Topic report 4/2003

# Air pollution in Europe 1990–2000

European Environment Agency

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# Contents

# Summary

The present report assesses the air pollution situation in Europe in the year 2000, particularly in the 31 EEA member countries (EEA-31), and analyses the evolution of air quality in the period 1990–2000 in relation to developments in the main economic sectors.

The report addresses the following key questions regarding air pollution:

1. **How are driving forces of air pollutant emissions developing, and what progress has been made in reducing air pollutant emissions in Europe?**

Driving forces considered are population, energy and fuel consumption in traffic, industry, agriculture and other sectors. Population has increased very slowly in Europe (2.5 % since 1990). Energy consumption has increased about 10 % in EU-15 since 1990, hence energy consumption per capita has increased. GDP increased by about 23 % (in constant prices), indicating an overall increase in energy efficiency. This energy efficiency improvement is mainly related to the industrial sector; in the road transport sector, energy use increases faster than the population.

☹ Final energy consumption grew steadily in EU-15 between 1990 and 2000, primarily due to growth in the transport sector, and to a lesser extent in the household and service sectors.

😐 Fossil fuels continue to dominate energy use in EU-15, but a switch can be observed from coal and lignite to relatively cleaner natural gas; nuclear energy is increasing.

☹ Economic growth in EU-15 is requiring less additional energy consumption (i.e. energy efficiency is improving), but energy consumption is still increasing.

☹ Energy consumption by transport is increasing rapidly, mainly as a result of growth in road transport both in EU-15 and ACs; aviation is the fastest growing energy consumer of the transport sector in EU-15, road transport in ACs. In both EU-15 and ACs, road transport is the sector's biggest energy consumer.

Air pollutant emissions in Europe show a general decreasing trend. This pertains to the major pollutants involved in urban and local air quality problems affecting human health and material degradation as well as regional scale impacts affecting ecosystems.

☺ Between 1990 and 2000, emissions of acidifying pollutants and ozone precursor gases decreased in the EEA-31 by 40 % and 29 %, respectively. All emission reductions have been realised despite the above mentioned general increase in economic production, energy consumption, and population across the EEA-31 region.

☺ The decreases are primarily due to large reductions of primary emissions of $NO_x$ (– 27 %), $SO_2$ (– 60 %) and NMVOCs (– 29 %), achieved through improved flue gas treatments, fuel switching, use of low sulphur fuels in power stations and the introduction of catalytic converters for cars. Reductions in emissions of acidifying gases in the main emitting sectors (1990–2000) were: energy industries, – 48 %; industry (energy and processes), – 51 %; other (energy and non-energy), – 54 %; transport, –25 %; and agriculture, – 17 %. Emissions of ozone precursors have been reduced: in the energy industries sector, by – 34 %; industry (energy and processes), – 26 %; other (energy and non-energy), – 21 %; transport, –31 %; and agriculture, – 28 %.

☺ Total emissions of fine particulates and particulate precursor gases have been reduced by 34 % between 1990 and 2000, again largely due to reduced emissions of secondary particulate precursors $SO_2$ and $NO_x$. The reduction of primary $PM_{10}$ from energy industries (– 46 %) also contributed significantly.

☹ For emissions of ground-level ozone precursors, only four EU Member States (United Kingdom, Germany, Netherlands and Finland) are below the linear target path towards meeting their obligations of emissions reductions under the EU national emission ceilings directive (NECD). Emissions of five countries, Portugal, Spain, Greece, Ireland and Belgium are substantially above the linear target path, and will require substantial future emission reductions to meet their respective emission targets. Of the accession countries, eight are below the linear target path to the 2010 targets, only Slovenia is above the linear target path. In order to meet the future targets, Slovenia as well as Hungary, Poland and the Czech Republic will require significant emission reductions.

☺ The EU is more than half way towards meeting the 2010 targets of the national emission ceilings directive for acidifying pollutants, although several Member States (Greece, Portugal, Ireland and Spain) are less than half way to their 2010 targets and above a linear target path towards their respective targets. Of the accession countries, all are below a linear path to the Gothenburg protocol target, and four countries (Latvia, Lithuania, Czech R. Slovakia) substantially so. A number of accession countries have already reached their respective emission targets.

**2. What is the state of air quality in Europe in 2000? Is it developing in line with the decreasing pollutant emissions?**

In the year 2000, air pollutant concentrations in many areas and locations in Europe were higher than the EU air quality directives limit and target values, to be met by 2005–10. Also, deposition of acidifying and eutrophying substances were higher than the critical loads in parts of the European area.

Urban and local concentrations of $PM_{10}$, $NO_2$ and $SO_2$, as well as acidifying deposition, decreased since 1990 approximately in parallel to the established downward trend in the related emissions. However, ground-level ozone concentrations did not develop in line with the decrease in European ozone precursor emissions of 25–30 % between 1990 and 2000. Annual average ozone concentrations have been increasing during the recent years; however, the indicator for short-term high eight-hour level has hardly changed. Probable causes of these trends are the non-linear chemistry by which ozone is formed, the increasing hemispheric background concentration and less scavenging of ozone by $NO_x$ emissions. For eutrophying deposition in Europe, there has been little change in observed depositions since 1990.

Health-related air pollution:

☺ The concentration of $PM_{10}$ has decreased. Results of an analysis of a consistent set of monitoring stations show that the annual average concentration relevant to the EU limit value decreased by 16–18 % between 1997 and 1999. Between 1999 and 2001 concentrations stabilised. The daily average concentration relevant to the EU limit value decreased between 1997 to 1999 by about 21 %, with little change between 1999 and 2000.The influence of meteorological conditions probably explains much of the interannual variations but has not been analysed yet.

☺ The concentration of $NO_2$ has decreased; the annual average and hourly concentration relevant to the EU limit value decreased by about 15 % since 1996, with some interannual variations including a peak in 1997. Again, the influence of meteorological conditions probably explains much of the interannual variations but has not been analysed yet.

☹ The air quality limit and target values for ozone, $PM_{10}$, and $NO_2$ that are to be met by 2005–10 are currently exceeded extensively in European cities, and, for ozone and to some extent for $PM_{10}$, in rural areas as well.

😐 For ozone, annual averages increased about 8 % since 1996, averaged over all station types, while maximum short-term concentrations (maximum and high percentiles of hourly concentrations) have shown a decreasing trend over the decade, in qualitative agreement with the decreasing precursor emissions. However, the health-related indicator of the new EU ozone directive (the 26th highest daily maximum eight-hour average concentration) has been rather unchanged since 1996, when averaged over a large, consistent set of stations. The resulting health implications of this composite picture should be the topic of specialised studies.

Ecosystem-related air pollution:

☹ In 2000, acidifying deposition was above critical loads in parts of central and north-west Europe. Eutrophying deposition above critical loads was more widespread.

☺ Sulphur deposition has fallen significantly by the year 2000, and large areas are now expected to be protected from further acidification. By 1999, most countries had made notable progress towards 2010 targets to reduce areas still subject to increasing acidification.

😐 Reductions in nitrogen deposition have been limited and scattered. Thus, there has been no systematic reduction in potentially eutrophying pollution. The nitrogen input to north European coastal waters has not decreased since the early 1990s. A few countries have experienced notable decreases in the land area subject to eutrophication between 1990 and 1999, but several countries are believed to have a worsening problem.

### 3. How are policy measures affecting the air pollution problems?

On a macro scale, it is possible to link the changes in air quality empirically to the developments in driving forces and to policy measures without resorting to air pollution dispersion and transport models.

The emissions trends can largely be explained by changes in population, economic growth, energy intensity and fuel intensity of the economies and abatement measures.

The improved energy intensity and fuel intensity of the European economies, and the shifts towards lighter fuels, both in the EU-15 and to a lesser extent in the accession countries, cannot explain the observed downward trends in emissions. It must be concluded that a substantial contribution to decreased emissions in Europe is due to the successful abatement of emissions from various sources, in particular large combustion plants and passenger cars. This contribution is probably mainly an effect of both EU legislation as well as UNECE CLRTAP agreements.

☺ Significant emission reductions occurred despite the growth in population, economic output and energy input into the economies of Europe. Abatement measures prompted by EU legislation and CLRTAP agreements must have had a substantial impact.

☺ The introduction of EU emission legislation for large combustion plants (EU large combustion plants directive) and national legislation has resulted in the observed decrease of acidification and in part to a decrease of the emission of primary and secondary particles.

☺ The introduction of catalysts on light vehicles, triggered by a series of EU directives, also decreased the emissions of secondary particle precursors and of ozone precursors.

😐 Although emissions of ozone precursor gases decreased substantially, mainly as an effect of introduction of catalysts on cars, both annual and eight-hourly average ground-level ozone concentrations relevant to EU limit values do not show a decrease.

# 1. Introduction

## 1.1. Objectives and coverage

This report provides an overview and analysis of the air pollution situation in Europe, in the year 2000 and the preceding decade, based on indicators for underlying sectoral driving forces, emissions, air quality, deposition and the effectiveness of policies and measures.

The information in the report is expected to be useful as a reference for the clean air for Europe (CAFE) programme, a thematic strategy under the EU sixth environmental action programme. CAFE uses 2000 as the reference year for its assessments of current (2000) and projected (2020) air pollution in Europe and the additional policies and measures required to achieve possible future air emission and air quality targets by 2020.

The main policy questions addressed in the report are:

- Which progress is being made towards meeting the EU national emission ceiling directive (NECD) and the UNECE CLRTAP emission targets?
- Which progress is being made towards meeting the air quality directives?
- What are trends in emissions of air pollution by the main socioeconomic sectors?
- What is the effectiveness of policies and measures for reducing air pollution?

The report is aimed at policy-makers and policy implementers at EU and national level, and is expected to be also of use for air pollution managers at the local level as well as the interested and informed public.

The report's focus is upon the local and regional air pollution issues in European urban and rural areas. Local scale sources, including traffic emissions, are the major contributor to exposure to air pollution of humans, requiring a local or national approach. However, a pan-European approach is also needed, not only because of the long-range transport of many of the pollutants but also because policies and measures are increasingly taken on the European scale, by the European Union and in the framework of the UNECE Convention for Long-Range Transboundary Air Pollution (CLRTAP). Effects of air pollution on ecosystems as well as on human health are also addressed.

Global air pollution issues and indoor air pollution are not covered in this report. Hazardous substances (toxics) are only addressed as far as emissions of some heavy metals and persistent organic pollutants are concerned.

The report covers the 31 EEA member countries and Switzerland. Where appropriate, the following geographical subdivisions have been used:

- EU-15: The 15 EU Member States
- AC-10: The 10 accession countries preparing for EU membership
- AC-13: The AC-10 plus Turkey, Malta and Cyprus
- EFTA-4: Iceland, Liechtenstein, Norway, Switzerland
- EEA-18: The 31 EEA member countries excluding the AC-13 countries (the 15 EU Member States plus Norway, Iceland and Liechtenstein).

## 1.2. Air pollution as a European environmental issue

Road transport, power and heat production, industry and agriculture are the main sectors that cause emissions of air pollutants. These emissions result in widespread exposure of the human population, as well as ecosystems and materials, to adverse air quality. Other sources of lesser significance, on the European scale, although important in some localities, are households (e.g. residential heating) and marine transport.

The emissions are dispersed in air, and chemical reactions occur after release in the atmosphere. They result in pollutant concentrations that vary strongly with location and time. Compounds like sulphur dioxide ($SO_2$), carbon monoxide (CO), nitrogen oxides ($NO_x$ and $NO_2$) typically occur in high concentrations locally, close to their sources (streets and industrial plants) and show low concentrations elsewhere. Compounds like ozone as well as the deposition of acid compounds occur over larger areas (both rural and urban), resulting in a ‘regional background’.

Particles in air (PM, such as $PM_{2.5}$ and $PM_{10}$) likewise show a rather high regional background level, to which the urban and local emissions can add significantly with high concentrations close to sources such as busy streets.

### 1.2.1. Air pollution issues

The main issues of concern in Europe, the spatial scale on which they are relevant and the time-scale for which the impacts are important (EEA, 2002) are:

| Issue | Spatial scale | Effects-related time scale |
|---|---|---|
| • Human health-related impacts due to exposure, to ozone and particles (and to a lesser extent to $NO_2$, $SO_2$, CO, lead, benzene) | Urban areas, streets<br>Ozone: also rural areas | Hours, days, year |
| • Acidification and eutrophication of water, soils and ecosystems | Range: 100–1 000 km | Year |
| • Damage to vegetation and crops due to exposure to ground-level ozone | Range: 100–1 000 km | Hours, growing season |
| • Damage to materials and cultural heritage due to exposure to acidifying compounds and ozone | Urban, rural areas | Year |
| • Impacts on human health and ecosystems from hazardous pollutants (heavy metals, HMs, and persistent organic pollutants, POPs) | Urban, rural areas | Year |

See Appendix 2 for a short description of these issues.

This report covers the issues relevant for human health and ecosystems, including crops. Pollutants and issues are:

- health-related: $PM_{10}$, ground-level ozone, $NO_2$;

- ecosystems-related: acidifying and eutrophying deposition, ground-level ozone.

No information is presented on CO and benzene. CO is a rapidly diminishing problem related only to some remaining hot-spot traffic or industry locations, while for benzene, the available data are insufficient for a Europe-wide assessment of the problem it represents. Regarding the issue of heavy metals (HM) and persistent organic pollutants (POP), this report only presents emission indicators. The impact from air pollution on materials and cultural heritage in Europe was described in other reports, including *Air quality in Europe* (EEA, 2002). Since there is not much more recent information available, this issue is not treated in this report.

The multi-pollutant, multi-effect system of air pollution is shown in Figure 1.1, which shows the interlinkages between sectors, their emissions, the air quality and the effect. The practical consequence of these interlinkages is that measures taken in sectors may benefit several air pollution problems at once. This is taken into account increasingly in recent policy development.

Recent EU and UNECE approaches reflect a coordinated approach to air pollution control, setting limit and target values in EU directives, for both national and sector specific emissions and for air quality. Appendix 1 lists the air quality limit and target values set by the EU, and guidelines from the WHO, and emission targets set by the EU and UNECE.

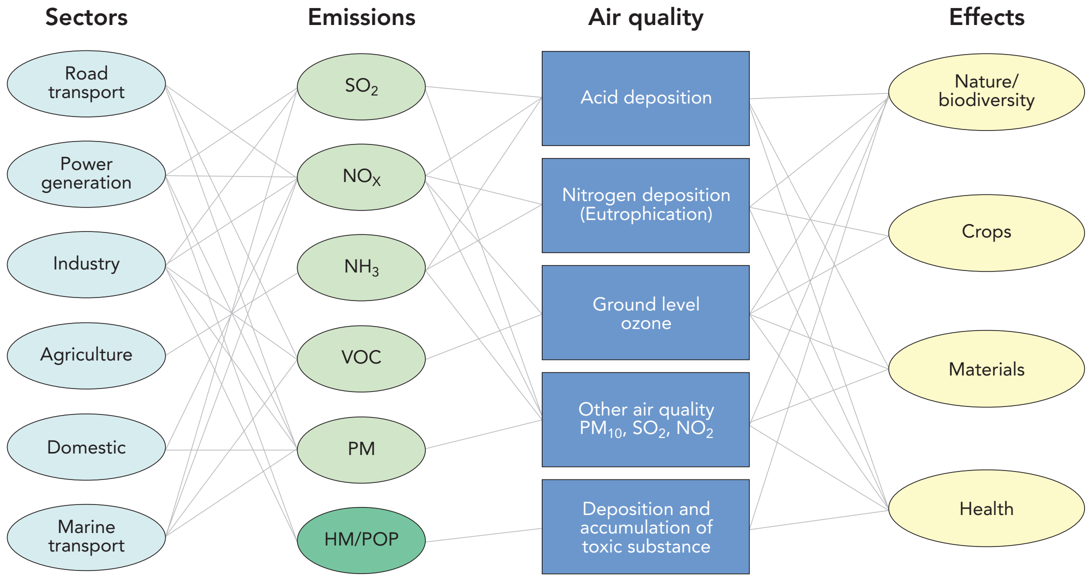
## 1.3. Indicators and data

### 1.3.1. Indicators

To a large extent, this report follows the well-known DPSIR assessment framework. The report is based on and consistent with the indicators and underlying data presented in the most recent EEA indicator-based report *Environmental signals 2002* (EEA, 2002b). The EEA is developing a core set of air pollution indicators and this report uses most of those proposed for the core set. The list of indicators used in this report is also consistent with the preliminary list discussed and developed within CAFE. Indicators have been selected on the basis of the following criteria; they should:

- answer main policy questions and communicate meaningful messages for policy-makers and implementers;
- be comparable between countries;

**Schematic relations between sectors and their emissions, air quality issues (local and regional scales) and effects themes** Figure 1.1



**Box 1.1: Selected air pollution indicators covered in this report**

| **Indicators:** | **Related to issue:** |
|---|---|
| Drivers (socioeconomic, sectors) | |
| • Contribution to emissions from various economic sectors | All issues (see Chapter 3) |
| • Eco-efficiency of economic sectors | All issues (see Chapters 2 and 5) |
| Pressure | |
| • Emissions of acidifying pollutants ($SO_2$, $NO_x$, $NH_x$) | Acidification and eutrofication (see Chapter 3) |
| • Emissions of ozone precursors ($NO_x$, NMVOC, $CH_4$, CO) | Ground-level ozone (see Chapter 3) |
| • Emissions of primary particles (as $PM_{10}$) and of precursor gases for secondary particle formation in the atmosphere:<br>— inorganic precursors: $SO_2$, $NO_x$, $NH_3$<br>— organic precursors: NMVOC | Particulate matter (see Chapter 3) |
| State | |
| • Exceedance of limit and target values for air quality ($PM_{10}$, $NO_2$, ozone) | Health-related air pollution (see Chapter 4.1) |
| • Area of exceedance of critical load for total acidity and for nitrogen | Ecosystems-related air pollution (see Chapter 4.2) |
| • Exposure of crops/vegetation to ozone | Ecosystems-related air pollution (see Chapter 4.2) |
| Impact | |
| • Population exposure to air pollutants and associated risk | Health-related air pollution. This indicator is not assessed in this report. Only an upper estimate of European population exposure is given (see Chapter 4.1) |
| Response (effectiveness of policies and measures) | |
| • Policy response to $SO_2$ and $NO_x$ emissions | Acidification, eutrophication, urban $NO_2$ concentrations (see Chapter 5) |
| • Policy response to $NO_x$ and VOC emissions | Ground-level ozone (see Chapter 5) |

- be transparent regarding the data used;
- be informative to a general public;
- provide the best available scientific insights.

The box shows the indicators covered in the report.

As indicated in the box above, acidification, eutrophication, ozone and secondary particle formation in the atmosphere are the result of a combination of precursor gases entering into chemical reactions taking place during their transport and dispersion in the atmosphere. The mechanisms are complex, and the resulting formation and effects are dependent upon many variables, such as meteorological conditions, location relative to large source areas and precursor concentrations.

In order to get a grip on how the trends in the emissions of the individual precursors will result in a combined effect on the environment, composite indicators have been defined, for the following:

- tropospheric ozone formation precursor gases, denoted 'TOFP';
- secondary inorganic particle precursor gases, denoted 'secondary $PM_{10}$';
- acidifying and eutrofying substances.

The composite emission indicators (see de Leeuw, 2002 and Appendix 3 for a detailed description) are based on a weighted summation of the emissions of the individual precursor gases. The applied weighting factors have been estimated on the results of various model studies (de Leeuw, 2002).

Similar procedures are, for example, defined in the Montreal Protocol for the protection of the stratospheric ozone layer, where pollutants are weighted according to their 'ozone depletion potential' (ODP), and in climate change, where emissions of greenhouse gases are aggregated using a global warming potential (GWP).

Combined indicators are used in Chapter 3 (on emissions) and in Chapter 5 (on response to policy measures) to give a first indication of the effect of combined emission trends on the scale of large European regions, such as the EU-15 or AC-10. They are also used to indicate the relative magnitude of contributions from economic sectors to the environmental effect, and as a basis for linking trends in emissions to trends in air quality and deposition (in Chapter 5). Still, the combined emissions indication represents a simplification of complex mechanisms, and will not be valid if applied to specific smaller areas/locations.

### 1.3.2. Data used

Emission data included are those officially submitted under the EU national emission ceilings directive and the UNECE Convention on LRTAP (various protocols). The air quality data included are taken from the AirBase air quality database of the ETC/ACC, which contains data reported by EU Member States according to the exchange of information (EoI) decision, as well as from accession countries and EFTA-4 countries, using the same format. Data on deposition and additional air quality data have been obtained from EMEP.

Activity data (economic and societal) have been taken from Eurostat's NewCronos database. More information on the data and their quality is provided in Appendix 3.

## 1.4. Report outline

The line of the report follows the DPSIR concept: Chapter 2 deals with driving forces; Chapter 3 summarises the air pollutant emissions (based on national data); Chapter 4 summarises the state of air pollution and deposition; Chapter 5 attempts to analyse the effect of air pollution policy measures on the development of emissions and the air pollution state. Impacts of air pollution are not addressed directly in terms of observed damage. Chapter 4 on air pollution state, however, includes indicators which are impact-related (exceedance of limit values and critical loads). All chapters present the status for 2000 as well as the development since 1990 as far as data are available.

Conclusions to the analysis and summaries are found at the start of each chapter.

# 2. How are the driving forces of air pollutant emissions developing?

😐 **Final energy consumption grew steadily in EU-15 between 1990 and 2000, primarily due to growth in the transport sector, and to a lesser extent in the household and service sectors.**

😐 **Fossil fuels continue to dominate energy use in EU-15, but a switch can be observed from coal and lignite to relatively cleaner natural gas; nuclear energy is increasing.**

☹ **Economic growth in EU-15 is requiring less additional energy consumption (i.e. improved energy efficiency), but energy consumption is still increasing.**

☹ **Energy consumption by transport is increasing rapidly, mainly as a result of growth in road transport both in EU-15 and ACs; aviation is the fastest growing energy consumer of the transport sector in EU-15, road transport in ACs. In both EU-15 and ACs, road transport is the sector's biggest energy consumer.**

The developments of the main 'driving forces' for air pollution in the period 1990 to 1999–2000 are presented for the EU-15 and the accession countries separately, mainly since for these groups of countries, the developments in this decade show remarkable differences, related to the transition to a market economy in the latter group. If the development of EU-15 and the accession countries were shown in one figure, the EU-15 would dominate the result because in absolute quantities the numbers are much larger, and the development of the accession countries would not be visible. Due to a lack of information, it is not always possible to show the development in the accession countries.

## 2.1. Population and production

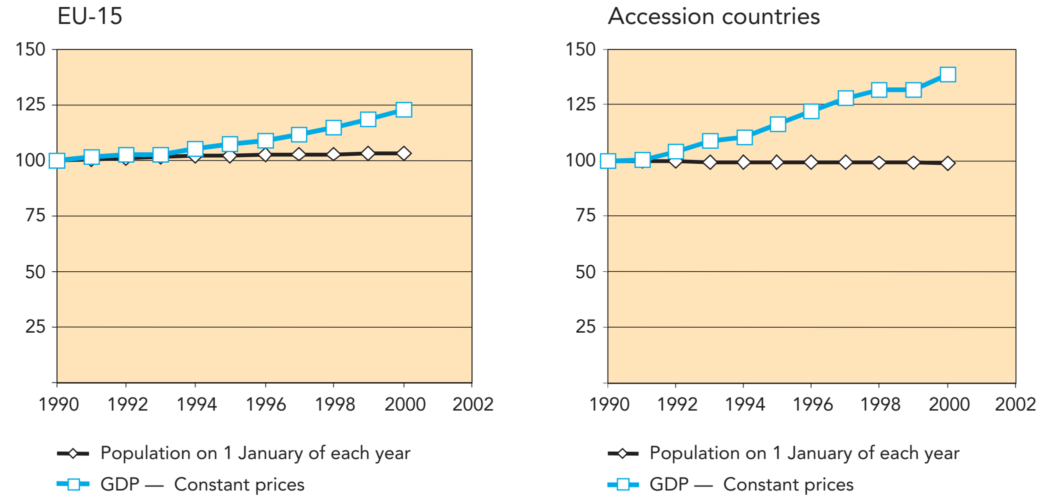
From Figure 2.1, we can observe the following:

- Population is slowly increasing in the EU-15, whereas it is slightly decreasing in the accession countries;
- in both groups of countries, the economy is growing faster than the population size, indicating a strong increase in per capita economic production. The accession countries' economies are growing faster than those of the EU Member States.

## 2.2. Energy and fuels

EU-15 final energy consumption (1) grew by an average of 1.0 % per year between 1990 and 2000, compared with an average gross

**Population and gross domestic product** Figure 2.1



**Source:** Eurostat, 2003.

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(1) Final energy consumption is the energy consumption of the transport, industry, household, agriculture and services sectors. It includes the consumption of converted energy (i.e. electricity, publicly supplied heat, refined oil products, coke, etc.) and the direct use of primary fuels such as natural gas or renewables (e.g. solar heat or biomass).

Figure 2.2 **Final energy consumption, EU-15 (Mtoe)**

**Source:** Eurostat, 2003.

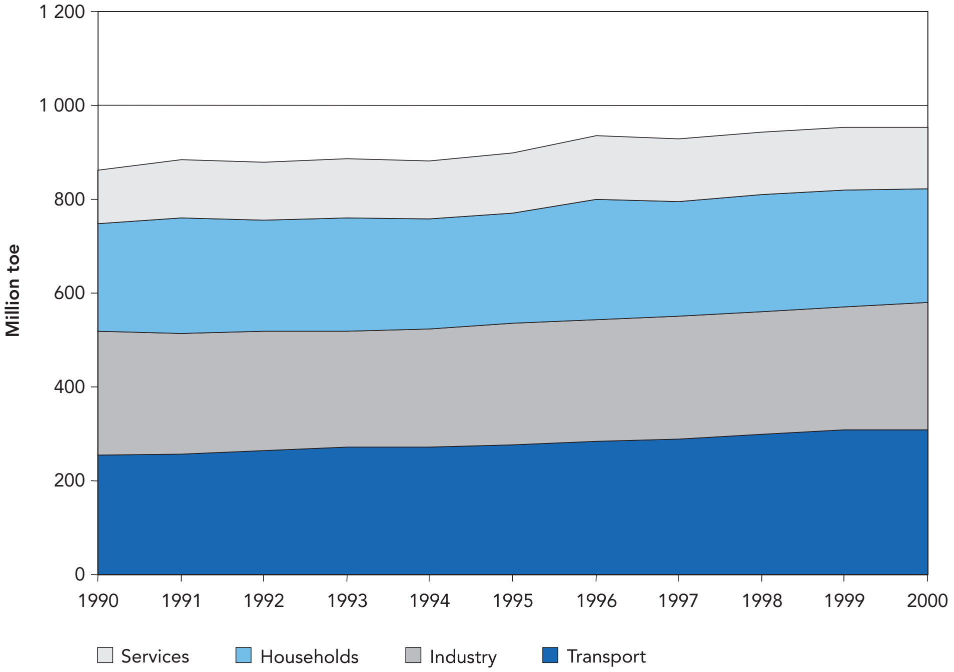


Table 2.1 **Shares of energy sources in EU-15 final energy demand**

**Source:** Eurostat, 2003.

| | 1990 | 2000 |
|---|---|---|
| Coal and lignite | 9 % | 4 % |
| Oil | 46 % | 46 % |
| Natural gas | 21 % | 25 % |
| Electricity | 18 % | 20 % |
| Other | 6 % | 5 % |

**Note:** Other energy sources are publicly supplied heat and direct use of renewable energy sources such as solar heat and biomass.

domestic product (GDP) growth of 2.1 % per year. Figure 2.2 shows that it increased in absolute terms in all sectors, although the increase in industry was small. The decline in industry's share of consumption reflects some efficiency improvements, but mainly structural changes, including a shift towards less energy-intensive industries, and a shift in the location of energy-intensive industries away from industrialised EU countries. The fastest growth in demand was transport, which increased its share from 29.4 % to 32.5 % over the period (EEA, 2003).

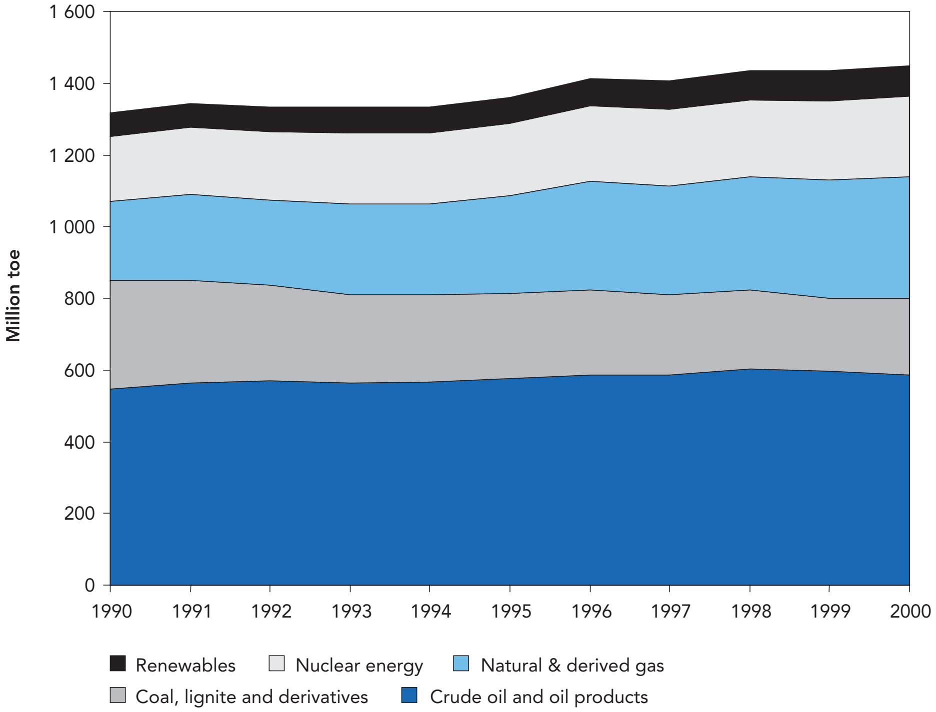
Important changes are occurring in the mix of energy sources (Table 2.1). Consumption of coal and lignite (outside electricity production) more than halved between 1990 and 2000, and is expected to decline further. Coal and lignite are the major sources of energy-related acidifying gases and particulate emissions, as well as releasing more carbon dioxide per unit of energy consumed than other fuels.

Total energy consumption, also known as gross inland energy consumption (GIEC), a measure of the energy inputs to an economy, can be calculated as the sum of total indigenous energy production, energy imports minus exports and net withdrawals from existing stocks. It includes transformation losses in power plants and refineries. EU-15 total energy consumption continued to increase between 1990 and 2000 at an average of 1 % per year (Figure 2.3). The share of fossil fuels in the total declined slightly, from 81 % in 1990 to 78 % in 2000, with a corresponding increase in the proportion of nuclear and renewable energy. (EEA, 2003).

Within fossil fuels, there was a major change in fuel mix, with coal and lignite losing about

**Total energy consumption by fuel, EU-15 (Mtoe)** Figure 2.3

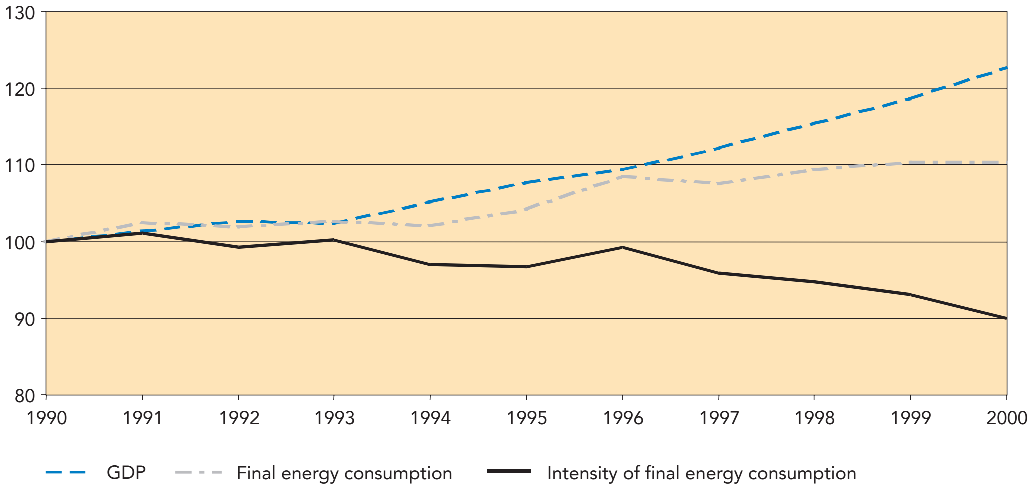
**Source:** Eurostat, 2003.



**Note:** Fuels other than those listed in the legend have been included in the diagram but their share is too small to be visible.

**Final energy consumption, GDP and intensity, EU-15** Figure 2.4

**Source:** Eurostat, 2003.



one third of their market, and being replaced by natural gas.

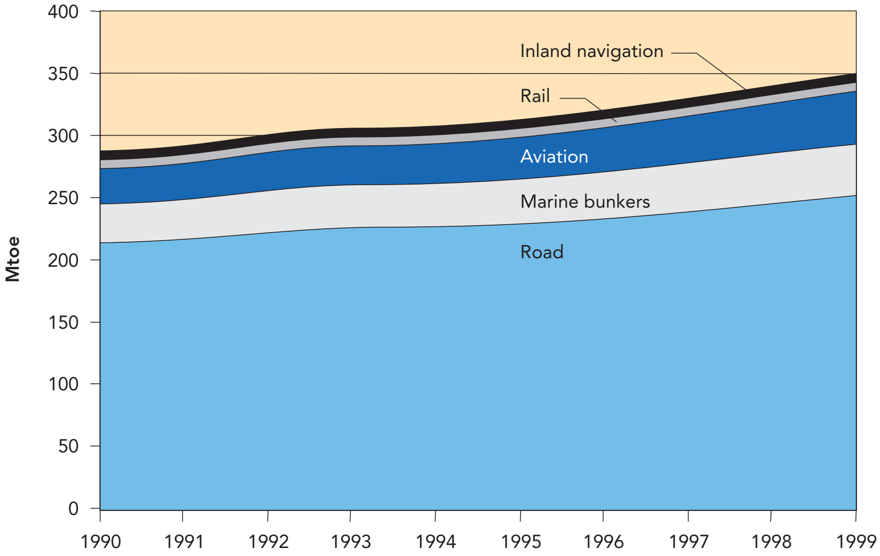
Final energy intensity (i.e. final energy consumption per unit of GDP), the indicator for overall performance in improving energy efficiency, fell in the EU-15 by an average of 1.1 % per annum between 1990 and 2000. However, this improvement was insufficient to prevent an increase in final energy consumption because average GDP growth was higher at 2.1 % per year (Figure 2.4) (EEA, 2003).

## 2.3. Transport

As can be seen in Figure 2.2, transport is the largest energy-consuming sector, being responsible for about 30 to 35 % of the total energy consumption in 1999. Aviation is the sector's fastest growing energy consumer and road the biggest, consuming around 72 % of transport energy consumption. Transport energy consumption in the ACs is still three to four times lower than in the EU. In the EU-15, it increased by 21 % between 1990 and 1999 (Figure 2.5).

