

## 3.4. Transboundary air pollution

### Main findings

Transboundary air pollution (generated in one country and impacting in others) makes a major contribution to acidification and summer smog (caused by tropospheric ozone), and also to eutrophication of soil and water and dispersion of hazardous substances. The main sources of this pollution are energy use and transport in which international shipping is of growing importance. The cost-effectiveness of measures to reduce emissions from ships has been demonstrated by the European Commission in its strategy to combat acidification. However, sufficient measures are yet to be implemented.

Major emission reductions for sulphur dioxide and nitrogen dioxide adopted under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) and EU legislation have reduced the harmful effects of transboundary air pollution. Projected further reductions fall short of EU targets for 2000 and 2010 and further initiatives are needed in the framework of integrated abatement strategies.

Projections for 2010 suggest that, despite the projected emission reductions, areas of the EU and (especially) the Accession Countries will continue to be affected by acid and nitrogen deposition above the level defined as the 'critical load'. Ecosystems in the EU still receive 7% acid deposition and 39% nitrogen deposition above their critical loads. European countries where over 70% of ecosystems will still be affected by excess nitrogen deposition include the Czech Republic, Lithuania, Poland, the Slovak Republic and Switzerland.

With respect to ozone, despite the considerable efforts in precursor emission reductions, the long-term objective for protection of crops is expected to be reached only in the north-west parts of Europe (Ireland, Scandinavia). The health-related ozone threshold concentration will continue to be exceeded 50 days per year. The highest number of exceedances will be found in the more densely-populated north-western part of Europe (Netherlands, Belgium and northern France).

Moreover, despite reductions in precursor emissions, smog will remain a health threat due to increases in ozone worldwide: this calls for action on a global scale to reduce emissions of carbon dioxide, nitrogen oxides and methane.

### 1. Transboundary air pollution: a complex problem

#### 1.1. It is all intertwined

Transboundary air pollution is a pan-European problem, requiring pan-European solutions. The main causes are emissions from transport and energy usage of sulphur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), volatile organic compounds (VOCs) and various toxic materials such as heavy metals and persistent organic pollutants (POPs). These pollutants (particularly carbon monoxide (CO) and methane (CH<sub>4</sub>)) can remain in the atmosphere sufficiently long to be transported thousands of kilometres and thus to spread over the whole of Europe, across national borders, far from the original sources of polluting emissions.

The main effects are manifested in acidification of water and soil, summer smog caused by tropospheric ozone, eutrophication of soils and waters, and dispersion of hazardous substances (see also Chapter 3.3). The environmental impacts caused by the main pollutants SO<sub>2</sub>, NO<sub>x</sub>, VOCs, ammonia (NH<sub>3</sub>) and toxic substances are summarised in Table 3.4.1.

Main air pollutants and their environmental impacts		Table 3.4.1.
Environmental Impact	Caused by	
Acidification	SO <sub>2</sub> , NO <sub>x</sub> , NH <sub>3</sub>	
Eutrophication	NO <sub>x</sub> , NH <sub>3</sub>	
Ozone	VOCs, NO <sub>x</sub>	
Bioaccumulation of toxic substances	Heavy metals, POPs	

Table 3.4.1 is of course a simplified summary, which abstracts from a reality of complex interactions. For instance, all the acidifying compounds are precursors of particulates which are harmful to human health, and VOC species such as benzene also have toxic effects and contribute to the formation of harmful particulates. VOC and  $\text{NO}_x$  emission controls vary in their effectiveness in reducing ozone concentrations. As a rule of thumb, ozone concentrations in highly polluted areas are most efficiently reduced by a combination of  $\text{NO}_x$  and VOC controls. In regions with low  $\text{NO}_x$  concentrations, both  $\text{NO}_x$  and VOC control reduces ozone levels but  $\text{NO}_x$  control is more effective. In parts of north-west Europe, reductions in  $\text{NO}_x$  emissions alone will actually *increase* ozone levels, although a reduction in  $\text{NO}_x$  emissions is still desirable to mitigate effects of acidification and eutrophication and to reduce ozone formation on the hemispheric and global scale.

Further complicating factors are the multiple environmental impacts of human activities. Thus, for example, energy-saving measures to reduce  $\text{CO}_2$  emissions and the ensuing pollutants released mitigate climate

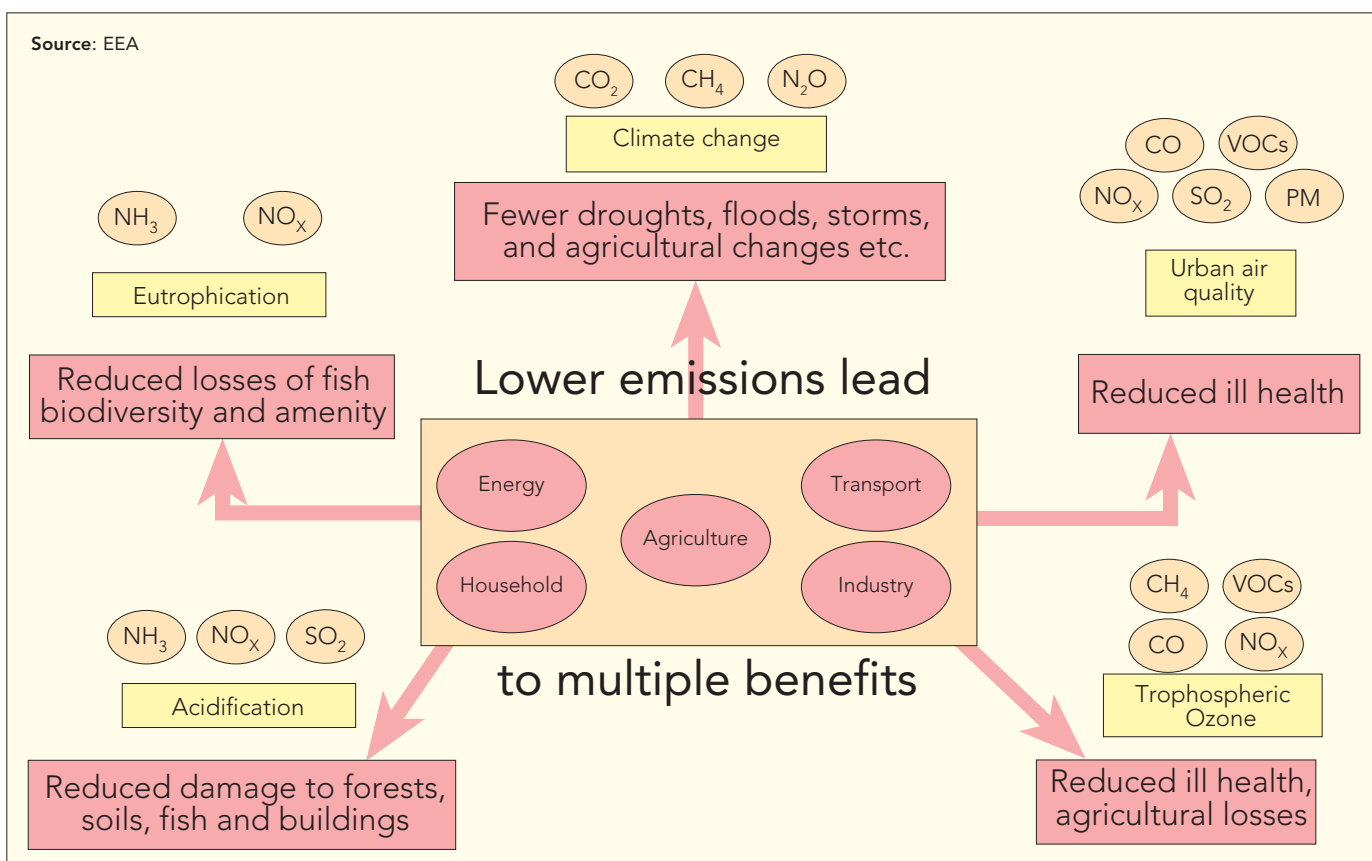
change (see Chapter 3.1) and also reduce  $\text{SO}_2$ ,  $\text{NO}_x$  and CO emissions, with beneficial impacts on acidification, tropospheric ozone and urban air quality (Figure 3.4.1).

### 1.2. Targets and policies at European level

The UNECE Convention on Long-Range Transboundary Air Pollution (CLTRAP) signed in Geneva in 1979 was the first multi-lateral treaty concerning air pollution. It has provided an important demonstration that international co-operation can achieve results. During its first 10-15 years, the CLTRAP resulted in protocols aiming at a reduction in acidifying emissions and abatement of ozone concentrations. Protocols on heavy metals and persistent organic pollutants (1998) aim at a reduction of emissions of these toxic materials. A second protocol on  $\text{NO}_x$  and  $\text{NH}_3$  emissions is under negotiation.

Parties to the CLTRAP were committed to a stabilisation of  $\text{NO}_x$  emissions at the 1987 level by December 1994. The VOC protocol signed in 1991 requires emissions to be either stabilised or reduced by at least 30% from the base year (usually 1988) in 1999. The second Sulphur Protocol signed in 1994

Figure 3.4.1 Multi-pollutants, multi-effects



has the objective to reduce the extent by which critical loads are exceeded in Europe by 60% in the year 2000; the various countries are required to reduce their emissions by different amounts. The Protocol also has obligatory clauses regarding emissions standards, including application of 'Best Available Technology' emission standards for new plants. A further requirement is a reduction in sulphur content to 0.2% and to 0.05% respectively in gas oil for stationary sources and in diesel fuel for road traffic.

EU limit, guide or target values for air quality concentration levels of pollutants including SO<sub>2</sub>, NO<sub>2</sub> and ozone are now being revised through so-called 'daughter directives' to the Air Quality Framework Directive (96/62/EC).

The EU Fifth Environmental Action Programme (5EAP) set emission targets up to the end of the century for reduction of acidifying compounds and ozone precursors. Further targets, up to 2010, were proposed in the 1997 Community Strategy to combat acidification (European Commission, 1997; Table 3.4.2). This strategy emphasised the multi-pollutant multi-effect framework and showed that, in terms of cost-effectiveness, there is more potential for reducing sulphur rather than nitrogen emissions; this is because SO<sub>2</sub> is mainly emitted from a small number of relatively controllable large sources (power plants) whereas NO<sub>x</sub> is also emitted from a wide range of smaller sources, including vehicles.

New strategies for emission abatement face the challenge of satisfying protection requirements from all inter-related effects caused by tropospheric ozone, acidification and eutrophication. The Commission is currently developing an ozone-abatement strategy. In line with the 5EAP, the aim is to address the 'symptoms' by setting interim and long-term air quality objectives and the 'causes' by developing strategies and measures to reduce polluting emissions and also to stimulate changes in society's patterns of behaviour. The new strategy will be linked with provisional national emission ceilings for SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub> and VOC.

More specific measures for abating precursor emissions are defined in a number of EU Directives:

- Large Combustion Plants Directive.
- Directives on Sulphur Content of Certain Liquid Fuels.

	EU air emissions reduction targets		Table 3.4.2.
	SO <sub>2</sub>	NO <sub>x</sub>	VOCs
5EAP	35% (1985-2000)	30% (1990-2000)	30% (1990-99)
CLRTAP	62% (1980-2000)	stabilise 1987 emission levels by 1994	30% (1987-99)
COM(97)88 (proposed targets)	84% (1990-2010)	55% (1990-2010)	

Source: European Commission, 1997; UN-ECE CLRTAP, 1998

- Integrated Pollution Prevention and Control Directive.
- Implementation of measures developed through the Auto-Oil Programme:
  - A two-step tightening of vehicle emission limit values for passenger cars and light commercial vehicles with the first step in the year 2000 and the second step in 2005;
  - new environmental specifications for petrol and diesel fuels to take effect from the year 2000; very low-sulphur fuels to be mandatory from 2005;
  - provision made for earlier phase-in of very low-sulphur fuels;
  - phase-out of leaded fuels by 2000.
- The Solvent Directive and the Directive to reduce emissions from storage and distribution of petrol aim at reduction of VOC emissions from stationary sources and at all stages of the chain of petrol storage, distribution and usage.

Guided by the work done by the WHO on human-health effects and by UNECE on effects on vegetation, the Commission has proposed new ozone reference levels (Table 3.4.3). In addition to the long-term objective for the protection of human health, threshold values to inform both the general and informed population have been defined. For the protection of human health, short-term concentrations (peak values over one to eight hours) are of concern. For protection of agricultural crops and forests, ozone concentrations integrated over the growing season are of importance.

