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Air quality in Europe

State and trends 1990–99

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Contents

Executive summary

Introduction
Air pollution in Europe continues to pose risks to and adverse effects on human health as well as natural and man-made environments. In the last two decades, significant and well-directed efforts made, particularly in the EU, have led to a reduction in risks and effects in some of the problem areas. These risk reductions were achieved despite increases in population and in economic activity in the energy, transport, industry and other sectors that potentially could have increased the pressures on the environment. However, these increases in driving forces have been compensated by technological development, in part resulting from environmental protection policies, resulting in reduced pressure.

This report intends to present a scientifically valid overview and evaluation of the air quality in Europe based on 1999 data. It covers the European area, including the first 18 EEA member countries as well as 13 PHARE countries in central and eastern Europe, as far as data is available. The report addresses human health, ecosystems and materials and how they are affected by air pollution. Under these topics, the various pollutants causing the main effects risks are presented.

Target audiences are environmental/air quality managers and policy makers as well as the general, informed public. In addition to describing the situation based on 1999 data, the report looks into the trends and tendencies over the past decade (1990–99), and looks into the future only to a very limited extent.

The report uses the limit values of the new EU air quality daughter directives as yardsticks for assessing the air quality in Europe, not with the intention to assess compliance with EU legislation, since these limit values are often not yet in force, but as information relevant to air quality management. Similarly, targets for reduction of emissions set by the ECE CLRTAP Convention and by the EU are used as yardsticks for evaluating the air emissions. Indicators are used throughout the report to visualise the assessment results. The latest selection of indicators of the European Environment Agency (EEA) is used. Acronyms and abbreviations are explained in Chapter 7.

Recent trends and remaining air pollution problems
The main driving forces causing air pollution are the economic sectors of energy, transport, industrial production and agriculture. While industrial and agricultural output has been relatively stable during the last decade, electricity production and transport volume have increased by about 15 %. Nevertheless, the eco-efficiency of the sectors with respect to air pollution has improved and the air emissions of many pollutants decreased substantially over the last decade. This pertains to sulphur dioxide (SO_2 and – to a lesser extent – to nitrogen oxides (NO_x) (relevant both to health effects and acidification of ecosystems), to volatile organic compounds (VOC[1]) that together with nitrogen oxides (NO_x) produce ground level ozone, to lead and to carbon monoxide (related to health risks).

The main air pollution issues still of concern, in relation to health and environmental risks and effects, are:

- human health impacts due to exposure to ozone and fine particulates, as well as other compounds (e.g. NO_2, benzene), especially in urban areas;
- eutrophication and acidification of water, soils and ecosystems; damage to forests and crops due to exposure to ozone and
- damage to materials due to exposure to acidifying compounds and ozone.

Air quality in 1999 as relevant to human health
The concentrations of air pollutants in cities and other areas in Europe still exceed the new Air Quality Directive limit values set to

(1) VOC: Volatile organic compounds. VOC is used throughout the report to indicate non-methane VOC (often denoted NMVOC).

protect the health of the population (see, e.g. Maps 2.1–2.10 below):

— PM_{10} concentrations higher than limit values are widespread. Urban background concentrations are higher than limit values in some 20 out of 80 cities with data available for this report. Hotspot (traffic) concentrations are also above limit values in a number of other cities. The limit value for daily average concentration is the most stringent one. The maximum daily average concentrations measured in 1999 were about twice as much as the limit value. Even in rural areas in some parts of Europe, the PM_{10} daily average concentration approaches and exceeds the limit value. The current limited spatial and temporal data coverage precludes conclusions on present trends in PM_{10} concentrations. The currently available data suggest, however, a reduction of PM_{10} concentrations in cities during the last three years.

— Exceedances of several NO_2 limit values are also widespread. The main concern is on exceedance for the limit value of the annual average concentration, which occurs in 127 out of 607 cities with reported data. The maximum hourly concentrations measured in 1999 were up to three times higher than the limit value. Population exposure to NO_2 is more of a general urban issue than a hot-spot problem. Rural concentrations are relatively low. Urban NO_2 concentrations in Europe have been rather stable during the five years preceding 1999.

— Exceedances of ozone target values are widespread. In most areas in Europe the rural population is most affected, since nitrogen oxides emissions in cities generally reduce the urban ozone concentrations. However, the highest concentrations occur in the surroundings of larger southern European cities during summer with photochemical ozone production due to strong solar radiation and long residence times of ozone and its precursors. The maximum 8-hour average concentrations measured in 1999 were about 50 % higher than the limit value.
The higher end of the hourly ozone concentration distribution shows a downward trend. Although maximum hourly concentrations have over the period 1994–99 been rather stable, the 98th percentile of hourly values on a yearly basis has been reduced on the average by about 3 % per year at the more than 1 000 ozone monitoring stations in Europe. But there are large year-to-year (and station-to-station) variations caused mainly by meteorological variability, which tends to mask the 'real' ozone trend. By contrast, annual average ozone concentrations have increased at many stations.

— Exceedances of SO_2 limit values are less widespread today due to control of sources (cleaner fuels and stack gas cleaning), but some industrial cities still have high concentrations. The limit value for daily average concentrations is the most stringent objective. The maximum daily average concentrations measured in 1999 were still more than 2 times the limit value. The present trend in SO_2 concentrations is, however, continuing downwards in most places.

— CO exceedances are no longer widespread, thanks to control of the main source, petrol-powered cars. However, there are still cases of high concentrations in cities in southern Europe. The maximum 8-hour average concentrations reported in 1999 were more than double the limit value.

— Benzene exceedances occur in many cities. It has been estimated from a modelling study that 50 % of the urban population in EU-15 is potentially exposed to concentrations above the limit value.

— Lead exceedances are limited to the immediate surroundings of industrial plants in those parts of Europe where lead has been removed from gasoline. In countries where lead is still used as additive to gasoline, high concentrations can be expected near traffic. Lead measurements for 1999 were reported to AirBase by only two countries.

When pollutant concentrations measured by the monitoring networks exceed limit values, health effects in the exposed population are to be expected. The extent of limit value exceedances and population potentially exposed to concentrations above the limit values have been estimated based upon the

AirBase urban background concentration data, as well as on results from other sources. The estimated fraction of the urban population potentially exposed to the main pollutants is:

— NO_2: 42 % (for 360 cities with about 43 % of the European urban population)
— O_3: 28 % (for 406 cities with about 44 % of the European urban population)
— PM_{10}: 12 % (for 80 cities with about 20 % of the European urban population).

Model estimates give similar fractions for O_3, but higher values (around 65 %) for NO_2.

Additional exposure above limit values occurs for NO_2 and PM_{10} at hot-spot locations (mainly near roads) and for ozone in rural areas. Ozone exceedances of the target value occur at 38 % of the rather dense network of rural monitoring stations.

How representative this exposure estimate is for the total European urban population must be left to judgement at the present time. The cities in AirBase represent 20, 43 and 44 % of the European urban population for PM_{10}, NO_2 and O_3, respectively.

There is also substantial population exposure to benzene above the limit value. The data for benzene is rather limited, but modelling work for a large number of cities has indicated that around 50 % of EU-15 cities have (pre- 2000) areas where the limit value is exceeded. After 1 January 2000 it is expected that the benzene levels in EU-15 will be reduced substantially as a result of reduction of the benzene content in gasoline to a maximum of 1 %.

It has not been the intention to present a health impact assessment in this report. Such an assessment combines data on population exposure with information on exposure response relationships derived from health effects studies to estimate the extent of health effects expected to result from exposure to air pollution.

Air quality and deposition in 1999 as relevant to impact on ecosystems

Direct impact of SO_2 and NO_x on vegetation

The annual average concentration of SO2 and NO_x in 1999 was equal to or higher than the EU limit value for protection of ecosystems in limited areas in several countries.

Tropospheric ozone and its impact on crops and forests

The long term objective for ozone exposure for protection of crops and vegetation (AOT40 of 6 µg/$m^3$2h) was exceeded in 1999 in large parts of the European area where monitoring data are available, except for in the areas north of 53º N latitude (see Figure 3.2 below).

The inter-annual variability in meteorological conditions prevents a clear statement to be made on the recent and present trend in this exposure.

Acidification and its impact on water, soil and vegetation

The largest acid deposition in 1999 was received in areas in the Netherlands, western Germany, UK, Czech Republic, Poland and other central European countries.

The capacity for absorbing the acidity without subsequent effects varies greatly between areas. Exceedances of the critical load for acidity, which takes account of the area specific buffering capacity, occurred in 1999 in localised areas in most European countries. The part of the ecosystems in each country where the critical load for acidity was exceeded varied from as high as 75–85 % in the Netherlands and the Czech Republic and down to very small parts in for example Portugal, Denmark and the Russian Federation (see Figure 3.7 below). The percentage area of exceedance of critical load has decreased significantly in most countries in Europe since 1990, with the exception of France, which has experienced an increase (see Figure 3.8 below).

Eutrophication and its impact on water and vegetation

Deposition of eutrophying (nitrogen) compounds in 1999 was largest in a belt reaching from Poland westwards around the southern North Sea to eastern England and northern France.

The critical load for eutrophication is exceeded in large parts of the ecosystems in most countries in Europe. In 17 countries, more than 80 % of sensitive ecosystems were exposed above the critical load in 1999. The eutrophying deposition has been reduced only to a rather small extent since 1990 (see Figure 3.8 below).

Air quality as relevant to impact on materials
The corrosion rate of materials is significantly increased above the background corrosion rate in most areas in Europe, but only moderately so in Nordic countries.

Limit values, such as for SO_2, designed to protect materials and cultural heritage, have not yet been developed. The present knowledge of materials corrosion in Europe suggests that such a limit value for SO_2 would be lower than the SO_2 limit value for protection of human health.

Contributions of economic sectors to air pollution issues
A summary of the contribution of economic sectors to the air pollution issues in EU-15 as a whole is presented in this report, in terms of their emissions of indicator pollutants. For individual countries, the contributions may differ significantly from the average presented (see Chapter 4 and Figure 4.1 below).

Health-related air pollution is represented by PM_{10}, NO_x, tropospheric ozone and SO_2. The main sectors contributing to these compounds were, in order of significance, the transport sector (34–65 % contribution to PM_{10}, NO_x or O_3), the energy sector (8–61 % contribution to O_3, NO_x, PM_{10}, SO_2), and the industry sector (7–17 % contribution).

Emissions of each of these pollutants (NO_x, PM_{10}, SO_2) in EU-15 have been reduced since 1990 through abatement predominantly in the energy and transport sectors by 25 % (NO_x) to 58 % (SO_2). PM_{10} primary emissions and precursor gases emissions were reduced by 33 %.

Tropospheric ozone and acidifying and eutrophying deposition are the main factors determining effects to ecosystems. The main contributing sectors to the emissions of most of the relevant pollutants were transport and agriculture, while for SO_2 emissions from energy and industry are dominant.

Emissions contributing to the ecosystems effects have been reduced in EU-15 by 55 % (acidifying gases), by 31 % (ozone precursors) and by 30 % (eutrophying gases) since 1990, through abatement measures in the energy, industry and transport sectors.

For SO_2 and ozone in relation to effects on materials, industry and transport are the main contributing sectors. SO_2 and ozone precursor emissions in EU-15 have been reduced by 58 % and 31 % respectively since 1990.

Responses:
Effects of air pollution abatement policies
Air pollution abatement policies in Europe include the EU Air Quality Directives, the CLRTAP emission reduction protocols, the EU National Emission Ceilings Directive (NECD), and more specific emission legislation, such as the EU Large Combustion Plant (LCP) and 'Solvents' Directives. The original EU Air Quality Directives (issued during 1980–92 for SO_2, NO_2, black smoke, TSP lead and ozone) and the CLRTAP first and second emission reduction protocols of 1985 and 1994 are recognised as major policy contributions to the improvements in emissions and air quality in the 1990s.

In this report, responses to policies have been considered in a simple manner. It is assumed that the emission reductions that have occurred are in part a response to European environmental policies, manifested in the directives mentioned above. The changes in the environment caused by these reductions are then estimated by comparing the rate of emission reductions with the measured trends and tendencies in air pollution concentrations, looking at Europe as a whole, for the period 1990–99. In summary, the results are:

- SO_2:
  Both emissions and concentrations have been reduced by about 50 %.

- Ozone:
  Emissions of ozone precursors have been reduced by about 30 % for 1990-99, and about 20 % for the 1994–99 period. Trend information on ground-level ozone concentrations representative for Europe is available for the 1994–99 period only. This is too short to make conclusive statements, but indications are that the European ozone peak (98th percentile of hourly concentrations) concentrations resulting from these precursor emissions have been reduced by about 27 %. Over the same period, annual average ozone concentrations have been increasing.

- NO_2:
  NO_x emissions have been reduced by about 14 % during 1995–99, while urban NO_2

concentrations have been rather stable during that period. The reason for this stability might be that, particularly during periods with high urban NO_2 concentrations, the NO_2 concentration is largely limited by the ozone background concentration, which has not changed very much.

These preliminary conclusions should be substantiated through more in-depth analysis in future reports.

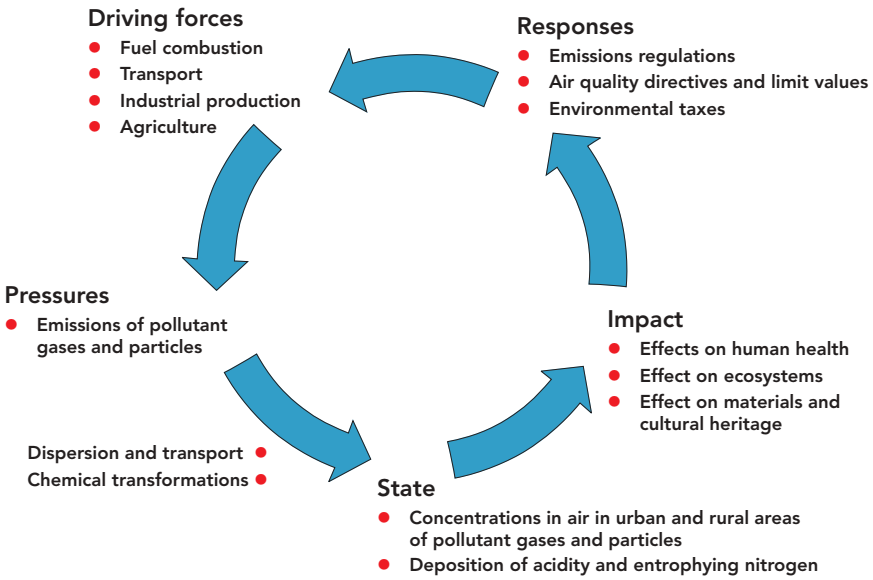
1. Introduction

1.1. Air pollution as a prominent environmental issue in Europe

Air pollution in Europe continues to pose risks and has adverse effects on human health as well as upon natural and man-made environments. Significant and well-directed efforts have been made in Europe (particularly in the EU and European Economic Area and EU accession candidate countries) over more than two decades, which have led to a reduction in the risks and effects in some of the problem areas. Examples include: the reduction of sulphur contents in fuels, and switch to cleaner fuels in industry and for power production; the removal of lead from petrol; and the vehicle emission regulations which have lead to technological improvements resulting in very significant decreases in emissions of toxic gases and particles.

These risk reductions were achieved despite expanding population and economic activity (e.g. power and industrial production, traffic and tourism) which potentially increase the pressures on the environment. This increase in driving forces has been compensated mainly by technological development, partly resulting from environmental protection policies, which have in practice reduced the pressures

Figure 1.1 **DPSIR assessment framework, example for local and regional air pollution issues**



Driving forces, such as population and economic growth, urbanisation and agricultural intensification, result in emissions of pollutants and other pressures that affect the state of the environment and, in turn, may impact on human health, ecosystems and the physical environment. Responses may address the driving forces themselves as well as seeking to reduce their effects or improve the state of the environment.

The relationships between pressures on the environment, resulting emissions of pollutants to air and the resulting air quality and its effects on health and environment is a complex picture involving many pollutant sources (e.g. power plants, vehicles, industrial processes,), compounds (e.g. O_3, SO_2, NO_x, PM), various spatial scales of pollutant transport, transformation and atmospheric deposition (street, urban, regional and larger scales) and various effect time scales (from hours or less to several years).

A framework suitable both for describing the cause-impact-abatement relationships and for analysing the need for and effects of policies and control measures to improve the environment is the driving forces-pressures-state-impact-responses (DPSIR) assessment framework. The DPSIR framework is explained in Figure 1.1, with local and regional air pollution as an example. The present report makes use of this framework in its presentations of air quality in Europe: It begins with state of the current situation, presents impacts and causes (drivers resulting in pressures), and there follows discussion on the effect of policies in place and then responses.

1.2. Recent trends in economic sectors relevant to air pollution in Europe

The main economic sectors that are driving forces for air pollution in Europe are power generation, transport, industry production and agriculture. Developments in the four main sectors in the EU-15 in recent years (1990–98) have been (Environmental Signals Report 2001, EEA):

— a 15.5 % increase in energy consumption
— an increase in road transport volume of 16 % (passenger-km) and 35 % (tonne-km)
— a fairly stable agricultural output (gross value added)
— a fairly stable industrial output (index of production)

These sectors exert an environmental 'pressure' by their emissions of gases and particles. The statistics in Table 1.1 show that although the driving force sectors have increased or maintained stable levels of activity, air pollution emissions sometimes have decreased very significantly. However, NO_x emissions from the industrial sector increased slightly between 1993 and 1996, as has fertiliser use in agriculture.

Thus, the pressure per unit production, the 'eco-efficiency' of the power, transport and industrial sectors has improved substantially.

The pressure reductions have been driven in part by the policy responses to increasing or persistent air pollution over the last decades: emission regulations for large source sectors (power plants and industries, vehicles etc.) in addition to directives setting limit and target values for pollutants and emission reduction protocols under the CLRTAP, etc.

In central and eastern Europe, the political changes in the early 1990s were generally connected with the adoption of environmental legislation transposing EU directives, in particular relating to air quality. This, in addition to the restructuring of industry (heavy industry reduction), the direct measures on air pollution sources (desulphurisation of flue gases), changes in the structure of fuel consumption, and improvement of car fleets led to the decrease of acidifying emissions in the majority of these countries. SO_2 emissions in ten candidate countries of central and eastern Europe decreased by 46 % in total in the period 1990–99, and in the Czech Republic by more than 85 %. NO_x emissions decreased over the same period by more than 37 %, and in the Slovak Republic by more than 47 %. VOC emission decreased in the region overall by more than 28 %, and in Bulgaria by more than 45 % . The most significant improvement was reached in the Black Triangle region where the air quality is now comparable with the concentrations achieved in EU countries. On the other hand, in south-eastern Europe and Upper Silesia, air quality problems mostly persist.

Developments in air pollution related societal driving forces and pressures in EU-15, 1990–98. (Environmental signals report 2001, EEA). Table 1.1

Sector	Driving force development 1990–98	Emissions development 1990–98
Energy	15.5 % increase in energy consumption	54 % and 38 % decrease in SO_2 and NO_x sector emissions respectively
Road Transport	Increase in road transport: + 16 % passenger-km +35 % tonne-km	23 % and 42 % decrease in NO_x and VOC road transport emissions respectively
Industry	Fairly stable industrial output (index of production)	54 % and 23 % decrease in SO_2 and NO_x industrial emissions respectively
Agriculture	Fairly stable agricultural output (gross value added)	6 % decrease in NH_x emissions

This improved performance has resulted in improvements for some air pollution issues:

- deposition of acidifying compounds has decreased significantly over most of Europe the last two decades.
- deposition of eutrophying nitrogen has marginally decreased since 1990
- tropospheric ozone has proved to be a rather persistent problem.
- air quality has improved significantly in the majority of cities for SO_2, CO and lead, but in many cities not for NO_2 in spite of overall eco-efficiency improvements for NO_x emissions. Possible reasons are that the main NO_x control technique (3-way catalyst for cars) affects NO rather than NO_2, and that NO_2 is more dependent on regional ozone concentrations, which have not decreased much. For PM_{10}, data from long time series is not extensive enough to establish a reliable trend over the last decade.

1.3. Main air pollution issues in Europe

The main air pollution issues of concern in Europe in view of their impact on human health, ecosystems and materials are (EEA 2001):

- acidification and eutrophication of water, soils and ecosystems.
- human health impacts due to exposure to ozone.
- damage to vegetation and crops due to exposure to ozone.
- human health impacts due to exposure to particles, NO_2, SO_2, CO, lead, benzene, especially in urban areas.
- damage to materials due to exposure to acidifying compounds and ozone.

1.4. Air quality limit values and targets

Air quality objectives for concentrations of air pollutants for the protection of health have been set in EU Directives on Air Quality (Nos 92/72/EEC, 96/62/EC, 99/30/EC, 2000/69/EC and 2002/3/EC), as well as the WHO Air Quality Guidelines (WHO, 2000). Targets for air quality as well as for deposition of acidifying and eutrophying compounds have been set for ecosystem protection in EU directives and by the UNECE Convention LRTAP. Emission reduction targets have been set both by CLRTAP and by the EU, recently with the National Emission Ceiling Directive 2001/81/EC (EC, 2001).

No guidelines or limit values have yet been set for protection of materials , but these benefit from the limit values set for SO_2 and ozone for the protection of health and ecosystems.

Boxes 1 and 2 give an overview of the various limit values, guidelines and targets.

1.5. Selected indicators of air pollution

Selected indicators for air emissions, air quality and its impacts can be used to present and summarise in a simplified way the complicated topic of air pollution. Indicators can be selected across the DPSIR chain (see Figure 1.1).

The European Environment Agency is working on the development of a core set of indicators (Goodwin et al., 2001). Indicators are selected on the basis of the following criteria; they should:

- answer main policy questions[2] and communicate meaningful messages regarding policy.
- be comparable between countries.
- be transparent regarding the data used in their calculations.
- provide the best available scientific insights.

Box 3 gives an overview of the indicators used in this report to give a summary of the present air quality in Europe, for the themes acidification, eutrophication, tropospheric ozone, and ambient air quality. It is also indicated where in the report the situation relative to the indicators is described.

The policy target indicators are expressed in terms of amount of emissions of precursor gases (for acidification/eutrophication and tropospheric ozone) and in terms of the extent of concentration exceedances for compounds for which EU directives and limit values have been issued.

There are various underlying (explaining) indicators for each theme, some for the environmental state (e.g. extent of exceedances of critical loads for acidification), some for environmental impact (e.g. population exposure and health risk), some for driving forces, pressure and policy response (e.g. contribution to emissions and pollutant occurrence from various economic sectors, and the eco-efficiency of these sectors.)

(2) For air pollution, main policy questions relate to progress towards meeting the National Emission Ceiling Directive 2001/81/EC and the Air Quality Framework Directive 96/62/EC and daughter Directives 1999/30/EC, 2000/69/EC and 2002/3/EC.

Box 1: Air pollution limit values and targets

Health-protection limit values and guidelines

EU Directives

Compound	Limit/target value			Target year
PM_{10} Stage 1	Annual average:	40 µg/m³		2005
	Daily average:	50 µg/m³	Not to be exceeded more than 35 days a year	2005
PM_{10} Stage 2	Annual average:	20 µg/m³	Indicative	2010
	Daily average:	50 µg/m³	Indicative; not to be exceeded more than 7 days a year	2010
NO_2	Annual average	40 µg/m³		2010
	Hourly average:	200 µg/m³	Not to be exceeded more than 18 hours per year	2010
Ozone	8-hour average:	120 µg/m³ (target value)	Not to be exceeded more than to 25 days per year (1)	2010
SO_2	Daily average:	125 µg/m³	Not to be exceeded more than 3 days per year	2005
	Hourly average:	350 µg/m³	Not to be exceeded more than 24 hours per year	2005
CO	8-hour average:	10 µg/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 European Commission before 19 July 2001.

WHO Guidelines

PM_{10}	No lower threshold for effects. Guideline is provided 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/m³	
	Daily average.	125 µg/m³	(As in EU Directive, 199/30/EC but allowable exceedances are not given.)
	10 minutes average:	500 µg/m³	
CO	8 hours:	10 µg/m³	(In addition, guidelines are given for 1 hour, 30 minute and 15 minute averages.)
Pb	Same as in EU directive 1999/30/EC		
Benzene	No safe level of exposure is recommended		

Ecosystems-protection limit values and targets

EU directives/CLRTAP/WHO

Compound	Limit/target value			Target year
SO_2	Annual or winter average:	20 µg/m³		2001
NO_x (as NO_2)	Annual average:	30 µg/m³		2001
Ozone	Accumulated exposure over a threshold of 40 ppb (AOT 40):			
	EU Directive (target)	18 000 µg/m³	•ha (vegetation)	2010
	EU Directive	6 000 µg/m³	•ha (vegetation)	Long term objective
	CLRTAP	6 000 µg/m³	•ha (crops, vegetation)	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

Box 2: Emission controls

EU Directive (NECD, 2000)

		Emission reduction required	Time period[1]
SO_2	Annual total	77 %	1990–2010
NO_x (as NO_2)	Annual total	51 %	1990–2010
VOC (non-methane)	Annual total	58 %	1990–2010
NH_3	Annual total	15 %	1990–2010

UN-ECE CLRTAP

SO_2	Annual total (1985) [2]	30 % all [3]	1980–93
	Annual total (1994)	62 % EU	1980–2000
	Annual total (1999)	75 % EU; 65 % all	1990–2010
NO_x (as NO_2)	Annual total (1988)	0 % EU; 0 % all	1987–94
	Annual total (1999)	49 % EU; 44 % all	1990-2010
	Annual total (1991)	30 % all	1984/90–99
VOC (non-methane)	Annual total (1999)	57 % EU; 49 % all	1990–2010
NH_3	Annual total (1999)	15 % EU; 17 % all	1990–2010

[1] The first year of the period constitutes the reference year
[2] Protocol year
[3] All signatory countries

Box 3: Selected air pollution indicators used in this report (DPSIR indicators)

Policy target indicators	*Underlying (sub-) indicators*
Ambient air quality and human health	
Exceedance of limit values of seven pollutants (SO_2, NO_2, PM_{10}, O_3, Pb, CO, benzene). **STATE** See Chapter 2, sections 2.1.1-2.1.7.	• Population exposure and risk by air pollutant. **IMPACT** See Chapter 3, section 3.1.
Acidification/eutrophication	
Emissions of acidifying pollutants (SO_2, NO_x, NH_x). **PRESSURE** See Chapter 4, section 4.3.	• Area of exceedance of critical load for total acidity (deposition of sulphur and nitrogen). **STATE** (surrogate **IMPACT** indicator) See Chapter 3, section 3.2.2. • Area of exceedance of critical load for nitrogen (deposition of N). **STATE** (surrogate **IMPACT** indicator) See Chapter 3, section 3.2.2. • Policy response, SO_2 and NO_x emissions. **PRESSURE AND POLICY RESPONSE** See Chapter 5.
Tropospheric ozone and ecosystems	
Emissions of ozone precursors (NO_x, VOC, CH_4, CO). **PRESSURE** See Chapter 4, section 4.3.	• Exposure of crops/vegetation to O_3: area of exceedance of target level. **STATE** (surrogate **IMPACT** indicator) See Chapter 3, section 3.2.1. • Policy response, NO_x and VOC emissions. **PRESSURE AND POLICY RESPONSE** See Chapter 5.
For all the 3 themes above	
	• Contribution from various economic sectors. **DRIVING FORCES** See Chapter 5. • Eco-efficiency of economic sectors, and its development. **DRIVING FORCES AND POLICY RESPONSE**

1.6. Data sources, spatial coverage, representativeness, data quality and background information

Box 4 describes briefly the data sources used in this report.

Appendix 1 provides information on 1999 air quality data and information on monitoring networks and stations reported by countries to AirBase according to the Exchange of Information Decision (97/101/EC) (EC, 1997a).

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. In addition, 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.

An analytical attempt has not been made at this stage to evaluate how well the cities and stations in the database represent the European population as a whole, and their exposure to air pollution. The selection of cities and stations in EuroAirnet (Larssen and Kozakovic, 2001), which is somewhat larger in coverage than the present 1999 database, represent about 55 % of the urban population in Europe. Each urban station 'represents' on the average about 125 000 inhabitants. No quantitative conclusions can be drawn from this regarding representativeness of the population. Only qualitatively can it be stated that the coverage of cities and stations is substantial, more so in some countries than in others.

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 air quality data exchange module (DEM) developed and made available by the European Topic Centre on Air and Climate Change. 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 like this, 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.

Box 4: Main data sources used[1]

1. AirBase, the European air quality database, at RIVM in the Netherlands, containing data from about 30 European countries, for SO_2, NO_2, ozone, CO, particulate matter (PM_{10}, TSP, black smoke), lead and benzene. Typically data from about 1 500 monitoring stations are entered into the database annually for SO_2, NO_2 and ozone, and less for the other compounds. Most stations are urban, but there are also many rural stations, especially for ozone. Data go back as far as the early 1980s and for certain compounds, further back in time (see Figure 1.2). AirBase also contains ozone exceedance data collected annually from 16 countries under the previous EU Ozone Directive (92/72/EEC), since 1994.

2. EBAS, the EMEP database at NILU, containing concentration and deposition data from more than 100 EMEP rural stations in 27 countries. Sulphur and nitrogen compounds, as well as ozone and VOC data. The data has been collected from 1978 onwards.

3. The database of the EMEP MSC-W modelling centre at DNMI, containing modelled concentration and deposition data within the EMEP grid (sulphur and nitrogen compounds, and ozone). Past and projected data.

4. The emissions database of the ETC-ACC, formerly ETC-AE (hosted by Umweltbundesamt Wien).

5. The emissions database of EMEP (hosted by DNMI).

(1) See acronyms and abbreviations, Chapter 7 below.

EMEP concentration and deposition data in EBAS are subject to extensive data quality work by EMEP-CCC at NILU.

For background information on pollution compounds, see the Position Papers on particulate matter (PM), NO_2, SO_2, lead, CO and benzene produced by EC Working Groups, preceding the development of the air quality directives, as well as more recent WHO publications (see the Reference list in the back of the report (Chapter 7)).

1.7. Goals, target audience and contents of this report

This report concentrates on the local and regional ambient air pollution issues, occurring in urban and rural areas. Global air pollution issues and indoor air quality are not covered.

The target audiences of the report are policy makers and environmental/air pollution managers, as well as the general, informed public.

The goal of the report is twofold:

— To inform a broad audience (general public, as well as experts) on air quality at the European level.
— To provide feedback information to those managing air quality in Europe: are we making progress?

To fulfil the first goal, we have attempted to provide summary information on the European air quality and its potential impacts in a concise manner, visualising the information as much as possible.

To fulfil the second goal, we have attempted to show relations between the development in air quality and impacts on the one hand and emissions, sectors and policies and measures at the other hand.

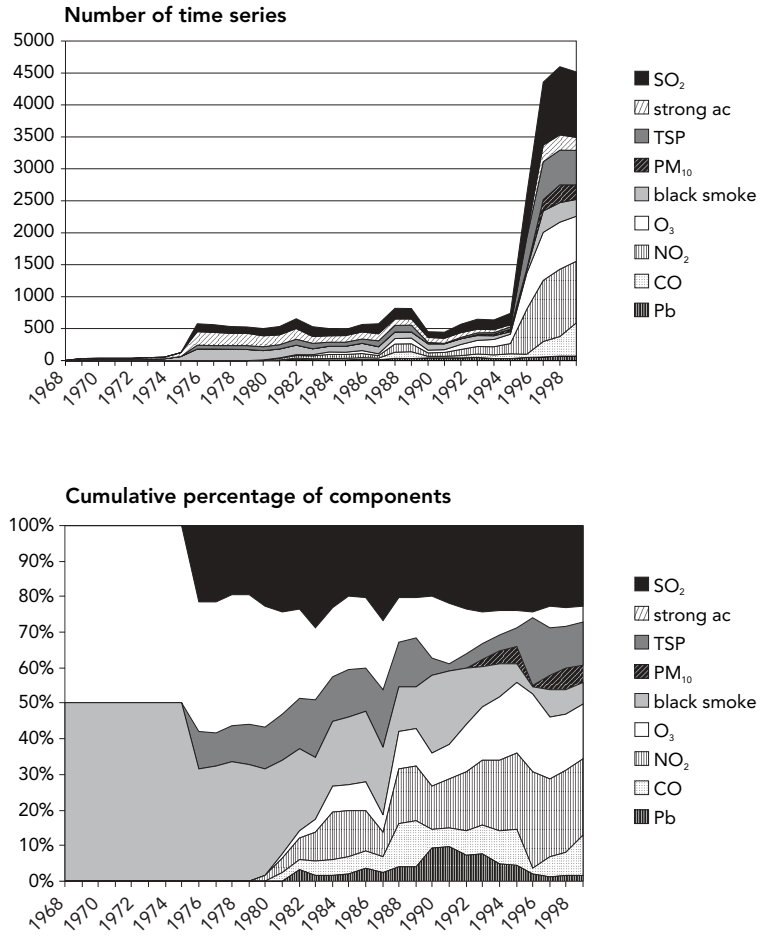
The report describes the state based upon 1999 data, and the developments in the preceding decade (1990–99). The report looks into the future only to a very limited extent.