Figure 2.5 **Total energy consumption in transport in EU-15**

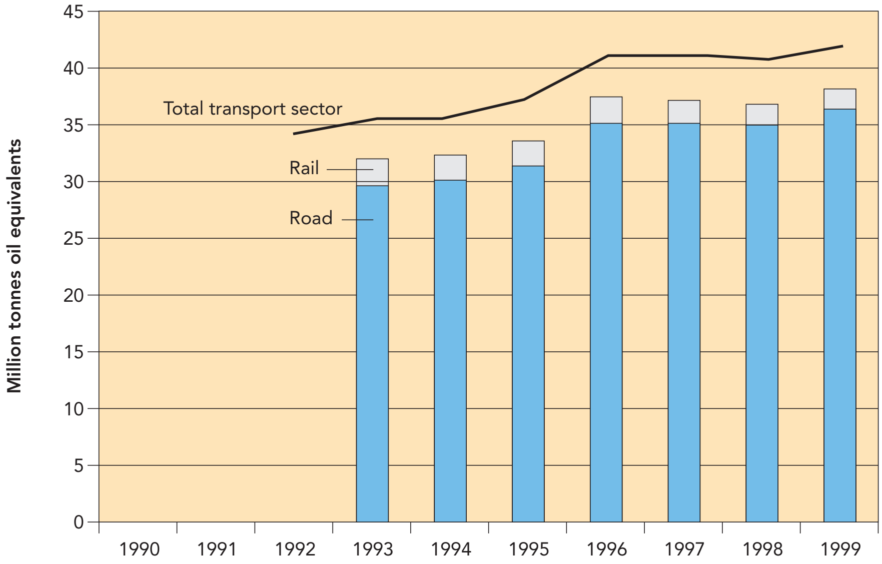
**Source:** Eurostat.



**Note:** Transport by oil pipelines is responsible for between 1 and 1.5 % of total energy consumption by transport and is therefore omitted.

Figure 2.6 **Transport energy consumption by mode in AC-13 excluding air and oil pipelines**

**Source:** Eurostat.



**Note:** The gap between road plus rail and total transport energy consumption is due to inland waterways, oil pipelines and aviation, for which too few mode specific data were available.

In the AC-13, transport energy consumption increased by around 22 % between 1992 and 1999. Figure 2.6 shows that this is mainly due to growth in road transport energy consumption. The transport sector's share of the final energy consumption is — with 19 % — still relatively low, when compared to the EU (30 to 35 % in 1999). Road transport is the biggest and fastest growing energy consumer, being responsible for about 87 % of transport energy consumption.

# 3. What progress has been made in reducing air pollutant emissions in Europe?

☺ **Between 1990 and 2000, emissions of acidifying pollutants and ozone formation precursor gases have decreased in the EEA-31 by 40 % and 29 %, respectively. All emission reductions have been realised despite a general increase in economic production, energy consumption, and population across the EEA-31 region.**

☺ **The decreases are primarily due to large reductions of primary emissions of $NO_x$ (– 27 %), $SO_2$ (– 60 %) and NMVOCs (– 29 %), achieved through improved flue gas treatments, fuel switching, use of low sulphur fuels in power stations and the introduction of catalytic converters for cars. Reductions in emissions of acidifying gases in the main emitting sectors (1990–2000) were: energy industries, – 48 %; industry (energy and processes), – 51 %; other (energy and non-energy), – 54 %; transport, – 25 %; and agriculture, – 17 %. Emissions of ozone precursors have been reduced: in the energy industries sector, by – 34 %; industry (energy and processes), – 26 %; other (energy and non-energy), – 21 %; transport, – 31 %; and agriculture, – 28 %.**

☺ **Total emissions of fine particulates and secondary inorganic particle precursor gases ('primary and secondary $PM_{10}$', 'particulate matter') have been reduced by 34 % between 1990 and 2000, again largely due to reduced emissions of secondary particulate precursors have been $SO_2$ and $NO_x$. The reduction of primary $PM_{10}$ from energy industries (– 46 %) also contributed significantly.**

☹ **For emissions of ozone precursors, only four EU Member States (United Kingdom, Germany, Netherlands and Finland) are below the linear target path towards meeting their obligations of emissions reductions under the EU national emission ceilings directive (NECD). Emissions of five countries (Portugal, Spain, Greece, Ireland and Belgium) are substantially above the linear target path, and will require substantial future emission reductions to meet their respective emission targets. Of the accession countries, eight are below the linear target path to the 2010 targets, only Slovenia is above the linear target path. In order to meet the future targets, Slovenia but also Hungary, Poland and the Czech Republic will require significant emission reductions.**

☺ **The EU is more than half way towards meeting the 2010 targets of the national emission ceilings directive for acidifying pollutants, although several Member States (Greece, Portugal, Ireland and Spain) are less than half way to their 2010 targets and above the linear target path towards their respective targets. Of the accession countries, all are below the linear path to the Gothenburg protocol target, and four countries (Latvia, Lithuania, Czech Republic and Slovakia) substantially so. A number of accession countries have already reached their respective emission targets.**

This chapter provides the following information on air pollutant emissions:

- Emissions by sector.
- Emissions compared to the internationally agreed national targets (EU NEC and UNECE CLRTAP) and an analysis by sector. More detailed explanations of the trends in these sectoral emissions are provided in Chapter 5.

Sources of the data are the national and sectoral emissions data that have been officially reported by countries to the UNECE CLRTAP. Where not reported, primary $PM_{10}$ national totals were obtained from the auto-oil II programme (European Commission 2000), and sectoral splits subsequently derived using sector weightings from CEPMEIP (2001). Data were gap-filled where required by the ETC-ACC to obtain consistent time-series information. Further information concerning the data and methodologies used to compile the emission statistics is available in Appendix 3, and in the air pollutant emissions fact sheet series from the EEA website.

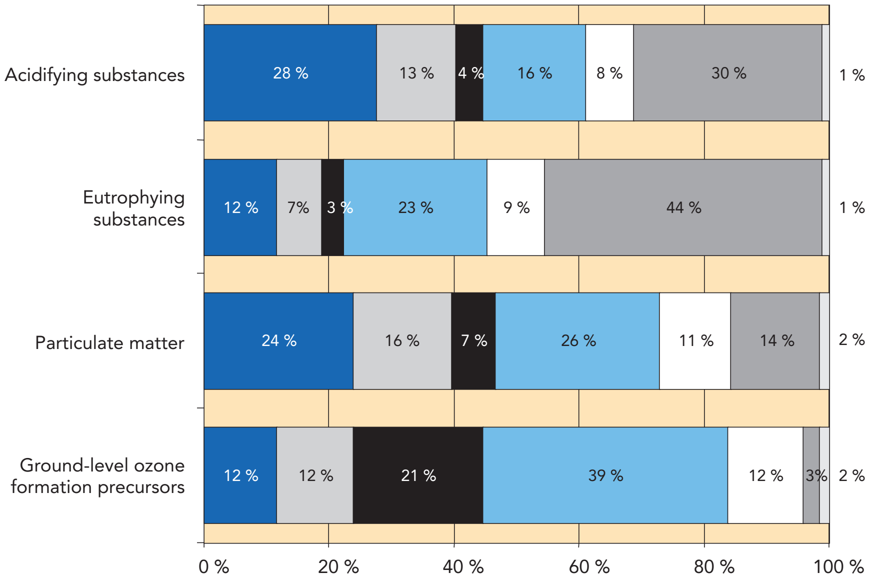
References within this chapter to 'EEA-31' and 'EEA-18' also include Switzerland.

## 3.1. Emissions by sector and pollutant

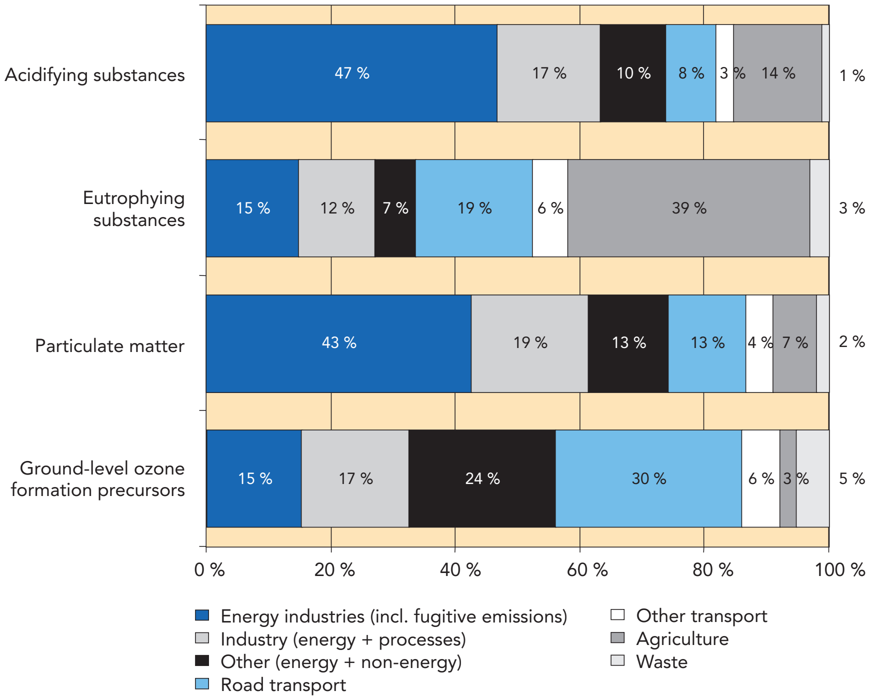
Figure 3.1 and Figure 3.2 summarise EEA-18 and AC-13 national emissions from the main sectors in 2000 for selected pollutants and their contribution to total emissions from four main emitting sectors.

**Figure 3.1** **Sector contributions to selected air pollution issues in 2000**

(a) EEA-18 countries



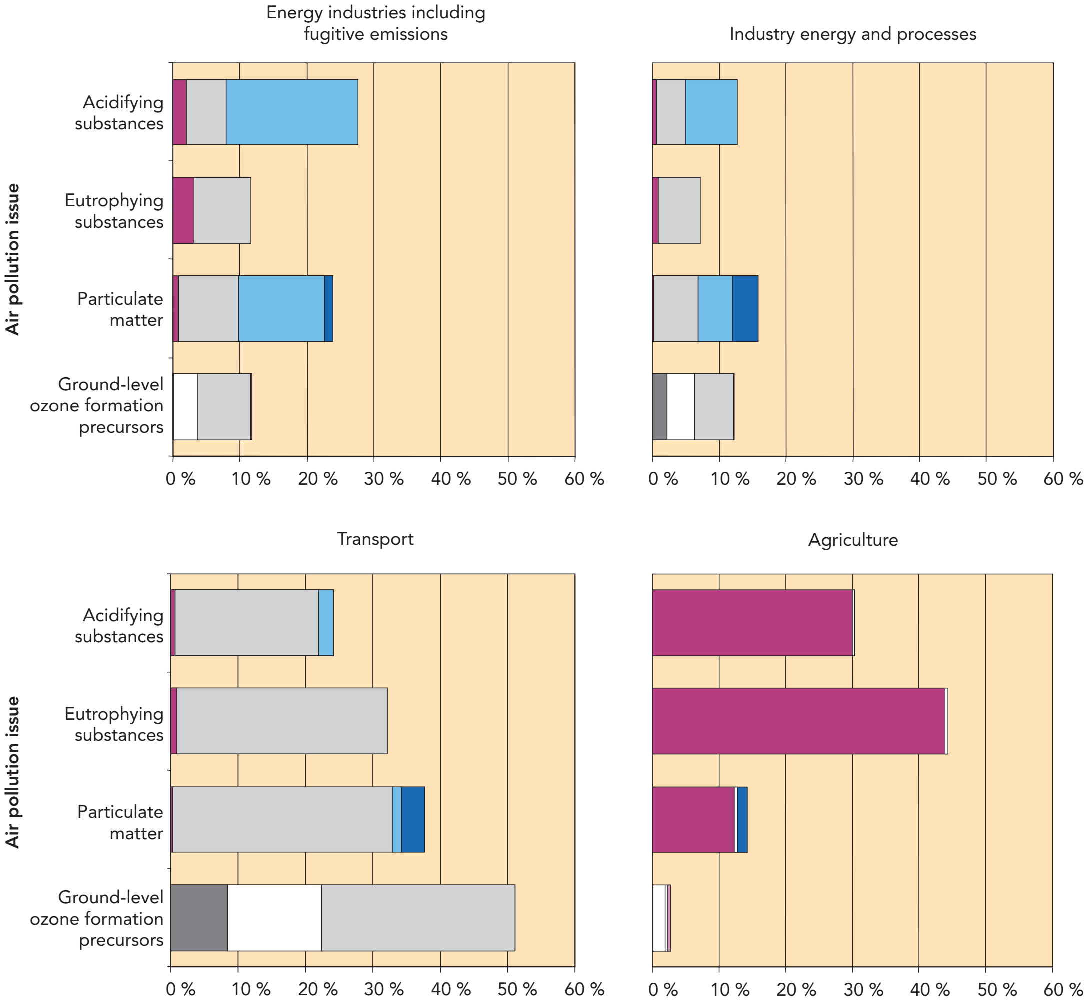
(b) AC-13 countries



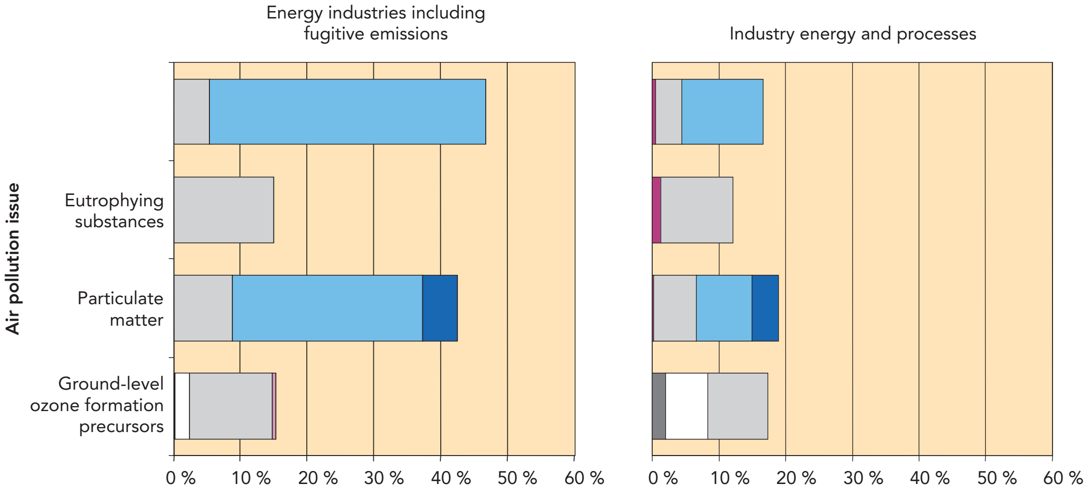
**Note:** Methodologies used to aggregate pollutants contributing to acidification, eutrophication and particulate matter are described in Appendix 3 and in more detail in the respective air pollution fact sheets (EEA, 2003a).

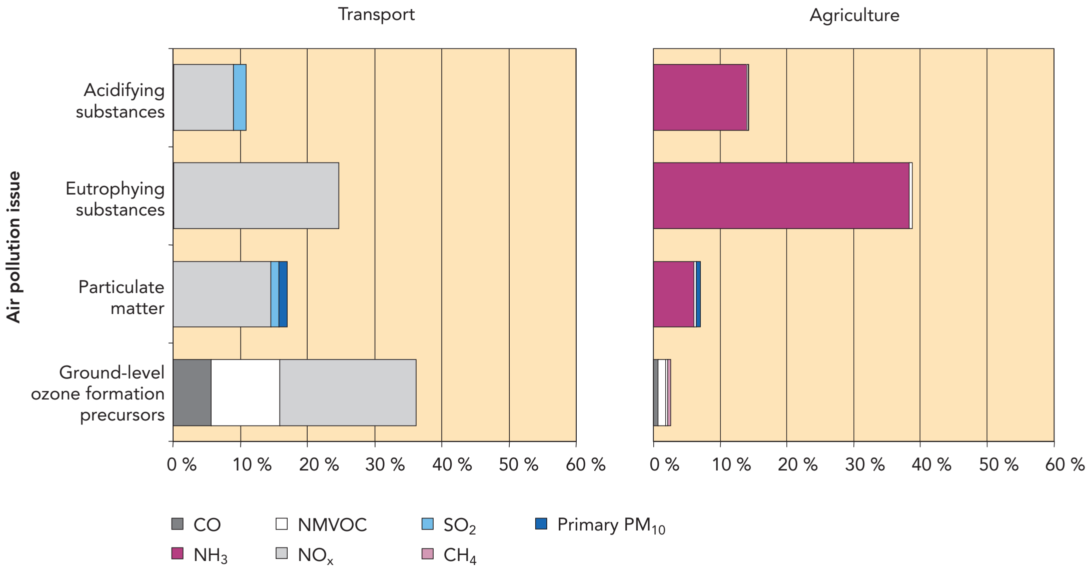
**Sector and pollutant compound contribution to air pollution issues in 2000** Figure 3.2

(a) EEA-18



(b) AC-13





**Note:** Methodologies used to aggregate pollutants contributing to acidification, eutrophication and particulate matter are described in Appendix 3 and in more detail in the respective air pollution fact sheets (EEA, 2003a).

The figures show large differences in sector contributions to air pollution issues between the EEA-18 and AC-13 countries. For the AC-13 countries, the relative contributions of the energy industries sector to emissions of acidifying substances and particulate matter are almost twice those observed for the EEA-18 countries. In contrast, the transport sector for the EEA-18 contributes proportionally more than in AC-13 countries across all four air pollution issues.

**Particulate matter**

Across the EEA-31, the sectors that were the largest contributors to emissions of primary $PM_{10}$ particles (2) (emissions in particulate form at the time of release) and secondary $PM_{10}$ (3) in 2000, were the energy industries (30 %), road transport (22 %), industry (17 %) and agricultural sectors (12 %).

The sectoral break-down of emissions was similar for EU-15 Member States, where the respective contributions to particulate emissions were energy industries (23 %), road transport (27 %), industry (16 %) and agriculture sectors (14 %). In contrast, particulate emissions in the accession countries grouping were dominated by energy industry sources (42 %), whereas road transport (13 %) and agriculture (7 %) were of lower relative significance compared with EU-15 and EFTA-4. Secondary particles formed from $NO_x$ and $SO_2$ emissions are the largest contributors to particle formation across all sectors; $NH_3$ emissions from the agricultural sector are also of significance.

**Ground-level ozone formation precursors (TOFP)**

Of the four pollutants ($CH_4$, CO, NMVOC and $NO_x$) that contribute to the formation of ground-level ozone, emissions of NMVOC (comprising 39 % of the total weighted formation potential in EEA-31) and $NO_x$ (46 %) were the most significant in 2000. Within the EU-15, contributions by NMVOC and $NO_x$ to total weighted emissions were similar to the EEA-31. For the accession and EFTA-4 countries, NMVOC contributed 34 % and 49 % respectively of the total ozone precursor emissions, and $NO_x$ contributed 48 % and 40 % in the respective country groupings. For all regions, carbon monoxide and methane contributed around 15 % and 1 % respectively. Road transport is the dominant source of ozone precursors for the EEA-31 (37 %). Other significant sources included solvents use, industry and energy industries (summed 37 %).

**Acidifying substances**

In 2000, the relative EEA-31 weighted emissions of acidifying pollutants were split between ammonia (29 %), nitrogen oxides (32 %) and sulphur dioxide (39 %). Table 3.1 shows the relative contributions that the same pollutants made to the total acidifying

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(2) The resuspension of road dust, which contributes to the atmospheric loading of $PM_{10}$, is not included in the emission data collected.

(3) particles formed chemically in the atmosphere after the emission, mainly from precursor pollutants nitrogen oxides $NO_x$, sulphur dioxide $SO_2$, and ammonia $NH_3$.

Table 3.1 Relative contribution of acidifying pollutants to the total emissions of acidifying substances in three groups of countries

| | Ammonia | Nitrogen oxides | Sulphur dioxide |
|---|---|---|---|
| EU-15 | 33 % | 34 % | 33 % |
| Accession countries | 15 % | 22 % | 63 % |
| EFTA | 67 % | 24 % | 9 % |

potential in each of the three groups of countries. The energy industries sector is primarily responsible for the larger proportion of sulphur dioxide emitted in the AC-13. Within the EEA-31, the most significant emission sources for these substances were energy industries, agriculture, transport and industry (summed 93 %).

**Eutrophying substances**

In 2000, the emissions of $NH_3$ and $NO_x$ contributed almost equally (48 % and 52 %, respectively) to relative EEA-31 emissions of eutrophying pollutants in 2000. In terms of sectoral contributions, the most significant emission sources across the EEA-31 countries were the agricultural, transport, and energy industries sectors (Figure 3.1). A similar sectoral breakdown was observed for both the EU-15 and accession countries.

## 3.2. Emissions of human health-related pollutants

This section describes trends in total emissions of pollutants that affect human health, and shows the extent to which progress has been made towards meeting the targets (emission ceilings) specified within the national emissions ceiling directive (NECD) for EU-15 Member States, and the 1999 CLRTAP Gothenburg protocol for EU-15, accession and EFTA-4 countries.

### 3.2.1. Total ground-level ozone formation precursors

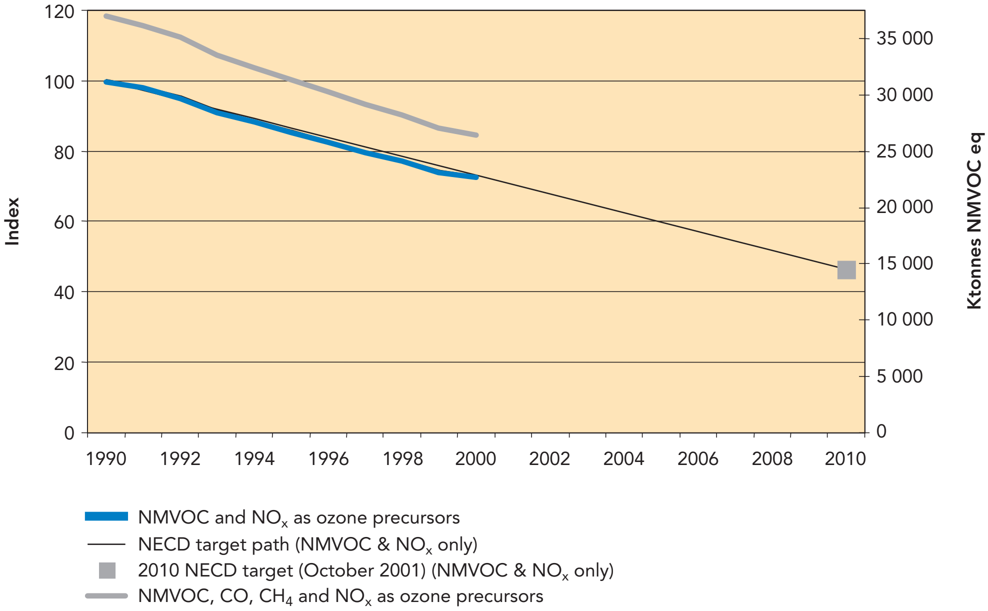
Within the EEA-31, emissions of ozone precursor gases (aggregated as TOFP) have been reduced by 31 % between 1990 and 2000. A similar magnitude of reduction occurred for EU-15 emissions over the same period (28 %) (Figure 3.3), and in the accession countries (30 %) (Figure 3.4). In contrast, a 16 % reduction occurred between 1990 and 2000 in EFTA-4 countries. Although total EU-15 emissions and those for four EU Member States (United Kingdom, Germany, Netherlands and Finland) are below linear target paths to the 2010 targets of the EU national emissions ceilings directive, substantial reductions of emissions of ozone precursors are still required in many countries to reach the 2010 targets. In particular, the emissions of five countries (Portugal, Spain, Greece, Ireland and Belgium) were substantially above their linear target paths.

Of the nine accession countries that have agreed emission ceilings under the Gothenburg protocol, eight are below a linear target path to the 2010 targets, only Slovenia is above the linear target path. In order to meet the future targets, Slovenia and also Hungary, Poland and the Czech Republic still require substantial emission reductions.

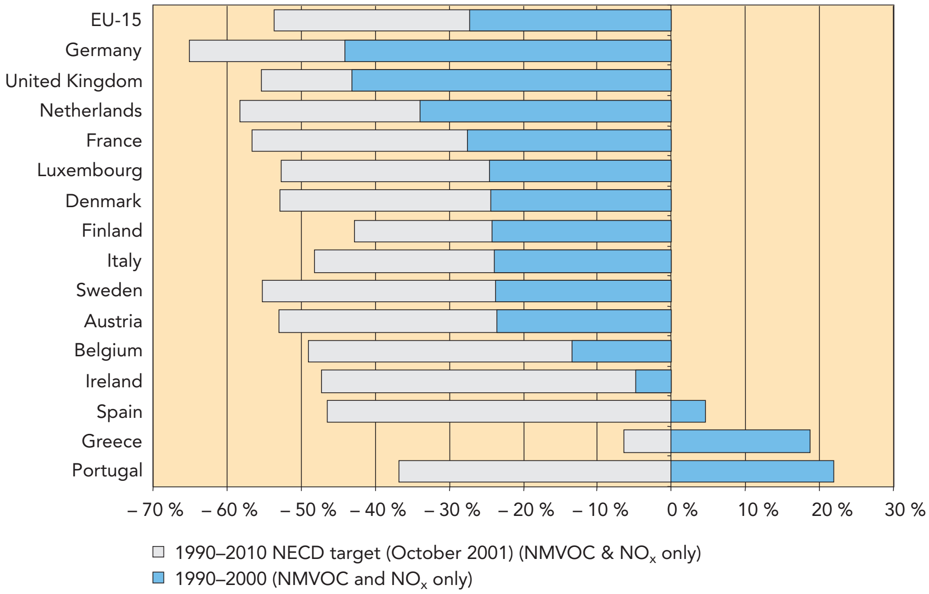
Of the EFTA-4 countries that have agreed emission ceilings under the Gothenburg protocol, both Liechtenstein and Switzerland lie below their linear target paths (both countries by 16 index points). In contrast, Norway is substantially above (by 16 index points) its linear path, as emissions increased by 7 % between 1990 and 2000. Norway will require a substantial emission reduction of 41 % from its reported emissions in 2000 in order to meet its 2010 target.

**Figure 3.3** **EU-15 emissions of ozone precursors**

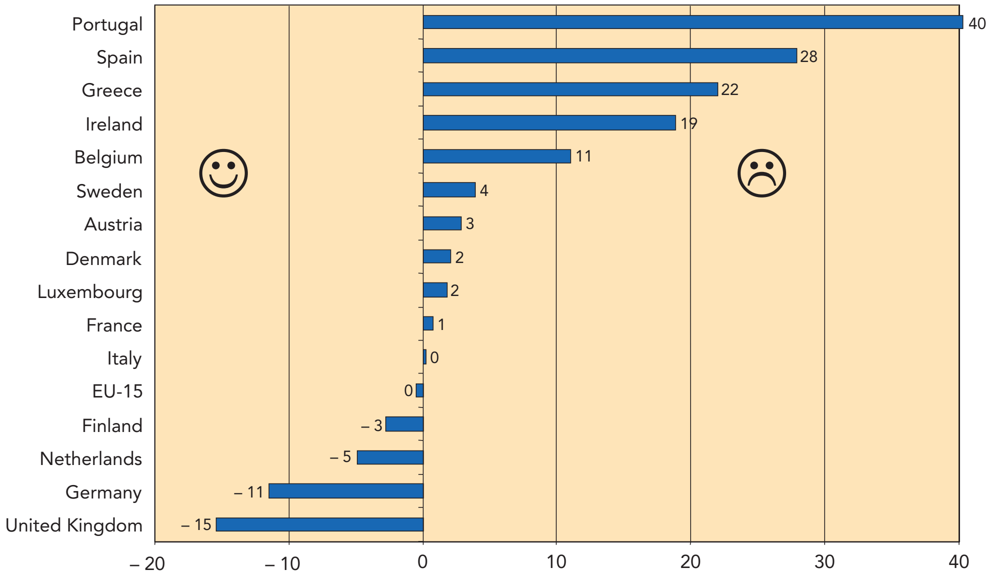
(a) EU-15 total



(b) Emission change, 1990–2000, by country



(c) Distance to target for individual countries



**Note:** The distance-to-target indicator (DTI) measures the deviation of actual emissions in 2000 from the (hypothetical) linear target path between 1990 and 2010. The DTI gives an indication on progress towards countries' targets. See Appendix 3 for an explanation of the DTI.

(d) Emission change by sector and pollutant, 1990–2000 (%)

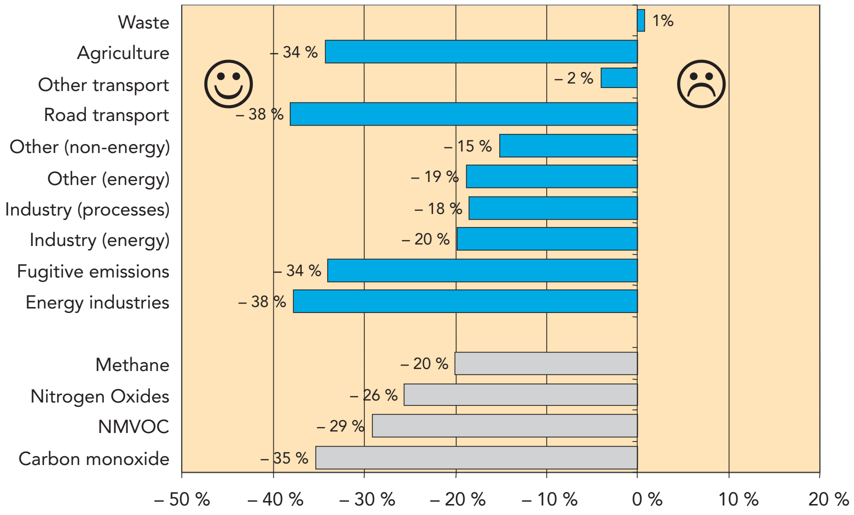
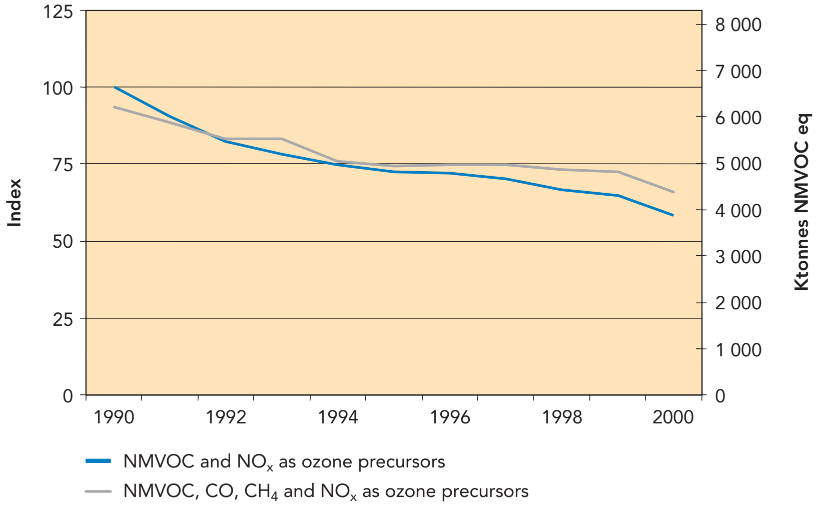
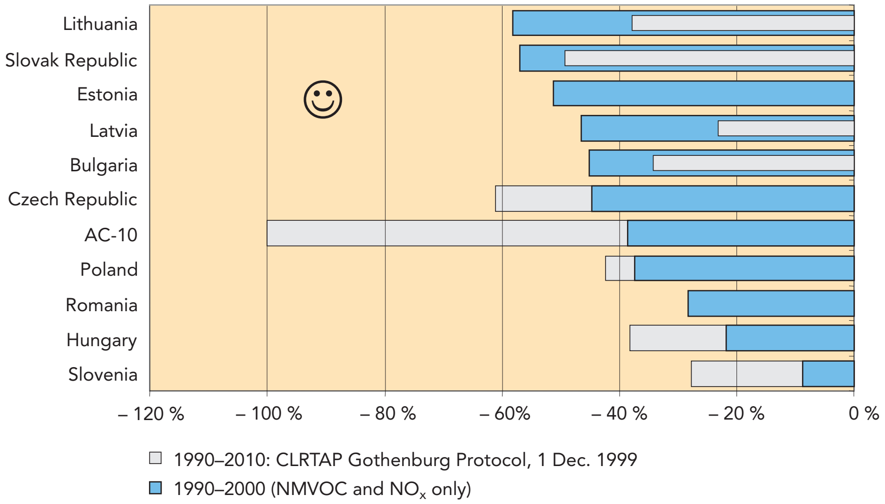


**Figure 3.4** **Accession country emissions of ozone precursors**

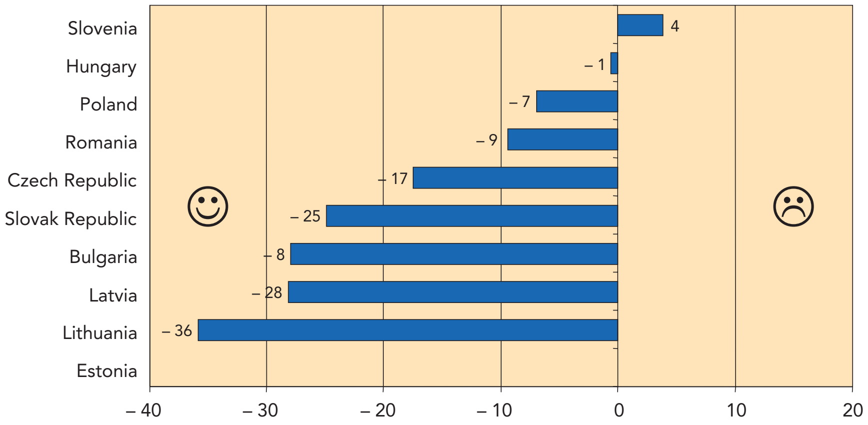
(a) AC-10 total



(b) Emission change, 1990–2000, by country

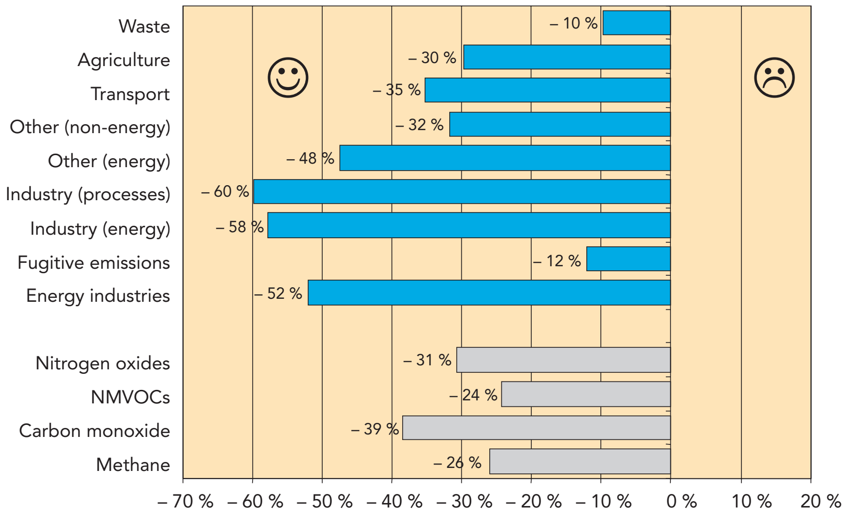


(c) Distance to target for individual countries



**Note:** The distance-to-target indicator (DTI) measures the deviation of actual emissions in 2000 from the (hypothetical) linear target path between 1990 and 2010. The DTI gives an indication on progress towards countries' targets. See Appendix 3 for an explanation of the DTI.

(d) Emission change by sector and pollutant, 1990–2000 (%)



Emission reductions of ozone precursors across the EEA-31 were mainly due to the introduction of catalysts on new cars, an increased market penetration of diesel vehicles and also the implementation of the solvents directive in industrial processes. Figure 3.5 shows the major contribution that the road transport sector makes to emissions of ozone precursors. In the EU Member States, the contribution decreased slightly from 47 % in 1990 to about 40 % in 2000, while in the accession countries, it increased from just below 30 % to slightly above 30 %. (see Section 5.3.2 for explanation). For both country groups, NO$_x$ was the predominant pollutant.

Unlike the other tropospheric ozone formation precursors (TOFP), carbon monoxide emissions (CO) from industry and transport sectors primarily contribute to localised air quality issues. Although new petrol-powered vehicles having improved motor technologies and catalytic converters have reduced CO emissions, CO emissions still lead to ambient concentrations exceeding limit values at hot spots in several cities across Europe.

