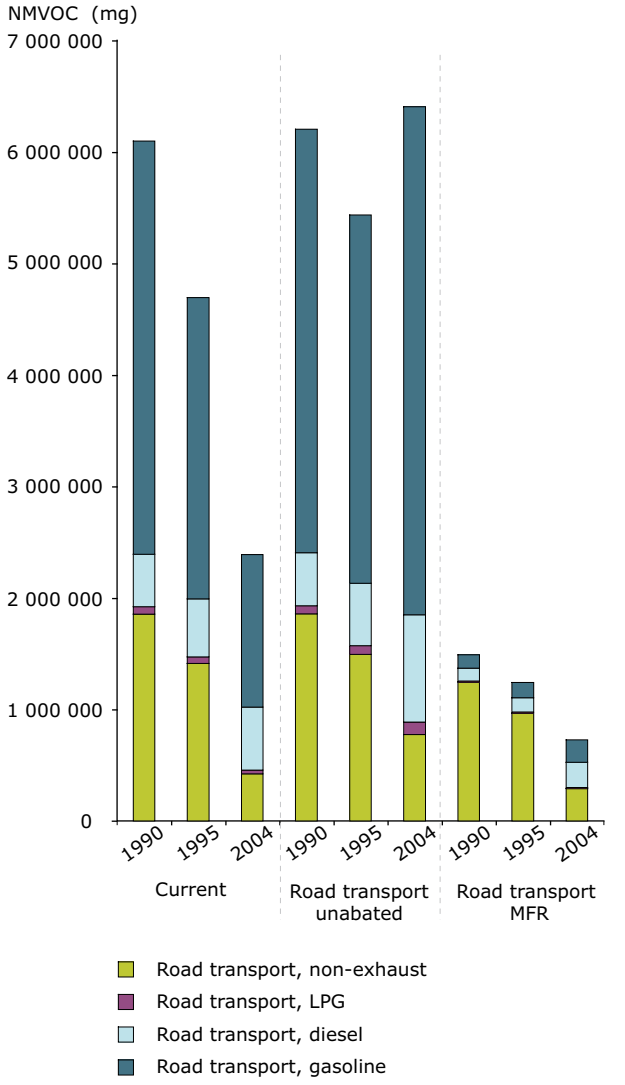
Figure 3.8 explores the contributions of different fuel categories of vehicular traffic to changes in NMVOC emissions. Reference is also made to the equivalent figure for NO_X emissions, which is shown in Section 3.4.5 in a specific analysis of NO_X reduction policy, as other emission sources are relevant to ozone production. Three alternative emission scenarios are compared: the current emission status, a scenario with road vehicle emissions unabated, and a scenario which assumes that maximum feasible emission reductions (MFR) are applied (see Table 3.1).

The following trends can be observed:

- Without traffic emission abatement ('Road transport unabated'), road transport emissions would have increased slightly compared to 1990 levels to approximately 6.5 Mt in 2004.
- Measures for petrol vehicles have contributed the most to emission reductions.
- A little under half of the feasible ozone precursor emission reductions for road transport have been achieved.
- Implementation of the LCP Directive (EC, 2001a) (see Figure 3.9) also currently realises about one half of the feasible emission reductions, but has less effect on ozone precursors.
- The effects of NMVOC and of NO_X emissions are similar (see Figure 3.9).

Regional computer modelling allows the geographical effect of abatement measures for road transport and for combustion plants to be explored. The effects are complex. In Figure 3.9 improvements are positive numbers displayed as yellow-red and higher ozone concentrations are negative numbers displayed as blue-purple. In the

Figure 3.8 The effect (for EU-25) of introducing vehicle emission standards in road transport on the emission of NMVOC



Source: EEA (ETC/ACC).

Mediterranean area the introduction of these policy measures has decreased ozone concentrations, whereas across a broad geographical band from the United Kingdom to southern Poland higher ozone concentrations have occurred. The same situation has been witnessed in highly populated areas surrounding larger cities. Thus, changes in ambient ozone concentrations have not entirely mirrored substantial reductions in emissions of precursors.

3.2.6 Projections of future ozone concentrations

Scenarios for future emissions developed under the CAFE programme include (as a baseline

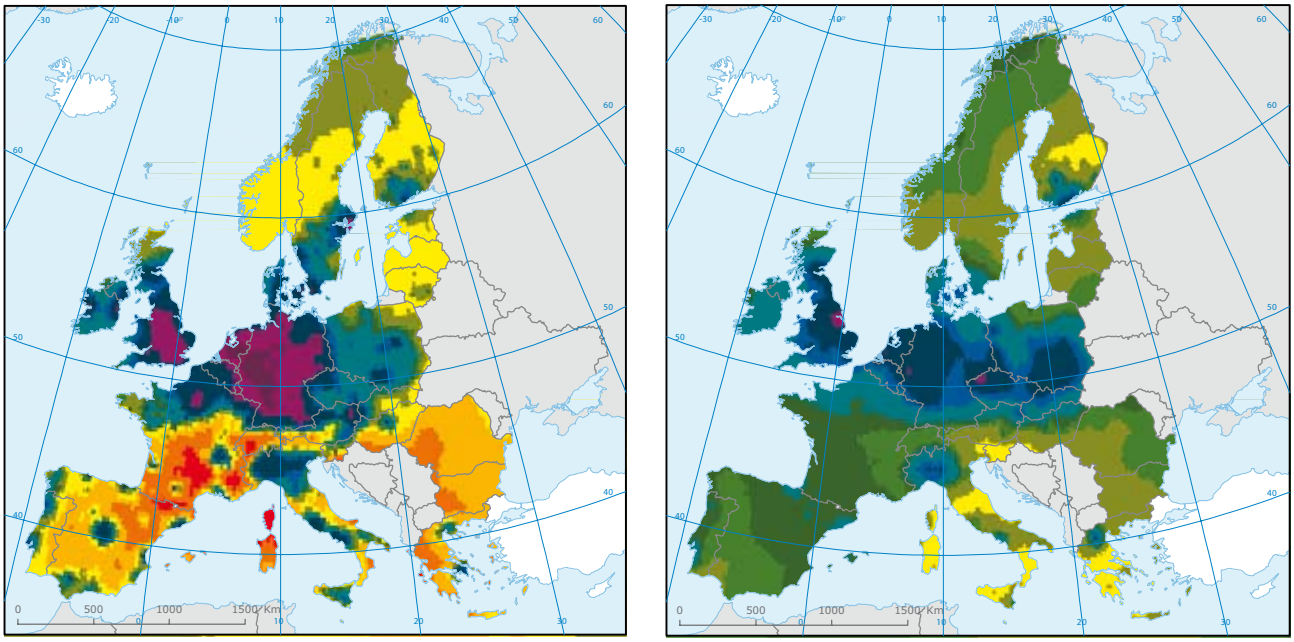
Table 3.1 Definition of policy analysis scenarios

Scenario	Description
Current	Represents the actual emissions in the years 1990, 1995, and 2004.
Road transport MFR *	Current situation for all sectors except Road Transport for which the 'highest' available (EURO IV) standards for 2005 measure emission factors (EFs) have been selected from RAINS online for 2005 (implies lowest available emission factors).
Road transport unabated	Current situation for sectors other than Road Transport, for which unabated emission factors have been used.
LCP MFR *	For the fuel combustion activities in the energy and manufacturing industry (NFR codes 1.A.1 and 1.A.2) the LCP Directive emission factors have been used. This is a best case scenario since not all combustion plants are > 50 MWth. For other activities, the current situation is shown.
LCP unabated	For the activities with NFR codes 1A1a and 1A2, the unabated emission factors for the specific years are used. For other activities the current situation is shown.

* MFR: Maximum Feasible Reduction.

scenario): the combination of legislation regarding large combustion plants, the EURO standards for vehicles and non-road mobile machinery, IPCC legislation, and national legislation and practice. The foreseen reduction in the emission of ozone precursor gases NO_x and VOC 2000–2010 is approximately 30 %. Most significant reductions will take place in the power generation sector (NO_x), in transport (both NO_x and VOC) and in solvent usage (VOC). Figure 3.10 shows modelled SOMO35 concentrations arising from emissions in 2000 and in 2010. To minimise potentially significant inter-annual meteorological variability, the maps display four-year averages. A small

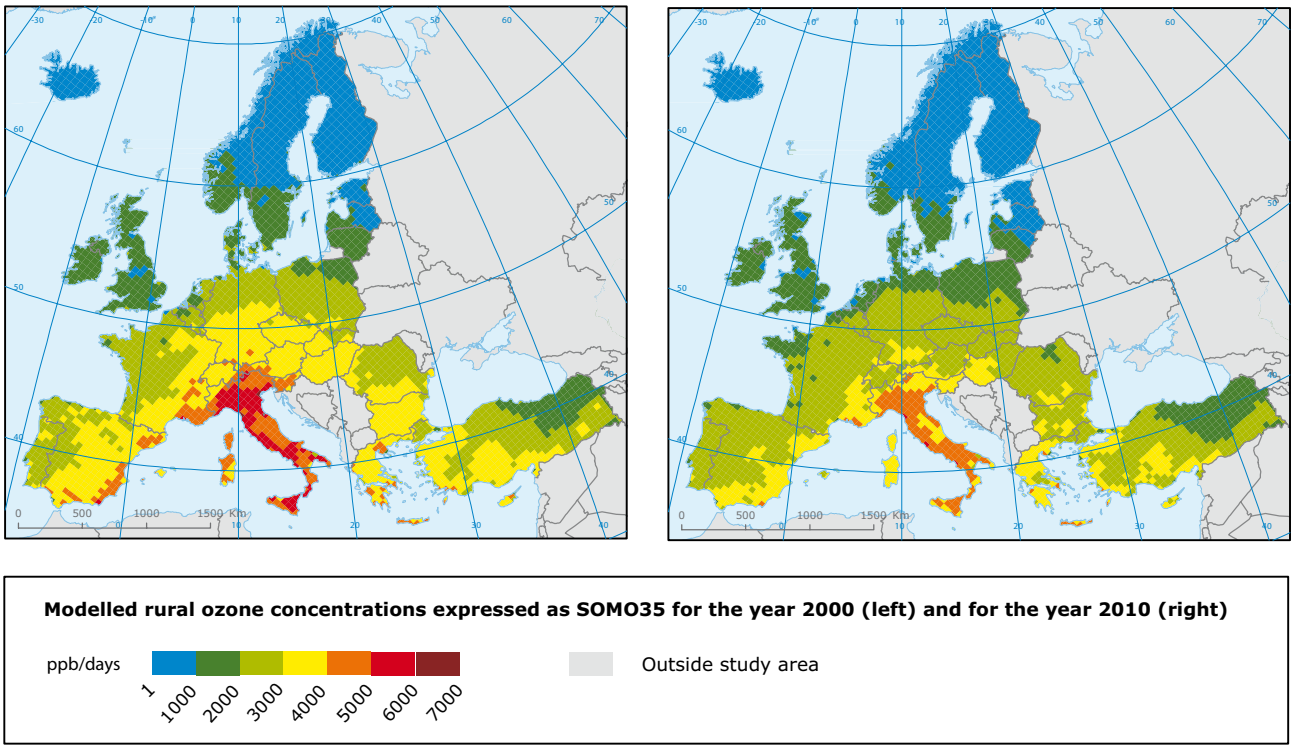
Figure 3.9 Modelled decreases in ozone concentrations in year 2003 due to the introduction of European road vehicle emission standards (left) and the Large Combustion Plant Directive (right)



Note: Improvements are values above zero (positive decrease in ozone concentrations).

Source: EEA (ETC/ACC)/TNO.

Figure 3.10 Modelled ozone concentrations expressed as SOMO35 for the year 2000 (left) and 2010 (right) for the CAFE baseline scenario



Source: IIASA.

decrease in the SOMO35 is expected over the whole of Europe, but is most pronounced in the countries around the Mediterranean.

3.3 Particulate matter

Key messages

- Exposure to particulate matter may lead to serious health effects. Taking anthropogenic primary PM and PM precursor emissions in year 2000, the average loss of life expectancy across the EEA countries (for which information was available) was estimated to be approximately nine months. However, notable geographical variation existed.
- $PM_{2.5}$ may be a better indicator for health effects than PM_{10}, but as yet significantly less monitoring data are available. Available information suggests that the 'cap value' in the proposed EU Air Quality Directive was exceeded in many urban areas in 2004.
- Limit values for daily and annual average PM_{10} concentrations were exceeded in 2004 in hot spot, urban and rural locations across Europe, notably in southern and eastern Europe as well as the Benelux countries.
- The upward trend of peak PM_{10} concentrations observed up to 2003 ceased and a large drop was seen in 2004. Model analysis suggests that this can be partly explained by meteorological variability affecting PM_{10} concentrations of 15–25 % in recent years, which probably masked the effect of decreasing primary and precursor PM emissions.
- Although primary PM emissions have decreased in Europe in general, there is wide variability in emission trends. In some countries reductions have been much larger than the average, whereas in others emissions have increased. The latter situation is especially due to emissions from the transport sector, where reductions resulting from a shift to lighter fuels are counteracted by an increasing share of diesel vehicles and rising traffic volumes.
- Current European and national legislation is projected to lead to improvements of both peak levels and annual average PM concentrations over the next five years. Uncertainty with respect to emissions is large; combined with meteorological variability the uncertainties for PM concentrations become larger than for other air pollutants.

3.3.1 Health impact of airborne particulate matter

Detrimental health effects from fine particulate matter (PM) are caused by inhalation and penetration of the lungs. Both chemical and physical interactions with lung tissues can induce irritation or damage. Since finer PM is better able to penetrate the lungs, the size of the particles is of significance. The current scientific understanding is that the mortality effects of PM are mainly associated with the $PM_{2.5}$ fraction of small particles, i.e. particles with an average diameter of 2.5 µm and below. However, effects can be seen with both the finer sub-2.5 µm and the coarser 2.5–10 µm fractions of PM_{10}.

Although evidence is growing that finer size fractions are perhaps the most important, current ambient air quality measurements and emission data are often only available for PM_{10}, i.e. particles of average 10 µm diameter and below. Thus, this report focuses mainly on PM_{10} concentrations unless sufficient information on the $PM_{2.5}$ fraction was available at the time. The PM_{10} fraction includes particles smaller than 2.5 µm. Wherever possible, observed relations between the $PM_{2.5}$ and PM_{10} fractions were used to assess the exposure to fine particulate matter.

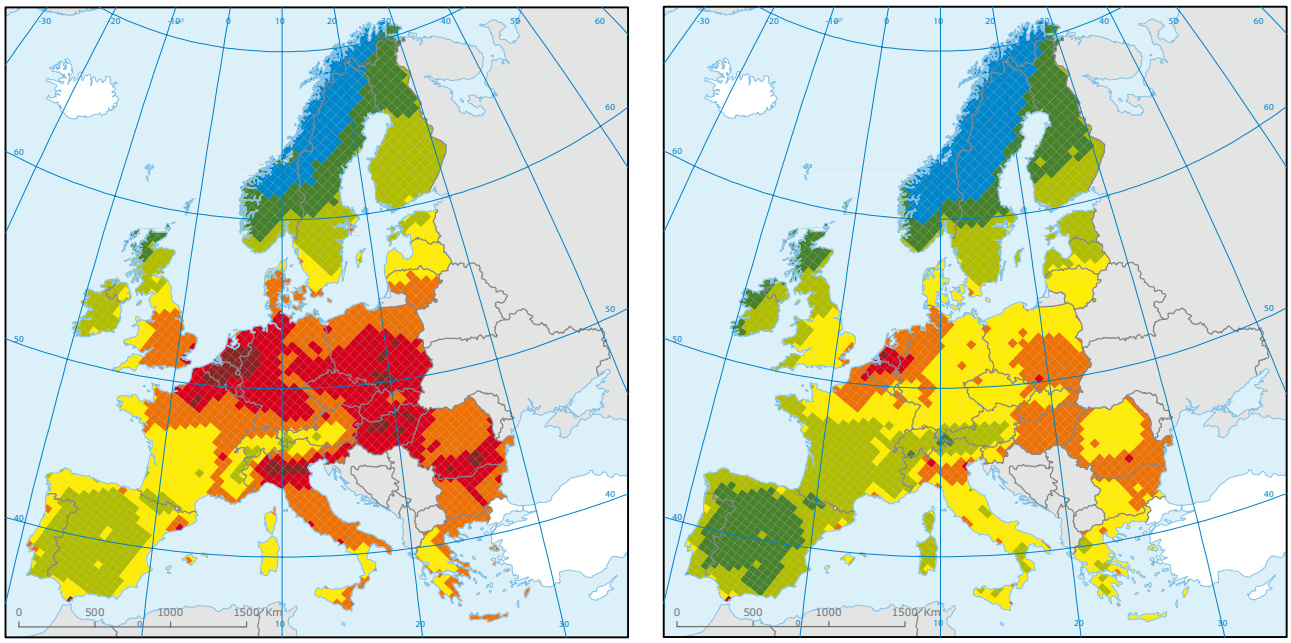
Assessment of health impact is described by rates of population morbidity and in mortality. Loss of life expectancy due to PM has been assessed for Europe, based upon accepted relationships between mortality rates and modelled annual average $PM_{2.5}$ concentrations (Amann *et al*., 2004; WHO, 2006).

The average loss of life expectancy due to particulate matter in 2000 was estimated at approximately nine months for the EEA countries where estimates were available. Maximum loss of life expectancy of 12–36 months occurs in Benelux, Silesia and the Po valley. The estimate is believed to be conservative, as mortality has only been calculated for the populations older than 30 years, and not for infants.

Comparison between $PM_{2.5}$ and PM_{10} concentrations in the air

Whilst current understanding is that mortality effects are mainly associated with the $PM_{2.5}$ fraction,

Figure 3.11 Health impact of PM mass concentrations (µg/m³). Loss in statistical life expectancy (months) that can be attributed to anthropogenic contributions to $PM_{2.5}$ for the year 2000 (left) and for 2020 (right) for the CAFE baseline scenario



Estimated losses in life expectancy attributable to exposure to fine particulate matter ($PM_{2.5}$) from anthropogenic emissions for 2000 (left) and 2020 (right)

Months 0 1 2 4 6 9 12 36 | No data | Outside study area

Source: IIASA.

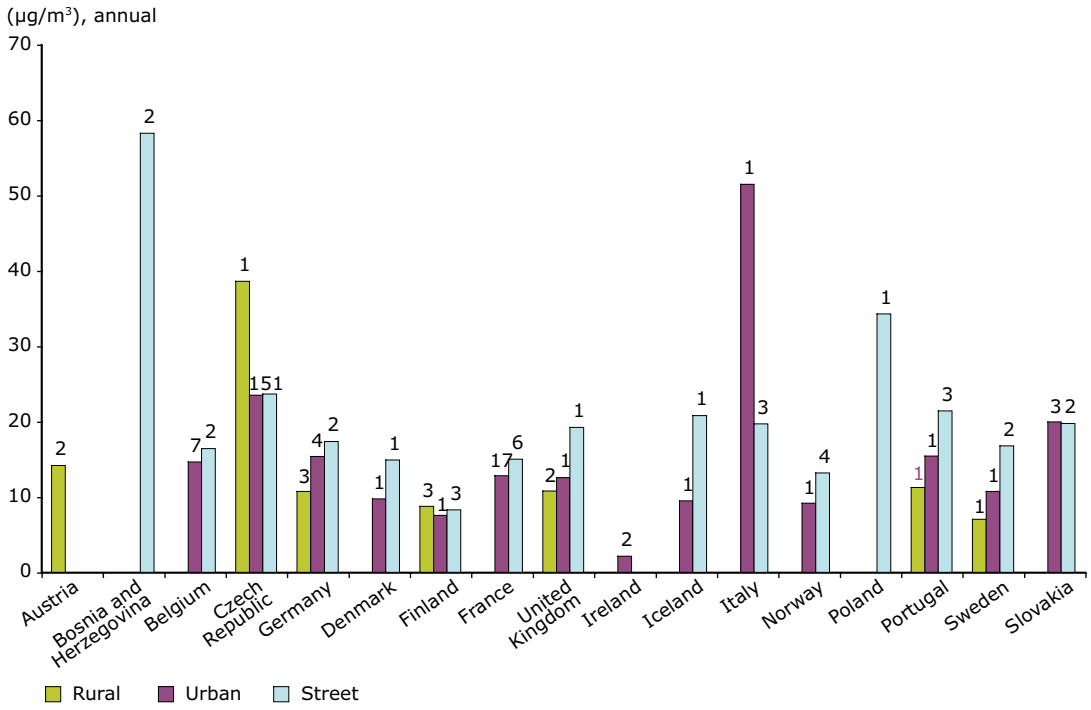
$PM_{2.5}$ air monitoring data are still fairly scarce in Europe. Hence, the effects assessment shown in Figure 3.11 is based upon modelling. Although the spatial coverage of monitoring stations is presently insufficient to assess variations across Europe, some comparison is possible between observations at monitoring stations reporting $PM_{2.5}$ and the 25 μg/m³ 'cap' value of the proposed Air Quality Framework Directive (COM(2005)447 final). According to the Air Quality Framework Directive those cap values will have to be met by 1 January 2010, agreed margins of tolerance establishing a present maximum of 30 μg/m³. Figure 3.12 summarises observations of $PM_{2.5}$ in 17 countries in Europe for 2004. As many current $PM_{2.5}$ monitor types significantly underestimate concentrations mass loss during sampling, real $PM_{2.5}$ concentrations would be higher than those shown.

The indication is that hot spot (traffic-related) locations may well exceed the cap value, although most PM observations are below the proposed limit. Concentrations generally increase from rural-to-urban-to-traffic locations, in accordance with increasing proximity to PM sources.

In recent years PM_{10} has been widely monitored; a total of 1 815 stations reporting in 2004. The relevance for health assessment is that PM_{10} measurements also capture the finer $PM_{2.5}$ particles. Indeed, health effects studies have used available PM_{10} measurements, and since the mid 1990s EU AQ limit values have been related to PM_{10}.

The ratio between $PM_{2.5}$ and PM_{10} emissions for all sectors is quite variable between countries, from 0.53 to 0.83 (Figure 3.13). Co-located monitoring of ambient air concentrations reports average ratios of 0.65, (range 0.42–0.82, std. dev. 0.09). Putaud *et al.* (2003) found an average ratio of 0.73 (range 0.57–0.85, std. dev. 0.15). Ratios closer to sources are generally lower (larger coarse fraction), whilst those farther away are higher (finer). Some sectors (e.g. industrial sources) contribute a large coarse fraction. However, PM from road transport — an important sector for population exposure — are generally finer than average and the range of the $PM_{2.5}$ / PM_{10} ratio is 0.67–0.90. Scandinavia is the exception; road transport emissions are generally coarser (0.24–0.64) here. This is due to the use of studded tyres in winter which contributes a large

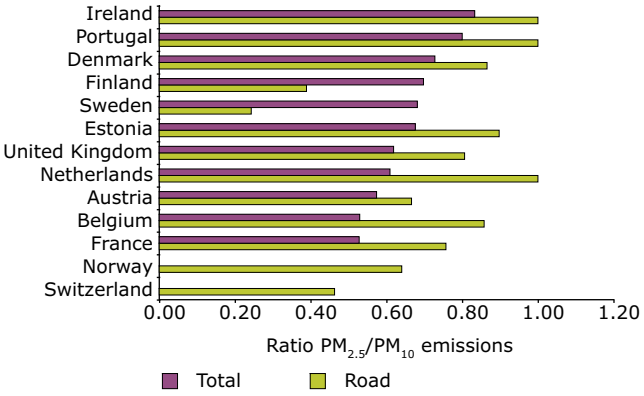
Figure 3.12 Measured $PM_{2.5}$ concentrations, 2004 (μg/m³, annual average) for several countries



Note: Each bar represents average concentrations for each station type. The number of stations is on top of bars.

Source: EEA (ETC/ACC).

Figure 3.13 $PM_{2.5}/PM_{10}$ **emissions ratios, total and for road transport**



Source: EEA (ETC/ACC).

fraction of coarse particles from the road caused by increased wear of the road surface.

