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Evaluation of progress under the EU National Emission Ceilings Directive

Progress towards EU air quality objectives

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European Environment Agency

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Executive summary

In 2001, the European Community adopted the National Emission Ceilings Directive (NEC Directive). Its objective is to limit the emissions of four important air pollutants in order to achieve the directive's interim environmental objectives concerning acidification and eutrophication in sensitive ecosystems, and health- and vegetation-related exposure to ground-level ozone. Over the past decade, the NEC Directive has formed a cornerstone of the European Union's (EU) air pollution policies, contributing to efforts to meet the long term objectives for air quality defined in the Sixth Environment Action Programme i.e. to achieve levels of air quality that do not give rise to significant negative impacts on, and pose risks to, human health and the environment.

In order to deliver the agreed interim environmental objectives set within the Directive, a set of legally binding emission ceilings were established — limits to be met by 2010 and in the years thereafter — for each Member State and the European Community (as it was then known) as a whole. These ceilings pertained to four important air pollutants that contribute to acidification, eutrophication and to the formation of ground-level ozone (see also Box ES.1):

- sulphur dioxide (SO_2)
- nitrogen oxides (NO_X)
- non-methane volatile organic compounds (NMVOC)
- ammonia (NH_3).

A separate analysis published earlier in 2012 by the European Environment Agency (EEA) documented the extent to which the national emission ceilings were met on the basis of official preliminary emissions data reported by Member States for 2010 (EEA, 2012a). This earlier analysis revealed that 12 EU Member States failed to keep emissions below their agreed ceilings. These were Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Malta, the Netherlands, Spain and Sweden. Using the officially-reported data, the analysis described in this report shows the extent to which the NEC Directive's interim environmental and health objectives for the year 2010 have been achieved.

Scientific knowledge concerning air pollution and its impacts has developed significantly over the past decade since the NEC Directive was agreed. These developments mean that a more nuanced analysis is needed of whether the objectives of the directive have been met:

- more complete and improved emission inventories for the base year (1990) are now available;
- the scientific knowledge on environmental and health impacts has improved, including the development of ecosystem-specific critical loads and revised response functions for ozone;
- the air pollution dispersion modelling approach used by the European Monitoring and Evaluation Programme (EMEP) ([1]) to calculate the impacts of air pollution has changed;
- the level of detail of the air pollution modelling computations has improved, with results now available on a 50 x 50 km grid cell basis, as compared to the older 150 x 150 km grid used at the time of determining the NEC Directive ceilings and its interim objectives.

In performing an assessment of progress made in reducing harm caused by air pollution, such advances in scientific knowledge should clearly not be disregarded: these allow a more accurate picture to be obtained than by using the original techniques alone. This report therefore employs two approaches in assessing the progress achieved toward meeting the interim environmental objectives of the NEC

([1]) Cooperative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe under the LRTAP Convention.

Directive, by performing assessments based as far as feasible upon:

A. The year 2000 knowledge base, i.e. 'original' knowledge comprising

- the emission estimates for the year 1990 that were available in the year 2000;
- the older Lagrangian EMEP air quality dispersion model that computed average depositions and concentrations;
- a 150 x 150 km^2 grid size;
- the critical loads approach as applied in 2000.

B. The latest scientific knowledge, i.e. 'present' knowledge, including:

- updated emissions inventory data reported in early 2012 for the years 1990 and 2010;
- the Eulerian EMEP air quality dispersion model that computes ecosystem-specific depositions;
- a 50 x 50 km^2 grid size;
- the current (ecosystems-based) critical loads approach that distinguishes between different ecosystems following the European Nature Information System (EUNIS) and improved critical loads, of nitrogen in particular.

Box ES.1 Air pollutants addressed in the NEC Directive, and their effects on human health and the environment

Sulphur dioxide (SO_2)

SO_2 is emitted when fuels containing sulphur are burned. It contributes to acid deposition, the impacts of which can be significant: adverse effects on aquatic ecosystems in rivers and lakes, and damage to forests. Sulphur dioxide can also aggravate asthma conditions, reduce lung function and inflame the respiratory tract. SO_2 also contributes to the formation of particulate matter (PM) in the air. 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 and can lead to health problems and premature mortality.