### 3.2.2. Particulate matter

Total emissions of fine particles (primary PM$_{10}$ plus secondary inorganic PM$_{10}$ precursors, that is the fraction of SO$_2$, NO$_x$ and NH$_3$ emissions which, as a result of chemical reactions in the atmosphere, transform into particulate matter) in both the EU-15 and accession country groupings were reduced by 35 % over the 1990 to 2000 period (Figure 3.6 and Figure 3.7); those across EFTA-4 countries decreased by 7 %. Within the EU, 10 countries have reduced their total emissions of fine particulates by more than 20 % since 1990. The majority of accession countries have also achieved significant reductions in emissions, with all countries except Turkey and Cyprus having decreases in excess of 20 %. There are no emission ceilings targets for particulates in EU or international legislation.

**Share of road traffic in total emissions of TOFP in EU-15 and accession countries (%)** Figure 3.5

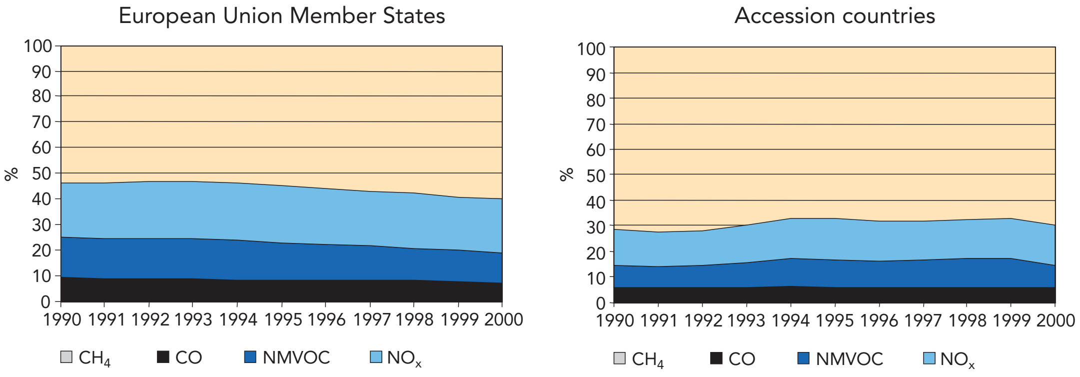
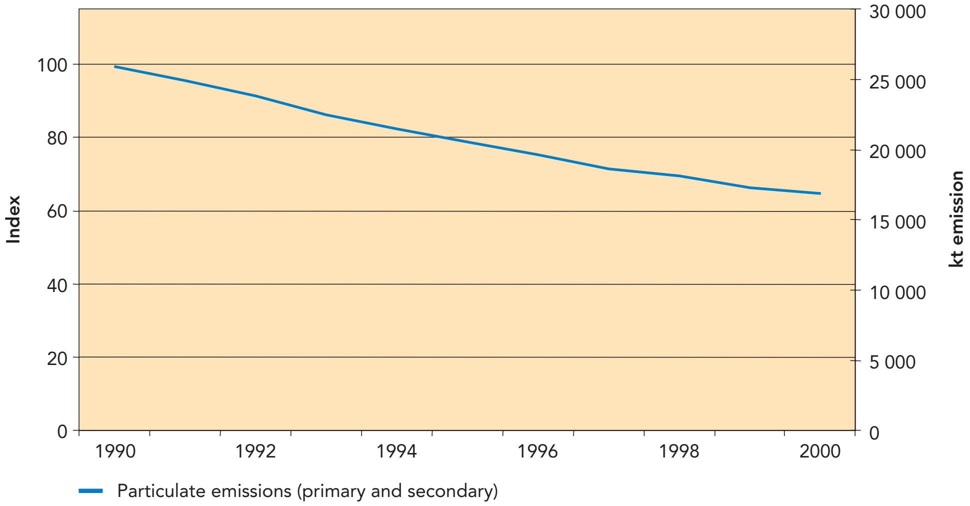
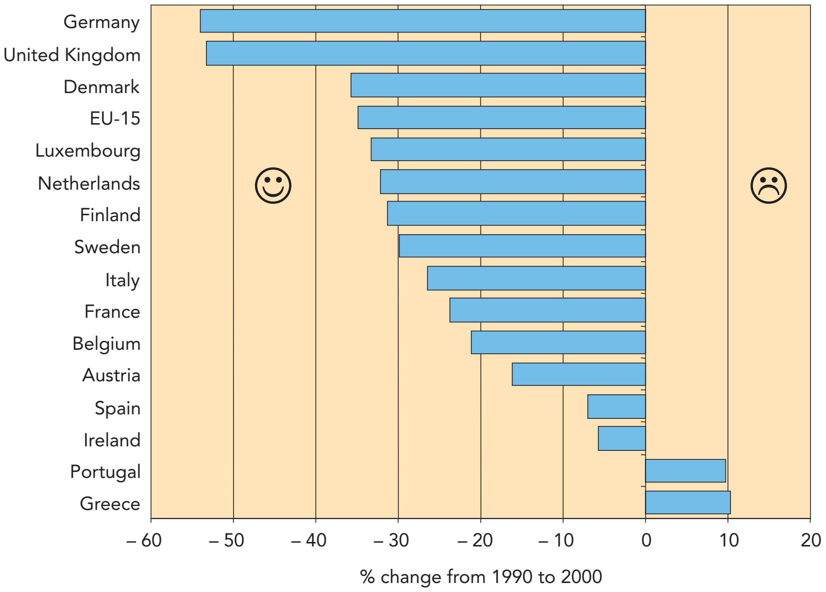


**Figure 3.6** **EU-15 emissions of primary and secondary fine particles**

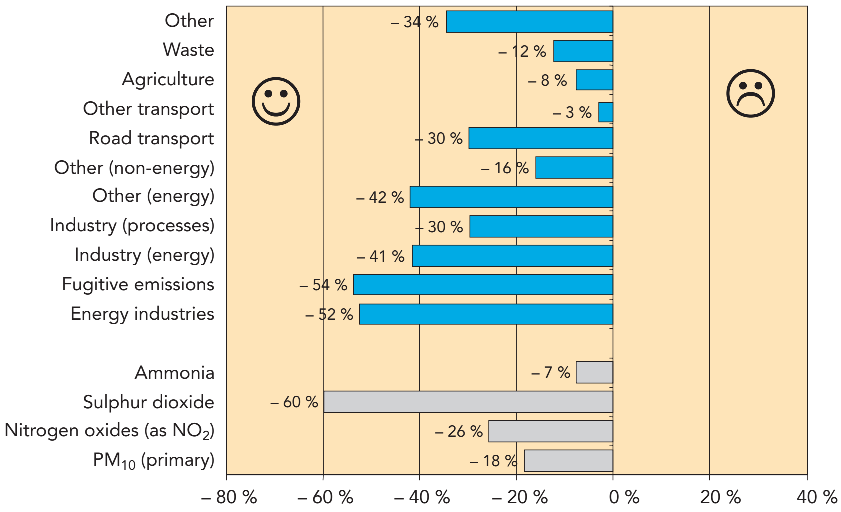
(a) EU-15



(b) Emission change, 1990–2000, by country

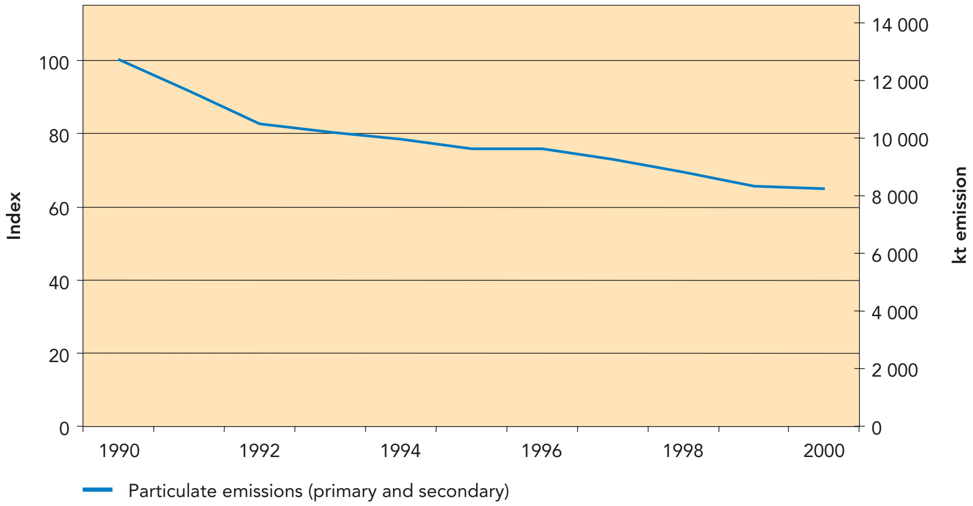


(c) Emission change by sector and pollutant, 1990–2000 (%)



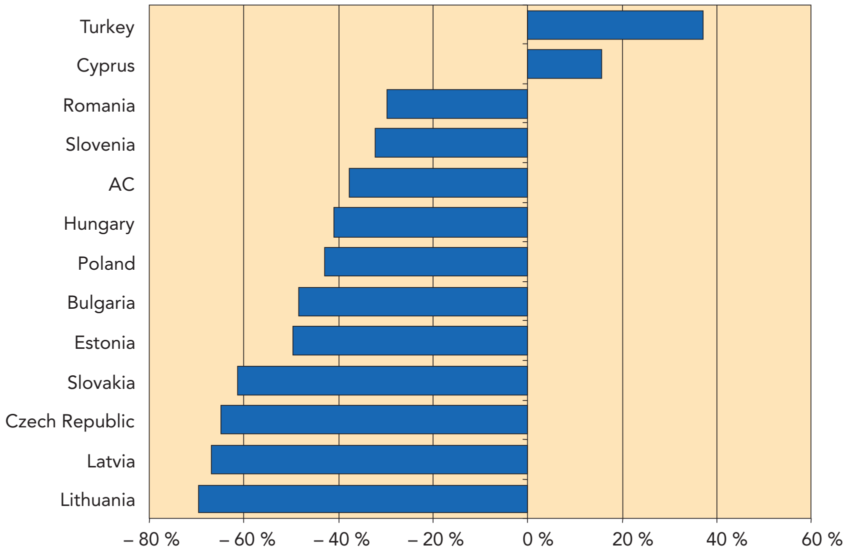
**Accession country emissions of primary and secondary fine particles** Figure 3.7

(a) AC-13

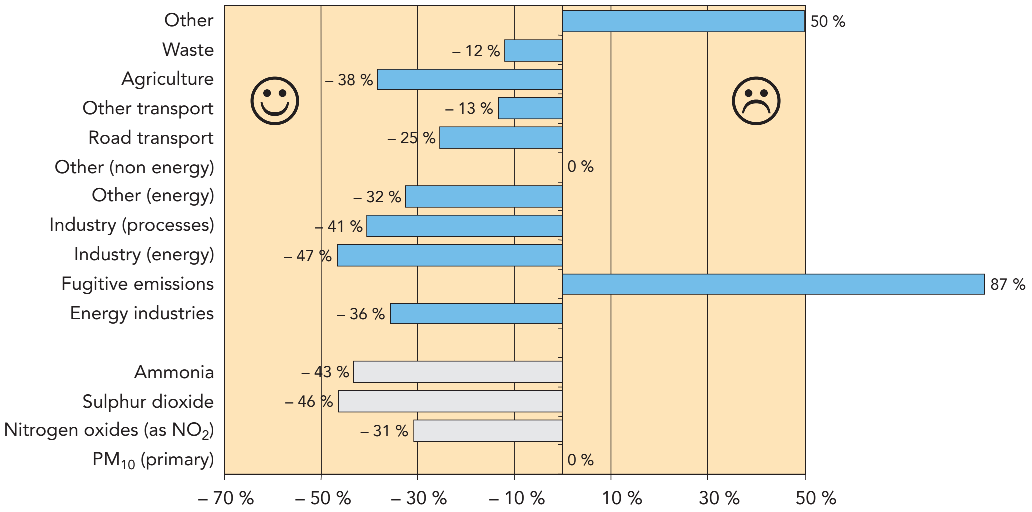


(b) Emission change, 1990–2000, by country

(% change from 1990 to 2000)



(c) Emission change by sector and pollutant, 1990–2000 (%)



**Note:** No data available for Malta. Primary $PM_{10}$ data not available for Turkey or Cyprus, and for other countries for 1995 only (years 1990–2000 assumed constant at 1995 values for each country).

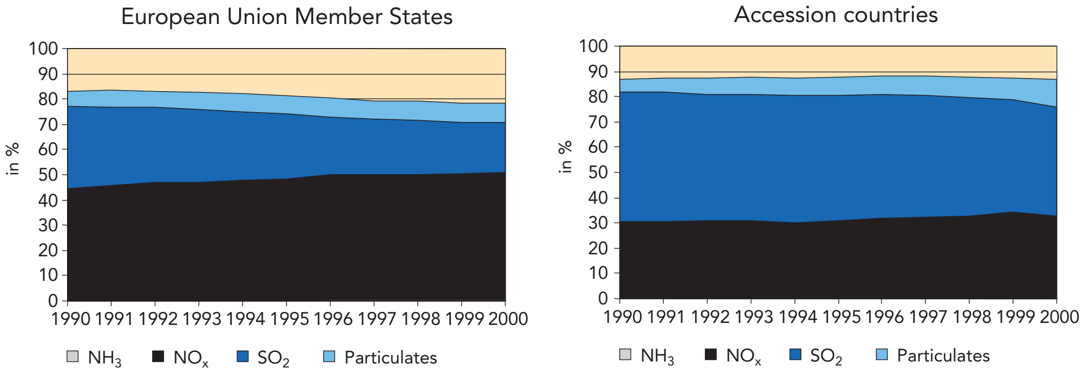
The reductions observed across the EEA-31 region have been mainly due to abatement measures adopted in the transport (– 23 %), energy industries (– 46 %), and industry sectors (– 41 %). The abatement measures have included fuel switching and new emission control technologies in the energy industries and industry sectors, as well as increased penetration of catalytic converters for new road vehicles reducing NO$_x$ emissions, and improvements to primary particulate emissions from diesel vehicles. Figure 3.8 shows that fuel combustion is the major contributor to emissions of primary and secondary inorganic PM$_{10}$. Between 1990 and 2000, in the EU-15, the contribution that fuel combustion made to these emissions decreased slightly from 83 % to 78 %, with the largest contribution estimated to be secondary particles from NO$_x$ emissions. In the accession countries, the share of fuel combustion in the emissions of primary and secondary particles remained constant at around 87 %, and in contrast to the EU-15, the contribution from SO$_2$ is largest in the accession countries. See for more explanation Section 5.3.1.

The transport sector is a major source primary PM$_{10}$ as well as of the fuel combustion NO$_x$ leading to secondary particle formation. While traffic activity has increased, this PM source has diminished since 1990, mainly due to penetration of catalytic converter technology on petrol-drivers vehicles (in Chapter 5.3.1). In 1999, 63 % of petrol-driven cars in the EU had catalytic converters (EEA, 2002c), with wide variations between Member States (the lowest shares for which data were available were in Spain (34 %) and Finland (52 %), the highest in Luxembourg, the Netherlands and Austria (all above 85 %)). In 1996, the share of petrol-engined cars fitted with catalytic converters in the accession countries was estimated at 7.7 % (EEA, 2002c). This corresponds to the situation in the EU in 1990, indicating a backlog in technology penetration within the accession countries of about six years. Again, there were wide variations between countries, with shares ranging from 0.2 % in Romania to 11 to 14 % in Slovakia, the Czech Republic and Hungary (no data were available for other countries). Much has changed since 1996, but no more recent AC-wide statistics are available in international databases.

### 3.2.3. Nitrogen oxides

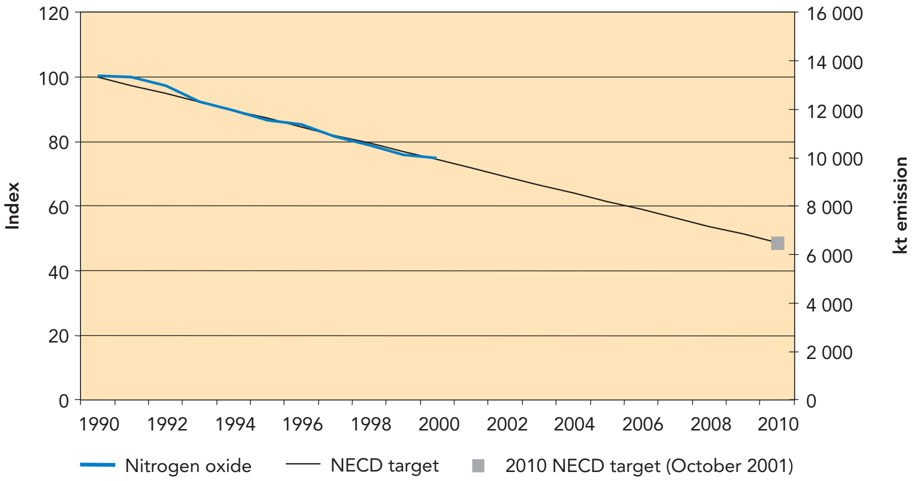
Across the EU-15, NO$_x$ emissions have decreased by 26 %, with a greater reduction achieved by the accession countries (31 %), but only a 14 % reduction in EFTA-4 countries. NO$_x$ emissions of EU-15 are slightly below a linear target path towards the 2010 target of the national emission ceilings directive, which is mainly due to the substantial emission reductions achieved in Germany and the UK. Ten Member States have emissions above a linear target path towards the 2010 NECD target, and in particular Portugal, Spain and Ireland need to reduce emissions substantially to meet their NECD targets. In contrast to the EU-15, for the accession countries, only the Czech Republic and Slovenia have not already met their respective 2010 Gothenburg protocol targets. Slovenia is the only country lying above a linear target path to its 2010 emission target.

Figure 3.8 **Contribution of fuel combustion to the total emissions of primary particles and secondary particles formed from aerosol precursors (SO$_2$, NO$_x$, NH$_3$) (%)**

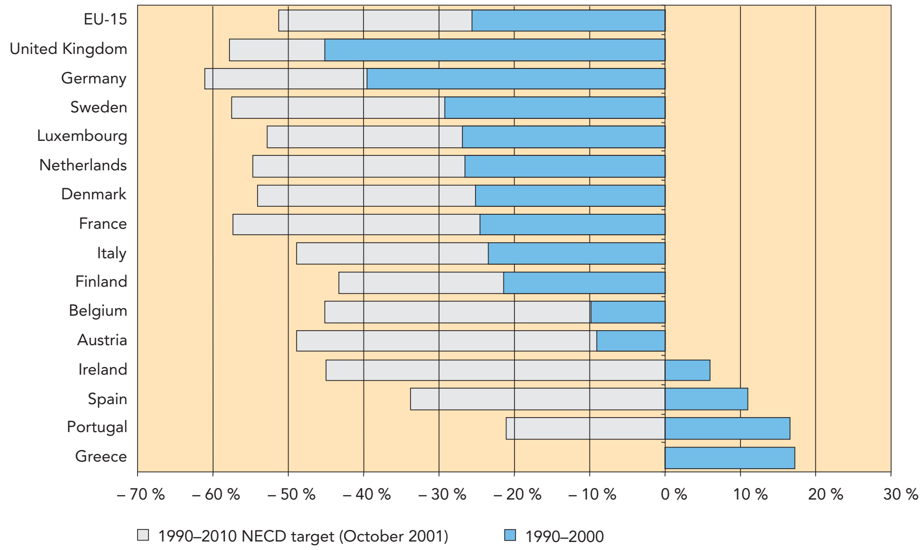


**EU-15 emissions of $NO_x$** Figure 3.9

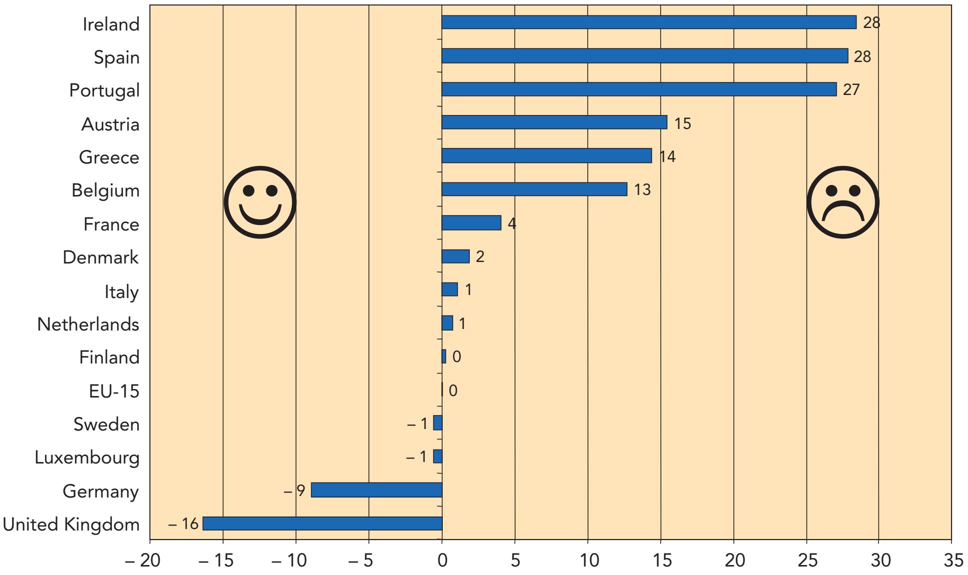
(a) EU-15 total



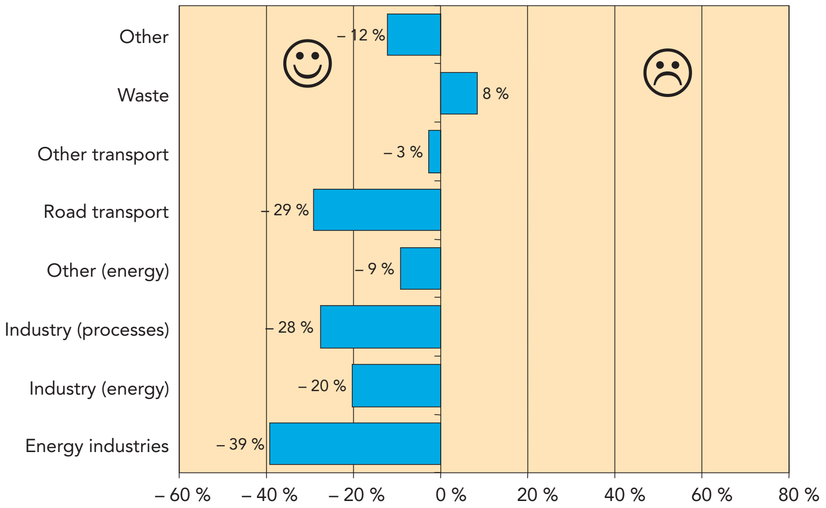
(b) Emission change, 1990–2000, by country



(c) Distance to target for individual countries



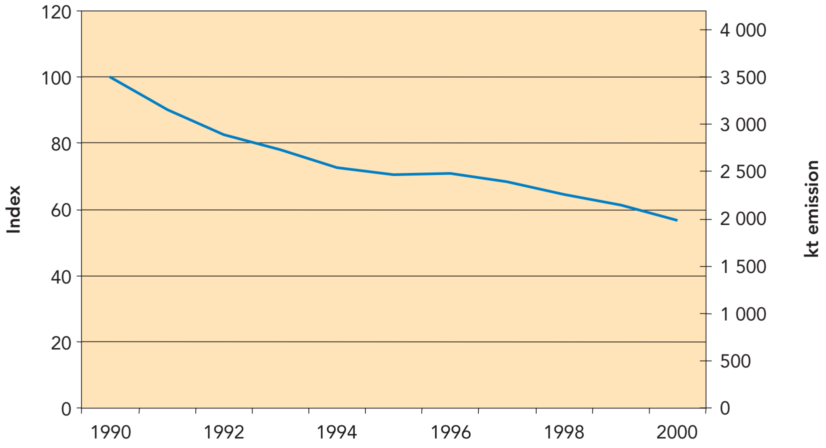
(d) Emission change by sector, 1990–2000 (%)



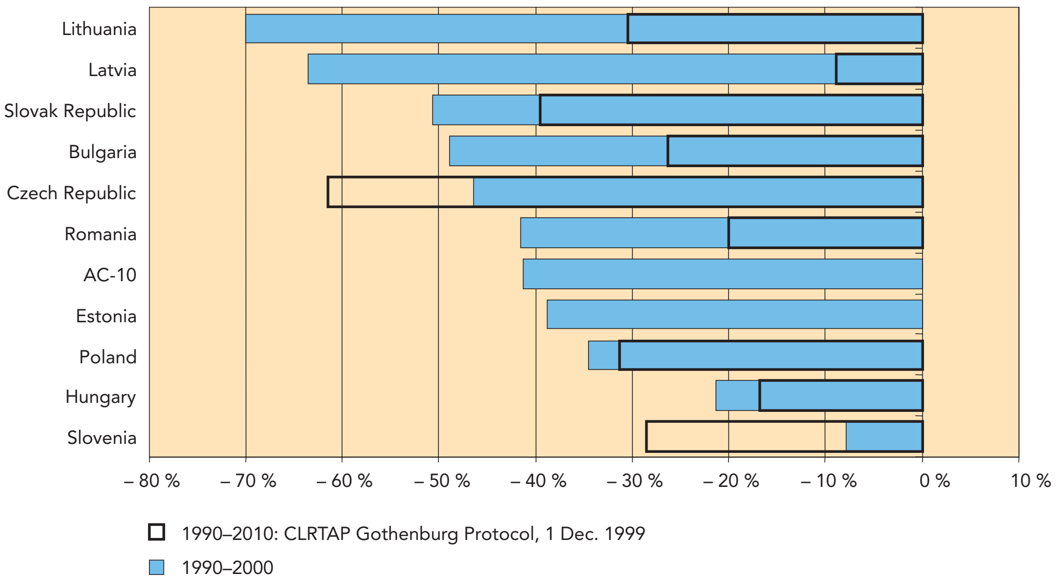
**Note:** The distance-to-target indicator (DTI) measures the deviation of actual emissions in 2000 from the (hypothetical) linear target path between 1990 and 2010. The DTI gives an indication on progress towards countries' targets. See Appendix 3 for an explanation of the DTI.

**Figure 3.10** **Accession country emissions of $NO_x$**

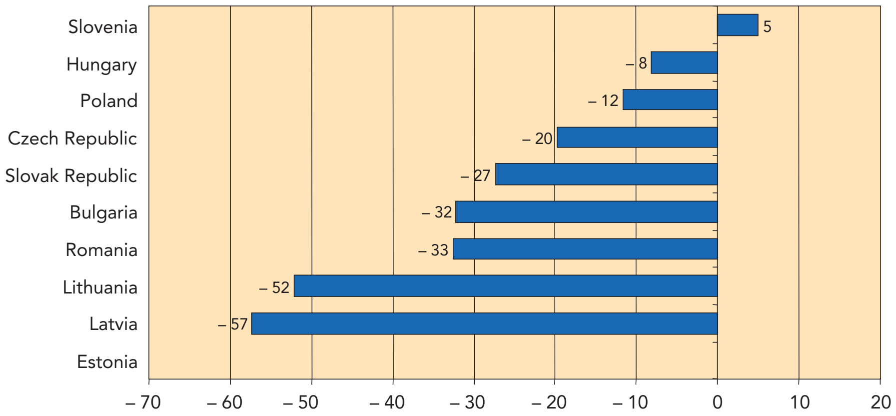
(a) AC-10 total



(b) Emission change (%), 1990–2000, by country

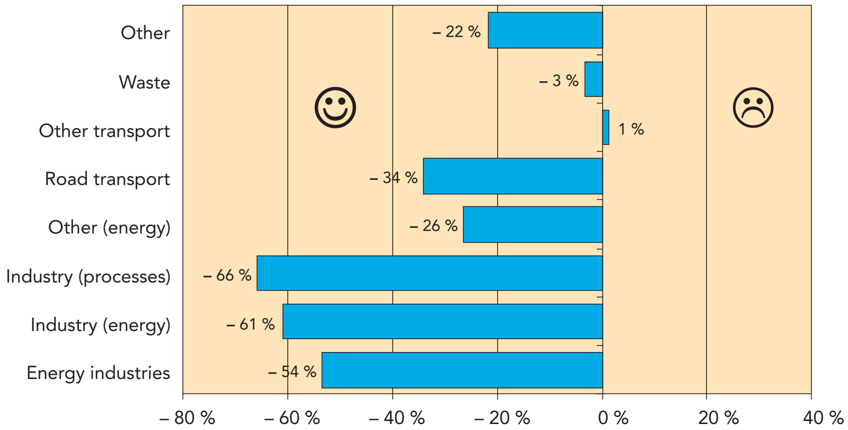


(c) Distance to target for individual countries



**Note:** The distance-to-target indicator (DTI) measures the deviation of actual emissions in 2000 from the (hypothetical) linear target path between 1990 and 2010. The DTI gives an indication on progress towards countries' targets. See Appendix 3 for an explanation of the DTI.

(d) Emission change by sector, 1990–2000 (%)



Within the EU, the anthropogenic emission of $NO_x$ originates mainly from the road and other transport sectors (52 %), energy industries (17 %) and industry 13 %). In the accession countries, the respective values for the same sectors were 42 %, 25 % and 18 %. Since 1990, both regions have seen emissions being significantly reduced from the road transport and energy sectors. The reduction in emissions is mainly due to the introduction of catalysts on new cars in and improved abatement and the introduction of combined cycle gas turbine (CCGT) power generation in the energy and industry sectors.

## 3.3. Emissions of ecosystems-related pollutants

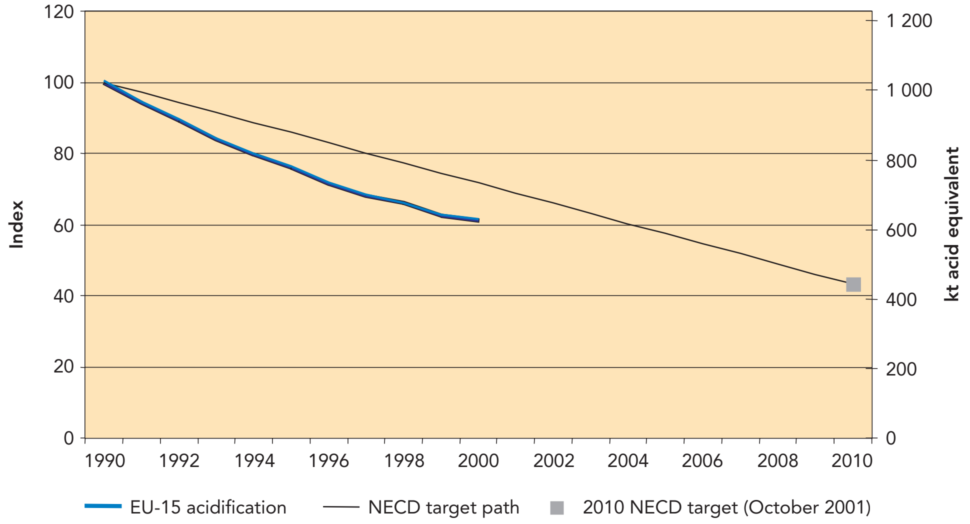
The emissions of ozone precursors, sulphur dioxide ($SO_2$), and acidifying gases in total causes various adverse impacts, on both human health and on ecosystems. Emissions of ozone precursors were previously presented in Section 3.2.1. This section describes trends in emissions of pollutants that affect ecosystems, in particular total acidifying pollutants and sulphur dioxide. It shows the extent to which progress has been made towards meeting the targets (emission ceilings) set in the national emissions ceiling directive (NECD) for EU-15 Member States, and the 1999 CLRTAP Gothenburg protocol for EU-15, accession and EFTA countries.

### 3.3.1. Total acidifying pollutants

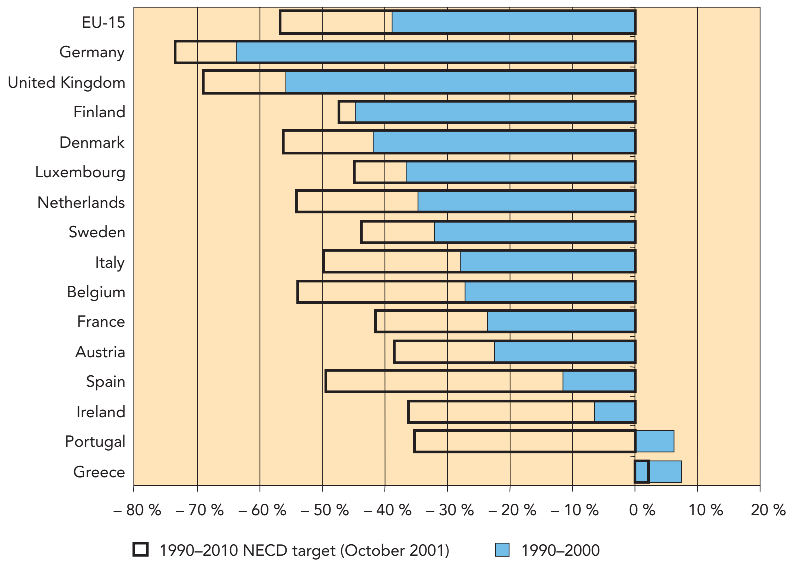
Emissions of acidifying substances in the EU have decreased by 39 %, and in the AC-10 countries by 53 %, between 1990 and 2000 (Figure 3.11 and Figure 3.12) despite increases in gross domestic product (GDP) in both regions during this time. Across the EEA-31 region, the reduction in acidifying substance emissions between 1990 and 2000

Figure 3.11 **EU-15 emissions of acidifying pollutants**

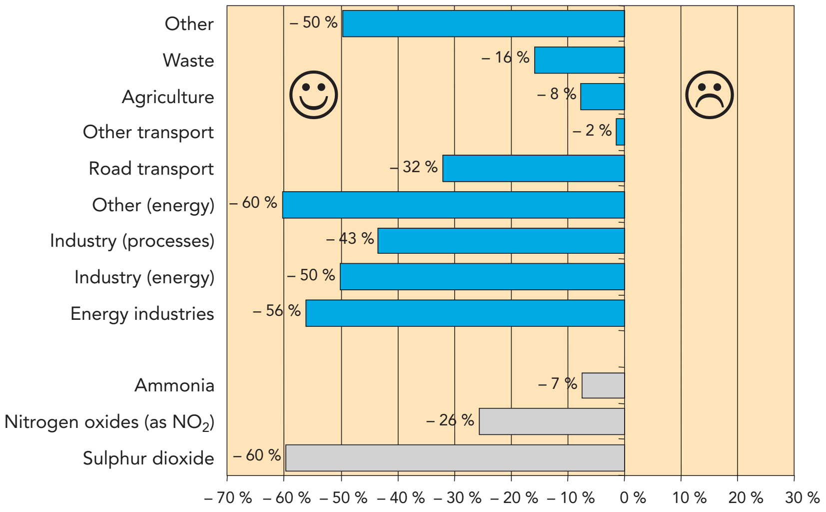
(a) EU-15 total

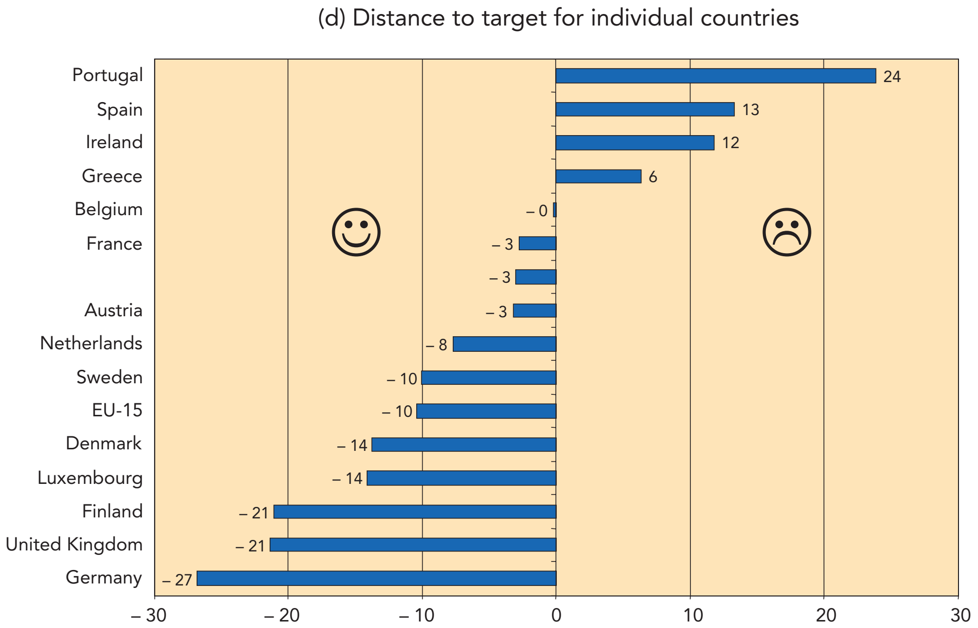


(b) Emission change, 1990–2000, by country



(c) Emission change by sector and pollutant, 1990–2000 (%)




(d) Distance to target for individual countries

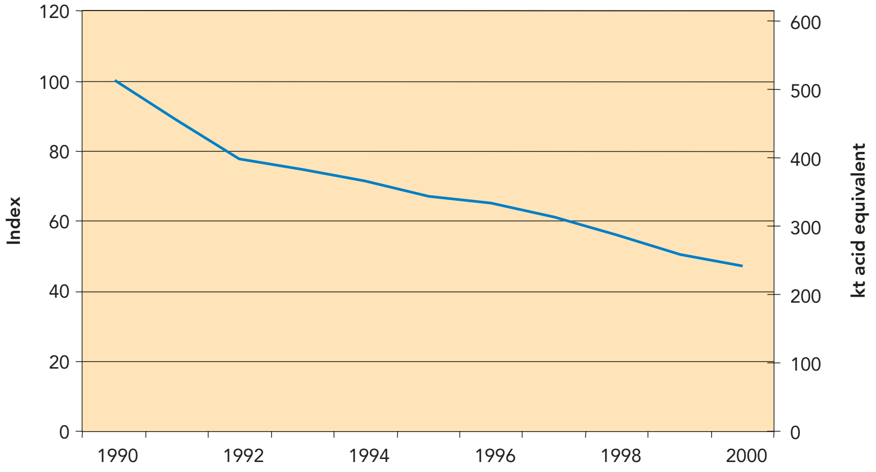
**Note:** The distance-to-target indicator (DTI) measures the deviation of actual emissions in 2000 from the (hypothetical) linear target path between 1990 and 2010. The DTI gives an indication on progress towards countries' targets. See Appendix 3 for an explanation of the DTI.

was 40 %. The EU is more than half way towards meeting the 2010 targets of the national emission ceilings directive, although several Member States (Greece, Portugal, Ireland and Spain) are less than half way to their 2010 targets and above a linear target path towards their respective targets.