The contents list gives an indication of the structure of the report. Chapter 2 covers the description of the air quality (state). It is subdivided into three sections according to the main effects that it is causing: air pollution affecting health, ecosystems and materials/cultural heritage respectively. To characterise the pollutant concentrations, the limit values set in the EU air quality directives (as given in Box 2) are used as reference levels. Each of the subsections include sections of the main effect-causing pollutants, their effects, sources, limit values, observed levels, and recent year tendencies or trends. The observed and modelled levels of concentration and deposition, at hundreds of stations in a large number of cities and countries, are summarised in maps and tables in an attempt to give an indication of the 'Europe-wide' situation.

Chapter 3 describes the potential impacts of air pollution on human health, ecosystems and materials. A full health impact assessment has not been attempted. Rather, the potential exposure of the European population to concentrations above limit values in EU air quality directives has been estimated. Regarding impacts on ecosystems, exceedance of impact-related indicators (AOT40 for ozone; SO_2 and NO_x concentrations; critical loads for acidification and eutrophication) is shown as a basis for an evaluation of the extent of impact. Corrosion rates are used as a basis for impact estimation on materials.

In Chapter 4 a summary is given of the air pollutant emissions in Europe (the pressures), and their trends and the contributions of the economic sectors to these emissions. This summary was extracted from the 'Air Emissions in Europe 1999' report, also prepared by the ETC-ACC (EEA, 2002), that mainly covers the EU-15 countries and ten accession countries. Chapter 5 presents a simple analysis of the effects of responses (i.e. policies), aimed at air pollution reductions, in terms of reduced emissions and improved air quality. The relationship between the emissions reductions and the actual improvements in air quality are briefly described.

Number of time series in AirBase, 1968–99, for main pollutants — Figure 1.2



2. Air quality in Europe

2.1. Air quality relevant to human health

2.1.1. Airborne particulate matter, urban and regional scales

A The issue

Exposure to particles measured as PM_{10} (particles with diameter less than 10 µm) in ambient air represents one of the largest human health risks related to air pollution. PM concentrations of concern to health occur predominantly on local (hotspot) and urban scales, but also on the regional scale in Europe.

Effects

Particulate matter (PM) is a mixture of particles and droplets that may vary in mass, size, and chemical composition, depending on the sources and the meteorological conditions involved. Epidemiological studies have reported statistical associations between short-term, and to a limited extent also long-term exposure to increased ambient PM concentrations and increased morbidity and (premature) mortality. Whether these associations are causal and what PM properties and/or mechanisms (PM_{10}, PM2.5, ultra fine-mode particles, physical properties, chemical or biological components) are responsible, is still unclear. With respect to PM particle size and composition, PM levels possibly relevant to human health effects are commonly expressed on the basis of the mass concentration of inhalable particles, defined to contain particles with an equivalent aerodynamic diameter equal to or less than 10 µm (PM_{10}). Health effects associations have also been observed with the PM2.5 fraction.

Although the body of evidence concerning the health effects of PM is rapidly increasing, it is not possible as yet to identify a threshold below which health effects are not detectable. Therefore there is no recommended WHO air quality guideline for PM.

Main sources/spatial scales

Small particles (PM_{10} and smaller) are deposited to the ground/surfaces at a low rate, and can thus be transported over long distances. Airborne particles are either primary (emitted directly as particles to air) or secondary, produced in the atmosphere from precursor gases. Primary particles come mostly from man-made sources, the most important in Europe being coal-fired power plants, wood combustion, diesel vehicles and industrial processes. Particle precursor gases such as SO_2, NO_x, NH_x, VOC are mainly man-made. Natural sources also contribute to both primary (e.g. sea spray, wind-blown dust, volcanoes) and secondary particles (e.g. release of organic compounds from vegetation). The man-made sources dominate the occurrence of airborne PM in most places where and when high concentrations occur.

The contribution to PM from secondary particles, which are formed during transport of air with precursor gases over larger distances, results in a significant background PM concentration all across Europe. This background is enhanced with primary particles, more so closer to areas with high population density and economic activity. Within urban areas, and finally at hot spots very close to sources or streets, the PM concentration is enhanced further.

This dynamic of emission, formation and transport of airborne particles creates a situation where human exposure to particles is normally highest in urban areas. However, in densely populated areas in Europe, concentrations may be only slightly lower in adjacent rural areas, and analysis of health impact of airborne particles in Europe must include both the urban and the rural populations.

Particle measurements

Particles were earlier measured as total suspended particles (TSP, total mass of particles) or as black smoke (BS, determined by the contents of soot-containing combustion particles from coal, diesel oil, wood, etc.). However, during the last decade PM_{10} (the mass of particles sampled with a 50 % cut-off diameter less than 10 µm) gradually emerged as a more appropriate health-effects relevant measure of the particle concentration in air. PM_{10} corresponds to the particle fraction that

enters the lower respiratory system passing the nose/mouth. More recent evidence indicates that even smaller particles, with a more aggressive chemical composition may be the dominating cause of effects. Therefore, there is increasing interest in fractions of smaller particles, such as PM2.5, PM1 and even PM0.1.

Measurement of PM_{10} shows discrepancies between results from various methods. Typically used continuous PM_{10} monitors have been shown to give lower PM_{10} concentrations than reference methods (filtering techniques with subsequent manual gravimetric analysis), depending upon locations, main sources of the PM_{10} and meteorological conditions. At this stage most countries have not applied correction factors, and there may be bias in the results summarised in the following. At this stage, no attempt could be made to correct for such possible bias.

B Limit values for PM_{10} in EU Directive 99/30/EC

Averaging time	Limit value		Target year
Annual average	40 µg/m³		2005
	20 µg/m³	Indicative value	2010
Daily average	50 µg/m³	May not be exceeded more than 35 days per year	2005
	50 µg/m³	Indicative value May not be exceeded more than 7 days per year	2010

C Indicators used

Policy target indicator:

- Extent of areas/cities with exceedance of PM_{10} limit values:
  - — Annual average
  - — 36th highest day per year

D PM_{10} in Europe, 1999

Maps 2.1 and 2.2 show PM_{10} concentrations in Europe in 1999, classified relative to the limit value (LV), based on data from 227 stations in 13 countries (refer to the section on the previous page on possible bias due to differences in measurement methods).

The PM_{10} concentration in urban background air in Europe is above the LV in 21 of the 80 cities that have reported measurements, and more than 50 % higher than the LV in five of those cities (Map 2.1). The Stage 2 upper assessment threshold (UAT) (indicative value, target year 2010) is exceeded in all but one city with measurement data. The annual average LV is exceeded to a lesser extent. At hot-spot stations (traffic and industrial type stations), PM_{10} concentrations are higher than at urban background stations (Map 2.2), with the majority of cities having hot-spot stations above the LV.

Table 2.1 lists the number of stations reporting concentrations above LV and UAT (Stage 2 indicative value for 2010) in each country. The highest annual average concentration reported for 1999 was 68 µg/m³, in Spain (LV = 40 µg/m³), and the highest 36th day concentration was 93 µg/m³, in Poland (LV = 50 µg/m³).

Figure 2.1 shows the actual concentrations at the stations with the highest concentration (urban background and hot-spot) in a number of the cities with concentrations above the LVs, as well as at regional stations above LV in some countries.

E Trends in PM_{10} concentrations

Data are available from a reasonable number of stations only for 1997–99. This three-year period is too short to detect trends; however, a tendency can be seen in the graphs (Figure 2.2). Annual average data from about 177 stations in 10 countries suggests a decreasing PM_{10} concentration for most of the countries, when averaged over all station types (hotspot, urban, rural). When restricted to urban background stations, the picture is similar for the seven countries (69 stations) with such data.

The 95th percentile of daily concentration for five countries (total 96 stations, only stations with instruments giving daily data) suggests a similar tendency.

A few stations in a few countries (e.g. the UK) have longer time series in AirBase (up to eight years). The tendency for most of these stations is of a steadily decreasing PM_{10} level. As more stations in more countries develop longer time series, it will be possible to conclude more definitely on the PM_{10} trend in areas in Europe.

F Discussion and conclusions

PM_{10} measurements were not mandatory in EU until 2001. PM_{10} was measured rather extensively in 1999 in many countries and cities in Europe. Data for recent years show that the PM_{10} concentrations are higher than the EU limit values in a number of cities, and even in some rural areas.

In many densely populated areas, e.g. in north-western Europe, the rural concentrations are almost as high as urban concentrations. This suggests that particles from long-range transport (natural and man-made sources, including secondary particles from precursor gases) make up a significant portion of the average PM_{10} concentrations in urban areas. Special conditions leading occasionally to high rural/urban PM_{10} concentrations are, in addition to 'winter smog' episodes in central and northern Europe, e.g., wind blown surface dust in arid regions in southern Europe as well as influx of Sahara dust, and resuspension of road dust from road surface worn down by studded winter tyres as well as from road sanding in Scandinavian and other cities.

Most of the hotspot stations with the highest concentrations are traffic type stations. These stations, located very close to a street, may not be representative of actual exposure of the population.

Longer-term data are currently available only from few stations. A general statement on recent PM_{10} trends cannot be given, but the available data indicate a downward tendency over the last 3 years.

Table 2.1 **PM_{10}: Number of stations with concentrations higher than the limit values (LV) and with concentrations between upper assessment threshold (UAT) and LV (1999).**

— Annual average: LV = 40 µg/m³ (Stage 1, 2005)
UAT = 24 µg/m³ (Stage 2, indicative, 2010)
— 36th highest daily value: LV = 50 µg/m³ (Stage 1, 2005)
— 8th highest daily value: LV = 50 µg/m³ (Stage 2, indicative, 2010)
— 8th highest daily value: UAT = 30 µg/m³ (Stage 2, indicative, 2010)

Country		Annual average			36th highest 24-hour value	8th highest 24-hour value	Maximum
		Number of stations with concentrations C		Maximum concentration	Number of stations with concentration C	Number of stations with concentration C	36th highest 24-hour concentration
	(Total number of stations)	C > 40	24 < C < 40	(µg/m³)	C > 50	30 < C < 50	(µg/m³)
Belgium	(14)	0	13	36	2	12	59
Czech Republic	(55)	3	30	46	16	39	82
Finland	(6)	0	0	22	0	6	36
France *							
Germany	(24)	4	8	52	7	17	84
Italy	(5)	3	2	60	4	1	89
Lithuania	(1)	0	1	28	0	1	45
Netherlands	(15)	1	14	42	11	4	67
Poland	(12)	6	6	54	11	1	93
Portugal	(3)	0	3	39	3	0	84
Spain	(28)	16	11	68	23	4	81
Sweden	(2)	0	0	21	0	2	38
Switzerland	(14)	1	6	41	4	10	64
United Kingdom	(48)	0	4	35	1	45	50
All countries	(232)	34	98	68	82	142	93

* France has a number of PM monitoring stations. However, in 1999 these measured a PM fraction different from PM_{10}; the data are thus not presented here.

PM_{10} in cities, 1999. Urban background (UB) stations Map 2.1

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

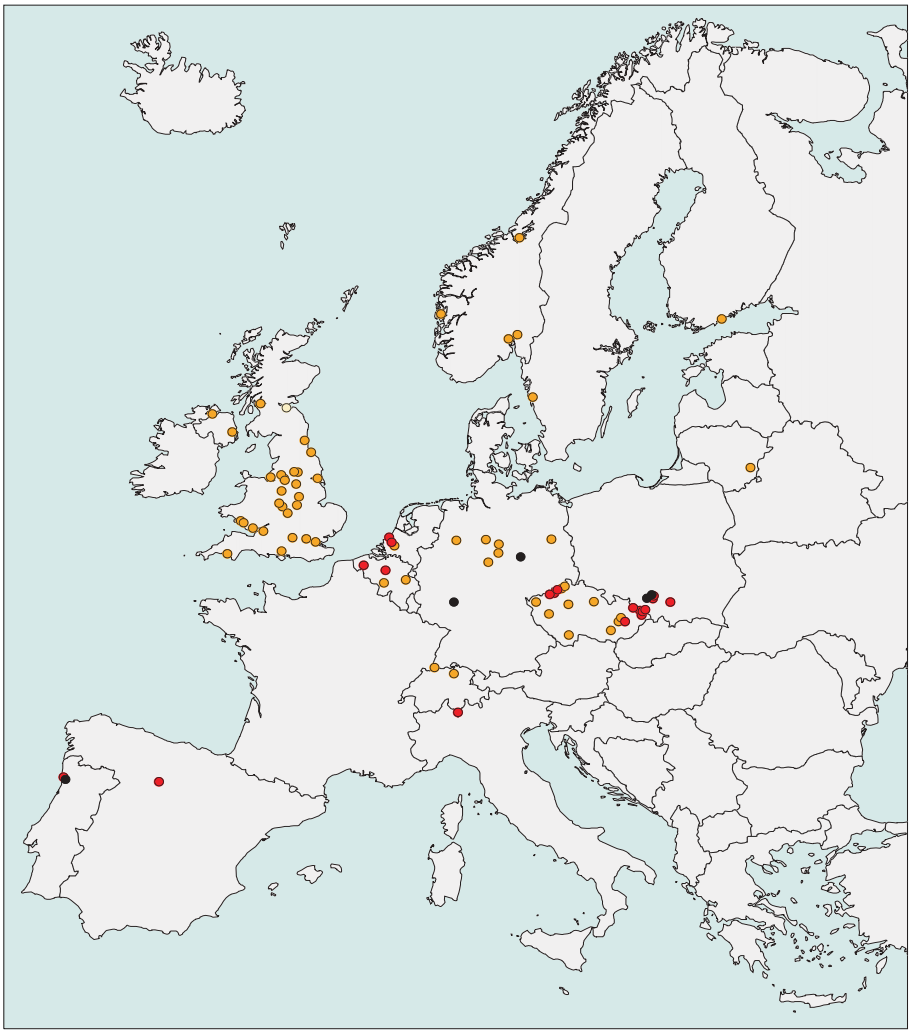
LV: 50 µg/m³, 36th highest daily concentration in a year
(Stage 1: Target year: 2005)

UAT: 30 µg/m³, 8th highest daily concentration in a year
(Stage 2: Target year: 2010, indicative value)

LAT: 20 µg/m³, 8th highest daily concentration in a year
(Stage 2: Target year: 2010, indicative value)

Data from French monitoring stations are not presented here since these measured a PM fraction different from PM_{10}.

Particulate matter



MAX 36
Urban background stations

- ≤ LAT
- > LAT and ≤ UAT
- > UAT and ≤ LV
- > LV and ≤ 50 % above LV
- > 50 % above LV

Map 2.2	**PM_{10} in cities, 1999. Hotspot stations (traffic, industrial)**

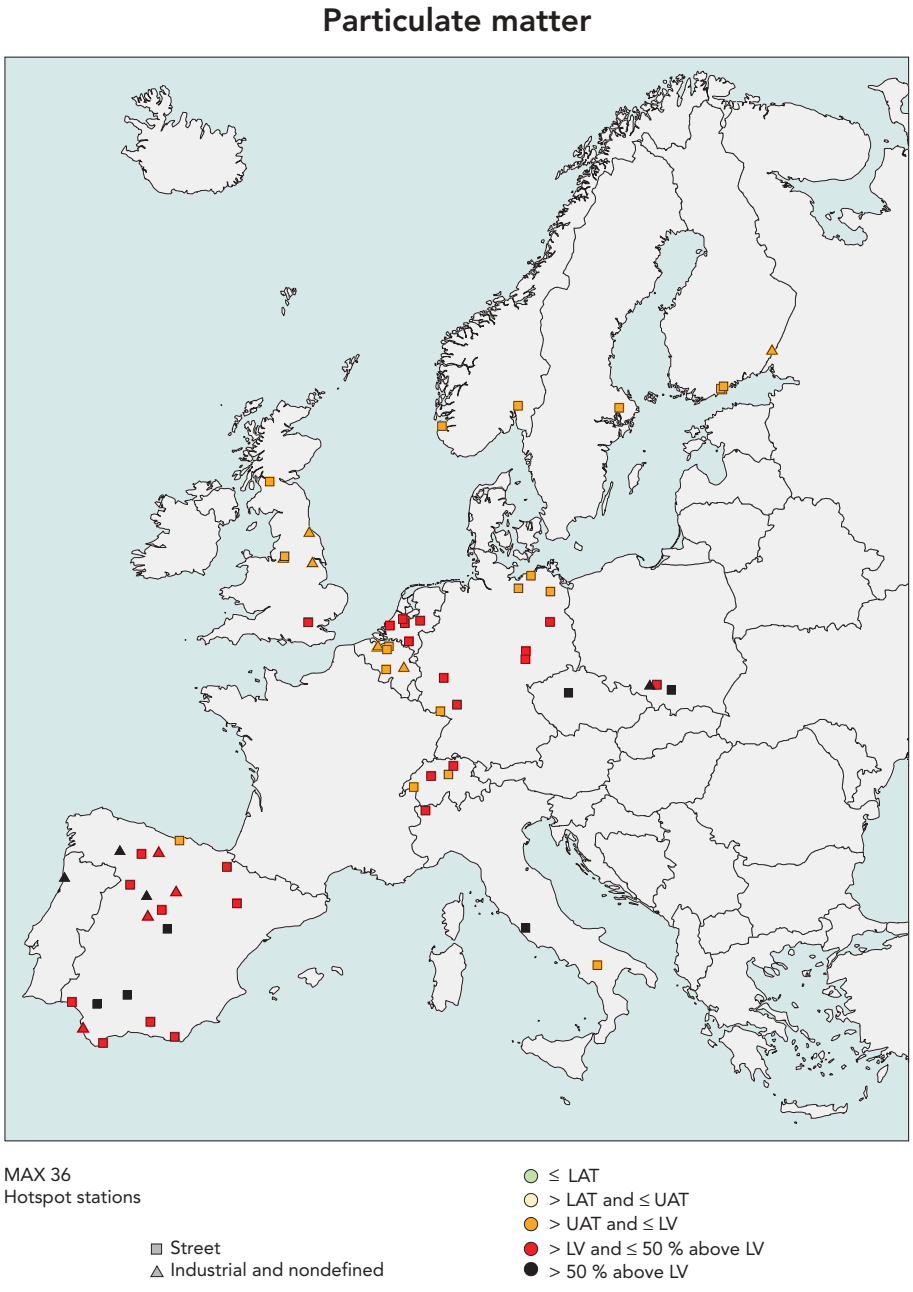
The maximum hotspot station in each city, relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT).

LV: 50 µg/m³, 36th highest daily concentration in a year
(Stage 1: Target year: 2005)

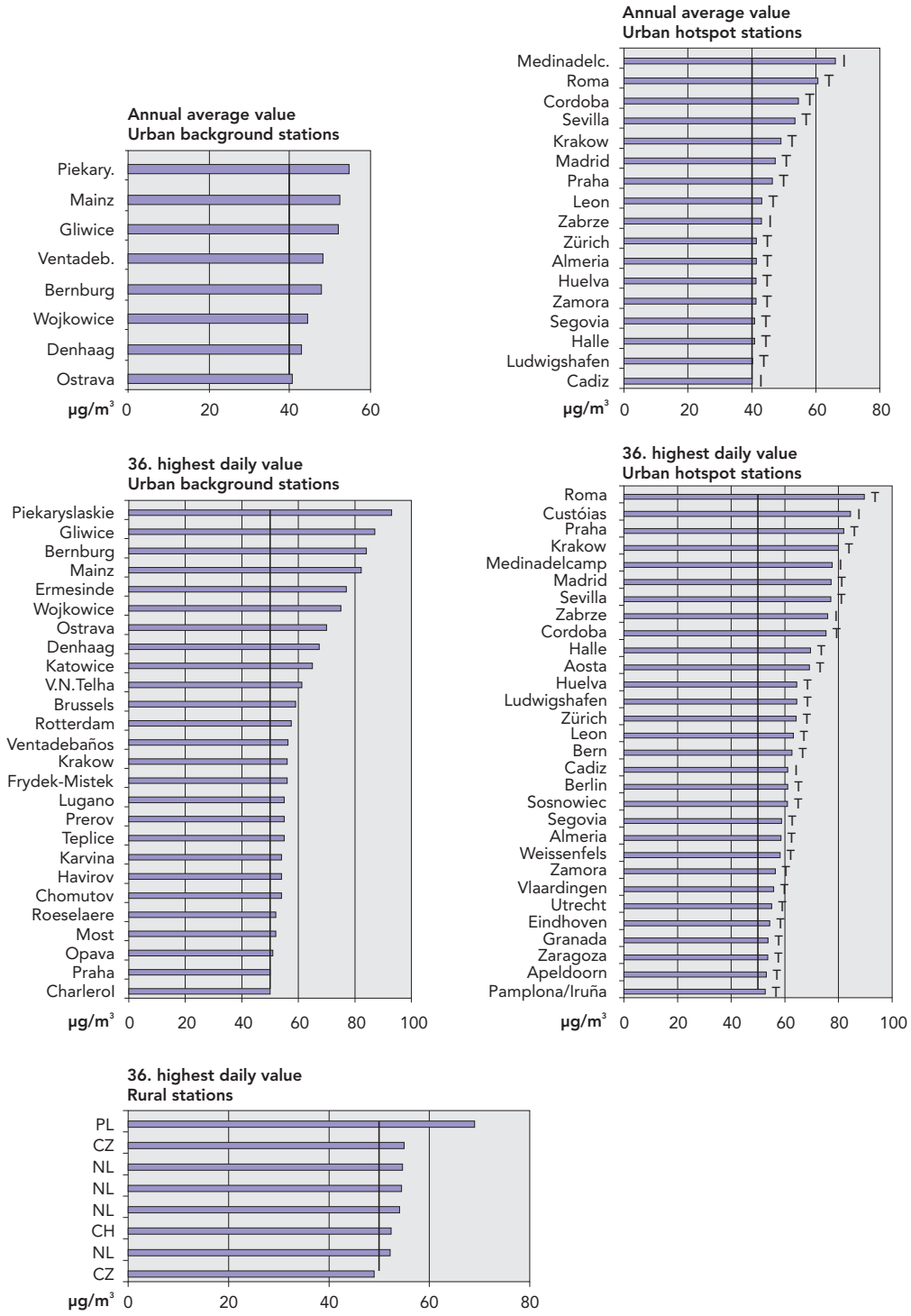
UAT: 30 µg/m³, 8th highest daily concentration in a year
(Stage 2: Target year: 2010, indicative value)

LAT: 20 µg/m³, 8th highest daily concentration in a year
(Stage 2: Target year: 2010, indicative value)

Data from French monitoring stations are not presented here since these measured a PM fraction different from PM_{10}.



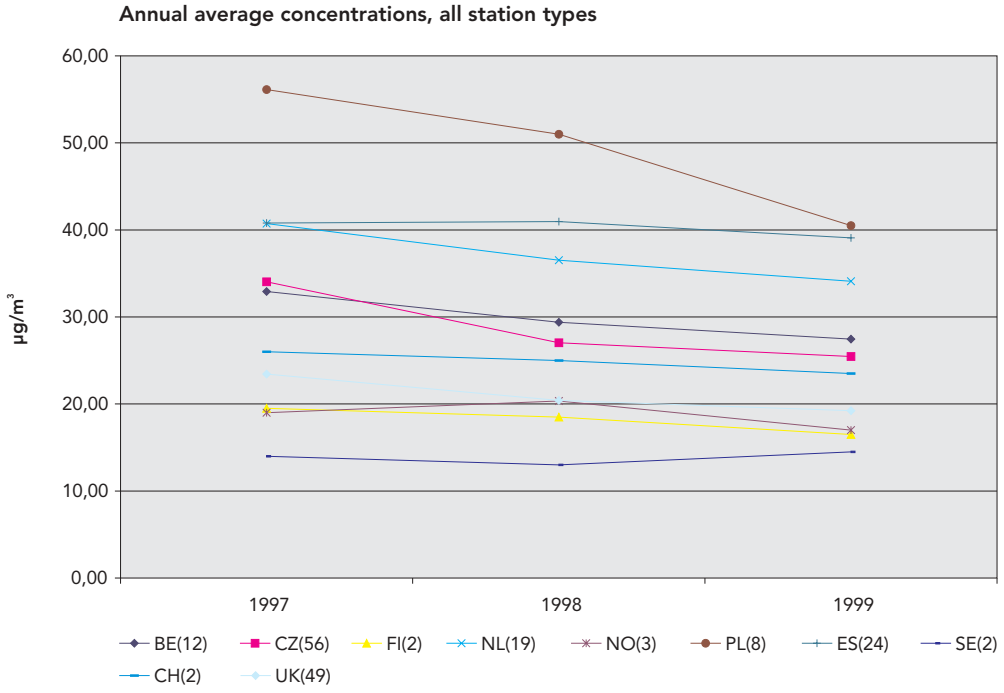
PM_{10} concentrations in cities and rural areas in Europe (1999) with reported concentrations higher than the EU limit values. Figure 2.1

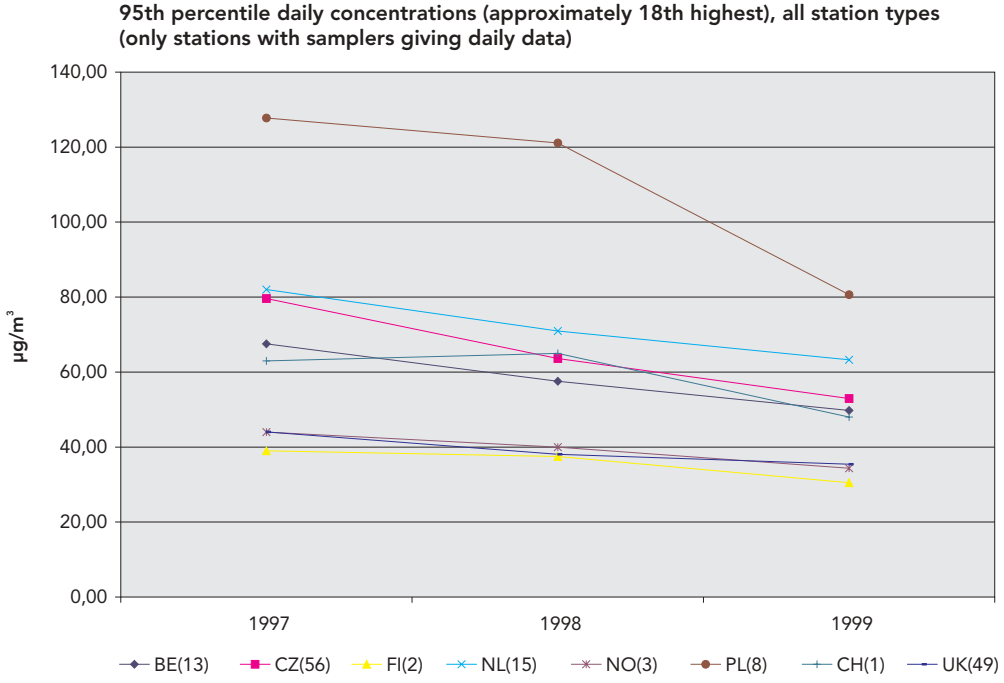


Note: Maximum station in each city.
Vertical lines indicate the LVs of the EU Directives. Hotspot stations: T – traffic; I – industry
For a specification of these stations, see Appendix 2

Figure 2.2

PM_{10} tendency 1997–99 (µg/m3).
Nationally averaged concentrations, for stations with data reported to AirBase for all the years.
(Numbers in brackets: number of stations).





2.1.2 Ozone, urban and regional scales

A The issue

Ozone is a strong photochemical oxidant. Ozone in ambient air causes serious health impacts and damages to ecosystems, agricultural crops and materials. Ozone is not directly emitted in the atmosphere but in the lower parts of the atmosphere it is formed by the reaction of volatile organic compounds (VOC) and NO_x in the presence of sunlight. Especially under hot summer weather conditions, ozone formation is efficient and high concentrations are

observed. Generally this is known as summer smog. Changing weather conditions contribute largely to the year-to-year fluctuations in ozone concentrations. The residence time of ozone and its precursors in the atmosphere is so long that this enables long-range transport over hundreds to thousands of kilometres. Ozone is a pan-European issue.

High ozone concentrations occur both on a regional scale in Europe as well as on an urban scale. Ozone is not a local, hotspot problem.

Upon inhalation, ozone may result in airway and lung damage and lung function loss, as demonstrated by epidemiology, controlled human and animal toxicity studies. Enhanced ozone levels during summer (smog) episodes appear to be associated with increased (premature) mortality and morbidity, lung function decline, airway irritation, and worsening of asthma. The recommended WHO Air Quality Guideline for ozone is the 8-hour average value of 120 ug/m^3, which is adopted by the EU as not to be exceeded on more than 25 days per year, averaged over a three-year period.

Ozone is measured intensively in all countries both in rural and in urban areas. The measurements clearly indicate that threshold values set for the protection of human health and for protection of vegetation are exceeded widely and frequently.

B Guidelines and target values

Averaging time	Target value		Target year
EU Directive*			
8 hours	120 µg/m^3	Maximum daily 8-hour average. May not be exceeded on more than 25 days per year.	2010
WHO			
8 hours	120 µg/m^3	Guideline	

* The new EC Ozone Directive (2002/3/EC).

C Selected indicators

For describing air pollution by ozone an indicator describing urban air pollution has been developed for the Environmental Signals reports (EEA, 2001). This indicator is related to human health effects and is based on threshold values defined in the 'old' EU Ozone Directive (92/72/EEC). The new Ozone Directive has recently been adopted (2002/3/EC). In this report the air quality in 1999 will be evaluated against the targets set for 2010 according to the new directive.

The indicator selected for evaluation of ground level ozone relative to health effects is:

Policy target indicator:

- Extent of areas/cities with exceedance of the target value of the new Ozone Directive:
  — the 26th highest 'ozone day per year' based upon the maximum 8-hour average value each day.

D Ozone in Europe, 1999

The target value for ozone was exceeded in 1999 at about 30 % of the cities and at 38 % of rural stations (Maps 2.3 and 2.4 and Figure 2.3).

Table 2.2 lists the number of stations reporting concentrations above the target value, and above an upper classification level (UCL) as well. (Upper and lower classification levels (UCL, LCL) have been set here, purely for classification purposes, see Maps 2.3 and 2.4.) The highest 26th highest ozone day reported had a concentration of 179 µg/m^3 (maximum 8-hour average), in Italy (target value = 120 µg/m^3). Austria had an almost as high value (178 µg/m^3). The cities and rural stations with the highest ozone concentrations in 1999 are shown in Figure 2.4. In general the urban concentrations are lower than the rural concentrations due to the chemical interaction with locally emitted NO.

Exceedances of LV occur mainly in central and southern European regions. In the northern regions, above 55º North latitude, and in the UK and Ireland no exceedances were observed in 1999.

E Trends in ozone concentrations

Maximum hourly ozone concentrations in rural areas in Europe have been rather stable during the 1990s. Figure 2.5 shows 10-year time series for 36 stations in six countries as well as for 216 stations in 11 countries for the five-year time series 1995–99. Time series at urban stations give the same picture; maximum hourly concentrations are about the same as at rural stations. Interannual variation is probably mainly due to varying meteorological conditions.

The annual average of ozone tends to be increasing in Europe over the later years (1995–99). Map 2.4 shows time series for 202 rural stations from 15 countries.

In a recent study the data submitted under the Ozone Directive up to the annual period 1998 was re-analysed (de Leeuw, 2000). The methodology described by de Leeuw has been applied on an extended data set covering the years 1994–99. The data has been analysed for a possible trend in the statistical parameters (50th and 98th percentiles) and number and severity of exceedances of threshold values defined in the old Ozone Directive (92/72/EEC). Time series are relatively short but the data suggest that there might be a small increasing trend in the 50 percentile values. The peak ozone concentrations, expressed as 98 percentiles or as number of exceedance days tend to decrease in the period 1994–99, see Map 2.5.

More specifically, results from this analysis were:

— The 98th percentile of hourly values (the 177th highest hourly value each year) showed a decrease since 1994 (a 3 % decrease per year as an average over more than a 1 000 monitoring stations).

— The 50th percentile showed a 5 % increase per year over the 1994–99 period as an average over more than a 1 000 stations. Both rural and urban stations show increasing annual average concentrations, but on average over all stations, the urban ozone concentration is some 20 μg/m^3 lower than the rural concentration.