## 2. Trends in emissions

### 2.1. Emissions of sulphur dioxide (SO<sub>2</sub>)

Since 1980, SO<sub>2</sub> emissions in Europe have been reduced considerably: by approximately 50% over the period 1980-1996 (Figure 3.4.2) although in comparisons between countries, allowance should be made for differences in initial emission rates and economic circumstances. In the EU, the 5EAP target of 35%

Table 3.4.3. Ozone air quality reference levels proposed in the working EU draft Ozone Directive

Source: European Commission, 1999b

Concern	Description	Metric	Value
Health	Long Term Objective value for the protection of human health	Moving 8 hours average concentration	120 mg/m <sup>3</sup> *
	Alert threshold sensitive population	1 hour average concentration	180 mg/m <sup>3</sup>
	Alert threshold general population	1 hour average concentration	240 mg/m <sup>3</sup>
Damage to crops and vegetation	Long Term Objective value for the protection of vegetation	AOT40, May-July, 08.00-20.00 CET	6 000 mg/m <sup>3</sup> .h**
	Reference level concerning visible damage on forests	AOT40, April-September, 08.00-20.00 CET	20 000 mg/m <sup>3</sup> .h

Ozone concentrations integrated over a certain period of time are indicated as AOTxx-values where xx is a threshold value expressed in ppb (1 ppb O<sub>3</sub> = 2 µg/m<sup>3</sup> O<sub>3</sub>). The AOT40, for example, is defined as the sum of all excess concentrations above the threshold of 40 ppb (80 µg/m<sup>3</sup>). It is calculated by subtracting 80 µg/m<sup>3</sup> from all hourly concentrations and subsequently summing all positive values.

\* In addition to the Long-term Objective, a Target value has been proposed: by the year 2011 a daily eight-hour maximum of 120 mg/m<sup>3</sup> may not be exceeded more than 20-25 times per calendar year averaged over 3 years. Current legislation (92/72/EC) has the limit value 110 mg/m<sup>3</sup> average over a fixed eight -hour period.

\*\* In addition to the Long-term Objective, a Target value has been proposed: by the year 2011 the AOT40 value may not exceed 18 000 mg/m<sup>3</sup>.h averaged over 5 years. Current legislation (92/72/EC) has the limit value 65 mg/m<sup>3</sup> average over 24 hours.

reduction from 1985 levels by the year 2000 was met in 1994. EU emissions were reduced from 19 600 ktonnes in 1985 to 10 700 ktonnes in 1995. The reduction, which will continue, is expected to meet the commitments of the Second Sulphur Protocol.

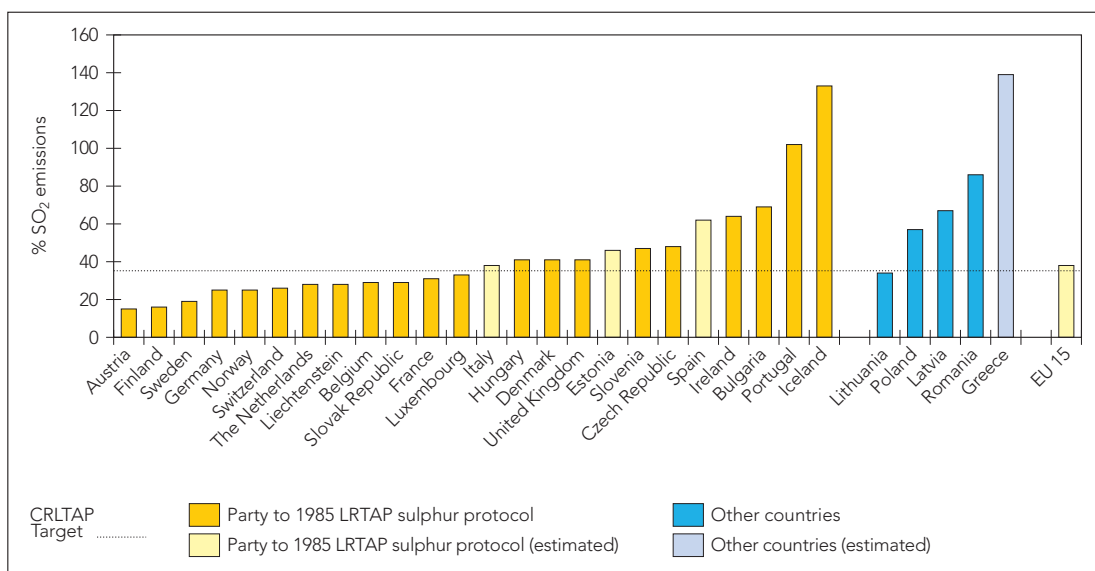
The decrease in emissions from the Accession Countries is most notable since 1990, largely caused by the economic reconstruc-

tion in these countries. Since 1994, the 5EAP target of 35% reduction has also been met by Accession Countries, as result of the general European overfulfilment of the 30% emission reduction objective set by the First Sulphur Protocol. At present, the relative reduction in emissions from the Accession Countries is similar to that in the EU, while their total emissions amounts to approximately one-quarter of EU emissions.

Figure 3.4.2 Sulphur dioxide emissions were strongly reduced between 1980 and 1996 (1980 = 100%)

In general, Parties to the 1985 LRTAP-Sulphur Protocol (on the left) have achieved a larger reduction than other countries (on the right). Data officially submitted is in dark colour, estimates are in light colour.

Source: EMEP/MSC-W, Report 1/98



**2.2. Emissions of nitrogen oxides (NO<sub>x</sub>) and ammonia (NH<sub>3</sub>)**

Emission targets for nitrogen oxides set in the 5EAP are far more restrictive than the stabilisation at 1987 levels required by the First NO<sub>x</sub> Protocol of the LRTAP Convention. By 1994, the average NO<sub>x</sub> emission reduction for the EEA and the Accession Countries was 13%, thus complying with the commitments of the First NO<sub>x</sub> Protocol (Figure 3.4.3). However, the EU (which had a reduction of 11%) is unlikely to achieve the 5<sup>th</sup> EAP emission target for 2000 of a 30% reduction; in contrast, the Accession Countries have already met this target according to the most recent official emission estimate.

Reported ammonia emissions decreased by 14% in the EEA and the Accession Countries, from 5 000 ktonnes in 1990 to 4 300 ktonnes in 1996. Again, emission reductions in Accession Countries are considerably higher (28%) than those reported from the EU (8%). At present, there are no emission targets for ammonia, but these are expected to be specified in the new multi-effect multi-pollutant directives and protocols.

**2.3. Emissions of volatile organic compounds (VOCs)**

The requirements for reduction of emissions of non-methane volatile organic compounds (VOCs) by 30% in 1999 are different on the choice of the base year: 1990 for the 5EAP

and 1987 for the VOC Protocol. For the year 1995, Accession Countries reported emissions well on the way to complying with the VOC Protocol, while VOC emission reduction in the EU amounted to 11% with respect to 1990 levels and 15% with respect to 1987 levels. EU emissions were reported to be 11 500 ktonnes in 1995, that is, six times higher than the reported emissions from the Accession Countries (Figure 3.4.4). Therefore, as in the case of NO<sub>x</sub> emissions, it is unlikely that the 5EAP VOC target emission reduction can be reached by 1999.

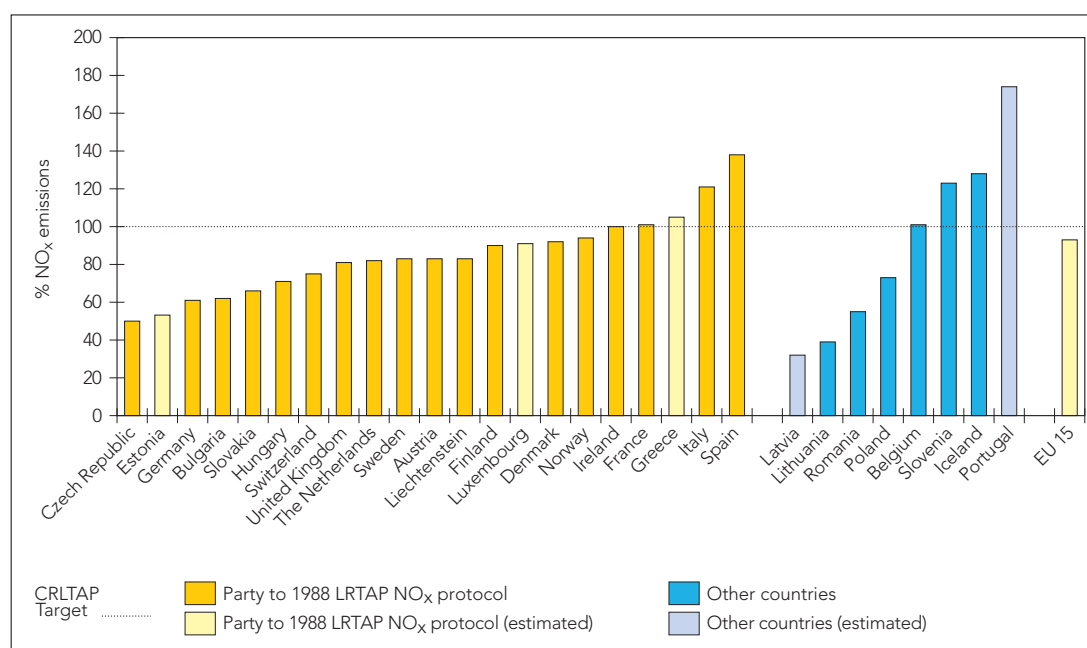
In contrast to other pollutants, a large proportion of VOCs are emitted by natural processes. Biogenic VOC emission strongly depends on temperature. During ozone smog episodes, the natural contribution might be as high as 60% (Slanina *et al.*, 1998) while on an annual basis, biogenic emission contributes 40% of total VOC emissions over Europe (Simpson *et al.*, 1999).

**3. Photochemical smog**

Photochemical smog, or simply *summer smog*, is formed in the lowest few kilometres of the atmosphere. It has adverse effects on human health, agricultural crops, natural vegetation, and materials. The main component of smog is ozone, although levels of other aggressive oxidants are elevated as well. There is, however, only limited information

Compared with 1987 (=100%) emissions of nitrogen oxides in 1996 show a reduction in most countries.

Figure 3.4.3



Parties to the 1988 NO<sub>x</sub> Protocol of the Convention on LRTAP are on the left in the diagram. Other countries are on the right. Data officially submitted is in a dark colour, estimates are in a light colour.

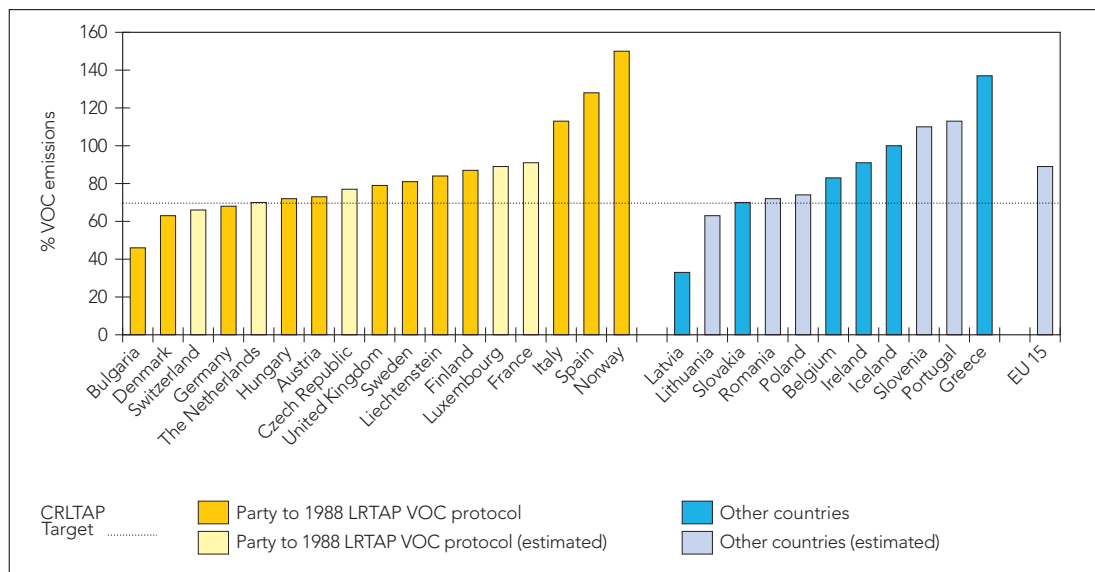
Source: EMEP/MSC-W Report 1/98

Figure 3.4.4

Compared with 1988 (=100%) most countries have achieved the reduction in VOC emissions

Parties to the CLRTAP VOC Protocol are on the left (officially submitted data in dark blue, estimates in light blue). Non-parties to the Protocol are on the right (officially submitted data in yellow, estimates in brown).

Source: EMEP MSC-W Report 1/98



available on concentrations and effects of these other oxidants. As no significant effects have been observed at current ambient levels, no international guidelines have been set for the other photochemical oxidants found in summer smog.

Ozone and its precursors have an atmospheric residence time of several days or more. Under average summer conditions, air pollutants are transported over distances of 400-500 km per day. Besides the transboundary character, summer smog may show a more local character. For example, in the Mediterranean Basin, air masses re-entering the source regions have been shown to raise pollution levels (Millan *et al.*, 1997).

High levels of ozone occur during short periods of two to four days. Threshold values set for the protection of human health are exceeded regularly over large parts of Europe. Smog episodes are often found during summer over most parts of the continent, during periods with clear skies, increased solar radiation and elevated temperatures (Map 3.4.1). The occurrence and duration of these episodes varies strongly from one year to the next.

### 3.1. Accumulated exposure

Based on a series of controlled exposure experiments, the concept of AOT<sub>40</sub> (accumulated ozone hourly concentrations above 80 µg/m<sup>3</sup>) is chosen as an indicator for exposure of ecosystems. The great advantage of the AOT concept is that it is indicative of

the ozone situation during the relevant growing season. The AOT is a practical indicator for ozone effects on vegetation. It must be realised, however, that it is only a first, crude estimate of the real ozone exposure of vegetation. Due to its simplifications, the link between AOT and actual vegetation damage might be weak.