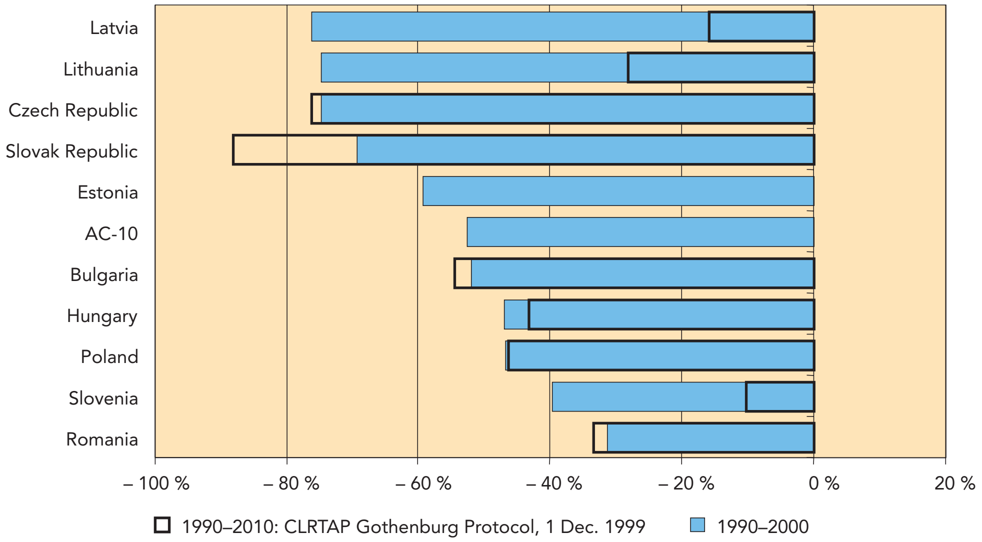
Of the accession countries, all are below a linear path to the Gothenburg protocol target, and four countries (Latvia, Lithuania, Czech Republic, Slovakia) substantially so. A number of accession countries have already reached their respective emission targets (Figure 3.12b). Of the EFTA-4 countries, only Switzerland lies below its linear target path (by 21 index points) for its 2010 Gothenburg protocol target. Liechtenstein lies slightly above its linear target path (2 index points), and Norway substantially so (by 63 index points). Emissions in Norway increased by 28 % between 1990 and 2000, and therefore a substantial reduction (77 % from 2000 emissions) will be required in order that the 2010 Gothenburg targets are met.

Figure 3.12 **Accession country emissions of acidifying pollutants**

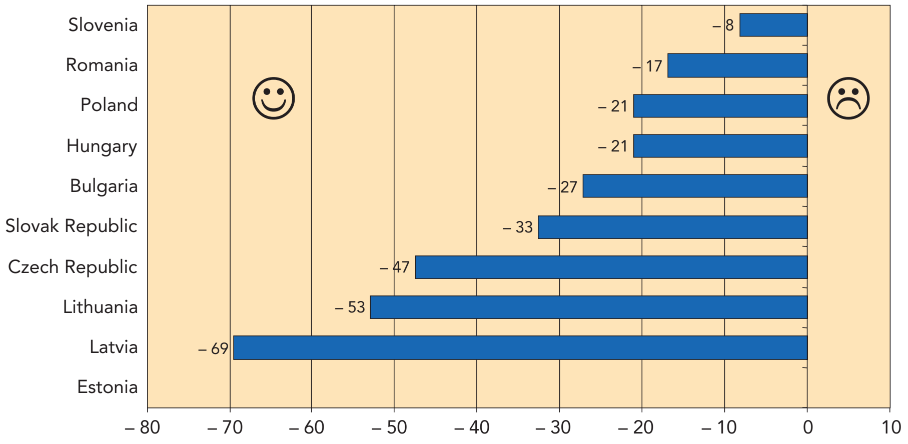
(a) AC-10 total

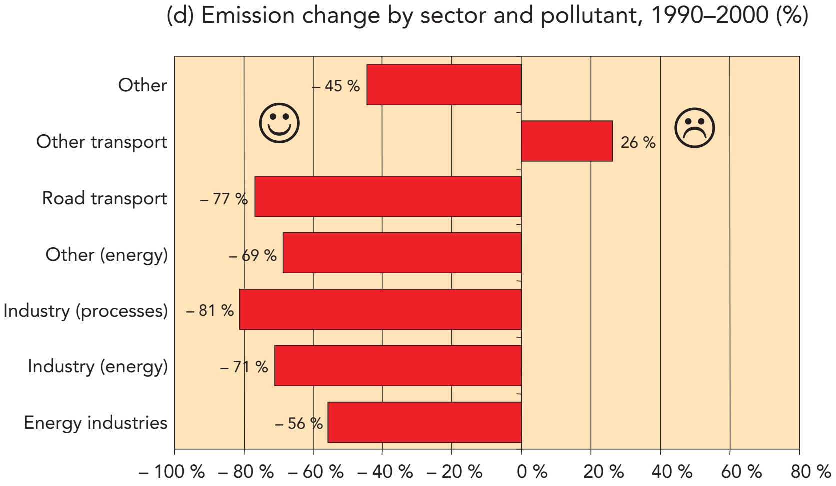


(b) Emission change, 1990–2000, by country



(c) Distance to target for individual countries

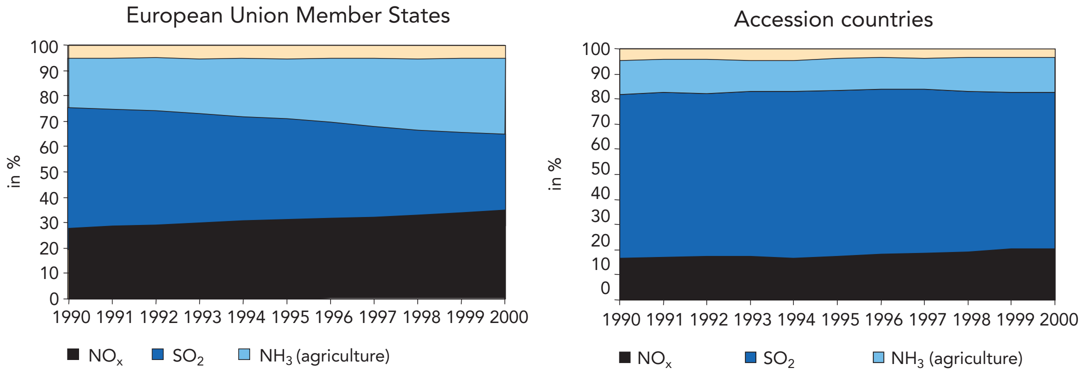



(d) Emission change by sector and pollutant, 1990–2000 (%)

**Note:** The distance-to-target indicator (DTI) measures the deviation of actual emissions in 2000 from the (hypothetical) linear target path between 1990 and 2010. The DTI gives an indication on progress towards countries' targets. See Appendix 3 for an explanation of the DTI.

**Share of fuel combustion and agriculture in total emissions of acidifying pollutants in the EU-15 and accession countries (%)**

**Figure 3.13**



The substantial decrease in emissions of acidifying substances is mainly due to reductions of sulphur dioxide emissions since 1990 (see Section 3.3.2 and Chapter 5). The reductions in emissions of nitrogen oxides are largely due to abatements in road transport and large combustion plants. Since 1990, EU emissions from energy industries have been reduced by 56 %, and those from the road transport sector by 32 %. EU agriculture emissions ($NH_3$) have been reduced by 8 % since 1990; a 41 % decrease in the same sector occurred in the accession countries.

The major emission sources of acidifying pollutants, accounting for 95 % of total emissions in both the EU-15 and accession countries, occur from fuel combustion ($NO_x$ and $SO_2$) and from animal husbandry ($NH_3$). Emissions of $NH_3$ are difficult to quantify accurately and hard to control, especially in the agricultural sector. As the emissions from the energy industry have decreased, the relative importance of agricultural emissions has increased from 18 % in 1990 to 25 % in 2000 across the EEA-31. EU-15 ammonia emissions decreased by 7 % between 1990 and 2000, those in accession countries decreased by 47 % over the same period. The most important source in agriculture is from manure management in livestock. Particularly large emissions occur from pigs, cattle and poultry rearing, and emission reductions have been mainly due to a reduction in livestock numbers, particularly for cattle, and improved manure management measures.

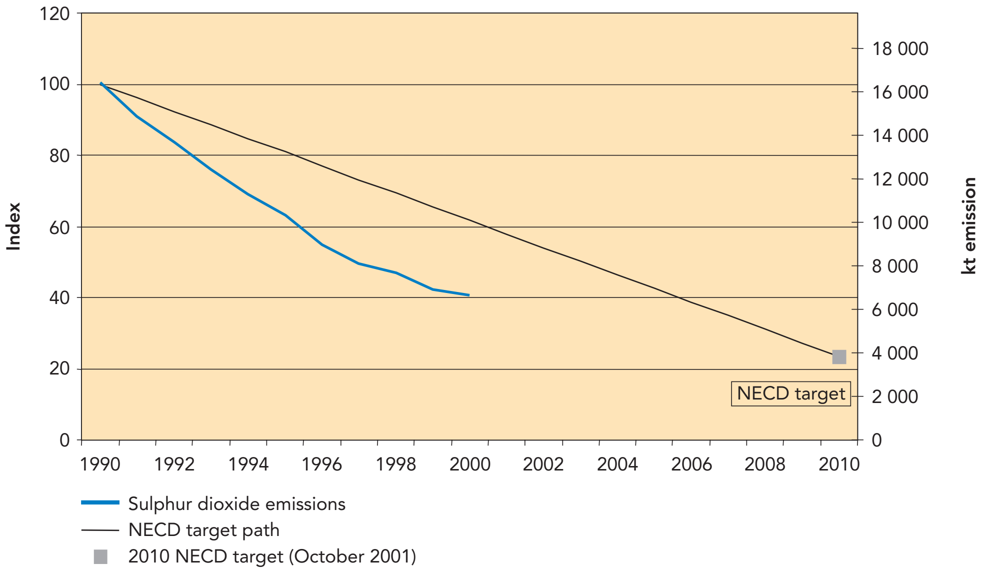
Figure 3.13 shows that the share of $NH_3$ from agriculture in the emissions of acidifying pollutants in the EU-15 has steadily increased over the last decade, and now accounts for around 35 % of acidifying emissions. In the accession countries, the share of fuel combustion is about 83 %, and the share of agriculture is about 13 %.

### 3.3.2. Sulphur dioxide

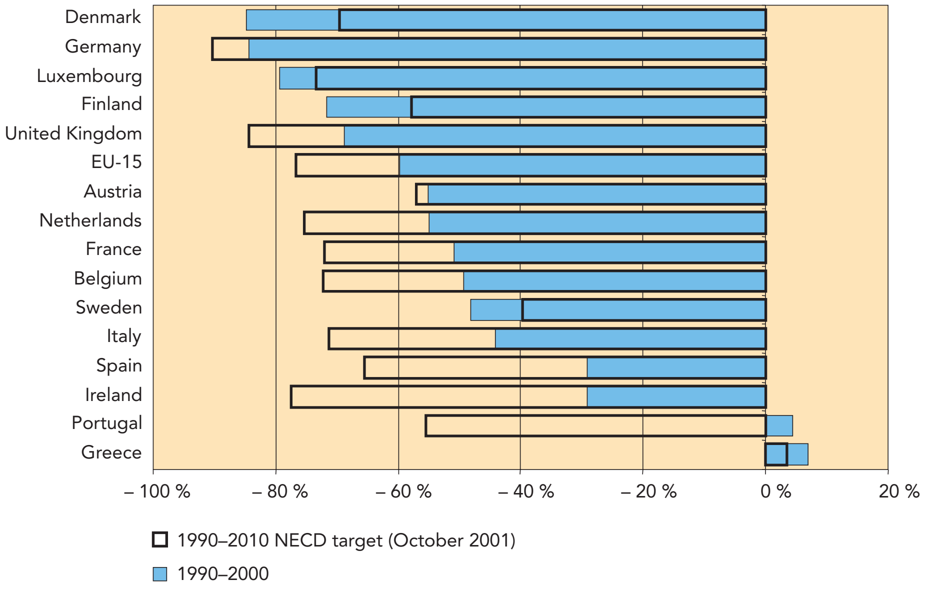
Sulphur dioxide, together with $NO_x$ and $NH_3$ (ammonia) are a major precursor to acidic deposition and to secondary $PM_{10}$ formation. Within the EU and accession countries, emissions of $SO_2$ have been reduced by approximately 60 % since 1990 (Figure 3.14 and Figure 3.15). Total EU emissions are significantly below a linear target path towards the 2010 target of the national emission ceilings directive, mainly due to the substantial emission reductions achieved in Germany and the UK. While on a national basis most EU Member States and three of the EFTA-4 countries have reduced their $SO_2$ emissions well below a linear target paths and are approaching or have reached the 2010 target, four EU countries (Portugal, Ireland, Greece and Spain) are above the linear target path and need to make significant reductions to reach their respective targets. Accession countries have made good progress towards meeting or exceeding the targets for $SO_2$ emissions under the Gothenburg protocol. All countries are below the linear target path and only Slovenia requires further significant reduction in future years to meet its target.

**Figure 3.14** **EU-15 emissions of $SO_2$**

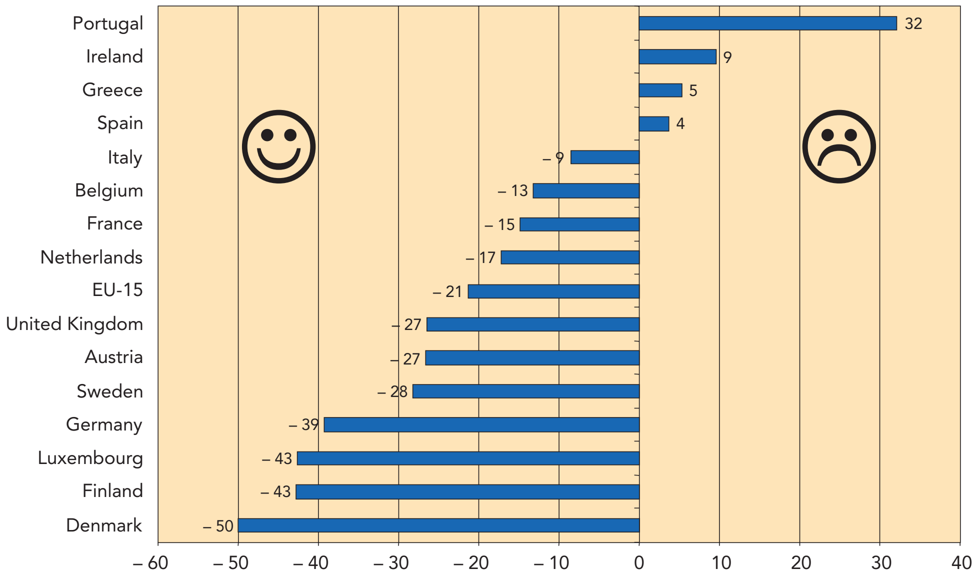
(a) EU-15 total



(b) Emission change, 1990–2000, by country

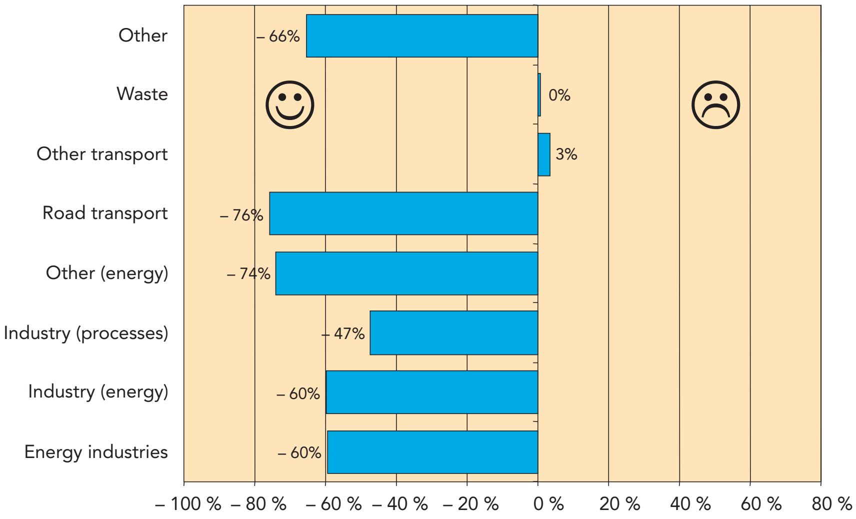


(c) Distance to target for individual countries



**Note:** The distance-to-target indicator (DTI) measures the deviation of actual emissions in 2000 from the (hypothetical) linear target path between 1990 and 2010. The DTI gives an indication on progress towards countries' targets. See Appendix 3 for an explanation of the DTI.

(d) Emission change by sector, 1990–2000 (%)

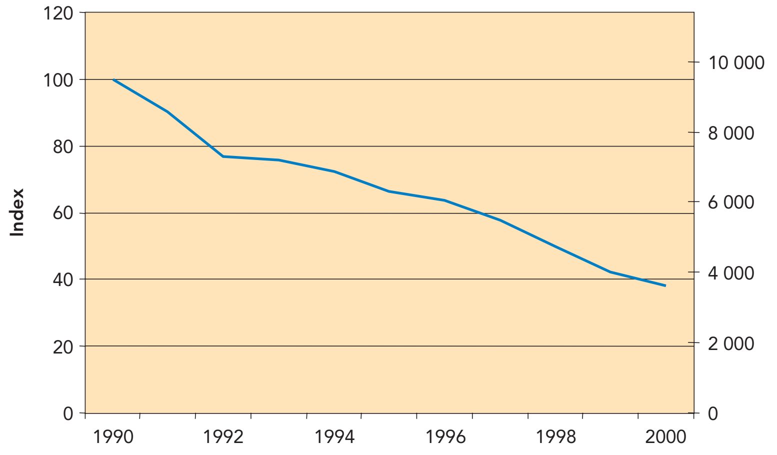


Of most significance for the overall decrease in EU emissions have been the reductions from energy industries (60 % between 1990 and 2000) and from energy use in industry (60 %). Large percentage decreases in $SO_2$ emissions have also been achieved in the accession countries, i.e. in energy use in industry (56 %), and from energy industries (39 %) between 1990 and 2000.

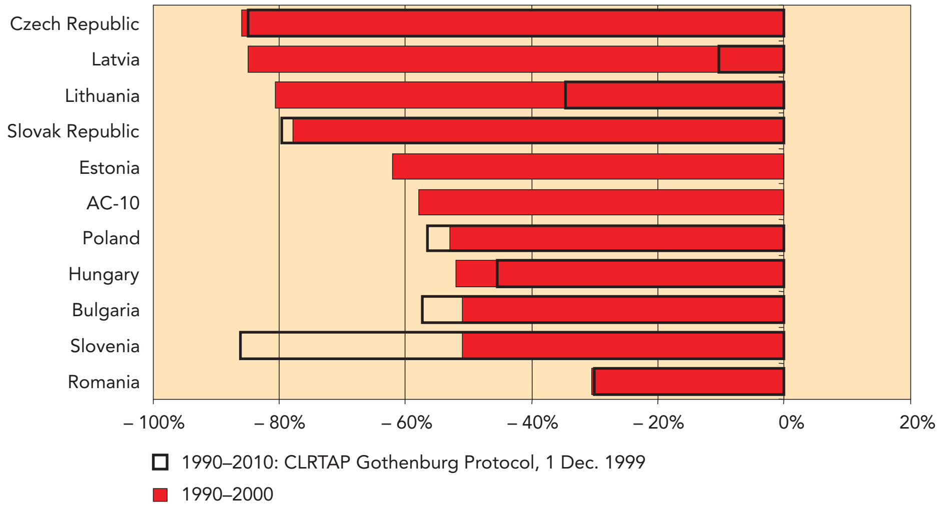
In both regions, the emission reduction has been mainly due to a switch from high sulphur solid and liquid fuels to natural gas in the energy industries, industry and domestic sectors, as well as construction of new power plants having improved pollution abatement equipment, and the use of low sulphur coal and introduction of flue gas desulphurisation in power plants.

**Figure 3.15** **Accession country emissions of $SO_2$**

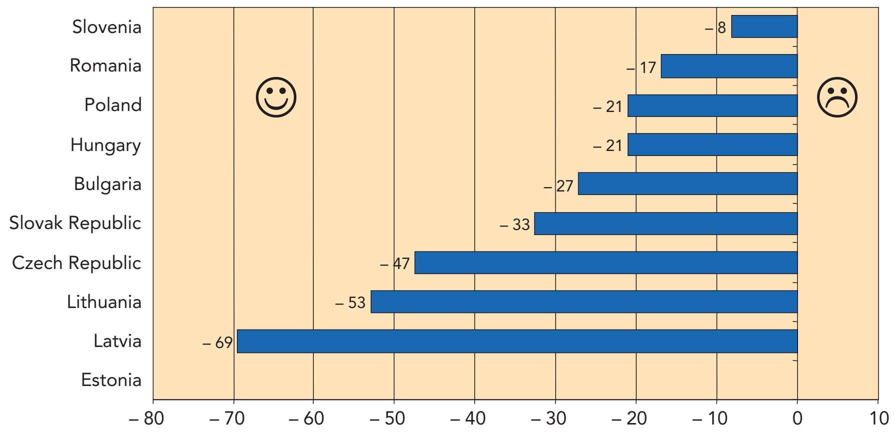
(a) AC-10 total



(b) Emission change (%), 1990–2000, by country



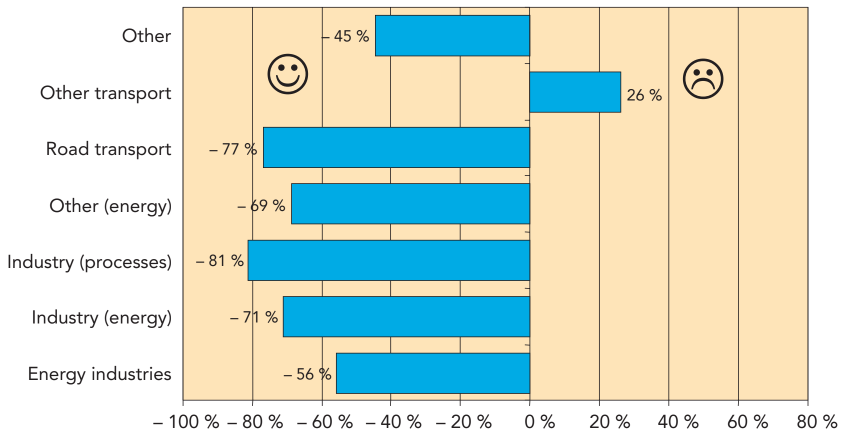
(c) Distance to target for individual countries



**Note:** The distance-to-target indicator (DTI) measures the deviation of actual emissions in 2000 from the (hypothetical) linear target path between 1990 and 2010. The DTI gives an indication on progress towards countries' targets. See Appendix 3 for an explanation of the DTI.

**Accession country emissions of $SO_2$, cont.** Figure 3.15

(d) Emission change by sector, 1990–2000 (%)



### Contribution by international aviation and shipping to pollutant emissions

Despite the significant contribution of international aviation flights and maritime sea traffic to overall emissions of $SO_2$ and $NO_x$ in Europe, the EU national emission ceiling directive and the Convention on Long-Range Transboundary Air Pollution do not cover emissions from international transport (aviation and shipping). These emissions are reported however, although not included in the national totals. Emissions from shipping in countries' internal waterways or territorial off-shore waters are included in the national emissions of each country.

Political interest in addressing international air transport emissions has increased in recent years, due in part to the continuing growth of the European aviation passenger and freight markets, and the arrival of low-cost airlines. Around airports, emissions of $NO_x$, unburned hydrocarbons, CO and $PM_{10}$ contribute to local air quality problems. Although air pollutant emissions from international aviation are not included in national emission ceilings, there are some emissions limits set by the International Civil Aviation Organisation (ICAO).

A recent survey of shipping movements in EU waters during 2000 (European Commission, 2002a) found that shipping contributed 3.6 million tonnes of $NO_x$, 2.6 million tonnes of $SO_2$, 134 000 tonnes of hydrocarbons and 21 000 tonnes of particulates. This equates to 39 % of total $SO_2$ emissions and 36 % of total $NO_x$ emissions from EU-15 countries as reported under UNECE guidelines (total ship emissions of hydrocarbons and for particulates in ports only, account for around 1.3 % and 0.1 % of national totals respectively). Most of the pollution is concentrated in the North, Baltic and Mediterranean Seas. The study also demonstrated that 80 % of the total shipping emissions of $NO_x$ and $SO_2$ arise from vessels at sea, other than ferries and fishing boats, with the largest proportion of this figure contributed by vessel movements between EU-15 ports (34 %). These emission estimates are substantially higher than previous estimates of 2.3 million tonnes of nitrogen oxides and 1.9 million tonnes of sulphur dioxide (European Commission, 2000b).

**Emissions of $SO_2$ and $NO_x$ in 1990 and targets for 2010 (million tonnes)**

| | 1990 $SO_2$ | 1990 $NO_x$ | 2010 $SO_2$ | 2010 $NO_x$ |
|---|---|---|---|---|
| EU-15 land-based | 16.3 | 13.2 | 3.8 (¹) | 6.5 (¹) |
| Non-EU land-based | 21.6 | 10.2 | 9.9 (²) | 7.3 (²) |
| International shipping | 2.8 | 4.0 | 2.8 (³) | 4.0 (³) |
| Total for Europe | 40.7 | 27.4 | 16.5 | 17.8 |

**Source:** European Commission, 2002a.
(¹) Target according to EU directive on national emissions ceilings (2001/81/EC).
(²) Target according to the Gothenburg protocol of 1999 under CLRTAP.
(³) Level of emissions in 1990.

If land-based emissions of $NO_x$ and $SO_x$ continue to fall as required according to the agreed targets (NEC and CLRTAP) and those at sea remain unchanged, by 2010, the relative proportion of emissions from shipping will rise considerably (see table), with $SO_2$ and $NO_x$ emissions in seas surrounding Europe equalling 74 % and 62 % respectively of all EU-15 land-based emissions. The European Commission has recently released a strategy and details of a proposed EU directive (European Union, 2002b) imposing limits on the sulphur content of fuel used in shipping, aiming to reduce emissions of $SO_2$ and particulates and hence reduce the impact of ships' atmospheric emissions on the environment and human health.

The proposed directive involves extending a 1999 directive on sulphur content in marine fuels to cover heavy fuel oil, the most widely used type. The new rules would see a 1.5 % sulphur limit imposed on all seagoing vessels in the North and Baltic Seas and the English Channel. The EU proposal is in line with sulphur limits outlined in Annex VI to the International Maritime Organisation (IMO) Marpol Convention. Other pollutants covered by the Commission's strategy include $NO_x$, $CO_2$, volatile organic compounds (VOCs) and halon.

## 3.4. Emission of toxic substances

There is currently little comprehensive information available concerning emissions of toxic (hazardous) substances, i.e. heavy metals and persistent organic pollutants (POPs), as not all countries report emissions of such substances to EMEP CLRTAP. Similarly, other toxic pollutants such as benzene are not reported at all to EMEP CLRTAP. Important examples of such substances are heavy metals including cadmium and mercury, and polycyclic aromatic hydrocarbons (PAHs).

An important piece of international legislation controlling emissions of heavy metals (cadmium, mercury and lead) and persistent organic pollutants (16 chemicals) are the two UNECE CLRTAP protocols adopted in 1999, the Aarhus Protocol on Heavy Metals and the Aarhus Protocol on persistent organic pollutants (POPs). As only a small number of ratifications are now required to bring these two agreements into force, it is expected that the terms of these agreements will become binding for signatory countries in the near future.

Both the heavy metals and the POPs protocols require parties to encourage monitoring of long-range transport and deposition levels and regulation of emissions on a regional basis. One of the basic obligations of the heavy metal protocol is that parties will have to reduce their emissions for the three metals below their 1990 levels (or an alternative year between 1985 and 1995). As well as banning and eliminating the use of a number of chemicals, the POPs protocol similarly requires parties to reduce their emissions of dioxins, furans, PAHs and hexachlorobenzene below their levels in 1990 (or an alternative year between 1985 and 1995).

**Polycyclic aromatic hydrocarbons**
The following table shows emissions of the representative group of toxic organic pollutants, PAHs, to the atmosphere.

By 2000, and using 1990 reported emissions as the baseline, all countries (for which data are available) except for Denmark, France, Estonia and Poland have reduced their emissions below their respective 1990 values. For these four countries, the amount by their which respective 1990 emission value is exceeded is less than 10 tonnes, and so only a relatively modest reduction in PAH emissions will be required to fulfil their obligations under the POPs protocol.

**Cadmium and lead**
Heavy metals are released from a number of sources. In particular, cadmium and lead are of concern for human health because of their toxicity, and their potential to cause harmful effects at low concentrations and to bio-accumulate. Both metals are included in the CLRTAP heavy metals protocol.

Implementation of measures to control diffuse emissions of cadmium and mercury is difficult. Point source emissions of these metals have declined through the 1990s due to improvements in abatement technologies for wastewater treatment, incinerators and for metal refining and smelting. Use of unleaded petrol in the transport sector from the early 1990s has contributed significantly to reductions of lead emissions. Together,

Table 3.1 **Anthropogenic emissions of PAHs to the atmosphere, tonnes/year**

**Source:** Submitted data for CLRTAP, with gap filling by the ETC/ACC.

| Region | 1990 | 1995 | 2000 | % change 1990–99 |
|---|---|---|---|---|
| EU-15 | 3 602 | 2 464 | 1 286 | – 64 % |
| EFTA-4 | 14.6 | 14.0 | 13.6 | – 7 % |
| Accession countries | 1 857 | 2 213 | 905 | – 49 % |

**Note:** Data not available for Greece, Ireland, Italy, Iceland, Liechtenstein, Switzerland, Cyprus, Latvia, Malta, Romania and Turkey.

Table 3.2 **Anthropogenic emissions of cadmium to the atmosphere, tonnes/year**

**Source:** Submitted data for CLRTAP, with gap filling by the ETC/ACC.

| Region | 1990 | 1995 | 2000 | % change 1990–99 |
|---|---|---|---|---|
| EU-15 | 164 | 99 | 88 | – 47 |
| EFTA-4 | 5.9 | 3.6 | 2.9 | – 50 |
| Accession countries | 149 | 120 | 79 | – 47 |

**Note:** Data not available for Ireland, Portugal, Iceland, Liechtenstein, Malta, Romania and Turkey.

these measures have helped to achieve large reductions in emissions of cadmium, lead and mercury, with emissions in 2000 being approximately 50 % of those in 1990.

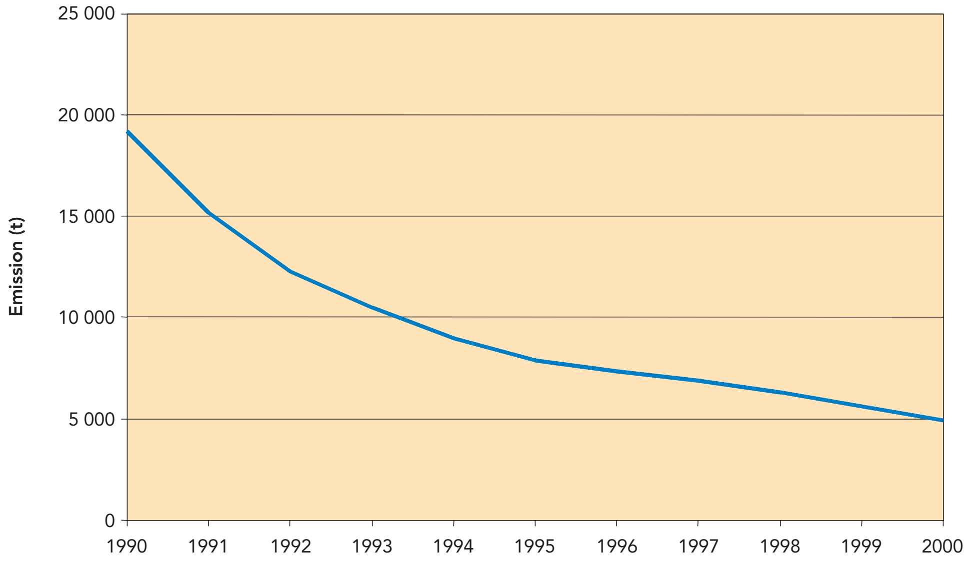
As was observed for PAHs, the vast majority of countries have already met their obligation under the heavy metals protocol to reduce emissions below 1990 levels (the assumed baseline year). The only exception is Spain, which in 2000 exceeded 1990 emissions by 36 % (five tonnes of Cd).

The major sources of Cd emissions include non-ferrous metal production, stationary fossil fuel combustion, and waste incineration. In percentage terms, Luxembourg achieved the greatest decrease in Cd emissions, however, in absolute amounts, Poland (– 41 t), Italy (– 24 t) and Germany (– 20 t) had the largest decreases. The decreases observed across Europe are mainly related to the employment of highly efficient emission control abatement to reduce the emissions of particles, mostly electrostatic precipitators (ESPs), multicyclones, and wet scrubbers. These are effective in reducing Cd emissions as the primary pathway of Cd into the environment is through adsorption on fine particles.