Nitrogen oxides (NO_x)

NO_x are emitted during fuel combustion, from sources such as industrial facilities and the transport sector. As with SO_2, NO_x contribute to acid deposition but also to eutrophication of soil and water. Of the chemical species that NO_x comprises, it is nitrogen dioxide (NO_2) that is associated with adverse effects on health: high concentrations cause inflammation of the airways and reduced lung function, increasing susceptibility to respiratory infection. NO_x also contribute to the formation of secondary inorganic PM and tropospheric (ground-level) O_3 with associated effects on human health and climate.

Non-methane volatile organic compounds (NMVOC)

NMVOC, 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 NMVOC are emitted by vegetation, with amounts dependent on the species and on temperature.

Ammonia (NH_3)

NH_3, like NO_x, contributes to both eutrophication and acidification and can also form secondary PM in the atmosphere following its release. The vast majority of NH_3 emissions — around 94 % in Europe — are generated by the agricultural sector, in connection with activities such as manure storage, slurry spreading and the use of synthetic nitrogenous fertilisers.

Ground-level ozone (O_3)

O_3 forms in the atmosphere as a result of complex chemical interactions between precursor pollutants, including NO_x and NMVOC. It harms human health, irritating the eyes, nose, throat and lungs, as well as potentially harming throat and lung tissue: this leads to decrease in lung function, respiratory symptoms, such as coughing and shortness of breath, aggravated asthma and other lung diseases. It can also lead to premature mortality. O_3 also harms vegetation, damaging vegetation by injuring leaves, reducing photosynthesis, impairing plant reproduction and growth, and decreasing crop yields. O_3 damage to plants can alter ecosystem structure, reduce biodiversity and decrease plant uptake of carbon dioxide (CO_2). O_3 is a greenhouse gas contributing to warming of the atmosphere.

The analysis was therefore conducted by using the same scientific methods of 2000 (original knowledge) and 2010 (present knowledge) that were, and continue to be used to support European air pollution abatement policies. Concerning the interim environmental objectives addressing ozone, only the response functions as defined in the 2001 NEC Directive were considered.

Achievement of the interim objective for acidification

The NEC Directive's 2010 objective for the protection of sensitive ecosystems from acidification is that areas where critical loads of acid deposition are exceeded should have been reduced by at least 50 % (in each grid cell) compared with the 1990 situation.

An assessment based upon 'original' knowledge shows that the 2010 interim objective has been achieved in the vast majority of grid cells i.e. the area at risk of acidification is reduced by more than 50 % in comparison to 1990 in all Member States, except for one grid cell located in northern Germany (Map ES.1). However, this is only the case when the original average deposition modelling approach is employed to assess attainment.

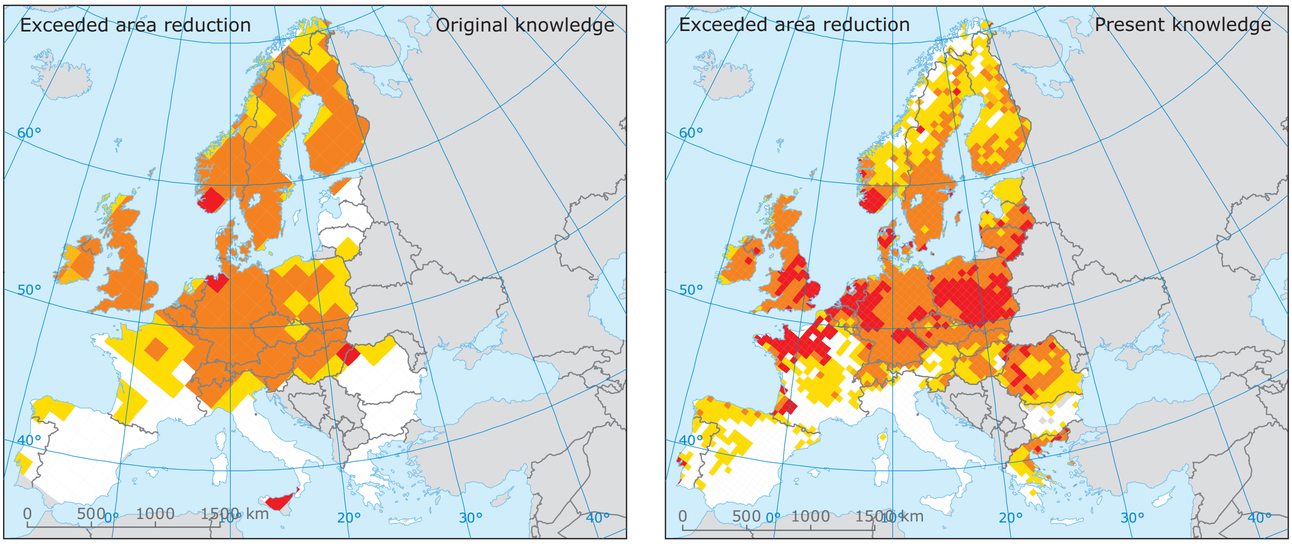
When 'present' knowledge is applied, many grid cells across a large number of EU Member States indicate areas that do not meet the NEC Directive's interim objective for acidification (Map ES.1). Use of the present critical loads exceedances approach involving determination of ecosystem specific effects, which incorporates higher deposition rates to forests, increases the number of grid cells that do not meet the acidification objective.