First of all, the AOT gives a *potential* but not an *actual* exposure of vegetation. Under dry and hot conditions, the plant protects itself by closing its stomata. Although ozone concentrations are likely to be high under these conditions, the closed stomata prevent uptake of ozone and the damaging effects of ozone will be small. In the AOT concept this can be included by adding a constraint on relative humidity. This makes it, however, more complex and less transparent.

In the newly proposed daughter directive on ozone, the integration time of AOT is clearly defined: May to July using all one-hourly values measured between 8 AM and 8 PM CET. This period may differ from the active period of the plants. Daylight hours, defined as solar radiation above a certain minimum might be more appropriate. Also the growing season varies all over Europe and in places extends beyond the three months specified in the directive.

The simple and clear definition of AOT suggests that monitoring will be easy. Unfortunately, there are a number of complicating factors which make the observed AOT value sensitive to monitoring conditions:

- the measuring height: monitoring ozone at a height of 1 m (crops) or at 10 m (at crown level of trees) might result in a factor of 2-3 difference in AOT;
- missing data will lead to systematic underestimation of the AOT; an agreed correction method will be required.

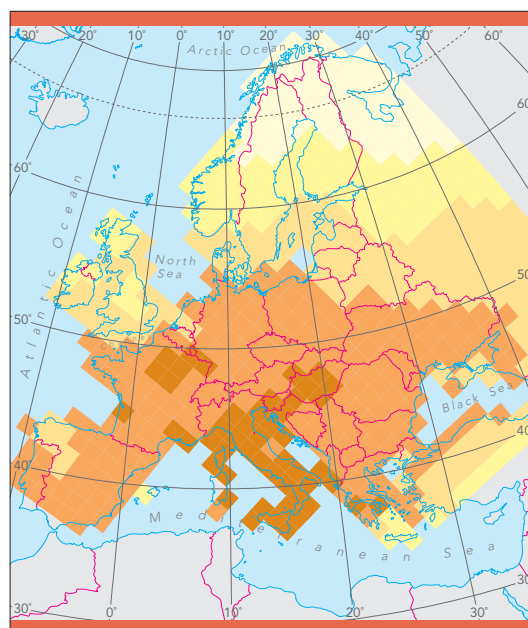
For practical reasons, the time resolution applied in the current atmospheric models is six hours, which is too coarse to calculate an AOT without further assumption on the diurnal variation of ozone. This problem will be solved in the next generation of models. Notwithstanding these drawbacks, the AOT40 is, according to current knowledge, the best indicator for vegetation exposure.

### 3.2. Threshold values for ozone are exceeded

All EU threshold values set for ozone under the current Ozone Directive (92/72/EC) have been exceeded since 1994, the year the Directive came into force. Thresholds set for the protection of human health and vegetation are exceeded in all Member States every year. Short-term thresholds for protection of vegetation and the threshold values for public information are exceeded in most Member States. The threshold concentration for warning the population is exceeded only occasionally (Beck *et al.*, 1998).

One of the 5EAP targets is that air quality guidelines recommended by the WHO should be mandatory by 1998. Routine monitoring (Hjellbrekke, 1997; de Leeuw and de Paus, 1998) indicates that the WHO value of  $120 \mu\text{g}/\text{m}^3$  eight-hour average is exceeded in all EU Member States and in all other European states which report data. Model calculations, allowing for estimation of exceedance in the whole of the European territory (Map 3.4.2) indicate that 99% of EU inhabitants are exposed to at least one exceedance per year. For the development of abatement strategies, the AOT60 (accumulated excess above  $120 \mu\text{g}/\text{m}^3$ ) has been taken as indicative of ozone health impacts.

According to WHO recommendations, the AOT40 for daylight hours in May-July should not exceed  $6\,000 \mu\text{g}/\text{m}^3\cdot\text{h}$  for the protection of natural vegetation and the prevention of more than 5% crop yield loss (this is also the critical level for ozone protection of crops under CLRTAP). According to observations, this AOT40 parameter exceeds  $6\,000 \mu\text{g}/\text{m}^3\cdot\text{h}$  in most of the EU, with the exception of northern parts of both Scandinavia and the UK (Hjellbrekke, 1997). Modelled results indicate that, averaged over five years, 94%



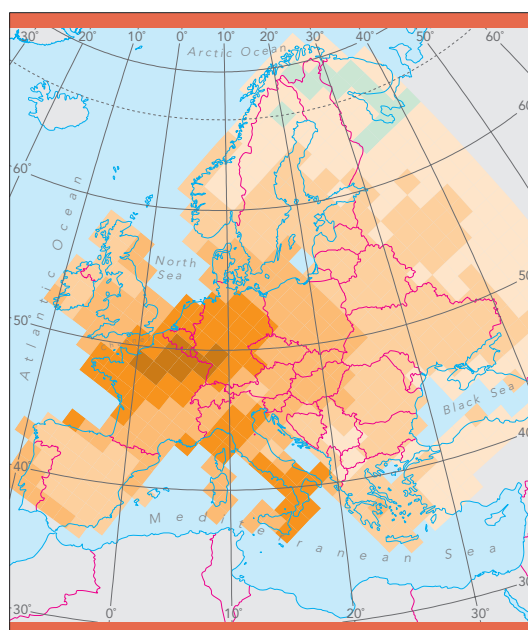
**Map 3.4.1**

The model indicates a clear gradient over Europe: summertime concentrations ranging from  $60 \text{ mg}/\text{m}^3$  in the northern part to more than  $100 \text{ mg}/\text{m}^3$  in the central part and in the Mediterranean region ( $1 \text{ ppb O}_3 \approx 2 \text{ mg}/\text{m}^3$ ).

Source: Simpson *et al.*, 1997

of arable land is exposed to exceedance of this WHO guideline.

For protection of forests, the WHO and CLRTAP have set a guideline/critical level of AOT40, 24 hours, April-September of  $20,000 \mu\text{g}/\text{m}^3\cdot\text{h}$ . Both monitoring and modelled data indicate that Scandinavia, Ireland and the UK are below the critical level most years. In the rest of Europe, the level is exceeded by up to a factor of three. Calculations indicate that about 35% of Europe's



**Map 3.4.2**

Almost the entire population of Europe is exposed to ozone levels exceeding the WHO guideline for protection of human health. This map shows the average accumulated excess of ozone concentration above a level of  $60 \text{ ppb}$  ( $=120 \text{ mg}/\text{m}^3$ ) modelled over five years.

Source: Simpson *et al.*, 1997

coniferous forests and 70% of broadleaf forests experience exceedances.

### 3.3. Ozone levels vary from year to year and over Europe

Ozone concentrations, particularly peak values, vary considerably from year to year due to specific meteorological conditions, whose occurrence is very variable in time and space (Figure 3.4.5). Typical variations from year to year for peak concentrations (98 percentile) are 10-15%, while AOT40 may show variations of about a factor of three.

Distribution of ozone concentrations over Europe also differs considerably from year to year. While the mean daily maximum value is highest in Italy and France, exceeding  $104 \mu\text{g}/\text{m}^3$  (see Map 3.4.1), the AOT60 is highest in northern France, Belgium and south western Germany (see Map 3.4.2).

Average ozone concentration in summer shows an increase from north-west to central Europe. In mountainous regions, average ozone concentrations are higher than in lowland plains. There are indications, still to be confirmed over the long-term, that peak ozone levels are higher in southern Europe than in the north. Characteristics of ozone formation and transport in major Mediterranean cities and coastal areas differ from those normally occurring in northern continental areas (Millan *et al.*, 1997).

### 3.4. Present trends in ozone are small, and hard to detect

In the late 1990s, rural ozone levels are three times higher than in the pre-industrial era. Around the year 1880, average ozone levels at a rural site near Paris were about  $20 \mu\text{g}/\text{m}^3$ , but by 1950, rural ozone levels had increased to  $30\text{--}40 \mu\text{g}/\text{m}^3$ , and to  $60 \mu\text{g}/\text{m}^3$  around 1980. However, trends in rural ozone in the last decade are statistically insignificant (Beck *et al.*, 1998). Studies are underway to try to explain these trends from the analysis of the trends in the emissions of ozone precursors (Lindskog *et al.*, 1998).

Trends in ozone episodes are even more difficult to assess because of annual variability of peak ozone concentrations (Figure 3.4.6). A recent analysis of peak ozone data submitted under the Ozone Directive (de Leeuw *et al.*, 1997) showed for 68 stations over the period 1989-1997 a significant upward trend at only two stations and a downward trend at 22 stations. For the majority of the 68 stations analysed, no significant trend was detected.

A detailed analysis of ozone data in the UK (PORC, 1997) showed a decrease in peak ozone levels. The hourly maximum ozone concentrations, averaged per month over the period 1986-1995, are  $40\text{--}60 \mu\text{g}/\text{m}^3$  below that during the period 1972-1985. At nine out of 16 rural stations, there is however a significant positive trend in annual mean concentrations.

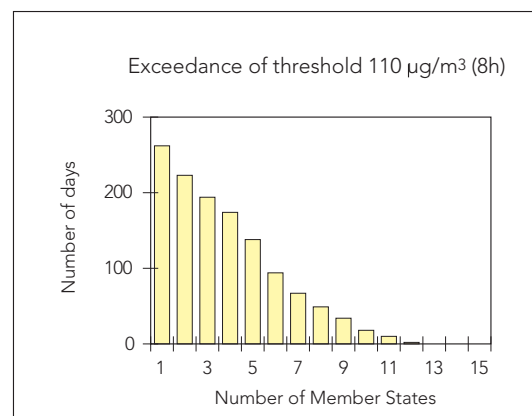
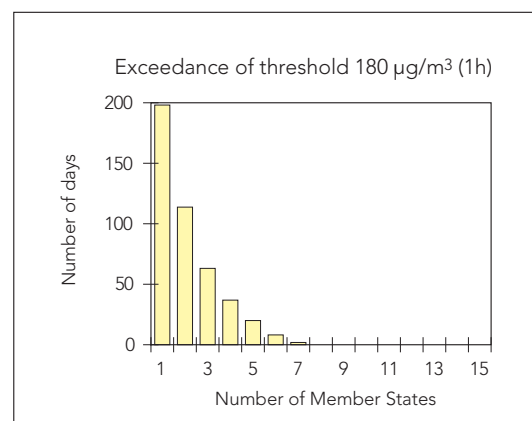
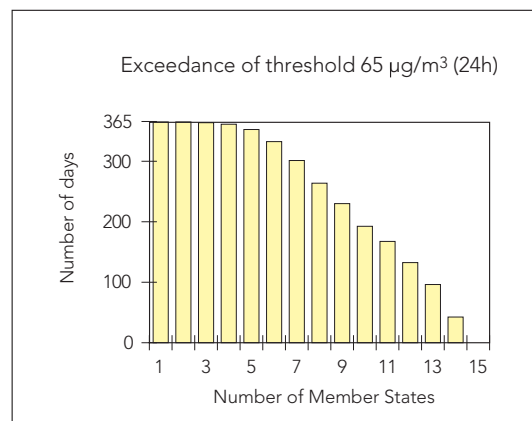
Urban ozone showed downward trends in Central London between 1973 and 1992, while monthly means increased by 15% per

Figure 3.4.5

Threshold values defined in the EU Ozone Directive (92/72/EC) are exceeded frequently and widely

This figure shows the number of days as a function of the minimum number of Member States where at least one exceedance of a threshold value was observed in 1997 (e.g. on 174 days the threshold value of  $110 \mu\text{g}/\text{m}^3$  was exceeded in at least four Member States). Note: information on exceedances of  $65 \mu\text{g}/\text{m}^3$  and  $110 \mu\text{g}/\text{m}^3$  were submitted by 14 Member States only.

Source: de Leeuw and de Paus, 1998





year at a suburban station in Athens in the period 1984-1989.

Ozone concentrations in 'unpolluted' air masses arriving over the North Atlantic region at the Irish station Mace Head appeared to increase over the 1990-1996 period with  $0.18 \mu\text{g}/\text{m}^3$  per year equivalent to 0.2% per year (PORG, 1997). Model calculations on a global scale support the findings of an ongoing change in chemical composition of tropospheric background air (Parrish *et al.*, 1993; Collins *et al.*, 1998; Berntsen *et al.*, 1997; Hov and Flatøy, 1997). Current daily mean concentrations of ozone are three to four times higher than in the pre-industrial era mainly as a result of the considerable growth in  $\text{NO}_x$  emissions from industry and the transport sector.