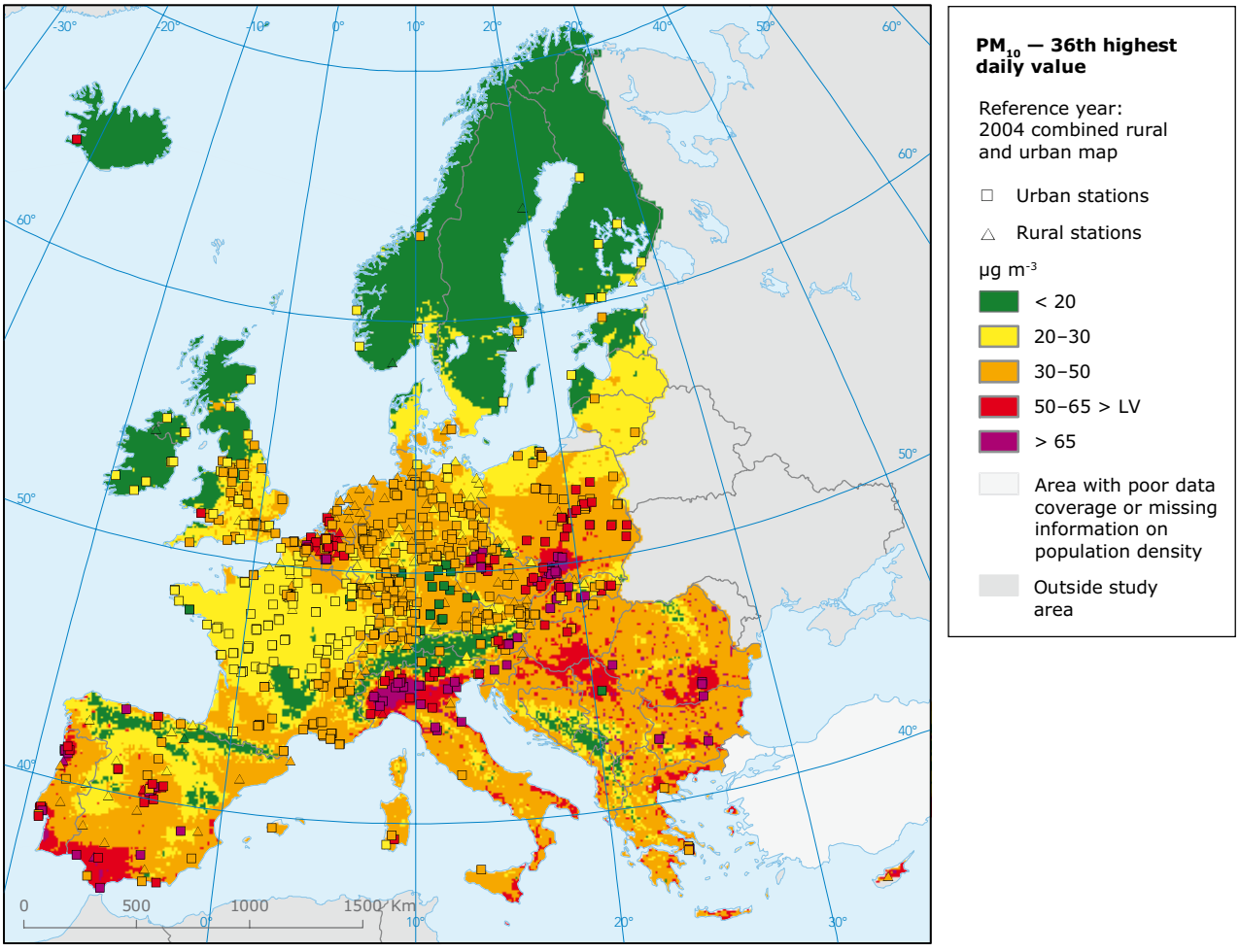
3.3.2 *PM_{10} concentrations in Europe in 2004*

Reporting of PM_{10} data to AirBase has improved steadily. In 2004, over 87 % of the 1 815 reporting stations (1 587) could boast 70 % data coverage or better. There were 180 stations in rural areas and 742 sub/urban background stations. From hot spot stations, there were 483 traffic and 190 industrial stations. Remaining stations were not type classified. This section compares average daily concentrations on:

1. 36th highest day in the year with the daily limit value of 50 µg/m^3 on no more than 35 days (Figure 3.14);
2. annual average concentrations with the annual limit value of 40 µg/m^3 (Figure 3.15).

Rural PM_{10} concentrations in 2004 were higher than limit values in some areas. Many locations

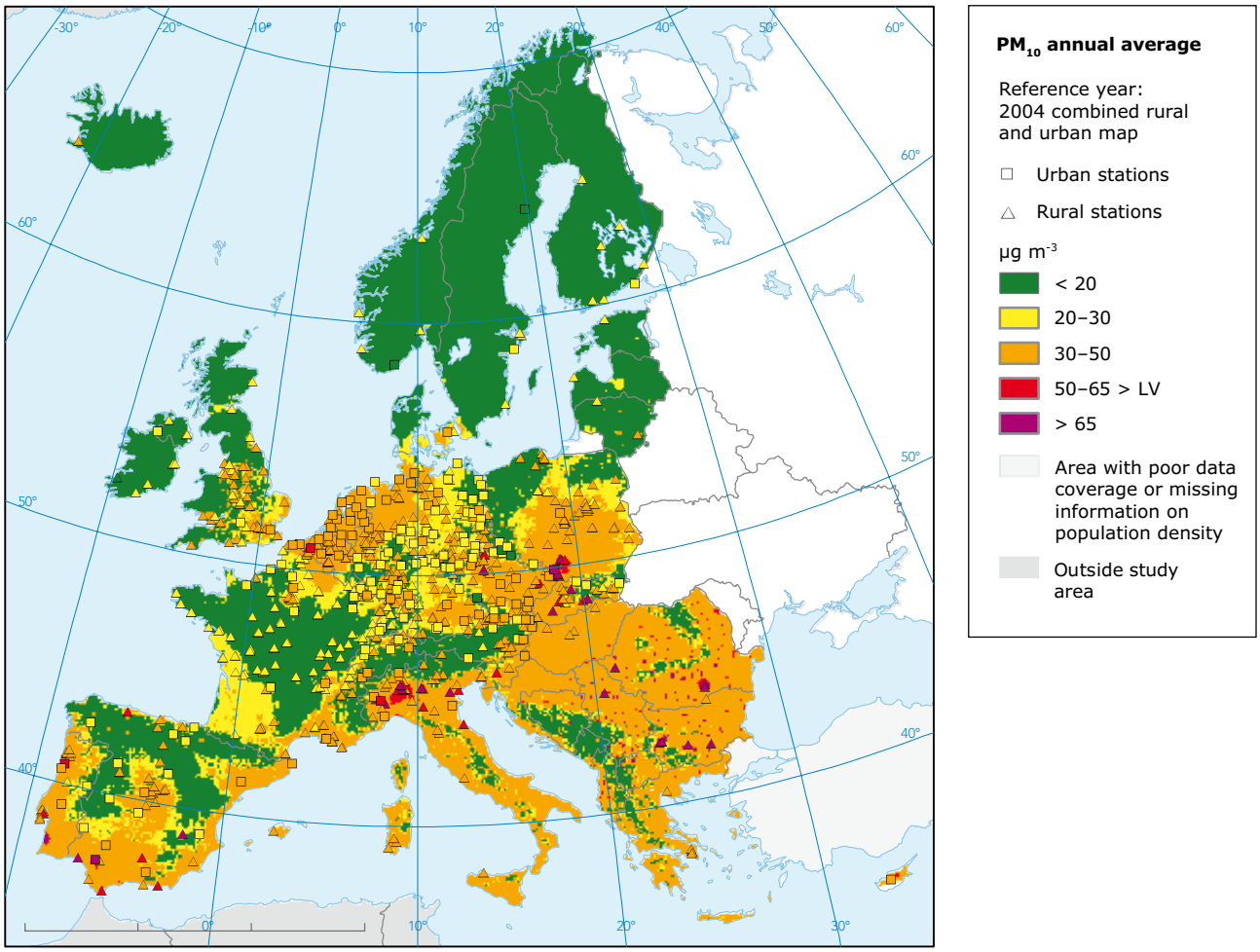
Figure 3.14 PM_{10} **concentrations in Europe 2004 showing the 36th highest daily value**



Note: The figures were constructed by combining rural and urban maps using population density. The measurement points were superimposed on interpolated concentrations. Red represents exceedances (ETC/ACC Technical Paper 2005/8).

Source: EEA (ETC/ACC).

Figure 3.15 PM_{10} concentrations in Europe 2004, showing annual average concentrations



Note: The figures were constructed by combining rural and urban maps using population density. The measurement points were superimposed on interpolated concentrations. Red represents exceedances (ETC/ACC Technical Paper 2005/8).

Source: EEA (ETC/ACC).

experienced daily average PM_{10} concentrations in excess of the criteria, and the annual limit value was also exceeded in areas such as Silesia and the Po valley. Figures combining observed and modelled information (Figure 3.14 and 3.15) show the progression of concentrations in rural background air moving from west to east across continental Europe as emissions are added. Scandinavian countries are largely shielded from continental PM.

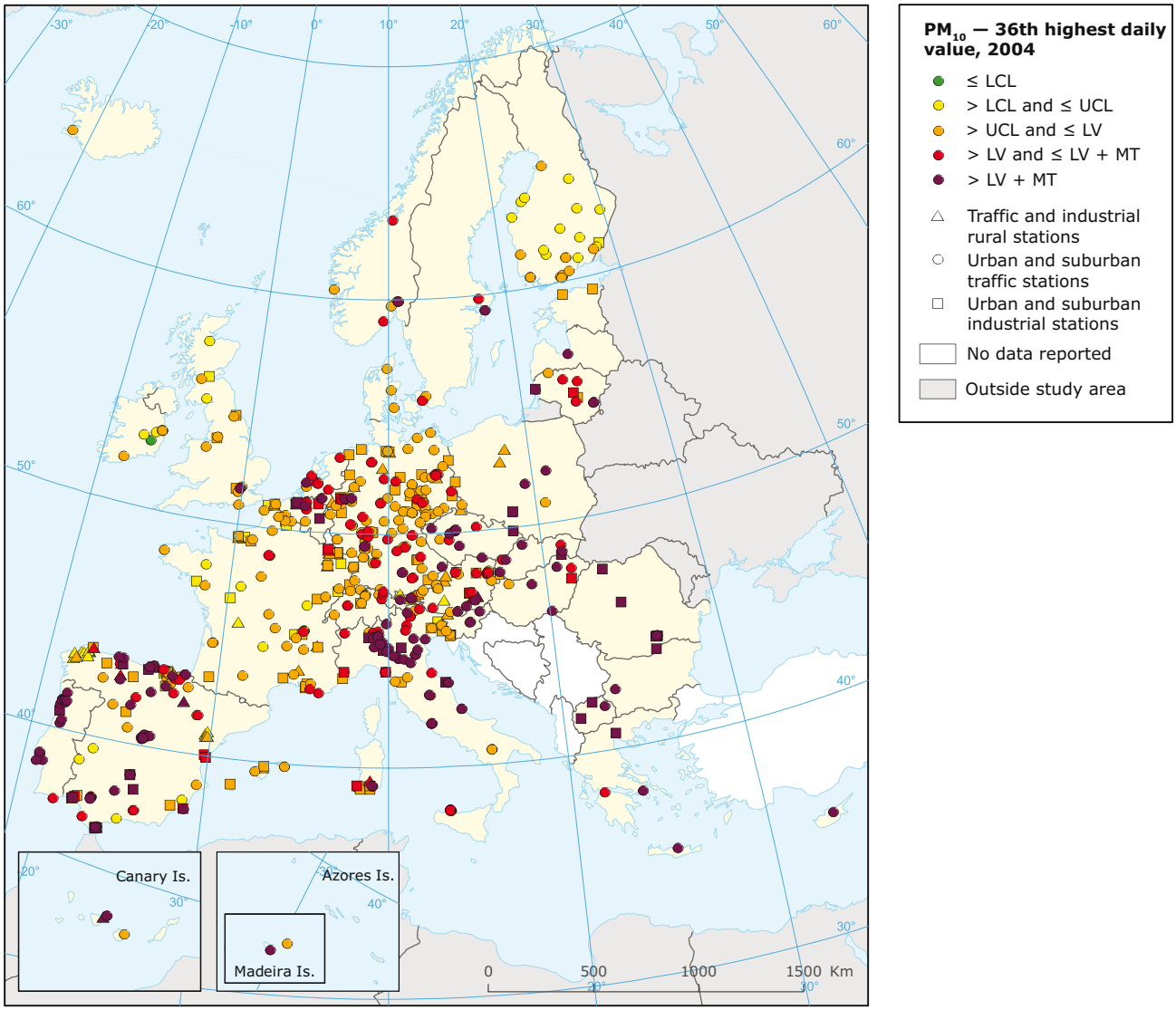
For $PM_{2.5}$, and considering that its ratio to PM_{10} in rural areas should be close to or higher than 0.8, annual average concentrations were likely to be higher than the cap value of 25 µg/m^3 in some rural areas, notably in the Czech Republic and the Benelux countries. In such a case, the whole population would have been subject to concentrations above the limit.

Urban background locations in 2004 frequently exceeded the daily PM_{10} limit value in several European regions. The highest urban concentrations were observed in Italy, the Czech Republic, Poland, Romania, Bulgaria and the Benelux countries as well as in cities in some other areas.

Traffic hot spot stations were found to exceed the daily PM_{10} limit value in many countries, such as in Italy, Spain and Portugal, Bulgaria, Romania and FYR of Macedonia in southern Europe, as well as in other countries. Figure 3.16 displays the cities with hot spot stations coded against the limit value.

Concentrations in the urban industrial stations did not deviate much from the typical urban/traffic hot spot concentrations. The maximum industrial station recorded 147 µg/m^3, and the maximum

Figure 3.16 **PM_{10} concentrations, 2004, hot spot traffic/industrial stations, 36th highest daily value**



Note: LCL/UCL: Lower (30 µg/m³)/Upper (50 µg/m³) classification level LV/MT: Limit value/Margin of tolerance.

Source: EEA (ETC/ACC).

traffic station had 118 µg/m³, on the 36th highest day. Fourteen hot spot stations had more than 100 µg/m³ on 36th highest day.

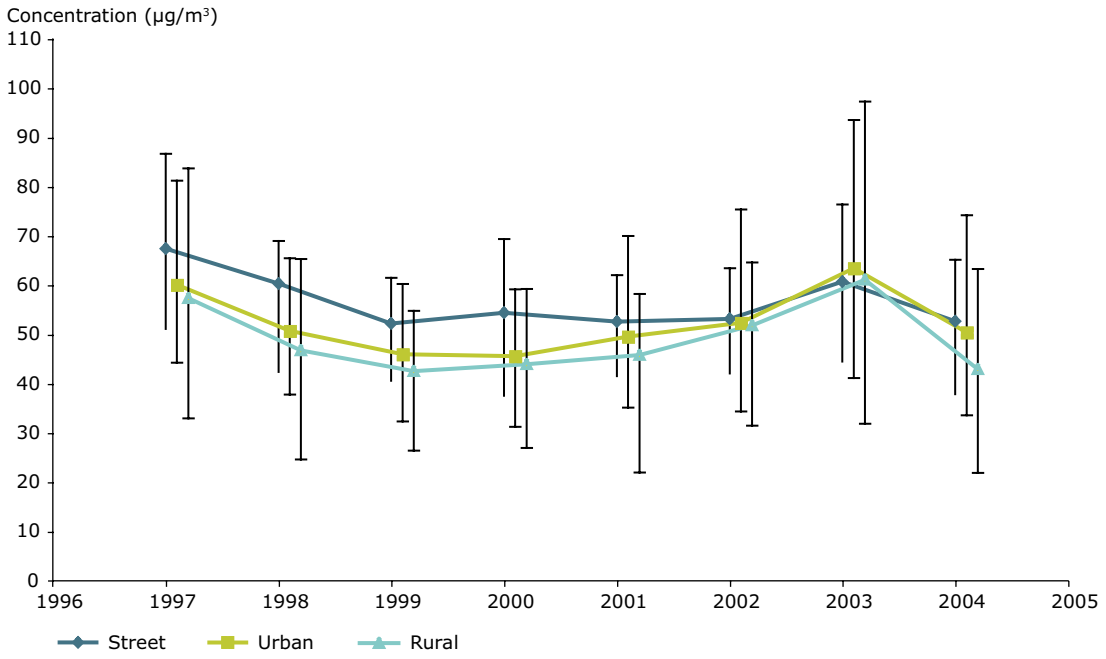
3.3.3 *Changes 1997–2004 and remaining distance-to-target*

Europe-wide developments, 1997–2004

To show Europe-wide tendencies (1997–2004) in short-term peak concentrations related to the daily PM_{10} limit value, results from 104 stations in eight countries with data for all years can be used (Figure 3.17). The tendency in the annual average concentration of the much larger 2001–2004 data set (not displayed) is very similar. The following observations can be made:

- PM_{10} concentrations in 2004 were approximately 20 % lower than in 1997. However, an actual net tendency in PM_{10} concentrations at these stations with full data coverage from 1997 onwards cannot be discerned due to the large inter-year variations over the entire period.
- Variations in meteorological conditions between years can explain part of these variations (Section 3.3.4). The analysis in Section 3.3.4 shows also that the amplitude

Figure 3.17 PM_{10}, inter-annual variations, 1997–2004, 36th highest daily value per year



Note: Street = 28 stations, Urban = 59 stations, Rural = 17 stations. Vertical bars: 10th and 90th percentiles.

Source: EEA (ETC/ACC).

of meteorological variations differs within Europe. Such regional differences should be kept in mind when comparing average inter-annual variations in PM_{10} concentrations at street, urban and rural stations as shown in Figure 3.17.

- Urban and rural background concentrations trends follow each other closely. The rural background concentration provides the dominating contribution to total urban PM_{10}.
- A much larger data set for 2001–2004 (539 stations, 19 countries) confirms the general tendency: increase towards 2003 and a substantial drop in 2004.
- PM_{10} concentrations at street level, represented by 171 traffic stations in 18 countries, are on average approximately 8 µg/m³ higher than the average concentrations measured at 301 urban stations in 19 countries.

Remaining distance-to-target

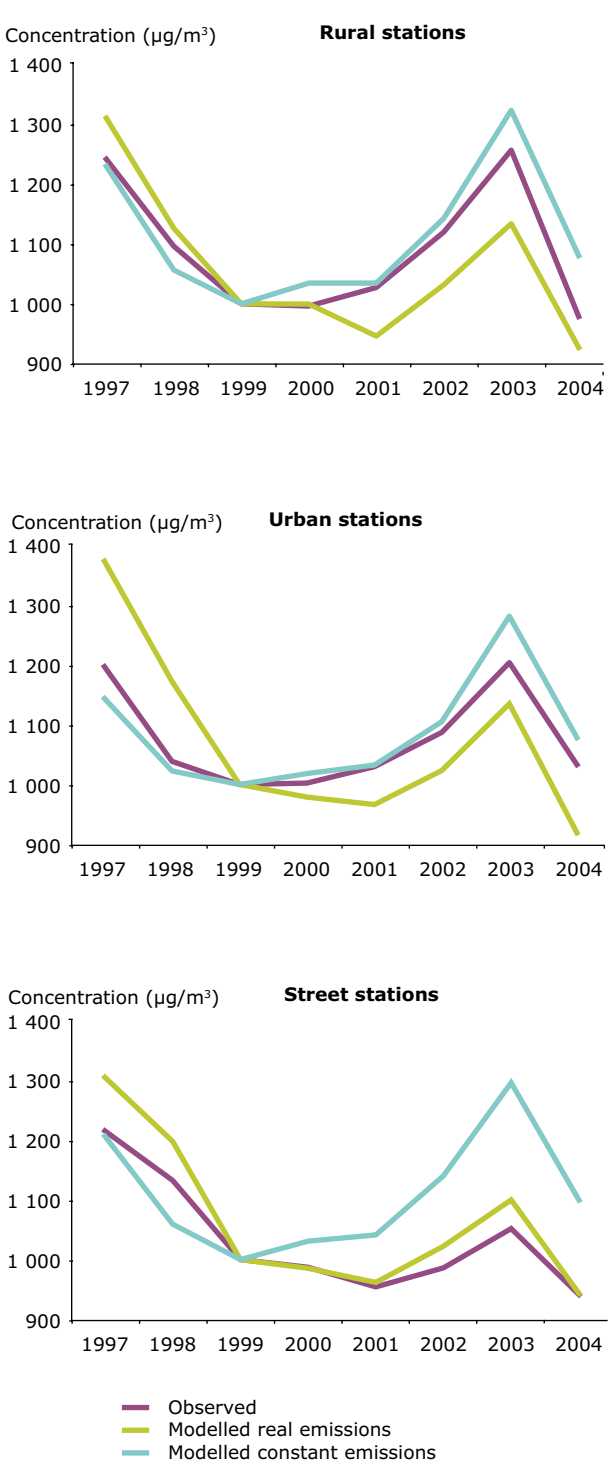
The extent of exceedance in 2004, and hence the degree of improvement required to achieve limit values (distance-to-target), is displayed in Figure 3.19. For the daily and annual limit values and for each station type — rural, urban background, and traffic hotspots — the figure shows: the average concentrations at all stations; the average concentration at only stations exceeding the limit value; and the maximum observed value. Observed PM_{10} concentrations at traffic stations is on average higher than daily limit values, and is close to them at urban background stations. Stations exceeding the criteria did so by approximately 30 % on average. The highest concentrations measured were about 2.7 times the limit value. Of the 717 urban/suburban background stations, 191 were in exceedance, and for street stations, 224 out of 459 stations were in exceedance. Achievement of the annual limit value was better, with 97 % of rural stations, over 91 % of urban background stations and almost 85 % of traffic stations meeting standards.

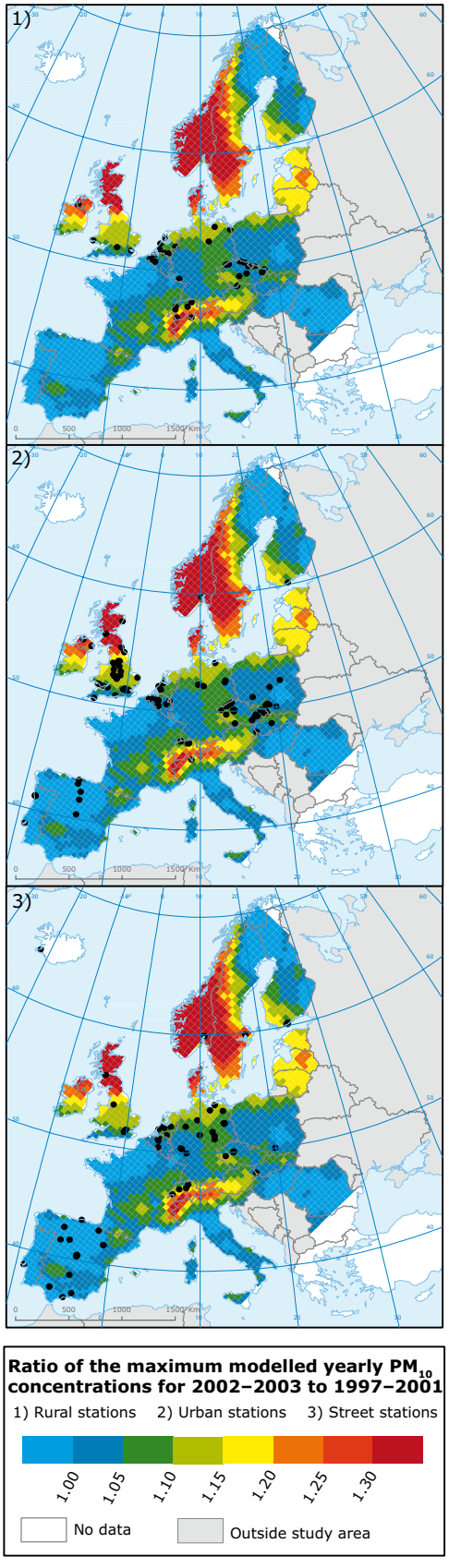
3.3.4 Impact of meteorological variability on PM_{10} levels

Concentrations of particulate matter depend on both emissions and atmospheric factors, with inter-annual variations in meteorology capable of affecting pollutant concentrations.