These conclusions must be interpreted carefully since over the relatively short time period considered here, meteorological factors may cause major inter-annual variations. The decrease in 98th percentile concentrations is most likely caused by the decrease in European ozone precursor emissions since 1990; sufficient data are not available to explain the increasing 50 percentile values. Possible explanations are an increase in tropospheric ozone background concentrations caused by a worldwide increase in CH_4, CO and NO_x emissions or a reduced ozone titration by reduced NO_x emissions on the local scale.

An overview of the 1994–99 statistical analysis is presented in Table 2.3.

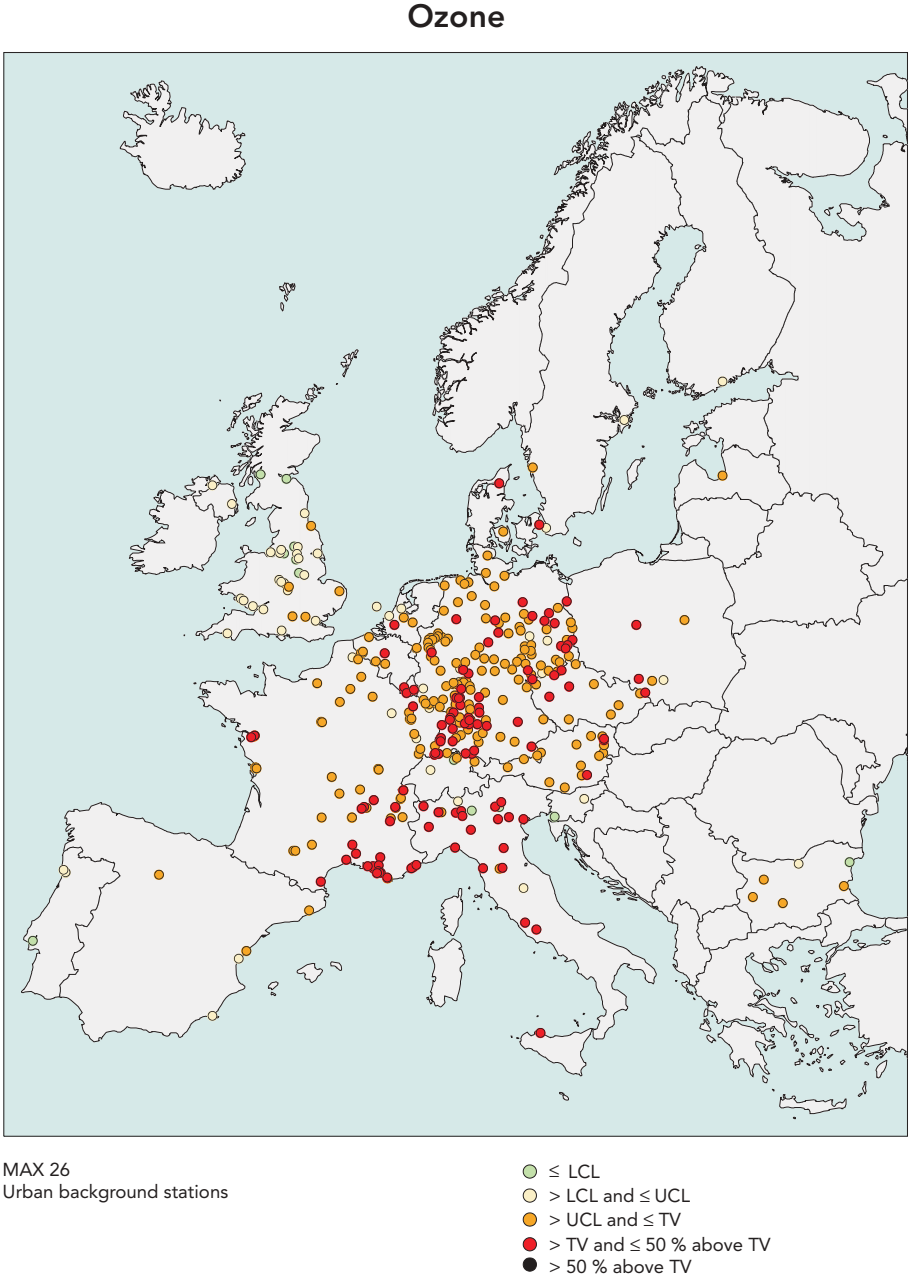
F Conclusion

A large fraction of the European population, and 10–40 % (depending on the year-to-year variations in meteorological conditions) of the EEA18 population is exposed to ground-level ozone concentrations above the health-protection-based target level in the EU ozone Directive. Reductions in precursor gas emissions (NO_x and VOC) have not yet been sufficient to reduce this health risk.

Ozone in cities, 1999. Urban background (UB) stations Map 2.3

26th highest daily maximum 8-hour concentration.
The maximum UB station in each city, relative to EU target value (TV) and upper and lower classification levels (UCL, LCL).

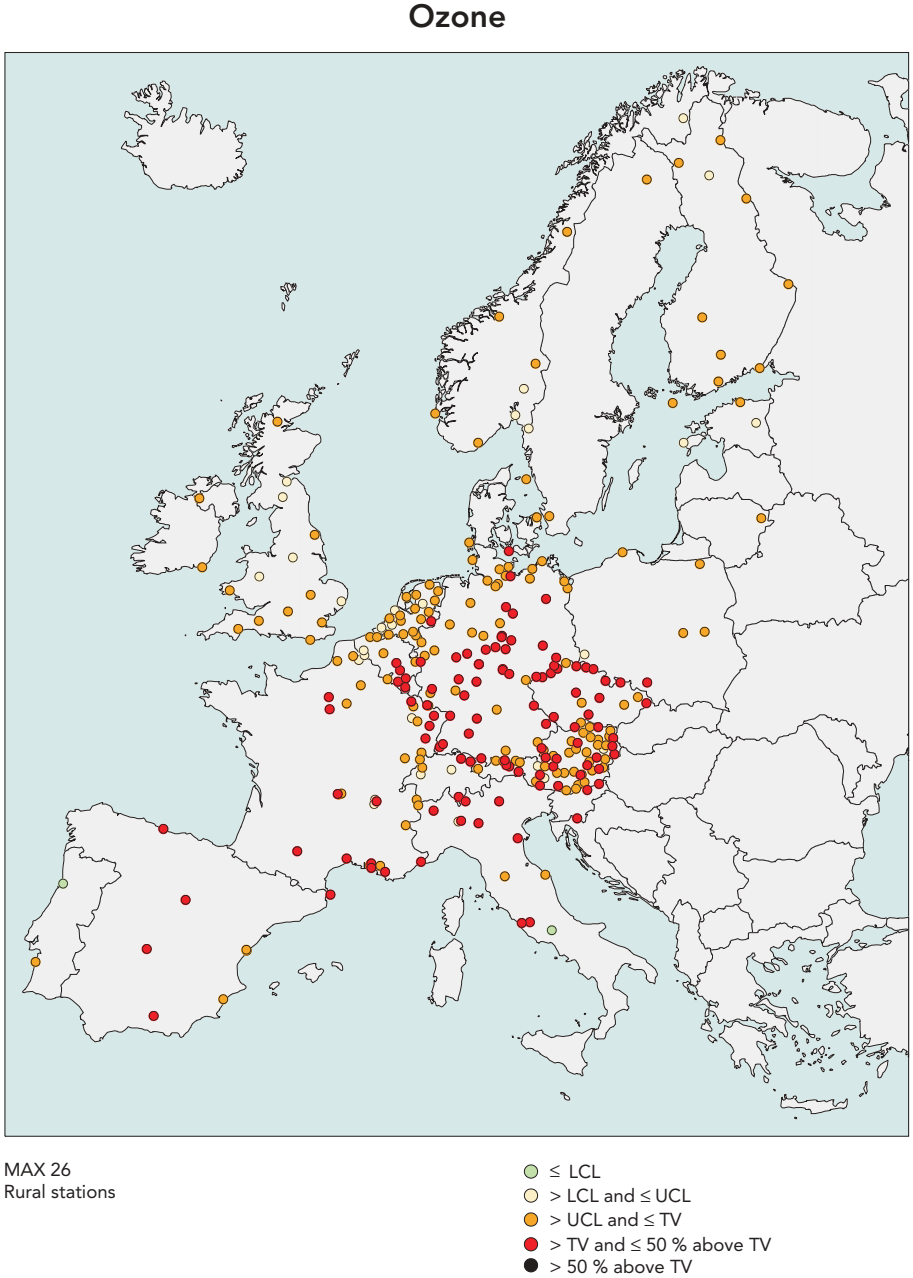
TV = 120 µg/m^3; UCL = 100 µg/m^3; LCL = 80 µg/m^3.



Map 2.4	Ozone at rural stations 1999

Ozone at rural stations 1999, relative to EU target value (TV) and upper and lower classification levels (UCL, LCL).
26th highest daily maximum 8-hour concentration.

TV = 120 µg/m^3; UCL = 100 µg/m^3; LCL = 80 µg/m^3.



Frequency distribution of maximum and 26th highest daily maximum of moving 8-hour average ozone concentration measured at urban/street and other stations (top) and rural stations (bottom).

Figure 2.3

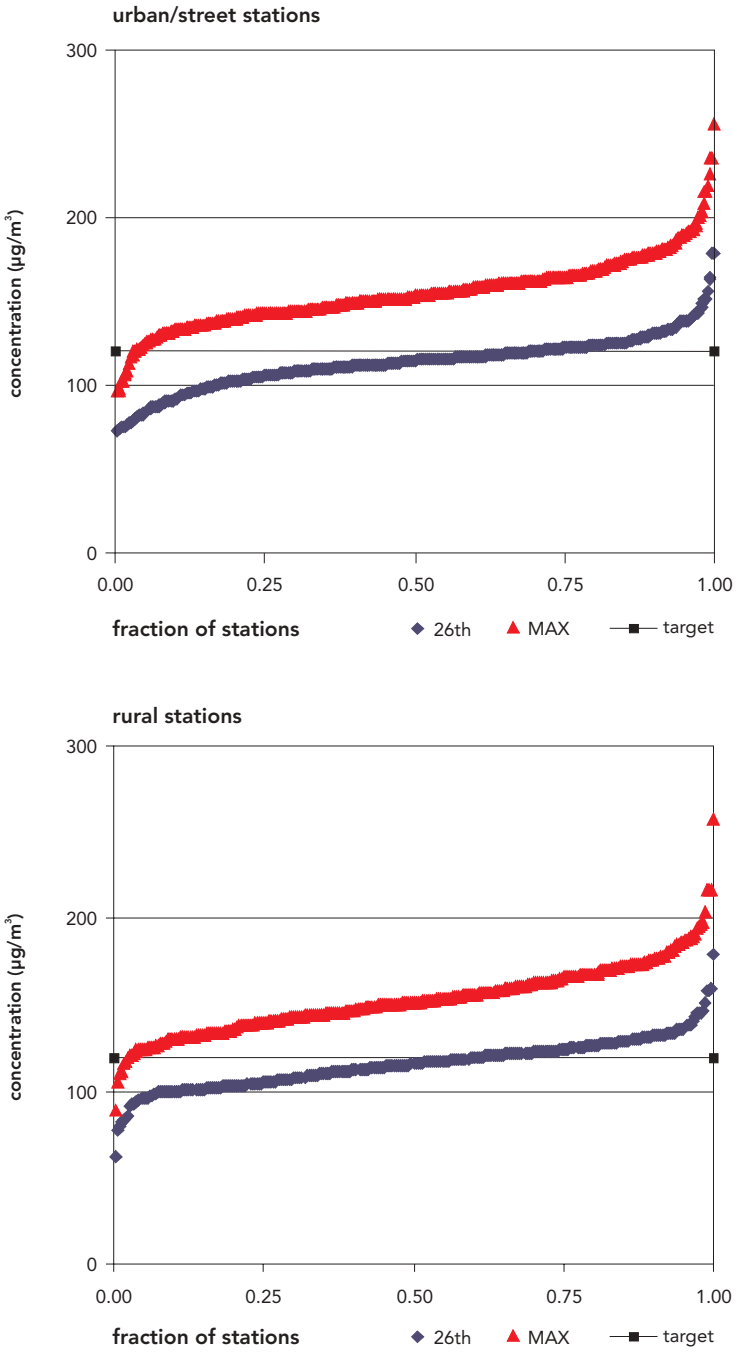
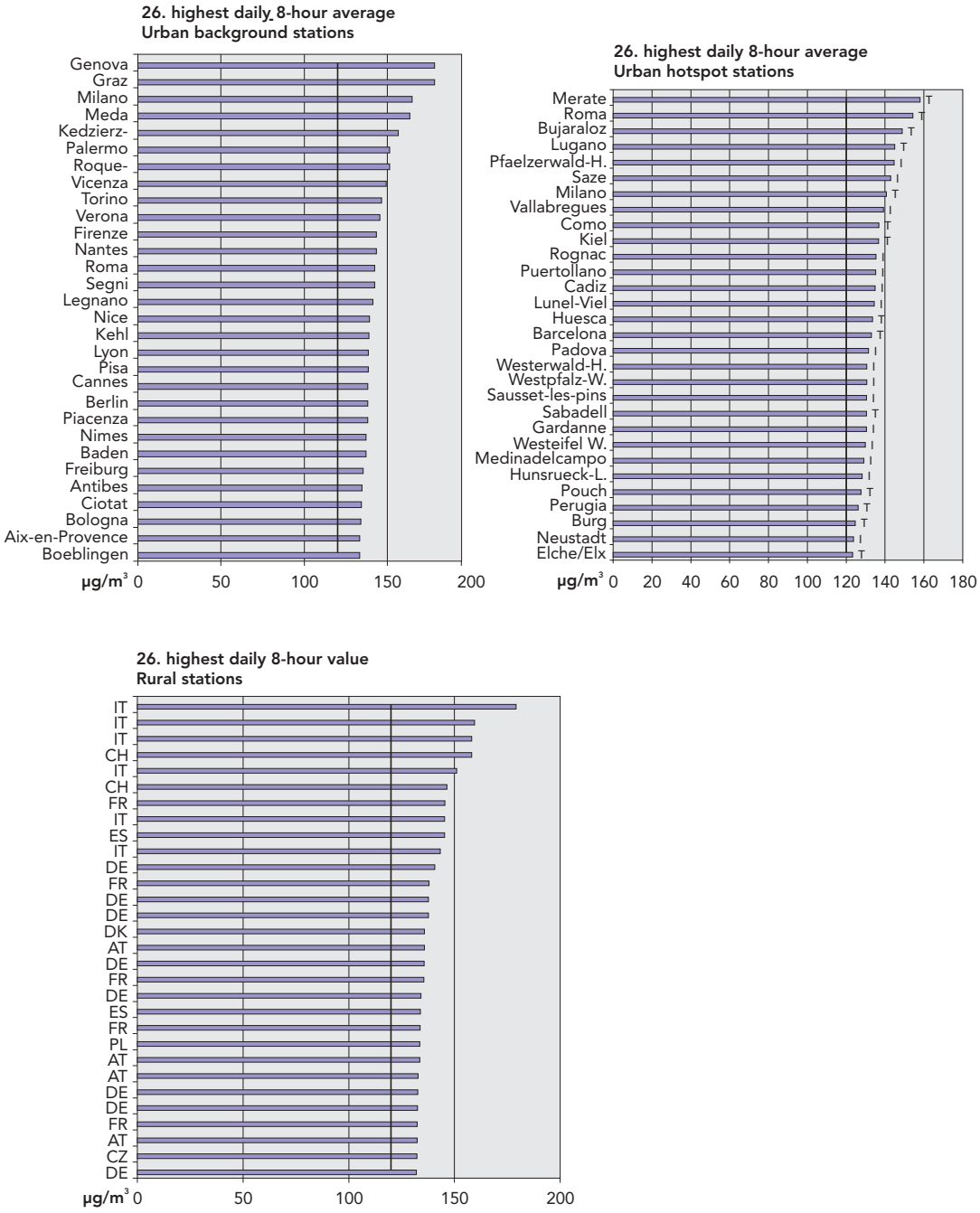


Figure 2.4 **Ozone concentrations in cities and rural areas in Europe (1999) with reported concentrations higher than the EU target value.**



Note: Maximum station in each city.
Vertical lines indicate the target value of the new EU Directive.

Ozone (µg/m³). Maximum hourly or annual average concentrations as a function of time. Nationally averaged concentrations, for stations with data reported to AirBase for all the years. (Numbers in brackets: number of stations).

Figure 2.5

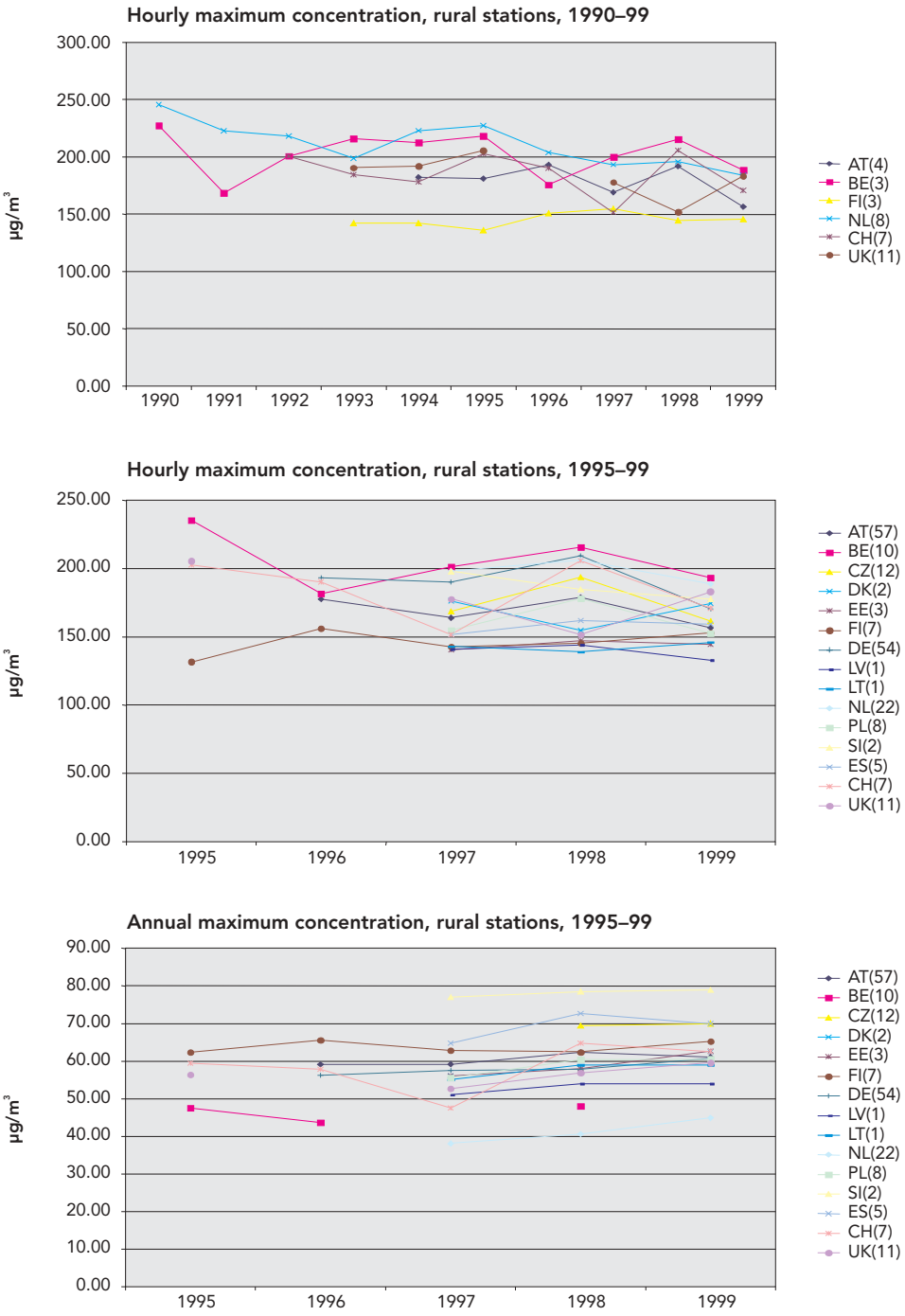


Table 2.2

Ozone: Number of stations with exceedances of target value (TV) of O_3 and with concentrations between upper classification level (UCL) and target value (TV) (1999).
26th highest daily 8-hour value
TV = 120 µg/m³, UCL = 100 µg/m³.

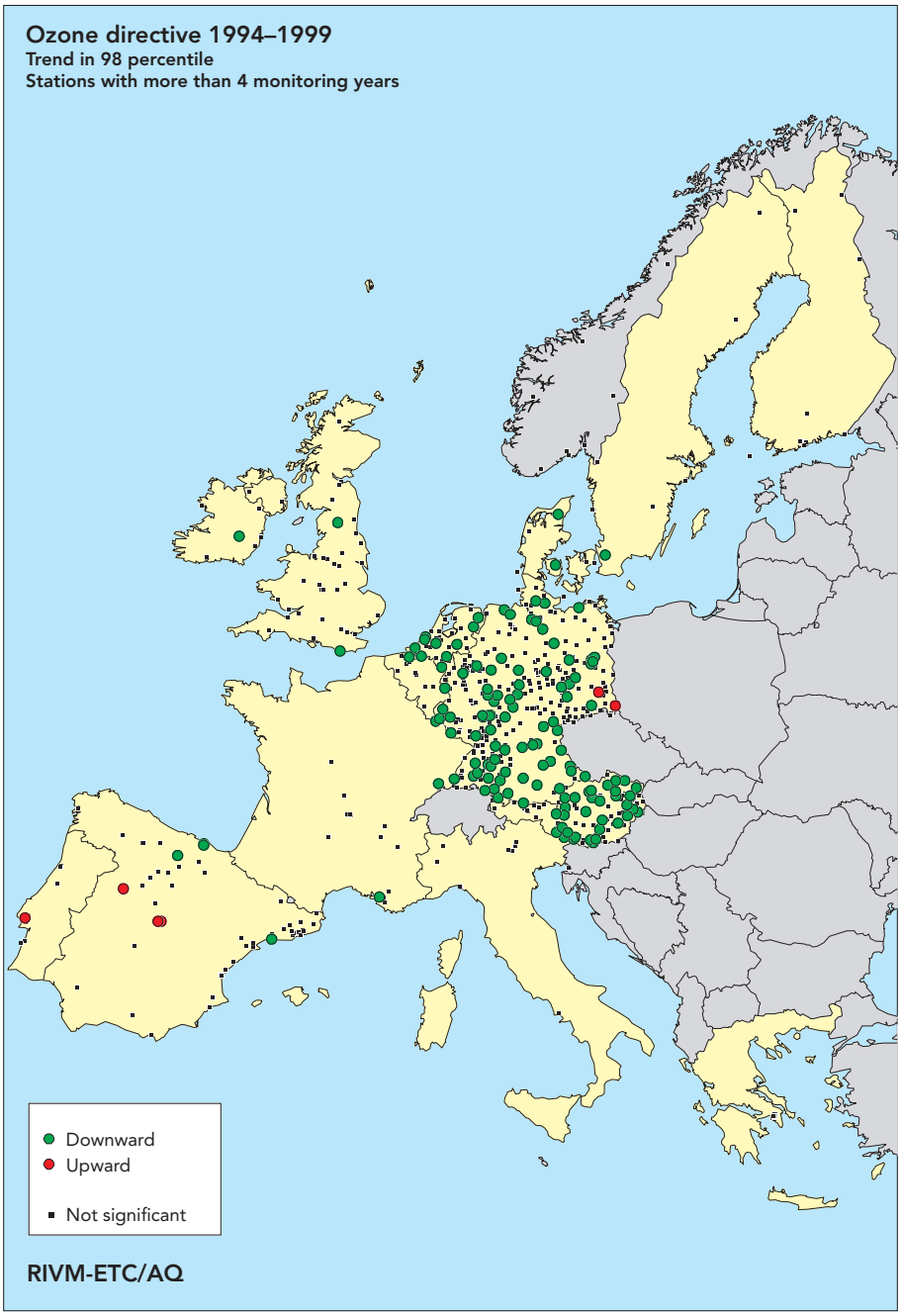
Country	(Total number of stations)	26th highest daily 8-hour value		
		Number of stations with concentrations C		Maximum concentration
		C > 120	100 < C < 120	(µg/m³)
Austria	(103)	27	63	178
Belgium	(24)	7	9	125
Bulgaria	(7)	0	5	115
Czech Republic	(33)	15	15	132
Denmark	(7)	3	2	136
Estonia	(4)	0	1	107
Finland	(12)	0	9	119
France	(228)	65	98	151
Germany	(326)	103	194	145
Greece	(7)	1	2	131
Hungary	(2)	0	1	101
Ireland	(11)	0	1	110
Italy	(75)	38	18	179
Latvia	(2)	0	1	103
Lithuania	(3)	0	2	112
Netherlands	(37)	2	19	123
Norway	(10)	0	5	109
Poland	(17)	4	7	156
Portugal	(17)	0	5	108
Slovenia	(5)	1	0	122
Spain	(107)	20	41	149
Sweden	(6)	0	4	107
Switzerland	(30)	6	10	158
United Kingdom	(69)	0	19	118
All countries	(1 142)	292	531	179

Table 2.3

Summary of trend evaluation of 50th and 98th percentiles of hourly average ozone concentrations and of number of exceedance days of the threshold levels of the 'old' EU Ozone Directive (92/72/EEC): 180 µg/m³ (1-hour average), 110 µg/m³ (8-hour average) and 65 µg/m³ (24-hour average). Monitoring period 1994–99.

	50th percentile	98th percentile	180 µg/m³ (1 hour)	110 µg/m³ (8 hour)	65 µg/m³ (24 hour)
Number of reporting stations	1 585	1 585	1 701	1 488	1 580
Number of stations with more than four monitoring years	685	685	713	647	650
Number of stations with statistically significant upward trend	120	6	4	16	50
Number of stations with statistically significant downward trend	12	138	118	122	64
Number of stations in compliance with threshold during the period 1994–99			96	4	0

Ozone: Trends in 98th percentile hourly concentrations over 1994–99 Map 2.5



2.1.3. Nitrogen dioxide, urban and local scales

A The issue

Nitrogen oxides in air

Nitrogen oxides in air originate mainly from combustion of fuels, where the nitrogen and oxygen in the combustion air react to form mainly nitrogen monoxide (NO) as well as smaller amounts of nitrogen dioxide (NO_2) and other oxides. After release to the atmosphere, NO is oxidised to NO_2 fairly rapidly by reactions with ozone and organic compounds in air. The scheme of the further reactions is a complicated one, and the balance between NO, NO_2 and ozone depends upon many factors, including solar radiation intensity, distance from and time after release to the atmosphere, and organic compound mix, reactivity and concentration. In urban areas, NO_2 constitutes typically 20-50 % of total NO_x, while in rural areas in general NO_2 makes up most of the NO_x concentration. Over the course of days, atmospheric reactions oxidise NO_x further to nitrite and nitrate, which are removed from the atmosphere by precipitation and dry deposition.

Effects

Exposure to NO_2 may result in airway and lung damage, lung function decline, as well as increased responsiveness to allergens following acute exposure. Long-term exposures in toxicology studies show that NO_2 is able to induce irreversible changes in lung structure and function. Epidemiological studies show that health effects like increased mortality and morbidity are associated with ambient NO_2 levels, however, it is assumed that NO_2 in these studies has not acted as a causal agent but should be considered as a surrogate or indicator of the air pollution mixture, perhaps to a certain extent motor vehicle exhaust-related. The recommended WHO Air Quality Guidelines for NO_2 are 200 µg/m³ 1-hour average and 40 G/m³ annual average to protect against acute and long-term effects, respectively. The EU has adopted these guidelines.

Sources

The main sources of NO_x emissions to air are road traffic, and power plants and industrial boilers, accounting for some 57 % and 39 % of European emissions respectively (1999). Wood combustion and industrial processes are other, minor sources.

Traffic is by far the largest source in urban areas where the NO_2 concentrations are highest. The cars emit the exhaust near ground level and close to where people live and move, causing sometimes high exposures. Smaller amounts of NO_x are also emitted from natural sources, such as from soil, volcanoes and lightning.

B Limit values for NO_2 in EU Directive 1999/30/EC

Averaging time	Limit value		Target year
Annual average	40 µg/m³		2010
Hourly average	200 µg/m³	May not be exceeded more than18 hours per year	2010

C. Selected indicators

Policy target indicator:

- Extent of areas/cities with exceedance of the NO_2 limit values:
  — Annual average concentration
  — The 19th highest hourly concentration per year

D NO_2 concentrations in Europe, 1999

For NO_2, it is the annual average concentration that is of most concern relative to limit values, while the short term concentrations (high hourly values) exceed limit values to a lesser degree. The annual average of NO_2 is higher than the LV at stations in about 30 cities in Europe that have reported data, and in five of these it is more than 50 % over the LV (Map 2.6). Many more cities have NO_2 concentrations above the upper assessment threshold (UAT). The cities reporting the highest annual averages of NO_2 in 1999 are predominantly in the UK, western part of Germany and northern Italy.

At hotspot stations in the cities (traffic stations) the NO_2 concentrations are significantly higher than in the urban background, with concentrations significantly above the LV in many cities. The high hourly concentrations may represent better the high end of the population exposure distribution. The short term LV (the 18th highest hourly concentration) is exceeded at traffic stations in about 18 cities that have reported data, mostly in southern European cities (Map 2. 7). These concentrations are of course highly dependent on the intensity of traffic near the stations, and it is assumed that traffic type stations are typically located near the busiest parts of the road network in the cities. Table 2.4 lists the number of stations with NO_2 concentrations higher than the LV and UAT in each country. In total, the annual average was above the LV at 268 stations, with a maximum value of 120 µg/m³ at a station in Spain (LV = 40 µg/m³). The hourly LV is exceeded at 38 stations, with a highest value of 407 µg/m³ in Spain (LV = 200 µg/m³). About 200 more cities have stations above the UAT.

The actual concentrations in the cities with highest NO_2 are shown in Figure 2.6.

E Tendencies in NO_2 concentrations

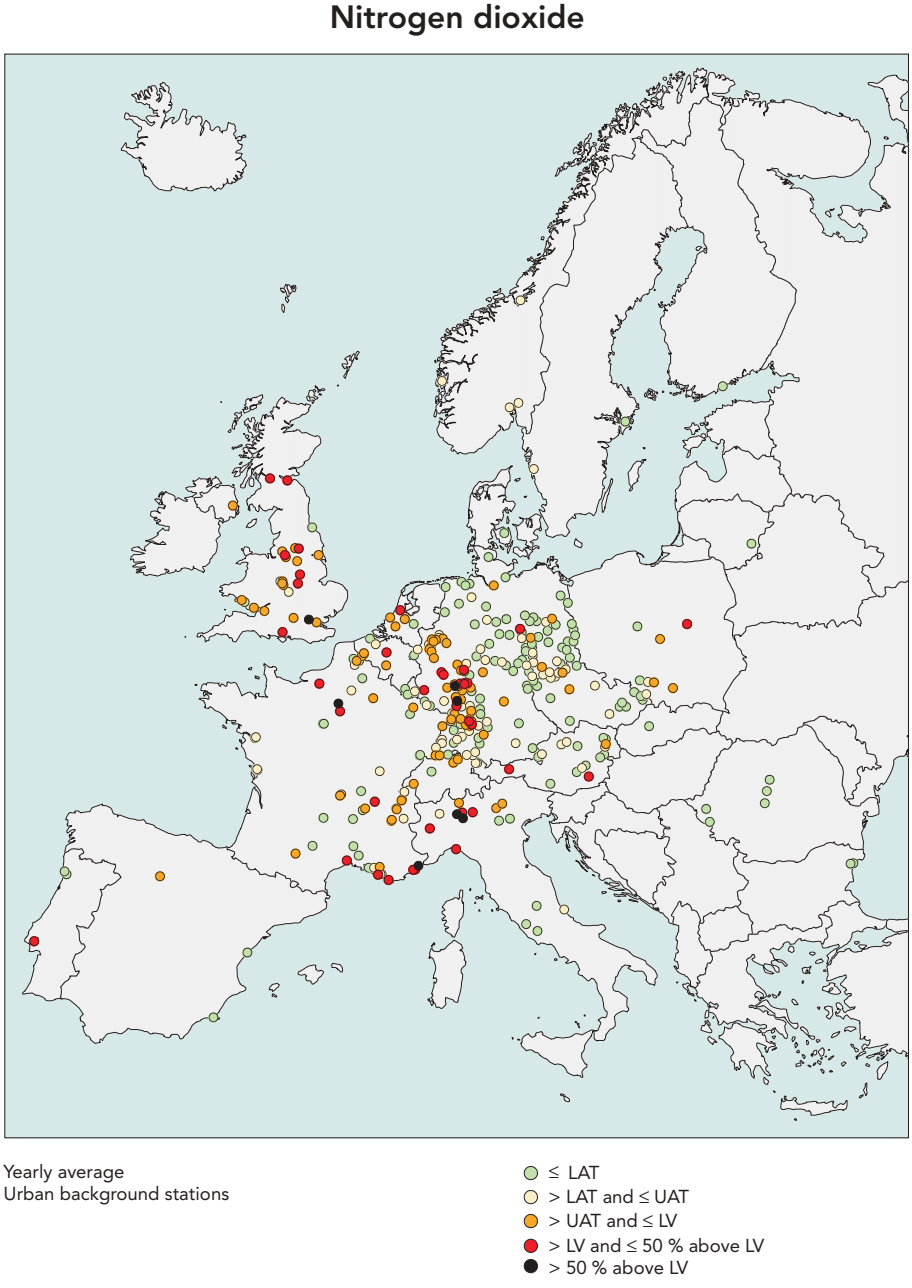
Annual average

Long time series (since 1989) are presented in terms of annual average, averaged over all stations with data for all the years indicated by the curves in the figures (total 97 stations) in 19 countries (irrespective of station type) (Figure 2.7). The station type mix has not changed over the period. There is a slight downward tendency for the countries with the longest time series. Since 1993–94, however, annual average NO_2 has been quite stable in most countries with data, except for inter-annual variations probably reflecting varying meteorological conditions.