## 4. Acidification

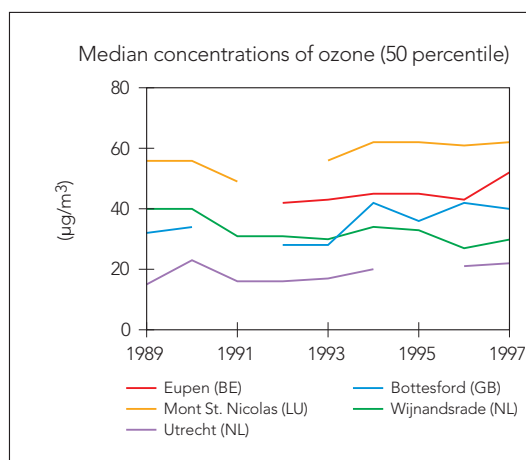
### 4.1. Critical loads

Acid deposition originates largely from man-made emissions of sulphur dioxide ( $\text{SO}_2$ ), nitrogen oxides ( $\text{NO}_x$ ) and ammonia ( $\text{NH}_3$ ). Major sources of these pollutants are the usage of fossil fuels for power generation, transport and agricultural practice. Deposition of these three primary components and their secondary-reaction products leads to acidification (sulphur and nitrogen deposition) and eutrophication (nitrogen deposition). Acidification is causing damage to freshwater systems, forest soils and natural ecosystems in large areas of Europe. The effects of acidification have been evident in various different ways, including defoliation and reduced vitality of trees, declining fish stocks and decreased diversity in acid-sensitive lakes, rivers and streams and changes in soil chemistry. Nitrogen contributes also to the eutrophication of terrestrial and marine ecosystems and it is an important precursor of ground-level ozone. Along with these effects on ecosystems, there are also corrosion effects on materials, cultural monuments and buildings. In addition, there is growing concern about the adverse health effects related to secondary-reaction products of acidifying and eutrophying pollutants.

Since the signature of the 1979 LRTAP Convention, significant reductions in harmful emissions have been achieved. Increasing attention is now being given to the analysis of effects of emissions, in order to differentiate reduction commitments according to the varying sensitivity of the natural environment. There is now an increasing focus on the

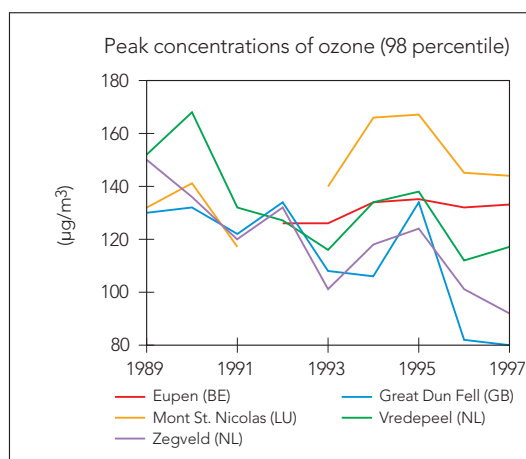
Ozone concentrations differ widely between monitoring stations

Figure 3.4.6



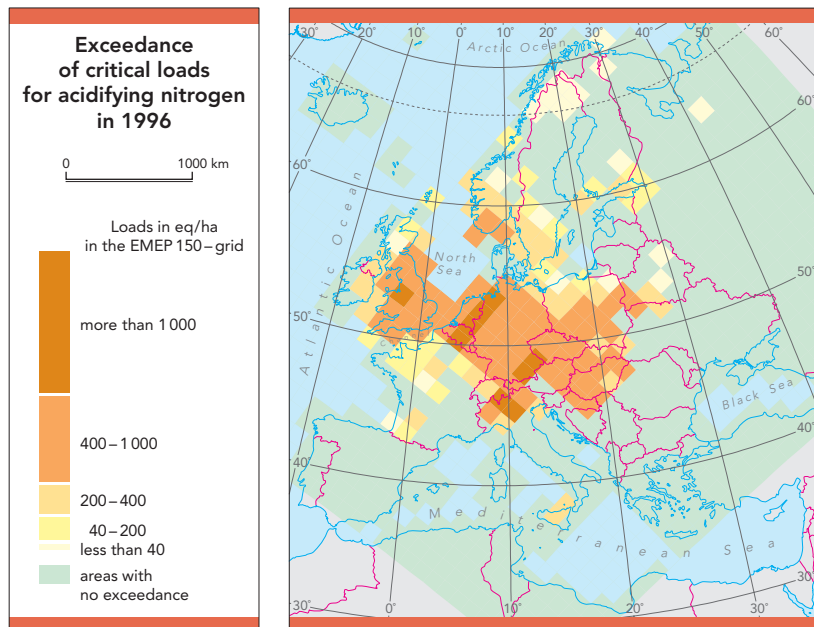
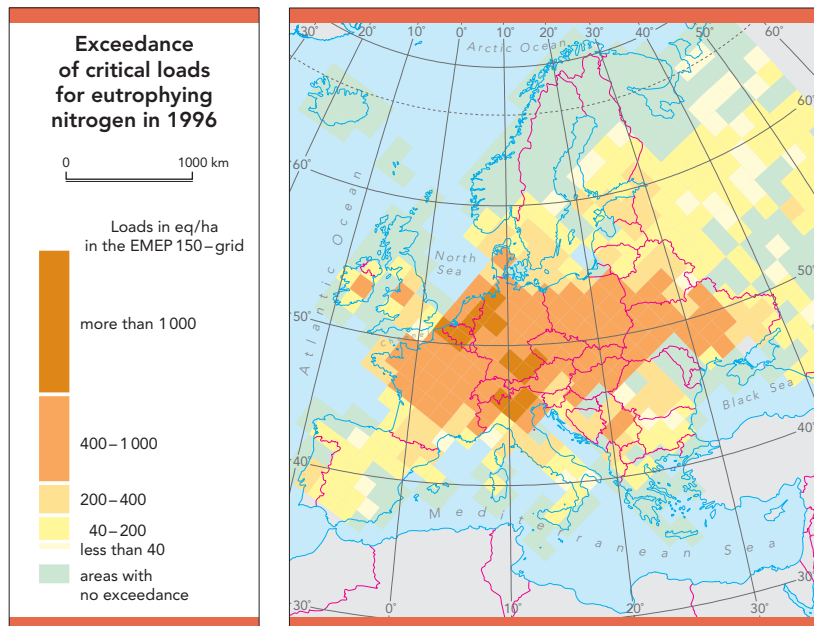
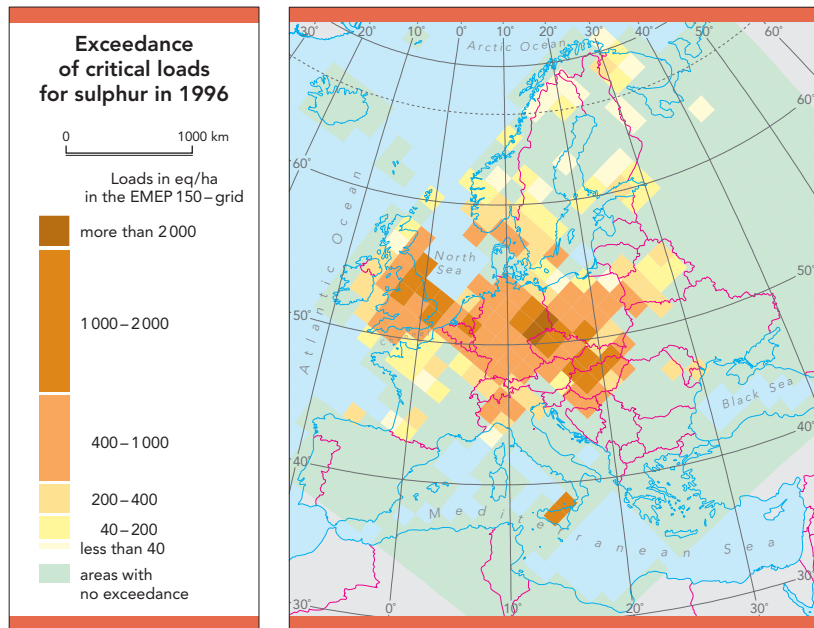
The reason for this difference is the local impact of  $\text{NO}_x$  sources: in urban areas and especially in streets the locally emitted traffic emissions result in a temporary reduction of ozone levels. Further downwind, ozone levels will resume previous high levels.

Source: de Leeuw *et al.*, 1997



concept of 'critical load', defined as the highest deposition of chemical compounds that will not cause long-term harmful effects on the ecosystem structure and function, in order to target emission reductions towards the actual damage. The critical load depends on characteristics of the soil and ecosystem and varies strongly over Europe. Lake systems in Scandinavia are very sensitive (low critical load) whereas the Iberian Peninsula is less sensitive – partly because the deposition of base cations (e.g. Sahara dust) neutralises the acid deposition to some extent.

The effects of acidification on forests and freshwater ecosystems and the effects of eutrophication on terrestrial ecosystems are included in the present definition of critical loads. Other effects, such as corrosion damage to monuments, eutrophication of marine ecosystems, or health effects, are not included within the critical load approach. The new strategies for emission reduction face the challenge of satisfying protection requirements from all these inter-related effects.



**4.2. Exceedances of critical loads**

Sulphur and nitrogen deposition combined contributes to exceedance of critical loads (Maps 3.4.3, 3.4.4, and 3.4.5; excess deposition was calculated as the percentage of ecosystems in each grid with acid deposition above the critical loads, for scenario calculations in preparation for the Second CLRTAP Sulphur Protocol. The excess deposition over the fifth percentile was used as the main criterion driving emission reductions.)

Pollution ‘hot spots’ can be identified, such as the so-called Black Triangle (Box 3.4.1). Exceedances of critical loads of acidification and eutrophication over Europe are at present mostly dominated by nitrogen deposition, the relative importance of which is increasing, showing the need for a new nitrogen protocol. There are different ways to determine critical loads and their exceedances, because the amount of nitrogen deposition that an ecosystem may tolerate without harmful effects also depends on the level of the sulphur deposition and vice versa. The critical load function for each separate ecosystem can be approximated taking account of sulphur deposition, acidifying nitrogen and eutrophying nitrogen. Exceedances are recorded for each particular ecosystem whenever the actual depositions fall outside the function.

In preparation for the EU acidification strategy, an ‘area of exceedance’ (AE) concept was developed for scenario analysis. The alternative way to calculate exceedances was to consider the area occupied by the ecosystems, rather than the number of ecosystems with depositions exceeding their critical loads.

Recently, a further refined measure for evaluating ecosystem protection has been developed. The so-called ‘average accumulated exceedance’ (AAE) actually calculates the exceedance of critical loads for all ecosystems in a given grid cell (Posch *et al.*, 1997). Exceedances of individual critical loads are added for all ecosystems and averaged in terms of the area covered by each individual ecosystem in the grid cell.

Map 3.4.3

Map 3.4.4

Map 3.4.5

Source: EMEP

**Box 3.4.1. Air pollution in the Black Triangle**

On a Europe-wide scale, problems with acidification are most serious within the Black Triangle. Exceedances of critical loads show their European maximum over this area and they are primarily related to sulphur deposition, despite effective reductions in past years. The brown coal belt, which forms the heart of the Black Triangle, stretches from Lower Silesia (Poland) to Southern Saxony (Germany) and Northern Bohemia (the Czech Republic). It covers a mountainous area with 6.4 million inhabitants. Climate, soils, geomorphology, and geology vary substantially. Poor and acid soils are common and low levels of critical loads of sulphur characterise these areas.

The long-term annual precipitation totals are in a range of 500 mm in the basin to 1 350 mm at higher altitudes. Annually, there are more than 50 days of continuous fog and 70% of the days are cloudy. Situations of stagnant air often occur during winter, causing accumulations and the highest concentrations of air pollutants.

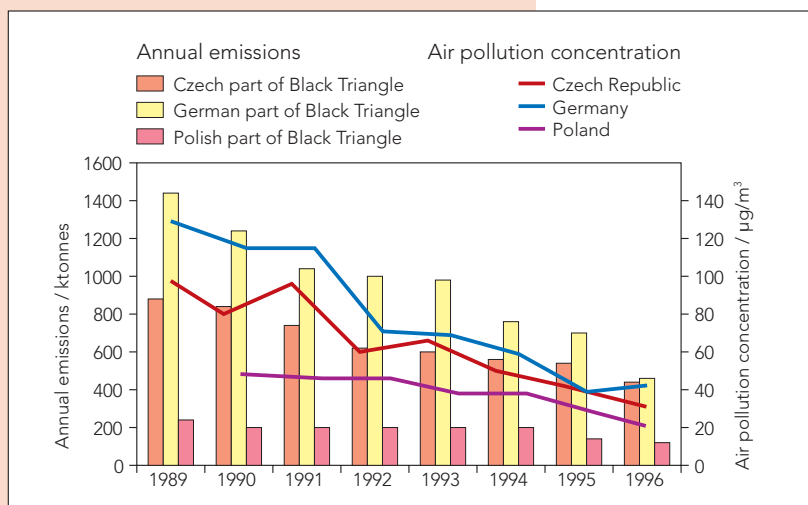
The intensive exploitation of lignite began in the 19<sup>th</sup> century and the development of mining, heavy and chemical industry intensified after World War II. The most dense concentration of large emission sources in the Black Triangle region is in industrial areas of Most, Chomutov and Ústí nad Labem in the Czech Republic and Zwickau, Chemnitz, Dresden, Plauen and Elsterber in Germany.

Between 1989 and 1996, the air emissions from the largest Black Triangle sources were reduced significantly (Figure 3.4.7). Sulphur dioxide emissions were reduced by 50% in Poland and the Czech Republic and to 30% in Germany. The nitrogen oxides emissions also decreased by 50% in the Czech Republic and Germany. The improvement of air quality in the Black Triangle region is the result of emission abatement of German and Czech sources, as well as the reconstruction of Turów Power Plant in Poland. There is also a remarkable decrease of coal consumption by small sources and households, due to substitution with gas and other types of fuel.

