THE EUROPEAN ENVIRONMENT

STATE AND OUTLOOK 2010

AIR POLLUTION

European Environment Agency

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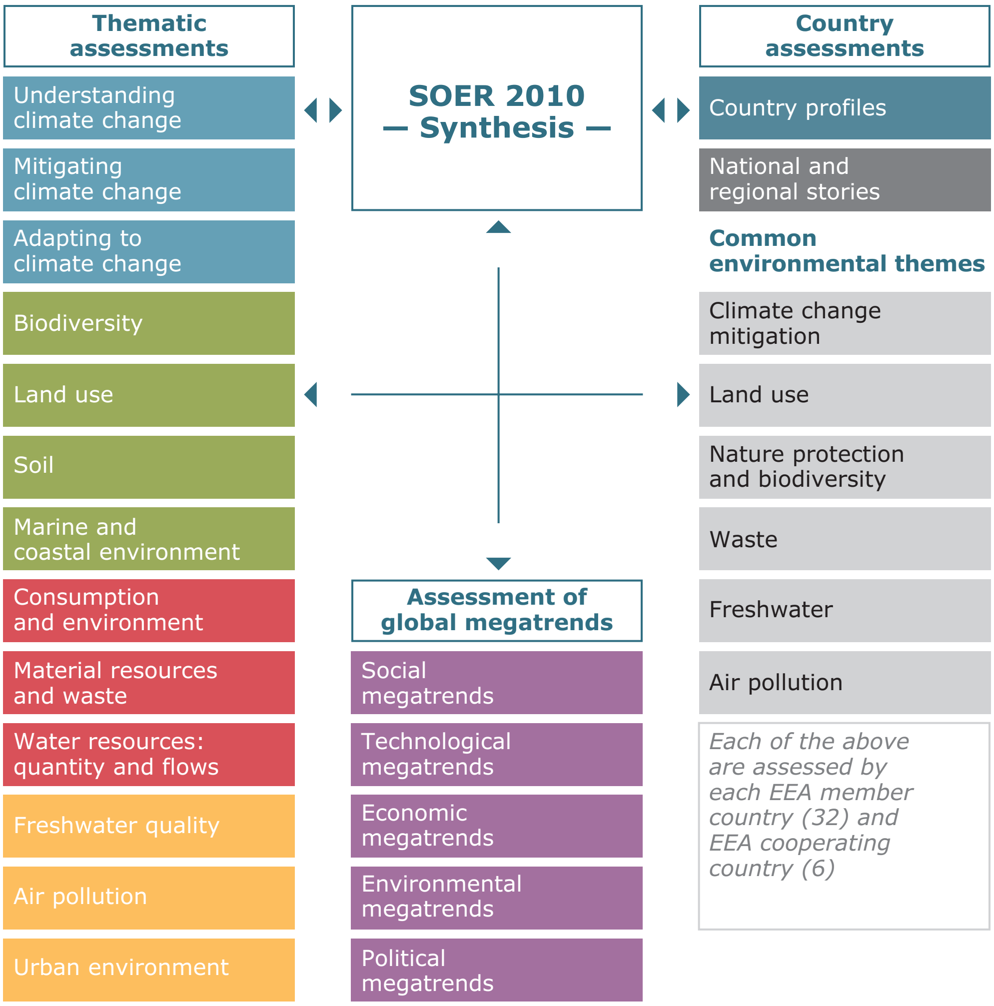
SOER 2010 assessments



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Air pollution

Summary

Emissions of air pollutants derive from almost all economic and societal activities. They result in clear risks to human health and ecosystems. In Europe, policies and actions at all levels have greatly reduced anthropogenic emissions and exposure but some air pollutants still harm human health. Similarly, as emissions of acidifying pollutants have reduced, the situation for Europe's rivers and lakes has improved but atmospheric nitrogen oversupply still threatens biodiversity in sensitive terrestrial and water ecosystems. The movement of atmospheric pollution between continents attracts increasing political attention. Greater international cooperation, also focusing on links between climate and air pollution policies, is required more than ever to address air pollution.

Emissions are declining but air quality still needs to improve

Emissions of the main air pollutants in Europe have declined significantly in recent decades, greatly reducing exposure to substances such as sulphur dioxide (SO_2) and lead (Pb). However, complex links between emissions and ambient air quality means that lower emissions have not always produced a corresponding drop in atmospheric concentrations. Many EU Member States do not comply with legally binding air quality limits protecting human health. Exposure of crops and other vegetation to ground-level ozone (O_3) will continue to exceed long-term EU objectives. In terms of controlling emissions, only 14 European countries expect to comply with all four pollutant-specific emission ceilings set under EU and international legislation for 2010. The upper limit for nitrogen oxides (NO_X) is the most challenging — 12 countries expect to exceed it, some by as much as 50 %.

Human health impacts

Presently, airborne particulate matter (PM), ground-level ozone (O_3) and nitrogen dioxide (NO_2) are Europe's most problematic pollutants in terms of harm to health. Effects can range from minor respiratory irritation to cardiovascular diseases and premature death. An estimated 5 million years of lost life per year are due to fine particles ($PM_{2.5}$) alone in the EEA-32.

Effects on ecosystems

Strictly speaking, the EU has not reached its interim environmental objective that was set to protect sensitive ecosystems from acidification. However, the ecosystem area in the EEA-32 countries affected by excess acidification from air pollution was reduced considerably between 1990 and 2010. This is mainly due to past SO_2 mitigation measures. Nitrogen (N) compounds, emitted as NO_X and ammonia (NH_3), are now the principal acidifying components in our air. In addition to its acidifying effects, N also contributes to nutrient oversupply in terrestrial and aquatic ecosystems, leading to changes in biodiversity. The area of sensitive ecosystems affected by excessive atmospheric nitrogen in the EEA-32 diminished only slightly between 1990 and 2010. Europe's ambient O_3 concentrations still reduce vegetation growth and crop yields.

Energy, transport and agriculture are key emission sources

The energy sector remains a large source of air pollution, accounting for around 70 % of Europe's sulphur oxides (SO_X) emissions and 21 % of NO_X output despite significant reductions since 1990. Road transport is another important source of pollution. Heavy-duty vehicles are an important emitter of NO_X, while passenger cars are among the top sources of carbon monoxide (CO), NO_X, $PM_{2.5}$ and non-methane volatile organic compounds (NMVOCs). Meanwhile, energy use by households — burning fuels such as wood and coal — is an important source of directly emitted $PM_{2.5}$ (primary $PM_{2.5}$). 94 % of Europe's NH_3 emissions come from agriculture.

Air pollutant emissions in the EEA-32 and Western Balkans have fallen since 1990. In 2008, SO_X emissions were 72 % below 1990 levels. Emissions of the main pollutants that cause ground-level O_3 also declined and emissions of primary $PM_{2.5}$ and PM_{10} have both decreased by 13 % since 2000. Nevertheless, Europe still contributes significantly to global emissions of air pollutants.

Outlook

Under a current policy scenario, the EEA-32 and western Balkan emissions of the main air pollutants, except NH_3, are projected to decline by 2020. Compared with 2008 levels, the largest proportional decreases are projected for emissions of NO_X and SO_2 — a reduction of some 45 % by 2020 in the absence of additional measures. EU-27 emissions of primary $PM_{2.5}$ and NH_3 are projected to be similar or even slightly higher than in 2008, although substantial reductions are technically possible.

Response

In Europe, various policies have targeted air pollution in recent years. For example, local and regional administrations must now develop and implement air quality management plans in areas of high air pollution, including initiatives such as low emission zones. Such actions complement national or regional measures, including the EU's National Emission Ceilings Directive and the UNECE Gothenburg Protocol, which set national emission limits for SO_2, NO_X, NMVOCs and NH_3. Likewise, the Euro vehicle emission standards and EU directives on large combustion plants have greatly reduced emissions of PM, NMVOCs, NO_X and SO_2.

Successfully addressing air pollution requires further international cooperation. There is growing recognition of the importance of the long-range movement of pollution between continents and of the links between air pollution and climate change. Factoring air quality into decisions about reaching climate change targets, and vice versa, can ensure that climate and air pollution policies deliver greater benefits to society.

1 Introduction

Human health and the environment are affected by poor air quality. The impacts of air pollution are clear — it damages health, both in the short and long term, it adversely affects ecosystems, and leads to corrosion and soiling of materials, including those used in objects of cultural heritage.

Within the European Union (EU), the Sixth Environment Action Programme (6EAP) set the long-term objective of achieving levels of air quality that do not give rise to significant negative impacts on, and risks to, human health and the environment. The Thematic Strategy on Air Pollution from the European Commission (EC, 2005) subsequently set interim objectives for the improvement of human health and the environment through the improvement of air quality to the year 2020.

There has been clear progress made across Europe in reducing anthropogenic emissions of the main air pollutants over recent decades. Nevertheless, poor air quality remains an important public health issue. At present, airborne particulate matter (PM), tropospheric (ground-level) ozone (O_3) and nitrogen dioxide (NO_2) are Europe's most problematic pollutants in terms of causing harm to health. Long-term and short-term high-level exposure to these pollutants can lead to a variety of adverse health effects, ranging from minor irritation of the respiratory system to contributing to increased prevalence and incidence of respiratory and cardiovascular diseases and premature death. While these pollutants can affect the cardio-respiratory system and harm people of all ages, they are known to pose an extra risk to those with existing heart, respiratory and other chronic diseases. Further, children, sick people and the elderly are more susceptible (WHO, 2005).

One of the great success stories of Europe's past air pollution policy has been the significant reduction in emissions of the acidifying pollutant sulphur dioxide (SO_2) achieved since the 1970s. Nitrogen (N), on the other hand, has not been dealt with as successfully. With sulphur dioxide emissions having declined significantly, nitrogen is now the principal acidifying component in our air.

Excess N pollution leads also to eutrophication. There are serious problems in Europe caused by excess N nutrient from atmospheric deposition and use of nitrogenous fertilisers on farmlands, and subsequent eutrophication of terrestrial, freshwater, coastal and marine ecosystems. Further information on eutrophication is found in the SOER 2010 water quality assessment (EEA, 2010l) and marine environment assessment (EEA, 2010m).

The air pollution issues, with which society is now dealing, require a greater degree of international cooperation than ever before. As European emissions of certain pollutants decrease, there is increasing recognition of the importance of long-range hemispheric transport of air pollutants to and from Europe and other continents, particularly North America and Asia. Improved international coordination will increasingly be required in order to successfully address the issue of long-range transboundary air pollution.

There is also an emerging recognition of the important links between air pollution and climate change. Both issues share common sources of emissions — primarily from fuel combustion in industry and households, transport and agriculture — but also through cross-issue pollutant effects. This can be illustrated by the example of particulate black carbon (BC), formed through the incomplete combustion of fossil fuels, biofuels and biomass. BC is both an air pollutant harmful to health but also acts in a similar way as a greenhouse gas by increasing atmospheric radiative forcing.

The scale of policy actions undertaken in Europe to specifically address issues concerning air pollution has increased over recent years. Strategies have been developed that require both reduction of emissions at source and reduction of exposures. Local and regional air quality management plans, including initiatives such as low emission zones in cities and congestion charging, must now be developed and implemented in areas of high air pollution. These actions complement measures taken at national level, including, for example, policies setting national emission ceilings, regulating emissions from mobile and stationary sources, introducing fuel quality regulations and establishing ambient air quality standards.

Box 1.1 The main air pollutants and their effects on human health and the environment

Nitrogen oxides (NO_x)
Nitrogen oxides (NO_x) are emitted during fuel combustion, such as by industrial facilities and the road transport sector. As with SO_2, NO_x contributes to acid deposition but also to eutrophication. Of the chemical species that comprise NO_x, it is NO_2 that is associated with adverse affects on health, as high concentrations cause inflammation of the airways and reduced lung function. NO_x also contributes to the formation of secondary inorganic particulate matter and tropospheric O_3 (see below).

Ammonia (NH_3)
Ammonia (NH_3), like NO_x, contributes to both eutrophication and acidification. The vast majority of NH_3 emissions — around 94 % in Europe — come from the agricultural sector, from activities such as manure storage, slurry spreading and the use of synthetic nitrogenous fertilisers.

Non-methane volatile organic compounds (NMVOCs)
NMVOCs, important O_3 precursors, are emitted from a large number of sources including paint application, road transport, dry-cleaning and other solvent uses. Certain NMVOC species, such as benzene (C_6H_6) and 1.3-butadiene, are directly hazardous to human health. Biogenic NMVOCs are emitted by vegetation, with amounts dependent on the species and on temperature.

Sulphur dioxide (SO_2)
Sulphur dioxide (SO_2) is emitted when fuels containing sulphur are burned. It contributes to acid deposition, the impacts of which can be significant, including adverse effects on aquatic ecosystems in rivers and lakes, and damage to forests.

Tropospheric or ground-level ozone (O_3)
Ozone (O_3) is a secondary pollutant formed in the troposphere, the lower part of the atmosphere, from complex photochemical reactions following emissions of precursor gases such as NO_x and NMVOCs. At the continental scale, methane (CH_4) and carbon monoxide (CO) also play a role in ozone formation. Ozone is a powerful and aggressive oxidising agent, elevated levels of which cause respiratory and cardiovascular health problems and lead to premature mortality. High levels of O_3 can also damage plants, leading to reduced agricultural crop yields and decreased forest growth.

Particulate matter (PM)
In terms of potential to harm human health, PM is one of the most important pollutants as it penetrates into sensitive regions of the respiratory system. PM in the air has many sources and is a complex heterogeneous mixture whose size and chemical composition change in time and space, depending on emission sources and atmospheric and weather conditions. Particulate matter includes both primary and secondary PM; primary PM is the fraction of PM that is emitted directly into the atmosphere, whereas secondary PM forms in the atmosphere following the oxidation and transformation of precursor gases (mainly SO_2, NO_x, NH_3 and some volatile organic compounds (VOCs)). Smaller sizes of particulate matter such as $PM_{2.5}$, with a diameter up to 2.5 µm, are considered particularly harmful due to their greater ability to penetrate deep into the lungs.

Benzo(a)pyrene (BaP)
BaP is a polycyclic aromatic hydrocarbon (PAH), formed mainly from the burning of organic material such as wood, and from car exhaust fumes especially from diesel vehicles. It is a known cancer-causing agent in humans. In Europe, BaP pollution is mainly a problem in certain areas such as western Poland, the Czech Republic and Austria where domestic coal and wood burning is common.

Heavy metals
The heavy metals arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg) and nickel (Ni) are emitted mainly as a result of various combustion processes and industrial activities. Both BaP and heavy metals can reside in or be attached to PM. As well as polluting the air, heavy metals can be deposited on terrestrial or water surfaces and subsequently build-up in soils or sediments. Heavy metals are persistent in the environment and may bio-accumulate in food-chains.

A description of the main sources of these air pollutants is provided later in this assessment.

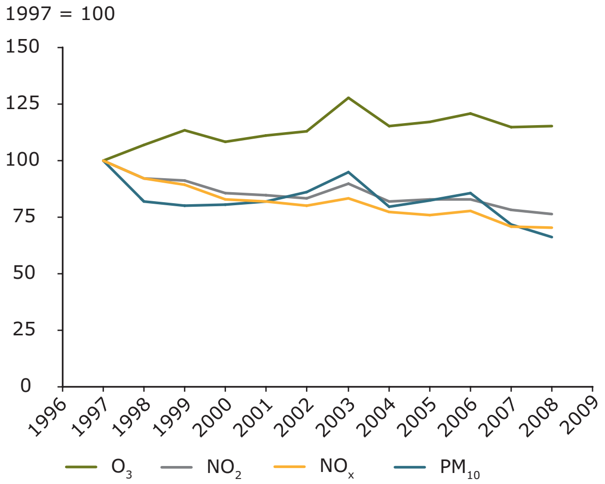
2 Air quality: state, trends and impacts

2.1 The state of air quality and its effects on human health

Many air pollutants, such as NO_X and SO_2, are directly emitted into the air following for example fuel combustion or releases from industrial processes. In contrast, O_3 and the major part of PM, form in the atmosphere following emissions of various precursor species, and their concentrations depend strongly on (changes in) meteorological conditions. This is particularly true for O_3 formation which is strongly promoted by high air temperatures and sunlight — episodes of high O_3 concentrations are therefore more common in summer during heat waves. To assess significant trends and to discern the effects of reduced anthropogenic precursor emissions, long time-series of measurements are needed (EEA, 2009).

Recent decades have seen significant declines in emissions of the main air pollutants in Europe (see Section 2.4). However, despite these reductions, measured concentrations of health-relevant pollutants such as PM and O_3 have not shown a corresponding improvement (Figure 2.1) ([1]). Similarly, exposure of the urban population to concentrations of air pollutants above selected air quality limit/target values has not changed significantly

Figure 2.1 Indexed trends in air quality



Note : Annual mean concentrations from AirBase measurements in urban areas (100 corresponds to the starting year 1997). Please note that as the figure is based on annual means, a general Europe-wide averaged picture is shown. This figure includes a bias towards certain regions (i.e. western and central Europe) that have high station density and long (10 years) time series. Only stations with at least 75 % data coverage per year were used (see also refined trend analyses for PM_{10} in ETC/ACC, 2010a).

Source: Based on ETC/ACC, 2009a.

Box 2.1 Air pollution — from emissions to impacts

Following emission from a particular source, air pollutants are subject to a range of atmospheric processes including atmospheric transport, mixing and chemical transformation, before exposure to humans or ecosystems may occur. Air pollutants also do not remain in the atmosphere forever. Depending on their physical-chemical characteristics and factors such as atmospheric conditions or roughness of receiving surfaces, they may be deposited after either short- (local, regional) or long-range (European, inter-continental) transport. Pollutants can be washed out of the atmosphere by precipitation — rain, snow, fog, dew, frost and hail — or deposited dry as gases or particulate matter, for example directly on vegetation surfaces such as crop or tree leaves.