NO_2 in cities, 1999. Urban background (UB) stations | Map 2.6

Annual average concentration.
The maximum UB station in each city, relative to EU limit value and upper and lower assessment thresholds (UAT, LAT).

LV = 40 µg/m³; UAT = 32 µg/m³; LAT = 26 µg/m³.



High percentiles

To find the tendency for a high percentile value corresponding to the short-term LV of the Directive (18th highest 1-hour average: approximately 99.8th percentile), the tendencies in the 99.9th percentile[3] is shown in Figure 2.7.

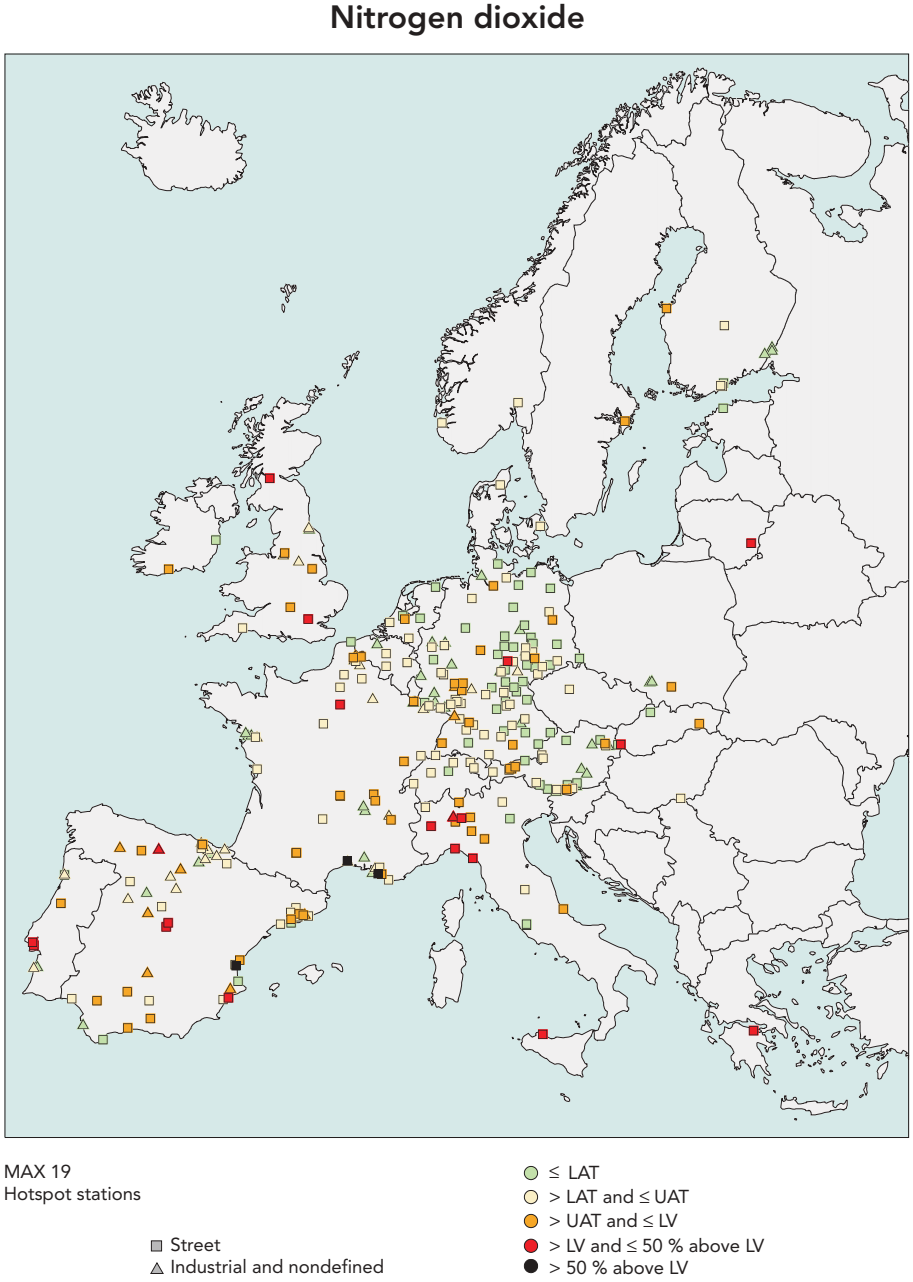
The 99.9th percentile shows more inter-annual variability, both for urban background and traffic stations separately. There is a slight downward tendency for many of the countries, but not so for others.

(3) This percentile was readily available for extraction from AirBase at the time the extraction was made (in 2001). The 99.8th percentile will be extractable from AirBase for the next Air Quality in Europe report).

Map 2.7	NO_2 in cities, 1999. Hotspot stations (traffic, industrial)

19th highest hourly concentration.
The maximum hotspot station in each city, relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT).

LV = 200 µg/m³; UAT = 140 µg/m³; LAT = 100 µg/m³.



NO_2: Number of stations with concentration higher than the limit values (LV) and with concentrations between the upper assessment threshold (UAT) and LV (1999). Table 2.4

Annual average concentration: LV = 40 µg/m³
UAT = 32 µg/m³

19th highest daily concentration: LV = 200 µg/m³
UAT = 140 µg/m³

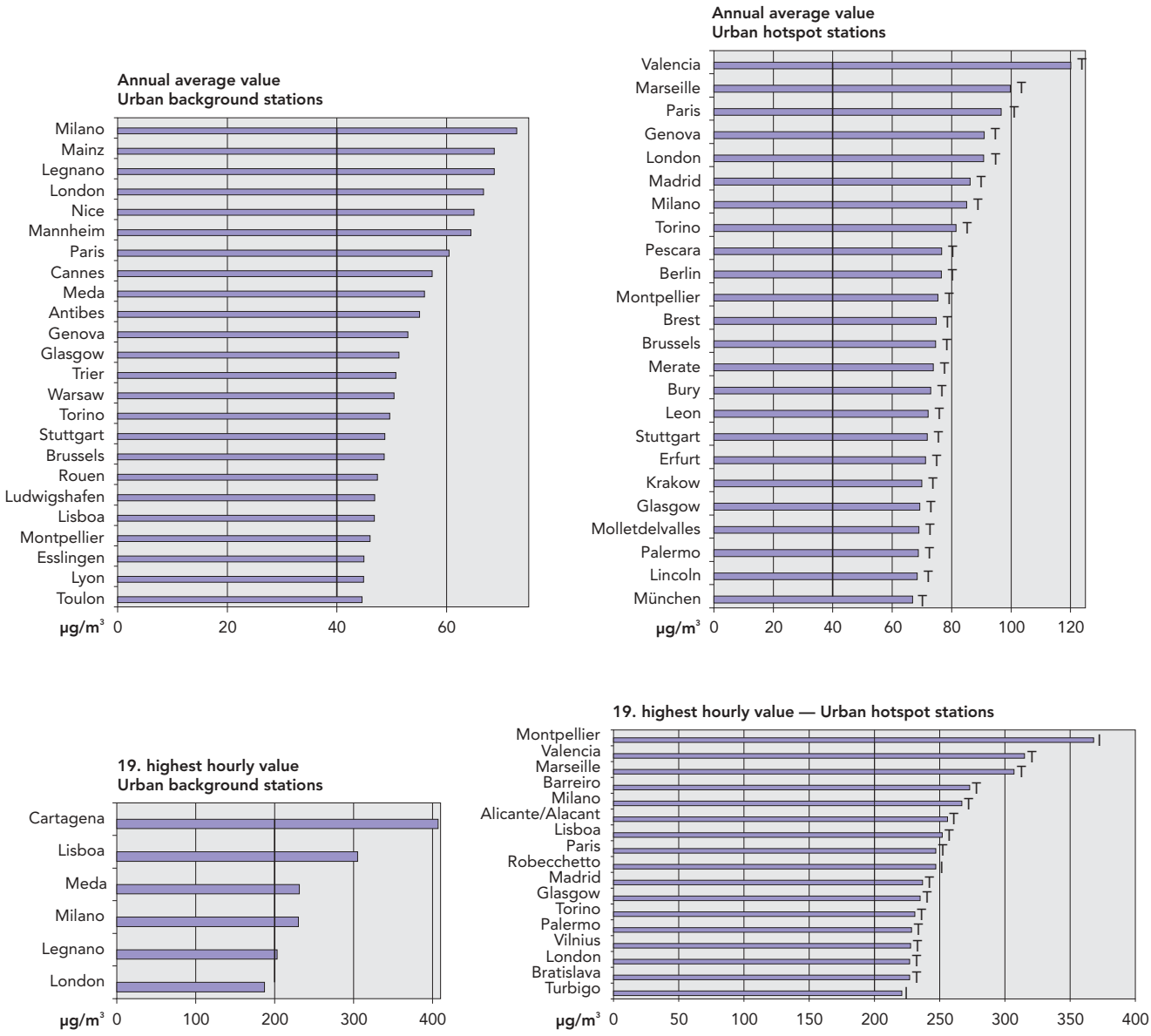
Country		Annual average			19th highest 1-hour concentration		
		Number of stations with concentrations C		Highest annual concentration	Number of stations with concentrations C		Highest 19th concentration
	(Total number of stations)	C > 40	32 < C < 40	(µg/m³)	C > 200	140 < C < 200	(µg/m³)
Austria	(109)	11	9	61	0	7	159
Belgium	(24)	5	6	75			
Czech Republic	(55)	3	3	41			
Denmark	(5)	2	0	47			
Finland	(15)	0	1	39	0	1	153
France	(211)	61	39	100	5	45	368
Germany	(371)	64	77	77	1	20	206
Greece	(3)				2	1	212
Ireland	(6)				0	2	165
Italy	(61)	36	6	91	17	12	267
Lithuania	(3)				2	0	228
Netherlands	(36)	8	5	63	0	1	152
Norway	(6)	0	1		0	0	
Poland	(23)	2	3	70			
Portugal	(22)	7	2	56			
Slovakia	(6)	1	2	58			
Spain	(79)	35	19	120	9	23	407
Sweden	(7)	1	0	58			
Switzerland	(29)	5	10	57	0	1	147
United Kingdom	(58)	27	20	91	2	14	235
All countries	(1 151)	268	203	120	38	127	407

F Discussion and conclusions

NO_2 is measured extensively in Europe, at hotspot, urban and rural stations. Significant parts of the population in many cities in Europe are exposed to concentrations of NO_2 higher than health-protection-based limit values in EU directives. Rural concentrations are far below the LV in most areas.

The tendency through the 1990s is of a moderately decreasing NO_2 concentration, but this observation is only indicative, since there are only a few countries with a substantial number of stations with such a long measurement series. More data are available for the last five years. The general picture then is of a rather stable annual average NO_2 concentration, while a slight downward tendency in the 99.9th percentile can be seen for many of the countries.

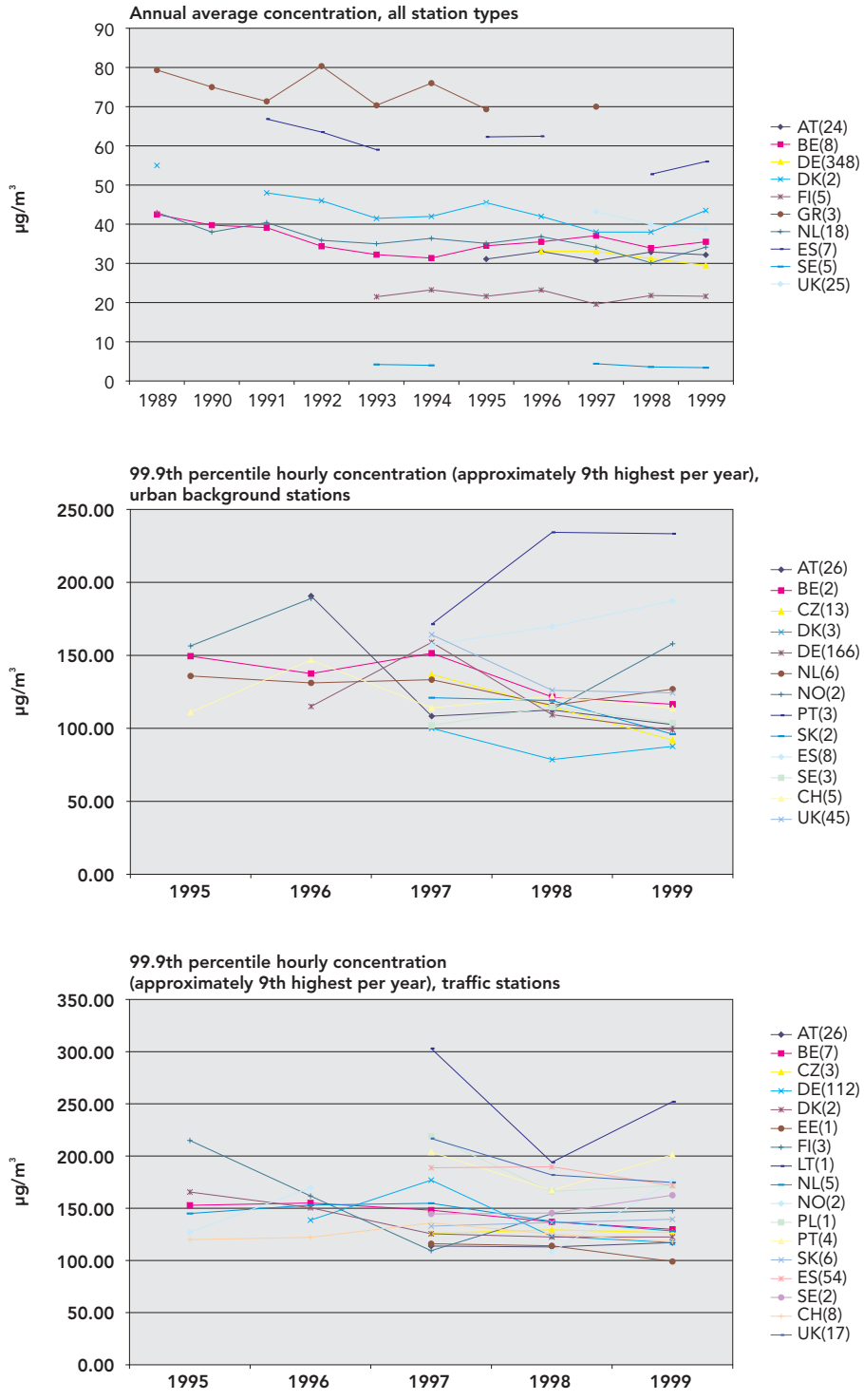
Figure 2.6 **Highest NO_2 concentrations in cities in Europe (1999) with exceedance of EU limit values**



Note: Maximum station in each city.
Vertical lines indicate the LVs of the EU Directive.
Hotspot stations: T – traffic; I – industry

NO_2 tendencies (µg/m³). Nationally-averaged concentrations, for stations with data reported to AirBase for all the years.

Figure 2.7



Note: (Numbers in brackets: number of stations.)

2.1.4. Sulphur dioxide, local and urban scales

A The issue

Sulphur dioxide in air

Sulphur dioxide (SO_2) in air originates from the sulphur contents in fuels and in mineral ores. It is emitted to air and oxidised to SO_2 during combustion of the fuels and the processing of the ores. Over the course of hours and days, SO_2 is further oxidised in the atmosphere to sulphate and sulphuric acid in the form of small particles, and removed from the air by precipitation and dry deposition. This sulphur deposition is, together with the similar nitrogen deposition from NO_x and NH_3 emissions, the cause of the acidification of the environment (soil, lakes and rivers).

Effects

Human exposure to sulphur dioxide (SO_2) can be toxic depending on exposure concentration and duration. Asthmatics may experience respiratory and pulmonary effects following high-level exposure at periods as short as 10 minutes. A WHO guideline is therefore recommended of 500 µg/m³ as a 10-minute average ambient concentration. Longer-term exposures (24-hour, or annual) have also recently been associated with excess effects on mortality, morbidity and lung function. As current ambient levels of SO_2 are much lower than in the past, SO_2 is considered not to be responsible for these effects but to act as a surrogate for the ambient particulate matter (PM) mixture. WHO recommends air quality guidelines for SO_2 as 125 and 50 µg/m³ as a 24-hour and annual mean, respectively.

Sources

Sulphur in coal, oil and mineral ores are the main sources of SO_2 to air. Apart from the man-made sources, there is a contribution from natural sources (volcanoes, oxidation of DMS). Up until the 1960s, coal and oil combustion in large and small sources was the typical situation in many European cities, resulting in very high SO_2 and PM concentrations, again resulting in health impacts in the urban populations. Since then, the combustion of sulphur-containing fuels has largely been removed from urban and other populated areas, first in western Europe and now also increasingly in most central and eastern European countries. Sulphur emissions are now concentrated in large sources (power plants and industries), most often away from population centres, with emissions through tall stacks. This still creates a background sulphur concentration in air in Europe which contributes to the remaining acidification. Increasingly, sulphur is cleaned from the power plant emissions or there is a shift to fuels with much less sulphur content, which contributes to further reducing the acidification.

B Limit values for SO_2 in EU Directive 1999/30/EC

Averaging time	Limit value		Target year
Daily average	125 µg/m³	May not be exceeded more than 3 days per year	2005
Hourly average	350 µg/m³	May not be exceeded more than 24 hours per year	2005

C Selected indicator

Policy target indicator:

- Extent of area/cities with exceedance of the SO_2 limit values:
  — the 4th highest daily value per year
  — the 25th highest hourly value per year

D SO_2 concentrations in Europe, 1999

SO_2 still represents an air pollution problem in some cities and locations in Europe. Limit values are given in EU directives both for daily (24-hour) averages and for hourly average concentrations. Relative to the LVs, it is the situation with high 24-hour averages that causes the most concern.

In some industrial cities the SO_2 concentration is still high even at urban background locations (Map 2.8). At hotspot (industrial type) stations, there are concentrations higher than the LV in some 12 cities in five countries that have reported data (Map 2.9).

Table 2.5 shows that the reported concentrations are higher than limit values and upper assessment threshold for SO_2 at a number of stations. The fourth highest daily concentration is higher than the LV at 23 stations in 8 countries, with the highest concentration being 327 µg/m³ in France (LV = 125 µg/m³). The 25th highest 1-hour concentration is higher than the LV at 6 stations in 4 countries, with a highest value of 587 µg/m³ in Portugal (LV = 350 µg/m³). The UAT is exceeded at an additional 64 stations.

The actual SO_2 concentration in the cities with highest SO_2 is shown in Figure 2.8.

E Trends in SO_2 concentrations

Long term SO_2 data are available in AirBase for an appreciable number of stations in many countries since 1993, and the result of the extraction of data is shown in Figure 2.9.

The urban and local SO_2 concentration continues to decrease in most areas in Europe.

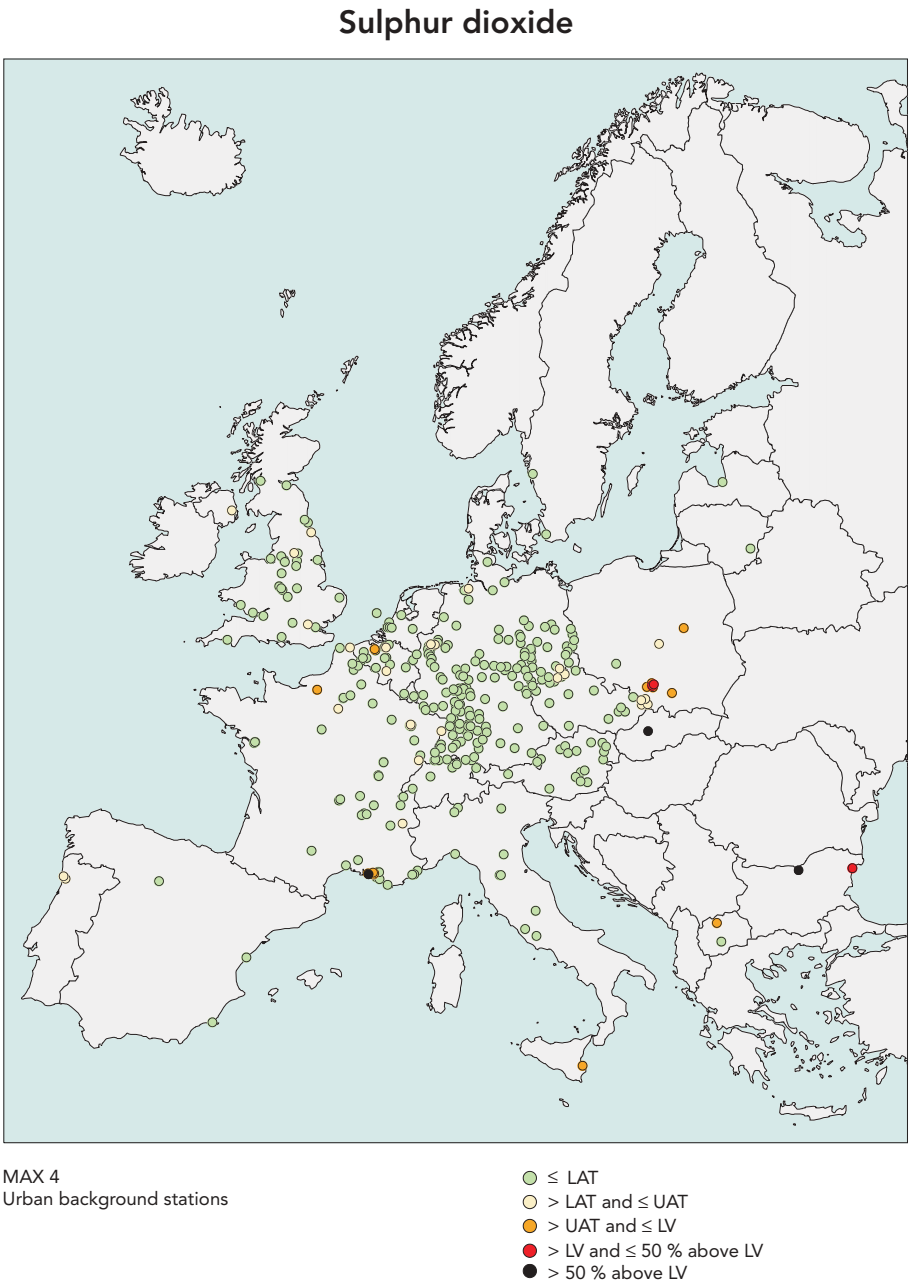
F Conclusions

SO_2 in air still persists as a potential human health risk in some locations in Europe, in particular those near power plants or industrial plants, where concentrations above limit values still exist. Trends from measurements at most stations show significantly decreasing concentrations over the last decades, which still continue at many of the stations which still have high concentrations.

SO_2 in cities in Europe, 1999. Urban background (UB) stations Map 2.8

4th highest daily concentration.
The highest UB station in each city, relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT).

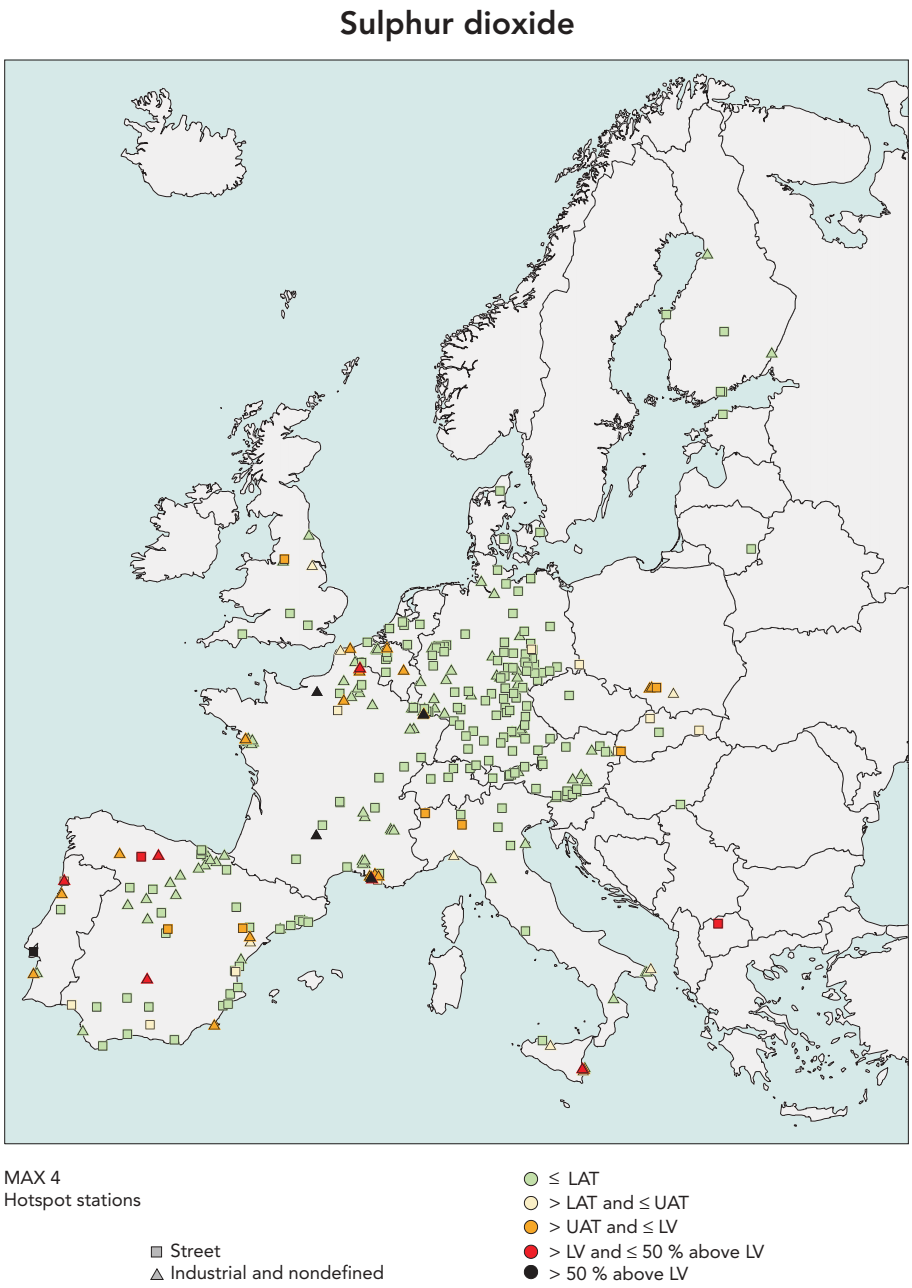
LV = 125 µg/m³; UAT = 75 µg/m³; LAT = 50 µg/m³



Map 2.9	SO_2 in cities in Europe, 1999. Hotspot stations (industrial, traffic)

4th highest daily concentration.
The maximum hotspot station in each city, relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT).

LV = 125 µg/m³; UAT = 75 µg/m³; LAT = 50 µg/m³

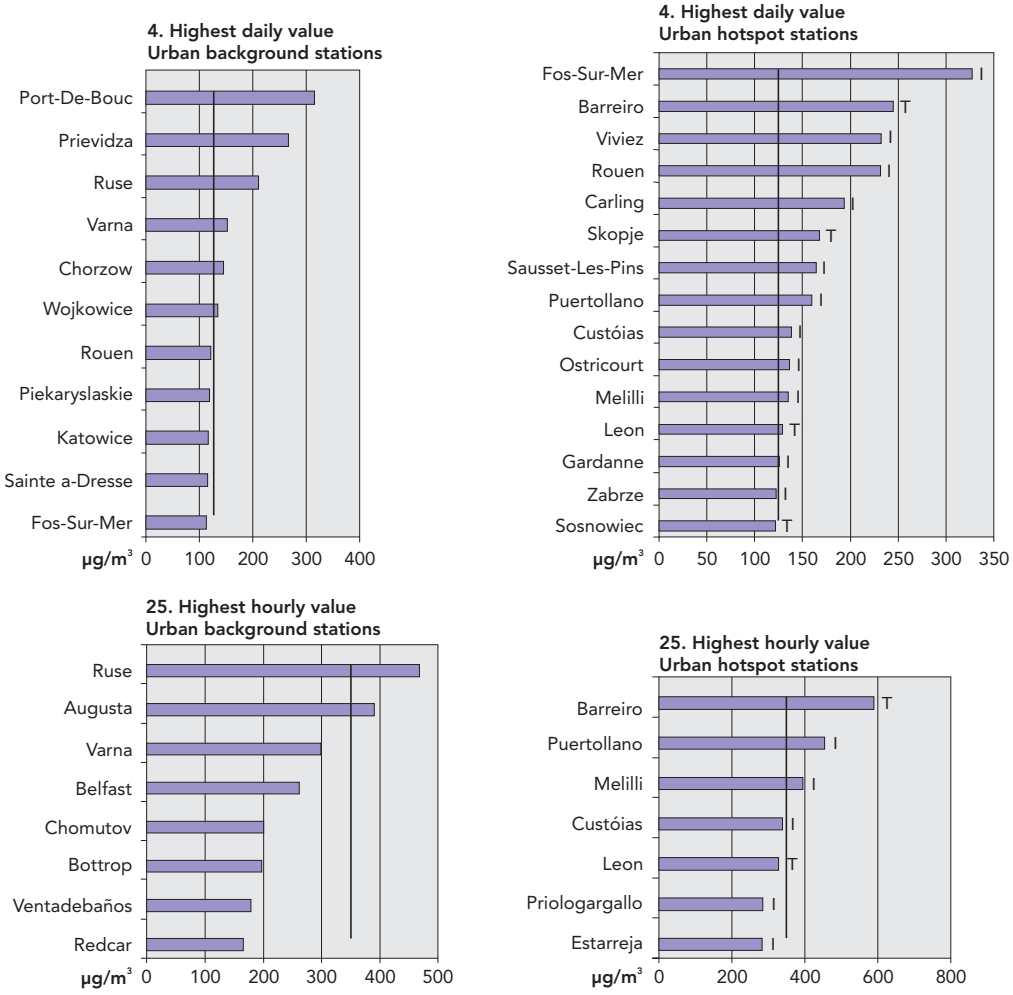


SO_2: Number of stations with exceedances of limit values (LV) of SO_2 and with concentrations between upper assessment threshold (UAT) and LV (1999). Table 2.5

4th highest 24-hour concentration: LV = 125 µg/m³, UAT = 75 µg/m³
25th highest 1-hour concentration: LV = 350 µg/m³

Country		4th highest 24-hour value			25th highest 1-hour value		
		Number of stations with concentrations		Highest concentration	Number of stations with concentrations		Highet concentration
	(Total number of stations)	C > 125	75 < C < 125	(µg/m³)	C > 350	210 < C < 350	(µg/m³)
Belgium	(47)	0	3	103	0	1	269
Bulgaria	(2)	2	0	209	1	1	467
France	(253)	11	27	327			
FYROM	(9)	1	5	167			
Germany	(385)	0	1	86	0	1	288
Italy	(56)	1	4	134	2	2	393
Norway	(8)	0	1	86			
Poland	(20)	2	10	144			
Portugal	(14)	2	3	244	1	3	587
Slovakia	(7)	1	1	266			
Spain	(89)	3	8	159	2	5	452
United Kingdom	(55)	0	1	75	0	1	261
All countries	(1 241)	23	64	327	6	14	587

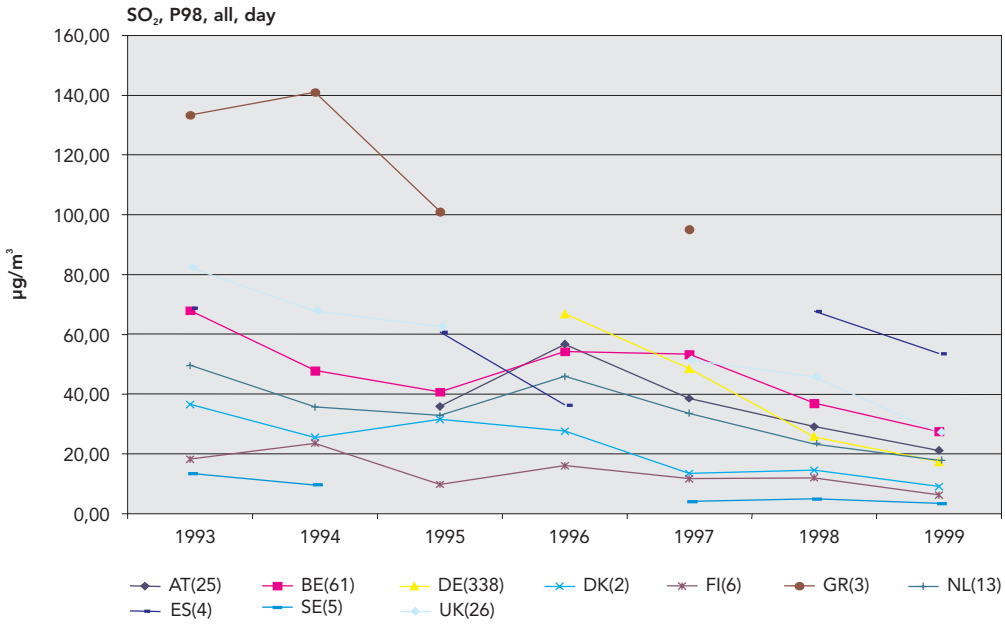
Cities with at least one station measuring SO_2 concentrations above or close to the relevant limit value, 1999. Figure 2.8



Note: Maximum station in each city.
Vertical lines indicate the LVs of the EU directives.
(T/I: traffic/industry hotspot stations).