Concentrations of sulphate and nitrates in precipitation show decreasing trends similar to those

**Time courses of total annual emissions and air pollution by sulphur dioxide in the Black Triangle**

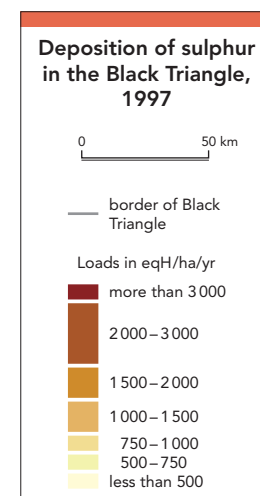
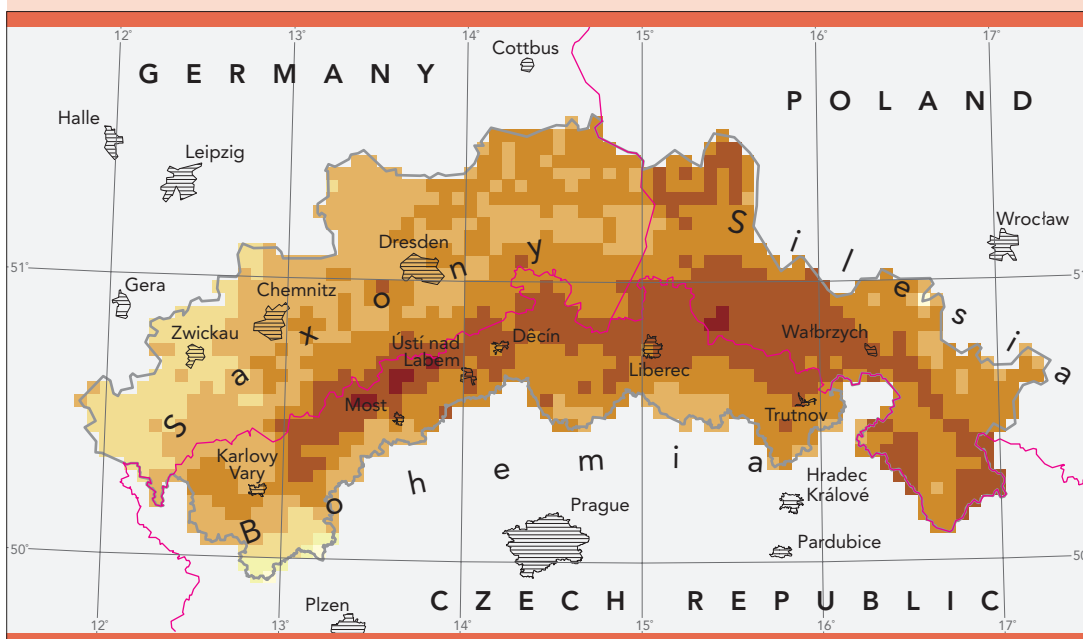
Figure 3.4.7



for emissions and air pollution. However, the deposition of sulphur and other acidifying substances in the Black Triangle area is still fairly high (Map 3.4.6). Sulphur deposition is expected to further decline from about 9 g/m<sup>2</sup>/year in 1990 to 1 g/m<sup>2</sup>/year in 2010.

Source: PHARE Topic link - ETC/AQ

The long-term exceedances of critical loads by atmospheric deposition of sulphur are highest on top of the mountains. These are the areas with the worst forest damage. During the period 1972-1989, about 50% of the coniferous forests in the Ore Mountains disappeared. The most affected areas were on slopes facing south and south-east. The absolute deforestation rate decreased from 26.7 km<sup>2</sup>/year in the beginning of the period to 7.8 km<sup>2</sup>/year in 1989. Only 26% of the Bohemian forest, 45% of the Saxonian forest, and 22% of the Silesian forest remains undamaged (Hlobil and Holub, 1997). Air pollution has changed the ecosystem in North Bohemia, which resulted in soil acidification, loss of base cations, changes in plant community composition and forest damage. Deforestation negatively influences availability and quality of water and soil erosion.



**Map 3.4.6**  
The demarcation is that of the EU PHARE-funded Black Triangle Project  
Source: Phare Topic Link/AQ

The various approaches to calculating exceedances of critical loads have implications for reaching the environmental goals set by present policies. The improved accuracy of the AAE approach allows quantification of environmental improvements that were largely underestimated by the calculations based on the AE of critical loads. For example, recent calculations (Amann *et al.*, 1998) indicate that scenarios aiming at a 90% reduction of the AAE exceedance of critical loads (90% AAE gap closure) did not reach a 50% reduction of the area exceedance in all places (50% AE gap closure), because the AE calculations had overestimated the actual exceedances.

The present critical loads evaluate damage to soils, vegetation and freshwater. The actual types of ecosystems considered in the calculations vary considerably from country to country. In all countries, the incorporation of other effects, such as adverse health effects or corrosion damage to materials in the critical load analysis is an important issue for integrated assessment, as new policies and responses will necessarily focus on the diverse effects of closely linked atmospheric pollutants. In addition, the consequences for the critical loads resulting from the interaction of different pollutants are not yet well understood. The study of damaging effects should combine the analysis of both tropospheric ozone and acidifying pollutants.

### 5. Effects on flora and fauna

The assessment of adverse effects on vegetation caused by ozone exposure is based on the critical level concept. In a series of international workshops organised under the auspices of UNECE CLRTAP, critical levels of ozone were agreed upon to prevent damage to the most sensitive crops, forests and natural vegetation.

The UNECE International Co-operative programme on assessment and monitoring of air pollution effects on Forests (ICP Forest) has observed the forests of Europe where tree crown condition has been deteriorating on a large scale over several years. Distinct areas with heavily damaged trees exist in various parts of Europe (Box 3.4.2). The deterioration is most severe in the regions of central Europe where sulphur and nitrogen depositions are highest. In some of those regions, Scots pine recovered after a decrease in air pollution and improved

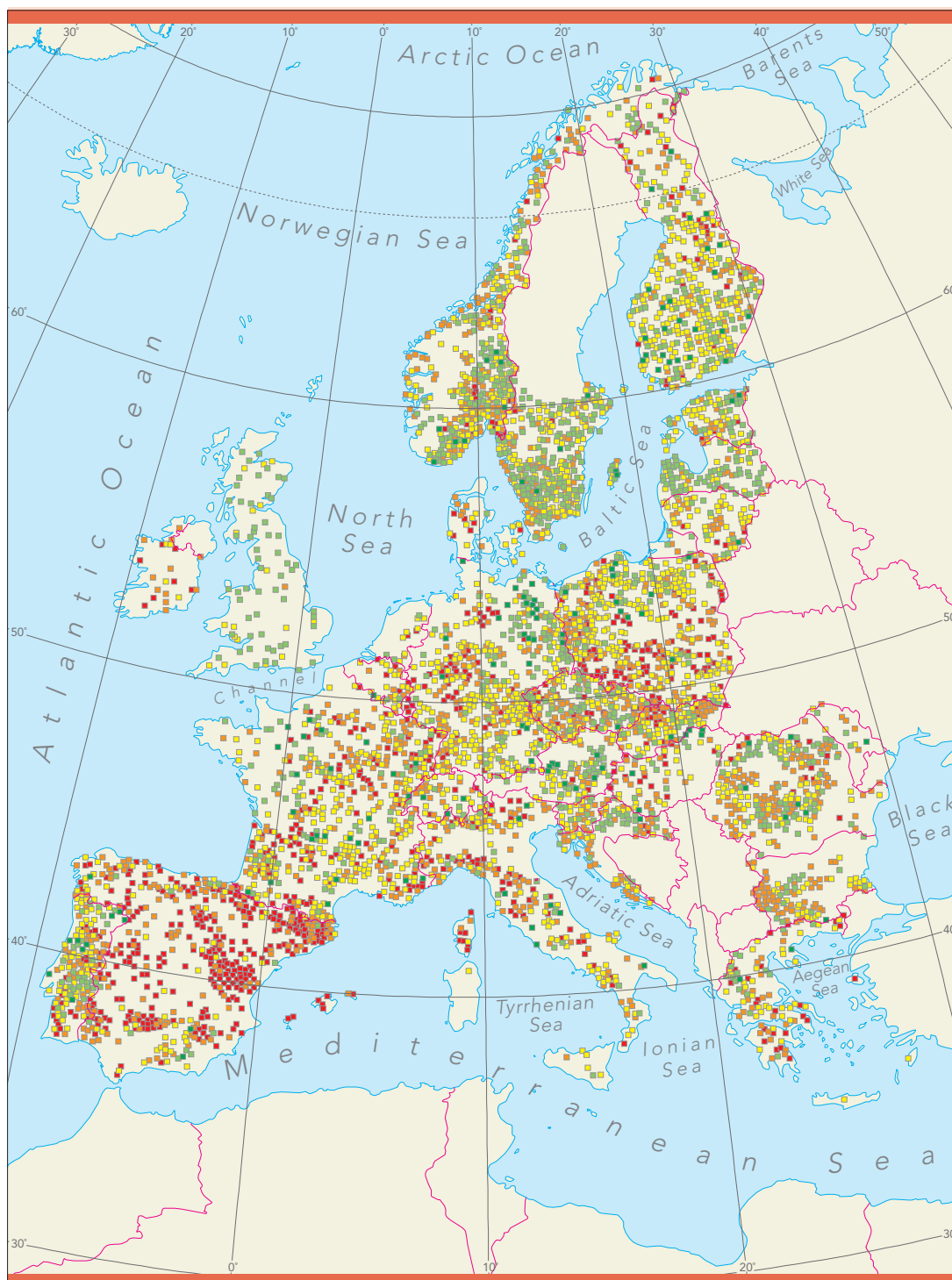
weather conditions. Crown conditions are affected by many stress factors and the trends of the most common species are related to soil and humus types. However, large-scale deterioration over more than a decade is not readily explicable by natural stresses alone (UNECE, 1998). On a large scale, air pollution is considered as a predisposing or triggering factor (see also Chapter 3.11).

Nitrogen deposition affects ecosystems in particular in nutrient-poor areas. The increasing domination of grass species on many lowland dry-heathlands in western Europe can largely be attributed to the effect of excess nutrient deposition. There is in fact growing evidence that excess nitrogen input increases frost and drought sensitivity of heather.

Transboundary transport and deposition of heavy metals lead to accumulation of these metals in the ecosystem. Acidification also increases the bio-availability of metals. The long-term accumulation of metals in the topsoil and vegetation also leads to increased concentrations in animals. It may be concluded that high concentrations of cadmium and lead found in birds and mammals (reindeer, moose) in remote areas are attributable to long-range transport. The reported concentrations are below the lowest acute effect-levels but sub-lethal effects (impaired vision, co-ordination and body movement) might well occur (AMAP, 1997).

The tendency of persistent organic pollutants to bio-accumulate and bio-magnify results in significant exposure levels for organisms at highest trophic levels, such as humans and marine mammals. It is known that POP exposure affects reproduction either by diminishing survival of offspring or by disrupting reproductive function and reproductive cycles of adult animals (see also Chapters 3.3 and 3.11).

Short-term exposure of crops during smog episodes may lead to visible injuries. However, the largest effect on agricultural crops is caused by chronic exposure during the growing season which might lead to reduction in crop yield. For the Netherlands alone, it is estimated that a 30% reduction in average ozone concentrations during the growing season will yield an annual benefit of 200 million euros (Tonneijck *et al.*, 1998). This compares with an estimated cost of half a million euros per year.



**Trend in defoliation for all tree species, 1989–1995**

0 500 km

- significant improvement
- improvement
- no clear trend
- deterioration
- significant deterioration

Map 3.4.7

Source: SC-DLO

**Box 3.4.2 Defoliation**

There is a distinct cluster of deterioration in central and eastern Europe and in Spain. It is well known that the air pollution differs strongly between the two regions, indicating that other factors than air pollution alone must be responsible for the decrease. There is however, a clear coincidence between the high air pollution in central Europe and the high deposition of acidity. In this area critical loads are strongly exceeded (Klap et al., 1997). The temporal changes in defoliation for the Norway Spruce, one of the most common coniferous trees over Europe (Figure 3.4.8) shows a

slow deterioration in crown conditions between 1989 and 1995 with a peak in 1992. The fraction of trees with a defoliation of more than 50% increased steadily over the period. The fraction of healthy trees (defoliation of 10% or less) decreased over the period from 47% in 1989 to 39% in 1995. However, the deterioration slowed down after 1992 with little change in crown condition occurring in the period 1993-1995 (see also Chapter 3.11).