The effect on PM of meteorological variability can be estimated through computer modelling scenarios. In an exercise conducted for this report using the Unified EMEP model, emissions were held constant for the years 1997–2004 whilst meteorological conditions were allowed

Figure 3.18 **Left panels: observed and modelled PM_{10} concentrations. Right panels: ratio of the maximum modelled yearly concentrations for 2002–2003 to 1997–2001**

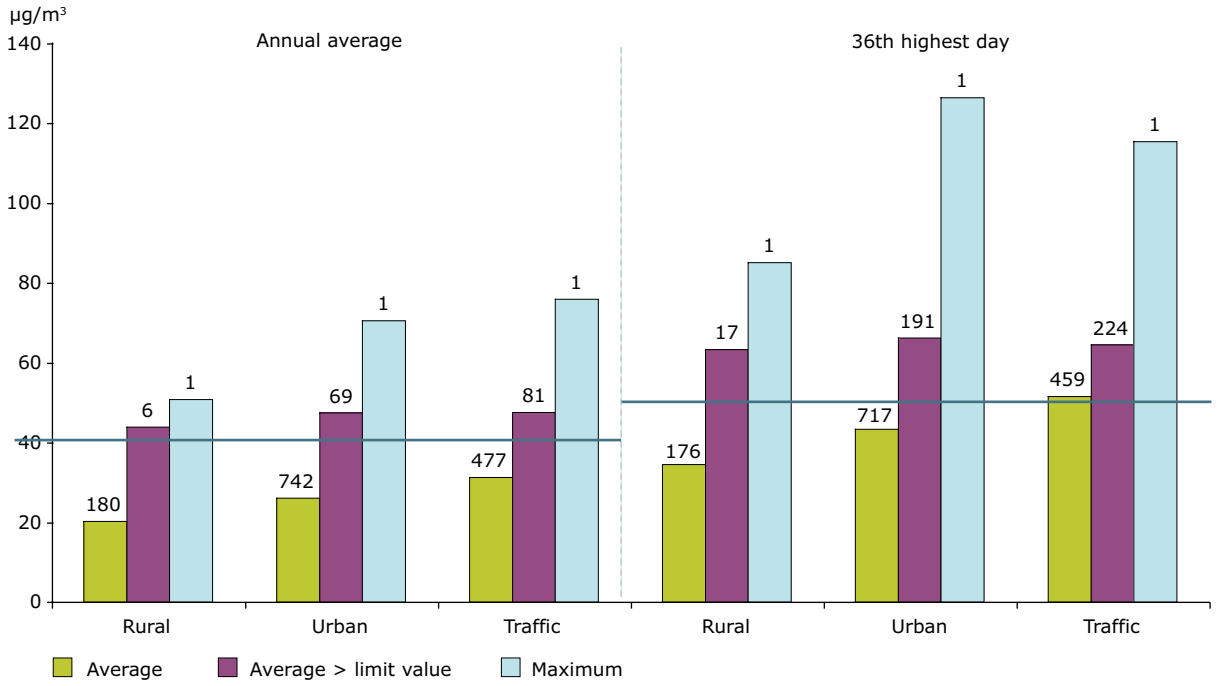




Note: Left column: Model calculations evaluated two cases: reported 'real' emissions and 'constant' emissions, i.e. unchanging year-to-year emissions. Right column: dots indicate the measurement sites.

Source: EEA/EMEP (MSC-West).

Figure 3.19 **PM_{10} distance-to-target, 2004: average concentrations, average at stations exceeding limit values, and maximum concentration**



Note: Numbers give stations in each category. Directive permits 35 days in excess of the daily limit value per year (First Daughter Directive; 1999/30/EC).

Source: EEA (ETC/ACC).

to vary. The relative differences between years can be evaluated by this method, although such continental scale modelling has difficulty with conditions that are smaller than the 50 km model resolution, for example urban/street concentrations.

Together with observed PM_{10} air concentrations, model estimates using both actual reported emissions and a scenario of constant emissions throughout the period are presented in Figure 3.18 for rural and urban background sites. The model reproduces the main signals in observations: a decrease towards 1999–2000, with a subsequent increase in air concentrations in 2002 and 2003 regardless of emission changes. The decline resumed again in 2004. This strong signal suggests that observed increased concentrations 2002–2003 may not have been due to increased emissions, but to meteorological conditions. The modelled rise in concentrations in the scenario where emissions were held constant was greater than actually measured. This suggests that emissions have in fact decreased in 2002–2003; this is in line with the emission inventory results (Chapter 2). Possible meteorological explanations for the increased observed PM_{10} levels in 2002–2003 include reduced precipitation with reduced washout of particulate material (thus higher air concentrations), warmer early-year temperatures in parts of Europe encouraging greater formation of secondary particulates, and relatively stable atmospheric conditions leading to reduced deposition, thus higher air concentrations.

The extent of the 2002–2003 increase is also mapped in Figure 3.18 as the ratio between the maximum modelled yearly average concentrations in the two periods 2002–2003 and 1997–2001 (assuming constant emissions). The locations of observation stations often lie in areas where the model gives higher max-year PM_{10} concentrations in 2002–2003 compared to 1997–2001, which are found over large parts of Europe. This suggests that the monitoring stations used (those with full data coverage) may reflect the areas most subject to the meteorological influence. The figure also indicates that in large areas in western and south-western Europe, as well as in far eastern Europe, modelled max-year PM_{10} levels are constant between the two periods. This again indicates that the displayed tendency in European PM_{10} concentrations, as shown in Figure 3.17, will depend on the areas that the monitoring stations represent.

3.3.5 *Differences between countries and cities*

In general, PM concentrations decreased towards 2000 and again in 2004 after a temporary upswing in 2003. As discussed in Section 3.3.4, this upswing was most likely partly caused by special meteorological conditions in 2003. The general background concentrations of PM, i.e. those observed at rural background stations dominate the PM concentrations in Europe on the average (Figure 3.17). However, Figure 3.15 shows that this contribution varies considerably across Europe. Figure 3.20 gives examples for three selected countries.

In some regions, e.g. in the Netherlands, PM concentrations in urban areas are only slightly higher than the rural PM background concentrations; in the Czech Republic, a lower rural background makes up approximately 75 % of the observed urban concentration; in the United Kingdom the lower rural background (although represented by only one rural station) contributes no more than 50–60 % of the concentrations seen in urban areas. Street level contributions to total PM_{10} are generally limited. However, where traffic intensity is high the street contribution is more substantial.

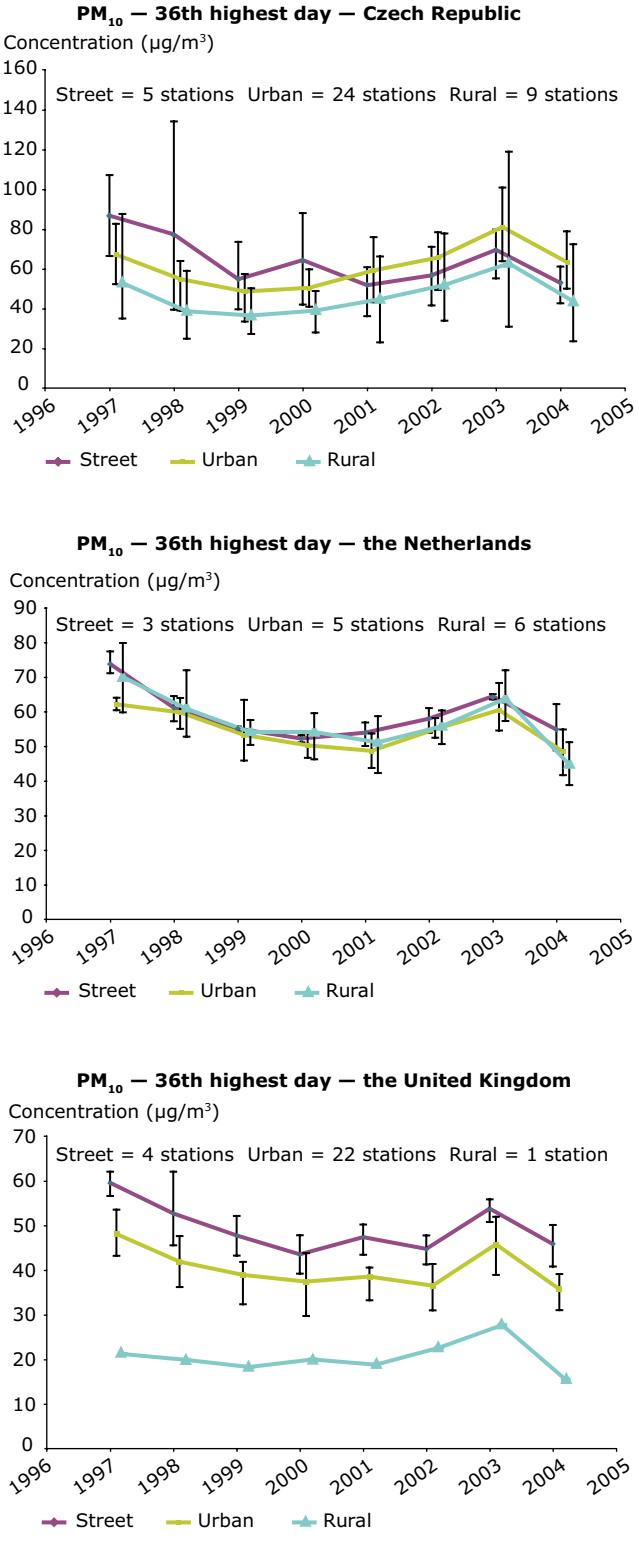
There are a number of factors behind these differences, including:

- the extent and scale of long-range atmospheric transport of PM_{10} within and to a country (dependent upon location and neighbour country emissions);
- the importance of natural sources (e.g. sea salt, desert dust);
- size of cities/agglomerations;
- distance to neighbouring major cities;
- density of traffic in the area;
- the main PM sources in the urban area and road traffic (e.g. domestic heating);
- national PM control measures;
- the formation of 'secondary' PM within a country by chemical reactions between gaseous pollutant emissions.

Observations of PM_{10} data indicate two separate trends after 1999:

- Increasing rural concentrations in central-eastern areas (extending to Sweden, with evidence of additional increases in urban contributions). For instance, the Czech Republic has witnessed a very substantial increase in background rural PM_{10} since 1999, a large urban contribution, and

Figure 3.20 Inter-annual variations of mean daily PM_{10} concentrations, 1997–2004



Note: Example countries: Czech Republic, the Netherlands and the United Kingdom. Vertical bars: 10th/90th percentiles.

Source: EEA (ETC/ACC).

indications of an increase in urban contribution. Upward trends can also be seen in Germany, Switzerland, Poland and Sweden.

- Decreasing or unchanging rural concentrations in the west to north-west (France, Belgium, the Netherlands and the United Kingdom); except for an increase in all areas from 2002 to 2003. Urban contributions have varied considerably between countries, yet have remained rather constant within individual countries. Whilst urban and street contributions in the Netherlands are very small, the urban contribution in the United Kingdom is greater. Concentrations in Belgium and France with smaller station numbers are also flat with rises in 2002–2003.

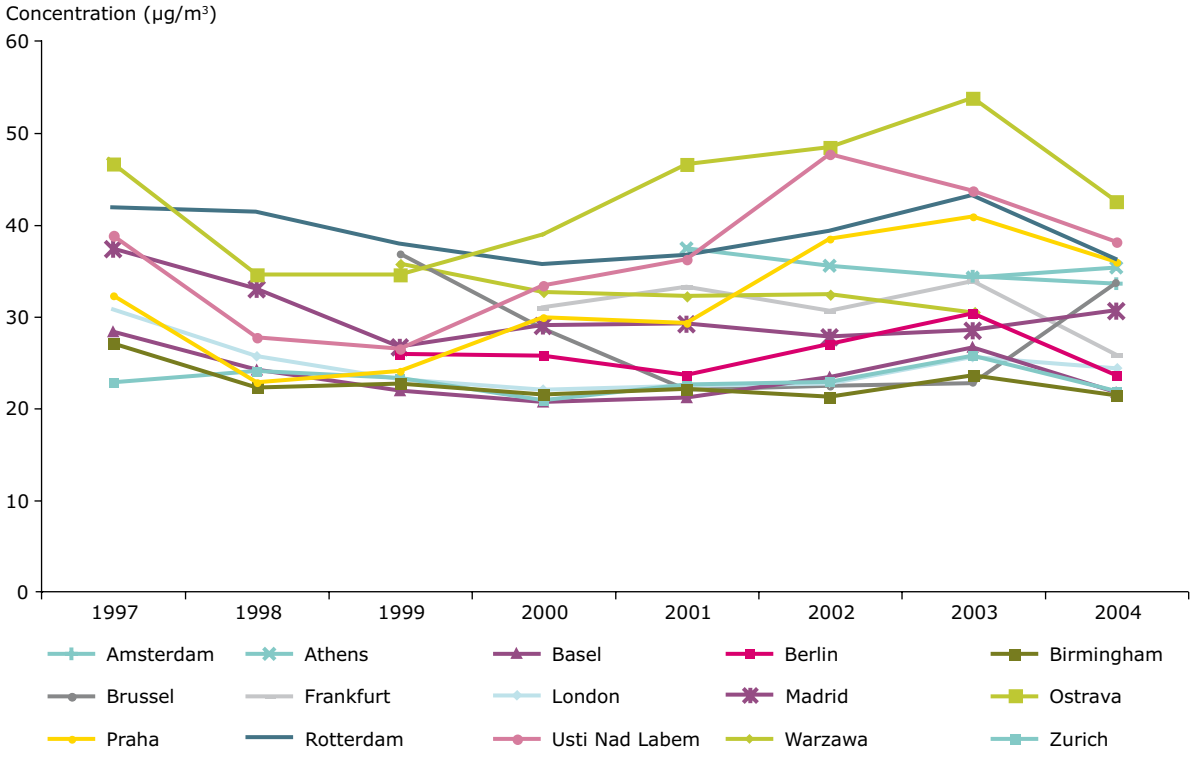
Station numbers elsewhere in Europe are too small, and the time series too short for clear conclusions to be drawn. Slight decreases in Spain and Slovakia are indicated, although limited data quantity makes its spatial representativity and quality difficult to establish.

Figure 3.21 shows PM_{10} developments in selected cities. Most of these cities display a similar tendency from 1997 to 2004, as shown for the average European urban air in Figure 3.17. Some cities deviate from this (e.g. Brussels, Madrid, Warszawa), indicating that specific local or urban-scale developments and abatement actions may play a large role for the PM concentrations.

3.3.6 Projections of future PM concentrations

The current legislation scenario for future PM emissions was developed under the CAFE programme. It includes as a baseline the combination of legislation in place as well as national legislation and practices. Legislation in place comprises emission reduction measures for large combustion plants, EURO standards for vehicles and non-road mobile machinery, and IPPC legislation on process sources. The following reductions in PM-related emission are foreseen for 2010 compared to 2000:

Figure 3.21 PM_{10} annual average inter-annual variations, 1997–2004 at selected urban background stations



Note: Only cities where measurements were available at two stations over the whole period 1997–2004 were selected (> 70 % data coverage annually).

Source: EEA (ETC/ACC).

- Primary PM_{10}: 23 % in EU-15 and 39 % in EU-10
- Primary $PM_{2.5}$: 28 % in EU-15 and 37 % in EU-10
- Secondary PM precursor gases: approximately 30 % reduction in NO_X and VOC, and almost no change in NH_3.

The most significant emission reductions in primary PM are foreseen to take place in the household and transport sectors, and also in the process and power generation sectors. Secondary precursor emissions will be reduced most in the power and transport sectors.

- This is predicted to result in reduced projected PM concentrations in Europe towards 2010, modulated by varying meteorological conditions between years. Figure 3.22 shows the estimated reduction in the anthropogenic contribution to rural $PM_{2.5}$ concentrations from 2000 to 2010, supposing a constant meteorology. Substantial reductions will take place in large areas of Europe, most significantly in central/eastern areas as well as in northern Italy. This reduction was not seen during the 2000–2003 period, but with successful implementation of legislation it should occur within the next five-year period.

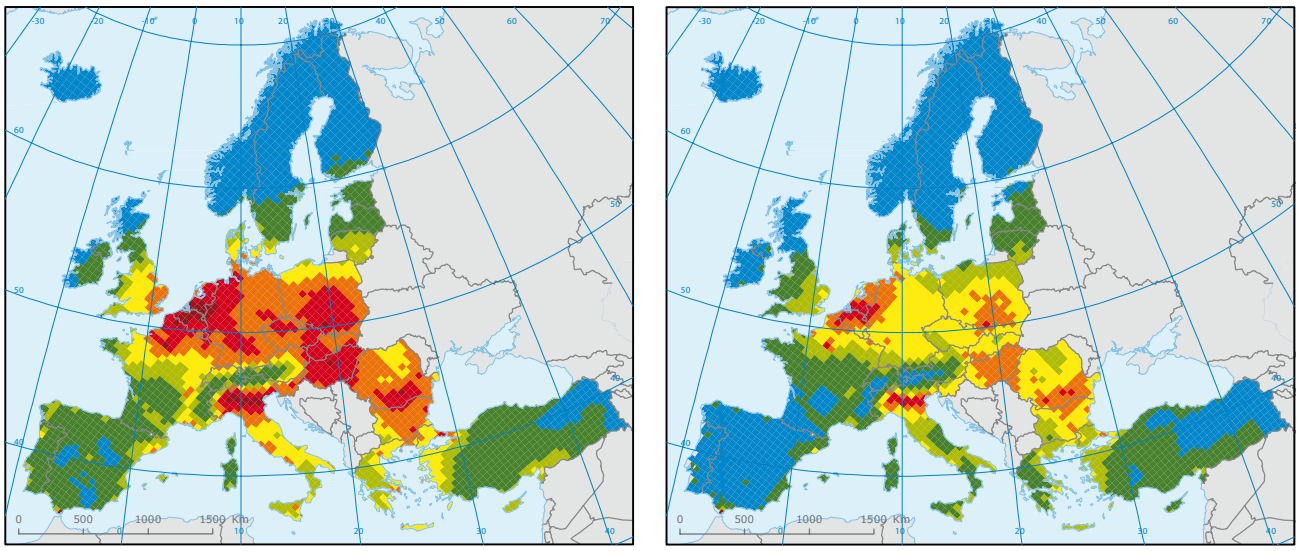
3.3.7 *Policy effectiveness*

PM Emissions reductions

Emissions trends are determined by socio-economic and technological developments as well as policy interventions:

- Population growth would, all other things remaining unchanged, have added more than 1 million tonnes of PM emissions to the EU-25 total 1990–2004.
- Economic growth would have meant an additional emission increase of almost 9 million tonnes.
- Increasing energy efficiency, however, has compensated for this to a large extent, contributing to a decrease of more than 7 million tonnes.
- The relative consumption of solid fuels decreased from 42 % in 1990 to 31 % in 2004, while gaseous fuel use increased from 21 % to 33 %. The relative use of liquid fuels did not change significantly. This fuel shift decreased emissions of particles forming pollutants by almost 4 million tonnes.

Figure 3.22 Identified anthropogenic contribution to rural $PM_{2.5}$ concentrations (annual mean, ug/m³) for 2000 and 2010, for CAFE baseline emissions; using four-year average meteorological conditions



Identified anthropogenic contribution to rural $PM_{2.5}$ concentrations for 2000 (left) and 2010 (right)

µg/m³ 0 5 8 10 12 15 20 75 Outside study area

Source: IIASA.

- Some changes have worked in the opposite direction. For instance, the increased share of diesel fuel in transport led to increases in primary particulate emissions, whilst the overall shift towards lighter fuels gave a decrease; the combined effect being a decrease of approximately 1.5 million tonnes.
- Further reductions were mainly achieved by specific abatement measures targeted at pollutants contributing to secondary particle formation:
  - more than 4 million tonnes from NO_X abatement, mainly through the introduction of catalystic converters in passenger cars and abatement at large industrial boilers;
  - more than 8 million tonnes from abatement of SO_X, due to flue gas desulphurisation and lower sulphur fuel oils;
  - reductions from ammonia abatement are negligible.

3.4 NO_2

Key messages

- Concentrations of NO_2 have been decreasing in recent years. Traffic sites generally exhibit higher concentrations than urban sites, which are more affected than rural locations.
- Population exposure has also decreased, although potentially 30 % of the urban population remain exposed to concentrations above levels for health protection. Local abatement measures may have a significant impact on emission and exposure levels.
- EU abatement of traffic-related NO_X emissions, and to a lesser extent abatement of large combustion plant emissions, has been the principal reason for falling ambient concentrations of NO_2.
- Despite improvements gained to date in road traffic emissions, this sector still requires significant attention in the future if target limit values are to be met.

3.4.1 Health impact of NO_2

Figure 3.1 has indicated that in excess of 1 in 5 of the urban population is regularly exposed to concentrations of NO_2 above the limit value (annual average). In 2004 the proportion stood at 23 %, measured as the fraction of Europe's urban population inhabiting cities recording NO_2 concentrations above values set for protection of human health (40 μg/m^3 annual mean). This percentage has decreased from over 40 % in the mid-nineties.

3.4.2 NO_2 concentrations in Europe, 2004

The number of stations reporting NO_2 data increased steadily to 2 327 in 2004; of which 2 090 in 31 countries had data coverage > 70 %. Of these, there were 285 rural background stations, 805 urban/suburban background stations, 610 urban/suburban traffic (street) stations, 181 urban/suburban industrial stations, 87 rural hotspot (traffic, industrial) stations, while 122 stations were not properly classified in AirBase. Densities of stations are somewhat thinner across much of Eastern Europe.

Figures 3.23 and 3.24 show the locations of stations with annual average concentrations, colours coded relative to the limit value (LV) for urban background and hot spot traffic stations respectively. Exceedances at hot spot locations are observed all across Europe. At urban background stations, the area subject to exceedance was more focused on the industrial axis stretching from central England through north-western Europe to northern Italy.

3.4.3 Changes between 1996–2004 and remaining distance to target

Across stations reporting observations for all years 1996–2004, the NO_2 concentration (annual average) decreased steadily towards 2004, with a somewhat increased level in 2003 (Figure 3.25). This decrease occurred at rural (83), urban (211) and traffic (112) stations. A larger group of stations for the period 1999–2004 (1 032 stations, 22 countries) supports this picture. The decrease was seen to be similar in almost all regions.

Concentrations of NO_X ($NO + NO_2$) across all stations for which data are available (1998–2004) have been reduced more substantially than for NO_2 alone (Figure 3.26). The average reduction in NO_X concentrations corresponds well with reductions of NO_X emissions over the same period.