Dispersion and/or chemical transport models are essential tools that address different spatial and temporal scales, linking emissions to calculated air pollutant concentrations or deposition fluxes. In an integrated assessment, air pollutant transport models are used to connect emissions with geographically-specific estimates of health and ecosystem impacts. Thus the effects of introducing different air pollution or greenhouse gas control strategies can be evaluated in terms of their environmental impacts.

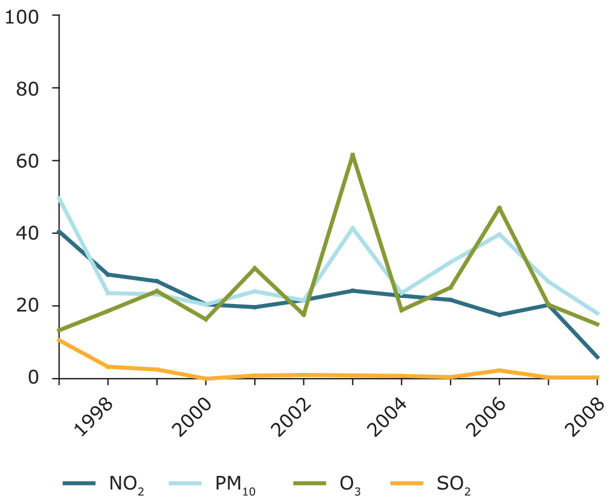
([1]) EU Member States are required to submit annual reports on air quality to the European Commission. This reporting is designed to allow an assessment of Member State compliance with their obligations under the Air Quality Directives (EC, 2004; EC 2008a). These reports are annually summarised (e.g. ETC/ACC, 2009c). In parallel, each year Member States send detailed air-quality information obtained from their measurement networks under the Exchange of Information Decision to the European database, AirBase (EC, 1997; EEA, 2010a). Based on this information, the EEA and its European Topic Centre on Air and Climate Change (ETC/ACC) publish an annual assessment of these reports (e.g. ETC/ACC, 2010a).

(Figure 2.2; Table 2.1). With the exceptions of SO_2 and carbon monoxide (CO), air pollutants remain a cause for concern for the health of urban populations. The main reasons for these general observations are explored in the following sections.

Particulate matter

PM_{10} is particulate matter with an aerodynamic diameter of 10 µm or less, suspended in the air. Over the past decade, 20–50 % of the urban population was exposed to PM_{10} concentrations in excess of the EU daily limit values set for the protection of human health (Figures 2.2 and 2.3) — a daily mean of 50 µg/m³ that should not be exceeded on more than 35 days in a calendar year. The number of monitoring stations in some areas of Europe is relatively small and therefore the data may not be representative for all of Europe for the analysed period (1997–2008). Measurements indicate a downward trend in the highest daily mean PM_{10} values. However, for the majority of stations, the observed change is not statistically significant. For a subset of stations operational for at least eight years over the period 1999–2008 and where annual mean values show a statistically significant downward trend, annual mean concentrations decreased by about 4 % (ETC/ACC, 2010a).

Figure 2.2 Percentage of urban population resident in areas where pollutant concentrations are higher than selected limit/target values, EEA member countries, 1997–2008



Note : The figure shows a steep percentage drop in NO_2 exposure based on measurements at urban background locations (2006–2008), i.e. urban areas where concentration levels are representative of the exposure of the general urban population. Note that exceedances of NO_2 limit values are particularly a problem at hot-spot traffic locations.

Source: EEA, 2010b (CSI 004).

While the annual average limit value of 40 µg/m³ is regularly exceeded at several urban background and traffic stations, there are hardly any exceedances at rural background locations ([2]) (ETC/ACC, 2009a). However, the Air Quality Guideline (AQG) level for PM_{10} set by the World Health Organisation (WHO) is 20 µg/m³. Exceedances of this level can be observed all over Europe, also in rural background environments.

In many European urban agglomerations, PM_{10} concentrations have not changed since about 2000. One of the reasons is the only minor decreases in emissions from urban road traffic. Increasing vehicle-km and dieselisation of the vehicle fleet jeopardise achievements from other PM reduction measures. Further, in several places emissions from the industry and domestic sectors — for example, from wood burning — may even have increased slightly. In rural areas, largely constant NH_3 emissions from agriculture have contributed to the formation of secondary particulate matter and prevented significant reductions of PM in, for example, the Netherlands and north-western Germany.

The EU Air Quality Directive of 2008 includes standards for fine PM ($PM_{2.5}$) (EC, 2008a): a yearly limit value that has to be attained in two stages, by 1 January 2015 (25 µg/m³) and by 1 January 2020 (20 µg/m³) (Table 2.1). Further, the directive defines an average exposure indicator (AEI) for each Member State, based on measurements at urban background stations. The required and absolute reduction targets for the AEI have to be attained by 2020. For 2008, only 331 of the $PM_{2.5}$ measurement stations reporting to the European air quality database, AirBase (EEA, 2010a), fulfilled the minimum data coverage criterion of at least 75 % coverage per year (ETC/ACC, 2010a). This number of stations is expected to increase over the coming years, due to the requirements of the directive (EC, 2008).

Measurement results reported by the EU-27 Member States to AirBase have been used to calculate population-weighted mean concentrations of PM_{10} and O_3 for urban agglomerations with more than 250 000 inhabitants (ETC/ACC, 2010b) (Figure 2.4). The result of the calculation is used in the EU structural indicator to follow the changes in urban population exposure to PM and O_3 (see also EEA, 2010n).

([2]) 'Background' locations are defined as places where concentration levels are regarded as representative of the exposure of the general urban or rural population (EC, 2008a).

Table 2.1 Summary of air-quality directive limit values, target values, assessment thresholds, long-term objectives, information thresholds and alert threshold values for the protection of human health

Human health	Limit or target (#) value				Time extension (***)	Long-term objective		Information (**) and alert thresholds	
Pollutant	Averaging period	Value	Maximum number of allowed occurrences	Date applic-able	New date applicable	Value	Date	Period	Threshold value
SO_2	Hour Day	350 µg/m³ 125 µg/m³	24 3	2005 2005				3 hours	500 µg/m³
NO_2	Hour Year	200 µg/m³ 40 µg/m³	18 0	2010 2010	2015			3 hours	400 µg/m³
Benzene (C_6H_6)	Year	5 µg/m³	0	2010	2015				
CO	Maximum daily 8-hour mean	10 mg/m³	0	2005					
PM_{10}	Day Year	50 µg/m³ 40 µg/m³	35 0	2005 2005 *	2011 2011				
$PM_{2.5}$	Year	25 µg/m³ (#) 20 µg/m³ (ECO)	0	2010 2015		8.5 to 18 µg/m³	2020		
Pb	Year	0.5 mg/m³ (#)	0	2005					
As	Year	6 ng/m³ (#)	0	2013					
Cd	Year	5 ng/m³ (#)	0	2013					
Ni	Year	20 ng/m³ (#)	0	2013					
BaP	Year	1 ng/m³ (#)	0	2013					
O_3	Maximum daily 8-hour mean averaged over 3 years	120 µg/m³ (#)	25	2010		120 µg/m³	Not defined	1 hour 3 hours	180 µg/m³ (**) 240 µg/m³

Note: The majority of EU Member States (MS) have not attained the PM_{10} limit values required by the Air Quality Directive by 2005 (EC, 2008a). In most urban environments, exceedance of the daily mean PM_{10} limit is the biggest PM compliance problem. 2010 is the attainment year for NO_2 and C_6H_6 limit values. A further important issue in European urban areas is also exceedance of the annual NO_2 limit value, particularly at urban traffic stations.

ECO: The exposure concentration obligation for $PM_{2.5}$, to be attained by 2015, is fixed on the basis of the average exposure indicator (see main text), with the aim of reducing harmful effects on human health. The range for the long-term objective (between 8.5 and 18) indicates that the value is depending on the initial concentrations in the various Member States.

(#) Signifies that this is a target value and not a legally binding limit value; see EC, 2008a for definition of legal terms (Article 2).
(*) Exceptions are Bulgaria and Romania, where the date applicable was 2007.
(**) Signifies that this is an information threshold and not an alert threshold; see EC, 2008a for definition of legal terms (Article 2).
(***) For countries that sought and qualified for time extension.

Source: EC, 1999a; EC, 2000; EC, 2002; EC 2004; EC, 2008a.

Table 2.2 Summary of air quality directive critical levels, target values and long-term objectives for the protection of vegetation

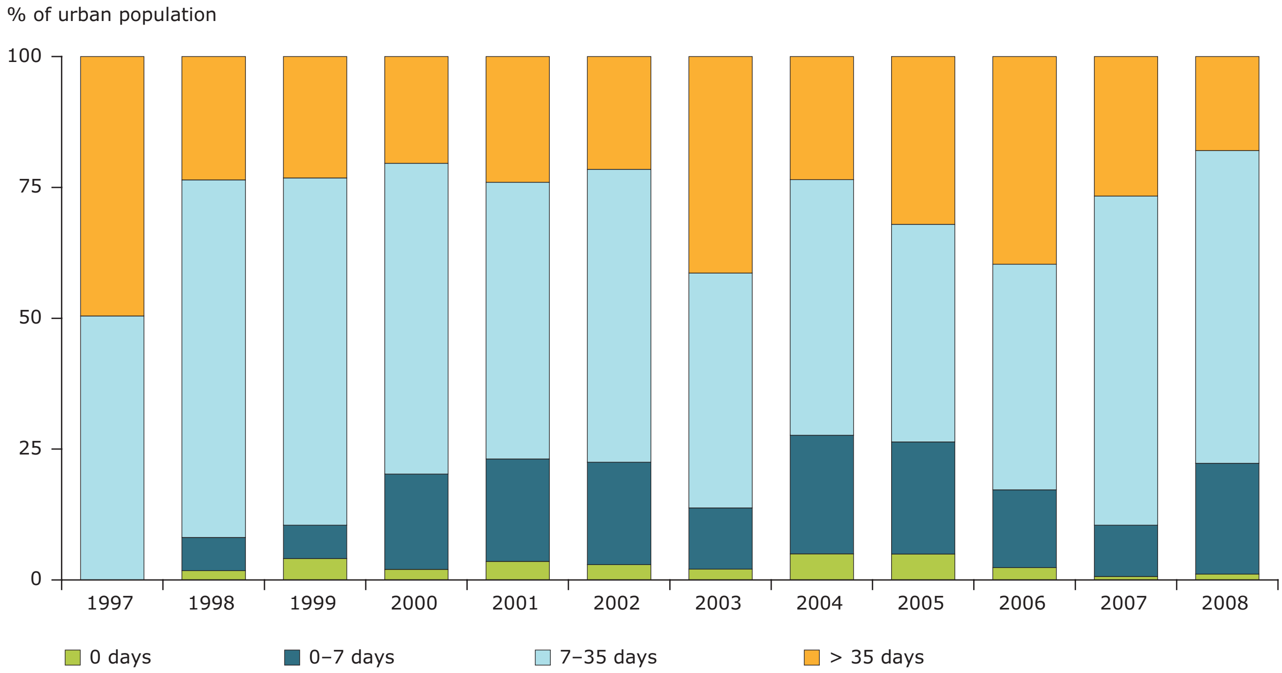
Vegetation	Critical level or target value (*)			Time extension	Long-term objective	
Pollutant	**Averaging period**	**Value**	**Date applicable**	**New date applicable**	**Value**	**Date**
SO_2	Calendar year and winter (October to March)	20 µg/m³				
NO_x	Calendar year	30 µg/m³				
O_3	May to July	AOT40 18 000 (µg/m³).hours averaged over 5 years	2010		AOT40 6 000 (µg/m³).hours	Not defined

Note: AOT40 is an accumulated ozone exposure, expressed in (µg/m³).hours. The metric is the sum of the amounts by which hourly mean ozone concentrations (in µg/m³) exceed 80 µg/m³ from 08.00 to 20.00 Central European Time each day, accumulated over a given period (usually three summer months). The target value given in the air quality legislation is 18 000 (µg/m³).hours and the long-term objective is 6 000 (µg/m³).hours.

(*) See EC, 2008a for definition of legal terms (Article 2).

Source: EC, 1999a; EC, 2002; EC, 2008a.

Figure 2.3 Percentage of population resident in urban areas potentially exposed to PM_{10} concentration levels exceeding the daily limit value, EEA member countries, 1997–2008



Source: EEA, 2010b (CSI 004).

Box 2.2 Short- and long-term health effects of particulate matter

As indicators of health risks, the WHO recommends using the mass concentration of PM_{10} and $PM_{2.5}$ (*), measured in micrograms (μg) per cubic meter (m³) of air (WHO, 2005; WHO, 2007). The coarse fraction of PM_{10} may affect airways and lungs. The fine fraction ($PM_{2.5}$) represents a particular health concern because it can penetrate the respiratory system deeply and be absorbed into the bloodstream or remain embedded in lung tissue for long periods. For the protection of human health, the Air Quality Directive (EC, 2008a), in addition to limit values for PM_{10}, also sets legally binding limit values for $PM_{2.5}$ (see Table 2.1).

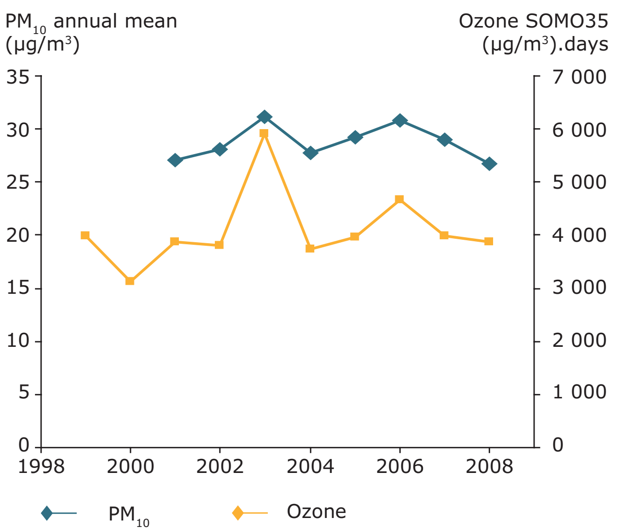
Exposure to PM air pollution can affect health in many ways, both in the short- and long-term. It is linked with respiratory problems such as asthma, acute and chronic cardiovascular effects, impaired lung development and lower lung function in children, reduced birth weight and premature death (WHO, 2005; WHO, 2006). Epidemiological studies indicate that there is no threshold concentration below which negative health effects from PM exposure both in terms of mortality and morbidity — cannot be expected. In many cases, only the severe health outcomes, such as increased risk of mortality and reduced life expectancy, are considered in epidemiological studies and risk analyses, due to the scarcity of other routinely collected health data (WHO, 2005).

Examples of short-term effects of air pollution include irritation of the eyes, nose and throat, respiratory inflammation and infections such as bronchitis and pneumonia. Other symptoms can include headaches, nausea, and allergic reactions. Long-term health effects include chronic respiratory disease, lung cancer, heart disease, and even damage to the brain, nerves, liver, and kidneys.

Note: (*) $PM_{2.5}$ is defined as the fraction of PM with a diameter of 2.5 micrometers or less. The PM_{coarse} fraction is defined as PM_{10} minus $PM_{2.5}$.

Current chemical transport models underestimate PM_{10} and $PM_{2.5}$ concentrations, mainly because not all PM components are included in the models and because of higher uncertainties in PM emission inventories compared to other pollutants. However, by interpolating PM_{10} measurements, using assumptions on $PM_{10}/PM_{2.5}$ ratios and modelling results, $PM_{2.5}$ concentration maps for Europe can be compiled and used to assess population-weighted concentrations as well as health impacts (ETC/ACC, 2009b). The results indicate that $PM_{2.5}$ pollution in EEA-32 countries may be associated with approximately 500 000 premature deaths in 2005. This corresponds to about 5 million years of life lost (YOLL; Map 2.1). These numbers support the previous model-based estimates made for the EU-25 during the Clean Air for Europe (CAFE) Programme which found largely similar impacts (EC, 2005).

Figure 2.4 Population-weighted concentrations of PM_{10} and O_3 in urban agglomerations of more than 250 000 inhabitants in EU-27



Note: The very high O_3 levels in 2003 were due to an exceptionally hot summer in Europe, with weather conditions favouring O_3 production in many regions. SOMO35 is an indicator of cumulative annual exposure of people — the sum of excess of maximum daily 8-hour averages over the cut-off of 70 μg/m³ calculated for all days in a year. The term stands for Sum Of Means Over 35 ppb (≅ 70 μg/m³; WHO, 2005).