As an example of a typical Mediterranean tree, the results for Holm oak (*Quercus ilex*) are shown in

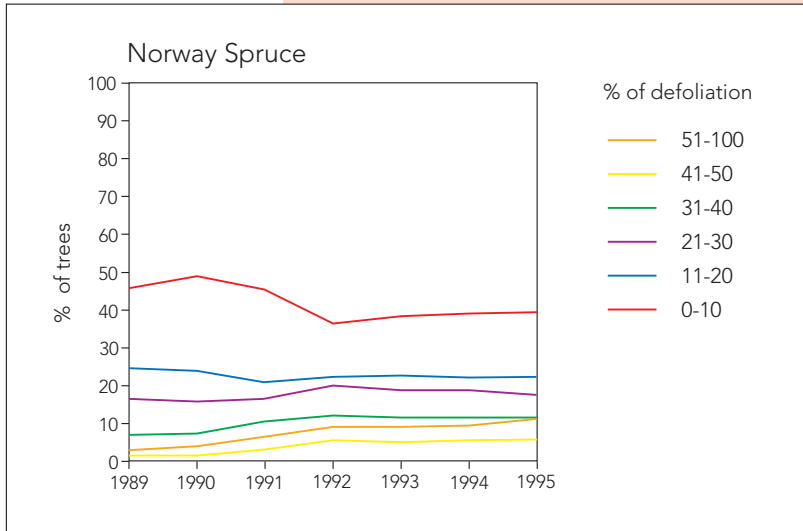


Figure 3.4.9. This species presents the most serious deterioration of all species considered by the UNECE International Co-operative programme on Forest. While crown condition improved between 1989 and 1990, it subsequently declined sharply. In 1989 more than 70% of Holm oaks were considered not defoliated whereas in 1995, nearly 80% of the trees showed some sign of defoliation (Müller-Edzards et al., 1997).

Figure 3.4.8  
Temporal changes in defoliation for the Norway Spruce

Source: SC-DLO

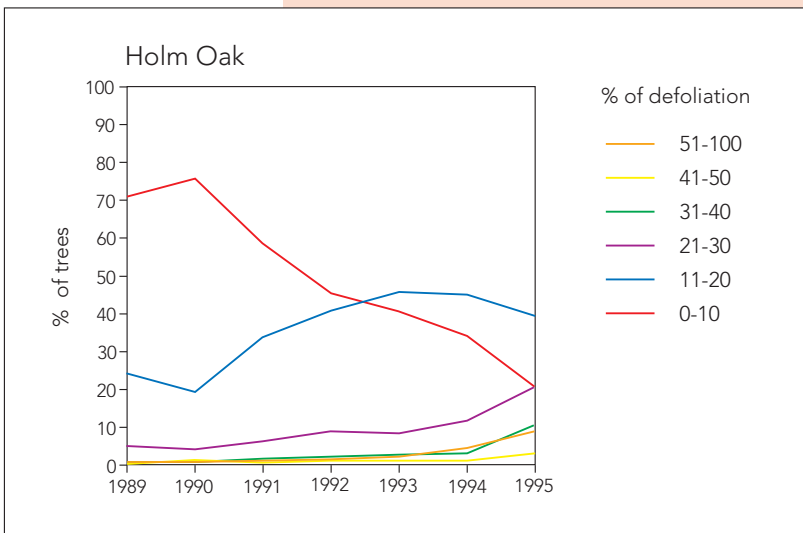


Figure 3.4.9  
Temporal changes in defoliation for the Holm Oak

Source: SC-DLO

## 6. Future trends

### 6.1. Total emissions

Implementation of policies in the pipeline is likely to substantially reduce emissions in Europe by 2010 (European Commission, 1999). For the EU and AC10 combined the SO<sub>2</sub> emissions are expected to decrease by 65% in 2010 from 1990 levels. NO<sub>x</sub> emissions are expected to decline by 40% and VOC emissions by 43%. It is anticipated that reductions in SO<sub>2</sub>, NO<sub>x</sub> and VOC emissions will be larger in the EU than in the Accession Countries (Table 3.4.4). The projected reduction in ammonia emissions is lower than for the other pollutants (14%). Germany and the Netherlands are projected to make significant contributions to these overall reductions. A small 1% reduction of NH<sub>3</sub> emissions is expected in the AC10 for the period 1990 to 2010, while substantial increases in NH<sub>3</sub> emissions are projected in some AC10 countries.

The implications of EU emission reductions against its targets are summarised in Table 3.4.5.

SO<sub>2</sub> emissions are mainly originating from the energy sector (power generation) and industry, while the most important sources of NO<sub>x</sub> emissions are the transport sector followed by the energy and industry sector. The main source of NH<sub>3</sub> emissions is agriculture.

Under the baseline scenario, the share of SO<sub>2</sub> emissions from energy is projected to decrease, due to measures such as fuel shift from coal to natural gas, while the share from industry is projected to increase (Table 3.4.6). However, all sectors are expected to substantially decrease SO<sub>2</sub> emissions in absolute terms. Also, NO<sub>x</sub> emissions from transport, energy and industry are projected to decrease substantially, resulting in a decrease in the share from transport. Only small reductions

of NH<sub>3</sub> emissions from agriculture are projected under the baseline scenario.

Transport and other sectors, mainly solvent use in industry and households, are the main sources of NMVOC emissions. Under the baseline scenario, emission reductions are mainly expected in the transport sector, resulting in a lower share in 2010.

### 6.2. Emissions from the transport sector

The transport sector accounts for a substantial proportion of VOC and NO<sub>x</sub> emissions, and is therefore a main contributor to the problem of tropospheric ozone and to a lesser extent acidification (EEA, 1998).

Total passenger-km travelled is projected to increase by 40% between 1990 and 2010 (Figure 3.4.10) (the figures for the EFTA and AC10 are 230% and 115% respectively). A 50% increase is projected in freight transport tonne/km between 1990 and 2010; projections also show 85% growth in road freight with an increase in fuel consumption of 70% – indicating some gains in fuel efficiency (for further details of these projections, see Chapter 2.2).

### 6.3. Emissions from ship traffic

The European Commission's acidification strategy (European Commission, 1997) recognises the cost-effectiveness of reducing emissions from ship traffic in the North Sea and the north-eastern Atlantic Ocean relative to reduction of land-based emissions.

In absolute values, the emissions of SO<sub>2</sub> and NO<sub>x</sub> from international ship traffic in 1995 were similar in magnitude to the contribution of individual large countries. The contribution of emissions from international ship traffic sources to the total deposition over western Europe is about 10-15% (Tsyrö and Berge, 1997).

Projected emission reductions in Europe (in ktonnes)						Table 3.4.4.
Pollutant	EU15			Accession Countries		
	1990	2010	reduction	1990	2010	reduction
SO <sub>2</sub>	16 300	4 800	71%	10 300	4 300	59%
NO <sub>x</sub>	13 200	7 300	45%	3 500	2 600	27%
NH <sub>3</sub>	3 600	2 900	14%	1 400	1 390	1%
VOC	14 000	7 200	49%	2 600	2 300	10%

Source: European Commission, 1999

EU progress in achieving key EU environmental targets (1990 = 100)				Table 3.4.5.
Acidification	target year	expected level in target year	target	
SO <sub>2</sub> emissions	2000	53*	60	
	2010	29	16**	
NO <sub>x</sub> emissions	2000	81*	70	
	2010	55	45	
NMVOC emissions	1999	81*	70	

\*) based on current reduction plans of Member States

\*\*\*) proposed target within the Acidification Strategy (European Commission, 1977) will be revised in the forthcoming National Emission Ceiling Directive, linked to the forthcoming combined EU ozone/acidification strategy.

Source: EEA

The relative importance of international ship traffic emissions will increase if no measures are taken to control this type of emission. Since the total reported emissions of SO<sub>2</sub> and NO<sub>x</sub> in European countries decreased markedly from 1990 to 1995, the relative contribution of international ship traffic increased in the period to 3.5% for SO<sub>2</sub> and 7.5% for NO<sub>x</sub>. If no further reductions are accomplished, it is expected that the relative contribution of emissions from

Contribution to EU emissions of SO <sub>2</sub> , NO <sub>x</sub> , NH <sub>3</sub> and NMVOC, per sector, in 1995 and in 2010									Table 3.4.6.
Sector	SO <sub>2</sub>		NO <sub>x</sub>		NH <sub>3</sub>		NMVOC		Source: European Commission, 1999
	1995	2010	1995	2010	1995	2010	1995	2010	
Energy	58	49	19	19	0	0	0	0	
Industry	25	32	12	17	2	2	8	13	
Agriculture	0	0	0	0	94	95	*)	*)	
Transport	7	7	63	55	4	3	40	29	
Other	10	12	6	10	0	0	52 <sup>*)</sup>	58 <sup>*)</sup>	

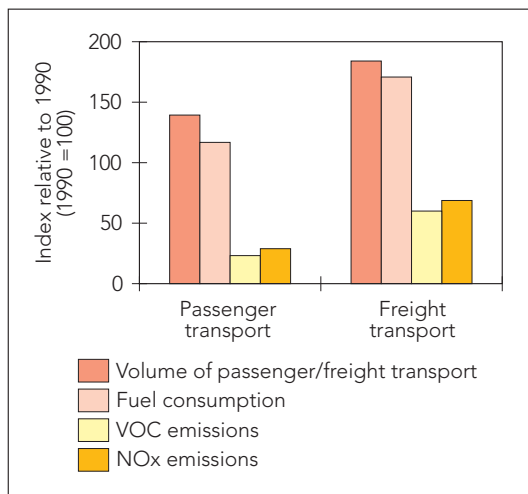
\*) VOCs from agriculture is included in 'other'. The dominating contribution in the sector 'other' is from solvent use within industry and households.

Figure 3.4.10

**Indexed EU development of various road transport parameters in 2010, relative to 1990**

Between 1990 and 2010, passenger and freight transport will grow by about 40% and 80% respectively. Consumption of fuel will grow less, with the introduction of more efficient engines. With the introduction of technical 'end-of-pipe' measures, a further reduction in emissions will be achieved. For NO<sub>x</sub> and VOC, a reduction substantially below the 1990 levels is projected.

Source: European Commission, 1999



international ship traffic will have doubled by the year 2010 (Figure 3.4.11).

As a consequence, reductions of emissions from international ship traffic would translate into considerable reductions of the pressures/depositions in western European countries, with the additional advantage of reducing the costs for reaching the established environmental targets.

In 1997, the International Convention for the Prevention of Pollution from Ships (MARPOL) proposed a new protocol to reduce pollution from ships' exhaust emissions. Reducing emission from international ship traffic could be more cost-effective than reducing land-based sources (Amann *et al.*, 1997). The estimated savings are about 1 000 million euros/year. While the costs for limiting the sulphur content of marine bunkers in the North Sea and the Baltic to 1.5% (the maximum value accepted by MARPOL) were estimated at about 87 million euros/year, land-based sources would experience a decline in their costs of about 1 150 million euros/year.

These values are presently under re-evaluation, taking into account revised emission estimates calculated by Lloyd's Register of Shipping. Since the latest emission estimates are more than a factor of two larger than before, the estimated cost-benefit could be even higher than 1 000 million euros/year.

#### 6.4. Emissions from aircraft

Although aircraft NO<sub>x</sub> emissions are in absolute terms small when compared with the NO<sub>x</sub> emissions from road transport, their impact on ozone formation is relatively large. In the main flight corridors about 1-4% of the ozone in the upper troposphere and lower stratosphere is formed from aircraft emissions (Brasseur *et al.*, 1998). According to aircraft scenarios the enhanced ozone formation will increase between 1990 and 2015 by 50-70% (Valks and Velders, 1999).

#### 6.5. Damage to ecosystems and health

Under the baseline scenario, significant improvements in the area of ecosystems which are protected against acidification and eutrophication will be achieved (Figure 3.14.12). The acidification impact reductions are concentrated in northern Europe: the UK, northern France, Belgium, the Netherlands, Germany, Poland, Czech Republic, Slovak Republic and Austria (see section 4.3 in Chapter 3.11). For eutrophication, the improvements are more dispersed across Europe.

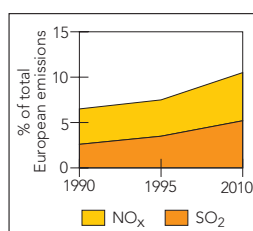
In the EU, ecosystems that receive acid deposition above their critical loads could decrease from 25% of the total (38.6 million ha) in 1990 to 7% in 2010 (10.6 million ha). Ecosystems in several countries, such as France, Ireland, Italy, Spain are virtually no longer exposed to exceedances of critical load. Other countries, where the proportion of ecosystems affected by acidification was high in 1990 show considerable improvement. In 2010, the two countries with the highest proportion of ecosystems affected by acidification remain Germany and the Netherlands, although considerable improvement will be experienced; there will be reductions from 84% above critical loads to 33% in Germany and 89% to 45% in the Netherlands.

Figure 3.4.11

**Contribution from international shipping in the North Sea and north-east Atlantic Ocean to total European acidifying emissions**

Nitrogen compounds and sulphur compounds each contribute about 50% to ongoing acidification.

Source: EMEP



In the AC10, the area of ecosystems with a deposition above the critical load for acidification could decrease from 44% of all natural and semi-natural ecosystems (18.1 million ha) to 6%. In Norway and Switzerland, these improvements are from 25% to 13% and from 38% to 4% respectively. Very



large improvements in the impact of acidification are projected for some Accession Countries. For example, the proportion of ecosystems adversely affected by acidification drops from 91% to 19% in the Czech Republic, from 44% to 4% in Lithuania, and from 73% to 8% in Poland.