Achievement of the objective for eutrophication

The eutrophication objective under the NEC Directive is that the area with depositions of nutrient nitrogen in excess of the critical loads is reduced by about 30% in 2010 compared to 1990.

When considering the European Union area as a whole, as stipulated in the NEC Directive, an assessment performed on the basis of 'original' knowledge indicates that the area at risk of eutrophication was reduced by 34 % in the EU-27 as a whole (and by 30 % in the EU-15), thus meeting the directive's objective at European Union level. The distribution of the level of eutrophication protection naturally varies across the different

Map ES.1 Grid cells indicating where areas at risk of acidification are reduced by more than 50 % (*dark orange shading*) and where the NEC Directive objective has not been met (*red shading*), according to original (*left*) and present (*right*) knowledge



Grid cells indicating where areas at risk of acidification are reduced by more than 50% (dark orange shading) and where the NEC objective has not been met (red shading)

% reduction

Never exceeded | Not any more exceeded | Spurious exceeded | > = 50 % reduction | < 50 % reduction | Outside coverage

Member States: in 11 EU-27 Member States, less than 30 % reduction of the area at risk of eutrophication has been achieved (Map ES.2).

However, when an assessment at EU level as a whole is performed using present knowledge, the NEC Directive eutrophication objective has not been met. In this case, the computed reduction of the area at risk turns out to be smaller than 30 % (22.5 % for the EU-27, and 22.8 % in the EU-15). While acidification in sensitive European ecosystems has been reduced, eutrophication caused by atmospheric deposition of nitrogen is now recognised as a major environmental problem, especially in the context of its potential impact on biodiversity.

Achievement of the interim objective for health-related ozone exposure

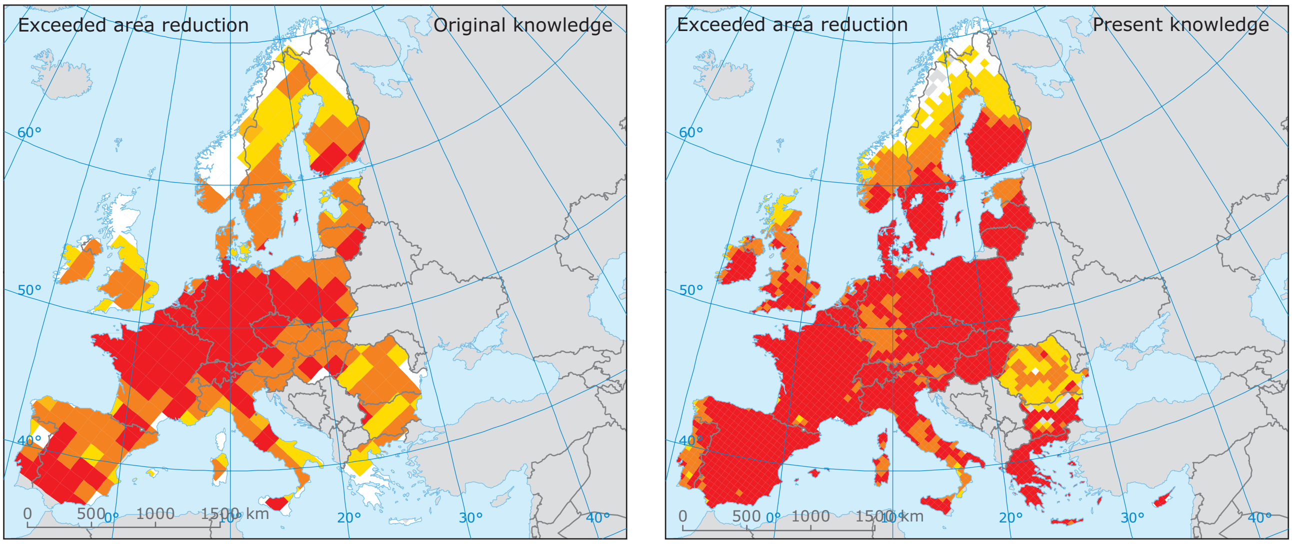
There are two objectives in the NEC Directive for ozone-related human health. Firstly, AOT60 (2) shall be reduced by two-thirds in all grid cells in 2010 compared to the 1990 situation. On the basis of 'present' knowledge, this objective has been achieved in almost the whole of Europe, except for a few grid cells in northern Italy, Portugal and Spain.