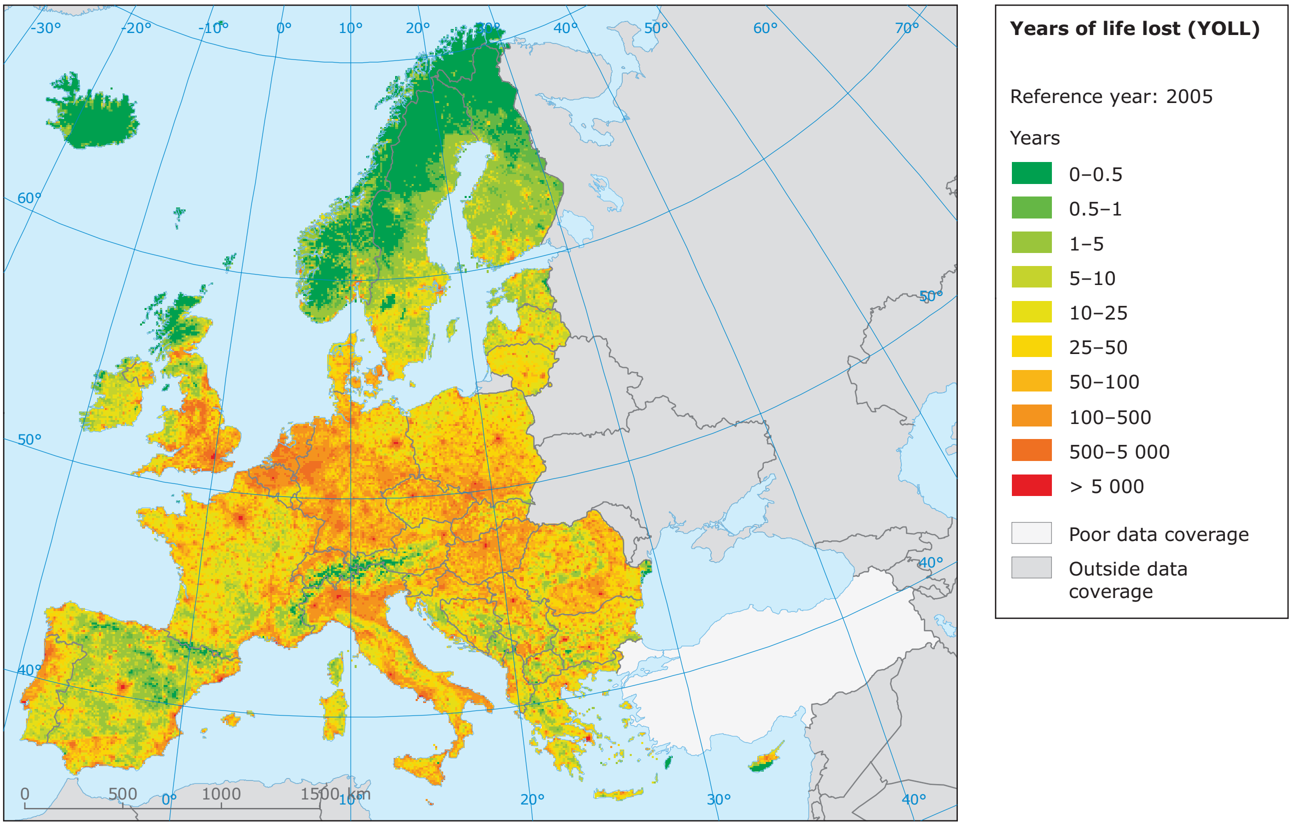
Source: Eurostat, 2010a.

Focusing on PM mass concentration limit values and exposure indicators does not address the complex physical and chemical characteristics of PM. While mass concentrations can be similar, people may be exposed to PM cocktails of very different chemical composition. There are not yet enough epidemiological health impact studies to clearly distinguish between possible differences in toxicity caused by different types of PM (WHO, 2007; UNECE, 2007a).

Ozone

Photochemical O_3 formation depends mainly on meteorological factors and on the concentrations of NO_X and volatile organic compounds (VOCs). Ozone concentrations in urban areas with high NO_X emissions are generally lower than in the countryside (Figure 2.5). This is due to the depletion of O_3 through a reaction with nitrogen monoxide (NO), a pollutant especially emitted by traffic — the titration effect. This explains why, in rural areas, where traffic levels and thus concentrations of NO are typically

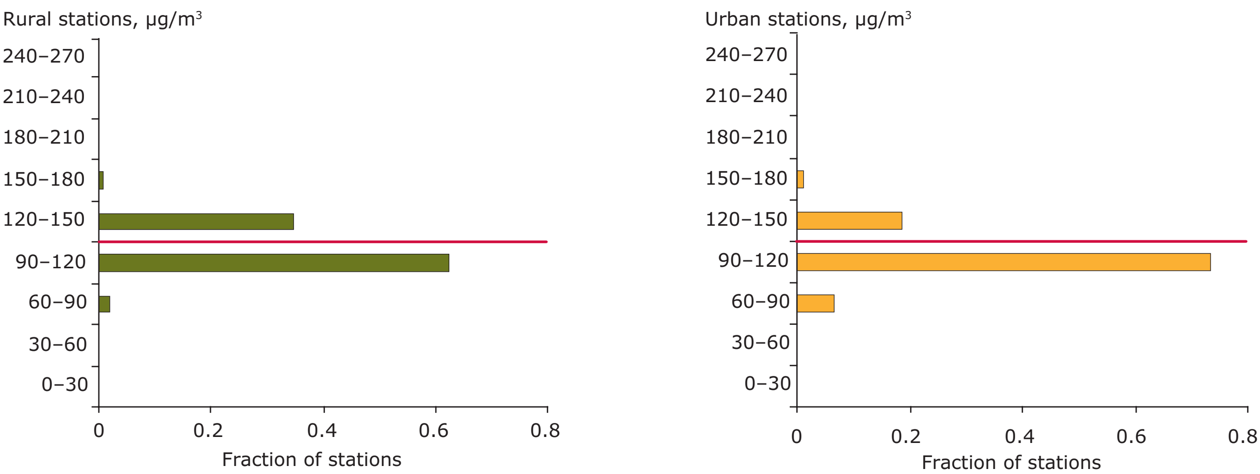
Map 2.1 **Years of life lost (YOLL) in EEA countries due to $PM_{2.5}$ pollution, 2005**



Note: This map (spatial resolution = 10 x 10 km²) was compiled based on the reference given below. It shows YOLLs (not premature deaths as in the original reference) and calculations are improved by including a correction factor for measured PM concentrations in France. For discussion of uncertainty and methodological details, see ETC/ACC, 2009b. Turkey is not included in the analysis due to a shortage of consistent measurement data.

Source: Based on ETC/ACC, 2009b.

Figure 2.5 **Distance-to-target for the environmental objectives set for the protection of human health, 2008**



Note: The red line indicates the target value of 120 µg/m³ (maximum daily 8-hour mean averaged over three years), not to be exceeded on more than 25 days.

Source: ETC/ACC, 2010a.

Box 2.3 MACC — Monitoring Atmospheric Composition and Climate

MACC is a European project under the EU Global Monitoring for Environment and Security (GMES) programme. MACC links *in situ* air quality data with remote observations obtained by satellites. The objective of the service is to provide forecasts and re-analyses ([a]) of the air quality situation on the regional scale over Europe (MACC, 2010).

MACC uses seven regional chemical transport models and analyses ([b]) to provide three-day European air quality forecasts and analysis fields in near real-time, for several pollutants including PM_{10} and O_3. MACC further monitors and forecasts *global* atmospheric composition. One benefit of the MACC service is its ability to provide information on air pollution episodes — both as they occur in near real-time but also to assess causes of past episodes:

Near real-time air quality monitoring and forecasts: In summer 2010, a high number of forest fires occurred in the Russian Federation during a sustained heat-wave. Using satellite measurements of thermal radiation, the MACC service provided daily estimates of particulate matter emitted from the fires and particulate optical depth, a measure of air transparency influenced by black carbon particles and other organic matter. Smoke from the fires over western Russia tended to be driven eastwards, but anti-cyclonic circulation and transport over the Baltic and Nordic countries was also observed. Elevated PM_{10} concentrations were recorded at monitoring stations, for example in central Finland.

Re-analysis of past situations — 2007: In early 2007 the limit value of 50 µg/m^3 (daily average) was exceeded at PM_{10} monitoring stations an exceptional number of times (compared to other years) in central and western Europe. Warm and dry meteorological conditions, non-standard for the season, allowed such an exceptional air pollution event to develop. During March and April two specific air pollution episodes were observed for which MACC has been able to retrospectively provide reasons for their occurrence.

1. The 23 to 31 March 2007 episode: It was first thought that the exceptionally high PM_{10} concentrations observed during this episode were attributable to one of the Saharan dust plumes which reach Europe frequently. However, using measurement equipment on the CALIPSO ([c]) satellite, it was subsequently shown that a dust cloud emerged during a storm blowing over Ukrainian dry agricultural areas: Chernozems ('black soil' in Russian). Because of drought, the soil was extremely dry and thus sensitive to wind erosion. The event left a clear footprint at PM_{10} measurements at stations throughout central and western Europe.

2. The 10 March to 20 April 2007 period: Chemical analyses of PM_{10} showed a large fraction of ammonium nitrate (NH_4NO_3) contributing up to 50 to 60 % of the mass concentration at some sites in western Europe. NH_4NO_3 forms from chemical reactions involving ammonia (NH_3) and nitric acid (HNO_3) in the atmosphere. In spring, when N-containing fertilizers are spread, the amount of these compounds in the air is elevated and this can also lead to increased PM_{10} formation. In spring 2007, this process was triggered by exceptionally high temperatures for that time of year, reaching about 25 °C on 15 April in areas in western Europe where NH_3 emissions where high.

Note: ([a]) Re-analysis is the assimilation of past air quality measurement data into air quality model runs in order to improve model performance.
([b]) Analysis is the assimilation of near-real-time measurement data into model runs to provide inter alia improved initial conditions for forecasts.
([c]) CALIPSO = Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations.

lower, ozone levels are generally higher, though fewer people are exposed.

In 2008, the health-related O_3 target (120 µg/m^3, not to be exceeded on more than 25 days in any one year) was exceeded at 35 % of all rural background measurement stations reporting to AirBase. In urban areas about 20 % of the stations recorded readings above the target value to be attained in 2010 (ETC/ACC, 2010a). The WHO air quality guideline recommends a lower level than that set in the EU legislation, an average concentration of 100 µg/m^3 (WHO, 2005; WHO, 2006; WHO, 2008). In the framework of the National Emission Ceilings Directive (EC, 2001a) impact assessment it was estimated that exposure to O_3 concentrations exceeding critical health levels is associated with more than 20 000 premature ([3]) deaths in the EU-25 annually (IIASA, 2008).

Differences in chemical composition of the air and climatic conditions along the north-south gradient in Europe result in considerable regional differences in summer O_3 concentrations: daily maximum temperatures averaged for the period April to September 1998–2009 show a clear correlation with O_3 concentrations (Figure 2.6). In 2009, measurements during summer at single or several monitoring stations in Bulgaria, France, the former Yugoslav Republic of Macedonia, Greece, Italy, Portugal, Romania, Spain and the United Kingdom occasionally showed O_3 concentrations above the alert threshold of 240 µg/m^3 (EEA, 2010c).

([3]) This estimate is based on the SOMO35 concept, an accumulated ozone concentration in excess of 70 µg/m^3, or 35 ppb, on each day in a calendar year. In fact, the real number of deaths may be much higher since all possible premature deaths attributable to levels below 35 ppb are not counted.

Box 2.4 Health effects of tropospheric ozone pollution

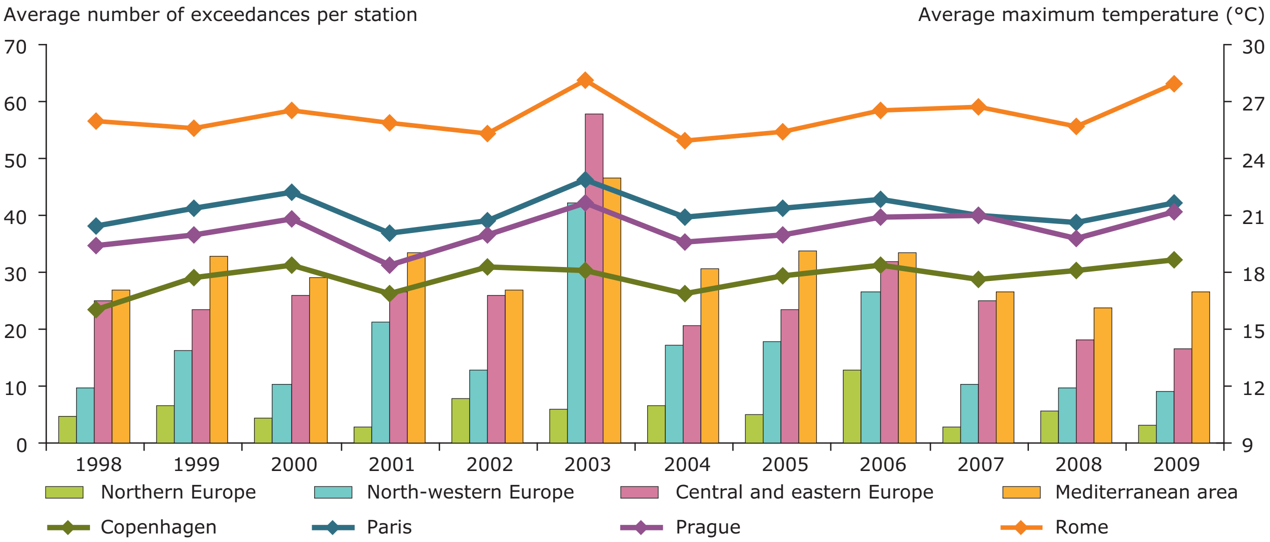
High levels of tropospheric (ground-level) O_3 are associated with increased hospital admissions and emergency room visits for asthma and other respiratory problems, as well as an increased risk of respiratory infections. Long-term, repeated exposure to high levels of O_3 may lead to reductions in lung function, inflammation of the lung lining and more frequent and severe respiratory discomfort. Ozone pollution is also linked to premature death. It is particularly dangerous for children, the elderly, and people with chronic lung and heart diseases, but can also affect healthy people who exercise outdoors. Children are at particular risk because their lungs are still growing and developing. They breathe more rapidly and more deeply than adults. Children also spend significantly more time outdoors, especially in summer when O_3 levels are higher.

The strong dependence of O_3 levels on atmospheric conditions suggests that the projected changes in climate leading to warmer temperatures could also result in increased ground-level O_3 concentrations in many regions of Europe. Over the past two decades, a warmer climate is thought to have already contributed to an increase of 1–2 % in average O_3 concentrations per decade in central and southern Europe (Andersson et al., 2007).

Measurement stations with long enough time-series from stable measurement networks allow meaningful statistical trend analyses (EEA, 2009). German measurements that meet these conditions show that both the number and the absolute levels of O_3 peak concentrations have decreased considerably over the period 1995 to 2007 (UBA, 2009). Measurements in the United Kingdom also indicate that episodic peak ozone levels have declined strongly between 1990 and 2007 (Derwent et al., 2010). Thus, abatement measures against 'summer smog', involving reductions in anthropogenic VOC and NO_X (ozone precursor) emissions in Europe have been at least partly successful.

However, annual mean daily maximum O_3 levels have risen, for example at monitoring sites within the midlands regions of the United Kingdom over the period 1990 to 2007 (Derwent et al., 2010). Reasons for the observed

Figure 2.6 Regional average number of exceedances of the EU long-term objective for ozone (120 µg/m³) per station during the summer for stations that reported at least one exceedance (columns)



Note: The respective lines show average maximum daily temperatures in selected cities.
Northern Europe: Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Norway, Sweden;
North-western Europe: Belgium, France (north of 45 ° latitude), Ireland, Luxembourg, the Netherlands, the United Kingdom;
Central and eastern Europe: Austria, Bulgaria, Czech Republic, Germany, Hungary, Liechtenstein, Poland, Romania, Slovakia, Switzerland;
Mediterranean area: Albania, Andorra, Bosnia and Herzegovina, Croatia, Cyprus, France south of 45 °N latitude, Greece, Italy, Malta, Monaco, Montenegro, Portugal, San Marino, Serbia, Slovenia, Spain, and the former Yugoslav Republic of Macedonia.

Source: EEA, 2010c.

increasing annual average concentrations at rural background measurement stations with long enough time-series include increasing inter-continental transport of O_3 and its precursors in the northern hemisphere. This is clearly seen at the remote measurement station at Mace Head on Ireland's Atlantic coast where polluted air masses from North America reach Europe. Here a gradual increase in annual O_3 background concentrations was measured over the period 1987–2007 (Derwent et al., 2007).

O_3 pollution as a global or hemispheric problem is also considered by the Task Force on Hemispheric Transport of Air Pollution (HTAP) under the United Nations Economic Commission for Europe's (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP Convention) (UNECE, 1979). The HTAP Task Force has recently produced an assessment of the importance of inter-continental transport of air pollution (Box 2.5).

In addition to the long-range transport of air pollutants, other factors help mask the positive effects of European measures to reduce O_3 precursor emissions from anthropogenic sources:

- Biogenic NMVOC emissions, mainly isoprene (C_8H_8) from forests can be important contributors to O_3 formation. Such emissions are spatially and temporally highly variable, and dependent on changes in climatic conditions such as temperature. The magnitude of biogenic emissions is difficult to quantify (The Royal Society, 2008);
- Fire plumes from forest and other biomass fires, some of which are transported inter-continentally, can also contribute significantly to O_3 formation (UNECE, 2007b).

Nitrogen dioxide and other air pollutants

Air pollutants such as NO_2, heavy metals, and organic compounds can also result in significant adverse impacts on human health (WHO, 2005). The current EU annual and hourly limit values for NO_2 have to be attained in 2010. Since NO_2 pollution is especially a problem in urban areas, exposure to NO_2 is discussed in more detail in the SOER 2010 urban environment assessment (EEA, 2010n).

Benzene (C_6H_6) is a carcinogenic aromatic hydrocarbon. The EU limit value for C_6H_6 has to be attained by 2010 (Table 2.1; EC, 2008a). In 2008, exceedances were recorded at a few traffic and industrial stations in, for example, Italy and Poland (ETC/ACC, 2010a).