Figure 2.9 **SO_2 trend. Nationally averaged concentrations, for stations with data reported to AirBase for all the years. (Numbers in brackets: number of stations).**

98th percentile of daily mean concentrations
(approximately 7th highest per year), all stations types



2.1.5. Carbon monoxide, local scale

A The issue

Human exposure to carbon monoxide (CO) can be toxic depending on exposure concentration and duration. CO displaces oxygen from haemoglobin in the blood resulting in hypoxic and ischaemic conditions, with heart and brains as sensitive organs. High levels of CO exposure can be directly lethal. Low-level CO exposure may cause reduced ability to concentrate and coordinate, nausea and cardiovascular malfunction. To protect foetuses in non-smoking pregnant woman from unwanted hypoxic effects, the CO-Hb level in blood should not exceed 2.5 %. A frequently used WHO guideline to limit such exposures to CO, even in people engaged in light or moderate exercise, is that ambient CO concentrations should not exceed the level of 10 µg/m^3 as an eight-hour average.

Presently CO in outdoor air has been reduced in most cities, as a result of control of its main source of high concentration, petrol-powered cars, especially at low driving speed. This source is being effectively controlled through improved motor technology and catalytic converters. However, concentrations are still higher than limit values at some traffic hotspot stations in Europe.

B Limit values for CO in EU Directive 2000/69/EC

Averaging time	Limit value	Comment	Target date
8-hour average	10 µg/m^3	No allowable exceedances	2005

C Indicator used

Policy target indicator:

- Extent of areas with exceedance of CO limit values:
  — maximum 8-hour average concentration

D CO concentrations in Europe, 1999

CO data were reported from 673 stations in 21 countries. Of these, 340 are hotspot stations, mainly traffic type stations. The CO concentration at about 20 of these stations is higher than the limit value, and of these there are four stations with concentration more than 50 % higher than LV (Map 2.10), in Portugal, Spain, Italy and Greece. The urban background concentration of CO is lower than the LV in all the cities with data, but in nine of the cities there are urban background stations with CO higher than the upper assessment threshold (UAT).

The number of stations in each country with CO concentration above the limit value and the UAT is shown in Table 2.6. The maximum 8-hour average concentration recorded in 1999 was 22 µg/m³, in Portugal (LV = 10 µg/m³).

The concentrations at the most exposed stations are shown in Figure 2.10.

E Conclusion

Although CO levels are being reduced in most countries due to penetration of three-way catalyst-equipped cars, high exposures to CO still occur in several cities, e.g. in southern Europe.

CO at hotspot stations, 1999 Map 2.10

Maximum 8-hour concentration.
The maximum station in each city relative to EU limit value (LV) and upper and lower assessment thresholds (UAT, LAT).

LV = 10 µg/m³; UAT = 7 µg/m³; LAT = 5 µg/ m³.

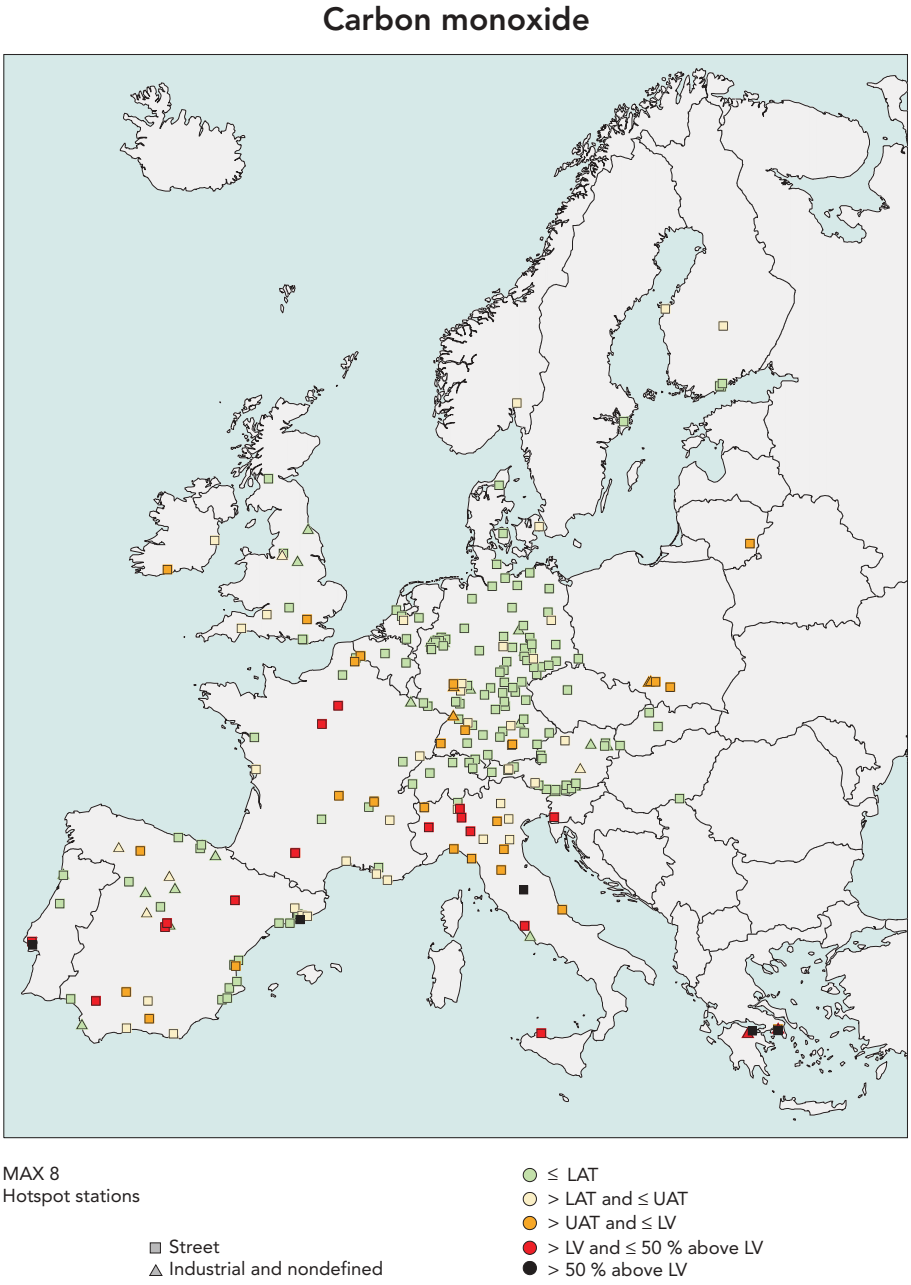
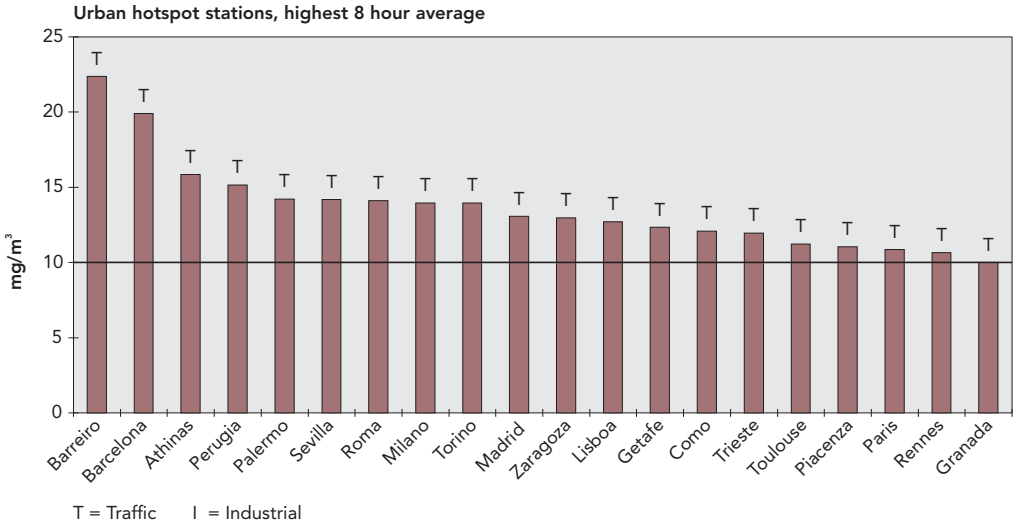


Table 2.6 **CO: Number of stations with concentration higher than the limit value (LV) and with concentrations between the upper threshold (UAT) and LV (1999).**

Maximum 8-hour average: LV = 10 µg/m³
UAT = 7 µg/m³

Country	(Total number of stations)	4th highest 24-hour value Maximum 8-hour value Number of stations with concentrations C		Maximum 8-hour value
		C > 10	7 < C < 10	(µg/m³)
France	(53)	3	10	11
Germany	(273)	0	9	9
Greece	(5)	4	1	19
Italy	(68)	18	15	15
Lithuania	(3)	0	2	9
Poland	(10)	0	6	10
Portugal	(14)	3	3	22
Spain	(58)	7	7	20
United Kingdom	(54)	0	1	8
All countries	(674)	35	54	22

Figure 2.10 **CO concentrations in cities in Europe (1999) with reported concentrations higher than the EU limit values**



Note: Highest station in each city.
Horizontal line indicates the LV of the EU Directive.

2.1.6. Benzene, local and urban scales

A The issue

Benzene is genotoxic and carcinogenic to humans and no safe level of exposure to protect human health can be recommended. WHO recommends in its Air Quality Guidelines a unit risk factor for leukaemia of 6×10^{-6} per µg/m³ for benzene associated with lifetime exposure. This is equivalent to an excess lifetime risk of one in a million people (1×10^{-6}) at a benzene level of 0.17 µg/m³. The EU has adopted a limit value of 5 µg/m³ benzene as an annual average (target year 2010) and has indicated a range of 0.2–20 µg/m³ as levels associated with a negligible excess lifetime risk.

Benzene in air originates from petroleum derivatives. Incomplete combustion of petroleum results in emission of benzene to air, partly from the benzene contents of the petroleum, partly as a result of other incompletely combusted petroleum

constituents. Benzene is also emitted by evaporation of petrol, such as from petrol filling stations and tanks of cars. Benzene emissions are controlled mainly by reducing the benzene content of petrol and by controlling the evaporation from tanks at filling stations and in cars.

Up until 1999, benzene concentrations were above the LV at locations in many European cities. Exposure is largest near traffic, and at petrol stations.

The available information is sufficient for an analysis of the tendency.

B Limit values for benzene in EU Directive 2000/69/EC

Averaging time	Limit value	Target year
Annual average	5 µg/m³	2010

C Selected indicator

Policy target indicator:

- Extent of area/cities where the benzene limit value is exceeded:
  — Annual average

D Benzene concentrations in air in Europe, 1999

Very few countries have so far reported monitoring data for benzene to AirBase. Valid 1999 data was reported only by Belgium (8 stations) and 1998 data was reported by the Netherlands (4 stations). Germany has reported benzene data, but the quality assessment of the data was not completed at the time of production of this report.

The 1999 Belgian benzene annual average concentrations were higher than the LV at all 8 stations, with maximum 21 µg/m³ (LV = 5 µg/m³). The 1998 results were significantly lower than in 1999. The Dutch 1998 data were all below the LV.

These data are obviously quite insufficient for making a European assessment.

The EU Working Group on benzene (EC, 1997b) collected available data from 1995–1996. A summary is shown in Table 2.7, together with monitoring data from Norway (1997–98). At that time, the benzene concentration in most urban background areas was below the LV, but some were above, and as high as 9 µg/m³. At traffic hotspots, the concentration was well above the LV at all stations, and as high as 32 µg/m³.

As seen from the above, the extent of available measured benzene data is very limited. The results from modelling exercises can broaden the picture.

Benzene concentrations in air was modelled in the Auto Oil 2 (AOP2) programme (detailed modelling in 10 cities as well as indicative modelling in 192 cities covering about 30 % of the urban population in EU-15 (de Leeuw et al. 2001)).

The 10-city modelling gave, for 1995, exceedance of the 5 µg/m³ annual averages of between 4 and 62 % of the population in the cities of Madrid (4 %), London (7 %), Milan (43 %), Lyons (50 %), Berlin (52 %) and Athens (62 %). The highest urban background concentration calculated was 22 µg/m³ (in Lyons). The 192-city modelling provided as an indicative result that about 50 % of the population in those cities was exposed above the LV.

The measured and modelled results both indicate that there was (before 2000) a significant benzene exposure problem in European cities.

The introduction of a maximum content of 1 % benzene in all petrol sold in Europe after 1 January 2000 is expected to reduce the benzene concentrations in air by at least 50 %. The AOP2 modelling indicates exceedance of the LV in only a few cities by 2010.

E Conclusion

The limited data that is available indicates that benzene exposure above the EU limit value was probably extensive up to 2000. It has been estimated from a modelling study that 50 % of the urban population in EU-15 is potentially exposed to concentrations above the limit value. The exposure above the EU limit value is expected to be significantly reduced as a result of the fuel directive restricting benzene contents in petrol to 1 %, to be complied with from 1 January 2001.

Table 2.7 **Summary of European benzene concentration data from 1995–97 (References: EC (1997b); Hagen (1999)).**

Germany (1995)				
Urban background	17 cities:	Mean:	3.5 µg/m³	One station above LV
Traffic hotspots	33 stations:	Mean:	9.2 µg/m³	All stations above LV
Industrial hotspot	1 station:		13 µg/m³	
Rural	6 stations		0.6–1.8 µg/m³	
Sweden (1995-96)				
Urban background (winter average)	43 cities/towns:	Mean	3.5 µg/m³	One station above LV
Firenze, Italy (1996)				
Urban background	2 stations:		6–9 µg/m³	Above LV
Traffic hotspot	1 station:		32 µg/m³	Above LV
Norway (1997–98)				
Urban background	3 cities:		3.7–4.3 µg/m³	
Traffic hotspot	3 stations:		7.4–13 µg/m³	All stations above LV
Suburban	3 stations:		2.2–3.8 µg/m³	
The Netherlands				
Modelled data, near road network	30 km of road have concentration >10 µg/m³			

2.1.7. Lead

A The issue

Human exposure to lead comes from lead intake via food, water, dust and air. Food represents the largest intake; for children intake through dust from the ground may be equally or more important. Intake via air ranks second (about half of the intake through food), at moderate air lead concentrations. In relation to general population, the most critical health effects of exposure to long-term, low-level lead concentrations are those on haem biosynthesis, erythopoiesis, the kidneys, the nervous system and blood pressure. Higher lead intake may cause (especially in children) learning difficulties and anaemia. For the protection of the population from lead exposure, WHO recommends that the annual average concentration in the ambient air should not exceed 0.5 µg/m³. The value recommended by WHO has been adopted by EU.

Until the middle and end of the 1980s, lead in car exhaust originating from lead additives to petrol was the dominant source of lead in air. By the early 1990s lead had been removed to a large extent from petrol in most European countries.

Lead in air was earlier monitored extensively, but at present it is measured to a much smaller extent.

B Limit values for lead in EU Directive 99/30/EC

Averaging time	Value	Target year
EU Directive		
Annual average	0.5 µg/m³	2005

C Selected indicator

Policy target indicator:

- Extent of area with lead concentrations higher than the limit value:
  — Annual average concentration.

D Lead concentrations in Europe, 1999

Lead concentrations in air are presently reported to AirBase only by very few countries. For 1999, data were reported from Belgium and Romania, in total 13 stations.

Of the 11 stations, 13 had annual average value higher than the limit value, and the

maximum annual average was as high as 3 µg/m³ in Romania, and 0.9 µg/m³ in Belgium.

E Conclusion

The data reported for 1999 are obviously not sufficient by far for an assessment of lead concentrations in air in Europe. Lead was measured and reported to a much larger extent earlier, especially between 1989 and 1995 (see Figure 1.2). The lead removal from petrol is the reason for this development. In those parts of Europe were lead has been removed from petrol lead exceedances are limited to some industrial areas. In countries where lead is still used as additive to gasoline, high concentrations can still be expected near traffic.

2.2. Air quality and deposition as relevant to ecosystems

2.2.1. Sulphur dioxide and nitrogen compounds

A The issue

Gaseous acidifying compounds have been found to have a direct adverse impact on vegetation quite separate from the issue of acidification. Of concern are the compounds sulphur dioxide (SO_2) and nitrogen oxides (NO_x). These can have various biochemical and physiological effects, such as degradation of chlorophyll in leaves, damage to biological membranes and chloroplasts, and reduced photosynthesis. Lower plants such as lichens and mosses are particularly sensitive. The magnitude of airborne concentrations, duration of exposure, and frequency of impact are decisive in determining the scale of effects on plants. While acute effects may only be observed near very large points of emission, long-term exposure at lower concentrations can induce chronic effects.

Emissions are driven largely by energy production, industrial activity, and transport, with combustion of fossil fuels having particular importance. These pollutants can remain in the atmosphere sufficiently long to be transported thousands of kilometres, and thus to spread far from the original source of the polluting emission, crossing national borders over the whole of Europe. Air concentrations in rural areas will generally be determined by emissions from distant sources.

B Guidelines/targets

Ambient air quality for SO_2 and NO_x is regulated by Directive No 99/30/EC. The limit values, to be achieved by 19 July 2001, are given below. The general objective is to avoid, reduce or prevent harmful effects on the environment. There is, however, wide variation in the sensitivities of ecosystems across Europe. Member States are encouraged to designate zones with more stringent limits where valuable sensitive ecosystems require greater protection.

Targets for the emissions of these substances to be reached by 2010 have been set both within the framework of the European Union (EC, 2001), and under the UN ECE Convention on Long Range Transboundary Air Pollution (UNECE, 1999). The UN ECE Protocol in addition quotes assumed 1990 baseline emission values. Using these, the targets are presented below in terms of required percentage emission reductions.

C Selected indicators

Policy target indicators:

- Extent of areas with exceedance of the limit values for ecosystems protection (see Table 2.8).
- Annual Emissions of SO_2 and NO_x.

D Regional SO_2 and NO_x concentrations in Europe, 1999

Evaluation of ambient air concentrations relevant to ecological protection requires information for areas representative of broad regional circumstances. Suitable observations are made within EuroAirnet and within the EMEP programme serving the 1979 Convention on Long Range Transboundary Air Pollution. Observed data for sulphur dioxide in 1999 is available from 90 EMEP and 155 EuroAirnet rural sites, and from 74 EMEP and 125 EuroAirnet rural sites for nitrogen dioxide. Thus there is ground truth data from which the status of regional air pollution of SO_2 and NO_x can be described.

However, on the European scale the distribution of monitoring stations is, to a degree, uneven. A technique for overcoming the misrepresentation of air pollution patterns that may result is to supplement measurement data with model estimates. This has been done in recent years in EMEP using results from regional scale modelling by MSC-W. This combined technique used here to display estimated air concentrations during 1999 allows maximum use of measured ground truth data while minimising uncertainties in poorly represented areas.

Table 2.8 **Ambient air limit values for ecosystem protection from acidifying components**

Component	Limit value	Averaging period	Target year
Sulphur dioxide	20 µg/m^3	Year/winter	2001
Nitrogen oxides[1]	30 µg/m^3	Year	2001

[1] Total of NO + NO_2 expressed as NO_2

Table 2.9 **Target emission reductions (in %) for EU Member States 1990–2010**

	EU NECD[1]	UN ECE-CLRTAP[2]	
		EU15	All Europe[3]
Sulphur dioxide	77	75	65
Nitrogen oxides	50	49	44
Ammonia	15	15	17

[1] Targets for EU-15 from the National Emissions Ceilings Directive (No 2001/81/EC).

[2] Targets from the multi-pollutant Protocol, 1999. Emission reduction target for the EU corresponds to the emission ceilings for each Member State.

[3] European countries listed in 1999 UN ECE Protocol, Russian Federation as PEMA area.

The technique is straightforward for sulphur dioxide, which is a single component. For nitrogen oxides, consisting of NO and NO_2, few stations monitor NO or the combination. Therefore, first the observed NO_2 data has been combined with model estimates as described above, and to this model estimates of NO have been added without reference to monitored values. NO model estimates are for a height of around 40 m above ground level, this generally exceeding ground level concentrations. The overestimate is estimated to be less than 10 % of total NO_x concentrations. Figures 2.11 and 2.12 display estimated 1999 annual average air concentrations for sulphur dioxide and for nitrogen oxides respectively.

Figure 2.11 reveals that for the greatest part of Europe concentrations of sulphur dioxide in rural/background areas do not approach the limit value of 20 µg/m^3 SO_2 as an annual mean. Indeed, many areas experience very low annual mean concentrations. Small areas within Poland, the Czech Republic, the Balkans and the UK may reach this level. In Sicily, natural volcanic sulphur dioxide emissions can be expected to play a significant role.

Figure 2.12 for nitrogen oxides indicates that concentrations across much of Europe are higher relative to the control criteria than is the case for sulphur dioxide. For notable areas in the Netherlands, Belgium and northern Italy the annual average NO_x concentrations may have been higher than the limit criteria to protect ecosystems. Smaller areas in several additional countries across the continent may also have reached this level, i.e. in Spain, UK, France, Germany, Switzerland, Poland, Ukraine, Hungary and Romania.

2.2.2. Tropospheric ozone

Ozone exposure of ecosystems and agricultural crops results in visible foliar injury and in reductions in crop yield and seed production.

The exposure of and impact on vegetation and crops from tropospheric ozone is treated in section 3.2.1 on impact.

For 'state' description regarding rural ozone concentrations in Europe, see section 2.1.2 on ozone, and especially Map 2.4 on concentrations at rural ozone stations, and Figure 2.3 on ozone trends at rural stations.

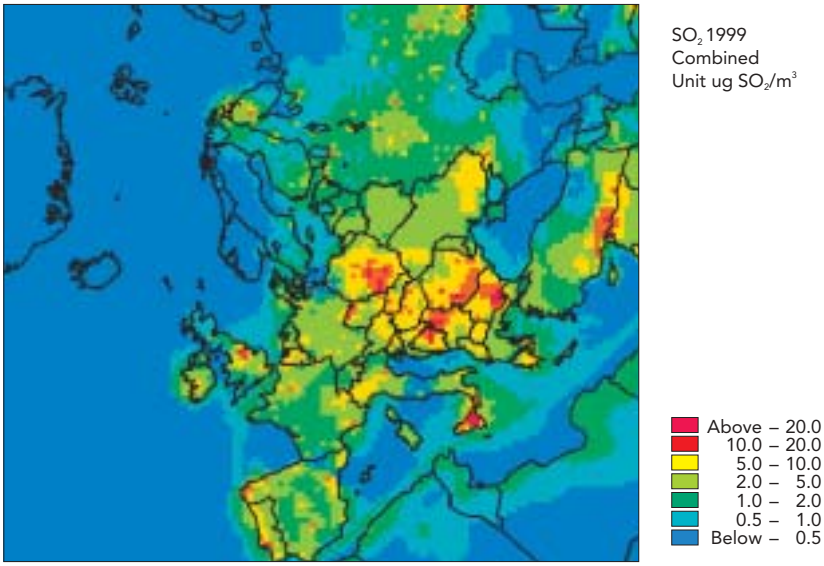
2.2.3. Deposition of acidifying and eutrophying compounds

A The issue

Observations in the 1960s that precipitation in Scandinavia was becoming more acid led to concern about acidification. The reaction of water with SO_2, oxidised nitrogen, and reduced nitrogen (NH_x – ammonia/ammonium) results in acidifying conditions. Consequences 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. Mechanisms are complex, but 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.

Air concentrations of sulphur dioxide (SO_2), annual average, µg/m³ 1999 Figure 2.11

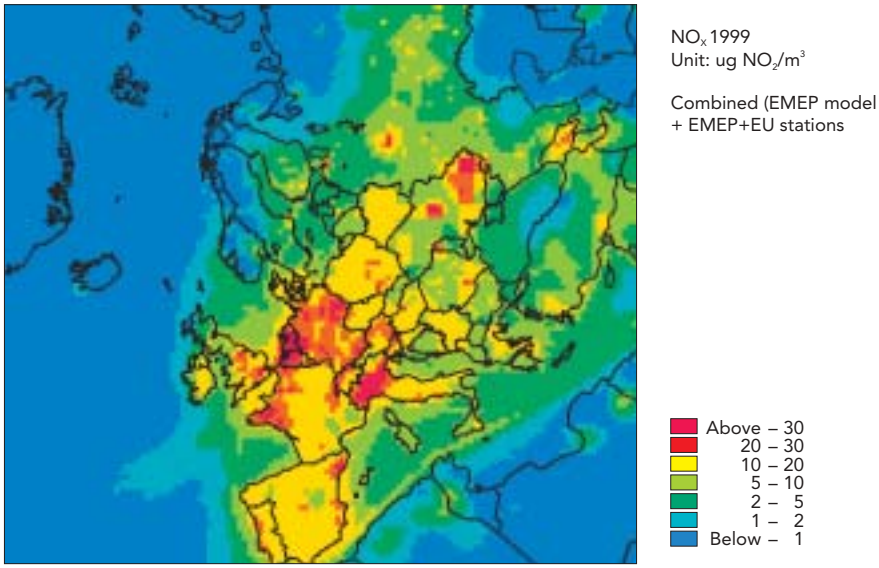
Observations from EuroAirnet and EMEP stations, and EMEP model estimates.



Produced ETC-ACC/NILU October 2001

Air concentrations of nitrogen oxides (NO_x), annual average, µg/m³ as NO_2, 1999 Figure 2.12

Observations from EuroAirnet and EMEP NO_2 stations, with EMEP modelled NO values



Produced ETC-ACC/NILU October 2001

Nitrogen is also a fundamental plant nutrient which is important for biological productivity. Thus, in addition to contributing to acidification, excess nitrogen deposition may overcome nutrient limitation. The enhanced growth, which results, 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, for example, to algae blooming.

The sources of sulphur and of nitrogen oxides involved, as described in section 2.2.1, are largely emissions from energy production, industrial activity and transport, with combustion of fossil fuels having significance. Ammonia is also a source of nitrogen, the sources of which are chiefly agriculture, with animal husbandry being predominant. This can have both eutrophying and acidifying effects. The point has been made earlier that acidifying pollutants can remain in the atmosphere sufficiently long to be spread far from the originating source of the polluting emission. Acidification is generally dependent upon emissions from distant sources.

B Guidelines/targets

A similar approach has been adopted by both the National Emissions Ceilings Directive [NECD] (No 2001/81/EC) of the European Union and by the multi-pollutant Protocol of the UN ECE (UNECE, 1999). Objectives of both include reduction of the deposition of acidifying components to the surface to a level at which significant harmful effects on sensitive elements of the environment do not occur. This threshold in depositions (below which such harm is avoided) is known as the critical load of acidity for acidification, and the critical load for nutrient nitrogen in the case of eutrophication. The intention is that atmospheric supply of sulphur and nitrogen will '…move towards the long-term objectives of not exceeding critical loads ...' NECD) and that this will be done '…in a stepwise approach' (UN ECE). However, the time scale for achieving the criteria of deposition below critical loads is unspecified by both measures. The NECD does set an interim target for deposition, but being expressed as a reduction of at least 50 % by 2010 of the area exceeding critical loads in 1990, this criterion pertains more properly to impact rather than state.

More attention is given to the emissions leading to the deposition, and defined emission rates with target dates are used as a surrogate for environmental objectives for direct deposition. Targets are listed as country-specific emission ceiling to be reached by 2010. The UN ECE Protocol also quotes assumed 1990 base year values, and taking these the EU and UN ECE targets are presented in Box 2 of Chapter 1 in terms of the percentage reductions in emissions which they require, aggregated for all EU Member States and other European states.

C Selected indicators

The state of the environment relevant to acidification and to eutrophication can be described by:

Policy target indicator:
- Annual emissions of SO_2, NO_x and NH_3 (pressure indicator, see Chapter 4).

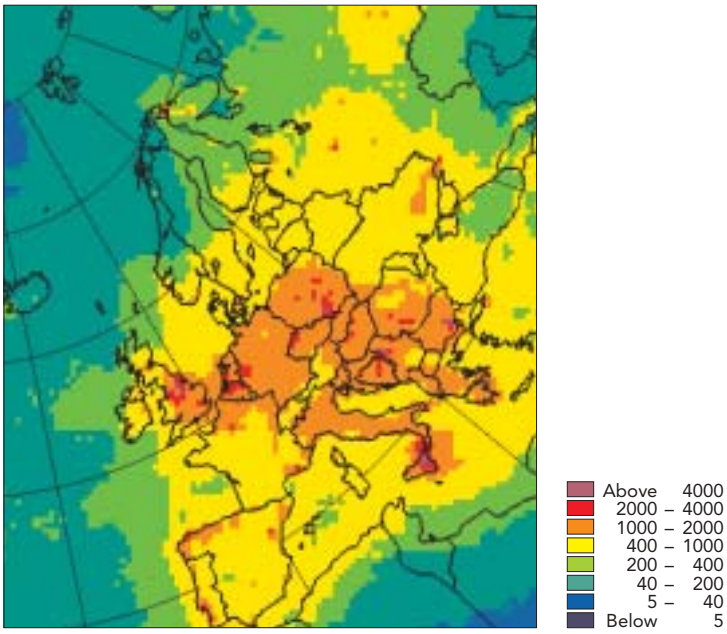
Explaining indicators:
- The total annual depositions of acidifying and eutrophying components in 1999, i.e. of sulphur and of total nitrogen, the latter combining both oxidised and reduced nitrogen

D Deposition of acidifying and eutrophying compounds in Europe, 1999

Since regional pollution is typically dependent upon pollutants emitted at great distances, EMEP has sought to gather information from regional background stations. At most of these, precipitation is sampled throughout the year and analysed for its nitrogen (86 stations) and sulphur (87 stations) content. These stations have irregular geographical coverage across Europe. No observations of precipitation deposition are available from AirBase. Further, neither programme monitors) dry deposition directly (the direct deposition to the surface of gases and aerosols, even though this can be substantial. Observations of air concentrations and sulphur components are more numerous than for the complete suite of nitrogen air components. In the light of the restricted data with consequent potential poor coverage of some regions, estimates of deposition of total sulphur and nitrogen (expressed in units of acidity equivalents) have been obtained from the model estimates made by MSC-W of EMEP. These modelling exercises have been conducted with close reference to available measurements in order to improve confidence in the estimated values.