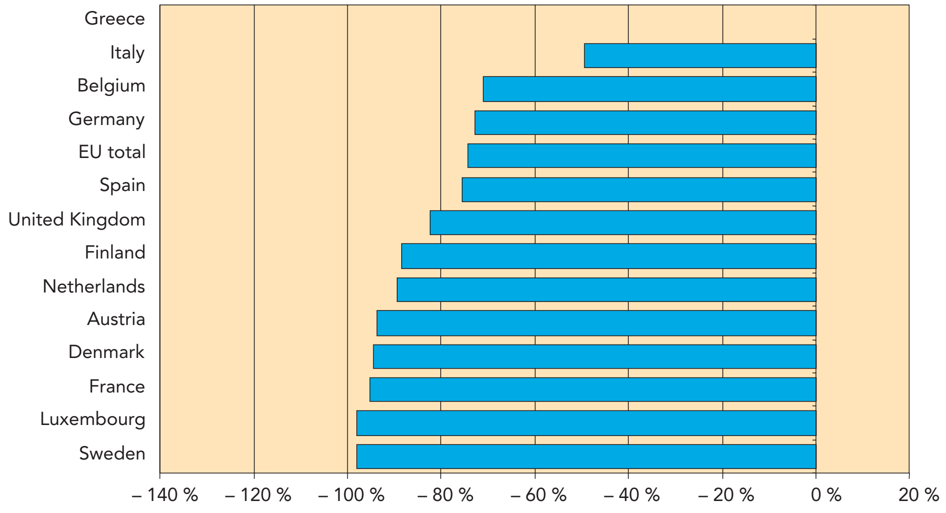
Across the European region, similarly large reductions in the anthropogenic emissions of lead have been achieved (Figure 3.16 and

**EU-15 emissions of lead** Figure 3.16

(a) EU-15 total



(b) Emission change, 1990–2000, by country

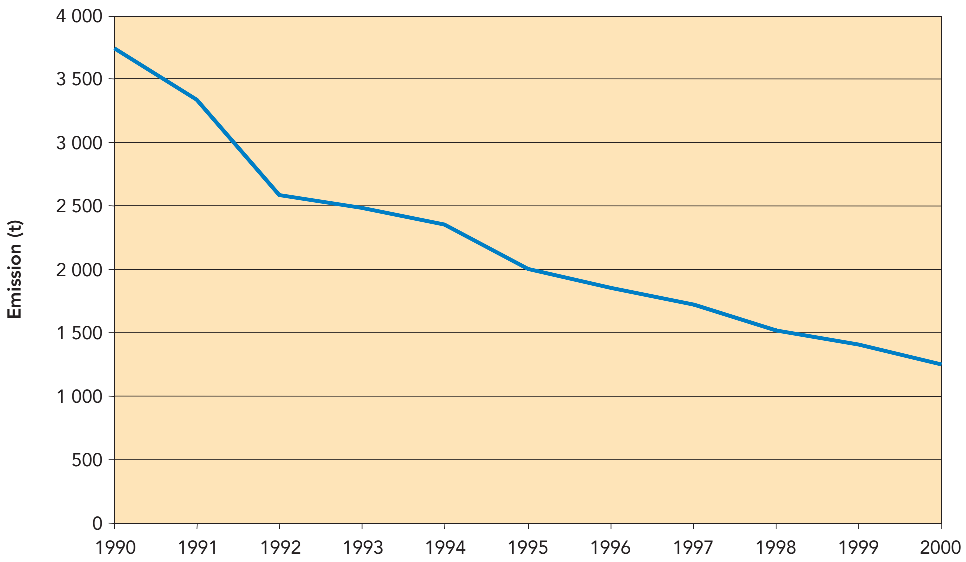


**Note:** Data not available for Ireland or Portugal.

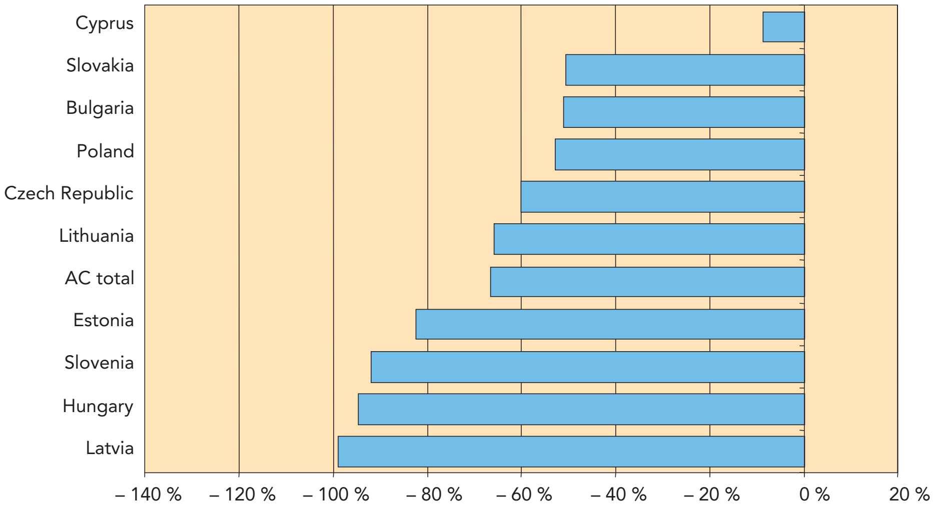
Figure 3.17). All EU and accession countries that reported lead emissions to the EMEP CLRTAP have reduced their emissions to below 1990 levels as required by the heavy metals protocol. The reductions in emissions have largely occurred through the introduction of improved abatement technologies for industrial processes, and the use of unleaded petrol in the transport sector as discussed above. The promotion of unleaded petrol within the EU through a combination of fiscal and regulatory measures has been a particular success story. The EU countries have completely phased out the use of leaded petrol (EEA, 2002c), a goal that was regulated by Directive 98/70/EC. In contrast, the uptake of unleaded petrol varied significantly among ACs in 1996, with a 100 % uptake in the Slovak Republic and only a 6 % uptake in Bulgaria.

**Figure 3.17** **Accession country emissions of lead**

(a) AC-13



(b) Emission change, 1990–2000, by country



**Note:** Data not available for Malta, Romania and Turkey.

# 4. What is the state of air quality in Europe in 2000, and is it developing in line with the decreasing pollutant emissions?

**Health-related air pollution:**

☹ **The air quality limit and target values for ozone, $PM_{10}$, and $NO_2$ that are to be met by 2005–2010 are currently exceeded extensively in European cities, and, for ozone and to some extent for $PM_{10}$, in rural areas as well.**

☺ **The concentrations of $PM_{10}$ and $NO_2$ have decreased. Summarising results of an analysis of a consistent set of monitoring stations can be summarised as follows:**
**$PM_{10}$: the annual average concentration decreased by 16–18 % between 1997 and 1999, but between 1999 and 2001 concentrations stabilised. The concentration on the 36th highest day decreased between 1997 and 1999 by about 21 %, with little change between 1999 and 2000.**
**$NO_2$: the annual average and 19th highest hourly concentration decreased by about 15 % since 1996, with some interannual variations including a peak in 1997.The influence of meteorological conditions that may explain much of the interannual variations has not been analysed yet.**

😐 **For ozone, the tendency in concentrations is more complex: annual averages have been increasing (about 8 % since 1996, averaged over all station types), while maximum and high percentiles of hourly concentrations have been decreasing over the decade. The health-related ozone indicator of the EU directive (26th highest daily maximum eight-hour average concentration) has been rather unchanged since 1996, when averaged over a large, consistent set of stations.**

**Ecosystem-related air pollution:**

☹ **Acidifying deposition was in 2000 above critical loads in parts of central and north-west Europe. Eutrophying deposition above critical loads was more widespread.**

☺ **Sulphur deposition has fallen significantly by the year 2000, and large areas are now protected from further acidification. Calculations indicate that by 1999 most countries have made notable progress towards 2010 targets to reduce areas still subject to increasing acidification.**

😐 **Reductions in nitrogen deposition have been limited and scattered. Thus, there has been no systematic reduction in potentially eutrophying pollution supply. The nitrogen input to north European coastal waters as derived from observations has not decreased since the early 1990s. A few countries have experienced notable decreases in the land area subject to further eutrophication between 1990 and 1999, but several countries are believed to have a worsening problem.**

This chapter provides information on concentrations and depositions of air pollutants from observations at a large number of monitoring stations across Europe, as well as from estimations by model calculations. This summary concentrates on $PM_{10}$, $O_3$ and $NO_2$ in air, and on deposition of acidifying and eutrophying compounds. The state in 2000 is presented, as well as trends and tendencies since 1990. These are briefly compared to the emission trends presented in Chapter 3; emission and air quality trends are further analysed in Chapter 5.

The air quality data where solely extracted from AirBase, the air quality database of the EC. EEA member countries as well as accession countries report time series annually to AirBase. The number of stations with data contained in AirBase increased by an order of magnitude in 1996, following the passing of the new exchange of information (EoI) decision of the EC. To benefit from the substantially increased data coverage, and thus the improved representativity of the data ensemble, the report concentrates on showing air quality trends and tendencies since 1996 (since 1997 for $PM_{10}$, when the number of $PM_{10}$ stations increased substantially). A number of stations in Europe, although limited, have been in operation throughout the 1990–2000 period. The trends shown by this limited selection of stations are also shown in Appendix 4, for $NO_2$ and ozone, to indicate the air quality changes over this longer period as well.

## 4.1. Health-related air pollution

The assessment of health-related air pollution for 2000 is based on data from about 1 500 stations in 28 European countries reporting data to AirBase. Most of the stations are located in the EU-15. The accession countries (AC-10) are not represented well enough by the existing stations, and no separate analysis on exceedances and trends in AC countries, and their possible deviation from the EU-15, can be presented.

This subchapter is structured as follows:

- first, an overview of trends and tendencies comparing the compounds ozone, $PM_{10}$, $NO_2$ and $SO_2$;
- then, more specific information of ozone, $PM_{10}$ and $NO_2$ in separate sections.

For each of the compounds, we present the state in 2000 (maps), the change in average concentration year-by-year per station class, and distance-to-target in terms of average and maximum extent of exceedances of limit and target values of the air quality directives (as given in Appendix 1). An example: The directive for $PM_{10}$ states that the daily limit value of 50 µg/m$^3$ can be exceeded on up to 35 days per year, without breach of the directive. We thus use the 36th highest daily value as the indicator for exceedance of that limit value. The same applies to ozone and $NO_2$.

Since the AirBase station coverage for Europe is limited, especially for $PM_{10}$, the full extent of data is always used in the summary assessment here, without attempting to look for differences for different European regions. An assessment of the regional representativeness of stations must be made before taking this step.

### 4.1.1. Overview of trends and tendencies

The graphs in Figure 4.1 show the tendencies in concentrations, as an average for all types of stations. For each year, the plotted value represents the average of all stations in all countries (only stations with data for all the years are shown). The concentrations relate to the limit values in Appendix 1, giving the concentration on the highest day or hour above x + 1, where x is the limit value not to be exceeded.

$SO_2$ shows a definite downward trend, while for $NO_2$ and $PM_{10}$, with a fairly substantial data coverage only since 1996, there is also a downward tendency when looking at the average of all stations. For ground-level ozone, the tendency is actually towards an increasing, or stable, concentration level (for annual average and high short-term concentrations respectively). Table 4.1 gives the number of stations involved in the tendency lines for annual average values of Figure 4.1, as well as the fraction of stations which have a downward and upward tendency (respectively with a significant or non-significant change over the given period). For $SO_2$, $NO_2$ and $PM_{10}$ the majority of stations have a downward trend/tendency. For only half of the $NO_2$ and $PM_{10}$ stations, this change over the period is significant. The stations showing upward tendencies are mainly hot-spot stations (traffic or industrial), dominated by local traffic or industrial plants which presumably are increasing in strength (e.g. streets with increasing amount of traffic). For ozone, the majority of stations have a (non-significant) upward tendency.

To expand the time horizon of ozone and $NO_2$ trends and tendencies, Appendix 4 shows figures with country-wise data since 1989 or 1990, averaged over the stations which have been in operation over the whole period towards 2000. The number of stations is limited and thus also the representativity of these data. For ozone, the figure gives the maximum one-hour concentration each year. The data indicate a decreasing trend in maximum one-hour concentration since 1990.

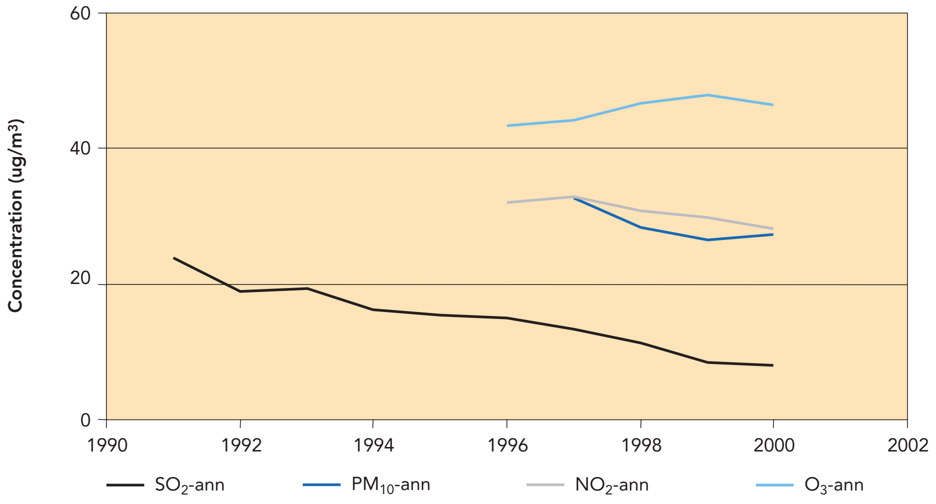
For $NO_2$, the figure gives the trend in annual average. The figure indicates a limited decrease from 1989 towards the middle of the decade. After that, the $NO_2$ tendency from the Appendix 4 figure is less obvious, while the ensemble average curve in Figure 4.1 indicates a slight downward tendency since 1996.

**Stations showing downward and upward tendencies, based on the annual average concentration values (Mann-Kendall test with 90 % confidence level)** Table 4.1

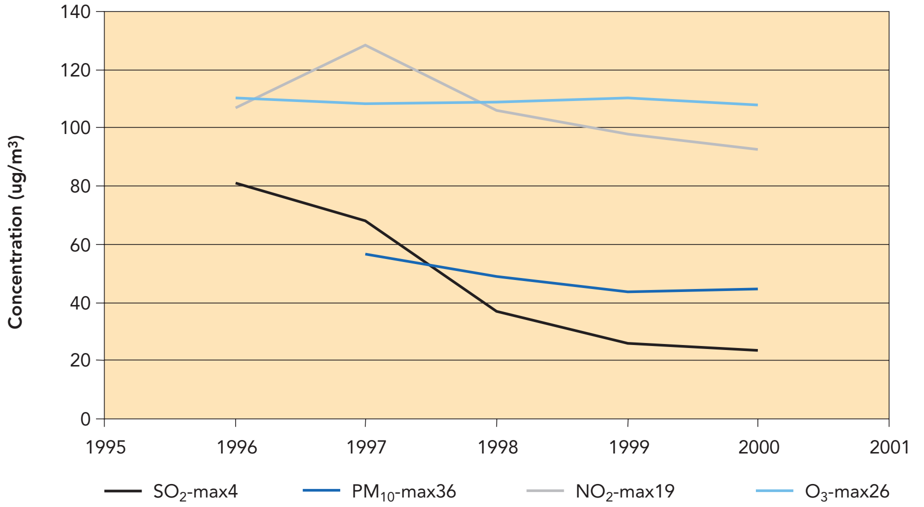
| Compound | Period | Number of stations | Downward % of stations | | Upward % of stations | |
|---|---|---|---|---|---|---|
| | | | Sign. | Non-sign. | Sign. | Non-sign. |
| $SO_2$ | 1996–2000 | 827 | 95 | | 5 | |
| $NO_2$ | 1996–2000 | 794 | 40 | 47 | | 13 |
| Ozone | 1996–2000 | 666 | 2 | 17 | 15 | 66 |
| $PM_{10}$ | 1997–2000 | 146 | 44 | 51 | | 5 |

**Summary of measured concentrations of $SO_2$, $NO_2$, $PM_{10}$ and ozone in Europe, all stations** Figure 4.1

Annual mean



High short-term (1-24 hour) values



**Note:** $SO_2$-max4:4th highest daily average $SO_2$ concentration
$PM_{10}$-max36:36th highest daily average $SO_2$ concentration
$NO_2$-max19:19th highest hourly average $NO_2$ concentration
$O_3$-max26:26th highest daily 8-hour max $O_3$ concentration

The spatial representativeness of these data for Europe as a whole, in terms of coverage of the population, is difficult to assess. Maps 4.1–4.6 at the end of this section show the coverage in terms of cities included, as well as rural ozone stations. Within the urban scale, the representativeness of the reported concentrations depends upon the number and types of stations in each city, and their representativeness of population exposure.

The influence of year-to-year variation of meteorological conditions has not been analysed yet. These two factors contribute to uncertainty in comparing concentration tendencies with emission trends.

Bearing these preconditions in mind, it is found that:

1. The decrease of $SO_2$ concentrations is well in line with the emissions trend given in Figure 3.6.
2. For $NO_2$ and $PM_{10}$, the measured decrease in annual average concentrations are also fairly well in line with the corresponding emissions reductions for 1996–2000 (Figure 3.4 for $PM_{10}$ and Figure 3.5 for $NO_x$).
3. For ozone, the substantial reductions in ozone precursor emissions (Figure 3.3) are not reflected by the measured ozone concentrations. This is not unexpected in view of the chemistry of ozone, the slowly increasing hemispheric background, and the decreased scavenging by NO as a consequence of lower $NO_x$ emissions.

Emissions and concentration reduction comparisons are further discussed in Chapter 5.

### 4.1.2. Ground-level ozone

In 2000, the ozone data reported to AirBase included in total 1 207 monitoring stations in 29 countries with data satisfying the completeness criteria of the air quality directives, of which 335 are in rural areas, and the rest distributed in about 650 cities. The total population in those cities was 93 million. Ozone data are available in AirBase from a substantial number of stations in many countries since 1996, the number increasing each year (see also Figure 4.8). Most of the stations are located in the EU-15, with only about 80 stations in the accession countries.

Figure 4.2 shows the change in ozone concentrations in Europe since from 1996 and onwards. The graphs show that there is a tendency towards increasing ozone when looking at the **annual** average concentrations, while the more short-term concentration levels (represented by the 26th highest daily eight-hour average, corresponding to the target value of the ozone directive) show an almost unchanged averaged level since 1996, in all three area types (rural, urban, traffic hot-spot). The short-term concentrations at the most exposed rural stations were highest in 1998 and in 2000, indicating that ozone episodes were most severe then.

The relationship between ozone levels at rural, urban and hot-spot locations is more complicated than for e.g. $PM_{10}$ and $NO_2$, 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 in southern Europe may lead to substantial photochemical production of ozone in and downwind of such urban areas. So here, maximum urban background concentrations sometimes exceed those in the nearby rural areas, while concentrations in hot-spots (e.g. near roads) will always be lower. This is due to the scavenging effect of NO on ozone, resulting in $NO_2$. This is the other main factor governing the ozone concentrations, leading in general to decreasing ozone levels as one moves from rural to urban to hot-spots. This mechanism will dominate the situations also in southern areas, when considering the long-term (e.g. annual) concentrations. For $PM_{10}$, $NO_2$ and other pollutants of mainly local origin, the trend is naturally opposite, with increasing concentrations as one moves from rural to urban to hot-spot areas.

The development of the ozone concentration over Europe during the last decade shows a composite picture:

- The maximum concentrations and high percentiles have been decreasing, as shown in Appendix 4, and documented in other studies as well, such as summarised in the Eurotrac2 synthesis report (Volz-Thomas *et al.,* 2002) and also by the Trotrep synthesis and integration report (Trotrep, 2003). These studies document that modelling studies support that there is a relationship between the decreasing precursor emissions and the decreasing maximum concentrations.
- The long-term (annual) average concentrations show an increasing tendency over the decade. This may be explained by the following:
  - — reduced $NO_x$ emissions resulting in less scavenging of ozone by NO;
  - — increased hemispheric ozone background levels.

The health-related indicator, the 26th highest daily maximum eight-hour average, shows a rather constant level since 1996.

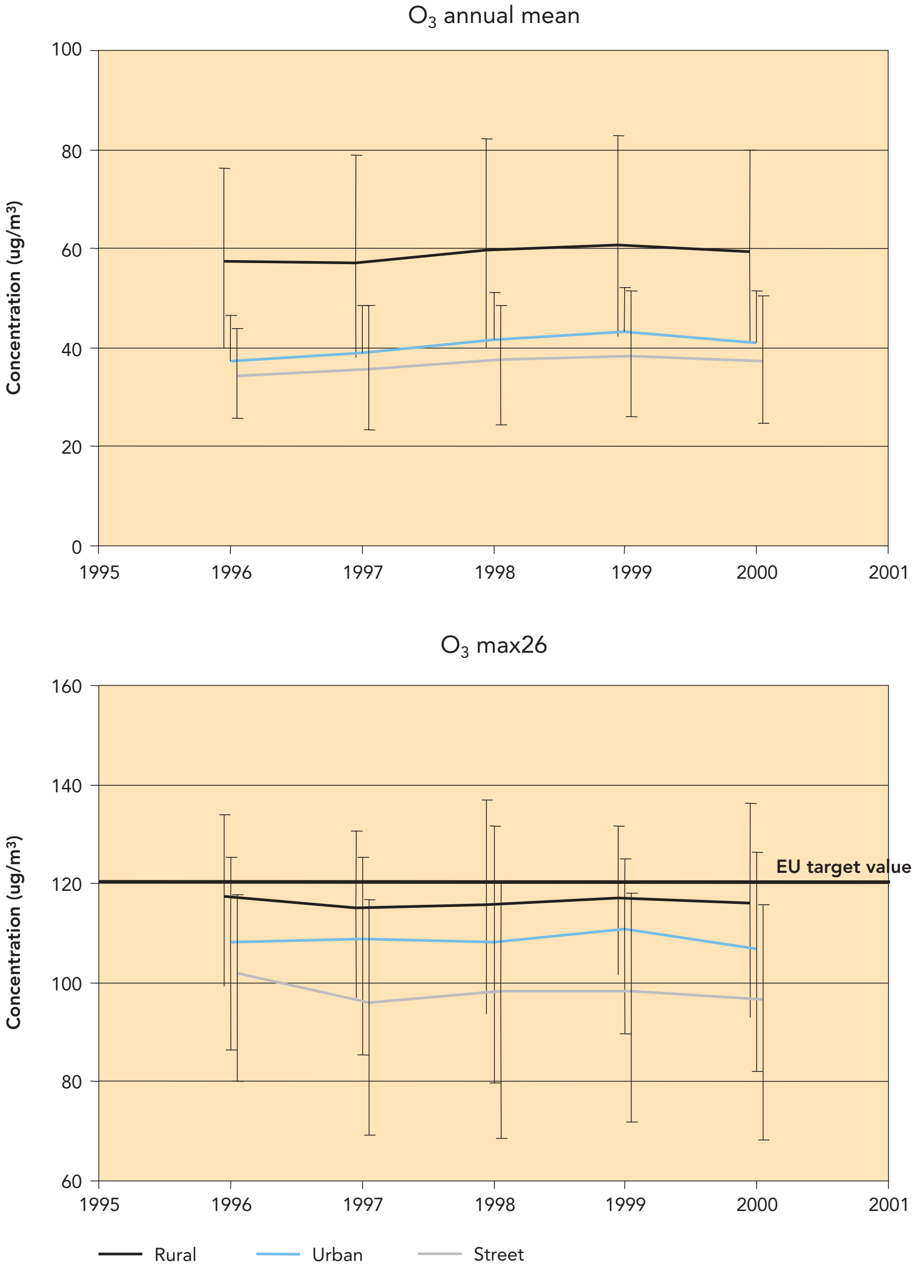
The implications of this complex behaviour for the population-averaged exposure to ozone and resulting changes in its possible health effects during the last decade should be a topic for specialised studies.

The observed changes in ozone concentrations in Europe do not parallel the significant reduction in ground-level ozone precursor emissions as described in Chapter 3 (Figure 3.3). Possible explanatory factors are:

- low sensitivity of photochemical ozone production to moderate changes in precursor levels;
- less ozone scavenging by NO with reduced emissions of $NO_x$;
- increased hemispheric ozone background levels.

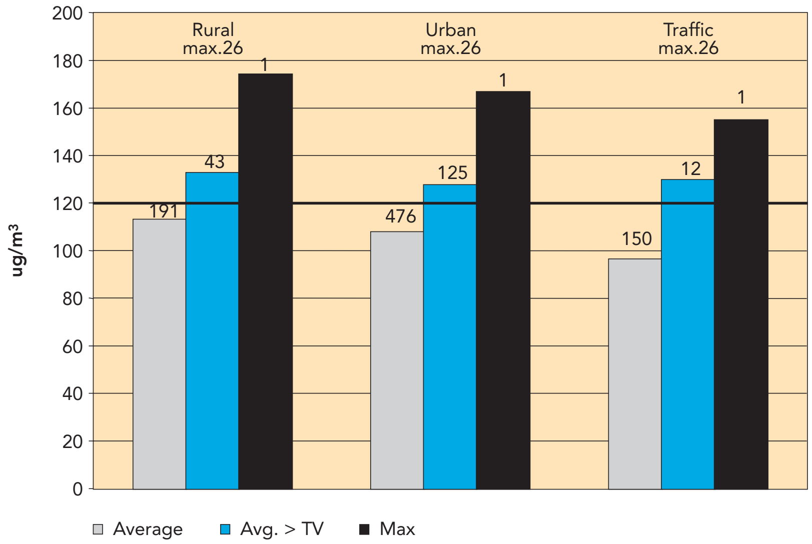
The data for 2000 in Figure 4.2 show that the ozone target value (120 µg/m$^3$ as 26th highest daily eight-hour max value) is exceeded at more than 10 % of the rural and urban background sites (as well as at some traffic sites). Maps 4.1 and 4.2 show the location of rural sites and cities with recorded exceedances in 2000. Of the 1 207 stations, 275 stations in 12 countries measured levels in exceedance of the target value, and another 371 had levels above an upper

**Ozone, interannual variations, 1996–2000** Figure 4.2



**Note:** Indicators: Annual mean and the 26th highest daily eight-hour average per year (the EU target value indicator). All stations with 4 or 5 monitoring years. Vertical bars: 10th and 90th percentiles

**Figure 4.3** **Distance-to-target, ozone over EU target value, 2000**



**Note:** Number of stations on top of bars.

classification level of 100 µg/m³ (as 26th highest daily eight-hour value). Maximum concentrations (eight-hour average) measured were 174 µg/m³ at an Italian station, while several countries has maximum levels close to 150 µg/m³. Target value exceedances were measured in about 135 cities with a total population of 18.5 million. Several cities with about six million inhabitants had ozone concentrations above the 120 µg/m³ mark of the target value (max. eight-hour average) on more than 50 days in 2000. Exceedances occur mainly in south European countries, as well as in central and eastern Europe (Switzerland, Austria, South and East Germany, Czech Republic, Slovakia and Poland).

Figure 4.3 shows the extent of exceedances in Europe in 2000 (distance-to-target); the bars show the concentration averaged over all stations, the concentration averaged over all stations exceeding the target value and the maximum concentration for rural, urban background and traffic stations, respectively. Maximum concentrations recorded in 2000 were close to 50 % above the target value. On average, the concentrations at stations with exceedance of the target value were 11 %, 7 % and 9 % above the target value respectively for rural, urban and traffic stations.

Concluding, exceedances of the ozone target value are found to be widespread in Europe, and the relevant concentration parameters have not been reduced since 1996.

### 4.1.3. Particulate matter — $PM_{10}$

Concentrations of particulate matter in air are presently measured predominantly as $PM_{10}$, the mass concentration of particles of (equivalent aerodynamic) diameter less than 10 µm that can enter the respiratory system. Other particle size fractions of health significance, such as $PM_{2.5}$, are measured only at a few stations in Europe.

For the year 2000, AirBase contained 498 $PM_{10}$ monitoring stations in 18 countries ([4]), and included stations in 342 cities with close to 100 million inhabitants. The quantity of $PM_{10}$ data in AirBase is substantial only from 1997 and onwards, so trend and tendency evaluations can only be made for the period from 1997. The accession countries (AC-10) are less well represented than EU-15 (75 of the stations are in AC-10, and of these 56 are in the Czech Republic). Thus, no separate analysis of the state and trend in AC-10, as opposed to EU-15 countries can be presented.

Figure 4.4 shows that there was a downward tendency in $PM_{10}$ concentrations in Europe from 1997 to 1999, while there was a slight increase from 1999 to 2000 (and preliminary 2001 data indicate a continuing slight upward tendency). The trends in emissions (Figure 3.4) and interannual variations in

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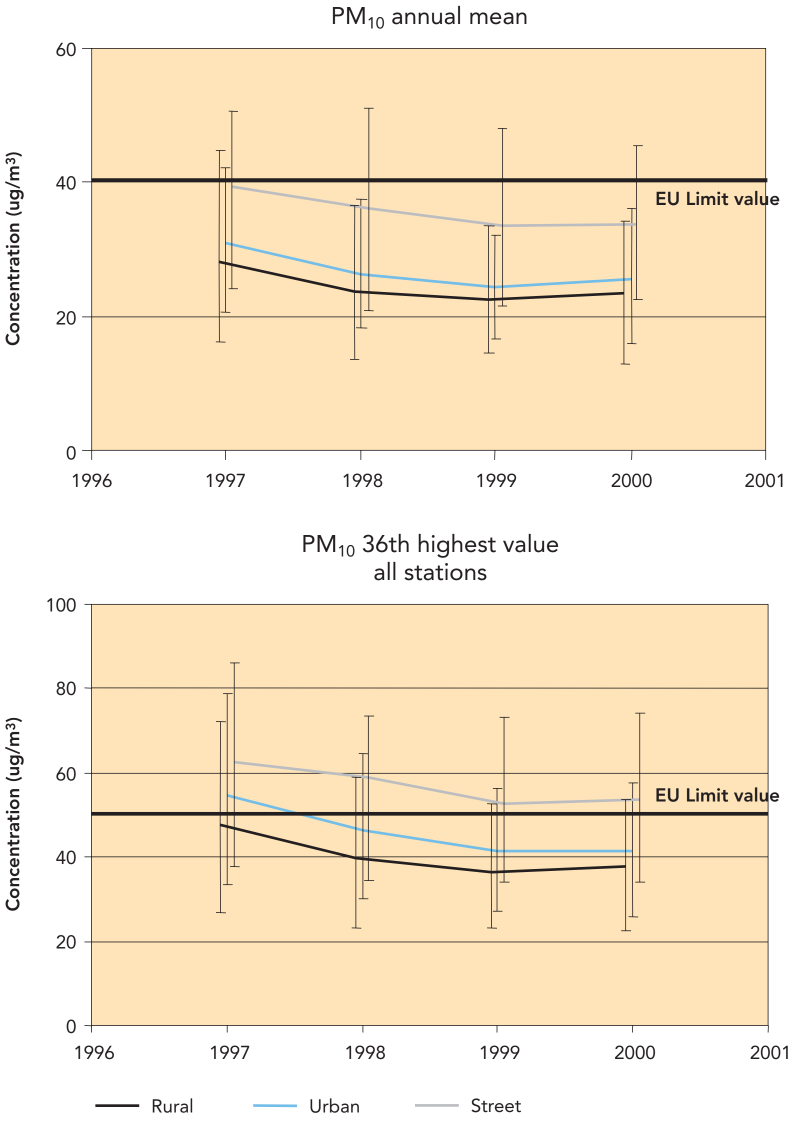
(4) French $PM_{10}$ data for 2000 as shown in maps and figures in this report were not yet uploaded into AirBase at the time of writing this report.

meteorological conditions work together to produce the $PM_{10}$ tendency. The increasing concentrations from rural to urban to traffic hot-spot areas are clearly shown, although this increase is (relatively) not as large as for $NO_2$ (see Figure 4.6). For $PM_{10}$, the rural background concentration is rather high compared to the urban concentrations, indicating the importance of the regional scale background which is the result of natural PM sources as well as formation of secondary particles (mainly inorganic particles formed from $SO_2$ and nitrogen compounds, while also secondary organic particles contribute). The urban emissions of primary particles then result in increased concentrations in the urban areas. Only in very large urban areas may secondary particle formation within the urban area play a role as well.

The data for 2000 in Figure 4.4 show that the annual average limit value (40 µg/m$^3$) was exceeded at several traffic hot spot stations. The limit value for daily concentrations (50 µg/m$^3$ as 36th highest daily value in a year) has been exceeded at a large number of stations including urban and rural background stations. Maps 4.3 and 4.4 show exceedances in many countries.

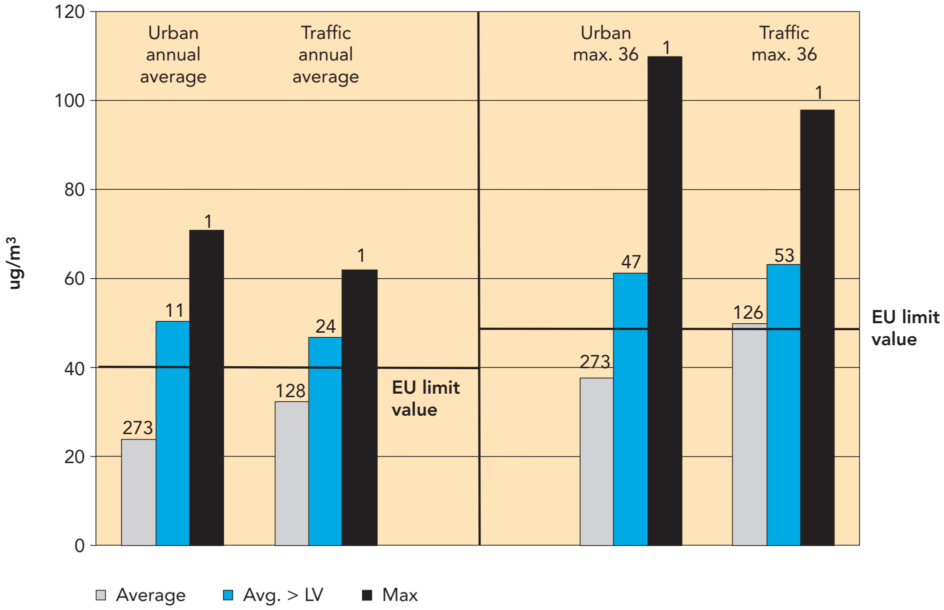
The extent of exceedances is indicated in Figure 4.5, which gives distance-to-target information. The average concentrations at the sites where they exceed the limit values are up to 27 % higher than their respective limit value. The maximum concentrations can reach a high as two times the limit value (Figure 4.5).

$PM_{10}$, interannual variations, 1997–2000 Figure 4.4



**Note:** Indicators: Annual mean and the 36th highest daily value per year (both are EU limit value indicators). All stations with 4 monitoring years. Vertical bars: 10th and 90th percentiles

**Figure 4.5** **Distance to target, $PM_{10}$ above EU limit value, 2000**



**Note:** Number of stations on top of bars.

Concluding, exceedances of $PM_{10}$ limit values are widespread in urban areas in Europe, and they are exceeded also in rural areas in some countries. The concentrations averaged over a limited set of stations decreased between 1997 and 1999 by 16 %, but there was a slight increase 1999–2000. The influence of the meteorological conditions on this tendency has not been analysed.

### 4.1.4. Nitrogen dioxide

For 2000, nitrogen dioxide ($NO_2$) monitoring data in AirBase include in total 1 274 stations in 23 countries. Some 915 of these stations are located in 670 cities with 120 million inhabitants. In all, 118 of the stations are located in eight accession countries, so these are not well enough represented to analyse the possible differences between EU-15 and AC-10 countries. For ozone and $PM_{10}$, the number of stations with data in AirBase is substantial from 1996 onwards, enabling an analysis of the tendency in air quality to be made for those years.