2008 was the first year for which reporting on heavy metals and polycyclic aromatic hydrocarbon (PAH), the components covered by the so-called fourth daughter directive (EC, 2004), was mandatory; target values are applicable in 2013. Benzo(a)pyrene (BaP) is one of the most potent carcinogens in the PAH group. It is emitted mainly from the burning of organic material such as wood and from car exhaust fumes especially from diesel vehicles. Ambient air measurements from 483 stations are available for 2008, but sufficient data coverage remains a problem. High levels of BaP occur in some regions of Europe, including parts of the Czech Republic and in Poland, exceeding the target value defined in the Air Quality Directive. Measurements of Pb, As, Cd and Ni concentrations were reported for 637 stations in 2008. Exceedances of the target values are mainly restricted to industrial hot-spot areas (ETC/ACC, 2010a).

Box 2.5 Inter-continental transport of air pollution

In their 2010 assessment of the inter-continental transport of air pollution (*), the UNECE LRTAP Convention's Task Force on Hemispheric Transport of Air Pollution (HTAP) finds that ozone, particulate matter, mercury, and persistent organic pollutants are significant environmental problems in many regions of the world. For each of these pollutants, the level of pollution at any given location depends not only on local and regional sources, but also on sources from other continents and, for all except some persistent organic pollutants, natural sources. In most cases, mitigating local or regional emission sources is the most efficient approach to mitigating local and regional impacts of air pollutants. For all of the pollutants studied, however, there is a significant contribution of inter-continental transport of air pollution. This contribution is particularly large for ozone, persistent organic pollutants, and mercury, and for particulate matter during episodes. Furthermore, reductions of methane emissions are as important as emission reductions of the 'classical' ozone precursors (NO_x, NMVOCs, CO) to reduce intercontinental transport of ozone.

Without further international cooperation to mitigate inter-continental flows of air pollution, the HTAP task force concluded that many nations are not able to meet their own goals and objectives for protecting public health and environmental quality. With changing global future emissions, it is likely that over the next 20 to 40 years it will become even more difficult for individual nations or regions to meet their environmental policy objectives without further inter-regional cooperation. Cooperation to decrease emissions that contribute to intercontinental transport of air pollution has significant benefits for both source and receptor countries.

Note: (*) The 2010 report will be published in the UNECE Air Pollution report series.

2.2 Effects of air pollutant deposition on ecosystems

While the reduction of sulphate (SO_4^{2-}) deposition on European ecosystems is a success story, reducing the deposition of nitrogen (N) has not been tackled as effectively. Most oxidized forms of reactive N such as NO_X and nitric acid (HNO_3) stem from combustion processes and can be transported over long distances in the atmosphere. In contrast, livestock manure and nitrogenous synthetic fertiliser use are the main emission sources of NH_3, which is generally only transported locally or regionally and thus rapidly deposited close to the sources. However, NH_3 also forms ammonium ions (NH_4^+) bound to particulate matter, which similarly to other inorganic PM, can be transported over longer distances.

The impact assessments for year 2010 shown below (Figure 2.7 and Map 2.2) are based on a 2008 scenario analysis that was consistent with the energy projection assumptions used in the development of the EU Climate and Renewable Energy Package (IIASA, 2008). The 'current legislation' scenario assumed full implementation of current policies in 2010, which thus presents a more optimistic view of the air pollution situation in 2010 than has in reality occurred (see Chapter 3).

Critical loads of acidity

To protect sensitive ecosystems in Europe, the EU has set a long-term objective of not exceeding critical loads of acidity (Box 2.6). In addition to this objective, the EU also has an interim environmental objective for 2010 — reducing areas where critical loads are exceeded by at least 50 % in each grid cell for which critical load exceedances are computed, compared with the 1990 situation (EC, 2001a).

Assuming full implementation of current policies in 2010, 84 % of European grid cells which had critical load exceedances in 1990 show a decline in exceeded area of more than 50 % (EEA, 2010d). Although the interim environmental objective for acidity has strictly speaking not been met, the improvements according to this scenario analyses are nevertheless considerable. Exceedance hot spots can still be found in Denmark, Germany, the Netherlands, and Poland (Figure 2.7). This is due mainly to a high local contribution of acidifying ammonium (NH_4^+), emitted as NH_3 from agricultural activities.

Critical loads of nutrient nitrogen

The EU has a long-term objective of not exceeding critical loads for nutrient N. Excess inputs to sensitive ecosystems can cause eutrophication and nutrient imbalances.

The magnitude of the risk of ecosystem eutrophication and its geographical coverage has diminished only slightly over the last decades. In 2000, rather large areas showed high exceedances of critical loads, especially in the western Europe, following the coastal regions from north-western France to Denmark (Map 2.2). In southern Europe high exceedances are only found in northern Italy. The modelled results for 2010 indicate that the risk of exceedance remains high even assuming that current legislation for reducing national emissions is fully implemented. In 13 EEA member countries, the percentage of sensitive ecosystem area at risk in 2010 is still close to 100 %.

Freshwater and soil acidification

Excess deposition of acidifying air pollutants in the past has led to a loss of key species in many sensitive freshwater ecosystems in Europe as a result of changes in the chemical balance of ecosystems — instances of disappearance of salmon, trout, snails and clams are well documented. Especially in the Nordic countries, where fishing and recreation in a natural environment are important elements of cultural life and human well-being, the problem of acid rain and the need to find solutions

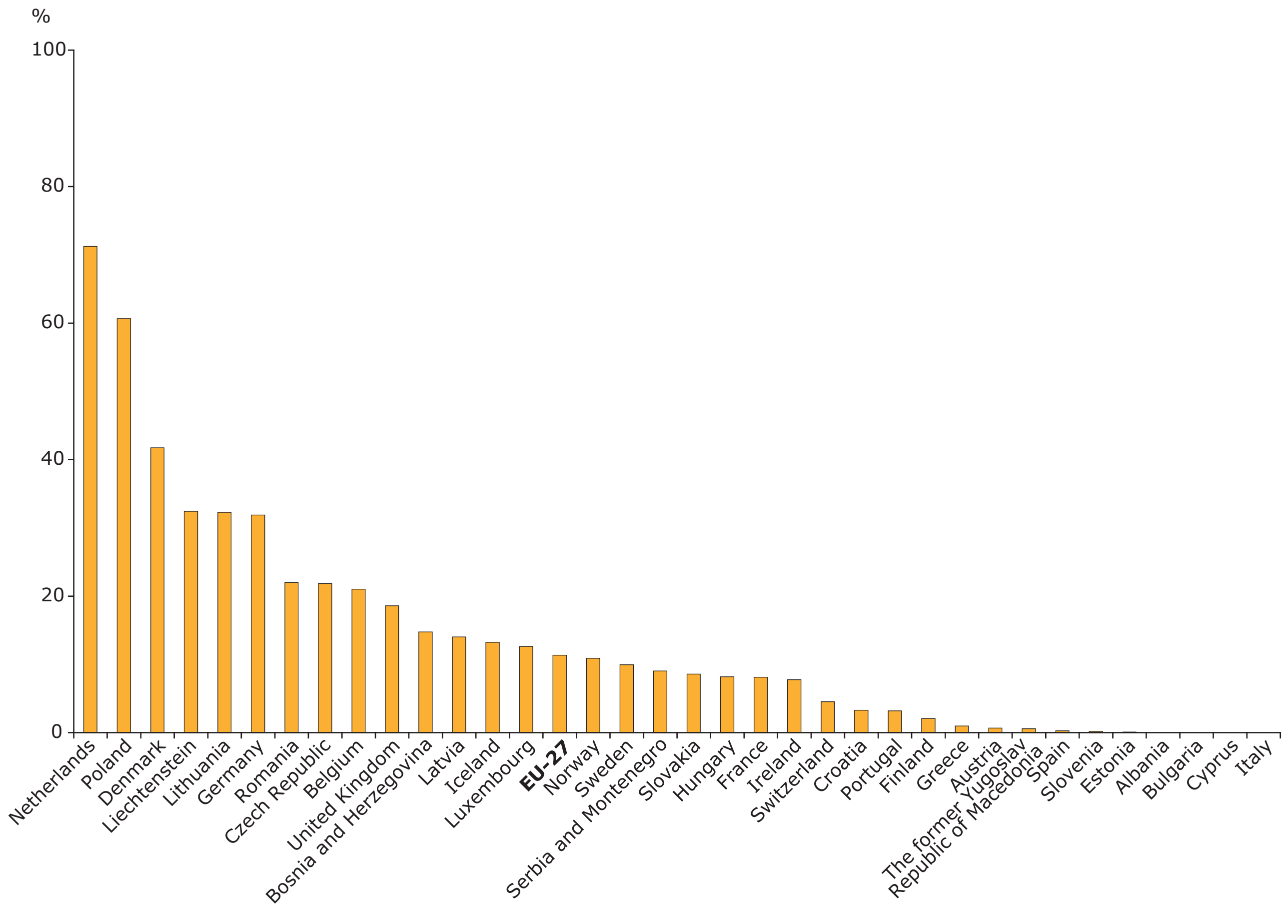
Box 2.6 The critical load concept

The general definition of a critical load is 'a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge' (UNECE, 2004). This definition applies to different receptors — terrestrial ecosystems, groundwater and aquatic ecosystems. Sensitive elements can be part or the whole of an ecosystem, or ecosystem development processes such as their structure and function.

The critical load concept has for example been used extensively within the UNECE LRTAP Convention (UNECE, 1979) and in the 2001 EU National Emission Ceilings Directive (NECD) (EC, 2001a), to take into account acidification of surface waters and soils, effects of eutrophication, and ground-level O_3.

To calculate a critical load, the target ecosystem must first be defined, for example a forest, and sensitive elements such as forest growth rate must be identified. The next step is to link the status of the elements to a chemical criterion, for example, the base cation (Bc) to aluminium (Al^{3+}) ratio in soil, and a critical limit, such as Bc/Al=1, that should not be exceeded. Finally, a mathematical model is applied to calculate the deposition loads that result in the critical limit being reached. The resulting deposition amount is called the critical load, and a positive difference between the current deposition load and the critical load is called the exceedance (UNECE, 2004).

Figure 2.7 **Percentage of ecosystem area (e.g. freshwaters and forests) at risk of acidification for EEA's member countries and cooperating (Western Balkan) countries in 2010 assuming that the current legislation has been implemented**



Note: Data not available for Malta. Turkey has not been included in the analysis due to insufficient data being available for calculating critical loads. In most southern European countries soil and water acidification is not a serious problem because the bedrock is mainly calcareous — the soils have high buffering capacities and rates.

Source: EEA, 2010d (CSI 005), prepared by CCE.

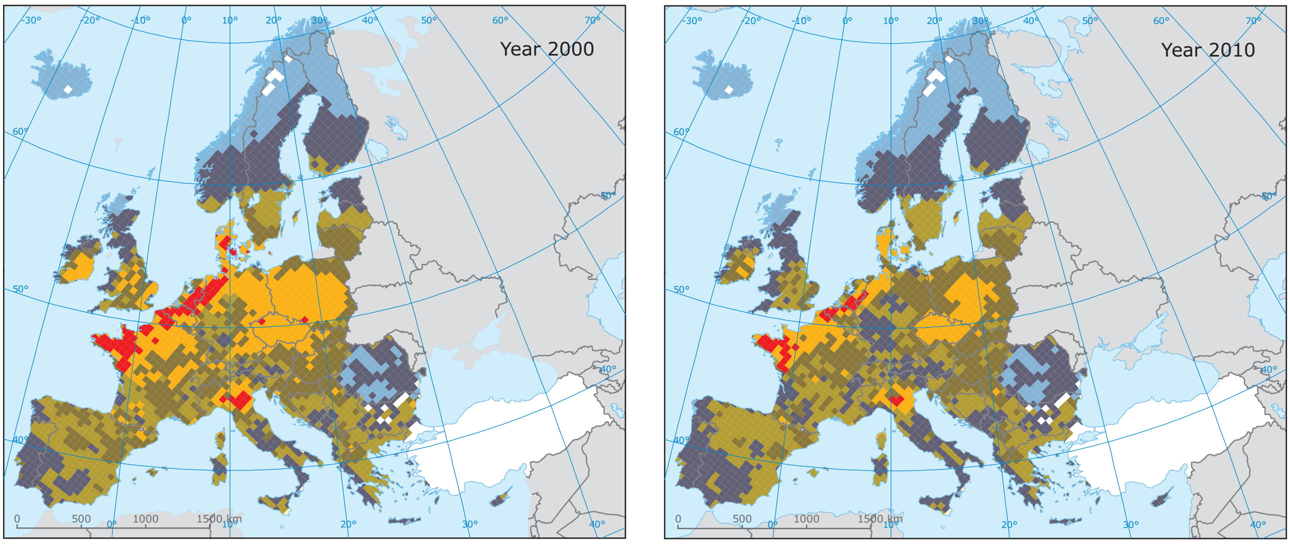
received significant public and political attention at the end of the last century. Today, as a result of reduced acidifying deposition following successful mitigation measures particularly for sulphur (S) emissions, sensitive European lakes and rivers are showing significant signs of recovery.

Chemical recovery has led to improved water quality in most areas of the Nordic countries, the United Kingdom and the Czech Republic, enough to allow the return of acid-sensitive species of fish, invertebrates and mussels. However, biological responses are slow and biological recovery is still lagging behind at many monitoring sites. Some streams in central Europe are located in catchments where large amounts of airborne S have been adsorbed in deep soils over recent decades. Some of these sites, for example in the Harz Mountains in Germany, still show only slight declines in sulphate (SO_4^{2-}) concentrations. Because of reduced inputs from the atmosphere, SO_4^{2-} desorption processes and subsequent SO_4^{2-} leaching by soil water leads to persistence of high concentrations in some surface waters (ICP Waters, 2010).

Most N deposited in areas with acid-sensitive freshwaters, mainly temperate and boreal regions, is retained in soils and vegetation. However, long-term monitoring results show that nitrate (NO_3^-) levels in such waters do not show any consistent decreasing trends as seen for SO_4^{2}. Sensitive freshwaters are continually enriched with nitrogen which increases the chance of NO_3^- leaching resulting in acidification and eutrophication (ICP Waters, 2010).

In the 1970s and 1980s there was significant concern when reports that forest trees were dying from the effects of acid rain became common. According to observations in 2007 at forest monitoring sites all over Europe, one fifth of assessed trees were still rated as damaged, still showing critical crown defoliation. The deposition of acidifying

Map 2.2 Exceedances of critical loads for eutrophication due to the deposition of nutrient N in 2000 (left) and 2010 (right)



Exceedance of nutrient nitrogen critical loads (eq $ha^{-1}a^{-1}$)

- No exceedance
- > 0–200
- 200–400
- 400–700
- 700–1 200
- 1 200–5 000
- Outside data coverage
- No data

Note: The results were computed using the 2008 Critical Loads database hosted by Coordination Centre for Effects (CCE). Turkey has not been included in the analyses due to insufficient data. No data were available for Malta. The territory of Serbia and Montenegro is treated as one critical load/exceedance area in the CCE dataset.

Source: EEA, 2010d (CSI 005), prepared by CCE.

S and N compounds was above critical loads at one quarter of 249 International Cooperative Programme (ICP) Forest plots assessed in 2005. Critical loads for nutrient N were exceeded at two thirds of all monitoring sites. The highest exceedances were observed in hot-spot areas with intensive livestock husbandry near-by. However, deposition of acidifying pollutants is not the only possible reason for tree damage; it can also be triggered by extreme weather conditions and the occurrence of insects and fungal diseases (ICP Forests, 2010).

Effects of excess nitrogen deposition on biodiversity

Alpine and sub-alpine grasslands and Arctic, alpine and sub-alpine scrub habitats are particularly endangered by excess atmospheric N inputs. Negative effects of high N fertilisation from the atmosphere include species loss; changes in inter-species competition and increased susceptibility to plant diseases; insect pests; and frost, drought and wind stress (ICP Vegetation, 2010).

Computed critical loads and exceedance estimates, described above, are risk assessment tools that have been successfully used for impact analyses and optimisation of reduction measures (see Box 2.6). Critical load exceedances can only provide an indirect indication of impacts on habitats, such as forests and grasslands, and are difficult to apply to species. However, the use of ensemble assessments, including empirical critical loads, give good indications of the areas of Europe and the extent of spatial variability where sensitive ecosystem areas are under threat from excess nutrient N deposition (Hettelingh et al., 2008).

Empirical critical loads are based on a combination of experiments and field observations. Another approach is the derivation of dose-response relationships between N load, exceedances and plant species richness in certain ecosystem and habitat classes such as grasslands, arctic, alpine and sub-alpine habitats and boreal coniferous woodlands (Bobbink, 2008). One conclusion of such an initial analysis is that typical nutrient-poor species may be replaced by invasive or N-loving species, without changing the overall species richness.

Natura 2000 is an EU-wide network of nature protection areas established under the 1992 Habitat Directive (Natura 2000). The Habitats and the Birds Directives provide a high level of protection for this network by taking a precautionary approach to controlling polluting activities (EC, 1992; EC, 2009). A focus on Natura 2000 habitats that are particularly vulnerable to atmospheric N inputs supports the hypothesis that N deposition represents a major anthropogenic threat to habitat structure and function within this network as well as to the conservation status of habitats and species listed under the Habitats Directive. The contrast between the high degree of protection afforded to Natura 2000 sites, and the actual high degree of critical load exceedances and current impacts in them is additional cause for concern (Sutton et al., 2009). Studies of forest, heathland, bog and grassland habitats suggest significant negative effects of critical load exceedances on the occurrence of threatened/protected species, including fauna species such as butterflies and birds (van Hinsberg et al., 2008).