Figure 3.27 shows the status in 2004 towards achieving future limit values established for 2010. The future LV for annual average concentrations (40 μg/m^3) was exceeded at under 10 % of sub/urban background stations (74 of 817) by on average 20 %, but at almost 50 % of traffic stations (299 of 613) by on average 35 %, with the highest

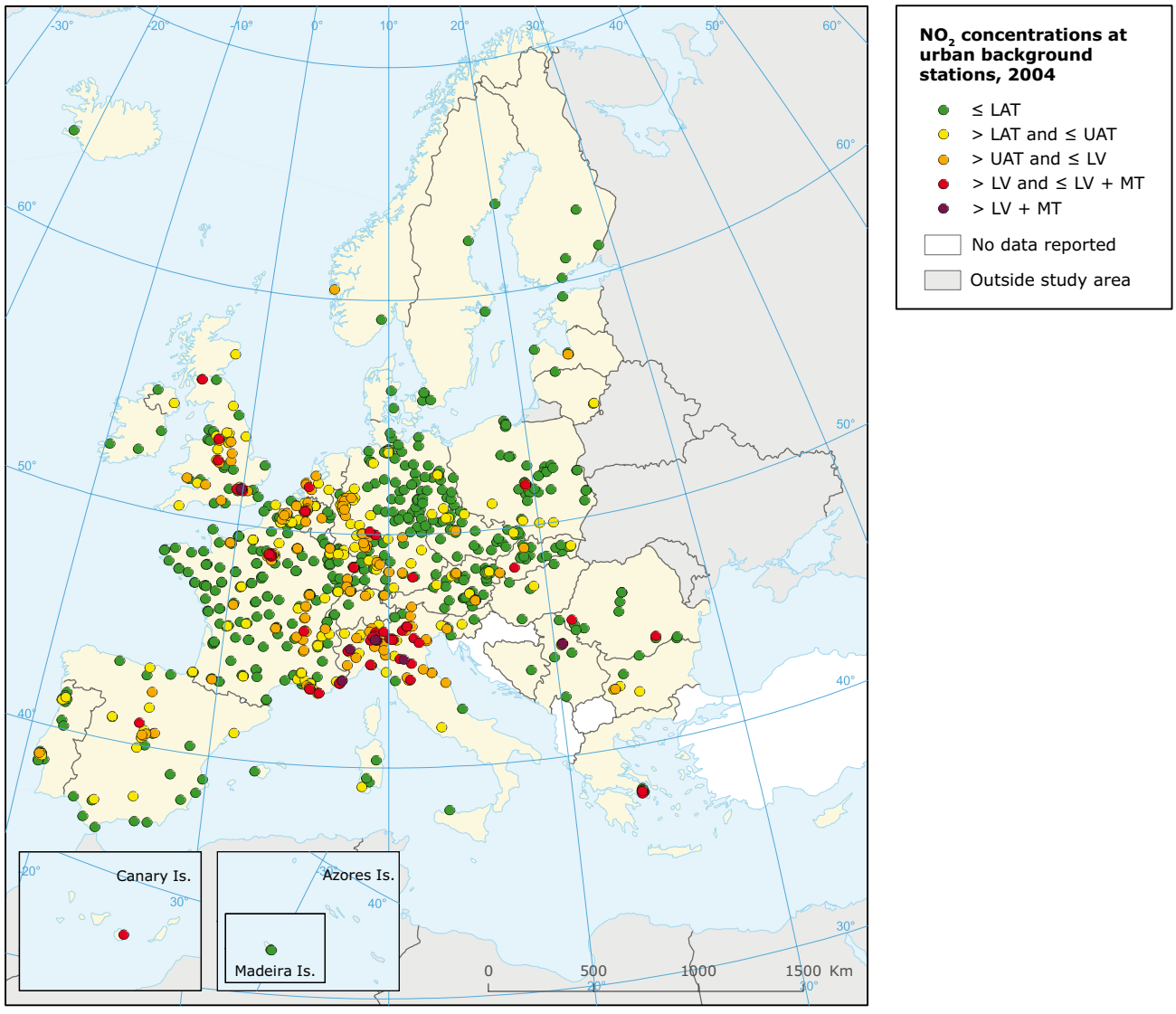
annual average concentrations close to 3 times the LV. The future peak concentration LV (18th highest hourly concentration of 200 µg/m^3) was exceeded at 10 sub/urban stations, but at 43 traffic stations, and by up to approximately 80 % above the LV. This underlines the importance of traffic emissions.

3.4.4 Differences between locations

Geographical patterns are expressed on a local scale as urban-rural differences. The clear progression in concentrations from street to urban to rural is seen in Figure 3.25. For NO_2, it is the urban contribution, especially in traffic areas, which dominates, with rural NO_2 concentrations closely following changes in NO_X. Whilst this would generally indicate the value of local control measures, the complexity of chemistry leads to an unusual situation: Falling NO_X (= NO + NO_2) concentrations correspond well with NO_X emission reductions. However, urban concentrations of NO_X have fallen much more substantially than those of NO_2. There are two possible reasons for this phenomenon:

1. Due to chemical balance reactions in the air, excess ozone reacts with NO to form NO_2. In this case NO_2 and total NO_X concentrations are closely linked. At trafficked sites, where ozone is chemically reduced, i.e. where no excess O_3 is available, conversion to NO_2 is less.

Figure 3.23 NO_2 concentrations, annual average, at urban background stations, 2004



Note: LAT/UAT: lower/upper assessment threshold; LV/MT: limit value/margin of tolerance.

Source: EEA (ETC/ACC).

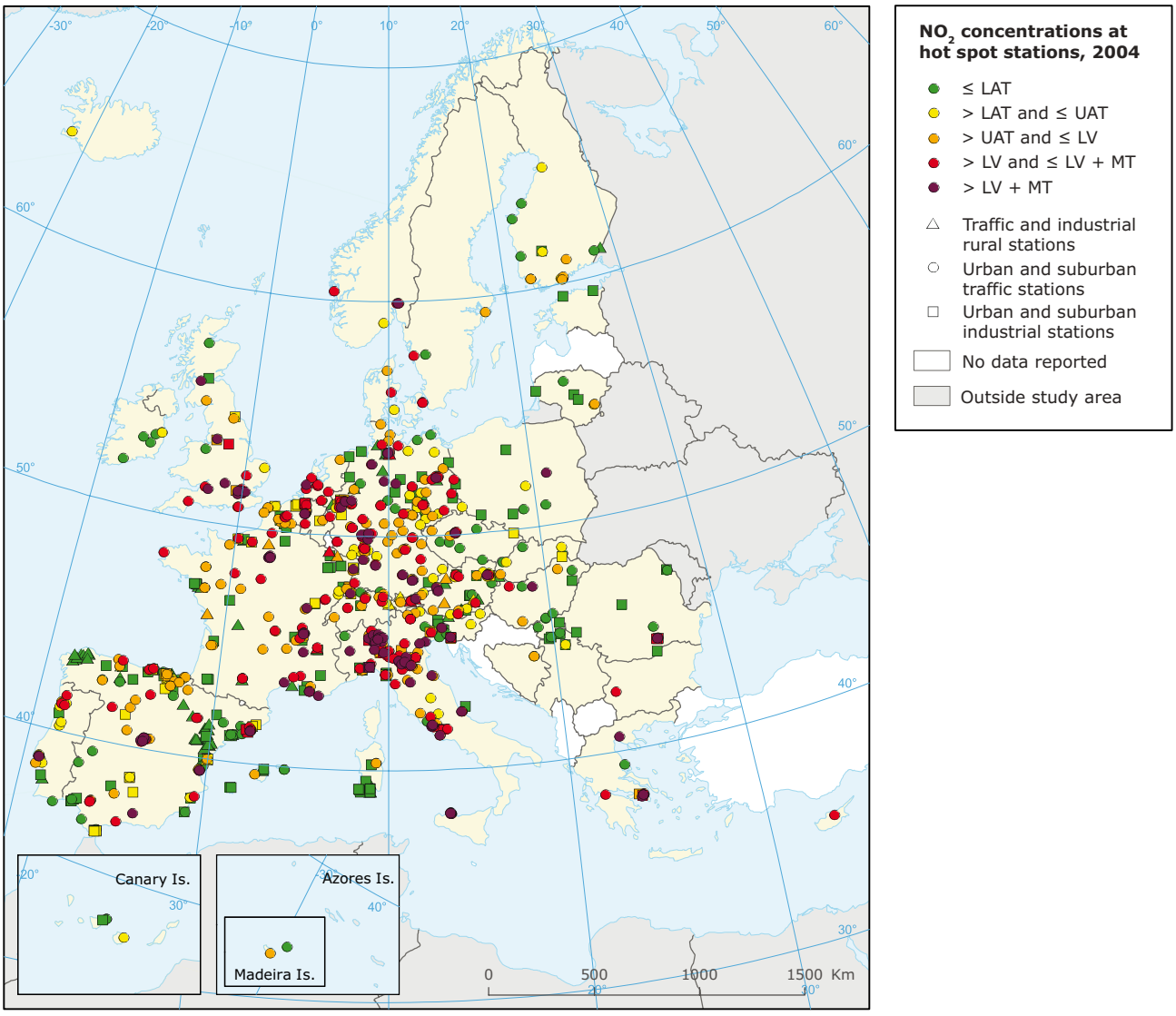
2. There is an indication of a relative increase in *direct* emissions of NO_2 from road vehicles, corresponding to an increase of the diesel fraction of light duty vehicles. Diesel engine particulate filters actually increase NO_2 during the process of removing soot from emissions.

In the first case, higher NO_2 concentrations can be observed though total NO_X emissions have not changed. In the second case, the gradual introduction of particle filters for diesel vehicles (light and heavy duty) leads to an increase in direct NO_2 emissions (with no changes in total NO_X emissions).

3.4.5 Policy effectiveness

In addition to direct emission, NO_2 is formed in the atmosphere through reaction with NO and ozone, and also hydrocarbons (VOC). Thus, NO_2 concentrations do not depend on NO_X emissions alone. Nevertheless, the magnitude of the reduction in NO_2 concentrations in Europe has been approximately equal to NO_X emissions reduction, at about 20 % since 1996. European control policy has focused on two source categories for which the European Union has developed specific emission abatement policies:

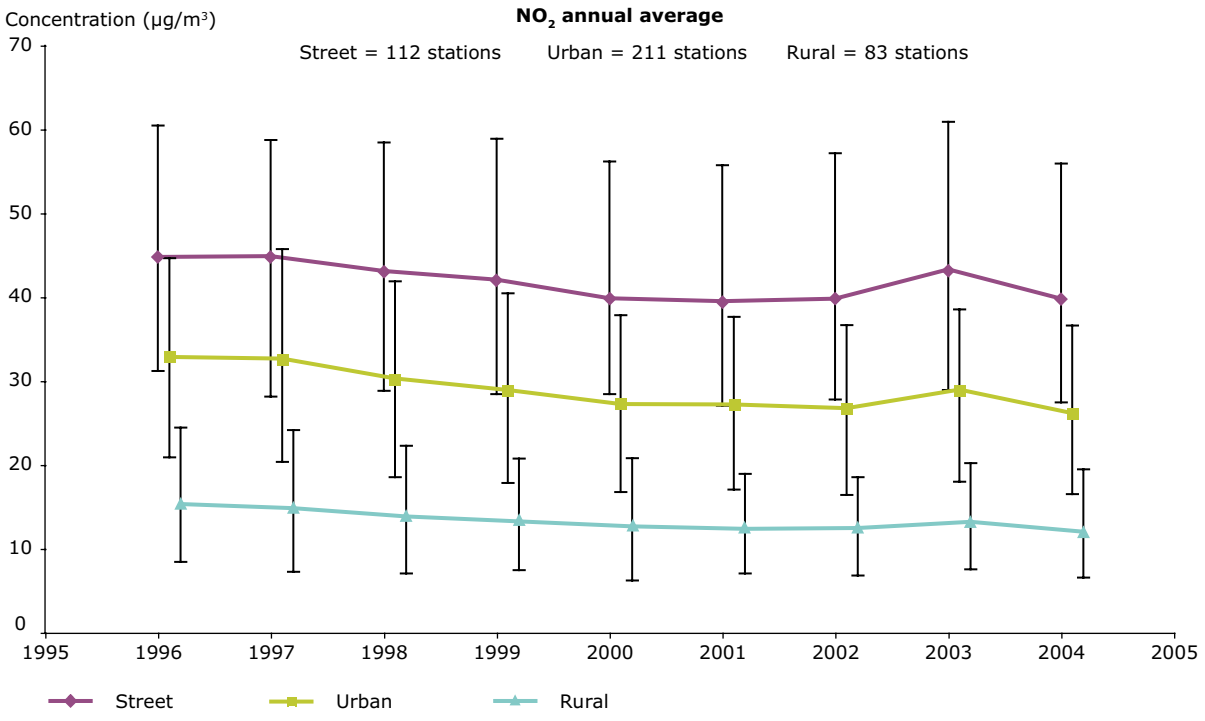
Figure 3.24 NO_2 concentrations, annual average, at hot spot stations in Europe, 2004



Note: LAT/UAT: lower/upper assessment threshold; LV/MT: limit value/margin of tolerance.

Source: EEA (ETC/ACC).

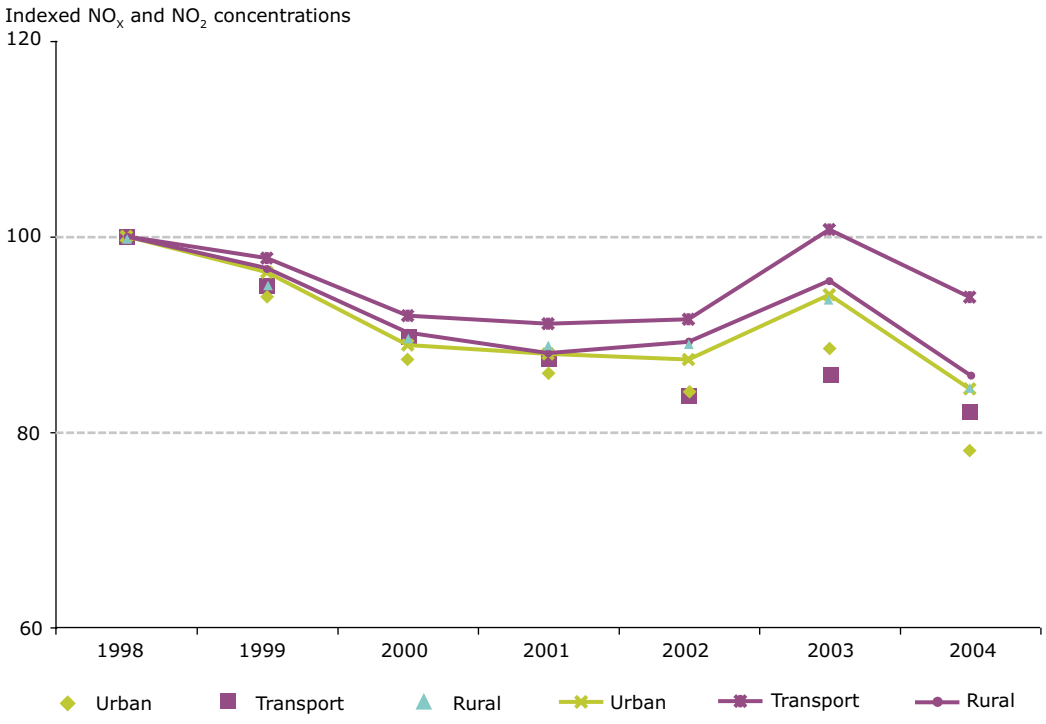
Figure 3.25 NO_2 inter-annual variations, 1996–2004 (all stations with 8 monitoring years)



Note: Vertical bars: 10th and 90th percentiles.

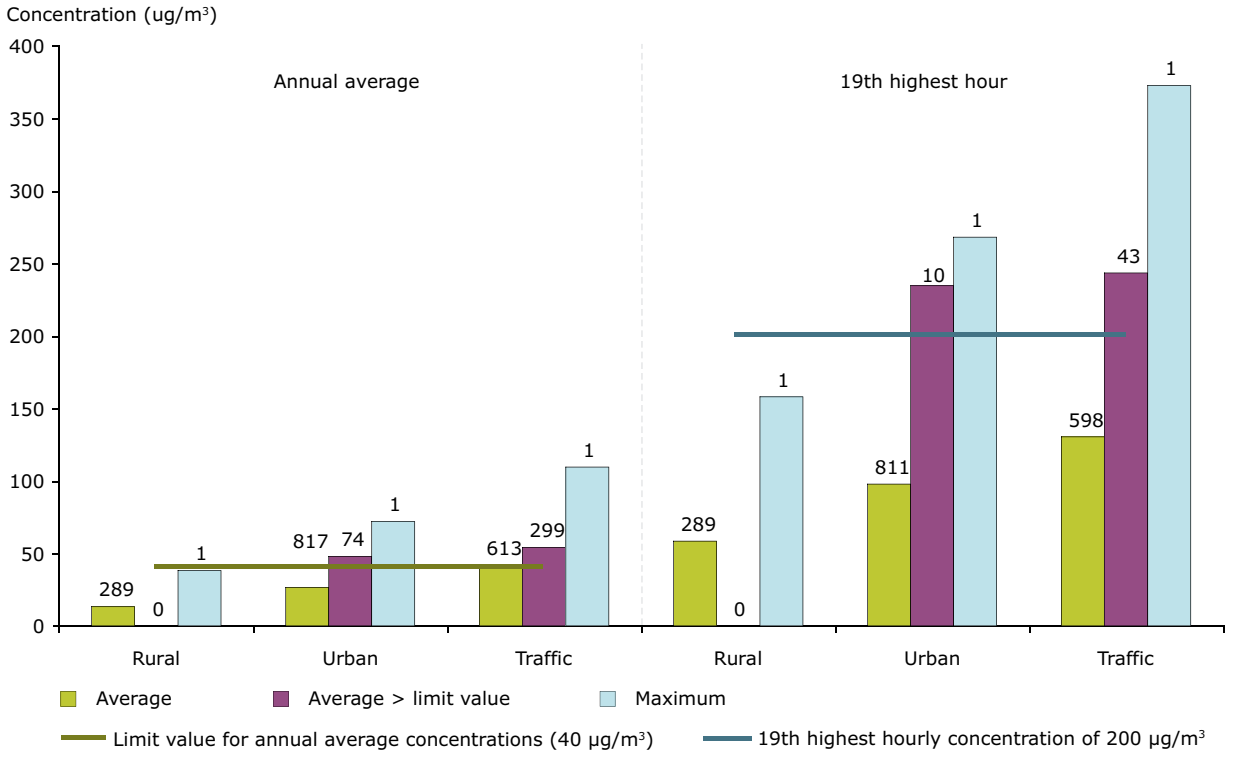
Source: EEA (ETC/ACC).

Figure 3.26 Development of concentrations of NO_x (dots) and NO_2 (lines) at 450 urban, transport and rural stations in eight countries with NO_x and NO_2 data for all years 1998–2004



Source: EEA (ETC/ACC).

Figure 3.27 Distance-to-target, NO_2 above EU limit values, 2004



Note: Station numbers are shown on top of bars. 'Average': all stations; 'Average > LV': stations above limit value; 'Max': station with highest concentration.

Source: EEA (ETC/ACC).

- Emissions from road transport by introducing emission standards for vehicles (EURO II, III, IV and V, and future EURO VI).
- Emissions from large combustion plants controlled under the LCP Directive (EC, 2001a) and the IPPC Directive (EC, 1996a).

Reported total NO_X emissions decreased steadily between 1990–2000. After 2000, the decrease almost stopped. For the road transport sector, the second largest sector and the most important urban emissions sector, reductions have continued. Figures 3.28 and 3.29 show this development in different European regions. Rates of reduction in total emissions have been much larger in northern and eastern regions (around 20 %, 1996–2003) than in the southern European region (around 5 %).

Reductions in road transport emissions have been similar in the various European regions, close to 30 % reduction in EEA-32 and EU-15, and slightly less for EU-10 (Figure 3.29). Reductions in EU-10 trailed the EU-15 until 1999, after which emissions control technology rapidly permeated the EU-10 car fleet.

The effects of these policy measures are evaluated by estimating:

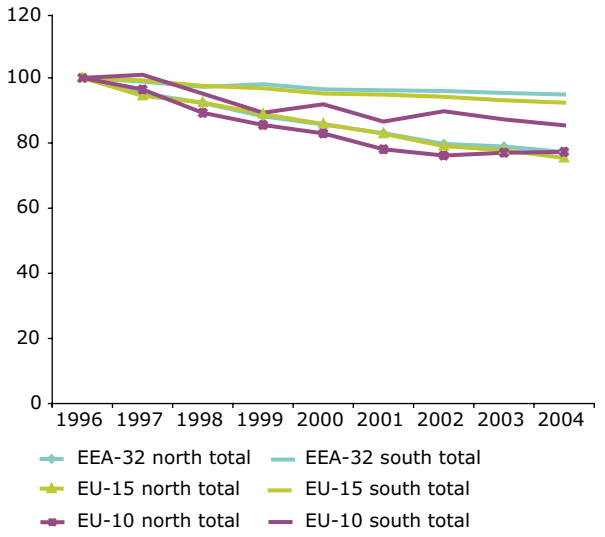
1. the emissions that would have been expected if these policy measures had not been taken; and
2. the level of potential emissions if policy measures were fully implemented.

Table 3.1 (Section 3.2.5) lists the various scenarios considered, and Figure 3.30 provides a summary of the analysis, from which the following points may be observed:

Road transport:

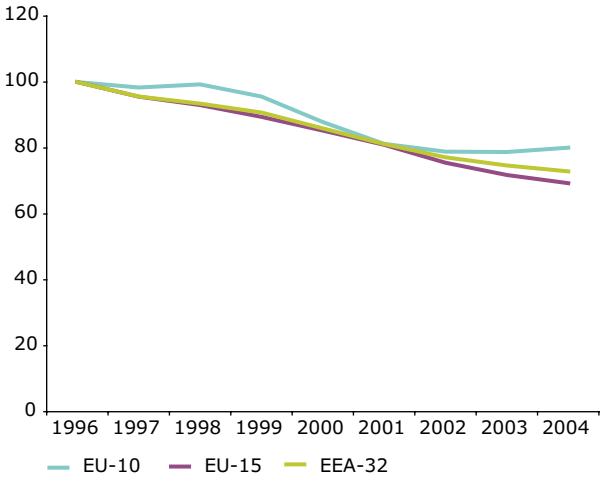
- If abatement measures for road transport had not been implemented ('Road transport unabated'), emissions from road transport would have increased from approximately 7.5 Mt in 1990 to over 9 Mt in 2004. Diesel fuelled cars would have been the main contributors, mainly due to the increasing share of diesel in road transport. Since part of the car fleet already complied with the regulation, the emissions in 1990 would have been somewhat higher ('Current situation').

Figure 3.28 **NO_x emission trend, all sectors, European regions, 1996–2004**



Source: EEA (ETC/ACC).

Figure 3.29 **NO_x emission trend, road transport sector, European regions, 1996–2004**



Source: EEA (ETC/ACC).

- If the most stringent abatement technology for road transport ('Road transport MFR') had been implemented from 1990 onwards, emissions from road transport would have been a factor of three lower than actual emissions.