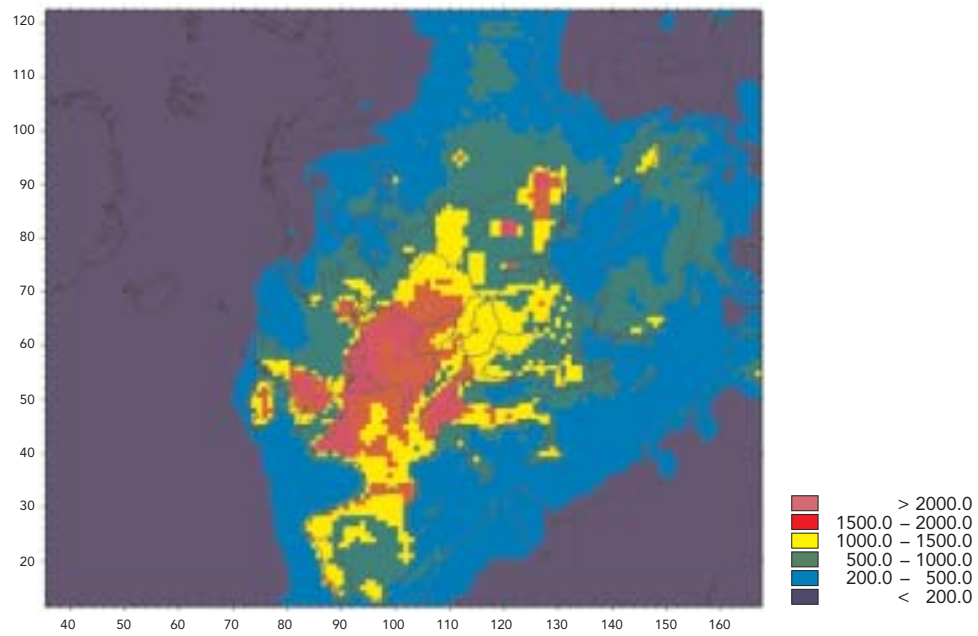
The central-eastern regions from Poland to the Balkans are still the areas receiving the greatest deposition of potentially acidifying air pollutants (Figure 2.13). A smaller region reaching from Germany through the Netherlands and Belgium to eastern England, also received acidity loadings of similar magnitude. The large deposition area in/near Sicily is due to emissions from the Etna volcano. Other localised depositions are also connected to local sources, usually anthropogenic. Figure 2.14 shows that the situation with regard to nitrogen alone is slightly different. Rather it is the northwest belt reaching from Poland around the southern North Sea to northern France and eastern England that is most heavily loaded.

Total deposition of acidity, 1999 combined total sulphur and nitrogen, expressed as H^+ equivalents per ha per annum. Figure 2.13



Calculated EMEP-MSCW

Total deposition of eutrophying nitrogen (oxidised + reduced), 1999 (mg (N)/m²/y) Figure 2.14



Calculated EMEP-MSCW

E Observed trends in deposition

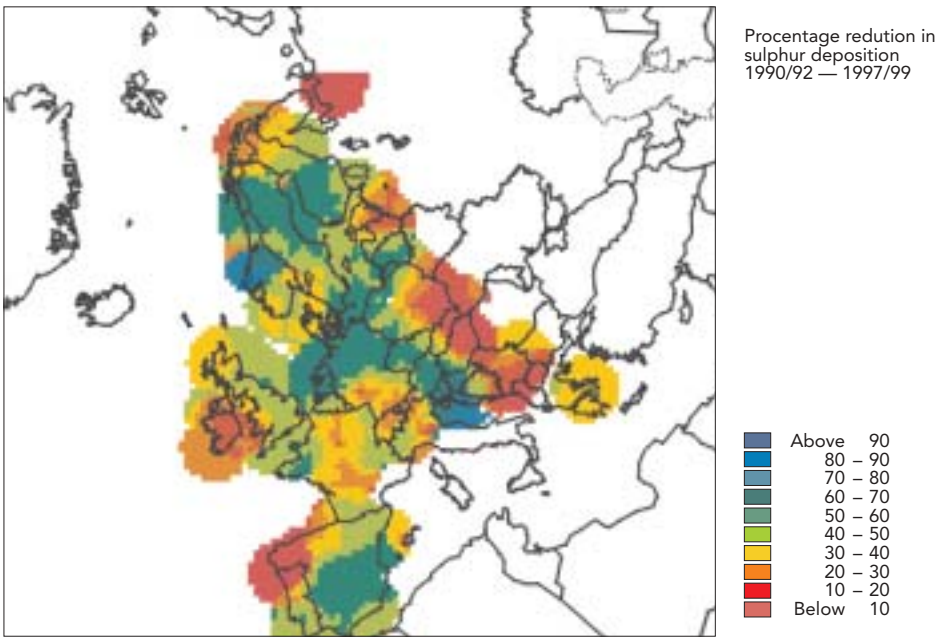
For Europe the monitoring programme operated under the UN ECE CLRTAP provides observations made consistently over extended periods and over wide areas and so can provide the ground truth data that permits the changing deposition of acidifying components to be evaluated. Attention to quality control and to consistency in measurements means that measurements across the continent can be reliably compared against each other as evidence of the success or otherwise of policies designed to abate acidification through air pollution.

Sulphur in precipitation and air has been measured extensively since the 1970s, allowing the observed changing sulphur deposition environment to be described cartographically for Europe. By combining observed wet depositions with calculated estimates of the direct 'dry' deposition to the surface based on observed concentrations of sulphur gas and particles, it is realistic to construct maps of observed total sulphur deposition. Construction of multi-year averages will notably reduce year-on-year variations due to weather differences. Figure 2.15 below displays the observed reductions in total deposition of potentially acidifying sulphur between 1990 and 1999. Here, the '1990' deposition values have been estimated as the average of observations for 1990–92, and the '1999' deposition values as the average of observations from 1997–99. By averaging over three years such a procedure will provide a more robust estimate of actual changes experienced in Europe. This shows the clear decreases in sulphur deposition that have occurred across Europe. For large stretches of northern, western and central Europe sulphur deposition in 1999 was around half, or less, than had occurred at the start of the decade. Beyond individual hotspots, the area with notably less improvement is the eastern belt from southeast Poland towards the south and east to the Balkans.

Observations of nitrogen began later and have been less extensive geographically throughout the whole of the decade. Thus it is not possible to present mapped changes in the same way. However, as a good guide to changes in nitrogen supply from the atmosphere the observations of oxidised and reduced nitrogen deposited in precipitation at 43 stations across Europe (Finland, Sweden, Norway, UK, France, Germany, Spain, Portugal, Switzerland, Italy, Czech Republic, Poland, Russia, Latvia, Lithuania, Yugoslavia) have been combined below in a single graph of percentage change (Figure 2.16). With the total depositions of oxidised and reduced nitrogen combined, normalised against the overall mean for each station, deposition throughout the 1990s is presented as a running 12-month average expressed as a percentage of depositions observed in 1990. The figure shows little change, and even some increase in the first years, and then a slight decrease in total wet nitrogen supply in the latter years. On average, wet depositions of total nitrogen in 1999 are estimated to have been at around 90 % of their 1990 level.

Derived from observed depositions of oxidised and reduced nitrogen in precipitation at 43 EMEP monitoring stations across Europe, 1990–99.

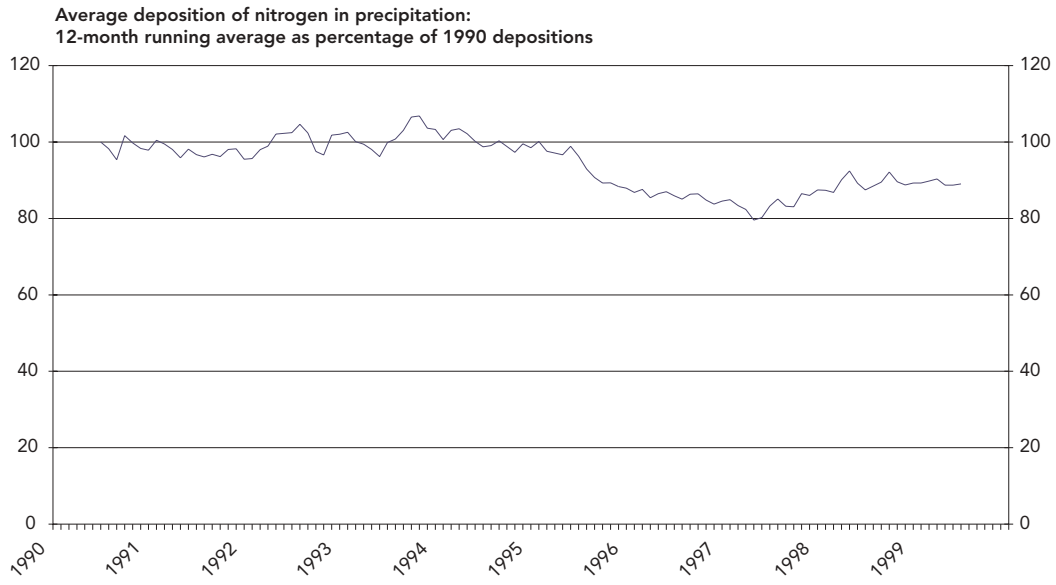
Figure 2.15 **Percentage reduction in annual sulphur deposition from 1990–92 to 1997–99[1]**



[1] Three-year averages.

Average deposition of nitrogen in precipitation:
12-month running average as a percentage of 1990 deposition.

Figure 2.16



2.3. Air quality as relevant to materials

A The issue

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 is dominating ('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 will increase the deterioration rates to materials. Also a mixture of other gases such as nitrogen dioxide and ozone will increase the natural corrosion. For the dose–response equation established today the dominating explanatory factors are sulphur dioxide and acid rain. For the moment 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 largest extent of impacts will occur there.

B Guidelines/targets

No limit or target values have been defined for atmospheric corrosion in the European Community work so far. The principles for how target values can be adapted have been developed by the UN/ECE ICP on Materials programme with support from ICP Modelling and Mapping, presented in a revised Manual (UN ECE, 2001). The Manual introduces the concept of acceptable rate of corrosion (K_a) and it is defined as a multiple factor (n) above the general background corrosion (K_b) in Europe ($K_a = n \cdot K_b$). The background corrosion rates are based in the results from the ECE ICP on Materials programme by using the lower 10th percentile of the observed corrosion rates as the background value, as given in Table 2.10. This background corrosion rate is in this concept considered constant across Europe, mainly because the data available are not sufficient to distinguish between areas in Europe.

Before the concept of acceptable rate of corrosion can be applied, agreement has to be reached on the value of the multiple factor (n). The value may be different for different areas, with a lower value for cultural heritage areas compared to more industrial areas. A multiple factor (n) in a range of 1.5–3 is considered to include the most acceptable values.

Table 2.10 **The values for the background corrosion rates (loss of material) as proposed in the ECE ICP on Materials programme.**

Material	1-year background corrosion rate, K_b
Weathering steel	72 g/m² (92 µm)
Zinc	3.3 g/m² (4.6 µm)
Aluminium	0.09 g/m²(uneven pitting corrosion)
Copper	3.0 g/m² (3.4 µm)
Bronze	2.1 g/m² (2.4 µm)
Limestone	3.2 µm
Sandstone	2.8 µm

C Atmospheric corrosion in Europe, 1999

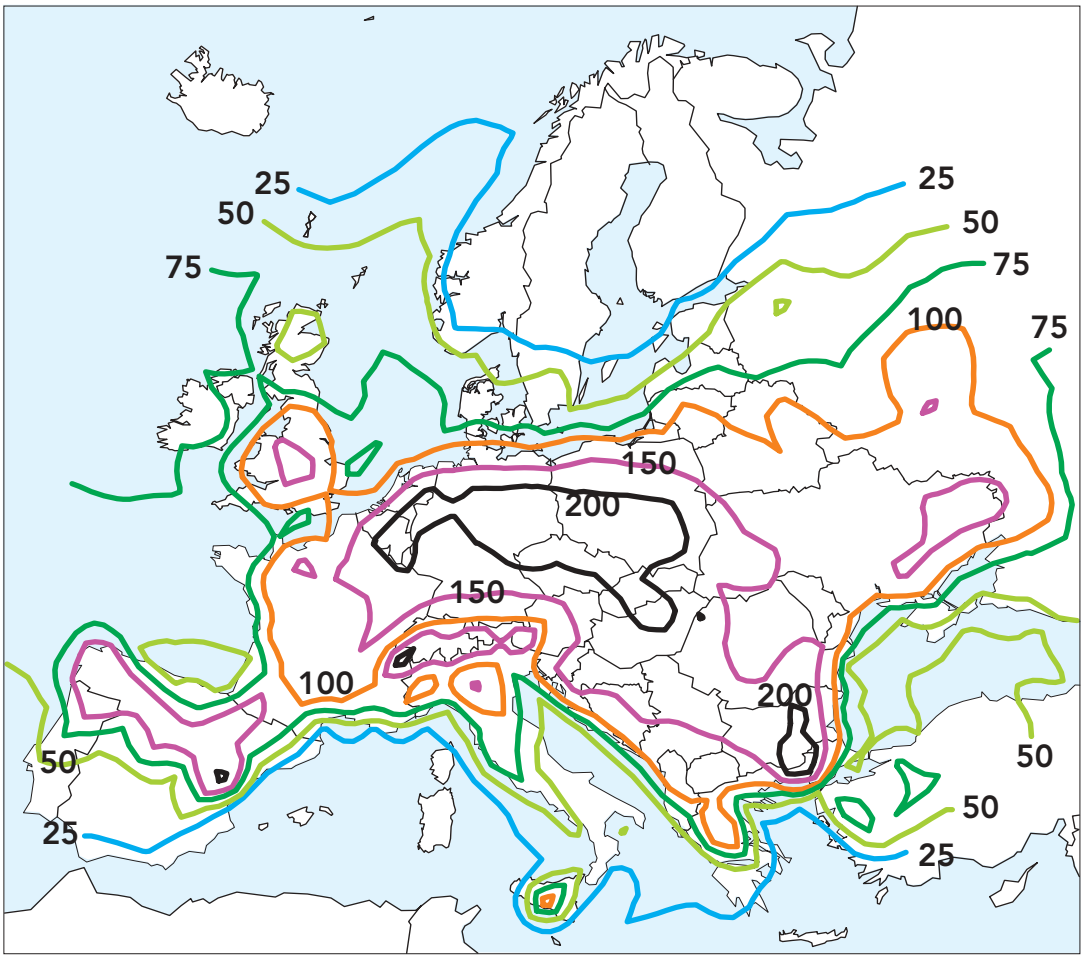
The ECE ICP on Materials programme has observed the corrosion trends in Europe since 1987. For almost all test sites a reduction of the corrosion has been recorded. The largest reduction has been observed at the most polluted sites. Even so, there is still fairly high corrosion above background at many places (Kreislova 1997).

Two different approaches can be used for illustrating the corrosion situation in Europe. The first is to use spatial distribution models for pollutants and to calculate the corrosion rates from these data by applying the dose–response equations for materials. The second is to expose samples of selected materials around in Europe and compare the annual corrosion rates obtained with one defined background corrosion rate. One example of both approaches is presented below.

For the spatial distribution approach copper has been selected as material and the EMEP Eulerian Model with values in 50 x 50 km grids for the spatial distribution of relevant pollutants. The results obtained are applicable for the rural part of Europe, while corrosion in

Map 2.11 **Copper corrosion rates above the background rate (in %)**

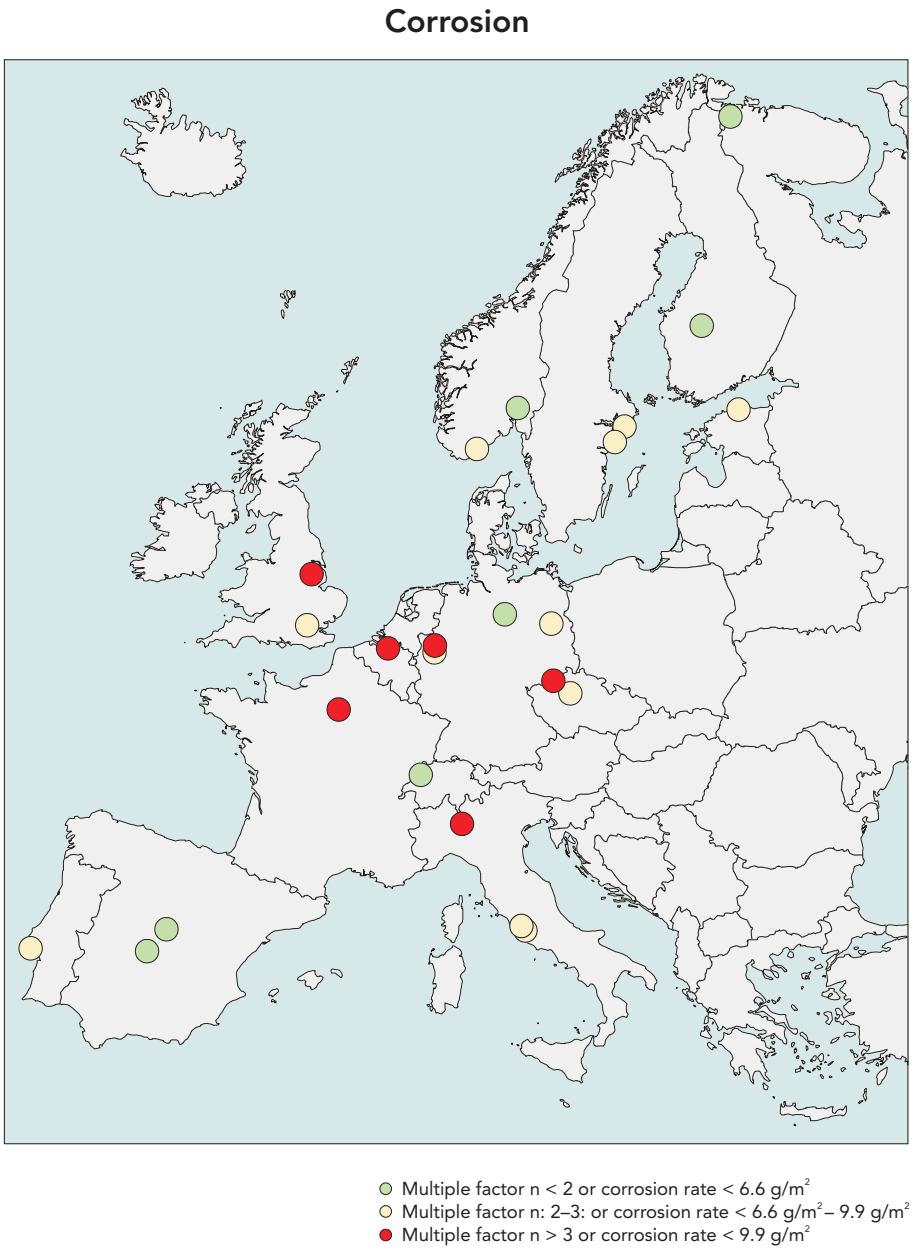
Source:
NILU/EMEP-MSCW



Zinc corrosion rates measured at exposure sites (1997–98) classified in terms of number of multiples above the background corrosion.

Map 2.12

Source:
NILU/EMEP-MSCW



urban areas will be higher. For the urban corrosion situation another spatial distribution model is needed. The results for the European rural scale are given in Map 2.11. The corrosion rate is divided in seven classes from below 25 % above and to above 200 % of the background. The highest corrosion still exist in the middle of Europe caused by sulphur dioxide, and in the inner part of the Mediterranean and an area north of the Black Sea because of the high ozone concentrations.

To give an example based upon the corrosion measurement approach, zinc corrosion measurements from the ECE ICP on Materials were selected. The results for zinc from 25 test sites in the programme are given in Map 2.12. The sites are not representatively distributed and will not give a complete picture of the total situation in Europe. Five sites have corrosion rates higher than three times the background rate (n>3), caused by poor air quality. Twelve sites have corrosion rates with multiple factor between 2 and 3, partly because of moderate pollution or with low pollution and higher wet acid load. Seven sites have low corrosion rates, some because they are dry sites such as in Spain or with low pollution and/or colder climate as in Finland and northern Norway

3. Impacts of air pollution

3.1. Impact on human health

A The issue

The limit values of EU directives and guidelines of the WHO have been set to protect the human population against unacceptable health risks associated with its exposure to air pollutants. The present extent of exceedances of the limit values was described in section 2.1.

When pollutant concentrations measured by the monitoring networks exceed limit values, health effects in the exposed populations are to be expected. For the purpose of this report, the extent of limit value exceedances and population potentially exposed to concentrations above the limits have been assessed. The fraction of the population in Europe potentially affected by exposure above limit values has been estimated as a first indication. However, the number and extent of exceedances of limit values do not represent the full extent of the health effects occurring in a population exposed to air pollution. This is especially the case for compounds for which there is no lower threshold of effects, although limit values have been established. For instance, for PM_{10} the WHO has found no evidence that there is a lower threshold of effects; therefore any increase in the PM_{10} concentration even from a very low concentration increases harmful effects in a population. For benzene, which is a carcinogen, there is also no lower effects threshold.

The extent of population exposure in Europe above the limit values has been estimated. As most people live in cities, and concentrations are often highest in cities, focus is here on urban air quality. It is not the intention to present a health impact assessment here. Such an assessment combines data on population exposure with information on exposure-response relationships derived from health effects studies to estimate the extent of health effects expected to result from exposure to air pollution.

B Selected indicator

The number of people potentially exposed to concentrations above the limit values for PM_{10}, ozone, NO_2, CO, lead and benzene.

C Population exposure to air pollutants in Europe, 1999

The cities for which data were reported to AirBase cover only a part of the whole urban population in the various countries, but it does represent a large sample of European cities. The maps in section 2.1 show the amount and distribution of cities with data for each compound. From this an estimate of the extent of exposure above limit values has been made.

As a start, the number of stations with concentrations above LV is summarised in Table 3.1. (Stations above UAT/UCL are included as well to broaden the picture with an indication of stations approaching the limit value (LV)). In all, 42 % of the urban PM_{10} stations and 29 % of the urban NO_2 stations were above the LV in 1999. All the rest of the urban PM_{10} stations were above UAT (Stage 2 indicative value, for 2010), and similarly another 20 % of the urban NO_2 stations were above the UAT for NO_2. For ozone, 26 % of the stations were above the target value (TV), both in rural and urban areas.

The number of cities with exceedances (at urban background and hotspot separately), and their total population, is given in Table 3.2.

The exposure situation for the urban European population covered by the measurement data in AirBase can be estimated as follows, taking PM_{10} as an example:

In all, 24 cities with 5.2 million inhabitants (out of the 80 cities monitored with 44.3 million inhabitants) have one or more urban background stations above the daily LV. Thus, 12 % of the total population in these 80 cities (representing about 20 % of European urban population) live in cities where the PM_{10} limit value is exceeded at urban background locations in part of their city.

The hotspot (mainly traffic) stations show exceedance of LV in 40 out of 65 cities with such stations.

The PM_{10} situation is visualised in Figure 3.1. After 1996 routine monitoring of PM_{10} has been introduced in EU-Member States in advance of the introduction of the first daughter directive. Therefore, the total population for which exposure estimates can be made increases strongly to about 50 million in 1999. In Figure 3.1 all types of stations (urban background and hotspot) are given the same weight. On that basis, in 1999, 38 % of the population had one or more monitoring stations in their city with PM_{10} concentration above the LV.

Similar estimates were made for NO_2 and O_3. For NO_2, about 42 % of the total population in 360 cities (representing 43 % of the European urban population) live in cities with exceedance of the long-term (annual) LV at urban background station(s).
In 23 out of 320 cities, there are hotspot (mainly traffic) stations with exceedance of the LV.

For O_3, about 28 % of the total population in 406 cities (representing 44 % of the European urban population) live in cities with exceedance of the short-term (8-hourly) TV. In addition comes the rural population, which also experiences ozone exceedances.

For SO_2 and CO, the extent of population exposure above LVs is presently much less than for NO_2, O_3 and PM_{10}. The urban SO_2 exposure situation has been substantially improved, even since the early 1990s.

In the Auto Oil 2 programme, estimates where made of population exposure above limit values for various compounds for the 1995 situation, based upon indicative modelling for 192 selected European cities, with a total population of 113 million (de Leeuw et al., 2001). From that exercise, the following estimates of population exposure above LVs in these 192 cities were made for the 1995 situation:

— NO_2:
About 65 % of the urban population live in cities with concentrations above LV in parts of the city.

— O_3:
About 25 % of the population in southern European cities and about 5 % of the population in northern European cities live in cities which are above LV in parts of the city.

— PM_{10}:
No estimate could be made, due to an uncertain model and lack of data for evaluation.

— Benzene:
About 50 % of the urban population live in cities above LV in parts of the city.

These fractions are not dramatically different from the fractions estimated from AirBase measurements, except for NO_2.

Note that in cities with exceedances, only part of the urban area is in exceedance. Measurements at hotspot locations show that the exposure above LV near the road network in cities is widespread. It is necessary to look in more detail into this topic, to find to what extent the traffic stations represent locations where people are actually exposed for at least 24-hour periods (i.e. whether they represent residential areas).

In addition to this urban exposure, the rural population is exposed to ozone above the limit value. Exceedances of the limit value were measured at 38 % of a large number of rural ozone stations in Europe, indicating that a similar fraction of the rural population is exposed to ozone levels higher than the LV.

How representative this exposure estimate for the cities included in AirBase is for the total European population must be left to judgement at the present time. As mentioned above, the cities in AirBase represent 20 %, 43 % and 44 % of the European urban population, for PM_{10}, NO_2 and O_3 respectively.

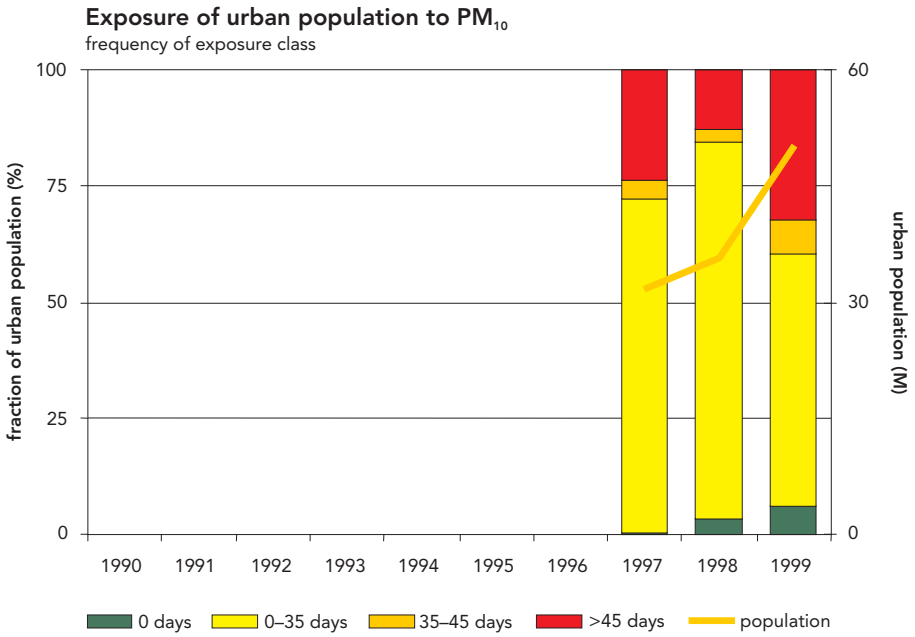
3.2. Impact on ecosystems

3.2.1. Impact of ozone

A Effects
Ozone exposure of ecosystems and agricultural crops results in visible foliar injury and in reductions in biomass production, crop yield and seed production. For vegetation, a long-term growing season cumulative exposure rather than an episodic exposure is of concern. Adverse effects on vegetation can be noted at relatively low ozone concentrations.

Figure 3.1 **Exposure of urban population in EEA18 countries to PM_{10}; exceedance days of 24-hour average PM_{10} concentration above 50 µg/m³, all types of stations.**

Source: Air quality database AirBase (ETC/ACC)



Note: Over the years the total population for which exposure estimates are made (right axis), increases strongly to about 50 million due to an increasing number of monitoring station reporting PM_{10} data. After 1996 routine monitoring of PM_{10} has been introduced in EU Member States in advance of the introduction of the first daughter directive.

Reference :http://themes.eea.eu.int/all_factsheets_box

Table 3.1 **Number of stations with exceedance of limit/ target values (LV/TV), and UAT/UCL(1), and maximum concentration measured relative to LV or TV (1999).**

	Total number of stations/ urban stations	No of stations >LV/TV		No of stations between LV/TV and UAT/UCL		Ratio between Max and LV or TV	
		Short term(2)	Long term(3)	Short term	Long term	Short term	Long term
PM_{10}	227/193	82	34	142	98	1.8	1.8
NO_2	1 145/926	38	268	127	203	2	3
O_3	1 142/512	292 (TV)	–	531 (UCL)	–	1.6	–
SO_2	1 241/850	6(h)	–	14 (UCL)	–	1.8	–
		23(d)	–	64	–	2.7	–
CO	673/673	35	–	54	–	2.2	–

(1) UAT (Upper Assessment Threshold) for PM_{10}, NO_2, CO and SO_2 (long term)
UCL (upper classification level) for O_3 and SO_2 (short term)
(In absence of upper assessment thresholds for O_3 and SO_2 (hourly values), UCLs were set for O_3 (at 100 µg/m³) and for SO_2 (at 210 µg/m³) purely for classification purpose).

(2) 1-hour, 8-hour or day, dependent upon compound

(3) Annual average
– Not applicable

B Ozone guidelines and target values

Parameter	Threshold value	Accumulating period	Comment	Target Year
AOT 40				
— EU Directive	18 000 µg/m³ .h	May–July	Target value, vegetation	2010
	6 000 µg/m³ .h	May–July	Long term objective, vegetation	
— CLRTAP	6 000 µg/m³ .h	Growing season	Long term critical level, crops and vegetation	

Number of cities and their population with reported data and with stations above LV and UAT/UCL (1999). Total European urban population: 234 million (in 29 EEA + PHARE countries). Table 3.2

		Cities w/data		Cities between LV/TV and UAT/UCL		Cities > LV		Cities > 1.5 x LV or TV	
		No	Popn	No	Popn	No	Popn	No	Popn
PM_{10}	UB	80	44.3	56	39.1	24	5.2	5	0.51
(day)	Hotspot	65		25		40		10	
NO_2	UB	360	100.0	81	31.2	45	41.5	7	21.3
(year)	Hotspot	320		62		23		3	
Ozone	UB	406	102.0	198	38.9	114	29.4	0	
(8-hour)									
SO_2	UB	366	94.7	14	4.4	6	0.7	3	0.25
(day)	Hotspot	338		30		13		5	

UB: Urban background stations
Hotspot: Traffic or industrial stations

C Selected indicators

Indicator:

- Area of exceedance of ozone target levels:
  — AOT40 for crops and vegetation

D Exposure and impact

Figure 3.2 shows areas in Europe where the AOT40 long-term objective for vegetation (6 000 µg/m^3 .h) was exceeded in 1999, based upon the rural type monitoring stations. Large-scale exceedances are prominent in most of Europe, where monitoring data are available, except for parts of the areas north of 53º N latitude. The target value (TV) of 18 000 µg/m^3.ha was also exceeded in large areas.

The area for which the measurements at the rural stations are assumed to be representative is tentatively indicated with a radius of 100 km. When evaluating the radius of what is representative, account should be taken of the emissions variations in the immediate surroundings and possible localised influence of dominating sources further away, as well as of topographical features influencing the dispersion and transport of the emissions. This will be attempted in future assessments of this kind. Thus, Figure 3.2 does not show the actual details in exposure in some areas, particularly in alpine regions. (de Leeuw et al., 2000).

Most vegetation in EEA18 countries is exposed to ozone concentrations exceeding the AOT40 guidelines. Large year-to-year fluctuations prevent firm conclusions on trends. The situation for EEA18 countries as a whole is shown in Figure 3.3 for 1999 as well as for years since 1990. In 1999, the critical level for crops was exceeded in about two thirds of the EEA18 area where data are available.

The area in Europe for which ozone data are available has increased steadily since 1990. The area of exceedance of critical levels has varied considerably between years. The tendency is that for crops, the area of non-exceedance 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.