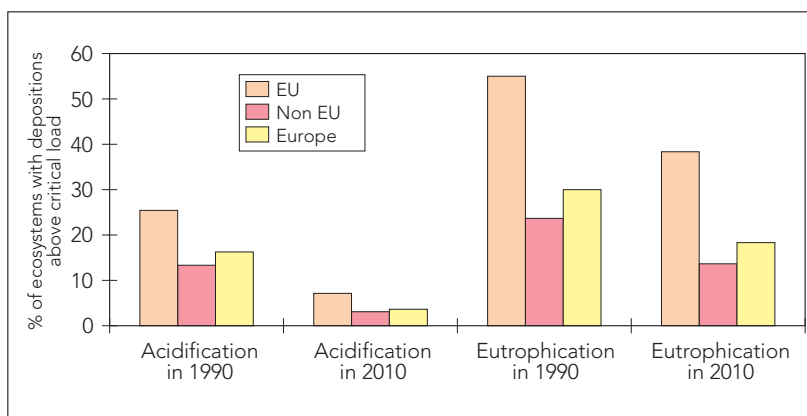
In the EU, the area of ecosystems that receives nitrogen deposition above critical loads for eutrophication could decrease from 55% (68.0 million ha) in 1990 to 39% in 2010 (48.8 million ha). Countries where a high proportion of ecosystems remains adversely affected by eutrophication in 2010 include Belgium, France, Germany, Luxembourg and the Netherlands.

Eutrophication impact levels, however, remain high in most of the EFTA countries and in the AC10. In the AC10, the eutrophication indicator improves to a lesser degree from 84% of the area (33.4 million ha) having a nitrogen deposition exceeding the critical load to 72%. Countries where over 70% of ecosystems will still be affected by excess nitrogen deposition include the Czech Republic, Lithuania, Poland, the Slovak Republic and Switzerland.

With respect to ozone, the reductions in precursor emissions will lead to a reduction of about 25% in AOT40 levels for crops (Figure 3.4.13). Despite the considerable efforts in emission reductions, the long-term objective of 6 000  $\mu\text{g}/\text{m}^3\cdot\text{h}$  will only be

Ecosystem damage in Europe: fraction of ecosystems with depositions above their critical loads

Figure 3.4.12



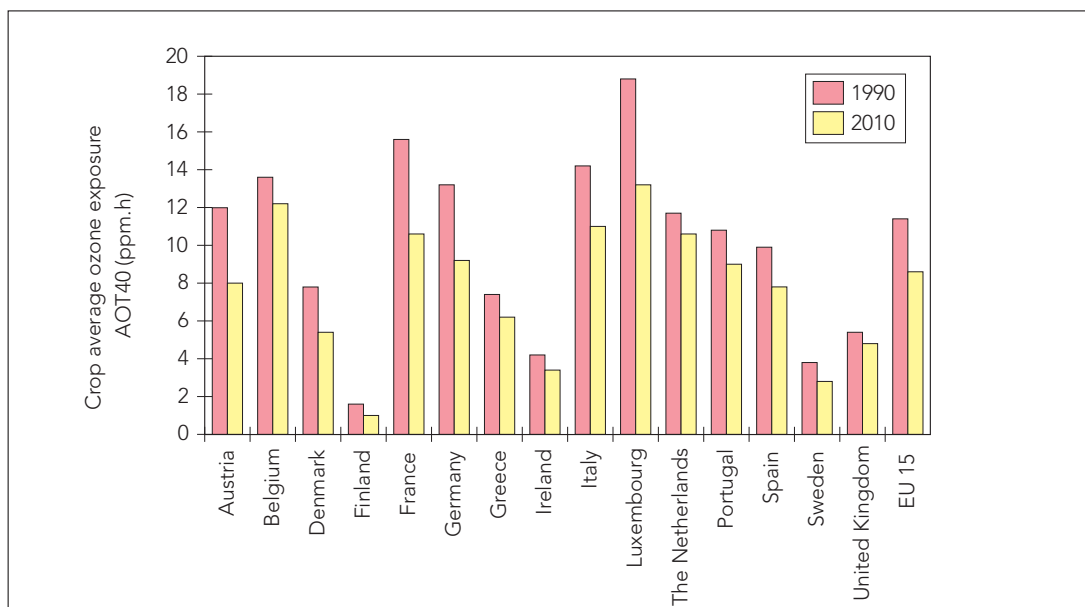
Source: European Commission, 1999

reached in the north-west outskirts of Europe (Ireland, Scandinavia). The target value of 16 000  $\mu\text{g}/\text{m}^3\cdot\text{h}$  will still be exceeded in seven EU Member States.

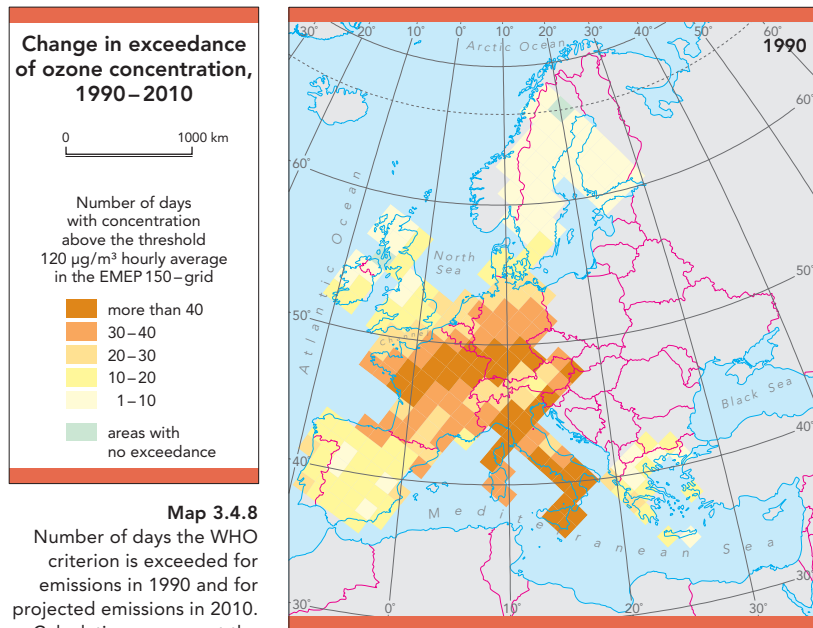
The reduction in the number of days with ozone above the health-related threshold of 120  $\mu\text{g}/\text{m}^3$  varies over Europe (Map 3.4.8). Under the assumption of the most unfavourable meteorological conditions, the number of days above the health-related threshold falls from 67 in 1990 to 49 in 2010. There is however, a shift in location: in 1990 the highest numbers of exceedances were found in southern Italy; in 2010 the highest number are found in the more densely populated north-western part of EU (the Netherlands, Belgium, and northern France).

Reduction in exposure of crops in 2010 in EU compared with the situation in 1990

Figure 3.4.13



Source: EMEP



**Map 3.4.8**

Number of days the WHO criterion is exceeded for emissions in 1990 and for projected emissions in 2010. Calculations represent the maximum of the three-year moving averages for the five-year period considered

Source: European Commission, 1999

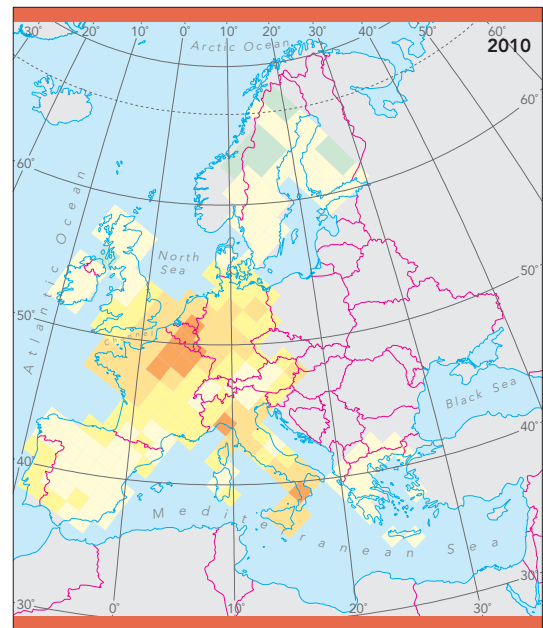
## 7. Future acidification and summer smog policies

### 7.1. Emission-oriented policies

An optimal emission-reduction strategy requires coordination of  $\text{SO}_2$ ,  $\text{NO}_x$ ,  $\text{NH}_3$  and VOC emission controls. At present, environmental problems are treated separately, so that acidification-related strategies emphasise reduction in  $\text{SO}_2$  and nitrogen emissions, ozone-related strategies prioritise  $\text{NO}_x$  and VOC measures, while eutrophication strategies suggest the importance of  $\text{NH}_3$  emission reductions. The focus on acidification abatement is presently on nitrogen compounds.  $\text{NO}_x$  emissions are major contributors to the acidification and eutrophication of ecosystems and are at the same time a precursor of ground-level ozone. This implies that any emission reduction scenario should combine the evaluation of the consequences on health and vegetation due to ozone exposure together with their impacts in acidification.

Both the EU and UNECE have been working since 1997 on a combined acidification/eutrophication/ozone abatement strategy, seeking cost-effective solutions to minimise the gap between critical load/level and ambient levels. With the use of the new AAE concept to calculate average accumulated exceedance to critical loads, significant and cost-effective reductions appear possible.

The analysis of all these effects combined increases the demand for further  $\text{NO}_x$  reductions, while the requirements on  $\text{SO}_2$  and VOC controls are somewhat relaxed and



the requirements for ammonia emission reductions remain almost unchanged (Amann *et al.*, 1998).

There is a – sometimes complex – relation between precursor emissions and environmental quality. If a target on environmental quality is set, such as full protection of all ecosystems from acidification, emission targets are implicitly set. So far, this interrelation has been included in the development of EU policies using expert judgements. Only recently have both the EU and UNECE adopted a broad approach which should help to abate the problems of acidification, eutrophication, as well as those of photochemical oxidants. This approach will seek to establish national emission ceilings for the relevant components that take into account the effect of the emission reduction in the various problem areas and the costs involved in emission abatement. For the first time, agreements on abating  $\text{NH}_3$  emissions will be made at an international level.

### 7.2. Air quality, deposition standards, and target levels

For the air pollutants causing acidification and summer smog, the WHO has recommended air quality guidelines for protection of human health and ecosystems (WHO, 1995 and 1996 a, b). These recommendations are applied to policy use in the European Union as well as the UN-ECE. At present the EU Council of Ministers has agreed on a common position on the proposed daughter directives on ozone,  $\text{PM}_{10}$ ,  $\text{SO}_2$ ,  $\text{NO}_2$  and other pollutants in the framework of the Air Quality Framework Directive

(European Community, 1996). Once adopted, this will lead to more stringent air quality targets.

For ambient SO<sub>2</sub> and NO<sub>2</sub> concentration, targets have been set both for protection of human health and to avoid damage to ecosystems. Generally, the requirements on emissions reduction to meet the deposition targets are more stringent than reductions needed to meet the concentration targets. However, close to sources, high concentrations may occur, such as in an industrial area or in a very busy street (see Chapter 3.12). Current air quality thresholds for the EU are defined in the Ozone Directive (92/72/EC). In 1999, a new ozone daughter directive was proposed by the Commission. A similar situation to the case with acidification abatement (section 5 of this chapter) evolved in defining an ozone-abatement strategy in the EU. To attain ambient ozone concentrations at a level below which adverse effects on human health and ecosystems are unlikely: European-wide emission reduction of 80% or more will be needed. Even with major improvements in current technologies, this will hardly be achievable and large changes in societal behaviour would be needed. Therefore, interim target values have been defined, taking into account realistic options for emission abatement.

A monitoring strategy is defined in the Air Quality Framework Directive (European Community, 1996) and the proposed daughter directive on ozone. This strategy is designed to assess the current ozone levels relevant for human health and ecosystems but it can only partially answer other important questions:

- Is the ozone situation improving? Trends in ozone concentrations are obscured by the large year-to-year variations caused by different weather conditions. To detect a possible trend, long-term measurements of high quality are needed.
- Is there compliance with agreed emission reductions? Ozone is a secondary pollutant, in the sense that it is formed by chemical processes from other substances emitted to the environment. Information on its precursor levels cannot be detected by monitoring ozone. Moreover, there is a strong non-linearity between ozone levels and precursor emissions: for a certain reduction in ozone levels, at least a threefold reduction in precursor emissions is

needed. Monitoring of NO<sub>x</sub> and VOC in combination with ozone monitoring is needed to follow the implementation of abatement measures.

## 8. Emerging Issues

### 8.1. Global tropospheric ozone

During the summer, there is a general blanket of medium to high ozone levels over Europe at least twice as high as during the 1850s (EEA, 1998). These background levels frequently exceed the concentrations at which damage to vegetation is expected. Model calculations indicate that the increase in these tropospheric background concentrations will continue. The steady growth in ozone is caused by increases in background levels of nitrogen oxides, carbon monoxide, as well as methane (see for example Berntsen *et al.*, 1997).