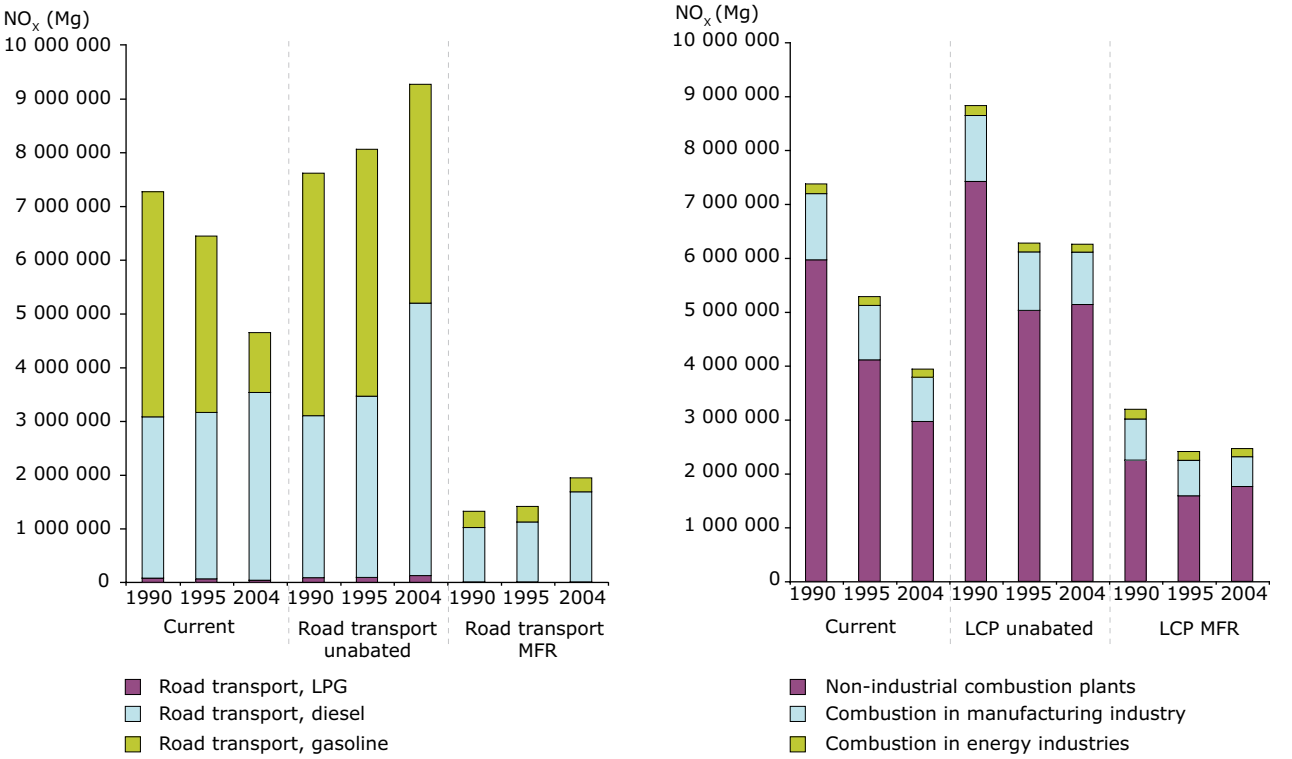
Large Combustion Plant Directive:

- The Large Combustion Plant Directive was introduced in the mid 1980s. New plants, constructed after 1987 in EU Member States should comply with more stringent emission standards. If the LCP Directive (EC, 2001a) had not been implemented, emissions from Stationary Combustion in 1990 would have been 1.5 Mt higher.
- Since 1995 a further emission reduction has occurred compared to the unabated scenario. This may reflect abatement in the new Member States.
- Full abatement according to the LCP Directive could have resulted in almost another 2 Mt lower emissions from stationary combustion in 2004. Only half of the potential effect of the LCP Directive (EC, 2001a) was achieved by 2004.

This analysis suggests that EU-25 policy measures introduced to abate NO_X emissions have contributed significantly. Using the LOTOS/EUROS chemical transport model, the effect of this abatement upon air concentrations of NO_2 has been evaluated. Figure 3.31 presents the estimated differences in NO_2 concentrations between the *unabated* scenario and the modelled situation in 2003 (Note: 2004 was not assessed). The following observations were made:

- NO_2 annual mean concentrations in a large part of north-western Europe (the United Kingdom, the Netherlands, Germany) fell to 5–7 µg/m^3 below the level that would have occurred in a business-as-usual scenario, i.e. without road transport abatement measures.
- NO_2 ambient concentrations in major towns and cities have decreased by 3–5 µg/m^3 through this policy measure.
- Under a scenario of full compliance by the current traffic fleet with EURO standards (MFR scenario), a further reduction of about 7 µg/m^3 NO_2 in the most polluted areas is predicted.
- The introduction of the LCP Directive (EC, 2001a) has yielded a smaller effect on ambient concentrations of NO_2: in a band from central United Kingdom via the Netherlands and Germany to the southern border of Poland NO_2 concentrations have been a few µg/m^3 below the level that would have occurred without the implementation of the LCP Directive.
- Full implementation of the LCP (LCP-MFR scenario) will result in a further reduction of 1–2 µg/m^3 NO_2.

Figure 3.30 The effect in the EU-25 of introducing vehicle emission standards in road transport (left) and emission abatement at large combustion plants (right) on the emission of NO_x



Source: EEA/IIASA (RAINS model).

3.5 Benzene

Key messages

- Combustion processes are the largest source of benzene in the atmosphere, with road traffic generally the biggest single source.
- Trafficked and urban locations are at current risk of exceeding limit values which will enter into force in 2010.
- Emissions of benzene are expected to decline owing to legislation. Between 1990 and 2010 urban emissions are expected to fall by more than 56 %.

3.5.1 Sources, chemistry and health aspects of benzene

Anthropogenic sources account for over 90 % of benzene found in the atmosphere. Incomplete burning from combustion is the most significant source (Note: benzene is an additive to petrol). At European level, 80–85 % of benzene emissions are due to vehicular traffic; concentrations are highest in densely populated areas with high traffic density. Domestic burning for heating is responsible for 3–7 % of benzene emissions in Europe. However, there are clear geographic patterns, e.g. higher emissions in Nordic countries where wood burning in the domestic sector is common. In Sweden the domestic contribution reaches over 50 %. Evaporation during fuel distribution also leads to benzene release. The only significant natural sources of benzene are biomass burning as well as bush and forest fires. However, these sources do not affect air quality in densely populated areas in the EU.

Chemical removal from the atmosphere can only be carried out by reaction with the hydroxyl (·OH) radical. Photo-oxidation contributes to ozone formation, although benzene reactivity is relatively low. A lifetime of several days at representative tropospheric ·OH concentrations is sufficient for benzene to be transported over long distances. Elevated concentrations in remote European sites can be observed as a consequence.

Chemical breakdown is thus important at regional level, but has negligible relevance at the urban level. The residence time of an air mass in a street canyon

is in the order of minutes, and in an urban area, a few hours; even in stagnant high pressure situations, as are frequent in southern and central Europe. Minor pathways of depletion in addition to chemical breakdown include surface adsorption on soil and particles, and solution in water (surfaces and rain). The latter is probably the second most important, and causes the transfer of benzene to surface water and into the food chain.

The second Daughter Directive (2000/69/EC) set an annual average concentration limit value of 5 µg/m^3 for benzene in ambient air, to be met by 2010. An EU working paper was commissioned to examine the sources and status of benzene (Working Group on Benzene, 1998) prior to directive agreement.

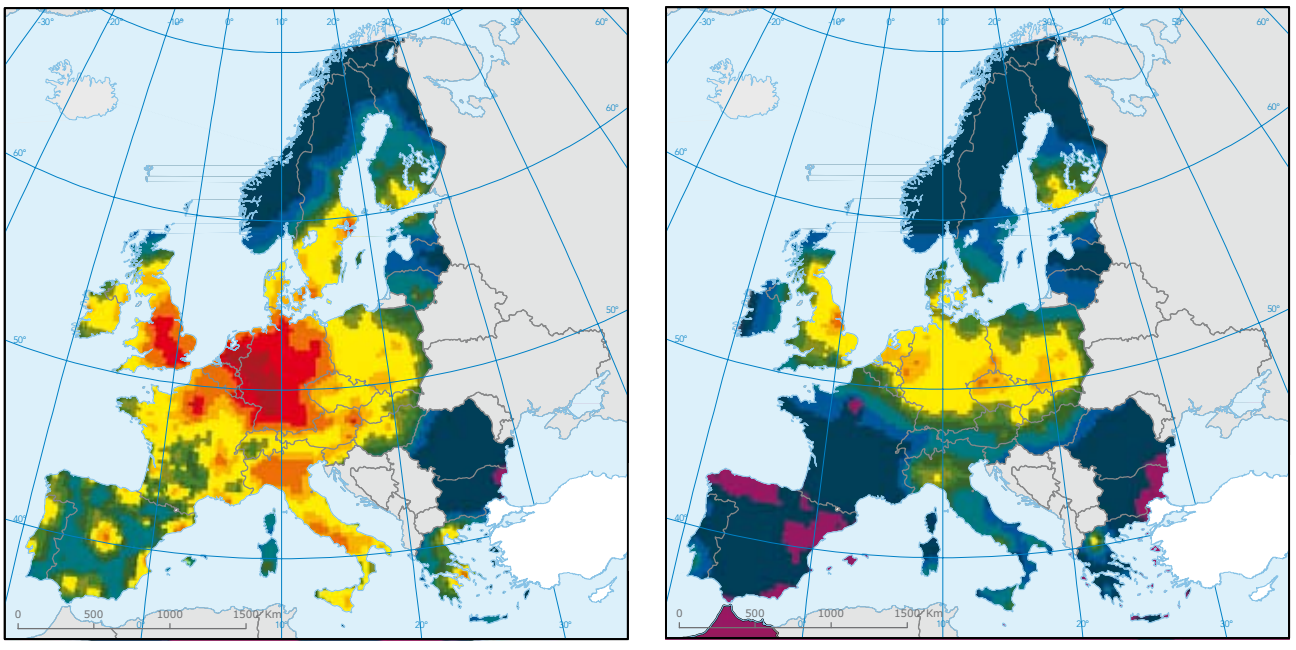
The genotoxicity of benzene has been extensively studied. Some studies in humans have demonstrated chromosomal effects at mean workplace exposures as low as 4–7 mg/m^3. *In-vivo* data indicates that benzene is mutagenic. Carcinogenicity has been established in humans, with increased mortality from leukaemia demonstrated with long-term exposure.

As a genotoxic carcinogen and with recent data suggesting mutagenic potential *in-vivo*, establishing exposure duration and concentration in human exposure studies is of major importance for the calculation of cancer risk. WHO's opinion on benzene is in line with the widely accepted precautionary approach that for genotoxic carcinogens safe exposure cannot be established.

3.5.2 Concentrations of benzene in Europe (2004) and distance-to-target

Observations for 2004 are presented in Figure 3.32 for a total of 129 stations in 12 countries. On average the benzene level was less than 40 % of the LV. Exceedances were measured at 3 stations, one in Greece (traffic), one in Romania (urban) and one in

Figure 3.31 Modelled decreases in NO_2 concentrations due to the introduction of European Road Vehicle emission standards (left) and the Large Combustion Plant Directive (right)



Note: Improvements are values above zero (positive decrease in NO_2 concentrations).

Source: EEA (ETC/ACC)/TNO.

the Czech Republic (industrial). Figure 3.33 presents the remaining distance to be covered to reach the target limit value.

3.6 Other compounds: heavy metals, PAHs, and carbon monoxide

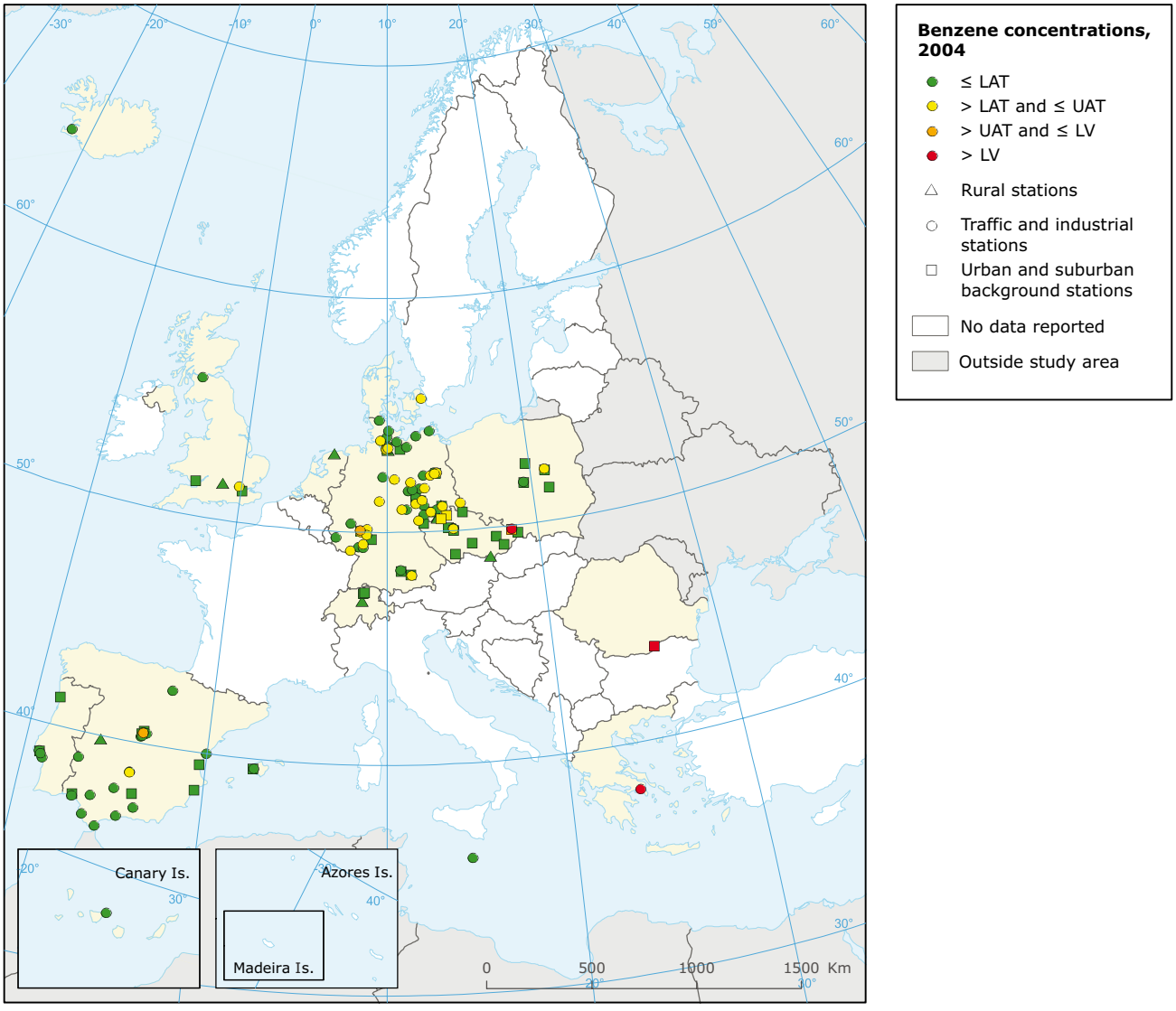
Key messages

- Due to the ban on the marketing of leaded petrol (1999), traffic is no longer a significant lead emission source. Isolated industrial sources have become the main polluters. Carbon monoxide is no longer an issue at the forefront.
- Cadmium and arsenic, which are mainly emitted by the industry and heating sectors, have the potential to exceed future standards in both urban and rural areas. Observed concentrations are notably above European background.

3.6.1 Emission changes

Between 1990 and 2004 emissions of lead in the EU-25 fell by approximately 90 % mainly due to the phasing out of leaded petrol (Figure 3.34). Emissions of cadmium have decreased by approximately 50 %, due largely to improvements in abatement technologies for incinerators, metal refining and smelting. Emissions of organic compounds are also

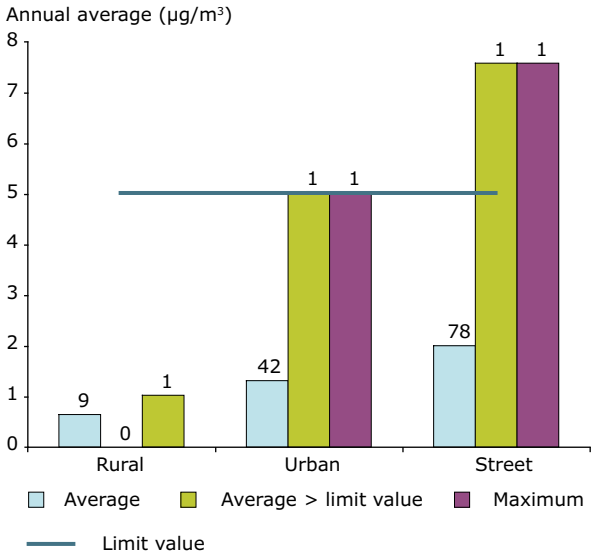
Figure 3.32 Benzene concentrations, annual average, at stations in Europe, 2004



Note: LAT/UAT: lower/upper assessment threshold; LV/MT: limit value/margin of tolerance.

Source: EEA (ETC/ACC).

Figure 3.33 Distance to target for benzene at urban and traffic stations, 2004



Note: 'Average' is across all stations, 'average > limit value' is average of stations exceeding the limit value, 'maximum' is the maximum station. Numbers above bars give number of stations in each category. Future limit value is 5 µg/m³.

Source: EEA (ETC/ACC).

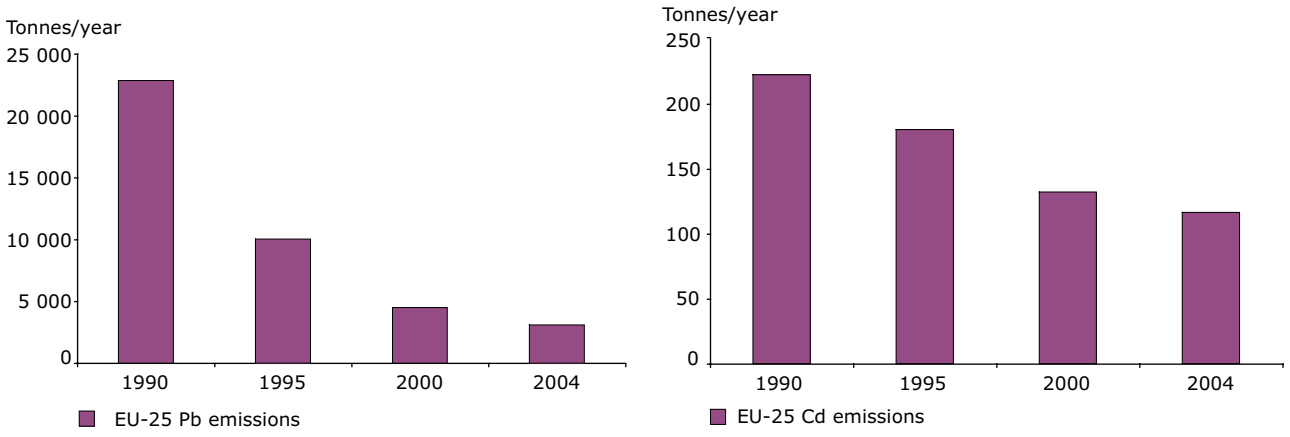
believed to have decreased across EU-25 since 1990, albeit less so, e.g. emissions of B[a]P (Table 3.2). The decline in emissions, which took place between 1990 and 2000 in EU-15 has now flattened, whereas in EU-10 emissions continued to rise to 200 tonnes per year (year 2000) before falling sharply. However, there is a greater degree of uncertainty surrounding heavy metal and POP emissions than, for example, acidifying compounds.

3.6.2 Concentrations in 2004

Lead and carbon monoxide: limit values have been set for lead and carbon monoxide, both limits to be applied from 2005. Figure 3.35 indicates the remaining distance to full compliance with air quality targets. In both cases reporting stations and geographical coverage are limited. The picture, although only indicative, suggests emissions from road traffic have diminished.

Following introduction of fuels free from lead additives, observed concentrations of lead in the atmosphere by 2004 were generally below target levels. Whereas some urban stations exceeded the

Figure 3.34 Trends in lead (Pb), and cadmium (Cd) emissions in EU-25, 1990–2004



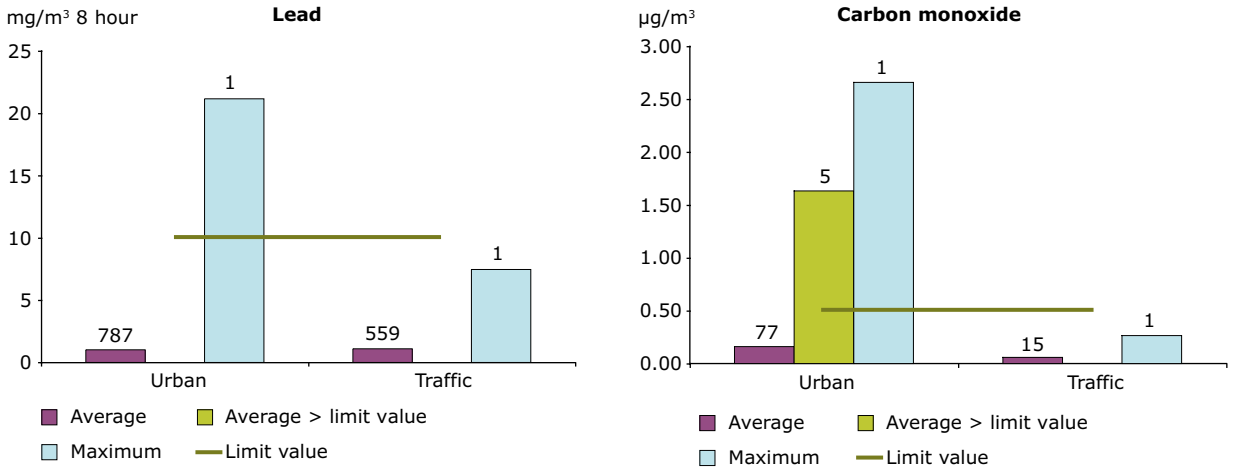
Source: EMEP.

Table 3.2 Emissions of benzo-(α)-pyrene (BaP), tonnes/year

Region	1990	1995	2000	2004	Change 1990–2004
EU-15	227	179	159	158	– 29 %
EU-10	122	135	103	91	– 25 %

Source: EMEP MSC-E (2007). http://www.msceast.org.

Figure 3.35 Traffic related toxics (2004): Distance to target for lead and carbon monoxide at urban and traffic stations



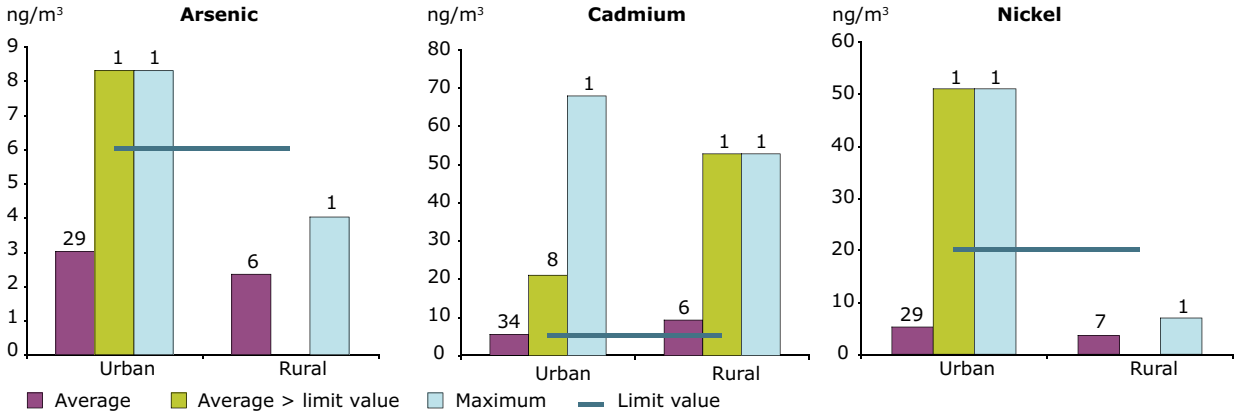
Note: The limit value is shown as a bold line, with observed concentrations as columns. 'Average' is average across all stations, 'average > limit value' is average of those stations exceeding the limit value, 'maximum' is the maximum station. Numbers indicate numbers of stations in each category.

Source: EEA (ETC/ACC).

target value, none of these were traffic monitoring stations; instead they were related to industrial emissions. All exceedances occurred in Romania. Furthermore, countries are not obliged to monitor in areas where problems are not suspected. The effect of this can be seen in the decline in traffic monitoring stations, down to 15 in 2004 from 59 in 2003 (and compared to 77 stations across urban areas in general). Observations similarly indicate that whereas carbon monoxide remains a major emission source from road traffic, the criteria for impact are no longer being exceeded at trafficked locations. Despite widespread monitoring, the single exceedance of the future target value was at a non-traffic urban location, suggesting that risk is now limited to a very few industrial sources.

Arsenic, cadmium and nickel: Industrial and space heating sources of emissions are the principal sources of three other toxics for which limits have been agreed from 2013 — arsenic, cadmium and nickel. In Figure 3.36 the 'distance-to-target' is

Figure 3.36 Distance to target (2004) for arsenic, cadmium and nickel at urban and rural stations



Note: 'Average' is average across all stations, 'avg > LV' is average of those stations exceeding the target value, 'max' is the maximum station. Numbers indicate category station numbers. Urban in includes all urban stations, trafficked or otherwise.