Ecosystem services — nitrogen deposition and carbon sequestration

Today, N is considered to be the nutrient in Europe that most often limits net primary biomass production in terrestrial and marine ecosystems ([4]), while production in freshwater ecosystems may be limited by both N and phosphorous (P).

N and C cycles are closely coupled. With respect to ecosystem services (Box 2.7), N deposition can have both negative and positive effects (Moldanova et al., 2009):

- Deposition of atmospheric N can stimulate photosynthetic uptake of CO_2. However, the response of C sequestration to N addition appears to vary considerably, depending, inter alia, on the total N deposition load and the ecosystem type. Sequestration is most efficient if N surplus stimulates the accumulation of woody biomass.
- The C/N ratio in soils and changes in temperature together have a major influence on N leaching to ground and surface waters.
- High tropospheric O_3 levels, in combination with other pollutants, are known to have detrimental effects on plant growth. This can counteract stimulation of C uptake in spite of increased N supply.
- Atmospheric deposition of reactive nitrogen compounds can enhance emissions of nitrous oxide (N_2O) from soils. N_2O is a long-lived greenhouse gas with an approximately 300 times greater Global Warming Potential (GWP) than CO_2.

Both synergies and trade-offs of high atmospheric N deposition have to be carefully considered when managing, for example, European forests and their potential as carbon sinks.

2.3 Effects of ground-level ozone on vegetation

Target values for ozone

In general, the highest O_3 concentrations are found in southern Europe, particularly in Italy, Greece, Slovenia, Spain and Switzerland. There is clear evidence that the ambient O_3 concentration levels observed in Europe can result in a range of effects on vegetation, including visible leaf injury, growth and yield reductions, and altered sensitivity to biotic and additional abiotic stresses including drought.

The EU has the objective of protecting vegetation, including crops, from accumulated O_3 exposure over the threshold of 40 ppb (≅ 80 μg/m^3), measured as hourly mean daytime concentration (AOT40). The accumulation period is the summer months May–July. The target value for 2010 is that the AOT40 stays below 18 000 (μg/m^3).hours. The long-term objective is 6 000 (μg/m^3).hours. The O_3 target value is being exceeded in a substantial proportion of the agricultural area in EEA-32 member countries — nearly 70 % of a total area of 2 024 million km^2 in 2006 and 32 % in 2007 (EEA, 2010d). June and July 2006 were characterised by a large number of

Box 2.7 Ecosystem services affected by atmospheric nitrogen deposition

Our health and wellbeing depends upon the services provided by ecosystems and their components: water, soil, nutrients and organisms. Atmospheric nitrogen deposition affects ecosystem services — in both negative and positive ways:

Diversity of plant species in ecosystems: impact on habitat function for wild plants, reducing biological and genetic diversity (provisioning service).

Primary production: provisioning service of wood/fibre and such supporting services as photosynthesis produces oxygen necessary for most non-plant organisms, and carbon sequestration (greenhouse-gas regulating service).

Water quality: acidity and leaching of nitrogen, aluminium and other metals to groundwater and surface water (regulating service providing clean soil and water).

Water quantity: hydrological budgets and groundwater recharge (water regulating service).

Source: After de Vries et al., 2009.

([4]) An exception is the Baltic Sea, which can, due to its low salinity, be regarded as being close to freshwaters (HELCOM, 2009).

O_3 episodes, resulting in much higher AOT40 values than in 2007. Exceedances of the target value were observed notably in southern, central and eastern Europe (Map 2.3).

In 2007, the long-term objective of 6 000 (μg/m^3).hours was met in 24 % of the total agricultural area — mainly in Ireland, the United Kingdom, and Scandinavia — compared to 2.4 % in 2006.

Impacts of ozone on vegetation

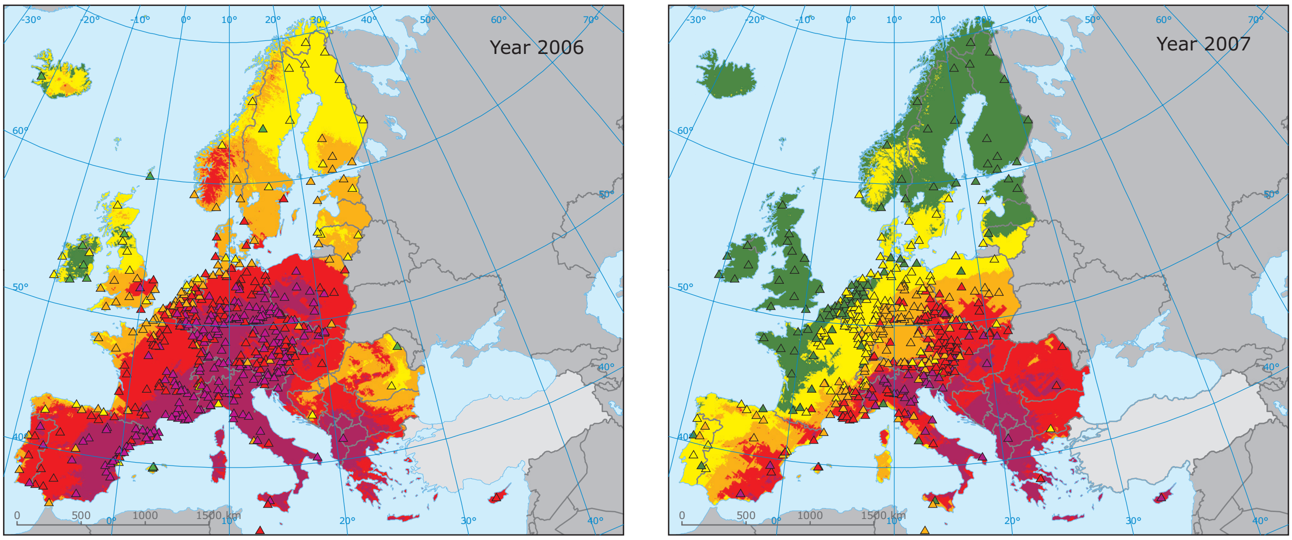
Since O_3 pollution leaves no elemental residue that can be detected by analytical techniques, visible injury to needles and leaves is the only easily detectable effect in the field (see photo). However, visible injury does not include all the possible forms of injury to trees and natural vegetation — pre-visible physiological changes, reduction in growth, etc.

Current O_3 concentrations continue to damage vegetation in Europe. Visible injury has, for example, been recorded in more than 30 crop species including bean, potato, maize, soybean and lettuce, and 80 other plant species (Hayes et al., 2007). Crop losses in the European region (5) and the associated economic loss were estimated for

Leaf damage observed near Torino, Italy caused by ozone for *Fagus sylvatica*, a beech species.

Photo: © M.J. Sanz and V. Calatayud (ICP Forests)

Map 2.3 Rural concentration map of the ozone indicator AOT40 for crops, 2006 and 2007



Ozone AOT40 for crops

Combination with EMEP Model, altitude and solar radiation

μg.m^{-3}.hours

< 6 000

6 000–12 000

12 000–18 000

18 000–27 000

27 000–64 000

Non–mapped countries

Poor data coverage

Rural background station

Note: Turkey is not included in the analysis due to a shortage of consistent measurement data. Modelled results for Turkey can be found in EMEP, 2010.

Source: EEA, 2010d (CSI 005).

(5) 'European region' refers here to the domain of the EMEP Regional Chemical Transport Model. The analysis was limited to five EMEP 50 x 50 km^2 grid cells, spread across the five climatic zones of Europe: Northern Europe, Atlantic and Continental Central Europe, Eastern and Western Mediterranean.

23 horticultural and agricultural crops for the base year 2000 to an equivalent to EUR 6.7 billion economic damage. (Holland et al., 2006). Results for 2000 indicate an overall loss of 3 % for all crop species considered.

AOT40-based risk maps can be used as regional-scale indicators of damage, for example on a 50 x 50 km^2 scale. However, exceedance of the traditional AOT40-based critical level for agricultural crops and forests appears to underestimate the potential for O_3 damage to vegetation in Europe. A newer method recommended by ICP Vegetation and ICP Forest uses a risk assessment approach to calculate and evaluate the Phytotoxic Ozone Dose (POD) based on the flux of O_3 to receptor sites within the leaf. The method gives a better indication of adverse effects, especially where O_3 concentrations are relatively low but fluxes are relatively high — such as in north and north-western Europe (UNECE, 2004; ICP Vegetation, 2010).

2.4 Key drivers and pressures affecting air pollutant concentrations

Driving forces

Knowledge of the levels of air pollutants and greenhouse gases emitted by different sources and activities is crucial to understanding and limiting the harm such emissions may cause to human health and the environment. Emissions of a range of air pollutants and greenhouse gases occur as a result of almost all economic and societal activities, including electricity generation and industrial production; transport; residential heating; and product use; agriculture and waste treatment. Emissions from forest fires and natural sources are also important for certain pollutants — PM from forest fires, sea-spray, and dust episodes from Sahara and other arid regions, and NMVOCs from forests and crops.

In addition to general measures of activity such as population and economic activity that can serve as proxy indicators of emission levels, more specific indicators of air pollution include energy consumption, industrial production levels, transport volumes and agricultural production.

- Since 1990, GDP in the EU has grown by about 45 % in real terms, and increased by around 2.1 % per year on average between 1990 and 2008 (ECFIN, 2010). In contrast, primary energy consumption growth over this period was 8 % (Eurostat, 2010b), which, given the GDP increase, represents a substantial improvement in energy efficiency in the production of goods and services. Emissions caused by energy consumption have thus been partly decoupled from basic economic activity.
- The transport sector has grown over recent years to become the largest energy-consuming sector in the EU-27, accounting for around one third of final energy consumption in 2008 (EEA, 2010e). Freight and passenger transport volumes, measured in tonne-km and passenger-km respectively, both continue to grow having increased by around 21 % and 10 % between 2000 and 2008 across EEA member countries (EEA, 2010f). Growth has been particularly pronounced in eastern Europe where increases in air travel have been fuelled by the expansion of low-cost carriers, and car ownership levels are converging with those in western Europe.
- Agricultural activities, including animal husbandry and nitrogenous fertiliser use, lead to the vast majority of NH_3 emissions. Between 1990 and 2008 NH_3 emissions have fallen, in part because the numbers of livestock — cattle, poultry, sheep, pigs, etc. — fell, but also because improvements in agricultural practices such as the management of manures and less use of nitrogen fertilisers have occurred. Further information on land use practices is available in the SOER 2010 land use assessment (EEA, 2010o).

Pressures — air pollutant emissions

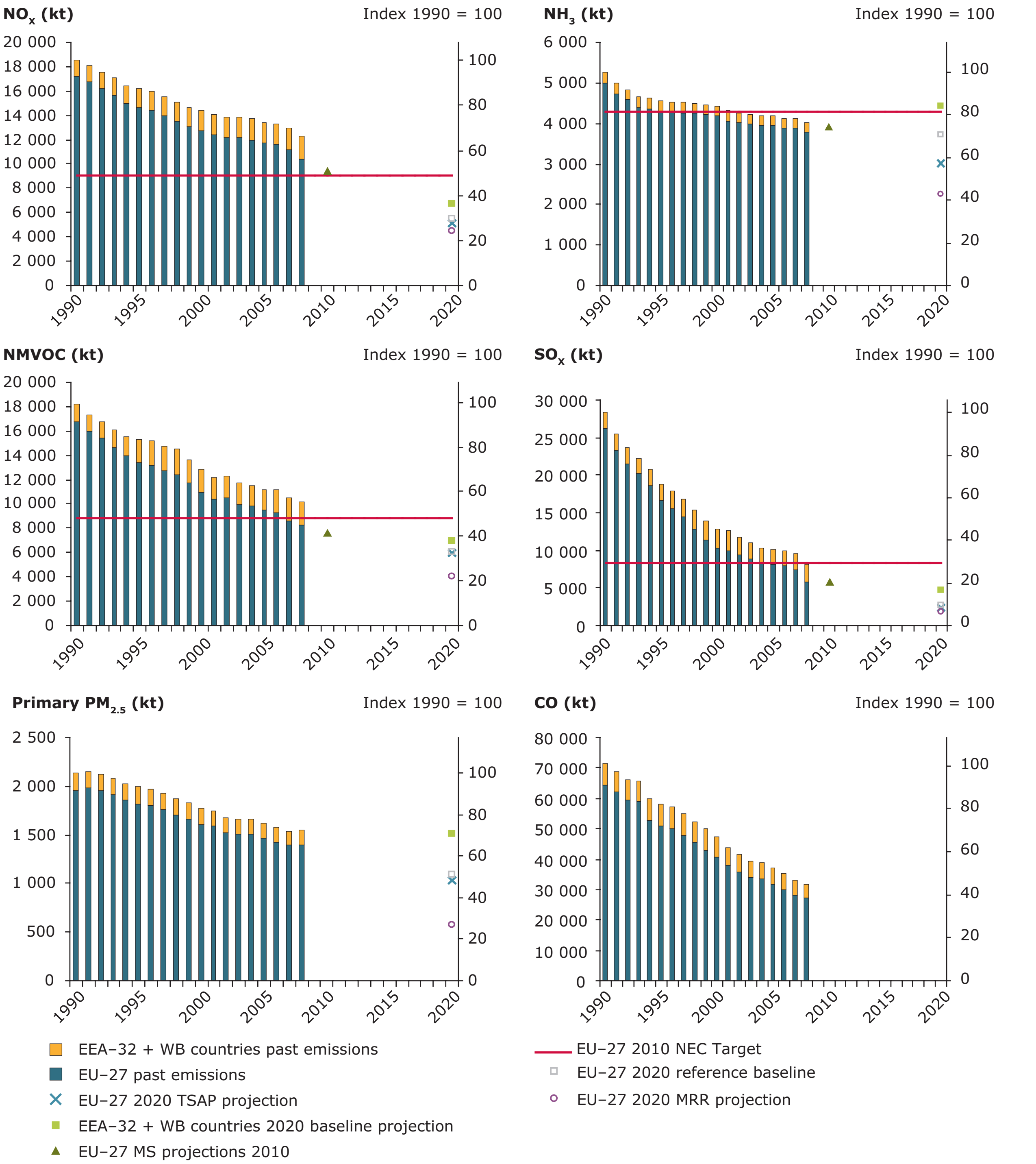
Emissions of the main air pollutants across the EEA-32 and the Western Balkan (WB) countries have decreased since 1990 (Figure 2.8). In 2008, sulphur oxide (SO_X) emissions had fallen by 72 % from 1990 levels. The downward trends of emissions of the three main pollutants which cause ground-level O_3 pollution have continued over recent years: CO has fallen by 55 %, NMVOCs by 44 % and NO_X by 34 %. Emissions of primary particulate matter, $PM_{2.5}$ and PM_{10}, have both decreased by about 13 % since 2000.

Despite such reductions, Europe still contributes significantly to global emissions of air pollutants. European emissions of NO_X for example are approximately 8 % of global emissions, around half the amount emitted by China and the USA, and Europe currently contributes about 15% of global SO_2 emissions (EC-JRC/PBL 2009).

Figure 2.9 shows the main emission sources of selected air pollutants. In terms of the main activities responsible for air pollution, the top polluting sources across Europe in 2008 included agriculture and fuel combustion by power plants, passenger and heavy-duty vehicles, and households:

- agricultural activities alone caused 95 % of Europe's NH_3 emissions;
- power plants producing electricity, and in some countries heat for district heating systems, have reduced emissions significantly since 1990 by improving abatement equipment, switching to cleaner

Figure 2.8 **Past and projected emissions of the main air pollutants and primary particulate matter. EEA-32 + Western Balkan countries**



Note: 1) The 2010 projections for the EU-27 are the aggregated projections reported by Member States in 2009 (EEA, 2010g) under the EU NECD (EC, 2001a). The horizontal red line indicates the aggregated sum of individual EU Member State emission ceilings to be attained by 2010 under the NECD.
2) The 2020 baseline scenario (based on the PRIMES 2010 energy reference scenario) and maximum emission reductions (MRR) projections are from IIASA (2010). The assumptions in the PRIMES 2010 energy reference include the effects of economic crisis in 2008 and 2009, as well as assuming the objectives of the EU Climate and Energy (C&E) package will be met, as well as the target for renewable energy.
3) 2020 projections data for Iceland and Liechtenstein are not available.
4) Excludes emissions from international shipping, and emissions from aviation not associated with flight landing and take-off movements.

Source: EEA; IIASA, 2010a.

fuels and improving energy efficiency. However the energy production and distribution sector remains a large source of air pollution, responsible for around 70 % of all European SO_X emissions and 21 % of total NO_X emissions;

- the road transport sector is a major source of air pollution. Heavy-duty vehicles are the single most important individual source of NO_X, while passenger cars are among the top sources of CO, NO_X, $PM_{2.5}$ and NMVOCs;
- energy use by households — the burning of wood, gas, coal etc. — is the single most important source of $PM_{2.5}$ and CO, and the third most important source of NMVOCs, NO_X and SO_X.

There are several important factors behind the large decrease in SO_X emissions. One of these is the shift in the energy-related sectors in the 1990s away from high-S fuels such as coal and heavy fuel-oils to low-S fuels such as natural gas. In recent years however, due to high energy prices, coal use by power plants in some countries is again increasing. The fitting of flue gas desulphurisation technology in industrial facilities and the impact of EU directives relating to the sulphur content of certain liquid fuels for transport are also important contributing factors. Many eastern European countries, including the newer EU Member States, underwent significant economic structural changes in the early 1990s which led to a decline in certain activities that previously contributed to high S emissions from heavy industry and the use of older inefficient power plants. Nevertheless, despite significant past reductions of SO_X from power plants, this single sector continues to be the main source of SO_X in Europe today. Household combustion of high-S fuels such as coal has largely ceased in many urban and other densely-populated areas, first in western Europe and more recently in most central and eastern European countries. However, as consumer fuel prices have risen in recent years, the domestic use of cheaper coal has increased again in some areas.