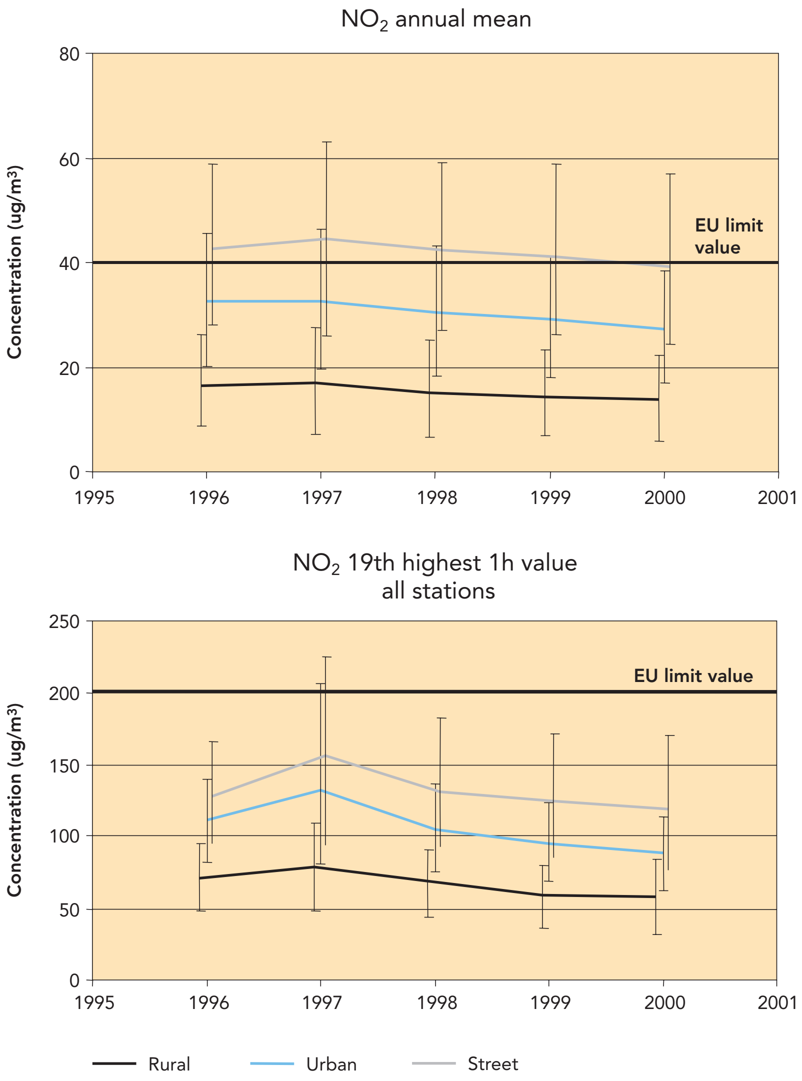
Figure 4.6 shows a downward tendency in $NO_2$ concentrations averaged over each of the three types of areas (rural, urban background, traffic hot-spot), both for annual average and the high short-term concentrations (the 19th highest hour, corresponding to the EU limit value). This slow downward tendency has continued since 1990, when more and more data became available to allow for an indication of a tendency in concentrations. The graphs show that it is the annual average limit value that is exceeded to the largest extent. The large difference in concentrations from rural to urban to hot-spot is clear from the graphs.

The 2000 data in Figure 4.6 shows that the annual EU limit value is exceeded to a large extent at traffic sites, and also at some urban background sites. Maps 4.4 and 4.5 show locations of cities with sites in exceedance. There are also exceedances of the hourly limit value at some traffic sites, but in a smaller extent (see Figure 4.7). Exceedances are found at 255 stations in 15 countries. The cities with measured exceedances represent a total population of about 40 million inhabitants.

Figure 4.7 shows the extent of exceedances above the EU limit values. The annual average limit value was exceeded the most. For the stations in exceedance, the average annual concentration was 18 % and 39 % above the limit value, for urban background and traffic stations respectively. The most exposed stations had concentrations up to three times the limit value.

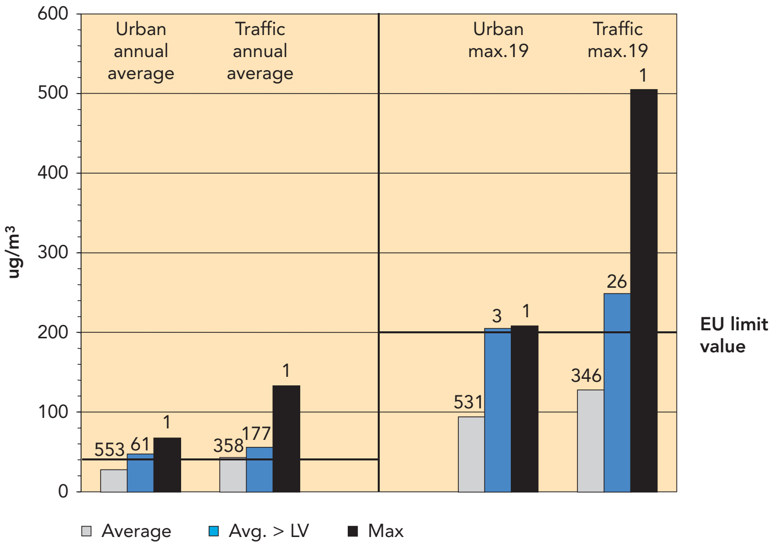
Thus, there are widespread exceedances of the EU limit values for $NO_2$ in cities in Europe. The concentrations tend to decrease. Between 1996 and 2000, the annual average $NO_2$ concentration averaged over the reported set of stations in all countries was reduced by 25 %. The influence of variations in meteorological conditions on this tendency has yet not been analysed.

**$NO_2$ interannual variations, 1996–2000** Figure 4.6



**Note:** Indicators: Annual mean and the 19th highest one-hour average value each year (both are EU limit value indicators). All stations with 4 or 5 monitoring years. Vertical bars: 10th and 90th percentiles

**Distance-to-target, $NO_2$ 2000 data** Figure 4.7



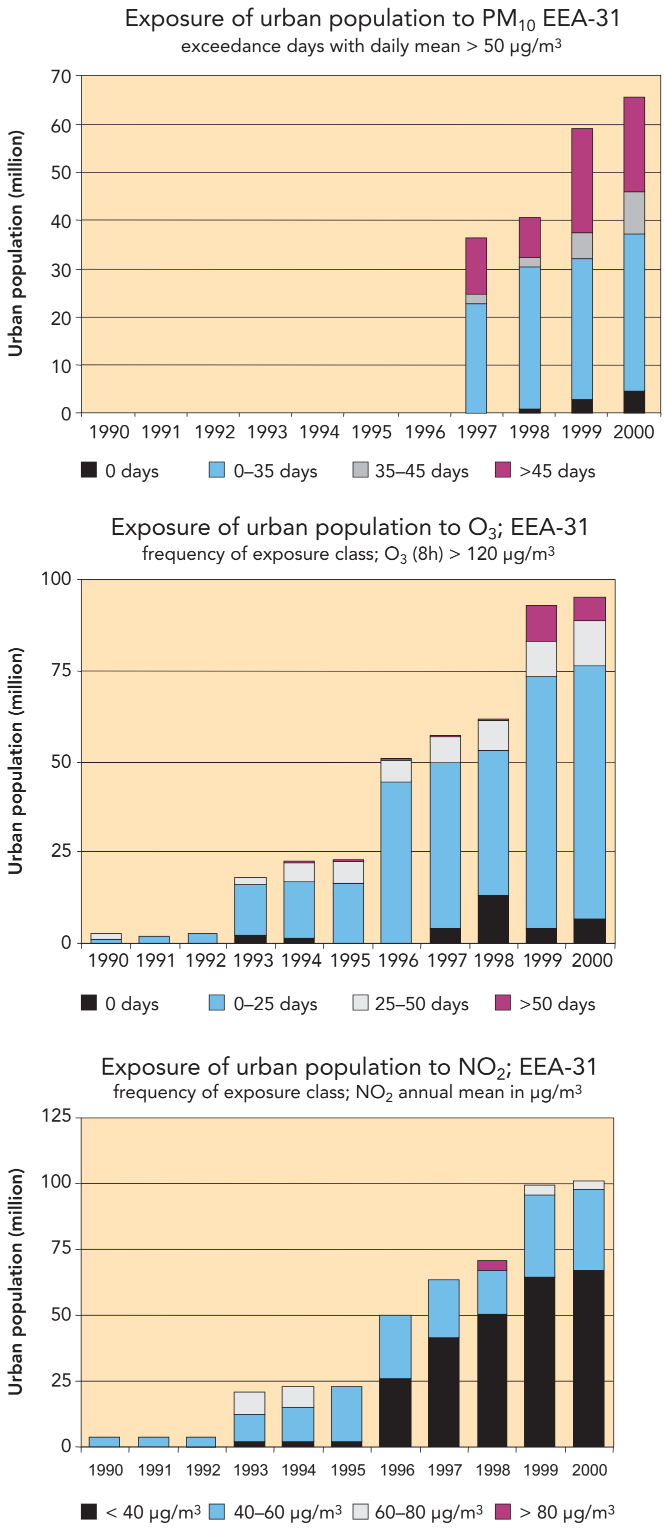
**Note:** Number of stations on top of bars.

### 4.1.5. Estimates of exposure of the European urban population to ozone, $PM_{10}$ and $NO_2$

Although the number of cities and stations represented in AirBase is large, it is not large enough to provide a basis for quantitative estimates of population exposure.

Figure 4.8 provides an indication of the development since 1990 in the total urban population of the cities covered by monitoring stations with data reported to AirBase. The exposure of this population is then classified in groups according to the measured concentrations. For each city, an average number of exceedance days is

Figure 4.8 **Coverage of the European (EEA-31) urban population with monitoring stations, and classification of their concentrations in terms of exceedance days per year for $PM_{10}$, ozone and $NO_2$**



calculated, based upon data from all the stations in the city, and all inhabitants are given this exposure. For $NO_2$ and ozone, only urban background stations are included, while for $PM_{10}$ also street stations have been included to increase the still limited coverage. The figure shows clearly the increasing monitoring coverage of the urban EEA-31 population.

For $NO_2$, about 45 million inhabitants of the 100 millions in the cities covered by AirBase

**Ozone in cities, 2000**
**Urban background stations, 26th highest daily eight-hour max value**

**Map 4.1**

The maximum station in each city, relative to EU target value and selected upper and lower 'classification levels' (UCL, LCL) (5).
Target value: 120 µg/$m^3$
UCL: 100 µg/$m^3$
LCL: 80 µg/$m^3$

MAX 26
Urban background stations

● ≤ LCL
● > LCL and ≤ UCL
● > UCL and ≤ TV
● > TV and ≤ 50 % above TV
● > 50 % above TV

---

(5) UCL and LCL have been selected in order to visualise in the map the range in concentration levels measured. For ozone, upper and lower assessment levels have not been given, such as for $PM_{10}$ and $NO_2$.

**Map 4.2**

**Ozone at rural stations, 2000**
**26th highest daily eight-hour max value**

Relative to EU target value (TV) and selected upper and lower 'classification levels' (UCL, LCL) (6).
Target value: 120 µg/m³
UCL: 100 µg/m³
LCL: 80 µg/m³

data were potentially exposed above the annual limit value of 40 µg/m³, in 1999 and 2000.

For $PM_{10}$, the population coverage is less, totally about 65 million inhabitants. Of these, about 28 millions were potentially exposed above the daily limit value of 50 µg/m³ (35 exceedances allowed).

For ozone, the urban population coverage of AirBase was about as for $NO_2$, some 94

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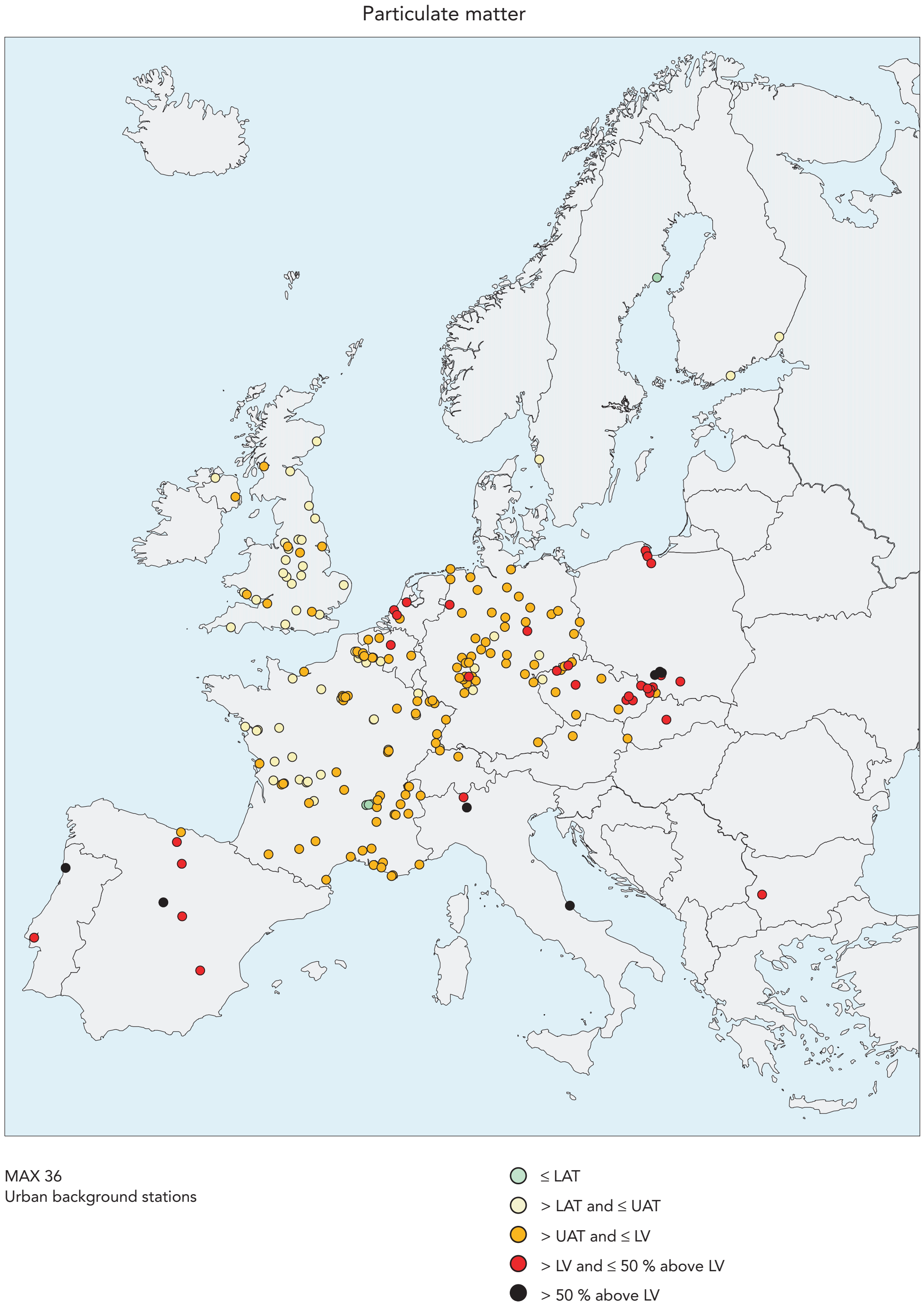
(6) UCL and LCL have been selected in order to visualise in the map the range in concentration levels measured. For ozone, upper and lower assessment levels have not been given, such as for $PM_{10}$ and $NO_2$.

**$PM_{10}$ in cities, 2000**
**Urban background (UB) stations, 36th highest daily value**

Map 4.3

The maximum UB station in each city with data, relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT) (7).
LV: 50 µg/m³
UAT: 30 µg/m³
LAT: 20 µg/m³



million people. Of these, about 18 millions were exposed to ozone above the target value of 120 µg/m³ (25 exceedances allowed).

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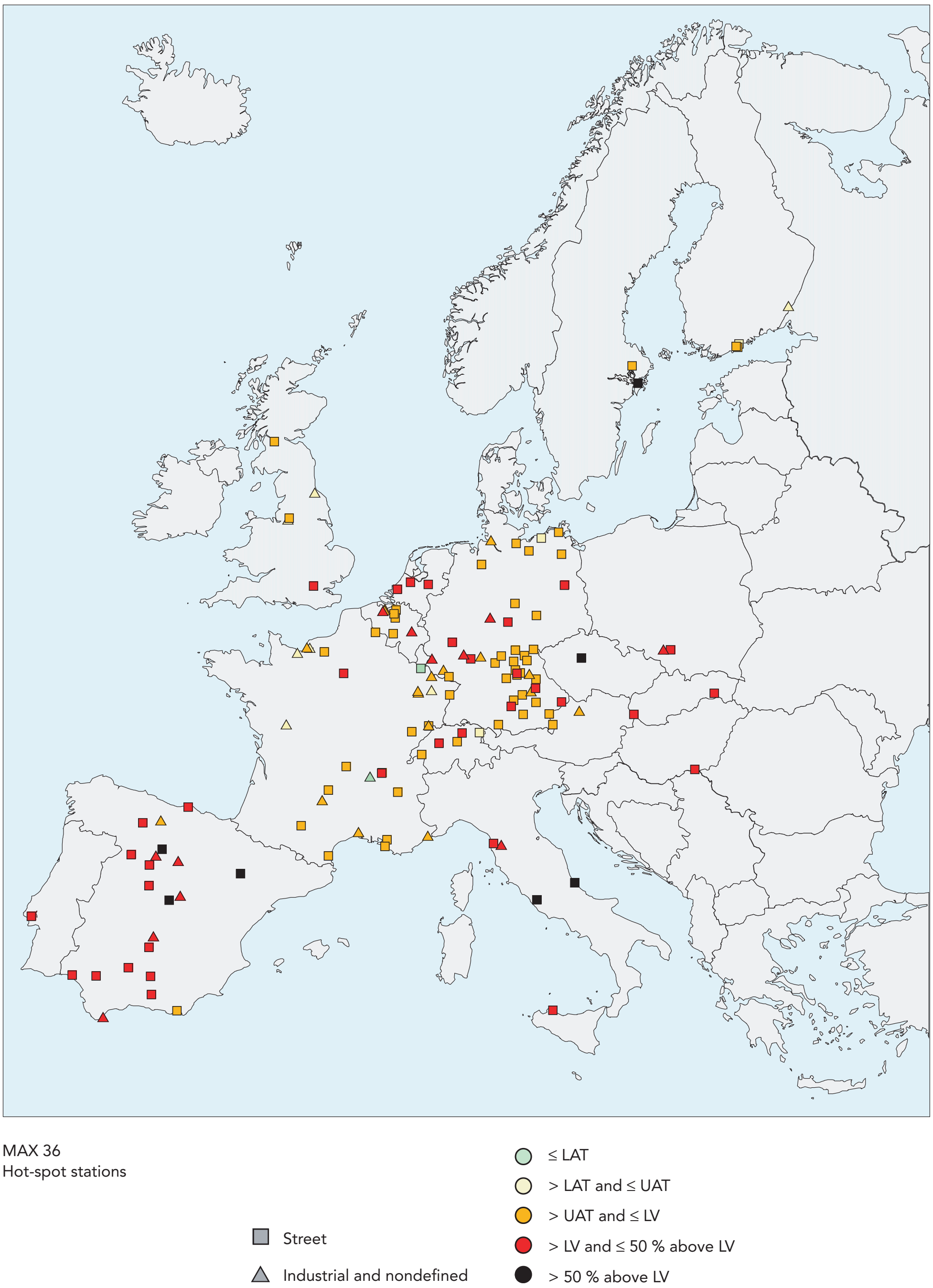
(7) The assessment thresholds for $PM_{10}$ in the first daughter directive are connected to the indicative limit values for 2010, and those values should not be exceeded more than seven times a year. In this map, the assessment threshold concentration value is used, but the colour coding is still linked to the 36th highest daily value, to show the range in concentration values measured.

**Map 4.4** **$PM_{10}$ in cities, 2000**
**Hot-spot stations (traffic, industrial), 36th highest daily value**

The maximum hot-spot station in each city, relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT) (8).
LV: 50 µg/$m^3$
UAT: 30 µg/$m^3$
LAT: 20 µg/$m^3$

Particulate matter



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(8) The assessment thresholds for $PM_{10}$ in the first daughter directive are connected to the indicative limit values for 2010, and those values should not be exceeded more than seven times a year. In this map, the assessment threshold concentration value is used, but the colour coding is still linked to the 36th highest daily value, to show the range in concentration values measured.

## NO$_2$ in cities, 2000
## Urban background stations, annual average

Map 4.5

The maximum UB station in each city with data, relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT).

LV: 40 µg/m$^3$
UAT: 32 µg/m$^3$
LAT: 26 µg/m$^3$

Nitrogen dioxide

Map 4.6

**$NO_2$ in cities, 2000**
**Hot-spot stations, 19th highest hourly value**

The maximum UB station in each city with data, relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT).

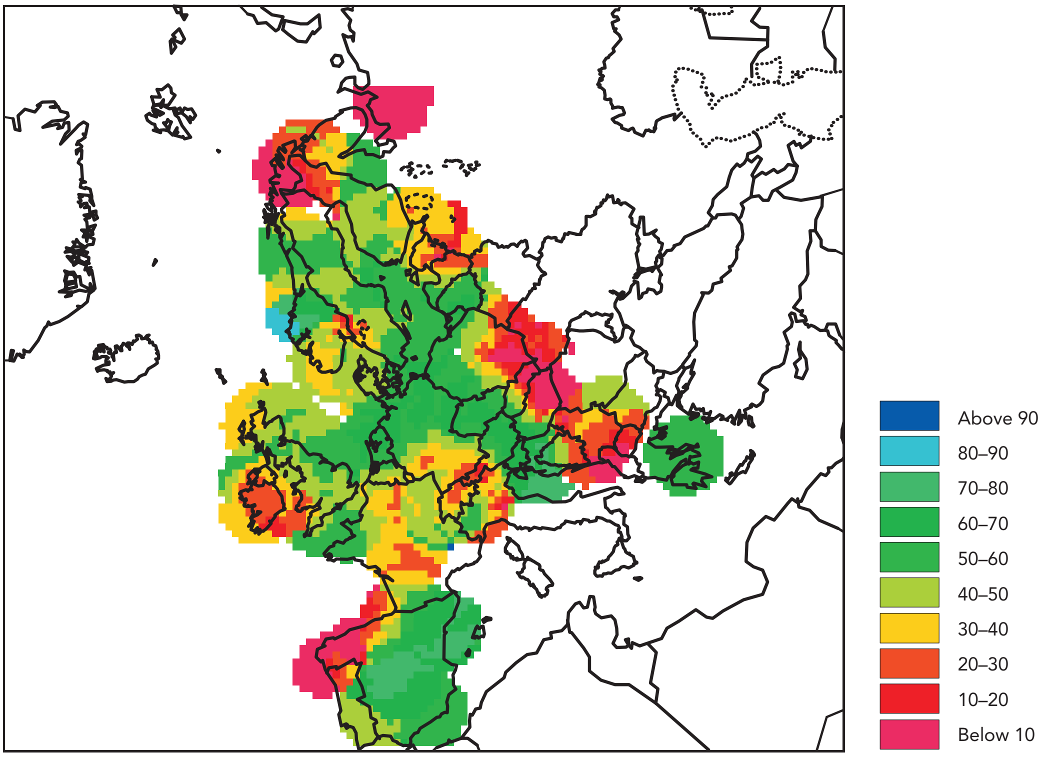
LV: 200 µg/m$^3$
UAT: 140 µg/m$^3$
LAT: 100 µg/m$^3$

## 4.2. Ecosystem-related air pollution

### 4.2.1. Acidifying air pollution

Sulphur in precipitation and air has been measured over a sufficient area and time period to allow the actual changes in sulphur deposition to be described. Observed wet depositions can be added to calculated direct 'dry' deposition of gases and particles to the surface based on observed sulphur air concentrations to give the total sulphur deposition at any time. In Map 4.7, the differences in the so obtained total deposition (wet and dry) of potentially acidifying sulphur between 1990 and 2000 are displayed. Values for '1990' have been estimated as the average of observations for 1990–92, and those for '2000' as the average

**Percentage reduction in observed annual sulphur deposition from 1990/92 to 1998/2000** Map 4.7



**Source:** NILU/EMEP-CCC.

of observations from 1998–2000. These three-year average values reduce the potentially misleading effect of interannual variability.

For large stretches of northern, western and central Europe, sulphur deposition in 2000 has fallen by 50 % or more as compared to the start of the decade. Beyond individual ‘hot-spots’ with little change, the area with notably less improvement is the eastern belt from south-east Poland towards south and east to the Balkans and Greece.

This picture shows good correspondence with the broad emission changes displayed in Figure 3.6. Furthermore, it displays the notable differences in rates of improvement, which have occurred between regions.

However, sulphur provides only part of the picture for acidification, as nitrogen compounds are also involved. Monitoring of these has been less extensive, such that the same mapping of changes is less feasible. However, the average changes in rates of nitrogen deposition to the surface monitored in precipitation at stations all across Europe can be examined. Averaging across 36 stations with at least 10 years of continuous monitoring, weighted by precipitation amount, this is displayed in Figure 4.9. The total rate of nitrogen deposition is here divided between the ‘oxidised’ component, which arises from industrial and transport emission sources, and the ‘reduced’ component arising principally from agriculture. Striking is the unchanging level of deposition in precipitation experienced at these stations during the 1990s for both forms of nitrogen. Air concentrations have not been used to derive estimated trends of dry deposition of nitrogen. The observed rather unchanged nitrogen deposition during the 1990s does not reflect the reduction in emissions of $NO_X$ in Europe (Figure 3.9). The reason for this is not understood.

To understand the combined impact of these differing changes in acidifying sulphur and nitrogen deposition to the surface, it is necessary to combine the components and to compare this with estimated ecosystem tolerance to acidifying pollution. Once rates of deposition to an ecosystem fall below a ‘critical load’ of deposition above which harm may be expected, they may be considered protected from further acidification. Given the restricted availability of observations of some components, this approach requires the use of calculated estimates of pollutant supply in order to gain sufficient spatial coverage across all Europe. Calculated estimates of the transport and deposition of acidifying compounds have been obtained from the EMEP, with the disclaimer that current calculation routines are under further development and should be taken as only indicative of the actual situation.

These estimates are combined with ecosystem data in Map 4.8 to indicate the degree of protection from further acidification which ecosystems are currently believed to experience. The concentration of impact (deposition above critical load) around north-west Europe is pronounced. Indeed, this impact concentration is perhaps greater than shown, as many areas shown as having > 80 % protection are actually 100 % protected. It is also to be observed that the areas which have seen greatest improvements with respect to sulphur supply are nevertheless still adversely effected, likely in part at least due to nitrogen deposition.

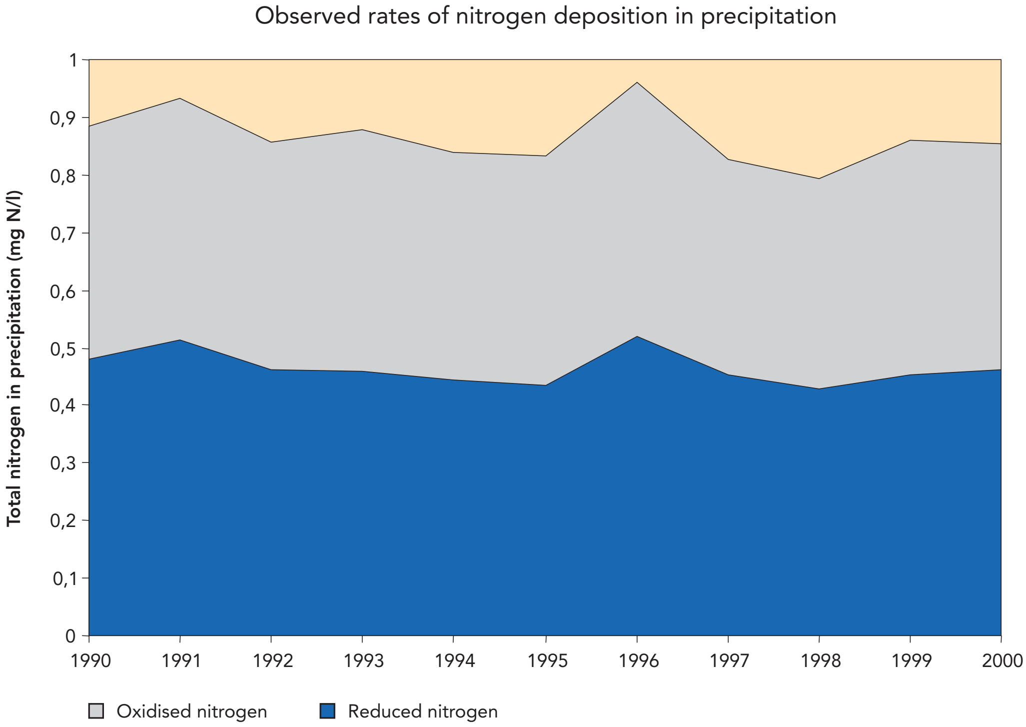
### 4.2.2. Eutrophying air pollution

Eutrophication of waters and soils can arise as a consequence of nitrogen supply. In Figure 4.9, the monitored changes in this supply at the European scale have been displayed, revealing little change during the last decade. There are regional differences, and the observation networks around north European marine regions allow the difference in potentially eutrophying nitrogen supply to be seen. Figure 4.10 displays information for the North and Baltic Seas, showing that the Baltic did experience a decline in nitrogen supply during the first years of the decade, but thereafter little change was seen. For the North Sea, there has been no observable decrease in nitrogen supply.

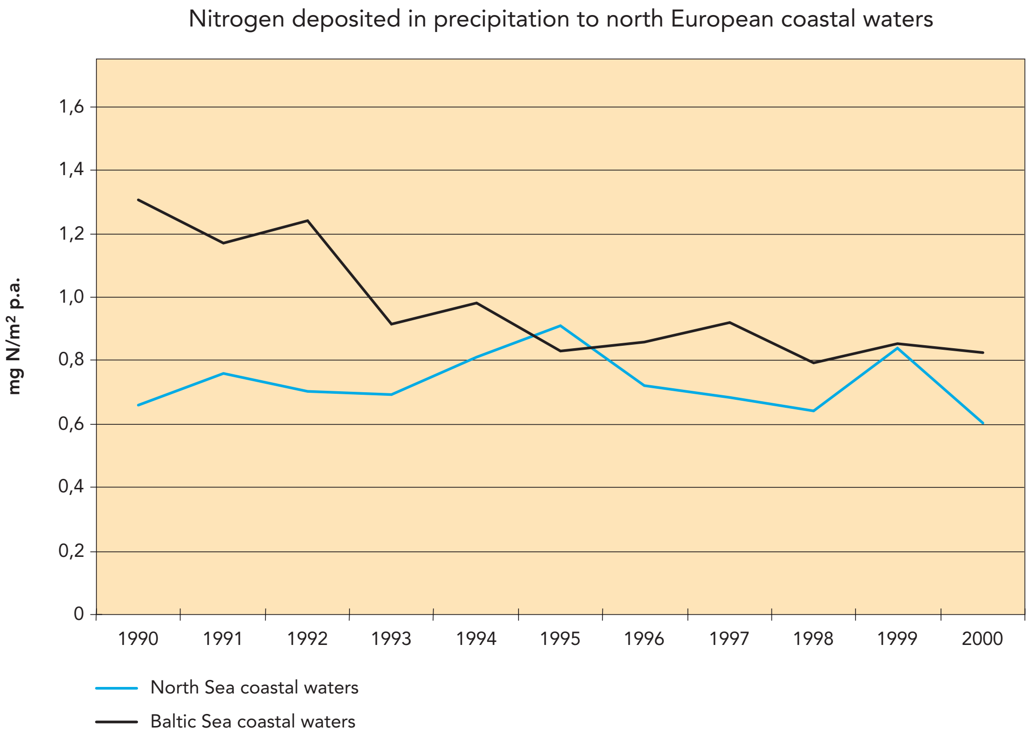
Figure 4.9

**Observed rates of nitrogen deposition in precipitation.**
**Precipitation weighted average annual deposition rates across 36 stations in 15 countries**

**Source:** NILU/EMEP-CCC.

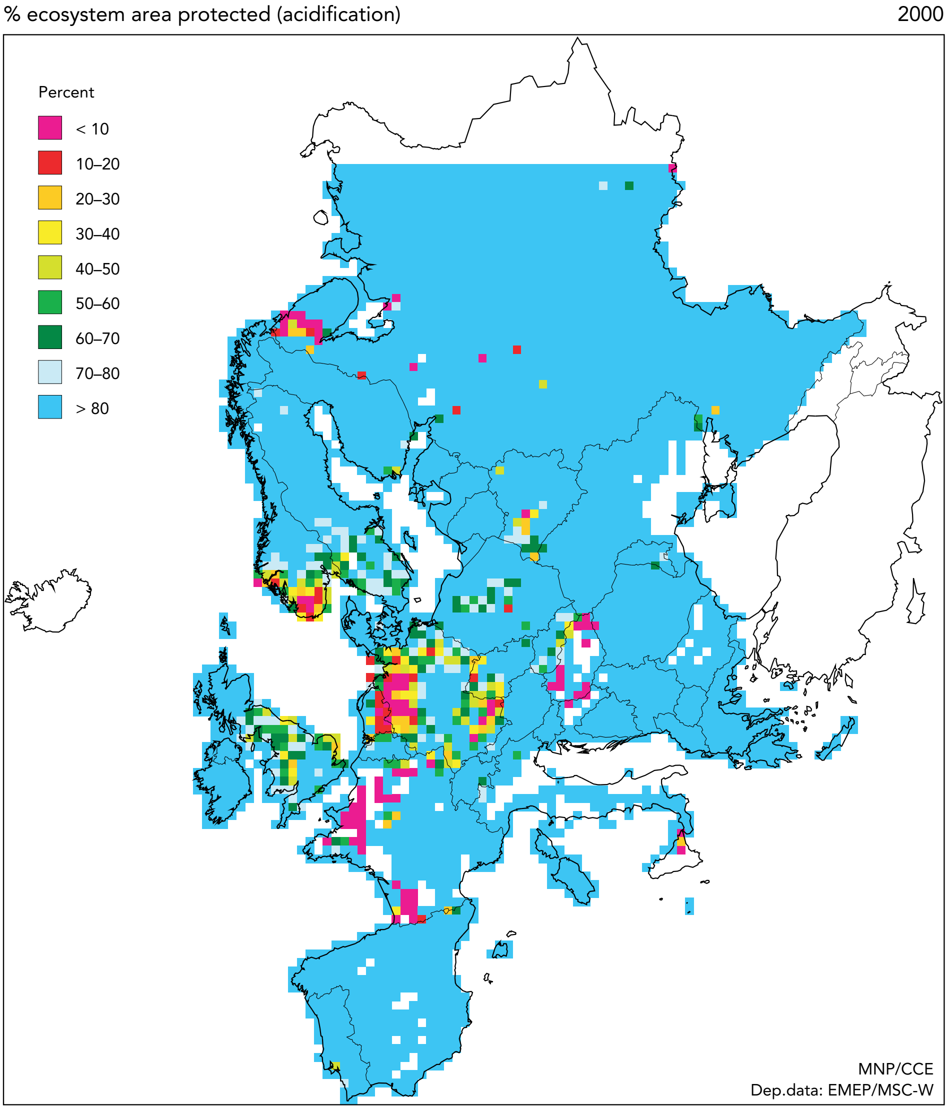


**Indicative trends in deposition of potentially eutrophying nitrogen to the North and Baltic Sea States** Figure 4.10



**Source:** OSPAR + Helcom monitoring programmes.

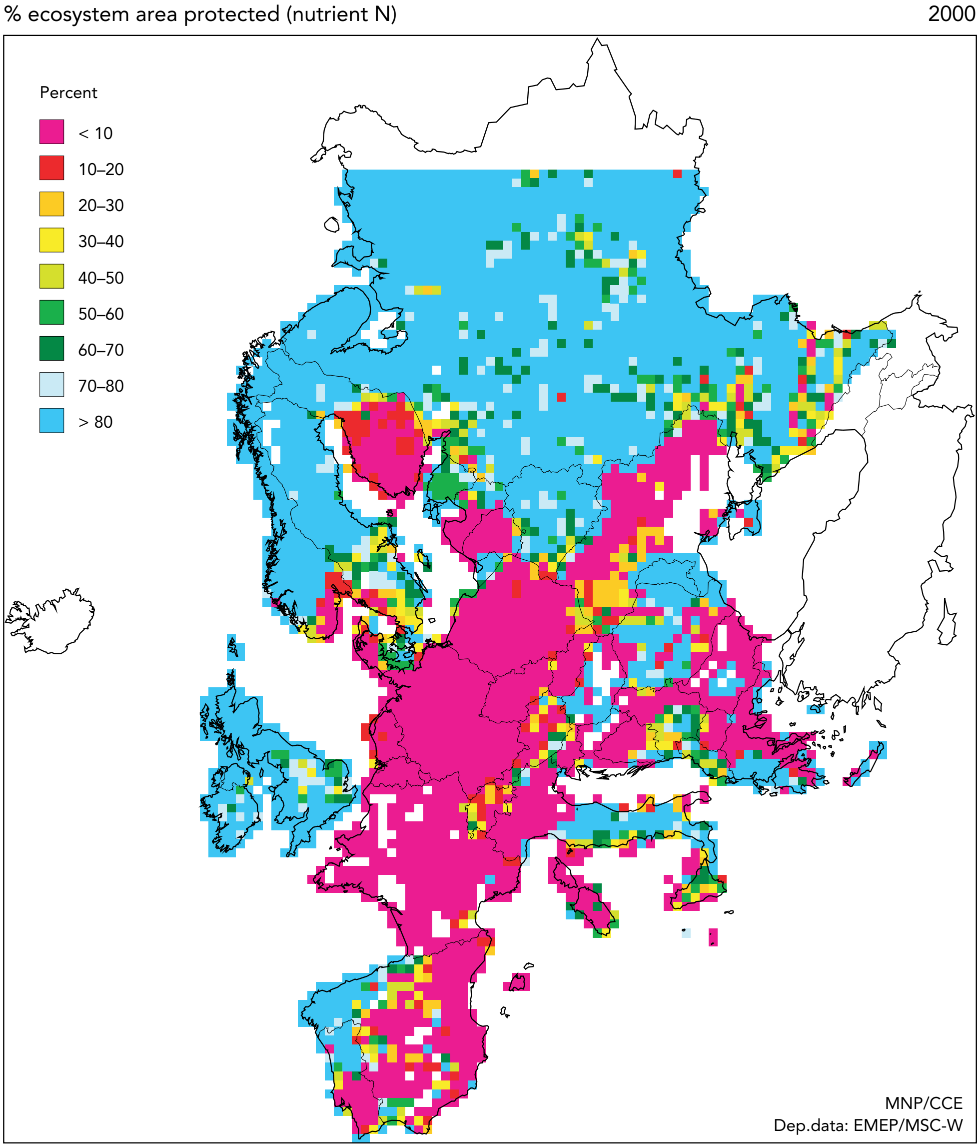
**Percentage of ecosystems protected from acidification, 2000** Map 4.8



**Source:** EMEP MSC-W WGE/CCE.

**Map 4.9** **Percentage of ecosystems protected from impact of eutrophication through atmospheric deposition of nitrogen**

**Source:** EMEP MSC-W WGE/CCE.



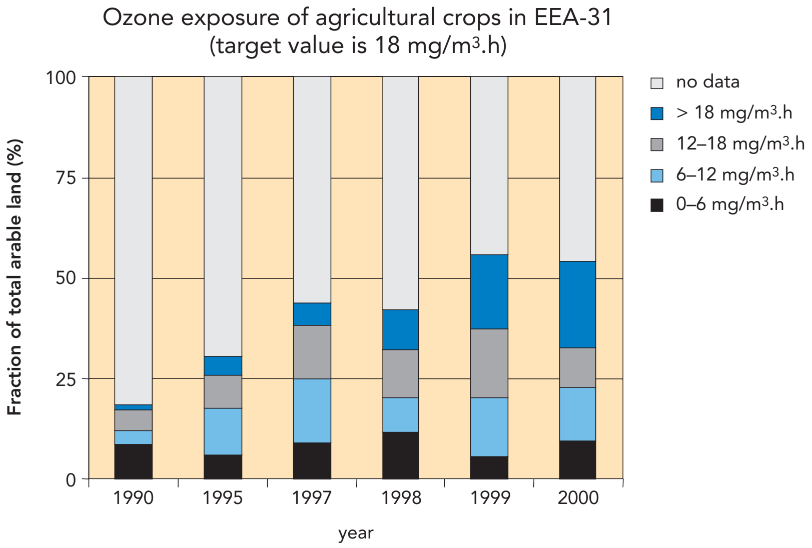
The calculated expected rates of nitrogen supply can be compared with estimated tolerance of ecosystems to give a picture of the degree of protection from further eutrophication experienced by ecosystems. This is done in Map 4.9 for terrestrial ecosystems, once again with the disclaimer that the current EMEP calculation routines are under further development, such that values should only be taken as indicative.