Source: EEA (ETC/ACC).

shown based on national data reports to AirBase (It should be noted that a very limited amount of data has been reported by countries to AirBase). This means that conclusions at this stage can only be indicative; a very small number of reporting stations means that overall averages can potentially be markedly influenced by outliers.

Arsenic observations exist for four countries. A single urban station in Slovakia was reported in 2004 as exceeding the intended target value. Otherwise, the mean urban and rural observations remain similar. Compliance with future cadmium targets is also widely expected, but is unclear from AirBase as some stations have not reliably been able to detect concentrations as low as the intended target value. Exclusion of these stations leaves only a number of stations in Romania exceeding the future standard. Whilst mean rural concentrations appear higher than mean urban, this picture is being driven by observations at a single site. It is anticipated that the actual mean rural observations will be below the limit value. Nickel observations show a similar pattern to those of arsenic — a single extreme exceedence in Belgium alongside otherwise very similar rural/urban concentrations below the target value.

Box 3.2 Case study: Arctic air pollution

- The atmosphere is a very significant long range transport route for pollutants found in the Arctic.
- European and further distant emission sources are responsible for a majority of the metal and persistent organic pollution in the Arctic.
- Exposure of indigenous people to harmful pollutants of atmospheric origin, e.g. mercury and PCBs, results from bioaccumulation and dietary habit.

Northern Europe forms a bridge between the heavily populated areas of central and southern Europe and the sparsely populated Arctic. From an environmental perspective, this bridge includes air and ocean currents as well as river systems connecting the two regions. The atmosphere is possibly the most significant long-range transport route for pollutants found in the Arctic (see Figure 3.37). Winter circulation patterns provide an effective conduit from the industrialised northern hemisphere regions of Europe and Siberia. Contamination released into the atmosphere in Europe can reach the Arctic within a matter of days. The polar night exacerbates the problem as the absence of sunlight inhibits photochemical degradation of some pollutants. Falling snow crystals efficiently scavenge pollutants and the spring melt then releases these contaminants, with additional pollutant loadings, via the large Arctic rivers. Whereas industry in and around the Arctic contributes significantly to contamination (e.g. from smelters on the Kola Peninsula and at Norilsk in Siberia), up to two-thirds of Arctic air pollution associated with some heavy metals and acidifying gases is attributed to emissions from Europe. The Arctic Monitoring and Assessment Programme (AMAP) has highlighted that most of the POPs derive from distant sources; the Arctic appears to be a unique sink for mercury. Current dietary exposure to these pollutants exceeds guidelines, thus posing a human health risk.

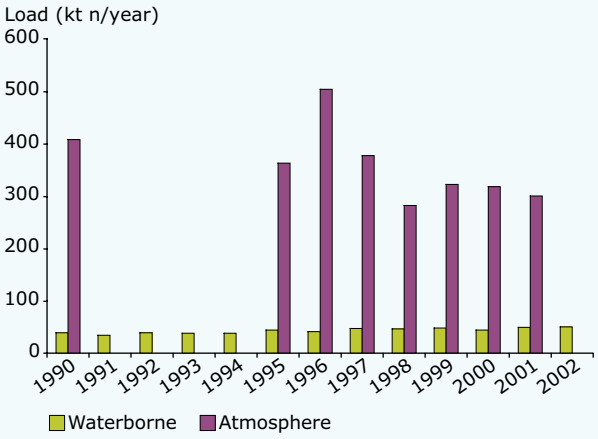
There was a 45 % decline in European emissions of mercury between 1990 and 2004 (see Figure 3.38). Observed air concentrations in the Arctic, which had declined and levelled out in the mid-1990s appear to have risen again after 2000. This is also seen in the deposition of mercury in precipitation (see Figure 3.39). In other words, the source of environmental pressure has been transferred from Europe to another part of the globe.

The Inuit of Greenland and Canada have some of the highest dietary exposures to mercury on Earth. Throughout the Arctic a large proportion of women have mercury levels in their blood which are significantly higher than levels set by regulatory authorities, such as the US EPA, Health Canada and others. Pregnant women and children are a special concern, as these contaminants pose a threat to a child's development, both in the womb and after birth. Recent studies in the Faroe Islands suggest that neuropsychological dysfunction in children, such as problems with fine motor control, mental concentration, language, visual-spatial abilities and verbal memory, are associated with elevated concentrations of mercury in the blood (EEA, 2003).

Heavy metal concentrations have in general remained largely unchanged since the early 1990s. Arsenic, cadmium and lead showed no decreasing trends in their observed air concentrations during the 1990s. Nickel, however, was an exception. It showed a significant decline of approximately 60 % from the early 1990s onwards. This is probably due to emissions control over industrial sources and reductions in coal burning.

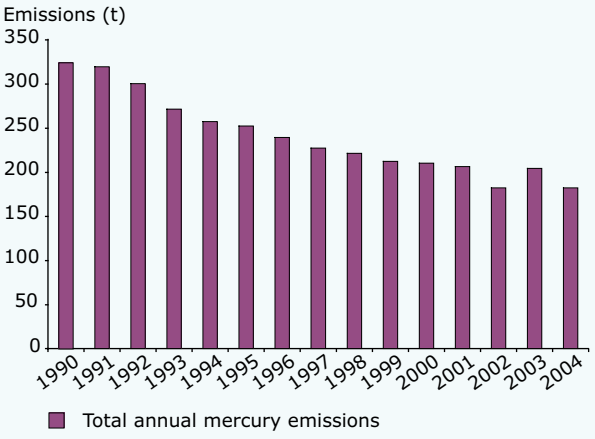
Box 3.2 Case study: Arctic air pollution (contd)

Figure 3.37 Comparative transport routes for nitrogen arriving in the Arctic waters of the North East Atlantic



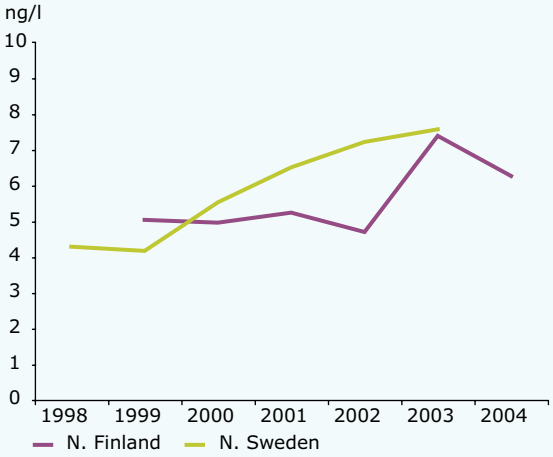
Source: OSPAR, 2005.

Figure 3.38 Emissions of mercury across the EEA-32 and the newly independent states, 1990–2004



Source: EMEP.

Figure 3.39 Observed concentrations of mercury in precipitation in the Arctic regions of Finland and Sweden



Source: AMAP Monitoring network, NILU.

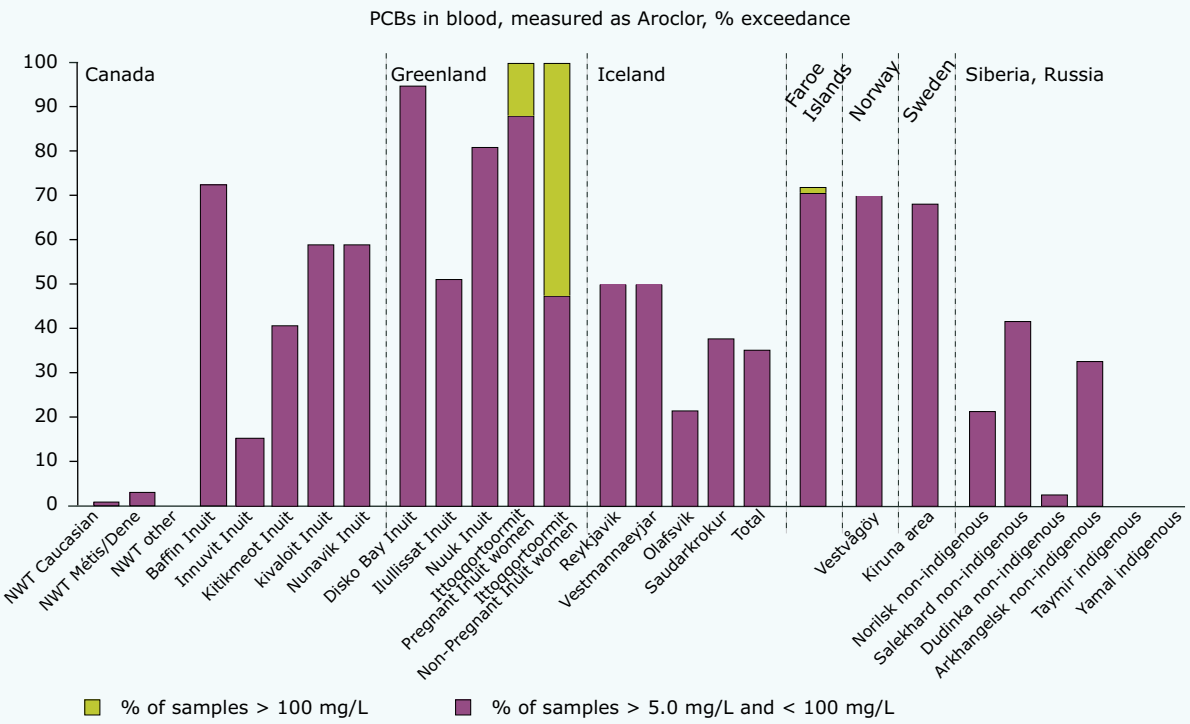
Among the longer studied or legacy **POPs**, downward trends have been observed in air concentrations of pesticides. This is notable for lindane in measurements made at Spitsbergen between 1993 and 2004; a period which parallels its phasing out in Europe (Note: France was the last country to cease use of lindane in 1998). For DDT, prohibited in Europe and North America over 30 years ago and already at low atmospheric concentrations by the early 1990s, the picture is less clear. Further declines before 2000 were significant, and there was even some increase up to 2002. The highest concentrations of lindane and DDT seen in Iceland and Spitsbergen occur in spring and summertime. The distant usage, e.g. in India and China, or the running down of stockpiles may be possible sources. For DDT, large scale counter-malaria campaigns in Asia and Africa are a major source of release. Higher concentrations in winter suggest that microbial breakdown under warmer conditions may be important.

Similarly, for PCBs no significant trend was observed in air concentrations during the 1990s. These industrial chemicals, which are highly persistent in the arctic environment, were prohibited in Europe in the 1980s but continue to be observed in the arctic air. Release into the air from the sea surface during the summer months and from large forest fires in Eurasia are believed to be significant. Bioaccumulation of PCBs in organisms, e.g. concentrations found in polar foxes, bears and seabirds, are sufficiently high enough to affect the immune defence and reproduction of those animals. Reduced reproduction has not only consequences for individuals but also for whole populations. Dietary habits mean that human blood PCB levels in Arctic areas are also very high, as shown in Figure 3.40.

'Newer' persistent organic compounds are becoming important. These emerging organic pollutants such as fluorinated compounds (e.g. PFOS) and brominated flame retardants (e.g. PBDEs) show an increasing trend in the arctic environment.

Box 3.2 Case study: Arctic air pollution (contd)

Figure 3.40 Blood PCB levels in humans, observed across the Arctic



Note: PCB levels in the blood of women of reproductive age. Percentage of samples exceeding public health levels for concern and action.

Source: EEA/AMAP.

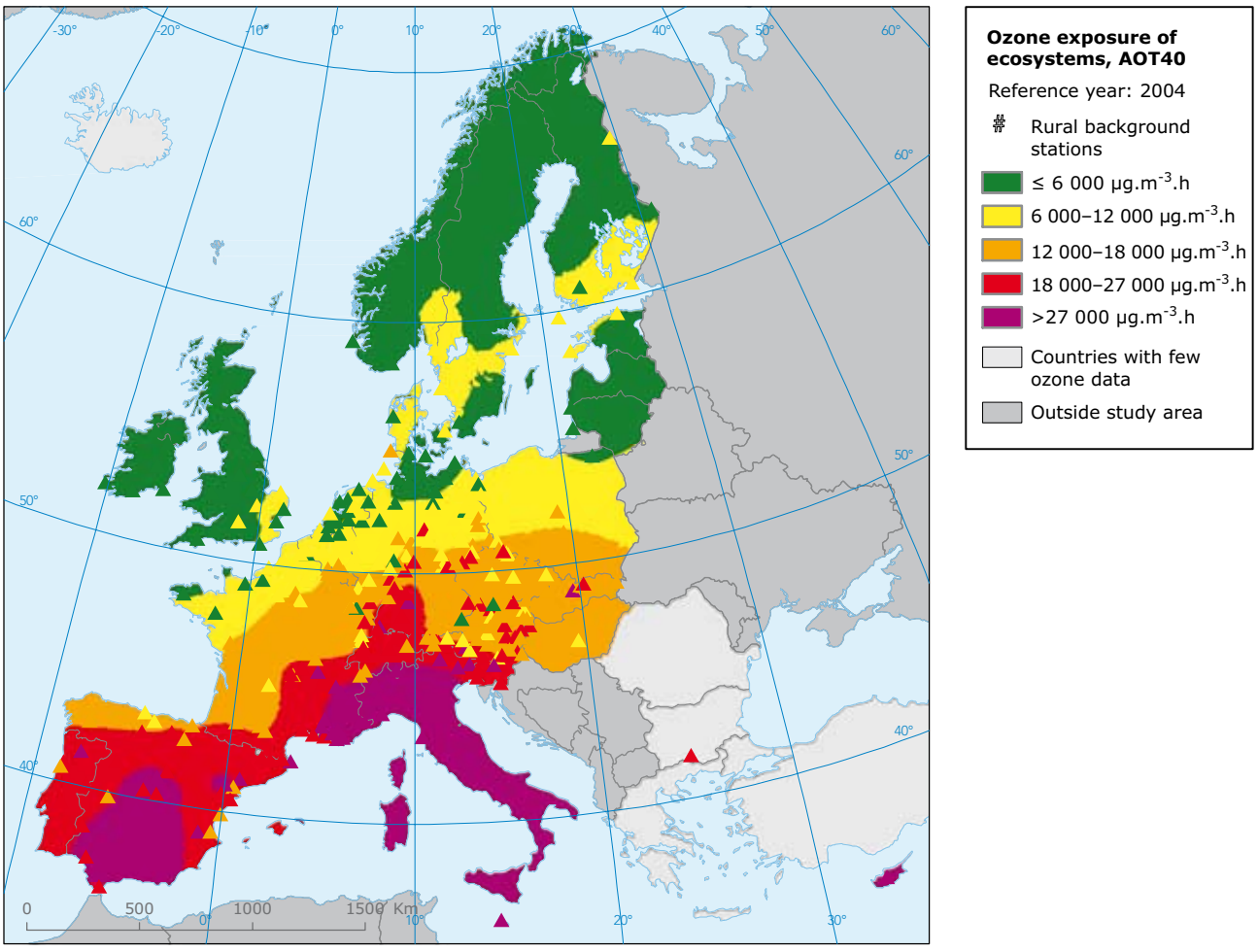
4 Ecosystems related Air Pollution Assessment

Key messages

- Acidifying emissions in Europe have declined substantially since 1990.
- Large areas in the north-east and south-east of Europe have seen clear declines in acid deposition and western areas have decreased, albeit more gradually.
- As sulphur emissions have fallen, nitrogen has become the predominant acidifying agent.
- Ozone concentrations have remained largely unchanged in recent years, even though emissions of precursor gases have been falling. The changing balance of pollutants in the atmosphere is not breaking down ozone as quickly as previously at some locations.

Exposure of vegetation to ozone exceeds criteria for protection over very large areas of central and southern Europe.

Figure 4.1 Ozone exposure of ecosystems, in terms of AOT40, 2004



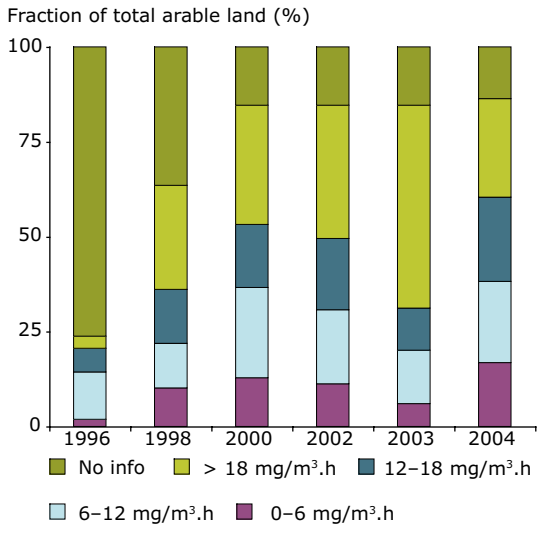
Source: EEA (ETC/ACC).

4.1 Overview

Deposition of sulphur and nitrogen compounds contributes to acidification of soils and surface waters, with leaching of plant nutrients and damage to flora and fauna. Deposition of nitrogen compounds can also exaggerate nutrient supply to the point of eutrophication, leading to disturbance of natural ecosystems, excessive algal blooms in coastal waters and increased concentrations of nitrate in ground water. Ozone, produced chemically in the atmosphere from nitrogen and volatile organic compound emissions, is an oxidant. Exposure of ecosystems and agricultural crops to ozone results in visible foliar injury and reduced crop yield and seed production.

The risk of damage is evaluated by comparing the estimated deposition of acidifying and eutrophying air pollutants and exposure to ground level ozone with the estimated capacity of each location to receive such pollutants without suffering harmful effects. This capacity or 'critical load' may be thought of as the threshold of air polluting compounds which should not be exceeded if ecosystems are to be protected from risk of damage. Thus, risk of damage occurs where pollutant supply exceeds the estimated critical load. In reality, critical load exceedance is a complex function of the supply of various pollutants and ecosystem, soil and water properties.

Figure 4.2 Ozone exposure of agricultural crops in EEA-32 relative to target levels



Source: EEA (ETC/ACC).

The approaches taken by the European Union and the UNECE to tackle acidification, eutrophication and ground level ozone aim to control the emissions of impacting or pre-cursor pollutants. Emissions of acidifying pollutants mainly occur from fuel combustion (NO_X and SO_2) and from animal husbandry (NH_3). These sources account for 95 % of emissions. The share of emissions from combustion sources in the EU-15 decreased from 75 % to 65 % (1990–2004), while the share of agricultural emissions increased. Eutrophying pollutants (NO_X and NH_X) and ozone precursors (NO_X and VOCs) emitted by the agriculture and transport sectors have adverse effects on ecosystem structure and function.

4.2 Tropospheric ozone

Key messages

- Large parts of the EEA-32 countries currently exceed exposure criteria for forests. More than half of the agricultural area exceeds criteria for crop protection, total crop yield losses reaching an estimated EUR 3 bn per annum in 2000.
- Since 2000 the exposure of crops has not been reduced. Furthermore, in a number of areas ozone concentrations have actually increased in recent years. Adverse meteorology and the changing balance of airborne pollutants lie behind this.
- Implementation of current legislation is expected to reduce current crop yield losses by approximately 50 % to EUR 1.5 bn per annum in 2020. Large areas of central and southern areas are also expected to continue to exceed forest protection criteria. For at least the next decade vegetation exposure to ozone is expected to remain well above long term objectives.

4.2.1 Impact of ozone

For vegetation under European conditions, it is the long term cumulative exposure to ozone during the growing season which is of concern and not episodic exposure. The common measure, AOT40 (accumulated hours of ozone over a threshold of 40 ppb), has an average period of three months for agricultural crops and six months for forest and natural ecosystems. The UNECE then specifies a no-effect critical level of exposure of 5 ppm hours for forest. According to modelled AOT40 for forest for the year 2000, exceedances of the

critical level are estimated for large parts of the EEA-32, especially in southern and central parts (Amann *et al.*, 2004). Assuming that emission abatement measures established by European current legislation are effective, modelled emission reductions by 2030 will improve the situation. However, they will not eliminate the risk of ozone damage. Total crop yield losses from ozone exposure for the EU-25 in the year 2000 are estimated at just under EUR 3 billion/year, reducing to about EUR 1.5 billion/year by 2020 (CAFE, 2005).

4.2.2 Observed concentrations, 2004

The influence of ozone on crops or ecosystems requires information from rural background stations and not from urban areas, where local influence is of relevance. In 2004, data for 408 rural stations were reported; this number has increased from 252 stations in 1997. The target value set in the ozone directive for protection of crops is 18 000 (µg/m^3) hours (corresponding to 9 ppm.hours) by 2010. The long-term objective is to reach 6 000 (µg/m^3) hours (corresponding to 3 ppm.hours).

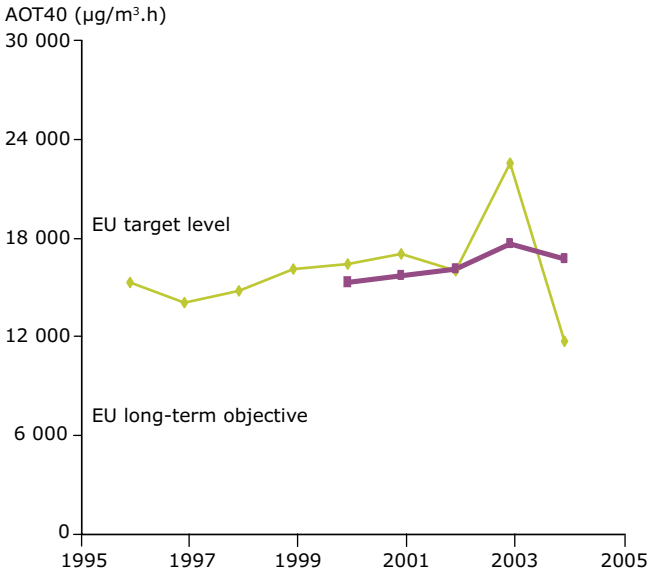
Approximately 26 % of a total area of the total EEA-32 agricultural area of 2.05 million km^2 exceeded the target value in 2004 (Figures 4.1 and 4.2). Exceedances were notable in southern, central and eastern Europe. The long-term objective is currently met in only 17 % of the total agricultural area, mainly in the United Kingdom, Ireland and the northern part of Scandinavia.

4.2.3 Trends in ozone exposure

Observed concentrations indicate increasing ecosystem exposure with significant variation. Over the period 1996–2004, most of 212 stations showed no significant trend (150 stations) and a quarter of stations showed a significant upward (54 stations) or downward trend (8 stations). Most stations are located in NW Europe (Austria, Czech Republic, Germany the Netherlands and the United Kingdom), with few located around the Mediterranean Sea. Thus, the selected stations are not representative for the whole of Europe.

Exposure of vegetation to ozone concentrations in the next decade is expected to remain well above the long-term objective despite emission reductions through EU legislation and UNECE protocols; by 2010 the closure of the gap between current exposure levels and the long-term objective is expected to be only 50 %.

Figure 4.3 Annual variation in the ozone AOT40 value (May–July)



Note: Average values over all rural stations which reported data over at least six years in the period 1996–2004. The thick line corresponds to the 5-year averaged value.

Source: EEA (ETC/ACC).

4.2.4 Policy effectiveness

Ozone control for ecological protection is equivalent to control for health protection. The principal measures taken and their effectiveness have been described in Section 3.2.5.

4.3 Acidification

Key messages

- Acidifying emissions have declined substantially in Europe, although less so in transport and agriculture which now represent 50 % of total acidifying emissions. Sulphur emissions have declined to the extent that nitrogen is now the principal acidifying component.
- There has been a clear decline in deposition of acidifying substances in north-east and south-east regions. Western Europe, however, has witnessed much smaller declines.
- Whereas the deposition of acidifying substances is greatest in central and southern areas of Europe, the greatest ecosystem impact caused by deposition continues to be felt in the north-west and central regions.