Reductions in NO_X emissions have occurred across nearly all economic sectors. The three sectors responsible for the majority of the decrease are road transport, contributing around 45 % of the reduction; power plants, around 30 %; and fuel combustion by industry, 10 %. In the power plant sector, reductions have occurred as a result of the implementation of measures such as combustion modification, introduction of flue-gas abatement techniques and fuel switching from coal to gas. As with SO_X, the significant economic structural changes in eastern European countries since the early 1990s have contributed to lower NO_X emissions. Reduced emissions from the road transport sector have occurred despite the general increase in activity within the sector, and have been achieved mainly as a result of fitting catalysts to vehicles, a process driven by the introduction of respective EU standards. It is important to note, however, that a number of NO_X vehicle emission standards have not been as effective in reducing real-world NO_X emissions as was originally anticipated, especially for diesel vehicles (both passenger vehicles and heavy- and light-duty vehicles). Much of the past reduction in NO_X from road transport can thus mainly be ascribed to gasoline passenger cars and not diesel vehicles (Vestreng et al., 2009).

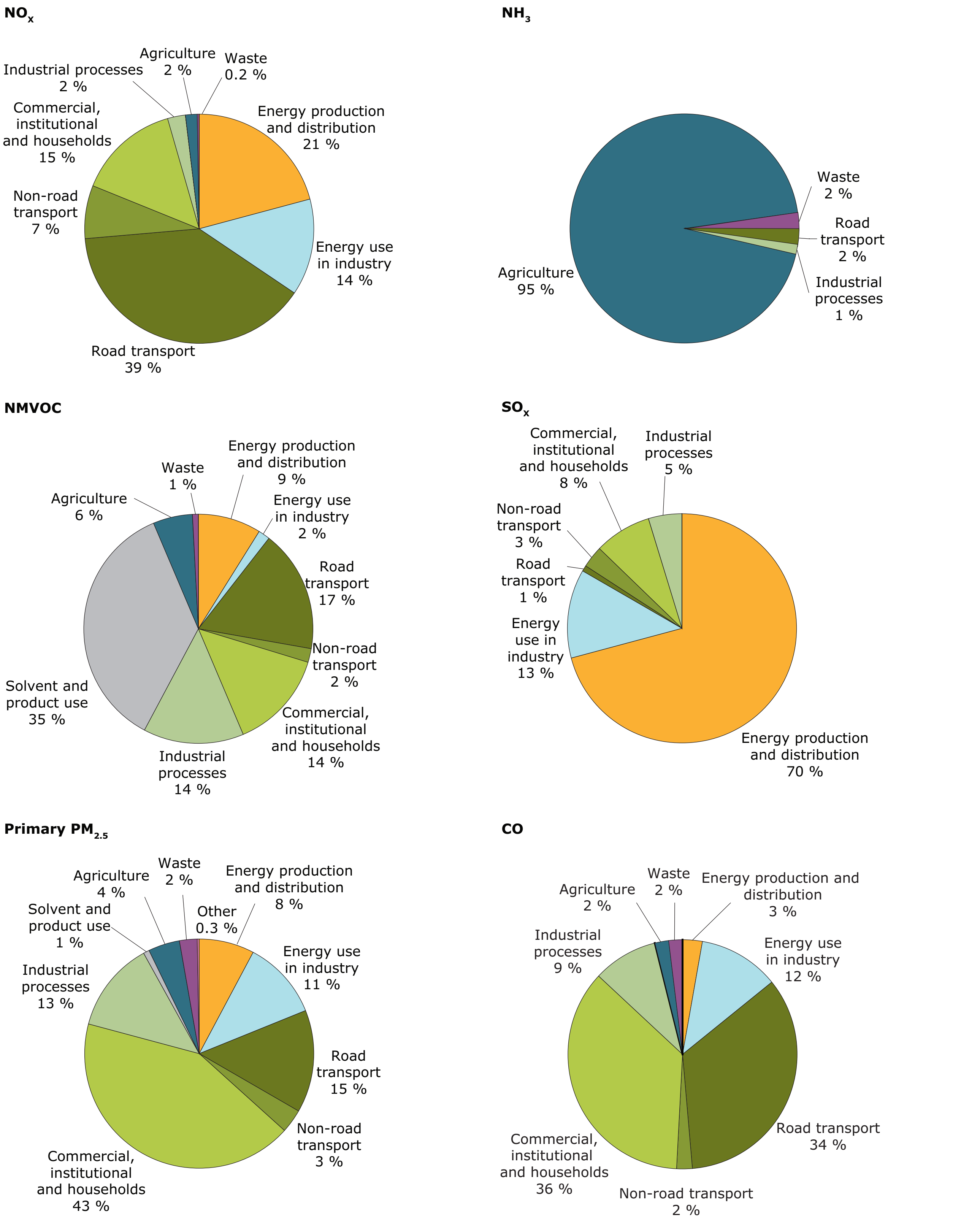
In addition, the oxidation catalysts used in diesel vehicles has caused an increase in the NO_2/NO_X ratio in these vehicles' exhausts (Carslaw, 2005). In turn, this makes a significant contribution to the exceedances of NO_2 concentration limits in many European cities and urban areas. Further, as emissions of NO_X from land-based sources decrease, there is a growing awareness of the increasingly important contribution to Europe's NO_X emissions from national and international shipping.

The underlying growth of transport demand has also led to large increases in greenhouse gas emissions (see EEA, 2010p). Measures that address air pollution abatement on vehicles also have the potential to lead to slightly higher CO_2 emissions in some forms of engine technology and exhaust treatment systems.

Figure 2.10 shows the main explanatory factors for the past changes in SO_2 and NO_X emissions from the power and heat generating sector. If the structure of this sector had remained unchanged from 1990, then emissions of SO_2 and NO_X by 2008 would have been around 30 % above 1990 levels. Increased utilisation of coal and the use of lignite in some countries has, in recent years, meant that the decline in SO_2 and NO_X emissions has slowed, although the significant specific reductions achieved by flue gas desulphurisation mean that SO_2 emissions have continued to fall in absolute terms while NO_X emissions have stayed broadly stable since 2000.

Emissions of NH_3, which contribute to acidification, eutrophication and particulate matter formation, have declined by around 20 % since 1990, although the rate of decrease has slowed in recent years. The greatest reduction has occurred in the agricultural sector, which accounts for the vast majority of emissions, due to reduced livestock numbers — especially cattle — since 1990, changes in the handling and management of organic manures, and the decreased use of nitrogenous fertilisers. The EU Nitrates Directive (EC, 1991) has contributed to the control of NH_3 emissions in many EU Member States. Further contributions to the reduction of NH_3 emissions may be achieved by this directive with the implementation of additional new abatement technologies. There is a close relationship between agricultural emissions of NH_3 and the greenhouse gas nitrous oxide (N_2O) — the latter is discussed in the

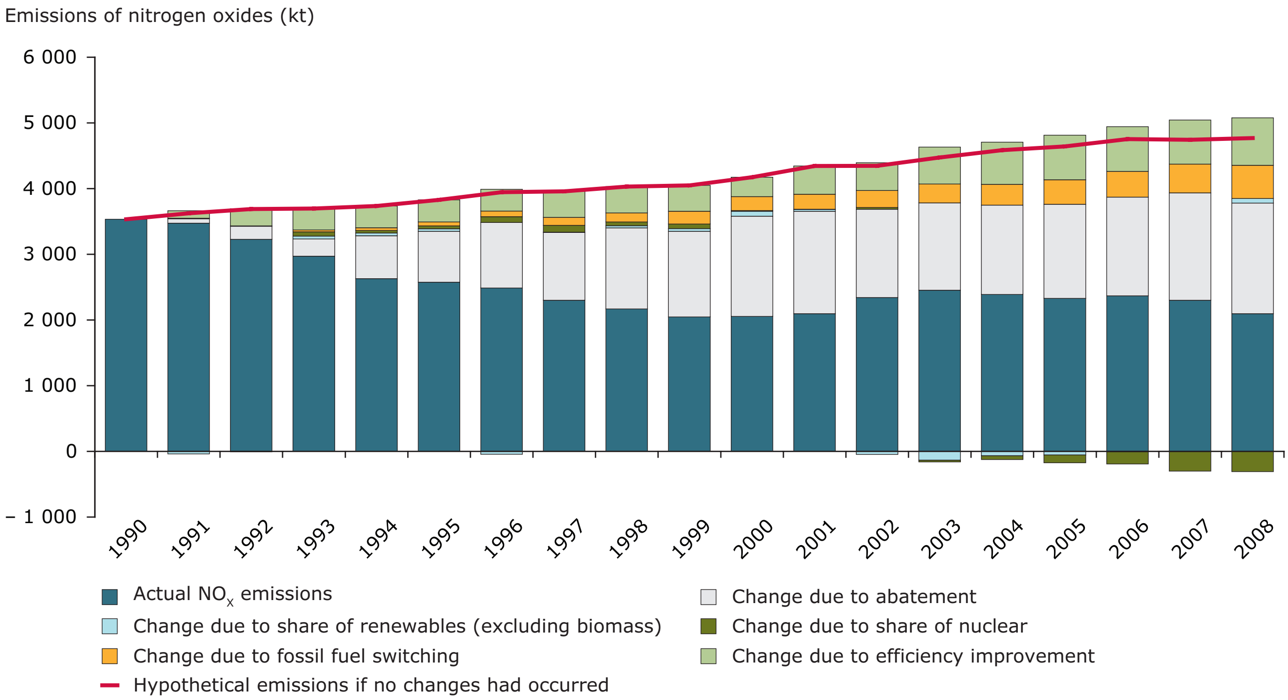
Figure 2.9 **Sources of selected air pollutants in 2008 for EEA-32 and Western Balkan countries**

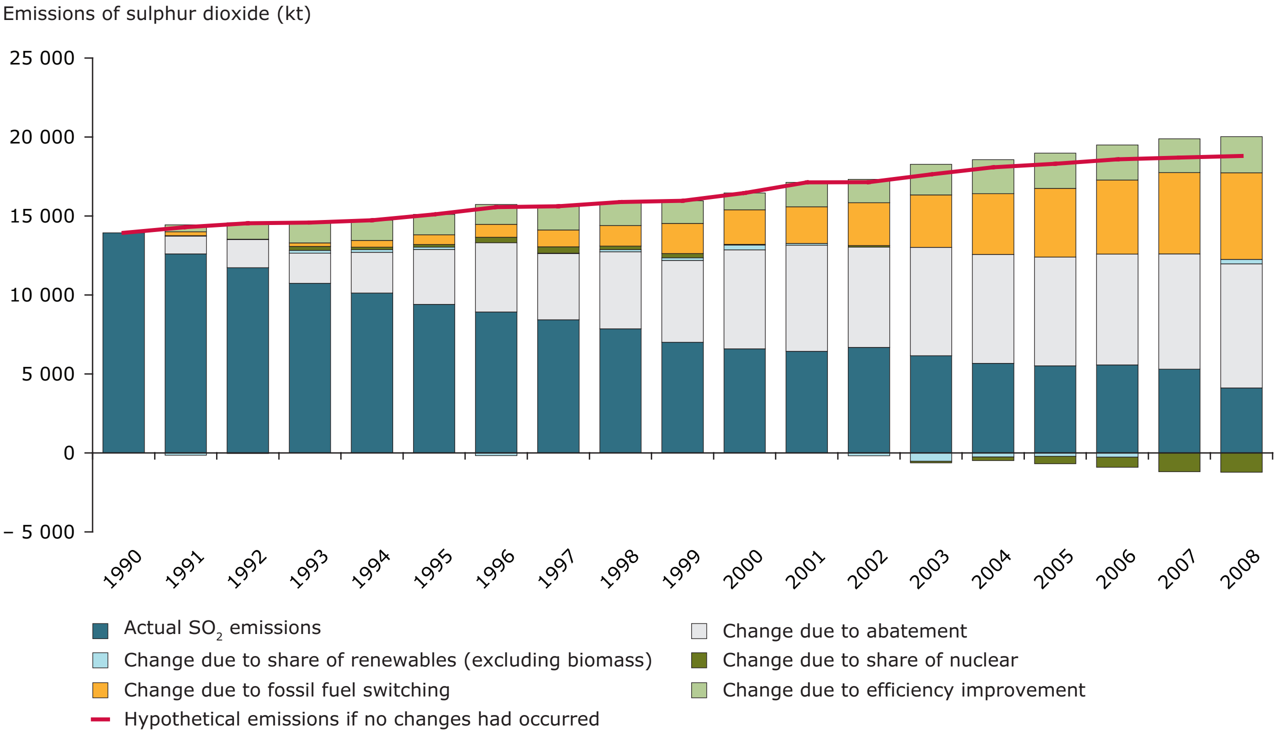


Note: Excludes emissions from international shipping, and emissions from aviation not associated with flight landing and take-off movements.

Source: EEA, 2010.

Figure 2.10 **Estimated impact of different factors on the reduction in emissions of NO_x (top) and SO_2 (bottom) from public electricity and heat production, EEA-32, 1990–2008**





Note: The charts show the estimated contributions of various factors affecting emissions from public electricity and heat production including public thermal, nuclear, hydro and wind plants. The top line represents the hypothetical development of emissions that would have occurred due to increasing public heat and electricity production between 1990 and 2008, if the structure and performance of electricity and heat production had remained unchanged. However, there were a number of changes to the sector's structure that tended to reduce emissions, and the contributions of each of these factors to the emission reduction are shown. The cumulative effect of all these changes was that emissions actually followed the trend shown by the lower bars.

Source: EEA, 2010h.

SOER 2010 mitigating climate change assessment (EEA, 2010p).

The decline in emissions of tropospheric O_3 precursor NMVOCs was due mainly to the introduction of vehicle catalytic converters as well as the introduction of legislative measures limiting the use of and emissions from solvents in non-combustion sectors.

At the regional scale, emissions of primary $PM_{2.5}$ make only a relatively small contribution to total $PM_{2.5}$ in the atmosphere. The majority comprises secondary particulate matter, formed in the atmosphere following the emission and oxidation of precursor gases. However, at the urban scale, the relative contribution of primary $PM_{2.5}$ emissions to $PM_{2.5}$ exposure is larger. Past reductions in primary $PM_{2.5}$ (Figure 2.8) are due mainly to improvements in the levels and performance of particulate abatement equipment at coal-fired power stations and industrial plants. This reduction means that combustion-related emissions from the heating of residential and commercial properties are now the single most important source of primary $PM_{2.5}$ in Europe, accounting for around 43 % of the total in 2008 (Figure 2.9). Emissions of both primary $PM_{2.5}$ and PM_{10}, and precursors of secondary PM, are expected to decrease as vehicle technologies are further improved and stationary fuel combustion emissions are controlled through abatement measures or the use of low-S fuels such as natural gas. Despite this, concentrations of PM_{10} and $PM_{2.5}$ in many urban areas across the EU are expected to remain above EU air-quality limit values in the next decade.

Europe has also successfully reduced emissions of certain other hazardous pollutants including persistent organic pollutants (POPs) and heavy metals. Improvements in abatement technologies for wastewater treatment, incinerators and in metal refining and smelting industries, and, in some countries, the closure of older industrial facilities as a consequence of economic restructuring, has helped reduce emissions of the heavy metal Pb by 90 %, mercury (Hg) by 61 % and Cd by 58 % between 1990 and 2008 in the EEA-32 (EEA, 2010i).

The promotion of unleaded petrol within the EEA-32 member countries through a combination of fiscal and regulatory measures has been a particular success story. EU Member States have, for example, completely phased out the use of leaded petrol, a goal that was regulated by Directive 98/70/EC (EC, 1998). From being the largest source of Pb in 1990 when it contributed more than 70 % of total emissions, emissions from the road transport sector have since decreased by more than 95 %.

Emissions of polycyclic aromatic hydrocarbons (PAHs), an important group of chemicals categorised as persistent organic pollutants (POPs), decreased by 60 % overall between 1990 and 2008 in the EEA-32 but increased in a small number of countries. Emissions of certain other POPs have decreased between 1990 and 2008 — hexachlorocyclohexane (HCH, by – 86 %), polychlorinated biphenyls (PCBs, by – 76 %) and dioxins and furans (by 81 %) — but as with PAHs, while the majority of individual countries report emissions of these substances have fallen during this period, a number report that increased emissions have occurred (EEA, 2010j). Important emission sources of many POPs include residential combustion processes — open fires, coal and wood burning for heating purposes, etc., industrial metal production processes and the road transport sector.