Ozone precursors may be transported over distances of hundreds to thousands of kilometres, resulting in ozone formation far from its source. An abatement policy at European level is therefore a key issue. Long-range intercontinental scale ozone formation and transport in the lower troposphere has also been postulated (Parrish *et al.*, 1993; Collins *et al.*, 1998): fringes of ozone leaving the east coast of North America spread out over the North Atlantic towards Europe; the European ozone plumes stretch out eastwards over the continent and join with the ozone peaks over the densely populated areas in Asia. It might be that the global background increase partly reverses the advantages of a European reduction program. The overall success of pan-European abatement policies will depend on actions on a hemispheric scale, a European scale and an urban scale.

On a global scale, production and use of fossil fuels are important sources of methane and CO emissions. Biomass burning, waste treatment and intensive cattle breeding are additional sources. An overview of global emissions is presented in Table 3.4.7.

Calculations using global-scale models (Collins *et al.*, 1998) indicate that ozone concentrations within Europe are more or less stable. The reduced ozone formation caused by reduction in NO<sub>x</sub> emissions within Europe appears to be just enough to counterbalance the increased ozone input from the global background. Actions on a global scale, in particular aiming at reductions of

Table 3.4.7. Global emissions in 1990 (Tg)

	Methane	CO	NO <sub>x</sub> <sup>(1)</sup>	VOC <sup>(2)</sup>
Fossil fuel production and combustion	94	263	72	69
Biofuel	14	181	5	31
Industrial processes	0.8	35	5	34
Land use/waste treatment	211	496	20	44
Total anthropogenic	320	974	102	177.5
European contribution (%) <sup>2</sup>	25	15	26	21
Natural emissions	160	70-280	23-131	1100

<sup>(1)</sup> in Tg NO<sub>2</sub><sup>(2)</sup> incl. Newly Independent States (of former USSR)

Source: Olivier et al., 1996; IPCC, 1996; EEA, 1995

emissions of CO, methane and NO<sub>x</sub> will be necessary to control ozone concentrations in Europe.

Ozone is also a greenhouse gas. The increase in tropospheric ozone has potentially important consequences for radiative forcing (See Chapter 3.1).

### 8.2. Is our cultural heritage more in danger than our ecosystems?

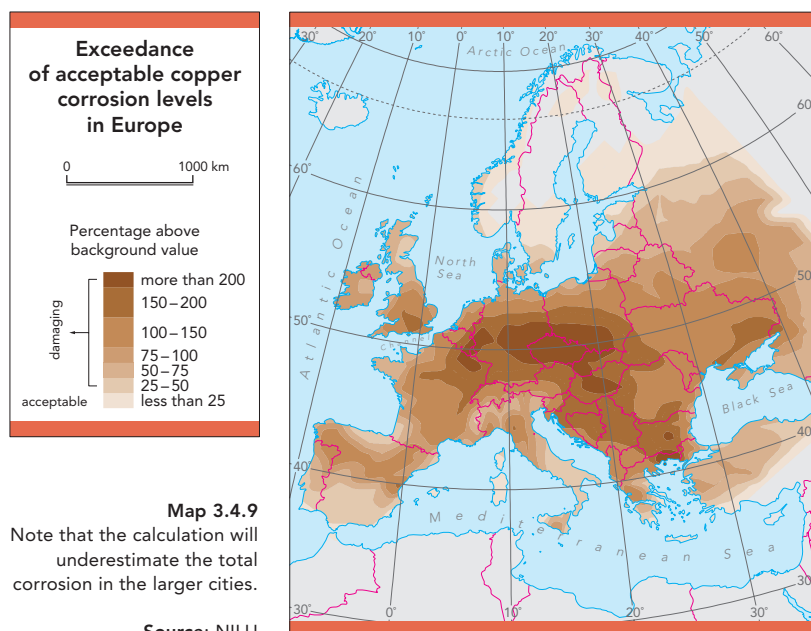
Exposure to acidifying and photo-oxidant air pollution increases the corrosion rate of materials. Gaseous SO<sub>2</sub> has been considered to be the main explanatory factor for corrosion damage to buildings and building materials. Ozone also affects materials such as natural and synthetic rubbers, coatings

and textiles. Recently, synergistic effects of ozone in combination with the acidifying components SO<sub>2</sub> and NO<sub>2</sub> have been reported to lead to increased corrosion. This affects in particular the materials most widely used in our cultural heritage, such as marble, calcareous stone and rendering, medieval glass, copper, bronze and most construction metals.

Recent results (ETSU, 1996) indicate that the average cost of material damage is approximately 1 130 euros per tonne SO<sub>2</sub> emitted, which implies a total damage cost of 13.5 billion euros per year for the EU in 1995. This probably underestimates the cost of the damages if the enhanced corrosion levels resulting from the combined exposure to O<sub>3</sub> and acidifying compounds were to be considered. There are two main reasons for this expected underestimation. First, the combination of SO<sub>2</sub> and O<sub>3</sub> increases the actual corrosive attack on materials. Second, the geographical distribution of potential corrosion is expected to change when synergetic effects are considered. Introducing the effect of ozone will probably enhance the corrosion levels in southern Europe, that is, in areas with an extensive cultural heritage where the impact of corrosion will cause more damage.

The distribution of copper corrosion rates illustrates well the above-mentioned geographical effect of the combined exposure to SO<sub>2</sub> and O<sub>3</sub> air concentrations. Copper corrosion has been calculated from 1996 European levels of SO<sub>2</sub>, NO<sub>2</sub> and O<sub>3</sub>. The actual corrosion levels have been compared to the corrosion caused by exposure to background air concentration. Corrosion rates approximately 25% higher than background corrosion are considered acceptable, above this corrosion levels are considered damaging. Acceptable corrosion rates are exceeded all over Europe (Map 3.4.9), and decay rates are doubled in most central European regions. The substantial emission reductions during recent years have reduced corrosion damage in Scandinavia. In central Europe we still see the effects of high levels of SO<sub>2</sub> pollution in areas of Germany, Poland and the Czech Republic where the corrosion rate still is more than three times the general background for Europe. In southern Europe the increased corrosion rate is mostly generated by the high ozone level, although SO<sub>2</sub> may still contribute in some areas.

Comparing the geographical distribution of exceedances of acceptable corrosion rates



and the distribution of exceedances of critical loads for acidification and eutrophication brings the focus towards southern and eastern Europe. This introduces new elements in the discussion of the harmful effects of transboundary air pollution that will be worth analysing in the future.

#### References

- Amann, M. et al., (1997) Cost-effective Control of Acidification and Ground-Level Ozone. Second Interim Report, IIASA, A-2361 Laxenburg Austria.
- Amann, M. et al., (1998) Cost-effective Control of Acidification and Ground-Level Ozone. Fifth Interim Report, IIASA, A-2361 Laxenburg Austria
- AMAP (1997) Arctic Pollution Issues. A state of the Arctic Environment Report. AMAP, Oslo, Norway.
- Beck J.P., Krzyzanowski M. and Koffi B. (1998) Tropospheric ozone in the European Union. 'The consolidated Report', European Commission Brussels. Also available at <http://eea.eu.int>.
- Berntsen, T.K. et al. (1997) Effects of anthropogenic emissions on tropospheric ozone and its radiative forcing. *J. Geophys. Res.* 102, 28101-28126
- Brasseur, G.P. et al., (1998) European scientific assessment of the atmospheric effect of aircraft emissions. *Atmospheric Environment* 32, 2329-2418.
- Collins W.J., Stevenson D.S., Johnson C.E., and Derwent R.G. (1998) The European regional ozone distribution and its links with the global scale for the years 1992 and 2015, to be published.
- De Leeuw F., Sluyter R. and van Zantvoort E. (1997) Air pollution by ozone in the European Union; exceedances of ozone threshold values in 1996 and summer 1997. EEA Topic Report 7-1997. EEA, Copenhagen.
- de Leeuw and de Paus, 1998. Air Pollution by ozone in Europe; 1997 - summer 1998. EEA Topic Report in press, EEA, Copenhagen.
- EEA (1995) Europe's Environment: the Dobris Assessment. Copenhagen.
- EEA (1998) Europe's Environment: the Second Assessment. Copenhagen.
- EMEP/MSC-W, Report 1/98. Transboundary Acidifying Air Pollution in Europe. DNMI, Norway.
- ETSU (1996) Economic evaluation of the draft directive on incineration of non-dangerous waste; report to EC-DGX1.
- European Commission (1997), Community Strategy to combat acidification COM(97)88 European Commission, Brussels.
- European Commission, 1999 (forthcoming). *Economic Assessment of Priorities for a European Environmental Policy Plan (working title)*. Report prepared by RIVM, EFTEC, NTUA and IIASA for Directorate General XI (Environment, Nuclear Safety and Civil Protection).
- European Commission (1999b), *draft Ozone Directive*, 1998 (to complete).
- European Community (1996) *Council Directive 96/62/EC on Ambient Air Quality Assessment and Management*.
- Hjellbrekke A.G. (1997) Ozone measurements 1995. EMEP/CCC-report 3/97, NILU, Kjeller, Norway
- Hlobil, P. and Holub, J. (1997) Conference on the Black Triangle. In Economy Press May 1997.
- Hov, Ø. and Flatøy (1997) Convective redistribution of ozone and nitrogen oxides in the troposphere over Europe in summer and fall. *J. Atm. Chem.* 28, 319-337.
- IPCC, (1996). *Second Assessment Climate Change 1995, Report of the Intergovernmental Panel on Climate Change. The Science of Climate Change, Contribution of Working Group I.* WMO, UNEP. Cambridge University Press.
- Klap J.M., de Vries W., Erismann J.W. and van Leeuwen E.P. (eds.) (1997) Relationships between forest condition and natural and anthropogenic stress factors on the European scale; pilot study. SC Report 150, DLO Winand Staring Centre, Wageningen.
- Lindskog, A., et al. EUROTRAC-2 Tropospheric Ozone Research, TOR-2. Full proposal. (1998) IVL, Göteborg, Sweden
- Millan, M.M., Salvador, R., Mantilla, E., Kallos, G. (1997) Photooxidant dynamics in the Mediterranean basin in summer: results from European research projects. *J. Geophys. Res.*, 102, 8811-8823.
- Müller-Edzards C., de Vries W. and Erismann J.W. (eds.) (1997) Ten years of monitoring forest conditions in Europe. Federal Research Centre for Forestry and Forest Products, Hamburg.
- NILU, Exceedances of acceptable copper corrosion levels in Europe due to the combined effect of SO<sub>2</sub>, NO<sub>2</sub> and ozone concentrations in air (to complete).
- Olivier J.G.J., Bouwman A.F., van der Maas C.W.M., Berdowski J.J.M., Veldt C., Bloos J.P.J., Visschedijk A.J.H., Zandveld P.Y.J. and Haverslag J.L. (1996) Description of EDGAR, version 2.0. Report 771060 002, RIVM, Bilthoven.
- Parrish D.D. et al., (1993) Export of North American ozone pollution to the North Atlantic Ocean. *Science*, 259, 1436-1439.
- PORG (1997), Ozone in the United Kingdom. Photochemical Oxidant Review Group, DOE, London.
- Posch, M., Hettelingh, J.P., de Smeets P.A.M., Downing, R.J. (eds.) (1997) Calculation and mapping of critical thresholds in Europe. Status report 1997. Coordination Center for Effects. Report 259101007, RIVM, Bilthoven, the Netherlands.
- Simpson, D. et al., (1997) Photochemical oxidant modelling in Europe: multi-annual modelling and source-receptor relationships. EMEP/CCC-Report 3/97, DNMI, Oslo, Norway.
- Simpson, D. et al. (1999) Inventorying emissions from nature in Europe. *J. Geophys. Res.* in press.
- Slanina, J. et al. (1998) Biogenic and anthropogenic volatile organic compounds in the atmosphere. SPB Academic Publishing, Amsterdam, the Netherlands.
- Tonneijk, A.E.G. et al., (1998) Economische aspecten van het effect van luchtverontreiniging op de gewasteelt in Nederland. Report 90, AB-DLO, Wageningen, the Netherlands.
- Tsyro, S. and Berge, E. (1997) *The contribution of ship emission from the North Sea and the north-eastern Atlantic Ocean to acidification in Europe*. EMEP/MSC-W Note 4/97, DNMI, Oslo, Norway.

UN-ECE (1998) 1998 Joint report of the international co-operative programmes and the mapping programme. EB.AIR/WG.1/1998/4.

UN-ECE (1998). *Convention on Long-Range Trans-boundary Air Pollution*, Internet web site ([http://www.unece.org/env/lrtap\\_h.htm](http://www.unece.org/env/lrtap_h.htm)), UN-ECE, Geneva.

Valks, P.J.M. and Velders, G.J.M. (1999) The present-day and future impact of NO<sub>x</sub> emissions from subsonic aircraft on the atmosphere in relation to the impact of NO<sub>x</sub> surface sources. *Annales Geophysicae* (in press).

WHO (1995). Update and revision of the Air Quality Guidelines for Europe. Meeting of the Working Group 'Classical' Air Pollutants. Copenhagen: World Health Organization: 1995.

WHO (1996a) Update and revision of the WHO air quality guidelines for Europe. Classical air pollutants ; ozone and other photochemical oxidants. European centre for environment and health, Bilthoven, the Netherlands.

WHO (1996b) Update and revision of the WHO air quality guidelines for Europe. Ecotoxic effects, ozone effects on vegetation. European centre for environment and health, Bilthoven, the Netherlands.