3.2.2. Impact of acidifying and eutrophying gases and deposition

A Effects

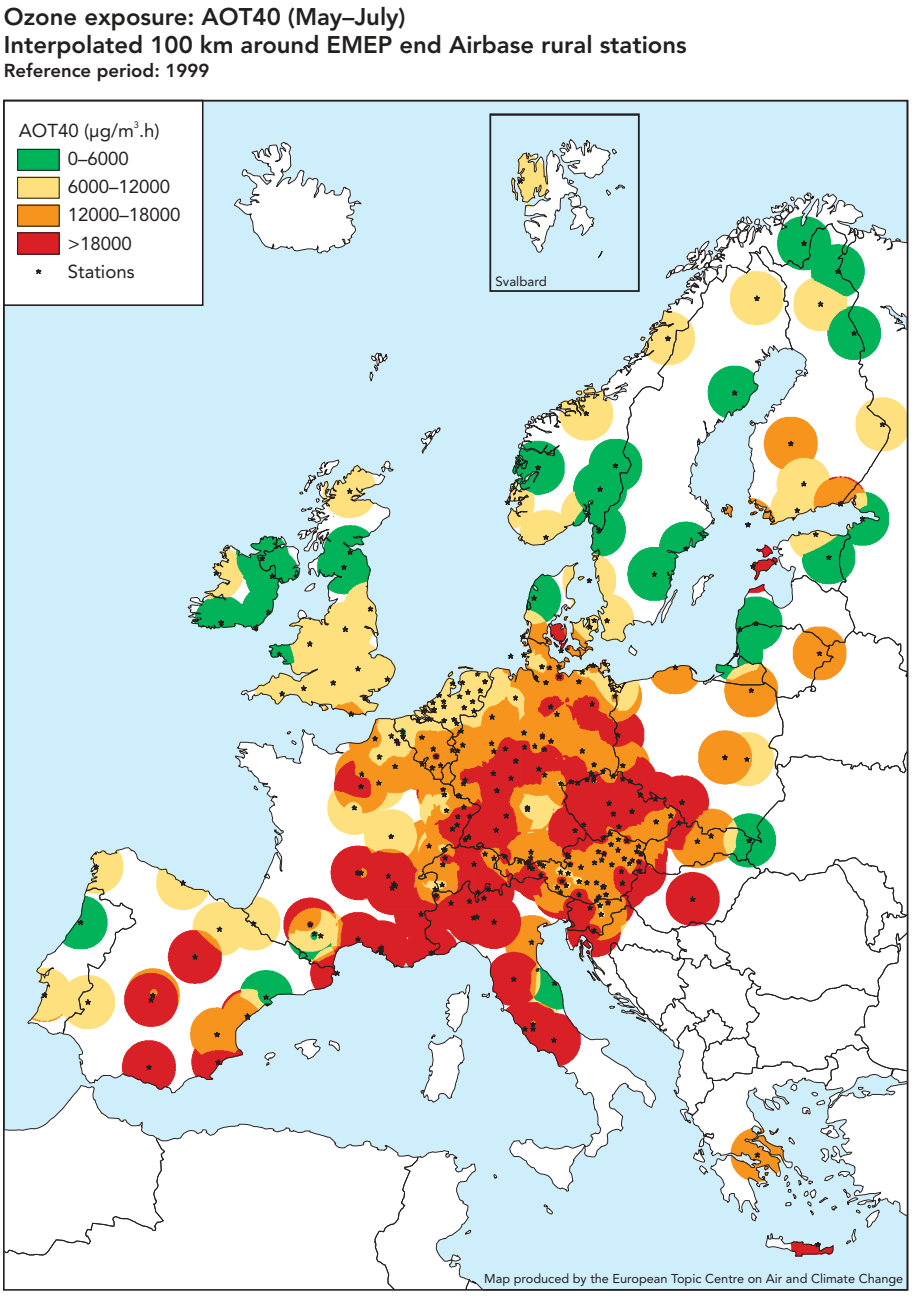
SO_2 and NO_x gases can have various biochemical and physiological effects on vegetation, such as degradation of chlorophyll in leaves, damage to biological membranes and chloroplasts, and reduced photosynthesis. Lower plants such as lichens and mosses are particularly sensitive. The magnitude of airborne concentrations, duration of exposure and frequency of impact are decisive in determining the scale of effects on plants. While acute effects may only be observed near very large points of emission, long-term exposure at lower concentrations can induce chronic effects.

Atmospheric deposition of acidifying and eutrophying compounds may also damage ecosystems. Soils and waters will have a natural capacity to absorb a certain quantity (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.

Figure 3.2 **Exposure above AOT40 threshold values for vegetation and crops around rural ozone stations 1999**

6 000 µg/m³ · ha: EU long-term objective for vegetation
CLRTAP long-term critical level for vegetation/crops

18 000 µg/m³ · ha: EU target value 2010 for vegetation



B Guidelines/targets

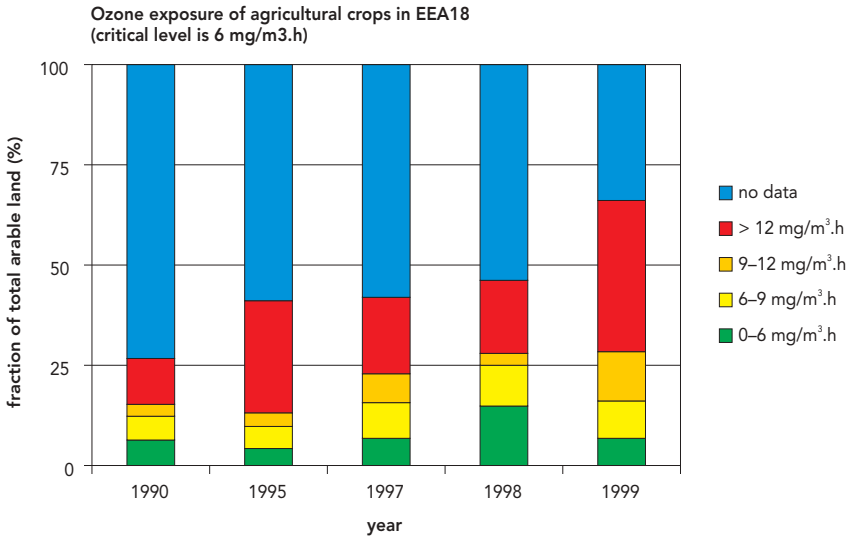
Air concentrations

The limit value (LV) for sulphur dioxide concentrations is 20 mg/m³ as both an annual average and as a wintertime average. For nitrogen oxides the LV is 30 µg/m³ annual average as NO_2.

Acidification and eutrophication

The objectives of both the EU NECD policy and the UN ECE multi-pollutant Protocol include reduction of the deposition of acidifying and eutrophying components to below relevant critical loads. Of these, the EU NECD includes the explicit interim objective to reduce by 50 % by 2010 the areas exceeding critical loads in 1990.

Tendency in exposure of vegetation to ozone (exposure expressed as AOT40 in µg/m³. ha) in EEA18 countries, 1990–99. Critical level is 6 µg/m³. ha. Figure 3.3



Reference: http://themes.eea.eu.int/all_factsheets_box

EU criteria for deposition of acidifying and eutrophying components Table 3.3

Criteria	Target	Time frame
Area exceeding critical loads	Reduced by 50 %	1990–2010

C. Exposure and impact

Air concentrations of SO_2 and NO_x gases

The map of annual average sulphur dioxide concentrations Figure 2.11 indicates no region experiencing adverse impacts from sulphur dioxide air concentrations. There is possibility of limited NO_x exceedance as may be seen in Figure 2.12.

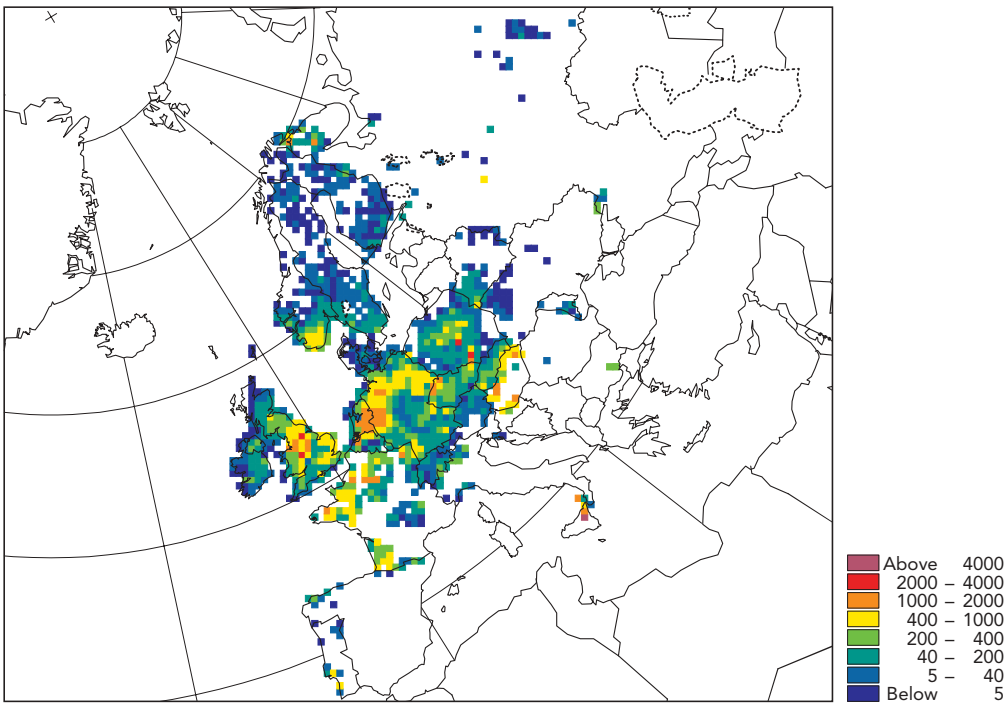
Critical loads for acidification and eutrophication

Estimation of the extent of exceedance of critical loads requires comparison of the estimated modelled deposition of sulphur and nitrogen with the calculated critical loads for acidity and nutrient nitrogen. This task is undertaken by the CCE/RIVM within EMEP. Results for 1999 are displayed in Figures 3.4 and 3.5.

The '5-percentile critical load' criteria represents the level at which 95 % of ecosystems in an area (commonly taken as 50 km² grid squares for CLRTAP or 150 km² grid squares in the NECD) will be protected from deposition of pollutants causing acidification or eutrophication. The areas that experience greatest exceedance are in northwest continental Europe. Areas in southern Europe are unaffected by acidification, while eutrophication is experienced more generally.

Critical load exceedance can also be evaluated in terms of the size of the areas experiencing exceedance. In Figures 3.6 and 3.7 the percentage of sensitive ecosystems in each country, which currently experience exceedance of their critical loads for acidity and for nutrient nitrogen are displayed. This shows that while there are some countries which still have very large proportions of their sensitive areas exceeding critical loads for acidity, for example the Netherlands at over 80 %, the Czech Republic at over 70 % and Germany and Hungary at over 50 %, the picture for nutrient nitrogen is more serious. Belgium, the Czech Republic, Luxembourg, Lithuania, France, the Netherlands and Germany have 100 % of their sensitive areas exceeding critical loads for nutrient nitrogen. While for acidity approximately 20 % of the EU's sensitive ecosystems are in exceedance, the figure for nutrient nitrogen is about 65 %.

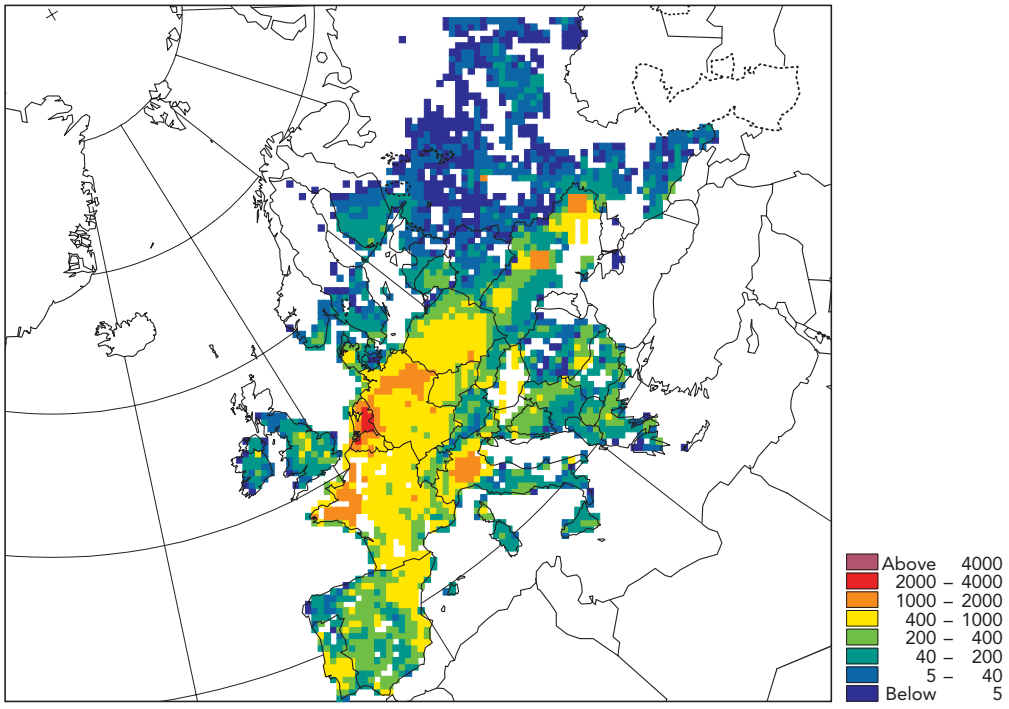
Figure 3.4 **Exceedance of the critical load* for acidity, 1999**



Calculations CCE-RIVM, depositions MSC-W

* Average accumulated exceedance of the 5-percentile critical load for acidity (eq/ha/yr).

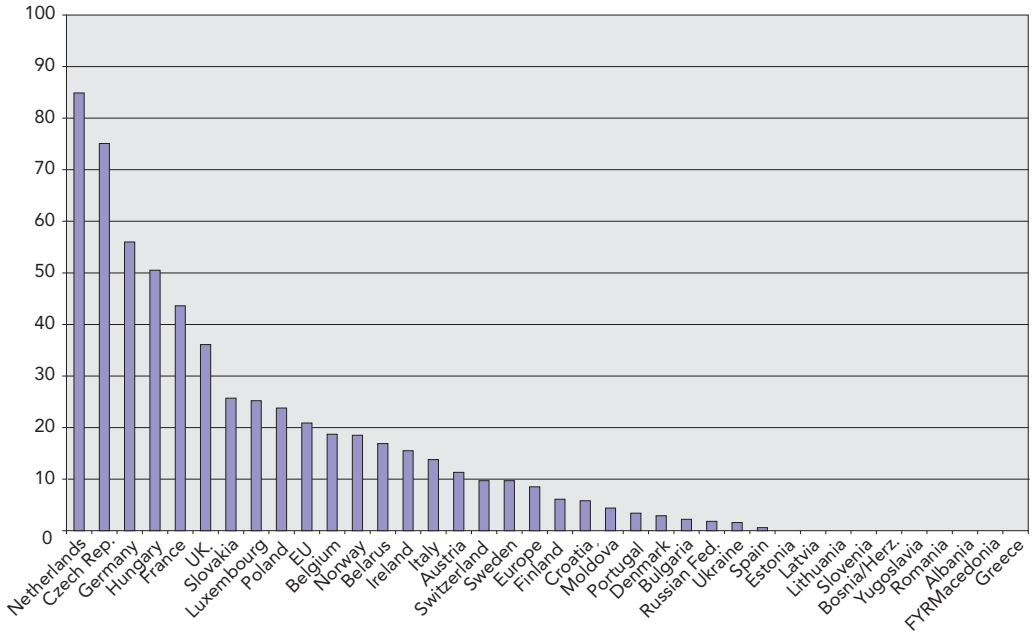
Figure 3.5 **Exceedance of the critical load* for nutrient nitrogen, 1999**



Calculations CCE-RIVM, depositions MSC-W

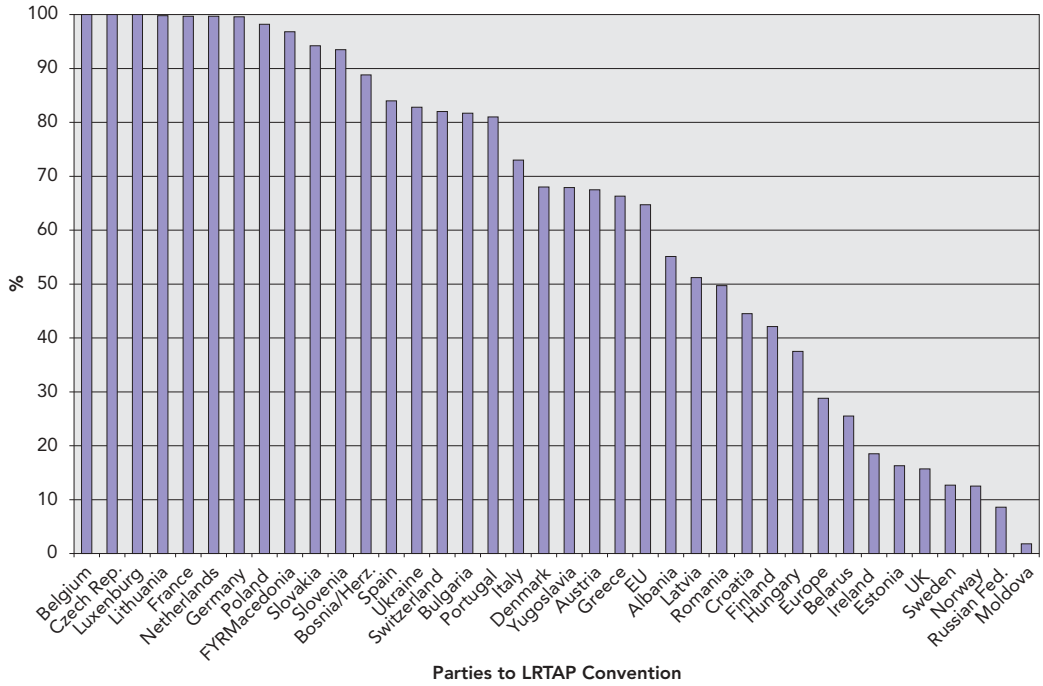
* Average accumulated exceedance of the 5-percentile critical load for nutrient nitrogen (eq/ha/yr).

Percentage of sensitive ecosystems area in each country exceeding critical load for acidity, 1999. Figure 3.6



Calculated by EMEP-MSCW

Percentage of sensitive ecosystems area in each country exceeding critical load for nutrient nitrogen, 1999. Figure 3.7

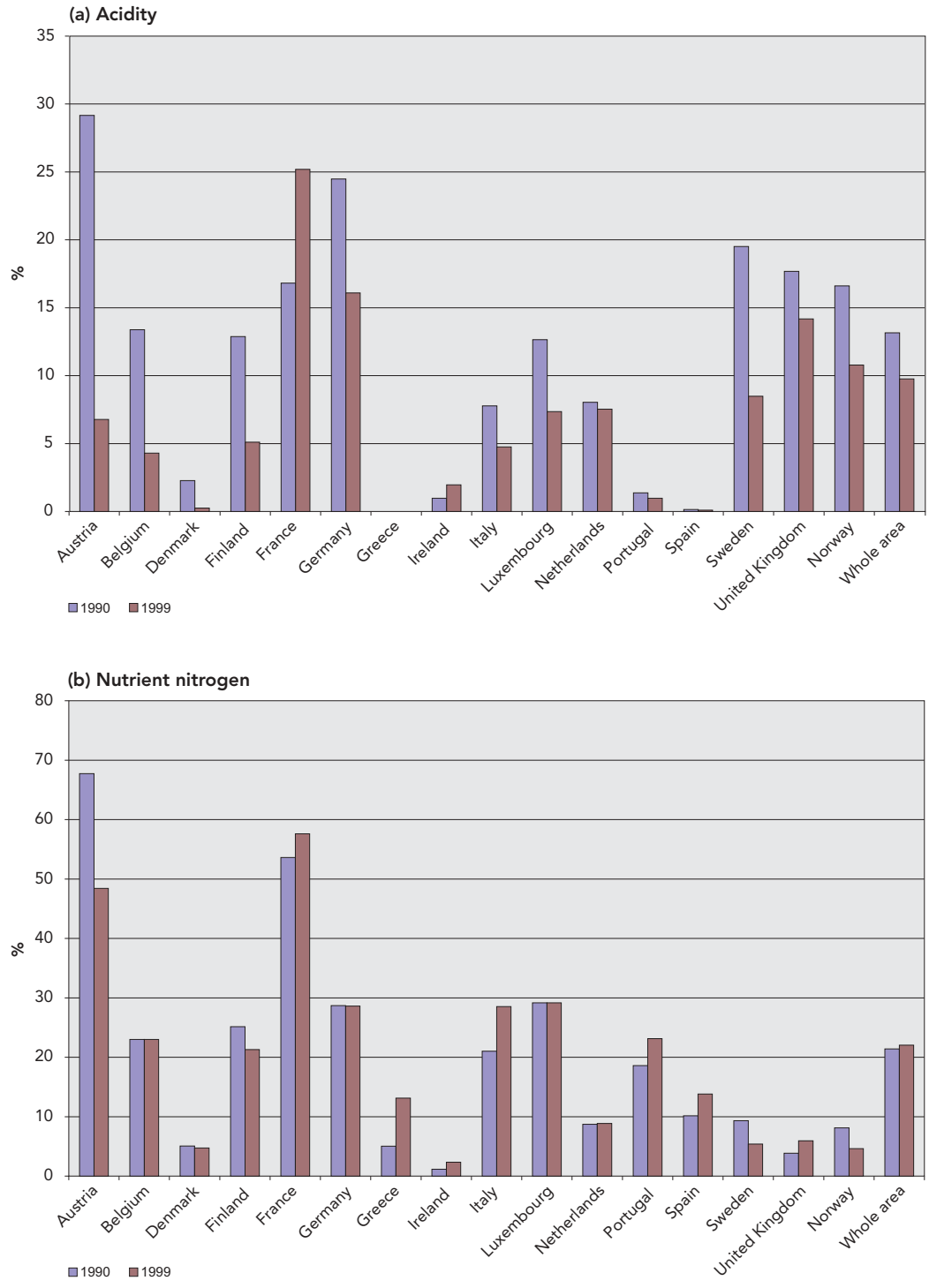


Calculated by EMEP-MSCW

The EU National Emissions Ceilings Directive (No 2001/81/EC) sets reductions in the size of areas exceeding critical loads as a target to be attained in future. Critical loads are set within grid squares overlaying Europe, and the criteria refer to reducing areas of these where the '5-percentile critical load' criteria is exceeded. Changes for individual countries during 1990–99 are shown in Figure 3.8 (a) and (b) for acidity and nutrient nitrogen, respectively. The trend for sulphur is fairly consistent across Europe, with most countries having 5–10 % less area in exceedance in 1999 than 1990. Austria,

Figure 3.8

Indicator of changing ecological impact: Areas of each country exceeding critical loads in 1990 and 1999 for: (a) acidity; (b) nutrient nitrogen.
(EEA18 except Iceland and Liechtenstein for which critical load data does not exist).



Calculated by EMEP-MSCW

with over 20 % of area achieving the criteria since 1990, and France, the only country with an increase in acidified areas (just short of 10 % extra of the country area), are the countries that do not follow the general pattern. As might be expected from the information on changing deposition of air pollution in section 2.2.3 D, the picture for nitrogen is more variable, and less obvious. Typical changes in land area exceedances have been of the order of a few percent since 1990, some countries showing greater and some lesser exceedance. These conclusions are, however, preliminary, since the information for 1990 and 1999 was calculated with different models.

3.3. Impacts on materials

Effects
A mixture of climatic affects all construction materials used and pollution parameters but the corrosion rates differ very much from one material to the next. In the 1960s and 1970s, sulphur was the most aggressive pollutant. Today the pollution situation is more complex and additional parameters are needed for explaining the corrosion behaviour. In coastal areas chloride is an aggressive parameter that increases the corrosion rate substantially.

Guidelines/targets
As explained in section 2.3 the concept of acceptable rate of corrosion (K_a) as a multiple factor (n) above the general background corrosion (K_b) in Europe is proposed as a basis for the evaluation of the corrosion situation. When an acceptable rate of corrosion is established, a 'back-calculated' acceptable concentration of pollutants can be established from the dose-response equations. This concentration will be different for different parts of Europe since the climatic impact is different. As an example, by using a multiple factor 2 and the climatic data for Paris, the acceptable annual value for SO_2 would be 7 µg/m^3, while using a factor 3, the acceptable SO_2 concentration would be 43 µg/m^3.

Selected indicators
In order to calculate corrosion cost on a European scale, information about the amount of materials exposed and its geographical distribution must be obtained. The percentage of the area or percentage of cities with corrosion rate above the acceptable rate may be used as an indicator of corrosion damage, as illustrated in Map 2.11 for copper and in Map 2.12 for zinc.

Impact
The costs related to material deterioration have been estimated in different studies and for different scales. In the most comprehensive study so far, ExternE (ApSimon, Pearce and Özdemiroglu, 1995) it was estimated that the corrosion costs caused by pollutants for Europe in 1995 was about 11 billion/year.

By using the geographical approach on copper corrosion and counting the grids with a corrosion ratewhich is more than double the background corrosion rate (n>2 or 100 % above background), 30 % of the land area has a corrosion rate above this limit (Map 2.11).

Based on the zinc corrosion measurements (Map 2.12), which include a higher percentage of polluted sites, 70 % of the sites have zinc corrosion more than double that of the background corrosion.

4. Economic sectors and sources of air pollution

4.1. Contributions to emissions from economic sectors — an overview

The focus of this chapter is on the economic sectors driving the polluting emissions that put pressure upon the environment. These driving forces are changing over time and hence, in addition to describing circumstances in 1999 the time evolution leading to current emission pressures are also presented. The relevant indicators for this are the emissions of gases and particles with potential impact upon policy target themes, and emission contributions from various economic sectors to each theme. Where appropriate eco-efficiency indicators of the economic sectors are considered. All information in this chapter has been derived from the companion report 'Emissions of atmospheric pollutants in Europe, 1990–1999', also prepared by the European Topic Centre on Air and Climate Change (EEA, 2002). Figures 4.2–4.7 have a different format than that of the corresponding figures shown in the Emissions report, as also shown in the emissions fact sheets. However, the underlying data are identical.

The three fields of impact are represented by the following groups of pollutants:

- Health impact:
  PM_{10}, tropospheric ozone, NO_2, SO_2
- Ecosystems impact:
  Acidifying potential, eutrophying potential, tropospheric ozone formation potential, SO_2, NO_x
- Materials impact: SO_2, ozone.

Below, the discussion in section 4.2 below is summarised.

Emissions contributions from sectors:
Figure 4.1 shows the relative importance of the different economic sectors that contribute to emissions of the relevant (groups of) substances. Emissions of acidifying pollutants and PM_{10} are defined as given in the report on Emissions of atmospheric pollutants in Europe, 1990–99. PM_{10} emissions are composed from emissions of SO_2, NO_x and NH_3, along with primary emissions of particles; ozone precursor emissions are composed of VOC, NO_x, CO and CH_4. Potentially eutrophying emissions are defined as $^{14}/_{17}\ NH_3 + {}^{14}/_{46}\ NO_2$ (de Leeuw, 2002).

The main sources of pressure on ecosystems come from transport, energy, and agriculture. For health and materials impact, the main sources are transport, energy, and industry. Transport is a major driving force for all air pollution issues.

Trends in sector activity and emissions:
Within the energy sector, emissions have decreased between 1990 and 1998 despite an increase in total energy consumption of 15 % in the same period. Reductions are due to implementation of end-of-pipe abatement measures, increased efficiency in power generation strategies and the increased share of natural gas.

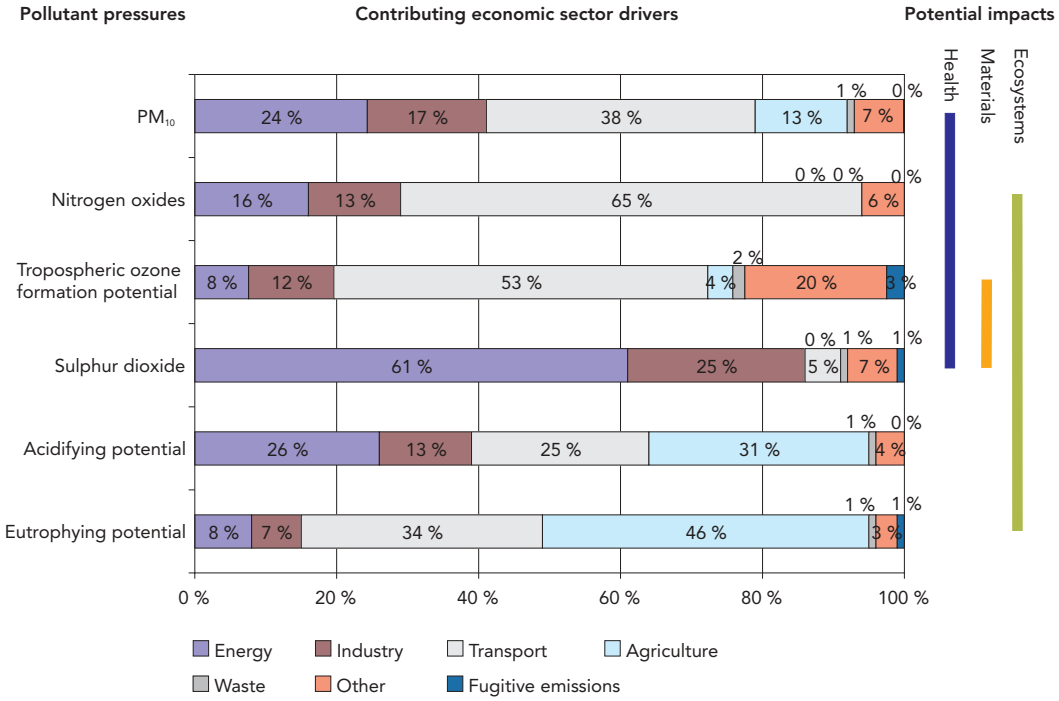
Industrial sector emissions also decreased, while production and energy use in 1998 remained around the 1990 levels. This suggests a positive development of eco-efficiency also in industry. Emission reductions are due to a range of abatement measures like end-of-pipe technology, increased energy efficiency and a trend from solid and liquid fuel to natural gas. The large combustion plant (LCP), the integrated pollution prevention and control (IPPC) and the VOC directives are expected to contribute to further emission reductions.

Transport sector emissions have also declined even though activity has increased (passenger road transport by 16 % during 1990–98). Emission reductions are mainly due to an increasing share of petrol driven passenger cars fitted with catalytic converters. There has, however, been little or no improvement in energy efficiency of transport. Reductions in agricultural sector emissions of ammonia and nitrous oxide have been mainly due to reductions in livestock numbers. Changes in agricultural practices will be necessary to reduce emissions further.

Figure 4.1 shows overlap between pollutants and fields of impact. Pollutants affecting materials are not exclusive to that impact, but also affect health and ecosystems as well. In the remainder of this chapter we will consider emissions within two broad categories: emissions and health, and emissions and ecosystems.

Sectoral contributions in the EU to emissions of pollutants relevant to health, ecosystems and materials, 1999.

Figure 4.1



Emission of Primary PM_{10} and PM_{10} precursors (NO_x, SO_2 and NH_3). Total and contribution from main sectors. 1990–99.