3 Outlook 2020

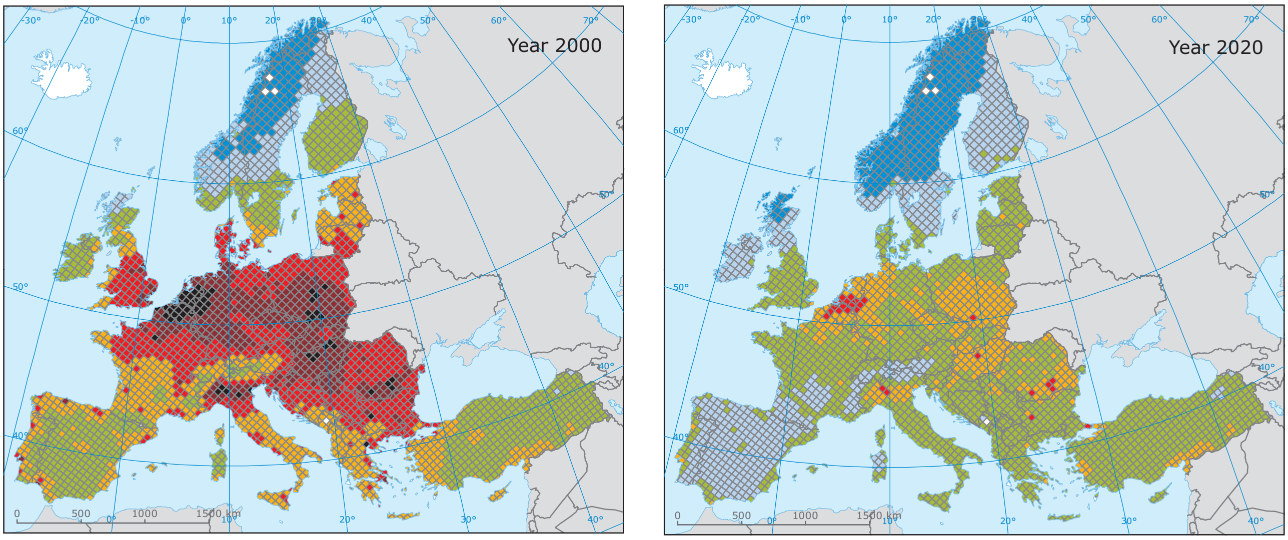
3.1 Emissions

Figure 2.8 shows estimated emissions for 2010 as reported by EU Member States and projected emissions for 2020 for the EEA-32 and the Western Balkan countries (IIASA, 2010a). The 2020 baseline outlooks are consistent with existing EU policies and include estimated impacts from the recent economic downturn.

Figure 2.8 shows that, under the current policy scenario, emissions of the main air pollutants, excepting NH_3, are all projected to decline by 2020 for the EEA-32 and Western Balkan countries. Compared with 2008 emission levels, the largest decreases in percentage terms are projected for emissions of NO_X and SO_2: a reduction of around 45 % by 2020 in the absence of additional measures to further reduce emissions. For $PM_{2.5}$ and NH_3 for which 2020 emissions are projected to be similar or slightly higher than in 2008, substantial reductions are technically possible, as shown by the maximum reduction (MRR) scenarios for the EU-27.

The on-going — as of 2010 — revision of the Gothenburg Protocol (UNECE, 1999) under the UNECE LRTAP

Map 3.1 Loss of average statistical life expectancy (months) attributable to the exposure to fine particulate matter ($PM_{2.5}$) in 2000 (left) and for the optimised * scenario in 2020 (right)



Estimated loss of statistical life expectancy attributable to the exposure of fine particulate matter ($PM_{2.5}$) in the year 2000 (left) and for the optimised scenario in 2020 (right)

Months

0–1 | 1–2 | 2–4 | 4–6 | 6–9 | 9–12 | 12–18 | Outside coverage | No data

Note: * 'Optimised' refers to the scenario run carried out to assess cost-effective emission reductions that achieve the environmental objectives set in the TSAP. Only $PM_{2.5}$ pollution from anthropogenic sources is considered.
The highest values were estimated for single grid cells in Hungary (up to 18 months), northern Italy (up to 17 months), Belgium, the Netherlands and in the German Ruhr area (up to 16 months) in 2000. For the 2020 scenario the four highest country averages (EU-27) were calculated for Belgium (6.6 months), Hungary and Poland (5.2 months) and Romania (4.9 months) (IIASA, 2010a).

Source: IIASA, 2010b (based on IIASA, 2010a).

Convention (UNECE, 1979) and the delayed revision of the EU NECD (EC, 2001a) are both expected to introduce stricter emission ceilings for 2020 for relevant countries and for the first time national limits on the emission of $PM_{2.5}$. Depending upon the ambition level to be agreed, the 2020 emission ceilings will require further emission reductions between those projected under the current baseline scenario and the level of a maximum reduction scenario. As an illustration, the levels of emission reduction compared to the baseline scenario required in the EU-27 in order to meet the environment and health objectives of the European Commission's Thematic Strategy on Air Pollution (EC, 2005) are shown in Figure 2.8, together with the MRR scenario for the EU-27.

A time horizon of 2050 has been suggested as an aspirational target year by which Europe's long-term objectives of achieving levels of air pollution that do not lead to unacceptable harm to human health and the environment should be met. Preliminary assessments indicate that in order to meet these objectives, for SO_2 there should be an emissions reduction in the range 40–60 % compared with 2010, especially in northern and central Europe. For NO_X and NH_3 the required reductions are in the range of 70–90 % and for O_3 precursors 70–80 %, in particular in southern, western and central Europe. In urban areas a 40–60 % emission reduction of PM would be needed (Maas et al., 2009).

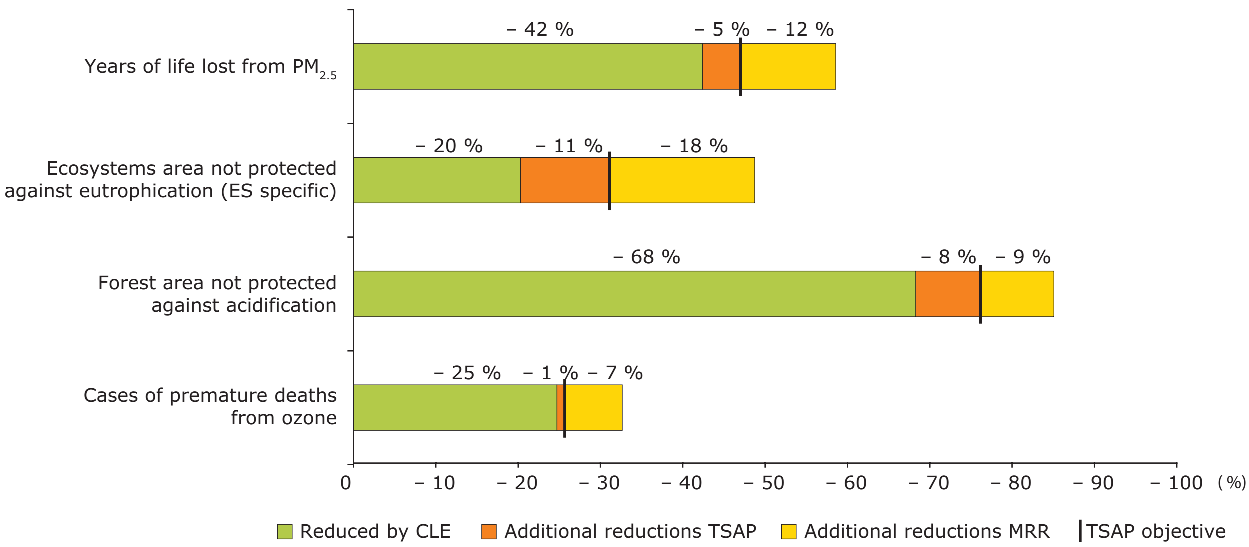
3.2 Air quality projections for 2020

According to the scenario that assumes that current policies and measures are fully implemented (IIASA, 2010a), the loss of statistical life expectancy attributable to the exposure to $PM_{2.5}$ will be 4.1 months in the EU-27 in 2020, compared to 8.0 months in 2000. The predicted loss when assuming a maximum reduction (MRR) scenario is 2.9 months for the EU-27 in 2020 (Map 3.1). The environmental objective of the Thematic Strategy on Air Pollution (TSAP; EC, 2005) is 3.8 months.

For ozone pollution the current policy scenario predicts about 17 100 premature deaths in 2020 compared to 22 700 in 2000. The respective numbers for the MRR scenario and the TSAP are approximately 15 300 and 16 900 (IIASA, 2010).

The objectives of the TSAP states that the number of years of life lost (YOLLs) due to $PM_{2.5}$ impacts should decline by 47 % between 2000 and 2020. The number of premature deaths attributable to the exposure to ground-level ozone should decline by at least 10 %. According to the TSAP, the area of sensitive ecosystems that is not protected against excess nitrogen deposition threatening biodiversity should be reduced by 43 % in comparison to 2000 and the forest area receiving unsustainable levels of acid deposition should shrink by 74 %.

Figure 3.1 Relative changes in environmental impact indicators in the EU-27 resulting from current legislation (CLE) in 2020 and the additional reductions in line with the TSAP, as well as maximum emission reductions (MRR), compared to 2000



Note: Eutrophication: a reduction of 43 % based on grid averages as used for CAFE Programme calculations translates into a reduction of 31 % when updated ecosystem (ES) specific critical loads are used (as done in IIASA, 2010a).

Source: Based on IIASA, 2010a.

Distance-to-target analyses show to which extent the environmental objectives are predicted to be met in 2020, assuming the current policy and maximum reduction scenarios (IIASA, 2010a). The results indicate that none of the TSAP objectives set for the protection of human health and ecosystems will be reached by current policies alone (Figure 3.1). For years of life lost (YOLL) due to $PM_{2.5}$ pollution, the achieved reductions will be approximately 5 % below the target. For O_3 (premature deaths) the difference is very small: only 1 %. The highest absolute reductions predicted under the scenario are found for the acidification of forest soils, although a further reduction of about 8 % is still needed to obtain the TSAP objective. Concerning ecosystem eutrophication, the distance-to-target is estimated to be as high as 11% in 2020.

4 Responses

4.1 Mitigation of emissions

To improve air quality, the strategy of European air-related legislation in recent years has been a twin-track approach of establishing air-quality objectives together with implementing air pollutant emission-reduction measures. The emission reductions reported in Section 2.4 have in general resulted from a combination of policy actions undertaken at both national and sectoral levels.

The EU's NECD (EC, 2001a) sets emission ceilings — limits to be met by 2010 and in the years thereafter — for the four main pollutants responsible for acidification, eutrophication and ground-level O_3 — SO_2, NO_X, NMVOCs and NH_3. The ceilings were designed to meet objectives for acidification, eutrophication and O_3 in the most cost-effective way. Internationally, the 1999 Gothenburg Protocol (UNECE, 1999) to the UNECE LRTAP Convention (UNECE, 1979) also sets emission ceilings for the same four pollutants and for more countries than just the EU Member States. For the EU Member States, the emission ceilings in the Gothenburg Protocol are either equal to or less ambitious than those in the EU NEC Directive.

Despite progress in reducing emissions, many countries will not meet the 2010 national emission ceiling limits set by the NECD or the LRTAP Convention (Table 4.1). Only 14 EU Member States anticipate that they will meet all four of the pollutant-specific emission ceilings in the NECD; with the remaining 13 indicating that they anticipate missing at least one of their ceilings (EEA, 2010g). Of the four ceilings, that for NO_X remains by far the most difficult for many countries to meet — 11 Member States estimate they will miss the ceiling for this pollutant. Several Member States, including Slovenia, Sweden and the United Kingdom, expect to exceed their respective NO_X ceilings by only small margins (less than 5 %). In contrast, France and Spain expect to exceed their ceilings by large amounts — 261 kt and 236 kt respectively — equivalent to exceedances of 32 % and 28 %. Other countries, while expecting lower exceedances in absolute terms, anticipate exceeding their ceilings by even larger margins, notably Austria (42 %), Belgium (43 %) and Ireland (58 %). One of the main contributory factors to the anticipated non-compliance of NO_X ceilings in many countries is that vehicle emission standards for NO_X (particularly for diesel vehicles) have not been as effective in reducing emissions as originally anticipated — see the preceding discussion in Section 2.4. Coupled to this, the need to reduce CO_2 has shifted the market in many European countries in favour of more fuel efficient diesel vehicles. In turn, this has caused a slow down of NO_X and PM emission reductions.

In contrast some countries will have successfully reduced emissions of some pollutants significantly below the levels required by the ceilings, over-achieving their original commitments.

For the three non-EU countries that have emission ceilings set under the Gothenburg Protocol — Liechtenstein, Norway and Switzerland — each anticipates missing at least one of the four ceilings (Table 4.1).

The 'with measures' (WM) projections ([6]) reported by Member States also imply that for some pollutants, the emission ceilings for the EU-27 as a whole, defined in the NECD's Annex I and II, will be exceeded for some pollutants. Only for SO_2 and NH_3 does the EU-27 seem certain to meet both the aggregated ceilings.

Within the EU, a number of sector-specific legislative measures supporting the objectives of the NECD have been implemented. These aim, for example, to reduce or control emissions from large combustion plants (LCP) through the LCP Directive (EC, 2001b), industrial activities through the Integrated Pollution Prevention and Control (IPPC) Directive (EC, 1996), road transport vehicles through implementation of successive Euro emission standards and fuel quality measures such as restrictions on the level of sulphur in fuels, and NMVOCs from solvent use through the Solvent Emissions Directive (EC, 1999b).

([6]) A 'with measures' (WM) projection takes into account all currently implemented and adopted policies and measures. A 'with additional measures' (WAM) projection takes into account, in addition, future planned policies and measures.

Table 4.1 Anticipated performance in meeting the four 2010 emission ceilings of the EU NECD for EU Member States and the 2010 ceilings of the UNECE LRTAP Convention's Gothenburg Protocol for the non-EU EEA member countries

Country	NO_x	NMVOC	SO_2	NH_3	Country	NO_x	NMVOC	SO_2	NH_3
Austria	x	x	√	√	Lithuania	√	√	√	√
Belgium	x	√	√	√	Luxembourg	x	√	√	√
Bulgaria	√	√	√	√	Malta	x	√	x	√
Cyprus	√	√	√	√	Netherlands	√	√	√	x
Czech Republic	√	√	√	√	Norway	x	√	x	√
Denmark	√	√	√	√	Poland	√	√	√	√
Estonia	√	√	√	√	Portugal	√	x	√	√
Finland	√	√	√	√	Romania	√	√	√	√
France	x	√	√	√	Slovakia	√	√	√	√
Germany	x	√	√	x	Slovenia	x	√	√	√
Greece	√	√	√	√	Spain	x	x	√	x
Hungary	√	√	√	√	Sweden	x	√	√	√
Ireland	x	√	√	√	Switzerland	√	√	√	x
Italy	√	√	√	√	United Kingdom	x	√	√	√
Liechtenstein	√	√	√	x					

Notes: Reported EU-27 Member States 'with measures' projections are compared to the emission ceilings of the NECD (EC, 2001a). Projections for Liechtenstein, Norway and Switzerland are those reported under the LRTAP Convention (UNECE, 1979) and are compared to the respective emission ceilings of the Gothenburg Protocol (UNECE, 1999). Liechtenstein has signed but not yet ratified the Gothenburg Protocol. Turkey and Iceland have not yet ratified the Gothenburg Protocol.

'√' indicates that a country anticipates meeting its respective emission ceiling on the basis of currently implemented and adopted policies and measures.

'x' Indicates that a ceiling will not be met without implementing additional measures to reduce emissions.

Emission ceilings are compared against reported 'with measures' (WM) projections. WM projections take into account currently implemented and adopted policies and measures.

4.2 Air-quality assessment and management

Current European air-quality legislation is based on the principle that Member States divide their territories into a number of air quality management zones in which countries are required to assess air quality using measurements, modelling or other objective-estimation techniques. Delimitations of zones may differ for different pollutants in order to optimise the management of air quality in the context of differences in sources and abatement strategies. Agglomerations, defined as urban areas with more than 250 000 inhabitants, are special types of zones.

The European Commission requires that causes of limit value exceedances are reported, and this reporting is the basis for the development of local or regional plans and programmes to improve the situation. In order to identify the probable causes, information on the strength of emissions from various sources and the spatial distribution of concentrations is essential. The European legislation encourages the use of so-called supplementary assessment methods such as air quality modelling. Guidance on the latter is provided by the Forum on Air Quality Modelling in Europe, a joint initiative of the EEA and the European Commission's Joint Research Centre (FAIRMODE, 2010).

To reduce the adverse effects of air pollution on health and the environment, various measures are taken at the EU level, including the introduction of fuel quality and product standards. However, in certain areas it is necessary for Member States to take further measures to ensure compliance. Examples of additional initiatives aimed at reducing urban pollution are summarised in Box 4.1.

Member States may notify the European Commission when in their opinion certain conditions in a zone justify an exemption from the PM_{10} limit value by 2011 and the NO_2 and C_6H_6 limit values by 2015. These conditions include that:

- the limit values for NO_2 and C_6H_6 could not be achieved by 1 January 2010;
- all appropriate measures have been taken at national, regional and local level to meet the deadline for the PM_{10} limit values — 1 January 2005;
- in respect of PM_{10} exemptions, the limit values cannot be achieved because of one or more of the following elements: site-specific dispersion characteristics,

Box 4.1 Examples of possible actions by local, regional and national authorities to reduce air pollution in urban areas

Transport
- establish low-emission zones that restrict access for more polluting vehicles;
- improve transport planning to encourage a shift of transport to less polluting modes including walking, cycling, and public transport;
- encourage cleaner fuels and vehicles including use of economic incentives;
- renew municipal vehicle fleets to introduce newer, cleaner vehicles;
- introduce retrofit programmes for road vehicles:
  - particle filters to reduce PM emissions, and modern de-NO_x technologies;
  - shift to compressed natural gas vehicles;
- introduce congestion charging, differentiated parking fees or a city toll;
- introduce speed limits and traffic calming measures, for example imposing lower speed limits on main roads;
- implement short-term actions such as traffic bans during high pollution episodes;
- introduce measures to reduce emissions from non-road vehicles used for example in construction activities.

Households, commercial and institutional buildings
- encourage fuel switching from more polluting to cleaner fuels, for example from coal to gas or electricity including use of financial incentives to achieve this;
- establish district heating schemes — heat and power cogeneration;
- implement rebate schemes that improve the insulation and energy efficiency of buildings;
- ensure industrial and commercial combustion sources (including for biomass) are fitted with emission control equipment or replaced.