### 4.2.3. Ground-level ozone

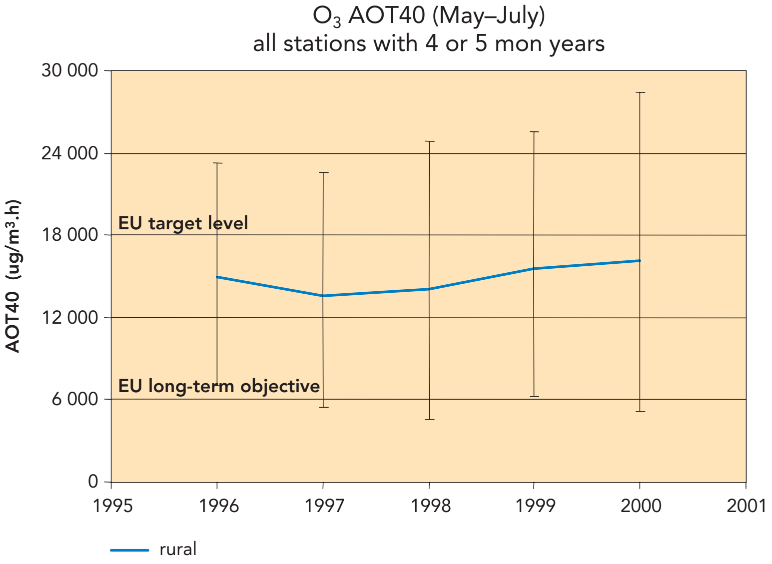
Ozone exposure of ecosystems and agricultural crops results in visible foliar injury and in the reduction in crop yield and seed production. For vegetation under European conditions, a long-term cumulative exposure during the growing season is of concern rather than an episodic exposure. The target level is expressed as AOT40 not to exceed 18 000 µg/m$^3$per hour and should be reached in 2010; the long-term objective is set at 6 000 µg/m$^3$per hour. Map 4.10 and Figures 4.11 and 4.12 show that the long-term objective for crops was exceeded in much of Europe, except in the UK and Nordic countries. In 2000, the long-term objective was exceeded in more than 80 % of the EEA-31 area where data are available. The target value is already complied with in 60 % of the area, with data mainly in the northern part of Europe.

Large year-to-year fluctuations in crop exposure to ozone prevent firm conclusions on trends. The situation for EEA-31 countries as a whole is shown in Figure 4.11 for years since 1990. The area in Europe for which ozone data are available in AirBase has increased steadily since 1990. The area of exceedance of critical levels has varied considerably between years. The tendency is

**Exposure of agricultural crops to ozone (exposure expressed as AOT40 in µg/m³ per hour)** Figure 4.11



**Average AOT40 for ozone at rural stations (May–June), EEA-31, 1996–2000** Figure 4.12

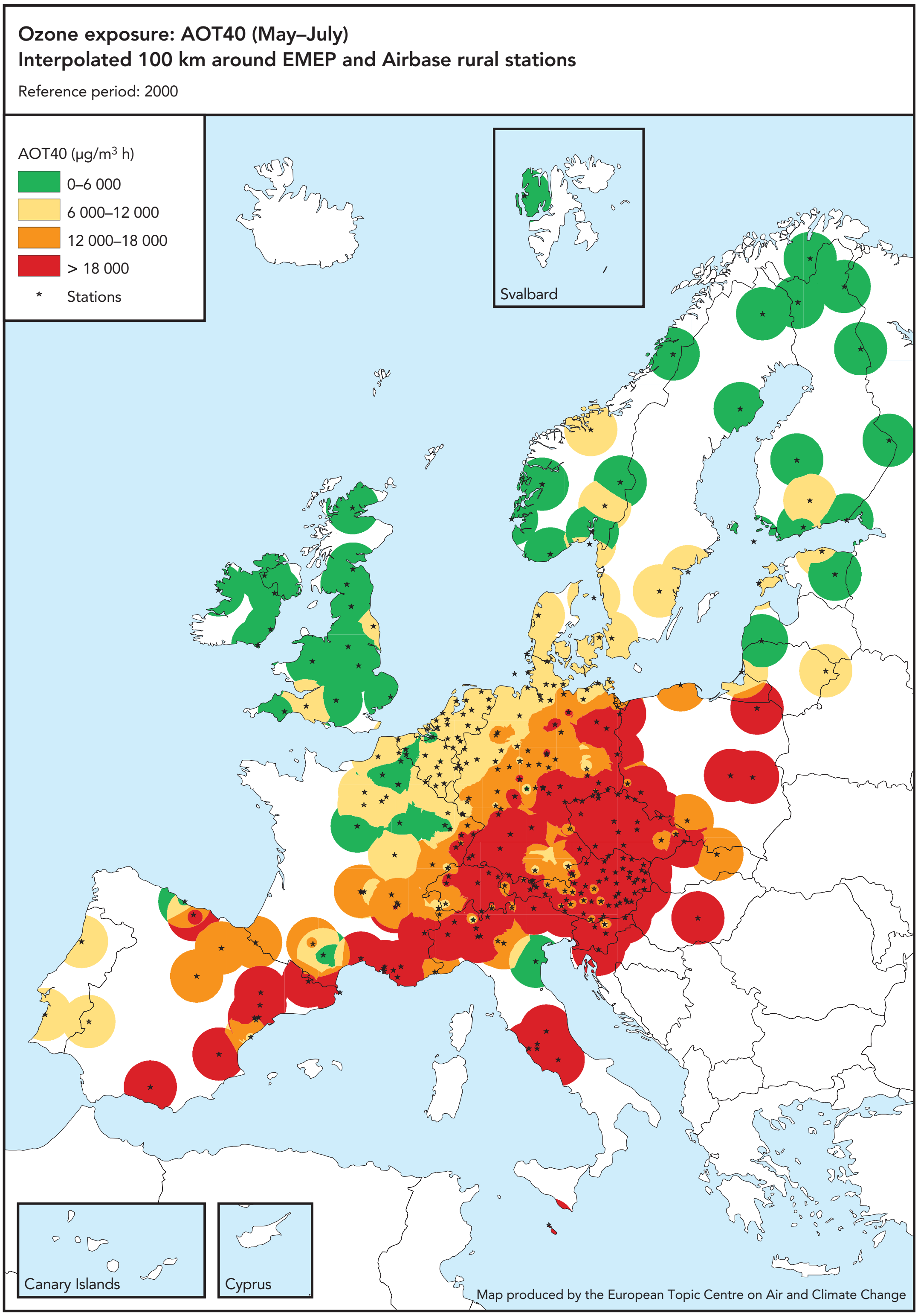


**Note:** Vertical bars indicate 10th and 90th percentile values

that for crops, the area of non-exceedance of the long-term objective (6 000 µg/m$^3$per hour) is small in all years, and as data for more areas become available, the areas with documented exceedance increases. There are, however, large variations from year to year in ozone due to meteorological variability, which may mask the real trend. The area with documented exceedance of the target value was in 1999 and 2000 about 20 % of the total arable land in EEA-31 countries.

The changes in the average observed AOT40 value over the last five years is presented in Figure 4.12, which shows the average AOT40 for all available data at rural stations in EEA-31 countries. Although this figure is based on stations having at least four years of data during the period 1996–2000, the number of stations differs somewhat from year to year. Data for 1996 are based on a relatively low number of stations. The data indicate over the years a somewhat increasing AOT40 average since 1997. It is not yet been established whether this is a significant real increase, and to what extent meteorological variability can explain the tendency.

Map 4.10 **Exposure above AOT40 target values for vegetation around rural ozone stations,2000**



# 5. How are policy measures affecting the air pollution problems?

☺ **Significant emission reductions occurred despite the growth in population, economic output and energy input into the economies of Europe. Abatement measures prompted by EU legislation and CLRTAP agreements must therefore have had a substantial impact.**

☺ **The introduction of EU emission legislation for large combustion plants (EU large combustion plants directive) and national legislation has resulted in the observed decrease of acidification and in part to a decrease of the emission of primary and secondary particles.**

☺ **The introduction of catalysts on light vehicles, triggered by a series of EU directives, also decreased the emissions of secondary particle precursors and of ozone precursors.**

☹ **Although emissions of ozone precursor gases decreased substantially, ozone concentrations at ground level, both annual averages and the 26th highest eight-hour average concentrations do not decrease. This may be due to non-linearities of the ozone formation chemistry, less local scavenging by NO emissions, and to increased northern hemispheric ozone background levels.**

## 5.1. Analysing policy responses

This chapter combines the results presented in the previous chapters and tries to explain the observed trends in pressures, state and impacts. These explanations are to be derived from the following aspects:

1. Trends observed in the activities determining the principle drivers: population growth, increased or decreased economic activities, transport demands, energy demand, etc.

2. Trends observed in the choices made by actors in the society and the economy such as:
   (a) fuel used in energy conversion and energy consumption usage;
   (b) changes in energy intensity of production processes;
   (c) implementation of abatement technologies or cleaner technologies.

3. Implementation and effectiveness of policies and measures.

Whereas (1) represents mainly autonomous development, largely independent of environmental policy, (2) reflects a mixture of autonomous and policy-influenced changes, and it is not always possible to attribute changes to the effect of policies and measures unambiguously. The analysis as presented below (Figures 5.2, 5.3 and 5.5) successively introduce these drivers in the analyses in the order as given above.

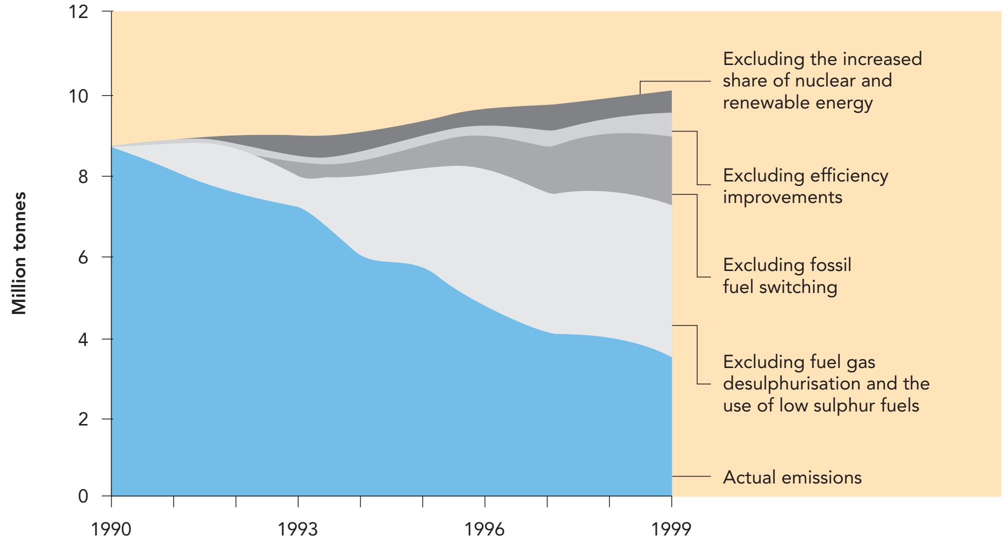
In the report *Energy and environment in the European Union* (EEA, 2002a), an analysis is presented to explain the changes in emissions of $SO_2$ in the electricity sector (see Figure 5.1). It attributes the changes in emissions of $SO_2$ from power plants to specific trends in the fuel mix, fuel specifications and abatement technology. Similar analyses have been made for other pollutants and in other sectors.

The analysis in this chapter further expands on this approach for 'acidifying pollutants', 'total ozone formation potential' and '$PM_{10,}$ primary and secondary inorganic particles' rather than for the individual pollutants, extending the explanation to all relevant sectors.

Section 5.2 presents a brief summary of the existing legislation in the EU, aimed at reducing air pollutant emissions. Section 5.3 concentrates on health-related air pollution, whereas Section 5.4 analyses the ecosystems-related air pollution. Since data availability is quite different for different pollutants and for different activities or sectors, we present some sample analyses without the objective of being complete. Section 5.5 summarises some generic conclusions on the methods used and the results obtained in this chapter.

Figure 5.1 **Explanations for the reduction of emissions of sulphur dioxide in the electricity sector, 1990–99**

**Source:** EEA, 2002a.



**Note:** Fuel switching refers to the replacement from for example coal to oil, and not to change to improved quality fuel within the same fuel type.

## 5.2. Present legislation at EU level

Through the existing EU legislation on air emission (see Box 5.1), European policy aims at a significant reduction of major air pollutants against the background of international agreements and protocols and at protecting human health and ecosystems. This legislation concentrates on $NO_x$, $SO_2$ and dust (particulates) from stationary sources and on CO, $NO_x$ and NMVOC from mobile sources.

$SO_2$ emissions sources are further regulated by setting limits to the sulphur contents of liquid fuels. The overview below does not include the national emission ceilings directive, since this directive does not directly relate to the sources of air pollutants, see Appendix 1, Box 2.

The EU air pollution legislation is related to the requirements from international conventions. Several directives are closely connected to the UNECE LRTAP convention and the respective protocols.

## 5.3. Health-related air pollution

### 5.3.1. Particulate matter

This paragraph presents an analysis of the influence of changes in the fuel quantities and fuel mix that occurred over the past eleven years in Europe. The analysis uses the trends in the driving forces as presented in Chapter 2 and is performed for the EU-15 and the accession countries separately.

Figure 3.8 shows that fuel combustion is the major source of particulate matter in the atmosphere. In the EU-15, a slight decrease of this contribution from 83 % in 1990 to 78 % in 2000 is observed. In the accession countries, the share of fuel combustion in the emissions of primary and secondary particulates is constant at around 87 %. In the EU Member States, the largest contribution is from $NO_x$, whereas the contribution from $SO_2$ is largest in the accession countries.

**Emission trends**

Figure 5.2 shows the results of the analysis, expressed as '$PM_{10}$ (primary and secondary particles)' (see Section 1.3.2). The following results are obtained in the EU-15:

(a) Keeping the per capita emissions of particulate matter constant at their 1990 value, the emissions would have increased in 2000 with 0.8 million tonnes due to population growth (corresponding to about 5 % of total 2000 emissions).
(b) The economic growth per capita in the same period would have caused an additional increase of 4.1 million tonnes.
(c) This economic growth was possible with a relatively lower input of fossil fuels, resulting in a decrease in emissions of 2.3 million tonnes.
(d) The relative use of solid fuels decreased from 8 % in 1990 to 4 % in 2000 and gaseous fuel use increased from 28 % in 1990 to 33 % in 2000. The relative use of liquid fuels did not change. This fuel

**Box 5.1: European legislation on sources of air pollutant emissions**

**Stationary source emissions**
**Large combustion plants:**

- Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants;
- Directive 88/609/EEC on the limitation of emissions of certain pollutants into the air from large combustion plants;
- Council Directive 94/66/EC amending Directive 88/609/EEC on the limitation of emissions of certain pollutants into the air from large combustion plants.

**Waste incineration plants:**

- Directive 89/369/EEC of 8 June 1989 on the prevention of air pollution from new municipal waste incineration plants;
- Directive 89/429/EEC of 21 June 1989 on the reduction of air pollution from existing municipal waste-incineration plants;
- Directive 94/67/EC on incineration of hazardous waste, latest amendment proposal COM(97) 604;
- Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste.

**VOCs:**

- Directive 94/63/EC of the European Parliament and of the Council on the control of VOC emissions resulting from the storage of petrol and its distribution from terminals to service stations;
- Council Directive 1999/13/EC on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations.

**Sulphur content of liquid fuels:**

- Directive 1999/32/EC on reduction of sulphur content of certain liquid fuels.

**Mobile source emissions**
**Road vehicles:**

*Light vehicles:*

- Directive 70/220/EEC on the approximation of the laws of the Member States relating to measures to be taken against air pollution by gases from positive-ignition engines of motor vehicles (16 amendments during 1974–2001).

*Heavy duty vehicles:*

- Directive 88/77/EEC on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous pollutants from diesel engines for use in vehicles (4 amendments during 1991–2001).

*Motorcycles and mopeds:*

- Directive 97/24/EC on certain components and characteristics of two or three-wheel motor vehicles.

*Roadworthiness of vehicles:*

- Directive 96/96/EC on the approximation of the laws of the Member States relating to roadworthiness tests for motor vehicles and their trailers;
- Directive 2000/30/EC as regards speed limiters and exhaust emissions of commercial vehicles.

**Non-road mobile machinery:**

- Directive 97/68/EC on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines;
- Directive 2000/25/EC on action to be taken against the emission of gaseous and particulate pollutants by engines intended to power agricultural or forestry tractors and amending Council Directive 74/150/EEC.

**Automotive fuel quality:**

- Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC;
- Commission Directive 2000/71/EC of 7 November 2000 to adapt the measuring methods as laid down in Annexes I, II, III and IV of Directive 98/70/EC of the European Parliament and of the Council to technical progress as foreseen in Article 10 of that directive.

shift decreased the emissions of particulate forming pollutants with 1.2 million tonnes.

(e) Further reductions were achieved by specific abatement measures:
   - 3.7 million tonnes by abatement of $NO_x$, mainly by the introduction of catalysts in passenger cars and abatement at large industrial boilers;
   - 5.7 million tonnes by the abatement of $SO_2$, due to flue gas desulphurisation and lower sulphur fuel oils.

(f) For the direct emission of particles two effects work in opposite directions: the increased share of diesel fuel in transport and the overall fuel shift towards lighter fuels, resulting in an increase of 0.3 million tonnes.

In the accession countries:

(a) Population decreased and the emissions of particulate matter would have decreased by 0.1 million tonnes, had per capita emissions not have changed between 1990 and 2000.

(b) The increase in GDP in these countries would have resulted in a 4.4 million tonne increase of emissions.

(c) Fossil fuel use however decreased slightly resulting in a decrease of emissions with 5.1 million tonnes.

(d) The relative use of solids decreased from 30 % in 1990 to 21 % in 2000, whereas the use of liquid fuels increased from 21 % in 1990 to 31 % in 2000. The use of gaseous fuels did not change significantly.
This fuel shift resulted in a slight increase in emissions (0.6 million tonnes), mainly due to the higher sulphur content of the liquid fuels as compared to the solid ones.

(e) Changes, due to abatement the different pollutants present a mixed picture:
  - $NO_x$ abatement decreased the emissions by 0.8 million tonnes;
  - $SO_2$ abatement resulted in a decrease of 3.3 million tonnes.

(f) Particulate emissions due to combustion however increased, resulting in an increase of 0.4 million tonnes of particulate formation equivalents.

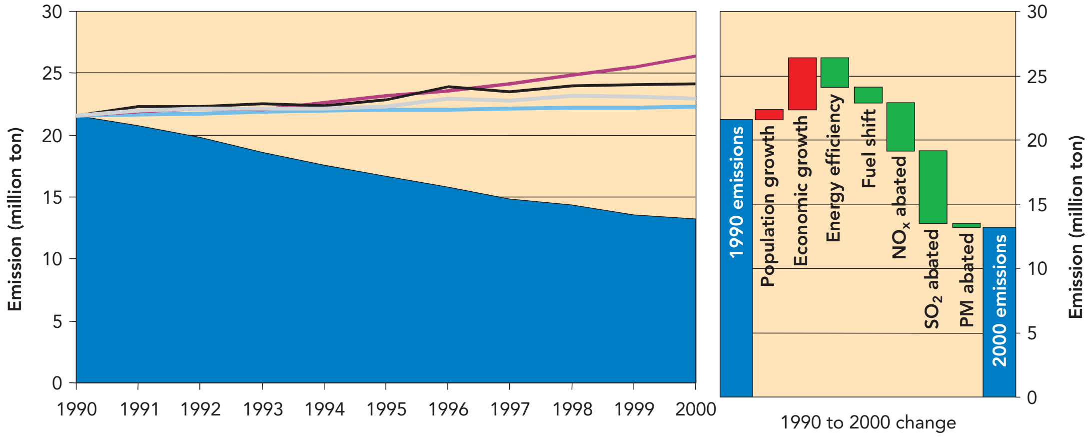
**Ambient concentration trends**
Ambient air concentrations of $PM_{10}$ are available since 1997 only. Figure 4.4 presents the trends as observed. The decrease by about 10 % in these four years appears to be consistent with the decrease in emissions as described above.

**Contribution of legislation to the trends**
Although at this stage data do not allow to show a direct link between the introduction of legislation to decrease emissions, and the actual trends, the following tentative conclusions, however, can be drawn:

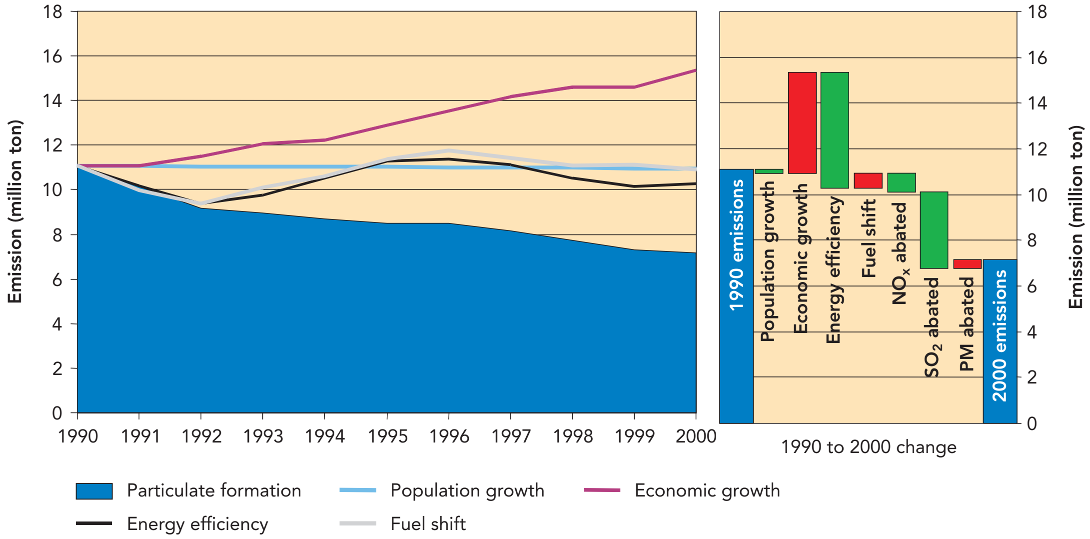
- $SO_2$ from fuel combustion is mainly emitted by large combustion plants in the energy and industry sectors. The decrease by 5.7 million tonnes of particulate formation potential, associated with $SO_2$ emissions in the EU Member States, is therefore probably largely due to the lower $SO_2$ emission limit values as set in the large combustion plant (LCP) directives and in the directive on sulphur content in liquid fuels.

**Trend analysis of $PM_{10}$ (primary and secondary particles) emission from fuel combustion in Europe** Figure 5.2

$PM_{10}$ (primary and secondary particles) in the EU-15



$PM_{10}$ (primary and secondary particles) in the accession countries



**Note:** Economic growth in this figure is expressed as GDP per capita.
Energy efficiency must be read as fossil fuel combustion per GDP unit.

Left: time series; right: contributions to the 1990 to 2000 change (red: increase; green: decrease)

- $NO_x$ from fuel combustion is partly emitted by (road) transport and partly by stationary sources (52 % and 30 % respectively); the decrease by 3.7 million tonnes of particulate formation associated with $NO_x$ emissions is probably in part due to both the LCP directives and the directives aiming at reducing road traffic emissions.
- Primary particulate emissions were not regulated in the earlier versions of the large combustion plant directive. The relatively small changes in the contribution of primary particulates emissions to the overall decrease of the particulate matter concentrations might be due to this fact. Since 'dust' (particulates) now is included in the large combustion plant directive, decreases of these emissions could be expected.

### 5.3.2. Ozone

Ozone is formed in a photochemical process from the so-called ozone precursors. Transport is the major contributor to these emissions; its contribution is slowly decreasing from 55 % in 1990 to just below 52 % in 2000 in the EU Member States and increasing from 34 % to 36 % in the accession countries (Figure 3.5). The main contributing pollutant is $NO_x$ in both country groups.

Since road traffic is the important source in the EU-15 and since detailed statistical data are available for these countries only, we will concentrate on the influence of trends in the road traffic developments on these emissions and the resulting ozone concentrations in the EU-15 Members States. Data are not sufficient for a similar analysis for the accession countries.

**Emission trends**

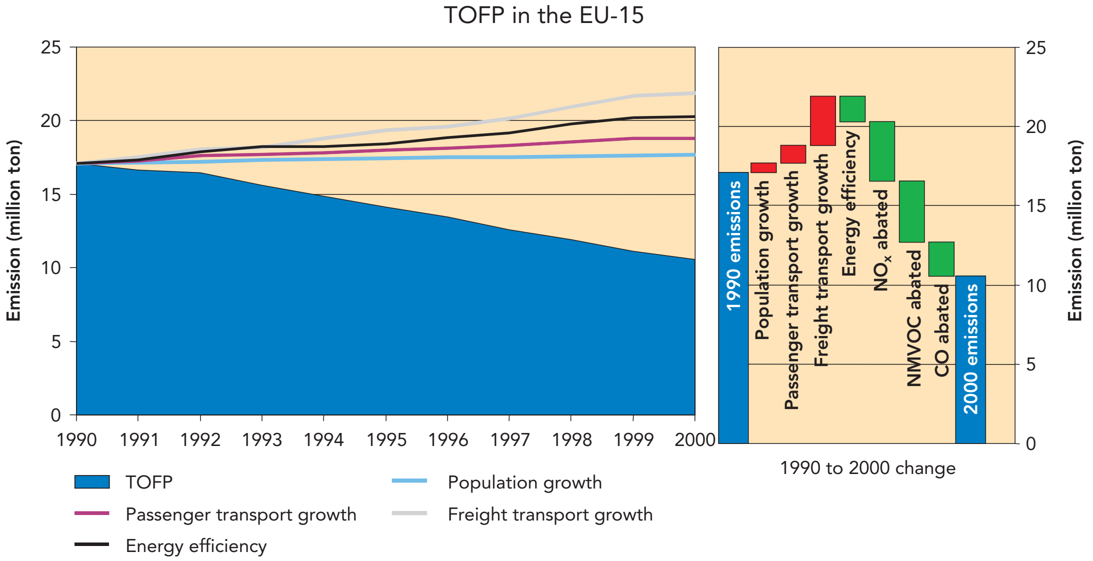
The emissions of total ozone formation precursor (TOFP) in the EU-15 decreased from 17.1 million tonnes/annum in 1990 to 10.6 million tons per annum in 2000. This decrease of 38 % in 11 years is explained in Figure 5.3, using the information of Chapter 2:

1. Due to increase of the population, ignoring all other changes, the emission would have increased by about 0.6 million tonnes.
2. Since traffic intensity increased more rapidly than population, an additional increase of four million tonnes of TOFP would have occurred (about one million tonnes from passenger transport, and three million tonnes freight transport).
3. These increases were compensated in part by the improved energy efficiency of the road transport system, resulting in a reduction of 1.4 million tonnes per annum.
4. A reduction of about 9.7 million tonnes per annum resulted from the introduction of catalysts in passenger cars leading to a reduction in emissions of the three components of TOFP:
    (a) 3.7 million tonnes due to the reduction in $NO_x$ emissions;
    (b) 3.9 million tonnes due to the reduction of NMVOC emissions;
    (c) 2.1 million tonnes due to the reduction of CO emissions.

Reductions of emissions of $NO_x$, NMVOC and CO have occurred in EU Member States as a result of the introduction of catalysts in passenger cars. Statistical data do not allow to actually attribute the observed emission reductions of these three components to the introduction of the catalysts. According to the EMEP Corinair guidebook, the efficiency of the three-way catalyst is 77, 91 and 94 % for $NO_x$, NMVOC and CO, respectively. Together with the observation that about 50 % of the EU-15 road traffic CO and $NO_x$ emissions and 60 % of the road traffic NMVOC emissions in 1990 are attributed to passenger cars (⁹) the above result is consistent with a (almost) complete implementation of catalysts in the EU-15 passenger car fleet in 2000.

Figure 5.4 shows the contribution of the different effects, explained in Figure 5.3, to the overall emission reduction in the EU-15. Without these developments (energy efficiency improvements and abated emissions) in road traffic, total ozone precursor (TOFP) emissions would have decreased with 9 % only as compared to the

Figure 5.3 **Trend analysis of ozone precursor (TOFP) emission from road traffic in the EU-15**



**Note:** Economic growth in this figure is per capita.
Energy efficiency must be read as fuel combustion per distance unit.

Left: time series; right: contributions to the 1990 to 2000 change. (red: increase; green: decrease)

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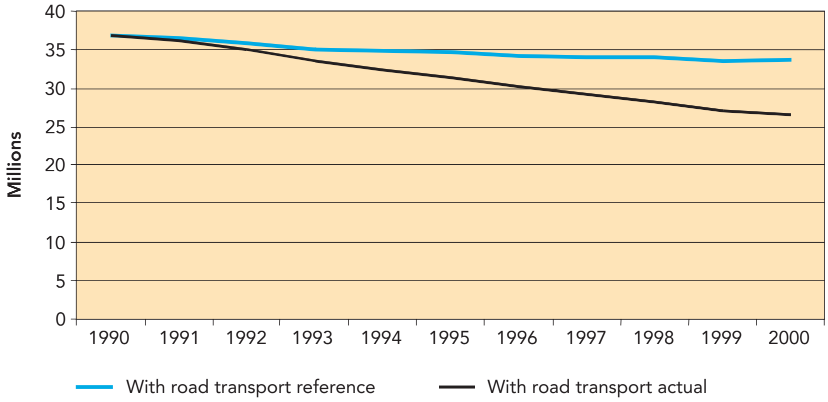
(9) UNECE EMEP/Corinair, 2001.

Influence of the ozone precursor (TOFP) emission reductions in road traffic on the total emissions of ozone precursors in EU-15

Figure 5.4



actual total emission reduction by 28 % that has been reported.

**Ambient concentration trends**
Figure 4.2 in Chapter 4 shows the observed time series of ozone concentrations in Europe. The relation between emissions and ozone concentrations is not linear, and the trend assessment of various ozone indicators shows a complicated picture. As described and explained in connection with Figure 4.2, the annual average ozone levels have an increasing trend, while the maximum concentrations, as well as high percentiles, show a decreasing trend, which is supported by modelling studies using the decreasing precursor emissions as input. The health-related indicator of the EU directive falls between these: a rather constant level since 1996.

**Contribution of legislation to the trends in emissions**
The analysis in this section shows the developments of the contribution from road traffic to the TOFP emissions. In the trend analyses of the emissions, we see two major contributions:

1. The implementation of more stringent emission limit values from vehicles, leading to the successive introduction of improved catalysts, has led to a decrease of 9.7 million tonnes of ozone formation precursors (as TOFP) by simultaneously reducing the emissions of $NO_x$, NMVOC and CO.

2. The decreased fuel use per distance travelled by road transport vehicles, leading to a decrease of 1.4 million tonnes of ozone formation potential.

## 5.4. Ecosystems-related air pollution

### 5.4.1. Acidification

Emissions of acidifying pollutants occur from fuel combustion ($NO_x$ and $SO_2$) and from animal husbandry ($NH_3$). These sources cause 95 % of these emissions. Figure 3.13 shows that the share of combustion in the emissions of acidifying pollutants in the EU-15 is decreasing from 75 % to 65 %. The share of $NH_3$ from agriculture is increasing. In the accession countries, the share of combustion is about 82 to 84 %, whereas the share of agriculture is about 12 to 14 %.