The directive also includes an objective of an upper limit for AOT60, which shall not exceed 2.9 ppm.h in any grid cell in 2010. This objective is achieved in most of Europe with the exception of northern Italy and some grid cells in the rest of Italy (Map ES.3).

Achievement of the interim objective for vegetation-related ozone exposure

As for health-related ozone exposure, the NEC Directive contains two interim objectives concerning vegetation-related ozone exposure. The first of these is a one third reduction objective for 2010 in all grid cells compared to the 1990 situation, while the second addresses the absolute concentration limits to be attained by 2010.

Map ES.2 **Grid cells indicating where areas at risk of eutrophication in 2010 are reduced by more (*dark orange shading*) and less (*red shading*) than 30 % in comparison to the 1990 situation, when using original (*left*) and present (*right*) knowledge**



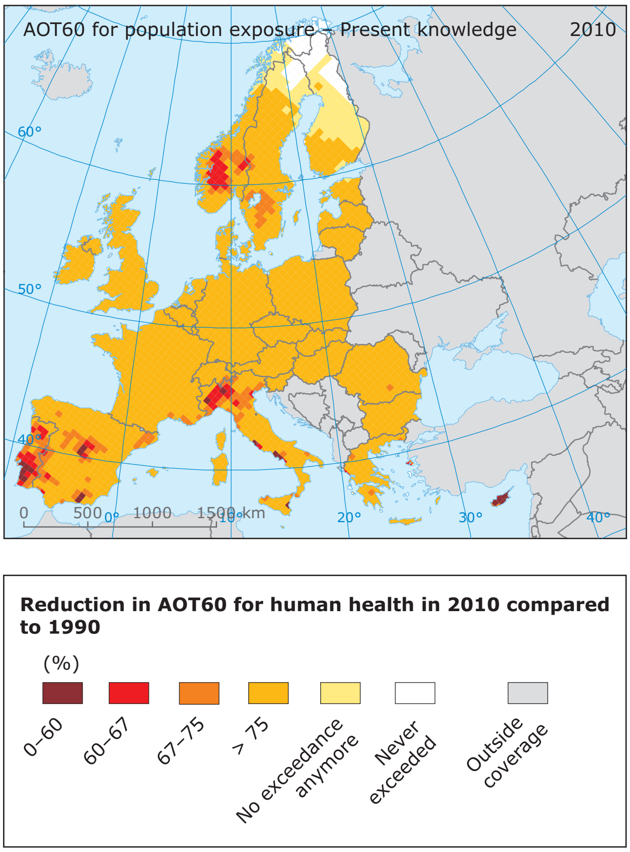
Grid cells indicating where areas at risk of eutrophication in 2010 are reduced by more (dark orange shading) and less (red shading) than 30 % in comparison to the 1990 situation

% reduction

Never exceeded	Not any more exceeded	Spurious exceeded	> = 30 % reduction	< 30 % reduction	Outside coverage

(2) AOT60. Accumulated ozone exposure over a threshold of 60 parts per billion. For the purposes of the NEC Directive, AOT60 means the sum of the difference between hourly concentrations of ground-level ozone greater than 120 µg m^{-3} (= 60 ppb) and 120 µg m^{-3} accumulated throughout the year.