4.3.1 *Impact of acid depositions*

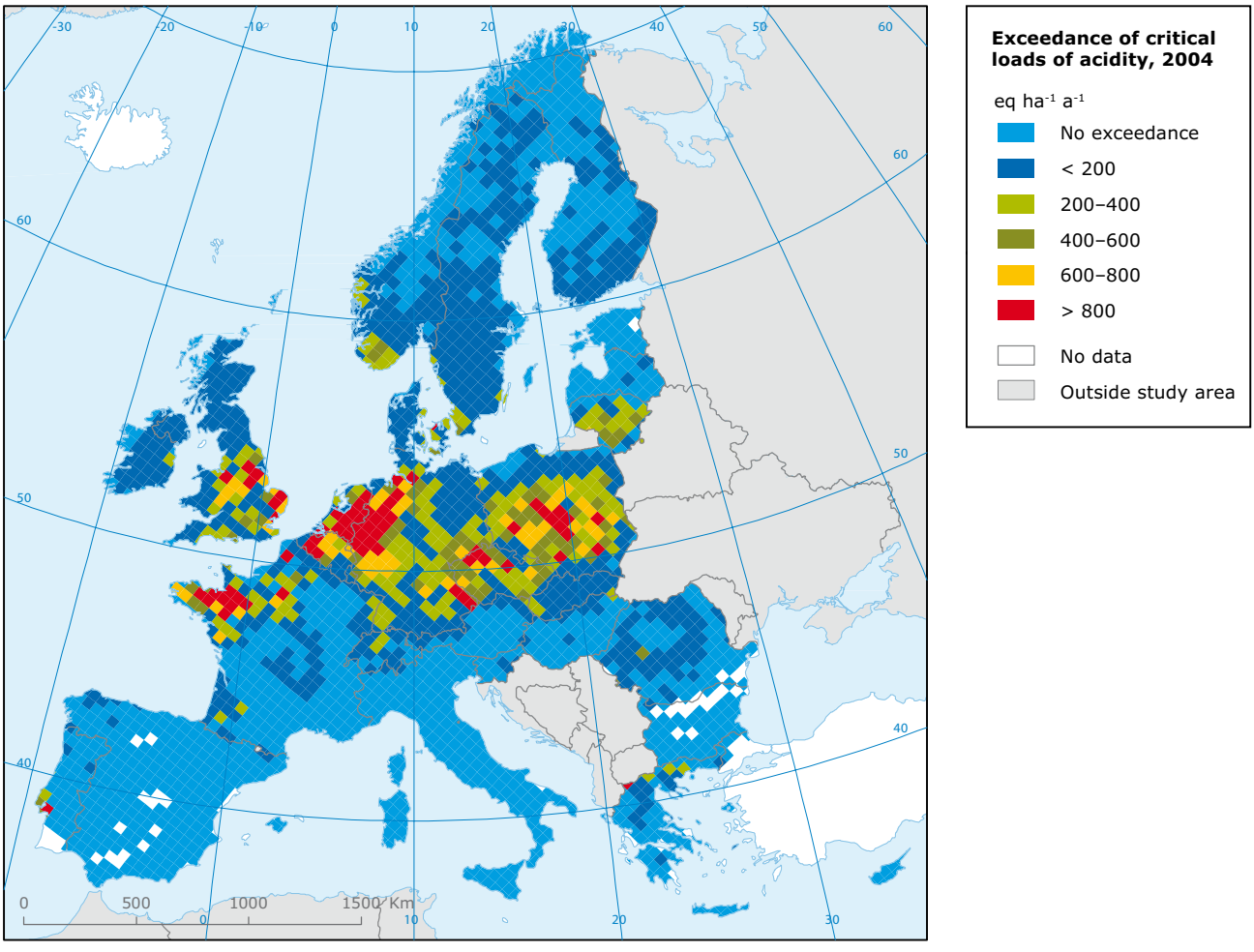
Critical loads of sulphur and nitrogen acidity for an ecosystem is defined as: 'the highest deposition of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on ecosystem structure and function' (Nilsson and Grennfelt, 1988).

The pattern of acidification through air pollution in Europe is shown in Figure 4.4. The problem of exceedance of critical loads of acidity continues to be focused in north-western and central Europe. Across the EU-25, the proportion of (semi-)natural ecosystem areas subject to acid deposition beyond their critical load was approximately 15 % in 2004 ([5]) (for details on critical load mapping see ICP M&M, 2004). It should be noted that inter-annual variability in acid deposition can be as much as one fifth.

4.3.2 *Comparison with emission changes and distance-to-target*

Emissions from the EU-10 are reported to have declined strongly, which would appear to be in line with decreases in depositions to the Baltic region.

Figure 4.4 Exceedance of critical loads of acidity, EMEP 2004 deposition data



Note: This map shows areas in Europe where ecosystems are exposed to atmospheric loads of acidity (sulphur plus nitrogen compounds) that are greater than the critical load for the most sensitive ecosystems in each 50 x 50 grid cell.

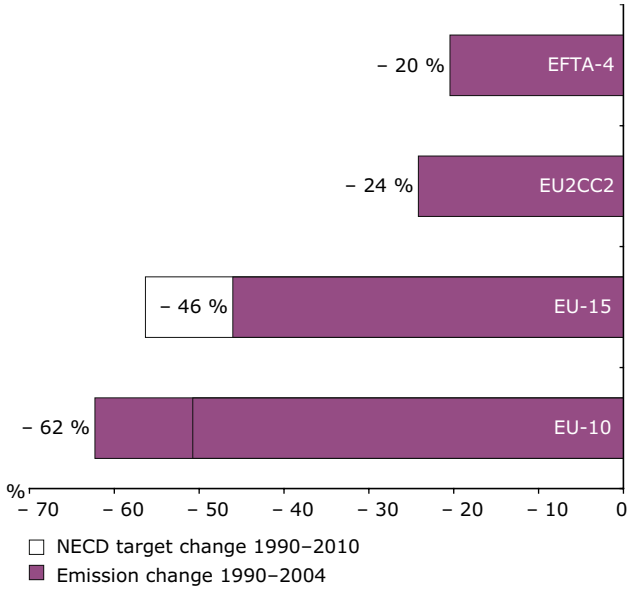
Source: CCE.

([5]) Here the term exceedance refers to the 'average accumulated exceedance' (AAE) of critical loads expressed as the ecosystem area percentage (%) that is unprotected from acidification. AAE is the area-weighted average of exceedances accumulated over all ecosystem points in a grid cell for which critical loads data has been reported to the EMEP Co-ordination Centre for Effects. AAE does not only refer to the exceedance of the most sensitive ecosystem.

Declines in emissions from Balkan candidate countries would also appear to be in agreement with observed wet deposition changes in the region. Across western parts of Europe, however, decreases in acidifying deposition are rather low despite the fact that sulphur emissions have declined strongly everywhere. The explanation lies in the difference between nitrogen emission trends. Whilst nitrogen emissions have fallen in the EU-10 (albeit less significantly than sulphur), the decrease in emissions in the EU-15 has been lower. Nitrogen has grown in relative significance as an acidifying agent in many western areas, as a result of sulphur abatement at most industrial combustion facilities.

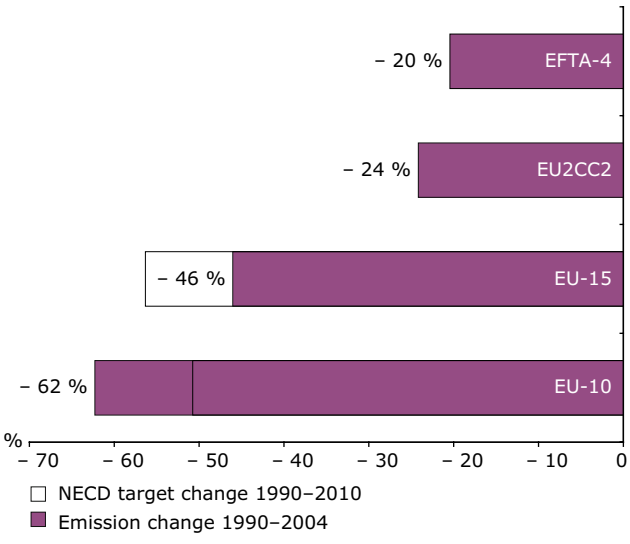
For the EU-10 and the EU2CC2 (excluding Turkey) acid emissions targets have already been met (Figure 4.5). The NIS is at a similar level of reduction. The EU-15 has also made good progress towards the 2010 NECD target for acidification, but additional efforts are still required. The main contributions to emissions reductions to date are from Germany (42 % of total EU-15 reduction) and the United Kingdom (26 % of total EU-15 reduction). Finland, Denmark, Luxembourg, Italy, Belgium and the Netherlands have also made good progress towards their targets.

Figure 4.5 Percentage changes in emissions of acidifying substances (SO_2, NO_X and NH_3) over the period 1990 to 2004, and comparison with NEC Directive targets



Source: EEA (ETC/ACC).

Figure 4.6 Percentage changes in eutrophying nitrogen emissions since 1990



Source: EEA (ETC/ACC).

4.4 Eutrophication

Key messages

- Across the EU-25, the proportion of (semi-)natural ecosystem areas subject o nutrient nitrogen deposition beyond their critical load was approximately 47 % in 2004.
- Decreases in eutrophying deposition of air pollutants have been modest since 1990. Across much of Europe declines have reached less than 20 %. This is broadly equivalent to changes estimated for emissions of nitrogen.

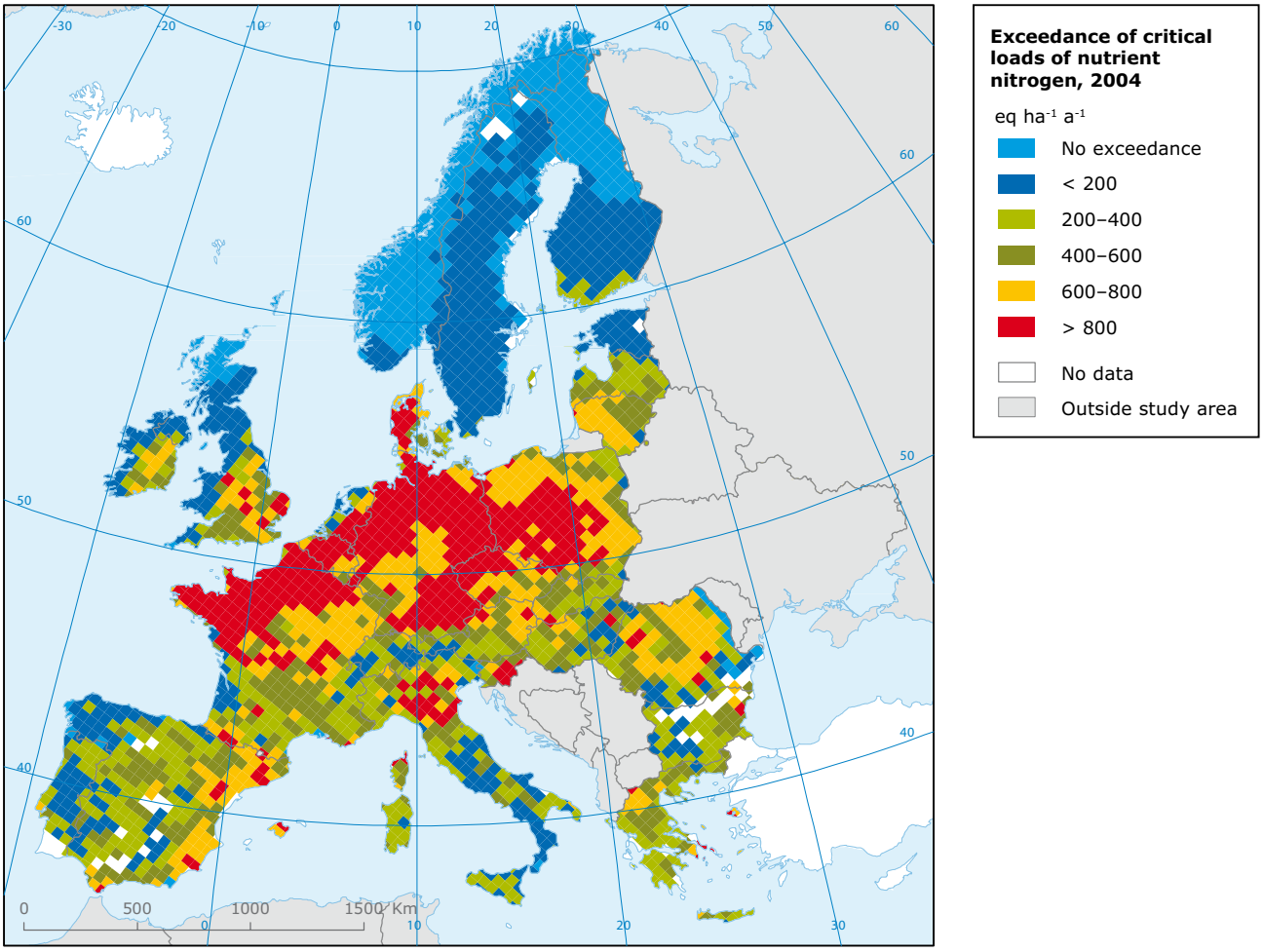
4.4.1 Impact of eutrophying depositions

The critical load of nutrient nitrogen is defined as 'the highest deposition of nitrogen as NO_X and/or NH_Y below which harmful effects in ecosystem structure and function do not occur according to present knowledge' (ICP M&M, 2004).

The excess supply of nitrogen, such that its fertilising nutrient quality may be outweighed by the resulting ecological disturbance and biodiversity loss, is shown in Figure 4.7. The pattern of exceedance of critical loads, which leads to eutrophication, shows that the focus remains on north-western continental Europe.

Across the EU-25, the proportion of (semi-)natural ecosystem areas subject o nutrient nitrogen

Figure 4.7 Exceedance of critical loads of nutrient nitrogen, 2004 EMEP NO_3-N and NH_4-N deposition data



Note: This map shows areas in Europe where ecosystems are exposed to atmospheric loads of nitrogen (NO_3-N and NH_4-N) that are greater than the critical load for the most sensitive ecosystems in each 50 x 50 grid cell.

Source: CCE.

deposition beyond their critical load was approximately 47 % in 2004 ([6]).

4.4.2 Comparison with emission changes

Over the period 1996 to 2004 the EU, NIS and EFTA countries have all seen 25 % to 20 % reductions in nitrogen emissions, accession/candidate countries as a whole lagging slightly at 12 % (Figure 4.6).

One explanation can be that nitrogen has a relatively long atmospheric lifespan and is subject to long-range transport. Distant sources from as far away as North America still contribute significantly to deposition.

([6]) Here the term exceedance refers to the 'average accumulated exceedance' (AAE) of critical loads expressed as the ecosystem area percentage (%) that is unprotected from eutrophication. AAE is the area-weighted average of exceedances accumulated over all ecosystem points in a grid cell for which critical loads data has been reported to the EMEP Co-ordination Centre for Effects. AAE does not only refer to the exceedance of the most sensitive ecosystem.

Box 4.1 Case study: Airborne contamination of the seas

- The scale of atmospheric deposition of pollutants to marine areas is frequently of the order of, or greater than, pollutant supplies through rivers.
- Nitrogen depositions to marine areas do not show a strong trend. However, although river inputs have declined the proportion arriving from the skies may have risen in recent years.
- Deposition of heavy metals into the North Sea has declined as European emissions have dropped.
- For some organics, such as the pesticide — lindane, the atmosphere is the principal supply route. Despite bans on its production and use within Europe, there is evidence of continued deposition.

Coastal zones are, by their nature, the interface and interplay between the terrestrial, marine and atmospheric environments. Their significance in Europe reflects a geography characterised by enclosed and semi-enclosed seas. Being densely populated by economically and culturally diverse societies, European coastal and marine environments are subject to significant anthropogenic driving pressures; pollutant discharges constitute one such pressure.

Often overlooked in deference to fluvial sources, deposition from the skies can sometimes dominate as the source of pollutants. Furthermore, as atmospheric transport can be on regional and hemispheric scales, the geographical dimension of source regions for pollutants depositing on the European sea surface can be far wider than the usual drainage basin scale focus of management.

However, many areas have little or no information on pollutant input from the atmosphere; at best we can only estimate general tendencies. This box draws on regions with observation programmes to indicate both the scale of pollutant deposition and the anticipated effectiveness of air pollution abatement measures across European coastal and regional seas.

Magnitudes of air inputs

For nitrogen, inter-governmental agencies have long estimated that the atmosphere delivers 30–40 % of all anthropogenic inputs to European regional seas (Table 4.1). This proportion is believed to have increased since the mid-1980s. Whereas river and directly discharged nitrogen inputs to the North Sea have fallen by approximately 30 %, atmospheric inputs have remained static (OSPAR, 2000). For sea areas farther away from land, the atmospheric contribution is larger. By 2000, the atmosphere was estimated to deliver approximately six times more nitrogen to Arctic waters than rivers (see Figure A.1, 'Arctic air pollution' box).

Atmospheric inputs of other pollutant inputs also dominate. For example, the atmosphere supplies as much as 85 % of the pesticide lindane found in the Baltic Sea as a whole (Breivik and Wania, 2002; Table 4.2). Mercury is another pollutant for which the atmosphere is the overriding pathway of delivery.

In mining areas, the rivers have long been the major source of local marine pollution, to the point where river names reflect the issue, e.g. the Rio Tinto in Spain, and the Red River in Cornwall, United Kingdom. However, this claim may have been overstated. For example, Table 4.3 shows the quantities of metals entering the western Mediterranean from the Rio Tinto and the atmosphere, and shows that the atmosphere can be of comparable significance to rivers even in heavily mined regions.

Table 4.1 Estimates from OSPAR and HELCOM of the proportion of nitrogen inputs to the North Sea/north-east Atlantic and the Baltic from atmospheric transport

Sea area	Contaminant	Atmospheric proportion of total
North Sea ([a])	Reduced nitrogen	32 %
	Oxidised nitrogen	37 %
Baltic ([b])	Total nitrogen	31 %

Source: a) OSPAR, 2000, b) HELCOM, 1996.

Box 4.1 Case study: Airborne contamination of the seas (contd)

Table 4.2 Relative importance (%) of rivers and the atmosphere in supply of lindane to various parts of the Baltic Sea

	Atmospheric deposition	Riverine inflow
Gulf of Finland	68	32
Gulf of Riga	52	48
Baltic Proper	88	12
Skagerrak	91	9
Whole Baltic Sea	85	15

Source: Breivik and Wania, 2002.

Table 4.3 Contaminant flows to western Mediterranean, tonnes/year

	Cu	Zn	Cd	As
Rio Tinto and other rivers	2 230	6 430	103	6 500
Atmosphere	600–1 200	3 200–5 100	35–60	

Source: Elbaz-Poulichet *et al.*, 2001.

Are pollutant depositions into the seas decreasing?
Various strategies have been established for the protection of the marine environment. The aim of the European Marine Strategy (EC, 2002) is '...to ...reduce ...emissions, and losses ...to the marine environment ...'. In some cases targets have been set. For the Baltic, HELCOM have agreed a 50 % reduction target for nitrogen input. A key question is whether we are achieving these policies.

In Figure 4.8 the estimated deposition of nitrogen to the North Sea over the past 15+ years is displayed. Changes appear to have been weak. Similarly, computer calculations for areas remote from observation points have shown very restricted change since the mid-1990s. One reason could be that the atmospheric transport of nitrogen (including hemispheric transport) is too great to allow European emissions to fully dictate nitrogen deposition to the sea. Uncertainties in emission inventories could be another factor (e.g. uncertainties in emissions from diffuse sources in the agricultural sector).

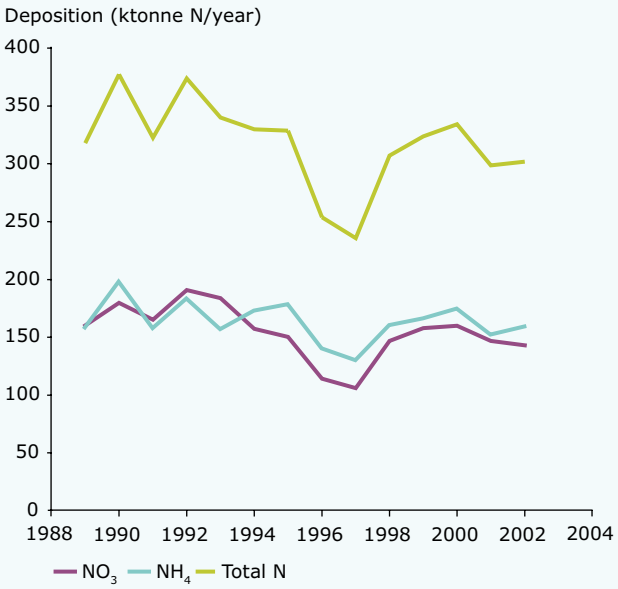
An uncertain picture can also be drawn for metal pollutants. Whereas emissions have decreased, changes in deposition of heavy metals into the North Sea have varied (Figure 4.9). The representativeness of monitoring sites, i.e. an unfortunate choice of sites, could be one reason. There has been a clear drop in lead, in accordance with the removal of lead from petrol, whilst observed changes for all other metals are frequently insignificant. For most metals, such as cadmium, copper, etc. there is a weak or no clear change. For zinc, depositions have increased (Figure 4.9).

An uncertain picture is also found for some organic pollutants subject to control. The value of the observation network around the North Sea is seen in the case of lindane. Primarily an atmospheric pollutant and banned across Europe since the late 1990s, an observable peak in depositions around the southern North Sea coast has occurred each spring (Figure 4.10). Far distant sources contribute to some of this (e.g. from Asia), but the magnitude of the peak indicates continued local use despite prohibition. The fact that the peak is declining over time, suggests a possible rundown of stockpiles.

Summary
The atmosphere is found to be a significant pathway for a number of pollutants deposited in the European marine environment. This is true for nutrients, metals and organic compounds. For some regions, such as the North Sea and the Baltic Sea, established monitoring and modelling programmes go some way to revealing the extent of the atmospheric pollutant supply. In these regions, declines in deposition have not necessarily been as great as one had hoped. For other regions, there is no such regular surveillance and patterns of pollutant supply can only be extrapolated from elsewhere.