**Emission trends**
Figure 5.5 presents an analysis of the time series of emissions of acidifying pollutants from fuel combustion in relation to changes in the activities. The following possible explanations of the trends in these emissions can be observed:

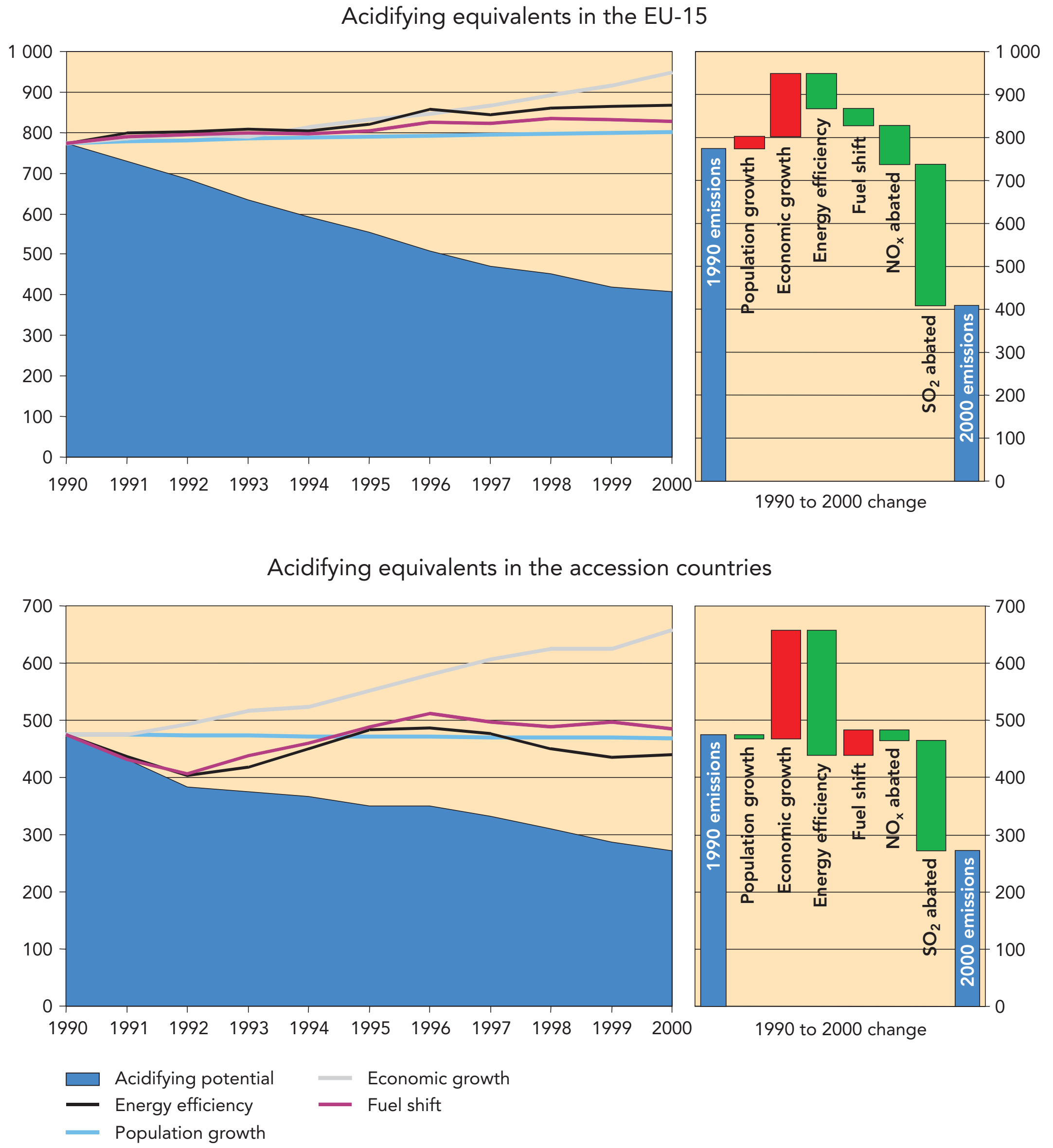
In the European Union Member States, emissions of acidifying pollutants decreased in total from 774 000 tonnes of acidifying equivalents in 1990 to 409 000 tonnes in 2000:

(a) Population growth would have resulted in an increase of 30 000 tonnes of acidifying equivalents, if the per capita emissions had not changed between 1990 and 2000.

(b) Economic growth would have caused an additional increase of 150 000 tonnes.

(c) The fuel use has not increased as much as the economic activity, resulting in a decrease of emissions by 80 000 tonnes.

**Figure 5.5** **Trend analysis of acidifying pollutants emission from fuel combustion in Europe**



Acidifying equivalents in the EU-15

Acidifying equivalents in the accession countries

**Note:** Economic growth in this figure is per capita.
Energy efficiency must be read as fuel combustion per GDP unit.

Left: time series; right: contributions to the 1990 to 2000 change (red: increase; green: decrease).

(d) The shift towards lighter fuels resulted in an additional decrease of 40 000 tonnes of acidifying equivalents.

(e) Pollutant specific abatement measures further decreased the emissions:
- of $NO_x$ by 90 000 tonnes;
- of $SO_2$ by 330 000 tonnes.

The emissions of acidifying pollutants in the accession countries decreased from 475 000 tonnes in 1990 to 272 000 tonnes in 2000:

(a) The decrease in population size in the accession countries would have resulted in a decrease of emissions with 10 000 tonnes.

(b) The increased economic production (GDP) would have resulted in an increase of 190 000 tonnes of acidifying pollutants.

(c) This however would have been more than compensated by the fact that the AC economies used less fossil fuels to achieve this production: this decreased the emissions by 220 000 tonnes.

(d) The fuel shift has increased acidifying pollutant emissions by 40 000 tonnes.

(e) Pollutant specific abatement measures further decreased the emissions:

- by 20 000 tonnes due to the abatement of $NO_x$ emissions;
- by 190 000 tonnes due to the abatement of $SO_2$ emissions.

**Deposition trends**

Map 4.7 and Figure 4.9 in Chapter 4 show the sulphur and nitrogen deposition since 1990. In case of sulphur deposition, a significant reduction of at least 50 % can be seen in a large part of Europe. This picture shows good correspondence with the emission decrease of approximately 60 % since 1990 (Figure 3.6), and the $SO_2$ abatement by fuel combustion (Figure 5.7). $NO_x$ emissions in Figure 3.5 show a significant but smaller decrease of 27 %. The nitrogen wet deposition (Figure 4.9) does not show a significant decrease.

The decrease in $SO_2$ emissions is clearly visible in the sulphur deposition trend (Map 4.7), while the decrease in $NO_x$ emissions seems to be too small to be seen in Figure 4.9.

**Contribution of legislation to the trends**

As a consequence of the fact that $SO_2$ emission reductions dominate the trends in acidification, the major contribution of legislation should be attributed to the large combustion plant directive and national measures related to that.

## 5.5. Generic conclusions

### 5.5.1. Trend analyses

This chapter applies a relatively simple analysis to explore correlations between changing driver parameters and the emissions in the EU-15 and in the accession countries.

Note that these analyses are mainly of a phenomenological nature and do not really prove or accurately quantify the contributions of the different developments in drivers or of the measures and policies. We show here that the trends in emissions are consistent with the trends in the European societies and economies, rather than prove that such trends necessarily cause the emission trends. To a certain extent, we might assume that the national experts compiling the emission inventories used in this study, are in fact translating these changes in their own countries' economies into the emissions estimates. Our analysis shows the relative importance of the different developments in a more or less quantitative way.

### 5.5.2. The success of abatement

Even though an increase in economic activity can be observed over the decade (1990–2000), a relative decrease can be seen in energy use. As can be seen in Chapter 2, transport and industrial activities as well as the GDP increased more than the amount of energy needed for these activities.

However, this increase in energy and fuel intensity of the European economies and societies cannot explain the observed downward trends in emissions. Also, the shifts towards lighter fuels, occurring both in the EU-15 and to a lesser extent in the accession countries cannot fully explain the observed decreases in emissions.

The major contribution to the decreased emissions in Europe is due to the successful abatement of sulphur dioxide emissions, by the UNECE LRTAP Convention and the European Union's large combustion plant directives. These directives also decreased the emissions of $NO_x$. Further reduction in emissions of this pollutant has been achieved by the introduction of catalysts in gasoline-fuelled passenger cars as a response to the successive road vehicle related EU directives. This technology also resulted in simultaneous reductions in the emissions of NMVOCs and CO.

Ambient air quality has followed largely the reductions in emissions, for $PM_{10}$, $NO_2$ and $SO_{2,}$ while for tropospheric ozone, the reductions in precursor emissions are not reflected in the atmospheric measurements

The emission reductions have resulted in notable decreases of the air pollution problems in the field of particulate matter and acidification.

### 5.5.3. Expectations for the future

The two major contributions to the improvements in the air quality that have been achieved are as follows: the successful reduction of sulphur dioxide emissions throughout Europe and the introduction of catalysts in passenger cars can be characterised as the 'low hanging fruits', which now have been almost completely picked. Further reductions of air pollution will be more difficult and costly. This applies to the reduction of emissions of nitrogen oxides, ammonia and NMVOC as required under the NEC directive and as relevant for eutrophication and ground-level ozone. Further reduction of the emission of these pollutants is also needed in order to bring concentrations of fine particulate matter below the limit values.

Ozone and $PM_{10}/PM_{2.5}$ are now generally seen as the priority pollutants with continued non-attainment of limit values and major implications for human health.

In view of the costs involved, optimisation of cost-effective reduction strategies for these two priority pollutants in integrated assessment is essential. Such integrated assessment modelling is the core activity in the Commission's clean air for Europe (CAFE) programme.

Many measures to reduce emissions of greenhouse gases reduce air pollutants as well. Implementation of the Kyoto Protocol is expected to result in lower cost of air pollution abatement in Europe. Considering greenhouse gas emissions and air pollutant emissions in a common framework is therefore recommended (EEA, 2003a).

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# 7. Acronyms and abbreviations

| | |
|---|---|
| AirBase | air quality database of the ETC/ACC |
| AOP2 | auto-oil programme II |
| AOT40 | accumulated ozone concentration above a threshold of 40 ppb (= 80 $\mu g/m^3$) |
| CCC | Chemical Coordination Centre (of EMEP) |
| CCE | Coordination Centre for Effects (UNECE) |
| $CH_4$ | methane |
| CLRTAP | Convention on Long Range Transboundary Air Pollution |
| CO | carbon monoxide |
| DEM | data exchange module |
| DNMI | Norwegian Meteorological Institute |
| DMS | dimethyl sulphide |
| EBAS | EMEP database at NILU |
| EEA | European Environment Agency |
| EMEP | cooperative programme for monitoring and evaluation of the long range transmission of air pollution in Europe |
| EoI | exchange of information |
| ETC/ACC | European Topic Centre on Air and Climate Change |
| EU | European Union |
| ICP | international cooperative programme (UNECE) |
| IPPC | integrated pollution prevention and control |
| LAT | lower assessment threshold |
| LCL | lower classification level |
| LCP | large combustion plant directive |
| LV | limit value |
| MSC-W | Meteorological Synthesising Centre-West (of EMEP) |
| NECD | national emission ceiling directive |
| $NH_3$ | ammonia |
| NILU | Norwegian Institute for Air Research |
| NMVOC | non-methane volatile organic compounds |
| NO | nitrogen monoxide |
| $NO_2$ | nitrogen dioxide |
| $NO_x$ | nitrogen oxides, sum of nitrogen oxide (NO) and nitrogen dioxide ($NO_2$) |
| $O_3$ | ozone |
| Pb | lead |
| $PM_{10}$ | particulate matter with an aerodynamic diameter of less than 10 mm |
| ppb | part per billion |
| RIVM | National Institute of Public Health and the Environment |
| $SO_2$ | sulphur dioxide |
| TOFP | tropospheric ozone formation potential |
| TSP | total suspended particulates |
| TV | target value |
| UAT | upper assessment threshold |
| UCL | upper classification level |
| UNECE | United Nations Economic Commission for Europe |
| VOC | volatile organic compounds |
| WHO | World Health Organisation |

# Appendix 1: Air pollution directives, targets and limit values

Recent EU policies and measures reflect a coordinated approach to air pollution control, setting limit and target values in directives, for both national and plant specific emissions and for acceptable air quality. The air quality framework directive (96/62/EC) established a framework under which the EU has set limit values for specific pollutants (so far for $SO_2$, $NO_2$, $PM_{10}$, lead, CO and benzene) as well as target levels for ozone, to protect human health and vegetation. Air quality guidelines for protection of human health have also been recommended by WHO. Member States must transpose the directives into their national law, monitor air quality according to certain requirements, and, where limit or target values are exceeded, develop abatement programmes and report on their implementation.

Emission reduction targets on national emissions have been set in the Gothenburg protocol by the CLRTAP, and by EU most recently with its national emission ceiling directive (NECD). This is intended to address, simultaneously, pollutant-specific ambient air quality problems affecting human health, as well as ground-level ozone, acidification and eutrophication affecting ecosystems. Specifically, these address sulphur dioxide, nitrogen oxides, ammonia and volatile organic compounds. The NECD is supported by legislation on specific sectors, such as those aimed at large combustion plants, the sulphur contents of vehicle fuels and the reduction of non-methane volatile organic compounds from use of solvents.

The air quality directives have target years of 2005 and 2010; both the emissions directive and the CLRTAP protocol have 2010 as its target year, by which limit values, targets or ceilings have to be achieved.

Boxes 1 and 2 give an overview of specifics of the limit and target values and ceilings in the directives.

**Box 1: Air pollution limit values and targets**

**Health-protection limit and target values**

**EU directives:** (European Commission, 2003)

| Compound | Limit/target value | | | Target year |
|---|---|---|---|---|
| $PM_{10}$ Stage 1 | Annual average: | 40 µg/m³ | | 2005 |
| | Daily average: | 50 µg/m³ | May be exceeded up to 35 days a year | 2005 |
| $PM_{10}$ Stage 2 | Annual average: | 20 µg/m³ | Indicative | 2010 |
| | Daily average: | 50 µg/m³ | Indicative; may be exceeded up to seven days a year | 2010 |
| $NO_2$ | Annual average | 40 µg/m³ | | 2010 |
| | Hourly average: | 200 µg/m³ | May be exceeded up to 18 hours per year | 2010 |
| Ozone | Eight-hour average: | 120 µg/m³ (target value) | May be exceeded up to 25 days per year (¹) | 2010 |
| $SO_2$ | Daily average: | 125 µg/m³ | May be exceeded up to three days per year | 2005 |
| | Hourly average: | 350 µg/m³ | May be exceeded up to 24 hours per year | 2005 |
| CO | Eight-hour average: | 10 mg/m³ | | 2005 |
| Pb | Annual average: | 0.5 µg/m³ | | 2005 (²) |
| Benzene | Annual average: | 5 µg/m³ | | 2010 |

(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.

**WHO guidelines:** (WHO, 2000)

| | | | |
|---|---|---|---|
| $PM_{10}$ | No lower threshold for effects. Guideline is given in terms of dose-response functions as a basis for risk estimates. | | |
| $NO_2$ | Guideline levels are the same as in the EU directive, but allowable exceedances are not given. | | |
| Ozone | Guideline level is the same as in the EU directive, but allowable exceedances are not given. | | |
| $SO_2$ | Annual average. | 50 µg/m$^3$ | |
| | Daily average. | 125 µg/m$^3$ | (as in EU directive, but allowable exceedances are not given.) |
| | 10 minutes average: | 500 µg/m$^3$ | |
| CO | 8 hours: | 10 mg/m$^3$ | (in addition, guidelines are given for 1-hour, 30 minutes and 15 minutes averages). |
| Cd | Annual average | 5 ng/m$^3$ | |
| Hg | Annual average | 1 µg/m$^3$ | (as inorganic mercury vapour) |
| Pb | Same as in EU directive | | |
| Benzene | No safe level of exposure is recommended | | |

**Limit values and targets for protection of vegetation**

**EU directives/CLRTAP**

| **Compound** | **Limit/target value** | | **Target year** |
|---|---|---|---|
| $SO_2$ | Annual/winter average: | 20 µg/m$^3$ | 2001 |
| $NO_x$ (as $NO_2$) | Annual average: | 30 µg/m$^3$ | 2001 |
| Ozone | Accumulated exposure over a threshold of 40 ppb (1) (AOT 40): | | |
| | EU directive (target) | 18 000 µg/m$^3$ · h | 2010 |
| | EU directive | 6 000 µg/m$^3$ · h | Long-term objective |
| | CLRTAP | 6 000 µg/m$^3$ · h | Long-term critical level |
| Acidifying and eutrophying components | Area exceeding critical loads: EU NECD | Reduced by 50 % within each grid Long-term objective: no exceedance of critical loads | 1990–2010 |

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

**Box 2: Emission controls**

**EU directive (NECD, 2000)**

| | | Emission change required<br>EU | | Time period (1) |
|---|---|---|---|---|
| | | (max. decrease) | (min. decrease) | |
| $SO_2$ | Annual total | – 77 % | (– 90, + 3) | 1990–2010 |
| $NO_x$ (as $NO_2$) | Annual total | – 51 % | (– 61, 0) | 1990–2010 |
| VOC (non-methane) | Annual total | – 58 % | (– 72, – 30) | 1990–2010 |
| $NH_3$ | Annual total | – 15 % | (– 43, + 1) | 1990–2010 |

**UNECE CLRTAP**

| | | Emission change required<br>EEA-18 + AC-10 | | Time period (1) |
|---|---|---|---|---|
| | | (max. decrease) | (min. decrease) | |
| $SO_2$ | Annual total (1999) (2) | – 69 % | (– 90, + 7) | 1990–2010 |
| $NO_x$ (as $NO_2$) | Annual total (1999) | – 46 % | (– 61, 0) | 1990–2010 |
| VOC (non-methane) | Annual total (1999) | – 51 % | (– 72, – 4) | 1990–2010 |
| $NH_3$ | Annual total (1999) | – 16 % | (– 43, + 19) | 1990–2010 |

(1) The first year of the period constitutes the reference year.
(2) Protocol year.

# Appendix 2: Air pollution themes and issues

The main air pollution issues of concern in Europe in view of their impact on human health, ecosystems and materials and cultural heritage, are (EEA, 2002):

- human health-related impacts due to exposure, in particular to ozone and particles and to a lesser extent to $NO_2$, $SO_2$, CO, lead, benzene;
- acidification and eutrophication of water, soils and ecosystems;
- damage to vegetation and crops due to exposure to ground-level ozone;
- damage to materials and cultural heritage due to exposure to acidifying compounds and ozone.

**Human health-related impacts (spatial scale: urban areas/streets; time profile: hours, days, years**

The impact of air pollutants on human health is a risk factor mainly at local and urban scales, where air pollutants may affect the sensitive parts of the population. Short-term as well as long-term effects occur. Main sources in most cities in Europe are road traffic, small-scale power/heat generation (from large buildings down to single houses/ apartments, e.g. small stoves burning wood, and other energy sources), and industrial processes in many cities. The often very close proximity between pollutant sources (e.g. cars in streets) and the population results in potentially high levels of exposure. These are often above the limit values designed to protect the population against deleterious effects. Potential increased deterioration of building materials and cultural monuments caused by air pollution is another risk factor of significance.

The main compounds with health implications for the population in cities at the present time in Europe, as elsewhere are particulate matter (PM, especially small particles less than 10 µm ($PM_{10}$) or even less than 1 µm ($PM_1$)), nitrogen dioxide ($NO_2$) and ozone ($O_3$). Sulphur dioxide ($SO_2$), benzene and carbon monoxide (CO) still present risks in some places. Urban traffic is the main source of many of these pollutants in typical cities in Europe, while space heating, especially using wood in small stoves, is also an important source of PM in cities wherever such heating during winter is necessary.

**Acidification and eutrophication of ecosystems (spatial scale: 1 000 km; time profile: days)**

The consequences of the deposition of acidifying substances include changes in the mineral balance in soils as nutrients are leached through increasing acidity, and changed water chemistry directly and as a consequence of soil leaching. The combination of greater acidity with increased mineral content can be toxic to aquatic life, whilst loss of nutrients and greater soil toxicity can affect vegetation.

Nitrogen is also a nutrient. Thus, excess nitrogen deposition may enhance growth. This begins as minor, or even desirable, but soon reaches a point where disturbance to ecological systems becomes detrimental. This process is known as eutrophication. As well as affecting terrestrial and freshwater ecosystems, coastal waters and shallow regional seas can also undergo eutrophication, contributing among other things to algae blooming.

Soils and waters will have a natural capacity to absorb a certain quantity termed, the critical load, of potentially polluting deposition. If these critical loads are exceeded, significant harm may be anticipated. For acidifying deposition, the capacity is for buffering the received acidity; for eutrophication it is the capacity to utilise and to immobilise nitrogen. The issue is exceedance of these loads.

The sources of sulphur and of nitrogen oxides involved, as described in Section 3.1, are largely emissions from energy production, industrial activity and transport, with combustion of fossil fuels having significance. Ammonia also supplies, the sources of which are chiefly agriculture, with animal husbandry being predominant. These pollutants can remain in the atmosphere sufficiently long to be spread far from the originating source of the polluting emission, so that the effects are generally dependent upon emissions from distant sources.

**Ground-level ozone (spatial scale: approx. 500 km; time profile: hours)**
Photochemical pollution is formed from emissions of nitrogen oxides ($NO_x$, where $NO_x = NO + NO_2$) and of volatile organic compounds (VOC) and carbon monoxide (CO) in the presence of sunlight. Ozone ($O_3$), the major photochemical pollutant, and its precursors are long-lived and transported across national boundaries (Simpson and Malik, 1996). Emissions of $NO_x$ are responsible for much of the ozone formation occurring in rural areas. In more densely populated regions, in particular close to cities, ozone formation is enhanced by VOC emissions. VOC are mainly released from road traffic and the use of products containing organic solvents. $NO_x$ and CO are mostly emitted from transport and combustion processes.

Exposure to ozone induces effects upon health and the environment, causing respiratory difficulties in sensitive people and possible damage to vegetation and ecosystems (WHO, 1996a, b). Significant responses in both humans and plants occur at or close to current ambient concentrations of ozone (UNECE, 1996). Ozone in the troposphere is also of relevance to climate change since ozone is a greenhouse gas. It is currently estimated that tropospheric ozone adds 0.35 $W.m^{-2}$ to the current enhanced climate forcing of 2.45 $W.m^{-2}$ by long-lived greenhouse gases. The total forcing is a result of the increase in long-lived compounds only ($CO_2$, $CH_4$, $N_2O$, halocarbons) (IPCC, 2001).

**Damage to materials and cultural heritage**
Atmospheric corrosion/deterioration is a cumulative, irreversible process that takes place under all climatic conditions. Acidifying air pollutants will increase the rate of the deterioration processes. The corrosion can be explained by two main reaction mechanisms. Close to the emission sources the direct effect of sulphur dioxide dominates ('dry' corrosion) while the effect of the acid part is more important in background areas ('wet' corrosion). Sulphur dioxide and the further oxidised sulphuric acid are known to have a strong effect on the processes. However, laboratory tests show that a mixture of gases like nitrogen dioxide and ozone will increase both the deterioration rates and materials. Also, a mixture of other gases will contribute to natural corrosion. In terms of dose-response, the dominating explanatory factors are sulphur dioxide and acid rain. Current findings indicate that only copper has a dose-response equation containing both sulphur dioxide and ozone concentrations.

Since most of the material objects are in urban and industrial areas, where the most of the emissions exist, the highest deterioration rates and greatest impacts will occur there. The present state of impact from air pollution on materials and cultural heritage in Europe was described in the air quality in Europe 1999 assessment report (EEA, 2002). The latest assessment of costs of the atmospheric deterioration of materials was estimated at EUR 11 billion/year in 1995 (ApSimon *et al.,* 1995).

More recent assessments are not available, and monitoring to improve the basis for such assessment is still going on. Therefore, this topic has not been treated further in this report.

# Appendix 3: Sources and quality of the information used

## Emissions data

Emission data used for this report are the official data submitted by countries to the various international reporting obligations:

- Acidifying pollutants, ozone precursors and heavy metals: Convention on Long-range Transboundary Air Pollution (CLRTAP, including various protocols).
- Methane: UN Framework Convention on Climate Change (UNFCCC) and EU Council decision on a monitoring mechanism of community $CO_2$ and other greenhouse gas emissions.

Copies of the data that have been officially reported by countries are compiled into a central database, maintained by the ETC/ACC called 'Corinair'. This database was used for the preparation of this report. Since October 1999, most of these data are also publicly available on the EEA website (http://service.eea.eu.int/).

For some gases, uncertainties in absolute emissions can be large (Eggleston, 1998) ranging broadly as follows for the total national emissions, on a gas-by-gas basis:

- $SO_2$: 10 %;
- $NO_x$: 30 %;
- NMVOC, $NH_3$: 50 %;
- $PM_{10}$: 50–100 %.

However, it should be noted that uncertainties in trends are likely to be significantly smaller than uncertainties in absolute numbers (Eggleston *et al.*, 1998). Within the IPCC, information has been collected and approaches developed aimed at providing better quantitative estimates of uncertainty than currently are available (IPCC/WMO/UNEP, 2000).

Four pollutants ($NO_x$, NMVOC, CO and $CH_4$) contribute to the formation of ground-level or tropospheric ozone (ozone precursors). Ozone precursor emissions can be aggregated by a weighted summation of the individual pollutants, where the weighting factor is a measure of the formation potential for ground-level ozone for each of the precursors (de Leeuw, 2002). The factors used are $NO_x$ 1.22, NMVOC 1, CO 0.11 and $CH_4$ 0.014, with results being expressed as NMVOC equivalents. See de Leeuw (2002) for a more extensive discussion on the uncertainties in these factors.

Emissions of acidifying pollutants ($SO_2$, $NO_x$ and $NH_3$) may be aggregated in a similar manner, with each individual pollutant weighted by an acid equivalency factor prior to aggregation to represent its respective acidification potential. The acid equivalency factors are given by: w ($SO_2$) = 2/64 acid eq/g = 31.25 acid eq/kg, w ($NO_x$) = 1/46 acid eq/g = 21.74 acid eq/kg and w ($NH_3$) = 1/17 acid eq/g = 58.82 acid eq/kg. Potentially eutrofying emissions are likewise aggregated, and are defined as 14/17 for $NH_3$ and 14/46 for $NO_x$, according to de Leeuw (2002).

Particulate matter emissions are comprised of primary $PM_{10}$ (particulate matter with a diameter of 10Ïm or less, emitted directly into the atmosphere — not including road dust resuspension particles), and secondary $PM_{10}$ precursors. Inorganic precursors: the fraction of $SO_2$, $NO_x$ and $NH_3$ emissions which, as a result of chemical reactions in the atmosphere, transform into particulate matter with a diameter of 10 µm or less. (Secondary organic precursors also exist, but have not been considered yet as part of the weighing procedure described below). Emissions of primary $PM_{10}$ and secondary $PM_{10}$ precursors may be weighted by a particulate formation factor prior to aggregation in order to determine total $PM_{10}$ particulate formation. The particulate formation factors are: w(primary $PM_{10}$) = 1, w($SO_2$) = 0.54, w($NO_x$) = 0.88, and w($NH_3$) = 0.64 (de Leeuw, 2002).

The definition of sectors used in this report is identical to that used in the EEA air pollutant emissions fact sheet series. Briefly, the energy industries sector includes public electricity and heat production, oil refining, production of solid fuels and fugitive emissions from fuels. The transport sector includes emissions from road and off-road sources (e.g. railways and vehicles used for agriculture and forestry). Industry (energy) relates to emissions from combustion processes used in the manufacturing industry including boilers, gas turbines and stationary engines, while industry (non-energy) are emissions generated by industry through non-combustion processes (e.g. manufacturing). 'Other (energy-related)' covers energy use principally in the services and household sectors. 'Other (non energy-related)' comprises solvent and other product use, such as those used in paint application, various chemical products, decreasing and in dry-cleaning processes. Finally, there are the agriculture and waste sectors.

**The linear distance-to-target analysis**
The distance-to-target indicator (DTI) is a measure for the deviation of actual emissions in 2000 from the (hypothetical) linear path between 1990 and 2010 (i.e. the target date for the EU national emissions ceiling directive and the UNECE CLRTAP Gothenburg protocol). The distance-to-target indicators are presented for each country, in order to evaluate their progress towards meeting their national targets. The distance-to-target assessment consists of four steps:

1. Plotting the index of actual performance (i. e. 1990–2000 index of pollutant emissions) against the index of the NECD or Gothenburg target path (hypothetical linear line between 1990 and 2010).

2. Calculating the hypothetical, interpolated, value on the target path in 2000.

3. Calculating the deviation of the emission index value in 2000 from the value on the target path.

4. Awarding smileys according to the achievements with the following ratings:
   ☺ positive contribution to trend: the negative distance-to-target indicator means that the country is below its linear target path;
   ☹ negative contribution to EU trend: the positive distance-to-target indicator means that the country is above its linear target path.

**Air quality data**
Air quality data used in this report are the official data on air quality and information on monitoring networks and stations submitted by countries according to the exchange of information decision (97/101/EC) (EC, 1997a). Data have been collected by the ETC/ACC and made publicly available using AirBase, the European air quality database (http://etc-acc.eionet.eu.int/databases). France has not delivered raw (hourly or daily) concentration data for $PM_{10}$ for the year 2000. The information on statistical parameters contributed by France to the Working Group on Particulate Matter of the EU CAFE programme has been used here.

The coverage, in spatial terms, of the data received is by no means uniform or consistent across Europe. The monitoring strategies may differ between countries, and such differences will influence the comparability between countries, and of the air quality 'picture' that is given by each individual country in this report. For instance, the coverage of hot-spot locations varies considerably between countries. Also, although the AirBase database in total covers most major cities in Europe, the number of stations, for a certain city size, varies widely. This again limits the direct comparability between cities.

The quality of the air quality data in AirBase is the responsibility of the data suppliers. The data have in recent years been transferred to AirBase using the data exchange module (DEM). Several quality checks of completeness and uniqueness of the data series are carried out using the DEM software. In addition to this, upon extracting data from AirBase for use in reports such as this one, some additional data validation checking is carried out in an attempt to detect obviously erroneous data. In the EuroAirnet monitoring network, criteria for classifying the QA/QC-procedures of the data suppliers have been developed, and requirements to minimum and complete QA/QC-procedures have been specified (EEA, 1999). These criteria and requirements have been evaluated in close cooperation between the ETC and the national reference centres. All data series and individual data passing these checks are accepted. The only further selection criterion used for the data presentation in this report is that the time coverage should be at least 90 % of the entire year. This corresponds to the data coverage requirement of the daughter directives.

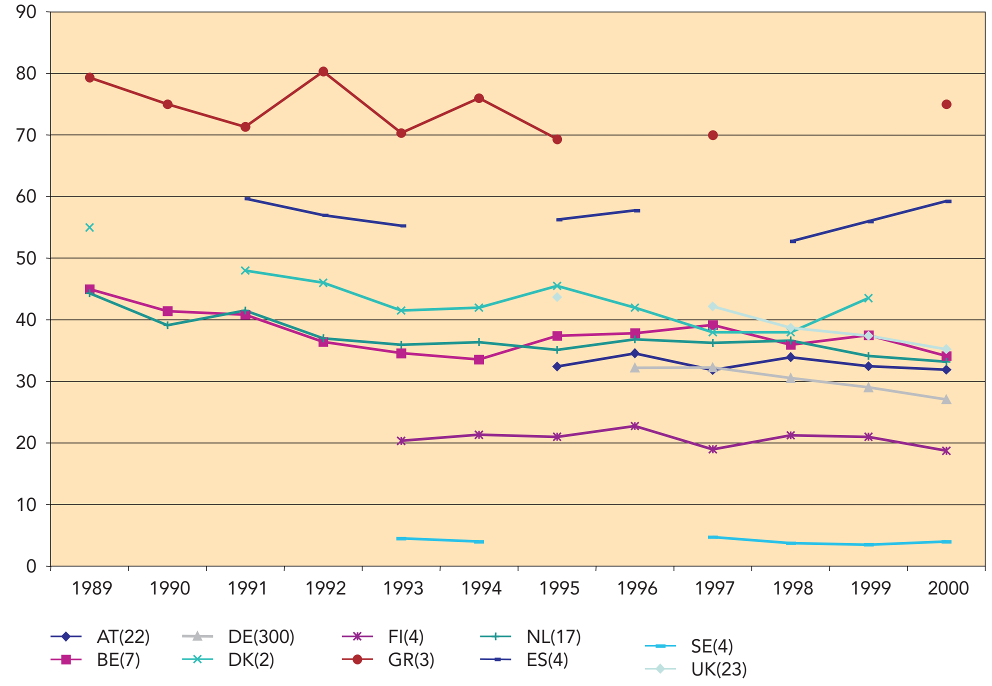
Additional air quality data, in particular on deposition, has been obtained from EMEP.

Under the UNECE CLRTAP data on concentrations in air and precipitation of sulphur and nitrogen compounds, as well as ozone and VOC data are collected from more than 100 EMEP rural stations in 27 countries. The data are subject to extensive data quality work by EMEP-CCC at NILU.

From the EMEP modelling centres MSC-E (Moscow) and MCS-W (Oslo) modelled concentration and deposition data (sulphur and nitrogen compounds, ozone, heavy metals and persistent organic pollutants) within the EMEP grid have been obtained.

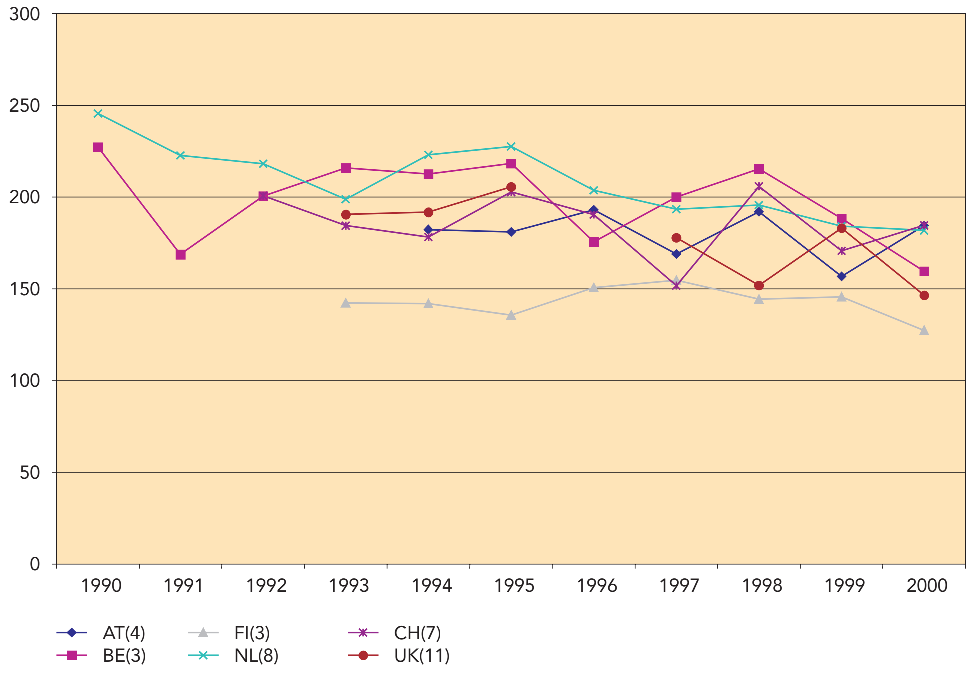
# Appendix 4: Trends 1990–2000 for $NO_2$ and ozone

### Trends at monitoring stations contained in AirBase, with data for all the years indicated



$NO_2$: annual average, all types of stations included

Avg, all, $NO_2$



$O_3$: Maximum one-hour concentration, at rural stations only

max, $O_3$, bak, rur

European Environment Agency

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