Figure 4.2

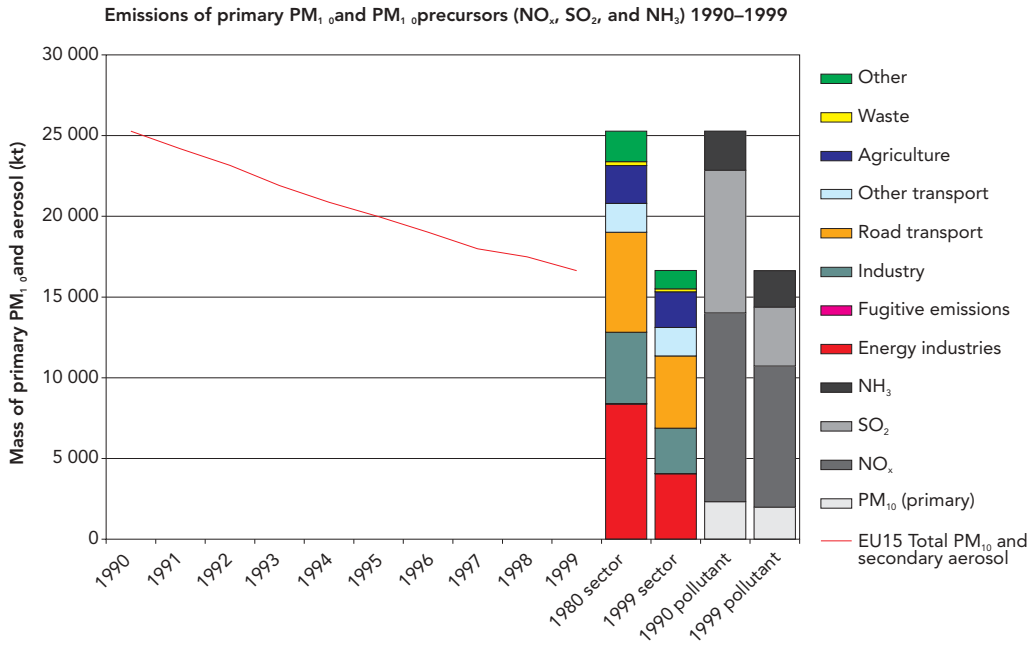
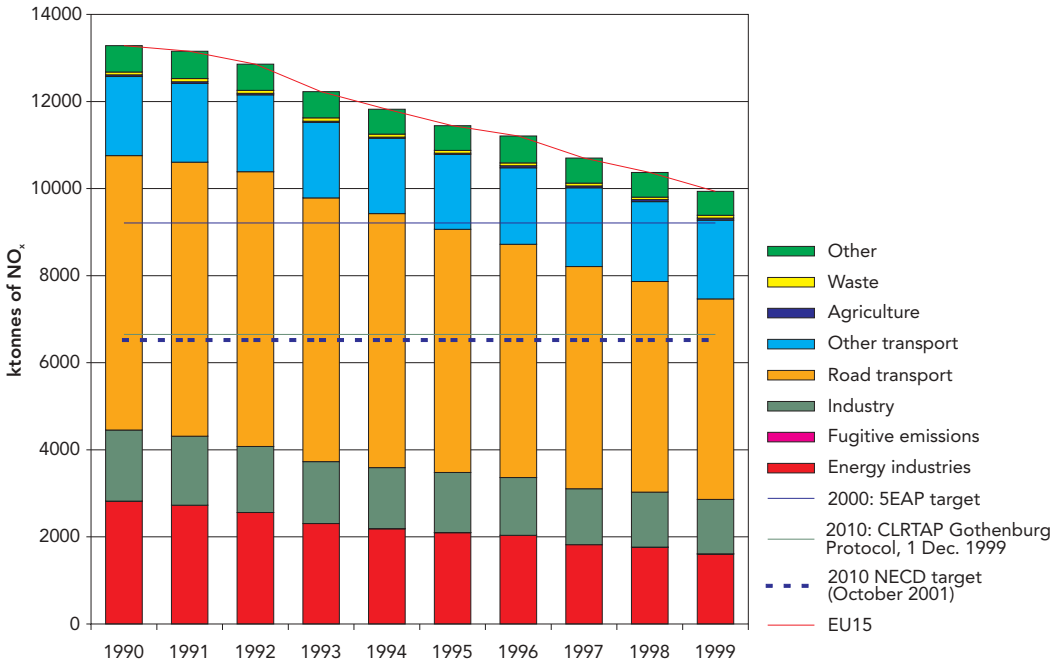


Figure 4.3 **EU-15 Emissions of NO_x, Total and contribution from main sectors compared with targets (1990–99)**



4.2. Emissions of compounds relevant for health

This section deals with PM_{10} and NO_x. Other pollutants that may have health effects, namely ozone and SO_2, also have ecological effects and will be considered in section 4.3, on emissions and ecosystems.

PM_{10}

Emissions of the precursor gases (NO_x and SO_2) to subsequent 'secondary' PM formed chemically in the atmosphere were estimated to be the most significant contributors (at 52 % and 23 % respectively) to averaged PM_{10} in Europe in 1999 as it occurs in air as a sum of primary and secondary particles, Emissions in particulate form at the time of release, known as primary PM contributed 13 % to PM_{10} (Figure 4.2). The largest contributors to emissions in 1999 were energy industries (24 %) and road transport (27 %). Energy industries, road transport and industry also contributed most strongly to the reductions between 1990 and 1999 through fuel switching and abatement in the energy and industry sectors, and increased penetration of catalytic converters for road vehicles. Primary PM_{10} and secondary PM_{10} precursor emissions are expected to reduce in the future through improved vehicle engine technology and stationary fuel combustion emission control through abatement or more widespread use of low sulphur fuels (e.g. natural gas).

NO_x

NO_x emissions (Figure 4.3) have been reduced by 26 % since 1990, largely as a result of the introduction of catalytic converters for cars, from fuel switching and from plant improvement in the energy industries. However, the Fifth Environmental Action Plan NO_x emission reduction target was not reached by 2000 as increasing road traffic has partly offset reductions achieved by emission abatement. The First CLRTAP NO_x Protocol (Sofia, 1988) which required stabilisation of emissions at 1987 levels by 1994 was achieved by the EU (although not by all individual EU Member States, some showing an increase). Meeting 2010 NECD targets will require substantial further emission reductions. Greater emission and energy efficiency (e.g. increased use of public transport) would help to reduce NO_x emissions.

For most central and eastern European countries, nitrogen oxides emissions decreased during 1990–96 by 30–60 %. Economic restructuring, fuel switching, de-NO_x installations in power plants and other measures lie behind this decrease.

However, additional measures are required in various countries to achieve the 2010 CLRTAP targets.

4.3. Emissions of compounds relevant for ecosystems

Ozone precursors

Four pollutants (NO_x, NMVOC, CO, CH_4) contribute to the formation of tropospheric ozone ('ozone precursors'). An indicator for ozone precursors emissions is a weighted summation of emission data for the precursors where the weight factor is a measure of the formation potential for tropospheric ozone by each of the precursors (de Leeuw, 2002). These emissions have decreased by 27 % since 1990, mainly due to introduction of catalysts on new cars, penetration of diesel, and implementation of the solvents directive in industrial processes (Figure 4.4).

There are major differences between EU Member States and other countries, with the largest (percentage) reductions occurring in Germany, Luxembourg and the United Kingdom. Eight Member States and the EU as a whole are more than half way towards the target for 2010. Nevertheless, overall current emissions are still about 60 % above targets set in the national emission ceiling directive. Emissions in Portugal and Greece have increased since 1990 and seven countries still need to make significant efforts to meet their targets. Substantial reductions of both non-methane volatile organic compounds and nitrogen oxides are still required. Emissions from most PHARE central and eastern European countries decreased between 1990 and 1996 by 10–70 %, probably as a consequence of economic restructuring. The Czech Republic and Poland will need further reductions to meet 2010 CLRTAP targets.

SO_2

Sulphur dioxide plays a role across the issues of ecosystem effects, health, and impact on materials. Anthropogenic emissions originate mainly from combustion of sulphur containing fuels. Main sources in 1999 (Figure 4.5) were the energy sector (61 %), industry (24 %), commercial/domestic combustion (7 %) and transport (7 %).

For the EU-15 the fifth EAP target of 35 % reduction from 1985 levels has been met; emissions have been reduced by 55 %. This is predominately the result of a switch from high sulphur solid and liquid fuels to natural gas in the energy, industry and domestic sectors, as well as construction of new power plants and the use of low sulphur coal and flue gas desulphurisation. Of most significance have been the reductions from energy industries (59 % between 1990 and 1999) and from industry (57 % between 1990 and 1999).

The target from the CLRTAP Second Sulphur Protocol of a reduction by 62 % from the 1980 levels has been reached for the EU as a whole. Most EU Member States have substantially reduced their emissions and several are approaching the proposed NECD targets for 2010. However, a number of Member States require substantial (additional) emission reductions to achieve the proposed 2010 NECD targets.

EU-15 emissions of ozone precursor gases (as tropospheric ozone formation potential, TOFP, equivalents) total and contribution from main sectors compared with targets: 1990–99. Figure 4.4

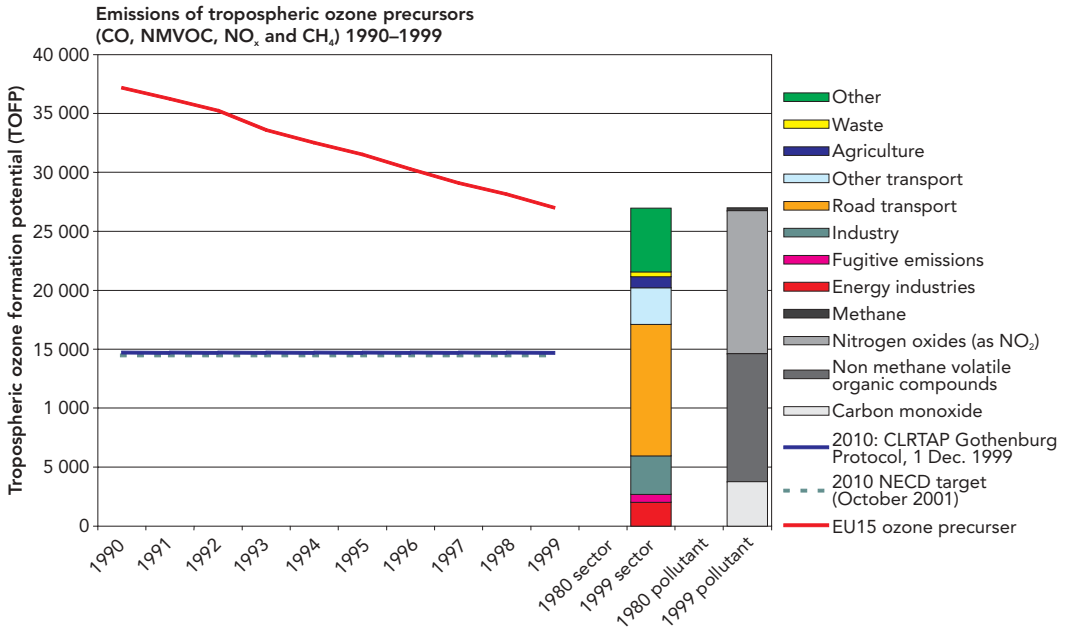
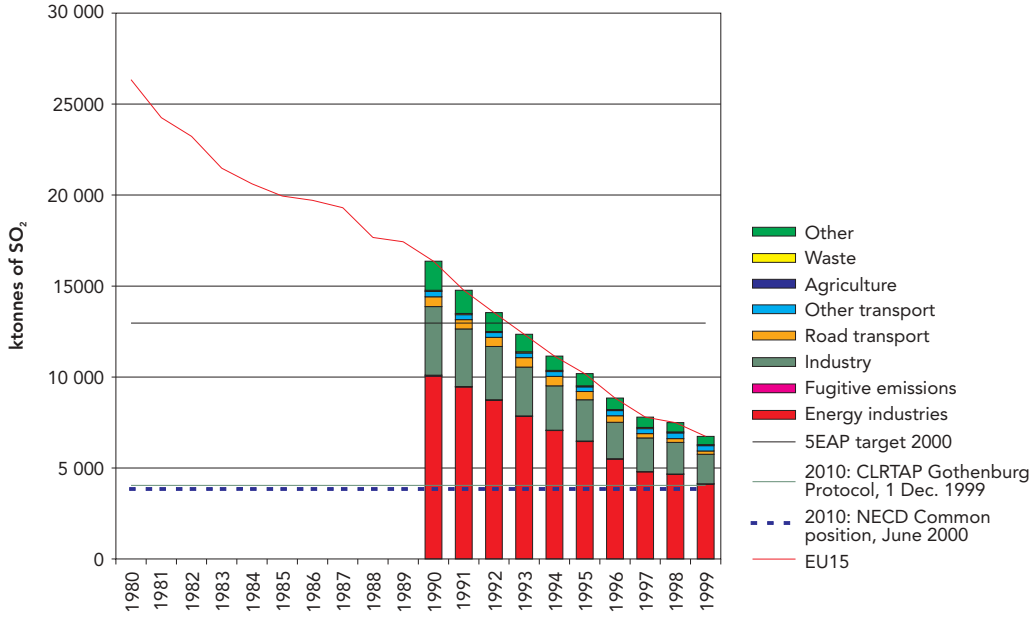


Figure 4.5 **EU-15 SO_2 emissions total and contribution from main sectors compared with targets: 1980–99**



Emissions of sulphur dioxide from most PHARE central and eastern European countries decreased by 1996 by up to 60 %, and emissions are already below the 2010 CLRTAP targets. This has been due largely to economic restructuring, fuel switching, and desulphurisation of emissions from power plants. In some countries additional measures will be needed.

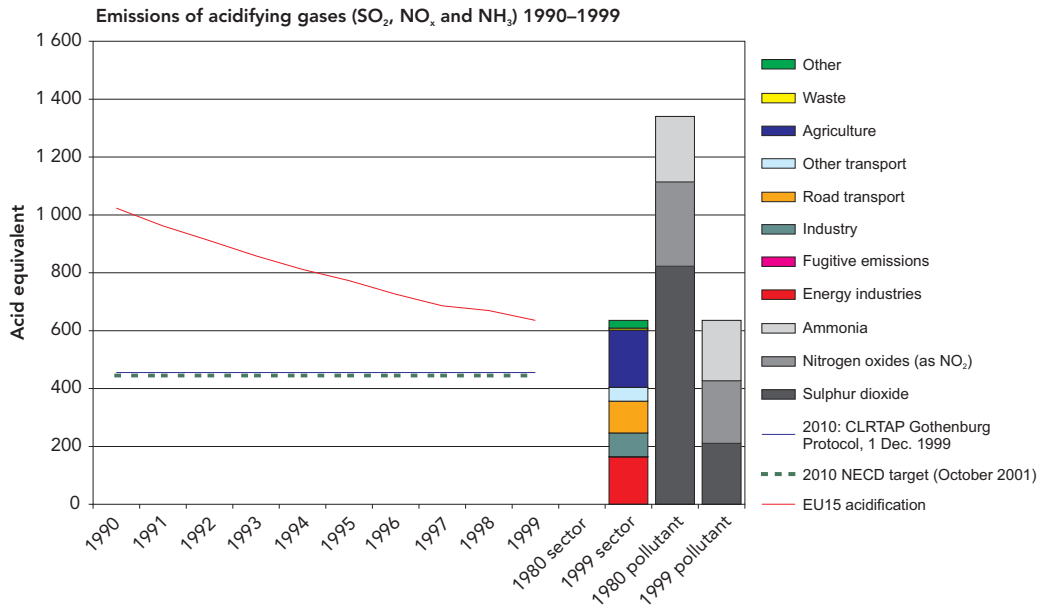
Acidifying gases

Sulphur dioxide also plays a large role in acidification. For acidifying gases as a whole EU emissions have been substantially reduced between 1990 and 1999 (Figure 4.6). This is mainly due to a reduction in sulphur dioxide emissions from reduced use of sulphurous fuels and from abatement measures in power plants such as flue gas desulphurisation. Nitrogen oxide reductions due to abatement in road transport and large combustion plants were to some extent off set by increased road traffic. Ammonia emissions are stabilising although agriculture emissions, the major source, are uncertain and difficult to control. Emissions in PHARE central and eastern European countries decreased (by between 10 % and 80 %), most likely due to economic restructuring. Even so, across Europe substantial further reductions of emissions of acidifying pollutants are needed to achieve the Gothenburg Protocol (December 1999) targets and the more recent national emission ceilings directive targets.

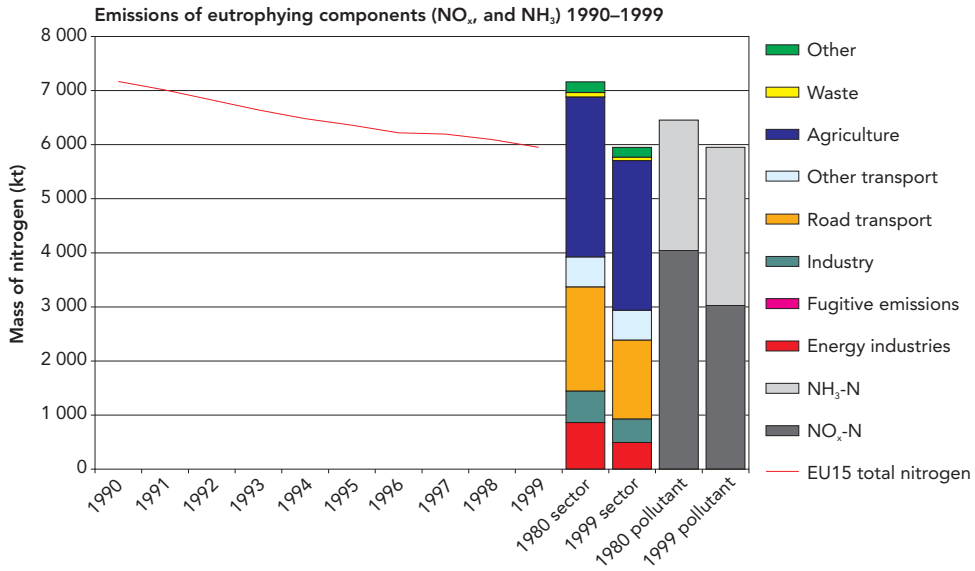
Eutrophying gases

Components contributing to eutrophication are those containing nitrogen, i.e. NO_x and ammonia (NH_3). In Figure 4.8 the combined trend and source emissions per economic sector are displayed. Throughout the 1990s there has been a steady gradual decrease in potentially eutrophying emissions. However, the figure shows the proportional rise in the contribution of ammonia (NH_3) to total nitrogen supply, which arises through reductions in emissions of NO_x. Abatement of oxidised nitrogen release from road transport and from large combustion plants has outstripped the reductions in ammonia release from agriculture, these being essentially due to fluctuating (falling) animal numbers.

EU emissions of acidifying gases (acid equivalents) total and contribution from main sectors compared with targets: 1990–99. Figure 4.6



Emissions of eutrophying components, total and contribution from main sectors: 1990–99 Figure 4.7



5. Effects of policy responses

The evolution in time of air quality and emissions in Europe over the last decade have been described in Chapter 2 and Chapter 4 respectively. The policies presently in place are summarised in section 1.4, in terms of directives on air quality setting limit values for several pollutants as well as targets for reduced deposition of acidifying and eutrophying compounds (Box 2). Also, the emissions reduction targets are presented there.

The original EU air quality directives are not included in Box 1. They were issued in 1980 (for SO_2/black smoke, TSP), in 1985 (for NO_2) and in 1992 (for ozone). The limit values in those directives were less strict than the present directives for SO_2 and NO_2, but actually stricter for ozone. For particulate matter, the old limit values related to black smoke and TSP, and not to PM_{10}, and these are difficult to compare.

It is reasonable to state that the 'old' directives combined with the emission reduction targets from the first and second CLRTAP protocols as well as the large combustion plant (LCP) directives (EC, 1988; EC, 2001b) has been an important framework for air pollution abatement in the EU and Europe as a whole during 1990–99. Increased efficiency in the economic sectors and technological development, such as towards less resource consumption, is also contributing to environmental improvements. The resulting emission reductions can be assessed quantitatively, as has been done in the Air Emissions in Europe 1999 report (EEA, 2002), and summarised in Chapter 4.

However, a quantitative evaluation of the response in the state of the environment is less easy to make, Comparing changes in emissions with changes in air quality and deposition involves the question of representativeness of monitored or modelled air quality and deposition values. In the following, the trends in emissions and the trends in air quality and deposition are just simply compared as a first indication of the response in air quality and deposition to the policies specified in the directives.

Air quality

A quantitative statement regarding responses to policies can be based upon the air quality trends found from the data in AirBase, as described in section 2.1.7. The trends described there partly cover 1990–99, and partly 1995–99:

- SO_2 concentrations (annual average and 98 percentile) have been reduced roughly by 50 % from 1993 to 1999 (averaged over 145 stations in nine countries) (Figure 2.9)

  The corresponding SO_2 emission reduction in the same period is also about 50 % (Figure 4.5).

- Hourly maximum ozone concentrations have been fairly stable during the 1990s (Figure 2.5). Since 1994, 98 percentiles have been *decreasing*, as much as some 15 % over the five-year period averaged over more than 1 000 stations. The median value, similarly averaged, has *increased* by as much as some 20–25 % over the five-year period 1994–99. Due to inter-annual variations in meteorology, these change estimates should be used with care, e.g. when compared with emission trends.

  The reduction over the same period in ozone precursor emissions in Europe (EU-15) is about 27 % (Figure 4.4). The mentioned reduction in the measured 98 percentiles could be a response to this precursor reduction, but at the same time the median and the maximums have not been reduced. Further analysis of the ozone precursor and concentration trends is necessary to substantiate links between pressure and state.

- NO_2 concentrations in cities have been fairly stable in the last years (Figure 2.7). In terms of annual average there was a slight decreasing tendency from 1989 to 1994, but rather stable since then (1995–99) in most countries, and this is also true for the high percentiles (98 and 99.9).

  NO_x emissions have been reduced by about 14 % during the period 1995–99. The lack of correspondence could be at least partly explained by the way one of the main

abatement measures, the three-way catalyst for cars, reduces NO substantially, but is less effective on the NO_2 fraction of NO_x, and also that the regional ozone, which transforms to NO_2 in urban areas by oxidation of the abundant NO, has been increasing on the average (while peaks have been decreasing) during this period.

The air quality directives require that the extent of exposure of the population above limit values should be reduced towards zero. The limit values of the 'old' directives were not associated with a target year, contrary to those in the new directives, where target years are 2005 and 2010. Statistics on how exceedances of limit values have developed during the 1990s are not available relative to the limit values in the new directives (section 3.1). For SO_2, only, the development in concentrations has been substantial enough to enable a statement that the population exposure has been reduced, even substantially, during the 1990s. For PM_{10}, NO_2 and O_3, clear statements on the trend in the exposure situation cannot be made, because relatively weak trends are affected by inter-annual meteorological variations as well as by the increasing number and thus changing representativeness of the reporting monitoring stations.

Acidifying depositions

Combining observations and modelling data for deposition of sulphur (Figure 2.15) and using observation data for nitrogen deposition (Figure 2.16), estimates of reductions in these depositions for the period 1990–99 have been made. The reductions in sulphur deposition are substantial, varying at around 30–70 % in most areas in Europe, but a bit less in some eastern and far western parts. In comparison, the reduction in emissions of acidifying gases in EU-15 over this period is about 37 % (Figure 4.6).

The reduction in deposited nitrogen is small, as an average looking across Europe, while the EU emissions reduction is about 18 % (Figure 4.7).

Summary

These comparisons give an indication of the response in selected air quality indicators to the relevant policies in place, as expressed in directives and protocols. More work is needed to substantiate this by in-depth analysis of the effect of these policy responses, and further quantification of population exposure above limit values for the various pollutants.

6. References

Relevant data and information available on the Internet:
All final EEA reports are available on the Internet, EEA website: http://www.eea.eu.int/.

The following websites contain some of the reports mentioned in this reference list or other data/information:

EEA: http://www.eea.eu.int

ETC-ACC: http://etc-acc.eionet.eu.int

UNECE/CLRTAP:
http://www.unece.org/env/lrtap/

EMEP: http://www.emep.int/index.html

European Commission, DG Environment:
http://europa.eu.int/comm/environment/

Position Papers for individual pollutants :
http://europa.eu.int/comm/environment/air/background.htm

EEA Fact sheets:
http://themes.eea.eu.int/all_factsheets_box

References

ApSimon, H., Pearce, D., Özdemiroglu, E. (eds), 1995, *Acid rain in Europe – Counting the cost,* Earthscan Publications, Ltd, London.

de Leeuw, F.A.A.M., 2000, 'Trend in ground level ozone concentrations in the European Union'. *Environmental Science & Policy*, 3, pp. 189-199.

de Leeuw, F.A.A.M. et al., 2001, *Air quality in larger cities in the European Union.* A contribution to the Auto-Oil II programme. Topic Report 3/2001. EEA Copenhagen.

de Leeuw, F.A.A.M., 2002, 'A set of emission indicators for long-range transboundary air pollution', *Environmental Science & Policy*, 5, pp. 135–145.

EC 1988, Council Directive 88/609/EEC on the limitation of emissions of certain pollutants into the air from large combustion plants . OJ L336/1-13EC 1992, Council Directive No 92/72/EEC on air pollution by ozone .OJ L297/1-7EC 1996, Council Directive 96/62/EC on ambient air quality assessment and management OJ L296/55-63.EC 1997a, Council Decision No 97/101/EC establishing a reciprocal exchange of information and data from networks and individual stations measuring ambient air pollution within the Member States, EC 1997b, Position Paper, Working Group on Benzene, Ambient Air Quality Assessment and Management, 26 June 1997 (see http address above).

EC 1997c, Position Paper: Nitrogen dioxide (see http address above).

EC 1997d, Position Paper: Lead (see http address above).

EC 1997e, Position Paper: Particulate matter, ambient air pollution (see http address above).

EC 1997f, Position Paper: SO_2. (See http address above).

EC 1999a, Council Directive No 99/30/EC relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air OJ L 163/41-60.

EC 1999b, Position Paper: Carbon monoxide, ambient air pollution, version 5.2 (see http address above).

EC 1999c, Position Paper: Ozone; Working Group on Ozone Reduction Strategy Development (see http address above).

EC 2000, Directive Directive of the European Parliament and Council 2000/69/EC relating to limit values for benzene and carbon monoxide in ambient air .OJ L313/12-21EC 2001a, Directive 2001/81/EC of the European Parliament and of the Council on national emission ceilings for certain atmospheric pollutants . OJ L309/22-30.

EC 2001b, Directive of the European Parliament and Council No 2001/80/EC on the limitation of emissions of certain

pollutants into the air from large combustion plants . OJ L 309/1-21.

EC 2002, Directive 2002/3/EC of the European Parliament and the Council relating to ozone in ambient air. OJ L 67/14-30.

EEA 1999, 'Criteria for EuroAirnet, The EEA Air Quality Monitoring and Information Network', Technical Report 12, Larssen, Sluyter, Helmis, EEA, Copenhagen.

EEA 2000, Environmental Signals 2000, European Environment Agency regular indicator report, *Environmental Assessment Report No 6*, EEA, Copenhagen.EEA 2001, Environmental Signals 2001, European Environment Agency regular indicator report, *Environmental Assessment Report No 8*, EEA, Copenhagen.

EEA 2002, *Emissions of atmospheric pollutants in Europe, 1990-1999,* EEA, Copenhagen.

EMEP 2001, *Transboundary acidification, eutrophication and ground level ozone in Europe.* EMEP summary report 2001. Report 1/2001.

Goodwin, J., de Leeuw, F., Wieringa, K., 2001, 'Core set of Air Pollution and Climate Change Indicators', Discussion paper, 17 September 2001, ETC-ACC/RIVM, Bilthoven.

Hagen, L.O., 1999, *Kartlegging av BTEX med passive proevetakere i Oslo, Drammen og Bergen May 1997–April 1998* (surveillance of BTEX using passive samplers in Oslo, Drammen, Bergen, May 1997–April 1998), NILU Report OR 12/99 (in Norwegian).Kreislova', K., Knotkova' D. and Boschek P., 1997, 'Trends of corrosivity based on corrosion rates', *Report 29*, SVUOM, Prague.

Larssen, S. and Kozakovic, L., 2001, EuroAirnet Status Report 2000, Draft Report, NILU.

UNECE 1999, Protocol to the 1979 Convention on Long Range Trans-boundary Air Pollution to abate Acidification, Eutrophication and Ground-Level Ozone, Gothenburg 1999.

UNECE 2001, *Manual on Methodologies and Criteria for Mapping Critical Levels/Loads and Geographical Areas where they are exceeded,* ed. Werner, B. and Spranger, T., ECE Convention on Long Range Trans-boundary Air Pollution.

WHO 2000, *Air quality Guidelines for Europe,* 2nd Edition, WHO Regional Publications. European series; No 91, WHO Copenhagen.

WHO 1999, *Monitoring Ambient Air Quality for Health Impact Assessment,* WHO Regional Publications, European Service, No 85.

7. Acronyms and abbreviations

AirBase	European Air Quality information system of the European Community
AOP2	Auto Oil Programme II
AOT40	accumulated ozone concentration above a threshold of 40 ppb (=80 µg/m^3)
CCC	Chemical Co-ordination Centre (of EMEP)
CCE	Co-ordination Centre for Effects (UNECE)
CH_4	methane
CLRTAP	Convention on Long Range Transboundary Air Pollution
CO	carbon monoxide
DEM	data exchange module
DNMI	The Norwegian Meteorological Institute
DMS	dimethyl sulphide
EBAS	The EMEP database at NILU
EEA	European Environment Agency
EMEP	Co-operative 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 Co-operative 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, including 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
TSP	total suspended particulates
TV	target value

UAT	upper assessment threshold
UCL	upper classification level
UN ECE	United Nations Economic Commission for Europe
VOC	volatile organic compounds
WHO	World Health Organisation

Appendix 1

Table A.1.1 **Number of stations for which 1999 data were accepted in AirBase for SO_2, NO_2, PM_{10}, Pb, CO, O_3 and benzene.**

Country	SO_2	NO_2	PM_{10}	Pb	CO	O_3	Benzene
Austria	117	109			50	103	
Belgium	47	24	14	19	6	24	9
Bulgaria	2	2			3	7	
Czech Republic	55	55	55		26	33	
Denmark	9	5		6	4	7	
Estonia	3	1				4	
Finland	13	15	6		6	12	
France	253	211			53	228	
FYROM	9						
Germany	385	371	24		273	326	
Greece	5	3			5	7	
Hungary	2	2			1	2	
Ireland		6			2	11	
Italy	56	61	5		68	75	
Latvia	3	3				2	
Lithuania	3	3	1		3	3	
Netherlands	38	36	15		20	37	4
Norway	8	6	5		1	10	
Poland	20	23	12		10	17	
Portugal	14	22	3		14	17	
Romania	23	14		8			
Slovakia	7	6			3		
Slovenia						5	
Spain	89	79	28	2	58	107	
Sweden	5	7	2		2	6	
Switzerland	20	29	14		12	30	
United Kingdom	55	58	48		54	69	
All countries	**1 241**	**1 151**	**232**	**35**	**674**	**1 142**	**13**

Appendix 2

Table A.2.1

PM_{10} at rural stations.
The rural stations with the highest 36th highest daily PM_{10} value.

Station name	Country	Coordinates		36th highest daily value ug/m³
		Latitude	Longitude	
Kuznia	PL	50.208	18.617	69
Vernovice	CZ	49.925	18.424	55
Vredepeel-Vredeweg	NL	51.541	5.854	54.7
Philippine-Stelleweg	NL	51.295	3.749	54.5
Westmaas-Groeneweg	NL	51.788	4.451	54
Magadino	CH	46.149	8.935	52.4
Wieringerwerf-Medemblikkerweg	NL	52.805	5.051	52.2
Vsechlapy	CZ	50.6	13.78	49

The stations included here are the rural stations included in AirBase which have the highest PM_{10} values. AirBase includes only a limited number of rural PM_{10} stations (39 stations in six countries). Thus, the areas and stations shown here do not necessarily represent the most exposed rural stations to PM_{10} in Europe. Many other areas may have similar or higher concentrations.

Appendix 3

Table A.3.1 **Ozone at rural stations.**
The rural stations with the highest 26th highest daily 8-hour value.

Station name	Country	Coordinates		26th highest daily value
		Latitude	Longitude	
Varenna	IT	46.009	9.286	179
Tenuta del Cavaliere	IT	41.94	12.66	159
Stuelegg	CH	47.395	9.395	158
Lacchiarella	IT	45.324	9.138	158
Castel di Guido	IT	41.9	12.29	151
Magadino	CH	46.149	8.935	146
Plandaups	FR	43.33	5.716	146
Viznar	ES	37.238	-3.474	145
Corte dei Cortesi	IT	45.28	10.004	145
Montegaza	IT	46.083	10.959	143
SchwarzwaldSüd	DE	47.809	7.765	141
Stpriest	FR	45.7	4.913	138
Schmücke	DE	50.656	10.771	138
Fichtelberg	DE	50.429	12.955	138
Hochwurzen	AT	47.358	13.633	136
Keldsnor/9055	DK	54.733	10.717	136
BurgHerzberg(Grebenau)	DE	50.772	9.461	136
2F78	FR	48.583	1.883	136
GroßerEisenberg	DE	50.62	10.789	134
Cabocreus	ES	42.319	3.317	134
Schlucht	FR	48.052	7.001	134
Sniezka	PL	50.733	15.733	134
GerlitzenSteinturm	AT	46.684	13.902	134
InnsbruckNordkette	AT	47.306	11.378	133
WelzheimerWald	DE	48.886	9.574	133
Brocken	DE	51.8	10.618	133
Sonnblick	AT	47.054	12.958	133
Miramasle Vieux	FR	43.563	5.024	133
RudolicevHorach	CZ	50.58	13.42	132
Witzenhausen/Wald	DE	51.294	9.776	132

The stations included here are the rural stations included in AirBase which have the highest ozone values. AirBase includes a fairly large number of rural ozone stations (309 stations in 22 countries). The areas and stations shown here do not necessarily represent the most exposed rural stations to PM_{10} in Europe. Other areas may have similar or higher concentrations.

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