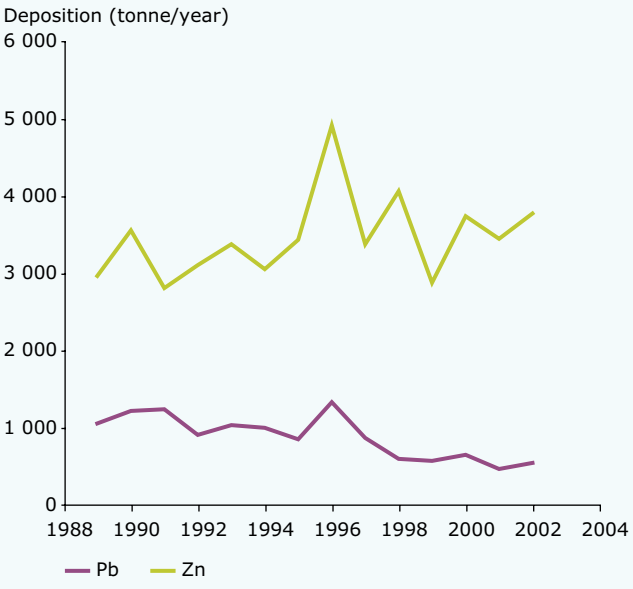
Box 4.1 Case study: Airborne contamination of the seas (contd)

Figure 4.8 Observed depositions of nitrogen to the North Sea



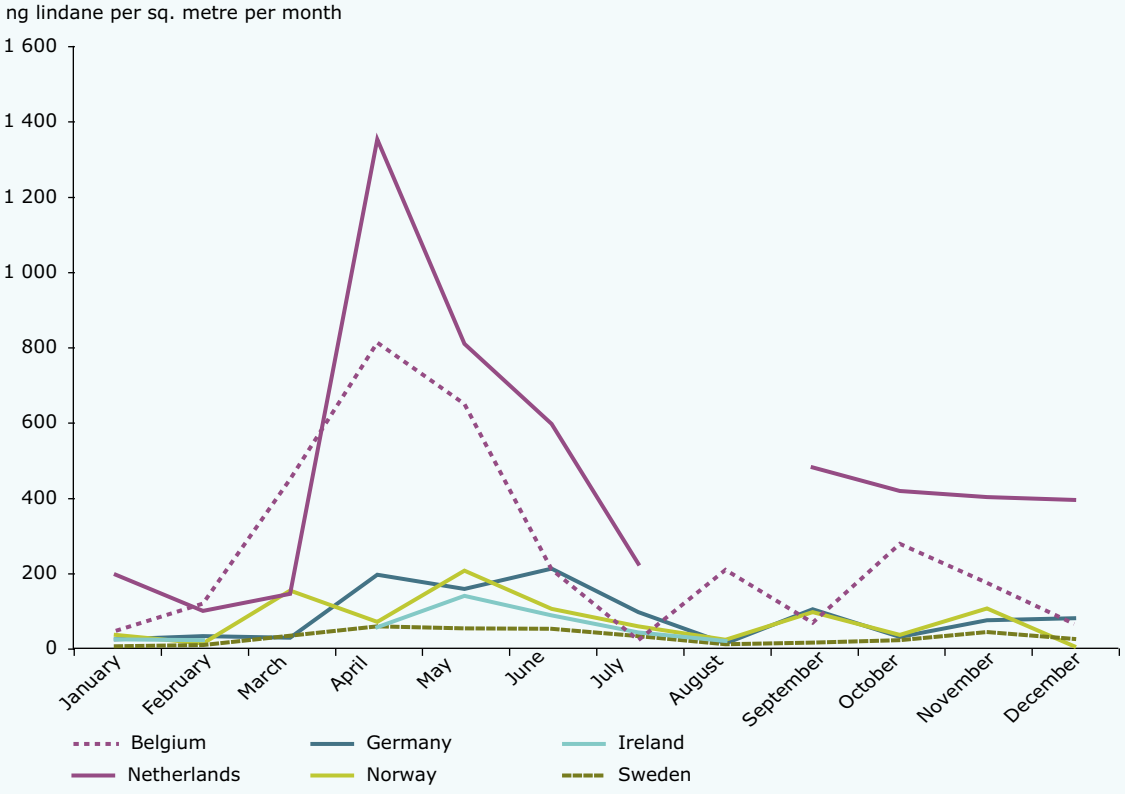
Source: OSPAR, 2005.

Figure 4.9 Observed depositions of lead and zinc to the North Sea



Source: OSPAR, 2005.

Figure 4.10 Observed coastal lindane deposition, 2003



Source: OSPAR, 2005.

4.5 Effectiveness of policy measures to reduce acidification and eutrophication through air pollution

4.5.1 Emission reductions

The emissions of acidifying pollutants in the EU-25 decreased by about 0.6 million tonnes of acidifying equivalents between 1990 and 2004.

The following conclusions can be drawn:

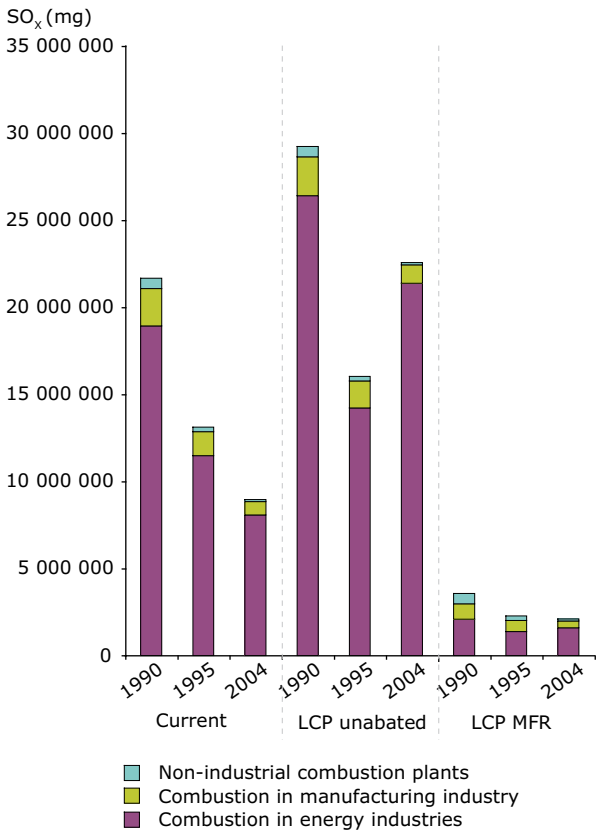
- Population growth would have resulted in an increase of 0.05 million tonnes of acidifying equivalents, if the per capita emission would not have been changed between 1990 and 2004.
- Economic growth would have caused an additional increase of about 0.3 million tonnes
- The fuel use has not increased as much as the economic activity, resulting in a decrease of emissions of approximately 0.3 million tonnes.
- The shift towards lighter fuels resulted in an additional decrease of about 0.1 million tonnes.
- Pollutant specific abatement measures further decreased the emissions:
  - Of SO_X by 0.5 million tonnes;
  - Of NO_X by 0.1 million tonnes.

An important EU policy measure to reduce the effects of acidification is the Large Combustion Plant Directive. The LCP Directive mainly resulted in a decrease of SO_2 emissions from energy industries, i.e. from power plants and refineries (Figure 4.11).

We observe the following from Figure 4.11:

- If the abatement measures for large combustion plants ('LCP unabated') had not been implemented, the emissions from large combustion plants would have increased to almost 22 Mt by 2004.
- Since part of the large combustion plants already complied with the LCP Directive, the emissions in 1990 would have been almost 8 Mt higher than the actual ones ('Current situation').

Figure 4.11 The estimated effect (for EU-25) of introduction of the Large Combustion Plant Directive on the emission of SO_2



Source: EEA/IIASA (RAINS model).

- Estimates calculated by the RAINS Model have shown that if the most stringent abatement technology (LCP most feasible reduction) had been implemented from 1990 onwards, the emissions from large combustion plants would have been more than a factor of four lower than the actual emissions in year 2004.

Abbreviations

AOT40	Accumulated Ozone over a threshold of 40ppb
AQFD	Air Quality Framework Directive
AQDD	Air Quality Daughter Directives
BeNeLux	Belgium, Luxembourg and the Netherlands
CAFE	Clean Air for Europe
CH_4	Methane
CLE	Current legislation
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO	Carbon monoxide
EoI	Exchange of Information Decision
EEA	European Environment Agency
EEA-32	32 members countries of the EEA (EU-15 + EU-10 + EFTA-4 + Romania, Bulgaria and Turkey)
EFTA	European Free Trade Association
EFTA-4	Iceland, Liechtenstein, Norway, Switzerland
EMEP	Cooperative programme for the monitoring and evaluation of the long range transmission of air pollutants in Europe (European monitoring and evaluation programme)
EU	European Union
EU-2	Bulgaria and Romania
EU-15	The 15 pre-2004 EU Member States
EU-10	The 10 countries that joined the EU in 2004
EU-25	The pre-2007 EU Member States
EU2CC2	Bulgaria, Rumania and Candidate Countries (EU)
FAO	Food and Agricultural Organisation
GDP	Gross domestic product
IPCC	Inter-Governmental Panel on Climate Change
LCP	Large combustion plant
LPG	Liquified petroleum gas
LV	Limit value
MFR	Maximum feasible reduction
NECD	National Emission Ceilings Directive
NH_3	Ammonia
NIS	Newly Independent States
NMVOC	Non-methane volatile organic compounds
NO	Nitrogen monoxide
NO_X	Nitrogen oxides
NO_2	Nitrogen dioxide
O_3	Ozone
OSPAR	Oslo and Paris Commission for Protection of the North Atlantic
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
PM	Particulate matter
$PM_{0.1}$	Particulate matter with an average aerodynamic diameter of up to 0.1 µm, referred to as ultrafine particle fraction.
$PM_{2.5}$	Particulate matter with an average aerodynamic diameter of up to 2.5 µm, referred to as the fine particle fraction (which per definition includes the ultrafine particles)
PM_{10}	Particulate matter with an average aerodynamic diameter of up to 10 µm, i.e. the fine and coarse particle fractions combined.
POP	Persistent organic pollutants
PPM	Primary particle matter
SI	Secondary inorganic
Silesia	Southern part of Poland and neighbouring small parts of Germany and the Czech Republic
SOMO35	For ozone, the Sum Of Means Over 35 ppb (daily maximum 8-hour)
SO_2	Sulphur dioxide
TOFP	Tropospheric ozone forming potential
TV	Target value
TWC	3-way catalyst
UN-ECE	United Nations Economic Commission for Europe
VOC	Volatile organic compounds
WHO	World Health Organization

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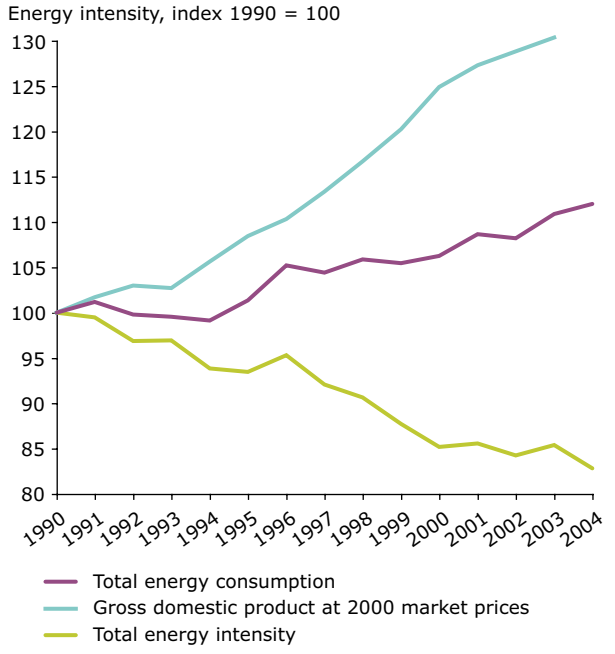
Annex A — Driving forces for air pollution

The driving forces behind air pollution are directly associated with human activities. One measure for those activities is the number of people and their activity as reflected by gross domestic product (GDP). More specifically, energy consumption, industrial activities, transport demand and agriculture husbandry are the driving forces which are most directly linked to air emissions. The development of these driving forces determines the development of the potential for air pollutant emissions. This potential is then modified by abatement policies to limit the emissions associated with the driving forces.

In this section we will address indicators on these driving forces. All material comes from the EEA core set of indicators, with latest updates from Eurostat and FAO.

Figure A.1 Total energy intensity, EU-25



Source: EEA (ETC/ACC).

Population and GDP

Europe's population is growing slowly and ageing; there has been small total increase in the EU-15 and small decrease in the new EU-10. The economy (expressed in GDP; see Figure A.1) in the EU-25 is growing faster than the population, indicating an increase in per capita economic production. The economies of the EU-10 are growing faster than those of the EU-15. Whereas population growth is slow, the number of households is rapidly increasing: ~ 11 % between 1990 and 2000. The majority of new households are small, reflecting social and lifestyle changes.

Energy consumption

Total energy consumption in the EU-25 grew at an annual rate of just above 0.8 % from 1990 to 2004, while gross domestic product (GDP) grew at an estimated average annual rate of 2.3 % (Figure A.1). As a result, total energy intensity in the EU-25 fell at an average rate of 1.2 % per year. Despite this relative decoupling of total energy consumption from economic growth, total energy consumption increased by 12 % over 1990–2004.

Over the period 1995–2004, all EU-25 Member States with the exception of Portugal and Austria experienced a decrease in total energy intensity; the increases in Portugal and Austria are marginal, total energy intensity in 2004 being less than 1 % higher than 1995. The average annual decrease from 1995 was 3.4 % in the EU-10 and 0.9 % in the EU-15. Despite this converging trend, total energy intensity in the EU-10 was still significantly higher than in the EU-15 Member States in 2004.

Final energy consumption ([7]) in the EU-25 increased by 12.7 % between 1990 and 2004 (Figure 1.5.2) despite significant changes in its structure in recent years. In terms of energy consumption,

([7]) Final energy consumption: energy consumption of the transport, industry, household, agriculture and services sectors.

transport was the fastest growing sector in the EU-25 between 1990 and 2004, final energy consumption increasing by 28.0 %. Services (including agriculture) and households' final energy consumption grew by 12.5 % and 17.6 % respectively whereas in the industry sector it fell by 4.5 % over the same period. These developments meant that by 2002, transport was the largest consumer of final energy, followed by industry, households and services.

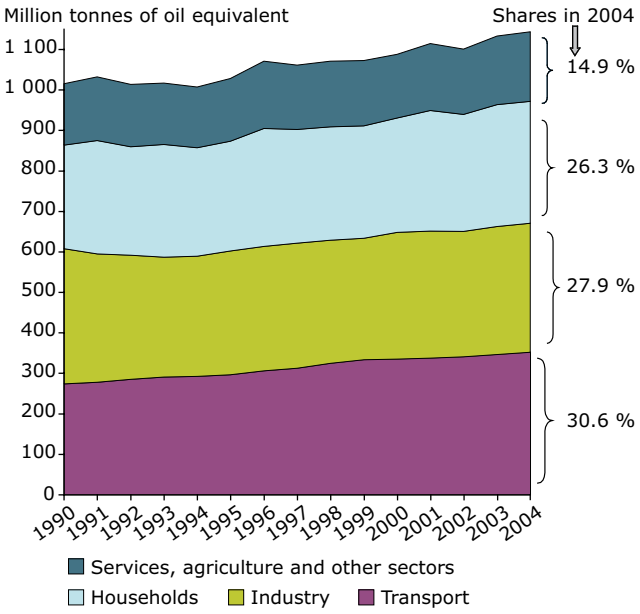
There are significant differences in the pattern of final energy consumption between the EU-15 Member States and new Member States. The new Member States have seen falling final energy consumption mainly as a result of economic restructuring following the political changes of the early 1990s. However, with the recovery in these countries' economies, final energy consumption grew slightly after 2000.

The share of fossil fuels, such as coal, lignite, oil and natural gas in total energy consumption declined only slightly between 1990 and 2004, to reach 79 % (Figure A.3). However, the fossil fuel mix changed with the share of coal and lignite declining continuously and becoming increasingly replaced by relatively cleaner natural gas, which now enjoys a 24 % share. Most of this switch within the fossil fuels occurred in the power generation sector. In the EU-15, this was supported by the implementation of environmental legislation and the liberalisation of electricity markets, which stimulated the use of combined-cycle gas plants due to their high efficiency, low capital cost, low gas prices in the early 1990s, and the expansion of the trans-EU gas network. In the new Member States fuel mix changes were induced by the process of economic transformation, which led to changes in fuel prices and taxation, the removal of energy subsidies, and policies to privatise and restructure the energy sector.

Transport

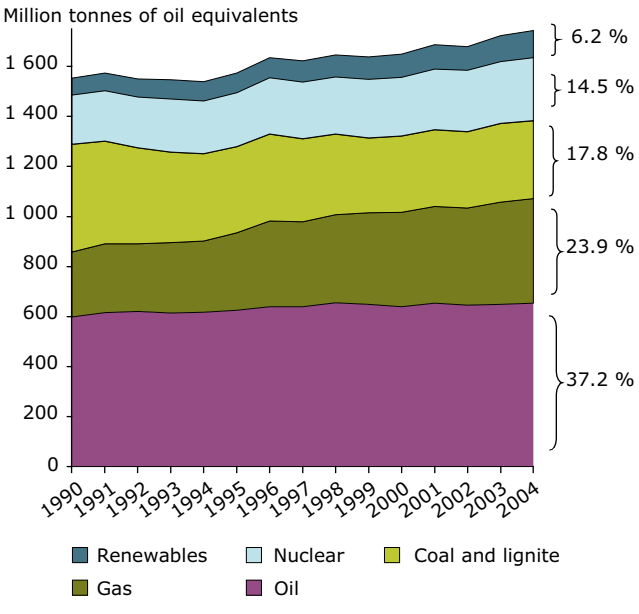
Freight transport is increasing at an annual rate of 3 %, which is faster than GDP. A greater than average growth (30–40 % increase in the period 1995–2004) was found for air, road and sea transport; a lesser than average growth was seen for pipelines (+ 18 %), inland shipping (+ 9 %) and rail (+ 6 %). The reasons for this are complex, but largely linked to socio-economic factors, such as the expansion of the EU internal market. Passenger transport is increasing at a rate of around 2 % annually, the average daily distance travelled by EU-25 citizens increased from 32 km in 1995 to 36 km in 2003. Increased car use in absolute numbers for commuting, leisure and tourism renders the passenger car, together with aviation, as the fastest growing modes of transport. Absolute

Figure A.2 Final energy consumption by sector, EU-25



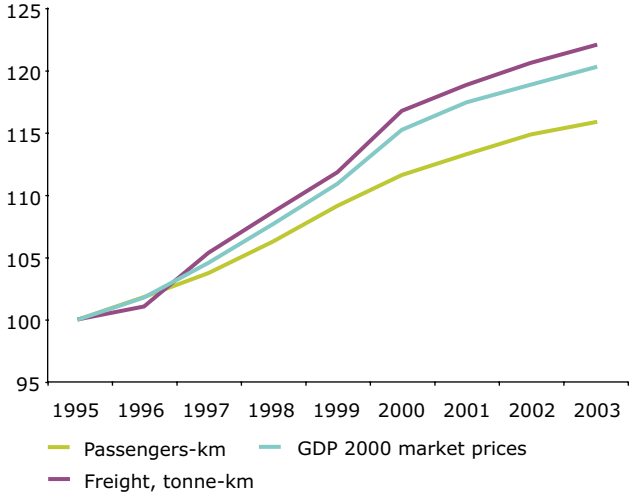
Source: EEA (ETC/ACC).

Figure A.3 Total energy consumption by fuel in the EU-25



Source: EEA (ETC/ACC).

Figure A.4 Passenger and freight transport demand for EU-25



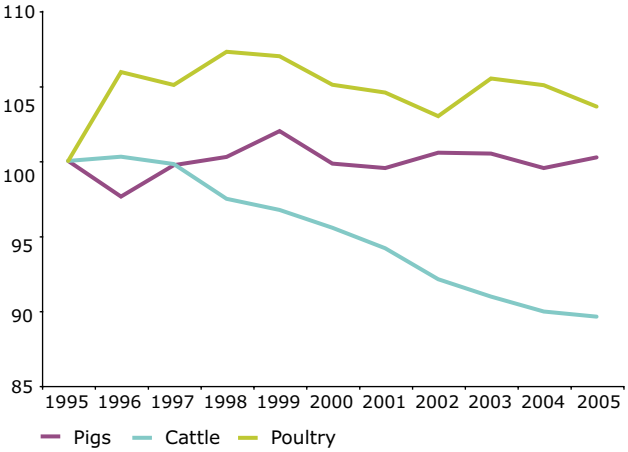
Source: EEA (ETC/ACC).

bus and rail numbers are slowly increasing, but their share of all transport is falling. The share taken by car transport is around 72 % and stable, while the share of air transport has grown from 6.0 % in 1995 to 7.5 % in 2003.

Agriculture

Animal husbandry is the most important agricultural activity in relation to air pollutant emissions. The number of cattle has fallen over the last decade by over 10 % (Figure A.5). Pig numbers are stable while poultry numbers increased by 5 %. The reasons for this are mainly due to the economic developments in the different agricultural sectors.

Figure A.5 Number of animals in EU-25



Source: EEA (ETC/ACC).

Annex B — Legislation

Table B.1 Air pollution limit values and target values established for the protection of human health

Compound	Limit value	Target value	Value		Entry into force
Particulate matter (PM_{10})	Annual average		40 µg/m³		2005
	Daily average		50 µg/m³		
				May be exceeded up to 35 days a year	2005
Nitrogen doxide (NO_2)	Annual average		40 µg/m³		2010
	Hourly average		200 µg/m³	May be exceeded up to 18 hours a year	2010
Ozone (O_3)		Eight-hour average	120 µg/m³	May be exceeded up to 25 days a year (1)	2010
Sulphur dioxide (SO_2)	Daily average		125 µg/m³	May be exceeded up to three days a year	2005
	Hourly average		350 µg/m³	May be exceeded up to 24 hours a year	2005
Carbon monoxide (CO)	Eight-hour average		10 mg/m³		2005
Lead (Pb)	Annual average		0.5 µg/m³		2005 (2)
Benzene (C_6H_6)	Annual average		5 µg/m³		2010
Arsenic (As)		Annual average	6 ng/m³		2013
Cadmium (Cd)		Annual average	5 ng/m³		2013
Nickel (Ni)		Annual average	20 ng/m³		2013
Benzo[a]pyrene		Annual average	1 ng/m³		2013

Note: (1) As an average over the three preceding years.
(2) 2010 in the immediate vicinity of specific industrial sources, notified to EC before 19 July 2001.

Source: Air Quality Directive.

Table B.2 WHO air quality guidelines for major air pollutants

Compound	
Particulate matter (PM_{10})	20 µg/m³ annual mean; 50 µg/m³ 24-hour mean
Particulate matter ($PM_{2.5}$)	10 µg/m³ annual mean; 25 µg/m³ 24-hour mean
Nitrogen dioxide (NO_2)	40 µg/m³ annual mean; 200 µg/m³ 1-hour mean
Ozone (O_3)	100 µg/m³ 8-hour mean
Sulphur dioxide (SO_2)	20 µg/m³ 24-hour mean; 500 µg/m³ 10-minute mean

Source: WHO, 2006.

Table B.3 Limit values and targets for protection of vegetation: EU directives/CLRTAP

Compound	Limit/target value	Target year
Sulphur dioxide (SO_2)	Annual and winter average: 20 µg/m³	2001
Nitrogen oxides (NO_x, as NO_2)	Annual average: 30 µg/m³	2001
Ozone (O_3)	Accumulated exposure over a threshold of 40 ppb [AOT 40] (1):	2010
	• EU directive (target) 18 000 (µg/m³)×h	
	• EU directive 6 000 (µg/m³)×h	Long-term objective
	• CLRTAP 6 000 (µg/m³)×h	Long-term objective
Acidifying and eutrophying components	Area exceeding critical loads: EU NECD	1990–2010
	Reduced by 50 % within each grid	
	Long-term objective: no exceedance of critical loads	

Note: (1) Accumulated exposure in the growing season (May–July).

Table B.4 Change in emissions required from 1990 according to the EU NEC Directive and the UNECE CLRTAP Gothenburg Protocol

NEC Directive		Emission change required EU-25		Time period(1)
		(av. decrease) (3)	(max, min. decrease)	
Sulphur dioxide (SO_2)	Annual total	– 73 %	(– 90, + 7)	1990–2010
Nitrogen oxides (NO_x, as NO_2)	Annual total	– 49 %	(– 63, + 28)	1990–2010
Non-methane volatile organic compounds (NMVOC)	Annual total	– 50 %	(– 72, 57)	1990–2010
Ammonia (NH_3)	Annual total	– 14 %	(– 49, + 241)	1990–2010
UNECE CLRTAP Gothenburg Protocol		**Emission change required EEA-32 (2)**		**Time period (1)**
		(av. decrease) (3)	(max, min. decrease)	
Sulphur dioxide (SO_2)	Annual total	– 49 %	(– 90, + 11)	1990–2010
Nitrogen oxides (NO_x, as NO_2)	Annual total	– 46 %	(– 62, + 19)	1990–2010
Non-methane volatile organic compounds (NMVOC)	Annual total	– 69 %	(– 72, + 13)	1990–2010
Ammonia (NH_3)	Annual total	– 16 %	(– 54, + 15)	1990–2010

Note: (1) The first year of the period constitutes the reference year used in this work.
(2) Values shown are for the 27 EEA-32 countries for which emission ceilings have been set under the Gothenburg Protocol.
(3) The aggregated EU-25/EEA-32 emission ceiling targets are calculated on the basis of % reduction required from 1990 (sum of individual country targets).

Sources: EC, 2001c; and UNECE, 1999.

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