General
- raise the awareness of citizens, provide easy-to-understand information on air quality and health effects of air pollutants;
- use air quality forecast and scenario tools to warn the general public and sensitive population groups about episodes of high air pollution.

adverse climatic conditions or transboundary contributions;
- compliance with the limit values is foreseen at the expiry of the postponement or exemption period.

4.3 Impacts of selected European policies on air quality

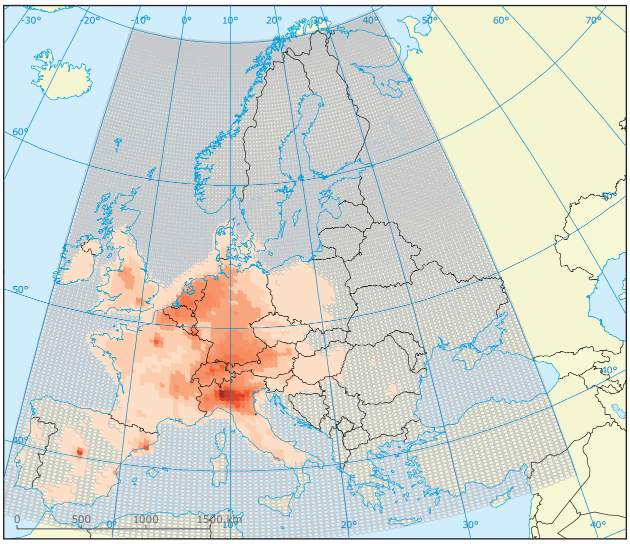
As previously noted, two sectors, road transport and power plants, contribute considerably to total emissions of many pollutants including NO_X, SO_X, NMVOCs, PM_{10} and $PM_{2.5}$. A recent assessment (EEA, 2010k) has shown how the introduction of selected air pollution policies has affected air pollution in Europe over the past few decades, and estimates the current unexploited potential to further reduce air pollution from these sectors.

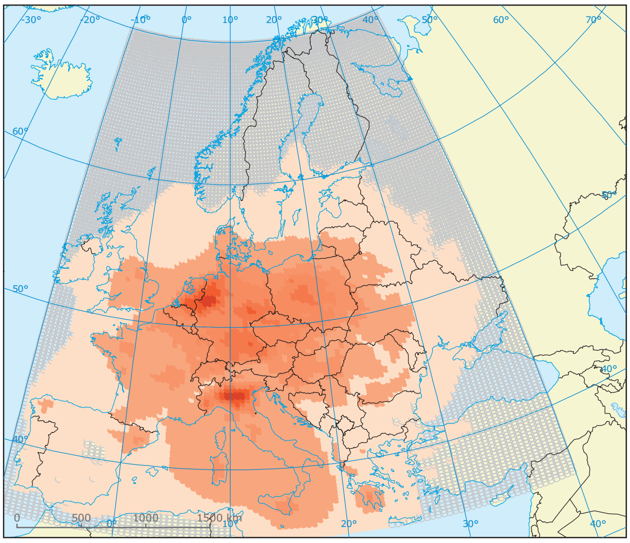
The assessment has shown that the successive introduction of the Euro vehicle emission standards together with the introduction of emission limits for large combustion plants under the LCP and IPPC Directives has led to a significant decrease in emissions and general improvement in air quality. Map 4.1 shows the modelled difference in $PM_{2.5}$ concentrations after comparing scenarios that either included or excluded the selected policies.

Major improvements in air quality have been achieved for PM, particularly in the heavily populated and industrialised regions of Europe, and which have resulted in health benefits. The benefits arising from reducing emissions from large combustion plants are greater, reflecting the larger reduction in $PM_{2.5}$ concentrations that has occurred as a result of introducing the policies for this sector.

The situation for O_3 is different. Although emissions of O_3 precursors have been reduced, ambient concentrations and hence the modelled impacts of O_3 have increased in some areas following introduction of the Euro standards (Map 4.2). The reasons for this are complex and are due to the complicated non-linear processes involved in atmospheric O_3 photochemistry and hemispheric transport of O_3 pollution (Box 2.5). To decrease O_3 concentrations further, specific sourc es of its precursors may need to be targeted, such as NO_X emissions from

Map 4.1 **The modelled effects of introducing road vehicle emissions standards (left) and the LCP/IPPC Directives for large combustion plants (right) on $PM_{2.5}$ concentrations in Europe in 2005**





Modelled effects of introducing road vehicle emissions standards on $PM_{2.5}$ concentrations in 2005

μg/m³

< 0.5, 0.5–1.0, 1.0–1.5, 1.5–2.0, 2.0–2.5, 2.5–3.0, 3.0–3.5, 3.5–4.0, 4.0–4.5, 4.5–5.0, > 5.0

Modelled effects of introducing the LCP/IPPC Directives for large combustion plants on $PM_{2.5}$ concentrations in 2005

μg/m³

< 2, 2–4, 4–6, 6–8, 8–10, 10–12, 12–14, 14–16, 16–18, 18–20

Notes: Areas of darker colour illustrate areas where larger improvements in air quality have occurred compared to a scenario in which the relevant policy measures had not been introduced.

Source: EEA, 2010k.

diesel-fuelled vehicles and NMVOC emissions from solvent use. It remains to be seen however, whether such targeted reductions will result in decreased O_3 levels. It is important to note that across Europe as a whole, the total health impact of introducing the policy measures for $PM_{2.5}$ and O_3 has been positive.

Despite past improvements, current air quality therefore continues to harm human health and the environment. Nonetheless, there is considerable potential to reduce emissions and further improve it. A hypothetical EEA scenario (EEA, 2010k) assumed the application of the latest Euro standards to all vehicles and that all large combustion plants achieve the associated emission level values (AELs) described in the LCP Best Available Techniques reference document (BREF) (EC, 2006). Results show that:

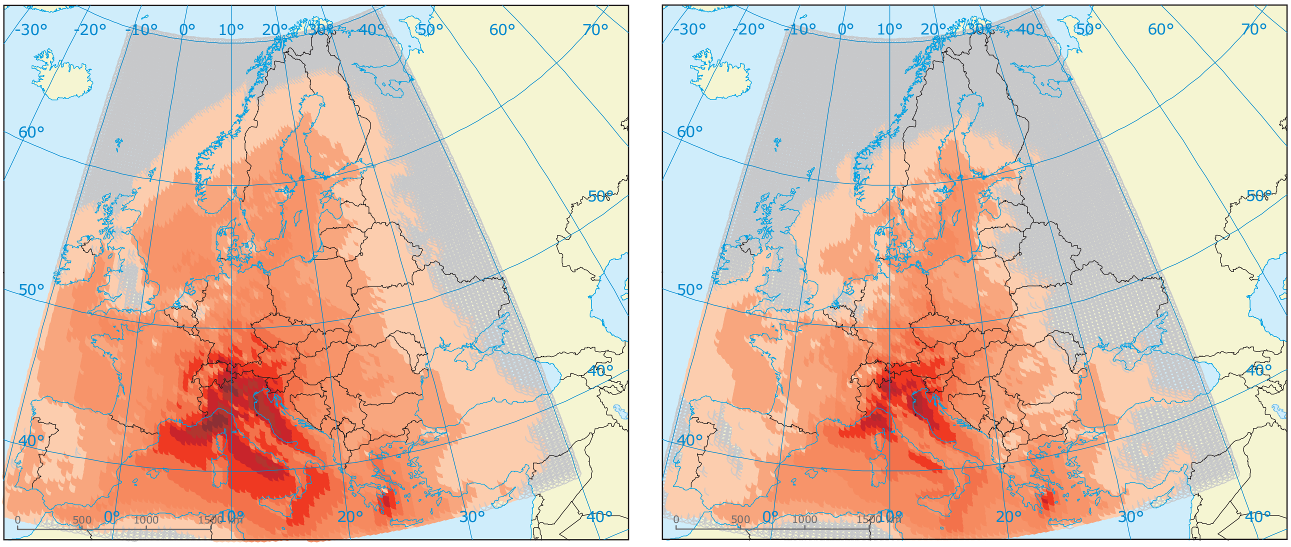
- further substantial emission reductions would be possible if all types and classes of vehicles would achieve the latest Euro standard emission limits;
- full application of the most stringent interpretations of the BREF AELs would result in substantial emission reductions from large combustion plants — reductions of a factor of 40 for SO_X and a factor of 8 for NO_X compared with the actual reductions that have occurred.

4.4 Air pollution and climate change interactions

In addition to their impacts as air pollutants, tropospheric O_3 and some constituents of PM affect the radiative forcing of the atmosphere. Their impacts are complicated to assess, but in general emissions of primary PM, such as black carbon and tropospheric O_3 increase radiative forcing leading to a net warming effect in the atmosphere, while secondary PM formed from precursor emissions reduces atmospheric radiative forcing (IPCC, 2007).

Measures to reduce emissions of certain O_3 precursors are therefore beneficial in terms of mitigating climate change as well as improving air quality. Similarly, actions implemented to reduce black carbon particulate matter, such as banning the uncontrolled burning of biomass and waste or fitting particulate filters in diesel vehicles, would

Map 4.2 **Difference in O_3 impact indicators of human health (SOMO35) (left), and ecosystems (AOT40) (right), in 2005 as a result of the introduction of Euro vehicle emission standards in road transport**



Difference in human health O_3 indicator (SOMO35) in 2005 following introduction of road vehicle emission standards

µg/m³.days

< 400, 400–800, 800–1 200, 1 200–1 600, 1 600–2 000, 2 000–2 400, 2 400–2 800, 2 800–3 200, 3 200–3 600, 3 600–4 000

Difference in ecosystems O_3 indicator (AOT40) in 2005 following introduction of road vehicle emission standards

µg/m³.hours

< 2 000, 2 000–4 000, 4 000–6 000, 6 000–8 000, 8 000–10 000, 10 000–12 000, 12 000–14 000, 14 000–16 000, 16 000–18 000, 18 000–20 000

Source: EEA, 2010k.

lead to benefits both for health and mitigating climate change. As CH_4 and black carbon are short-lived gases or compounds, with the main climate impact on a time scale of less than 20 years, cutting emissions of these pollutants would also lead directly to climate change benefits in the short-term.

Measures to abate air pollution and greenhouse gases often target the same emission sources — combustion facilities, vehicle exhausts, and the management of manure. It is important to note, however, that efforts to control emissions of one group of pollutants can have either synergistic or sometimes antagonistic effects on other pollutants, in turn leading to unforeseen benefits or disadvantages. Examples include:

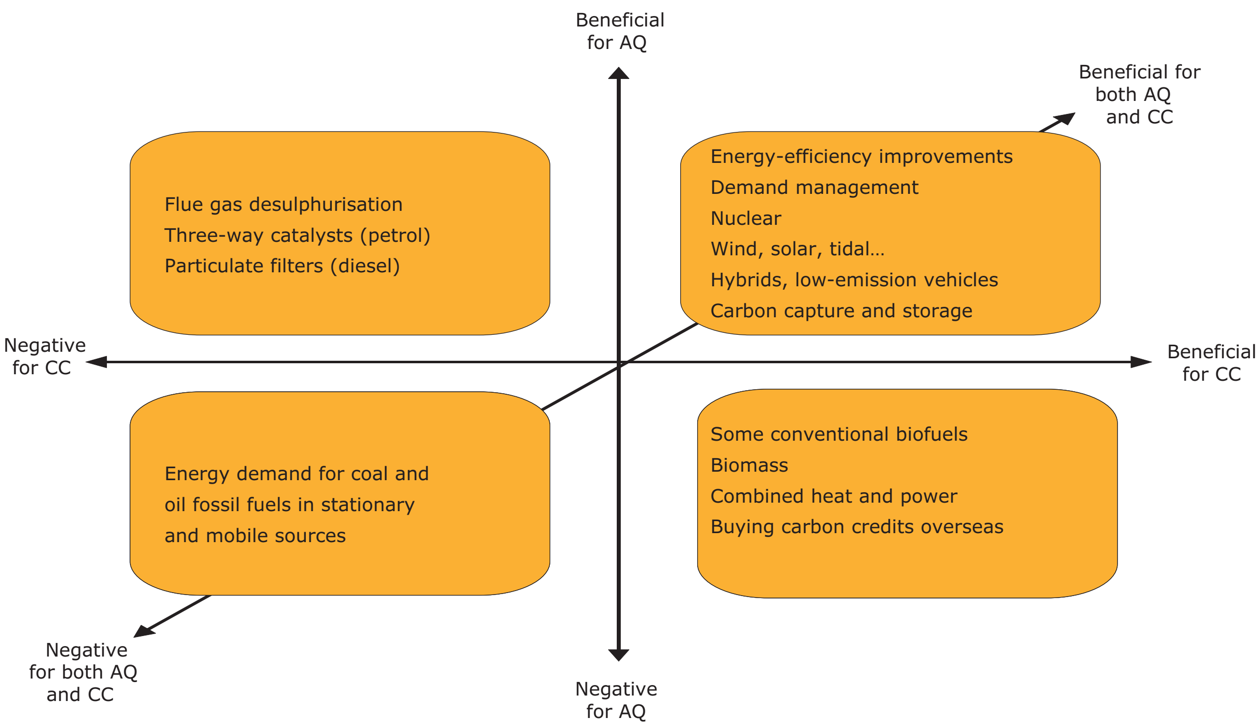
- energy efficiency and other measures that encourage reducing fossil fuel combustion provide general benefits by also reducing emissions of air pollutants;
- the effect of renewable energy sources may be positive — the availability of wind and solar energy — or negative — the increased use of biofuels while nominally CO_2 'neutral', could lead to increased emissions of other air pollutants over a life-cycle basis;
- the expanded use of (renewable) biomass for residential heating, especially in urban areas, needs to be very carefully managed in order to minimise negative impacts on urban air quality (Defra, 2010);
- flue gas desulphurisation at industrial facilities requires extra energy, leading to additional CO_2 emissions, as do some technologies for reducing vehicle emissions of air pollutants;
- introduction of carbon capture and storage (CCS) may require the additional consumption of energy and hence additional emissions of air pollutants. Emissions of air pollutants per unit electricity produced at future power plants equipped with CCS will depend to a large extent on the technology employed — integrated gasification combined cycle (IGCC) technology will tend to decrease emissions of NO_X and SO_X, while CCS post-combustion technology will substantially decrease SO_X but may increase NO_X emissions (TNO, 2008);

- a future large scale uptake of electric vehicles could lead to significant benefits arising from the displacement of harmful air pollutants from urban to rural areas (where fossil-fuelled power stations are typically situated) where population exposure is lower. Electricity sourced from non-combustion renewable sources would lead to further benefits. However the size of any benefits will depend upon the particular grid mix properties and on the type of conventional vehicles that have been substituted by electric vehicles. Assuming more stringent power plant emission regulations in the future, the benefit of electric vehicle operation with regard to air quality improvement could further increase (ETC/ACC, 2009d);
- the flexibility that the EU Emission Trading Scheme (ETS) is designed to create may be limited by the need to meet national emission ceilings or local air quality limits at the Member State level. Governments may thus need to impose air pollutant control measures at ETS facilities going beyond Best Available Techniques, which in turn could increase emissions of greenhouse gases. The extent to which such additional policies effectively constitute negative impacts on the ETS sector is unclear;
- emission trading of CO_2 and particularly the use of flexible mechanisms may export co-benefits of greenhouse gas mitigation — lower air pollution — to other regions of Europe or the world. Therefore, if decisions to buy CO_2 emission credits abroad are motivated only by minimising the costs of climate change policies, this could result in a less cost-efficient overall solution.

A better scientific understanding of many of the synergies and trade-offs between air quality and climate change measures is still needed to help inform future decisions. Figure 4.1 provides a summary of some of the key interactions.

Implementation of policies for climate change mitigation are however generally positive for air pollution and can lead to considerable benefits and monetary savings. This is clearly seen for the EU's climate and energy package adopted in 2009. The costs of the package are estimated to be EUR 120 billion per year from 2020 (EC, 2008b). If the policies and measures for meeting the package's targets are implemented, the costs of implementing future air pollution policy in Europe may be reduced by around EUR 16 billion per year. Factoring air quality into decisions about how to reach climate change targets, and vice-versa, results in policy situations with greater benefits to society.

Figure 4.1 Air quality (AQ) and climate change (CC) synergies and tradeoffs



Source: Adapted from Defra, 2010.

Box 4.2 Recognising the links between air pollution and climate change

Two hundred scientists, experts and policymakers from more than 30 countries met in Gothenburg, Sweden in late 2009 under the Swedish EU presidency. Participants discussed interactions between air pollution and climate change, and considered how future well-designed air pollution policies might also assist in mitigating climate change. A key theme was the need to continue to build links between existing regional agreements and networks for air pollution and climate change.

While further scientific knowledge is needed to fully understand interactions between the different kinds of pollutants, the general links between greenhouse gases and air pollution are widely accepted at the technical level. However, the co-benefits and synergies that can arise as a result of such links are not yet explicitly taken into account under either UNFCCC or the UNECE LRTAP Convention.

A joint strategy to meet both air quality and climate change targets would aim to find an optimal mix of cost-effective measures taking into account technological developments and the atmospheric processes through which air pollutants can affect climate change and vice versa.

Developing a coordinated approach for controlling air pollutant and greenhouse gas emissions is however typically made difficult in many countries and organisations by the division of policy responsibilities among different departments or ministries. The need to develop strong links between international climate and air pollution strategies was highlighted as one of the best and more realistic options to reduce global emissions of greenhouse gases and air pollutants in the most cost-effective manner (Swedish EPA, 2009).

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