Map ES.3 Reduction (%) in AOT60 for human health in 2010 compared to 1990, calculated with present knowledge



With respect to the first objective addressing the exposure of crops and semi-natural vegetation to ground-level ozone (the AOT40 ([3])), assessment is based upon AOT40. Critical AOT40 values are 3 ppm.h for crops and semi-natural vegetation, and 10 ppm.h for forests. An assessment performed using 'original' knowledge shows that the AOT40 for crops above the critical level was reduced by more than 40 % in large parts of Europe in 2010 compared with 1990 (Map ES.4). In parts of Italy and Greece, reductions between 33 % and 40 % occurred. Only in parts of Spain and Portugal is the calculated reduction in AOT40 less than 33 %. AOT40 levels are sensitive to the background concentration of ozone, for which transboundary import of an upwards trend was observed from 1990 to 2010. Without considering this trend, the objective would also have been achieved in these countries.

The objective for the AOT40 for forests is clearly not achieved in most of Europe, with the exception of Scandinavia and the United Kingdom. Although the objective for forests has not been met for a large area of the EU-27, the calculated AOT40 for forests above the critical level of 10 ppm.h has been reduced significantly in Europe from 1990 to 2010. Reductions of more than 33 % are evident in almost all of Europe.

Verification of study results with measured air quality data

There are a number of uncertainties inherent in air quality models. These include, for example, uncertainties concerning the accuracy of input data, the model's numerical performance, as well as elements such as the spatial and temporal representativeness of results. Acknowledging such uncertainties, the findings from the modelling assessments performed in this report have been compared with those from other studies where ground-level ozone measurement data were used to improve modelling results, for example, by assimilating such data directly into modelling runs. The results of the present study were also compared to ozone measurements averaged over two periods (1990 to 1992 and 2008 to 2010). Averaged values were used to take the strong influence of meteorological variability on ozone concentrations into account. In general, the observations lead to a similar conclusion as the model calculations, in that the interim objectives to reduce the excess concentration of ozone above the critical levels for crops and forests are largely met in the Member States considered in the presented analysis. However, the measurement results showed slightly lower reductions may have occurred than indicated by the model calculations. This is particularly the case for areas in southern Europe and at air quality stations located at high altitudes where small changes in ground-level background ozone concentrations are detectable.

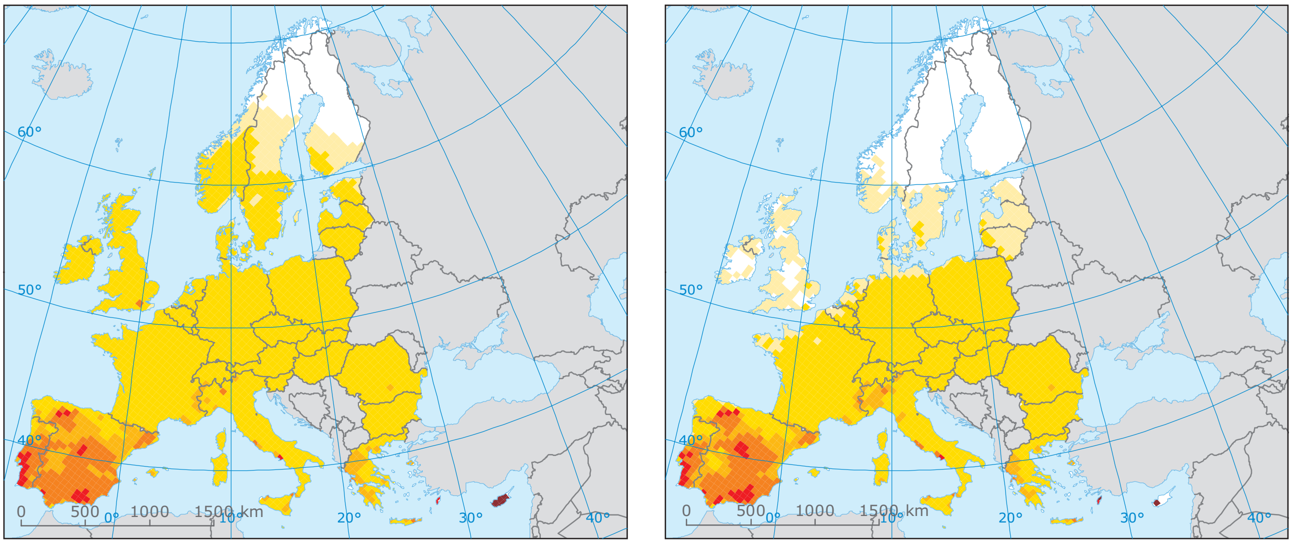
([3]) AOT40. Accumulated ozone exposure over a threshold of 40 parts per billion. For the purposes of the NEC Directive, AOT40 means the sum of the difference between hourly concentrations of ground-level ozone greater than 80 µg m^{-3} (= 40 ppb) and 80 µg m^{-3} during daylight hours accumulated from May to July each year.

Summary

The interim environmental objectives set in the NEC Directive for 2010 are broadly met — based upon an assessment performed using the original 2001 scientific knowledge. However, over the last two decades the understanding of air pollution processes and impacts has evolved. The modelling techniques used to calculate the dispersion of air pollutants in the atmosphere on the regional scale have greatly improved. The science on the impacts side has also evolved, as demonstrated by the incorporation of ecosystem specific dimensions into the assessments of critical load exceedances. Application of the latest knowledge indicates that a number of the NEC Directive's original objectives have not been achieved. Poor air quality persists in many parts of Europe.

There is therefore a clear need for further improvements to be made to protect health and the environment from the adverse effects of air pollution. The European Commission is currently reviewing the EU's air policy, and, amongst other initiatives, is expected to propose a revised NEC Directive by 2013 at the latest. A revised directive would build on the findings of the policy review, and is likely to set objectives addressing human health and the environment for 2020 and beyond, for relevant air pollutants. In the absence of new legislation, however, the NEC Directive remains in force and requires countries to keep emissions below national ceilings also in the years beyond 2010.

Map ES.4 **Percentage reduction in AOT40 for crops and semi-natural vegetation above 3 ppm.h in 2010 (*left*) and percentage reduction in AOT40 for forests above 10 ppm.h in 2010 (*right*); both compared to 1990 calculated using present knowledge on a 50 x 50 km² grid**



Percentage reduction in AOT40 for crops and semi–natural vegetation above 3 ppm.h in 2010 (left) and percentage reduction in AOT40 for forests above 10 ppm.h in 2010 (right)

Reduction in %

Increased | 0–25 | 25–33 | 33–40 | > 40 | No exceedance anymore | Never exceeded | Outside coverage

1 Introduction

Human health and the environment are both harmed 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 it leads to the corrosion and soiling of materials, including those used in objects of cultural heritage.

Within the European Union (EU), the present Sixth Environment Action Programme (6EAP) contains the long-term objective of achieving levels of air quality that do not give rise to significant negative impacts on, and pose risks to, human health and the environment. In order to improve air quality, the EU has acted at a number of levels to reduce exposure to air pollution: through legislation, through cooperation with organisations responsible for air pollution in different sectors, through national and regional authorities and non-government organisations, and through research.

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 call for both reduction of emissions at source and reduction of exposures. 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.

Progress has been made across Europe in reducing anthropogenic emissions of the main air pollutants. 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.

One of the cornerstones of the EU's air pollution policy over the past decade has been Directive 2001/81/EC of the European Parliament and the Council on National Emission Ceilings for certain atmospheric pollutants (hereafter referred to as the NEC Directive). The directive was adopted in 2001 in line with the overall approach and strategy of the Fifth Environment Action programme. This required all European citizens to be effectively protected against health risks from air pollution, and for permitted levels of pollution to take into account environmental protection.

More specifically, however, the NEC Directive defined quantitative interim environmental objectives designed to be met by 2010. These objectives (contained in Article 5 of the NEC Directive) address the following issues:

- acidification
- health-related ground-level ozone exposure
- vegetation-related ground-level ozone exposure.

The directive further contains a separate objective for eutrophication that was expected to be met through the attainment of the interim objectives. Box 1.1 provides additional details concerning the NEC Directive's quantitative objectives.

In order to meet the interim environmental objectives, the directive established a set of legally binding emission ceilings — limits to be met by 2010 and in the years thereafter — for each Member State and the European Community (as it was then known) as a whole (EU-15). These ceilings pertained to four main pollutants that contribute to acidification, eutrophication and ground-level ozone:

- emissions of sulphur dioxide (SO_2)
- emissions of nitrogen oxides (NO_X)
- emissions of non-methane volatile organic compounds (NMVOC)
- emissions of ammonia (NH_3).

The emission ceilings contained in the NEC Directive were designed to ensure that the interim objectives were met in a cost-effective manner, and moreover, allowed the Community and Member States flexibility in determining how to comply with them, i.e. by delegating to Member States the responsibility to implement emission reduction measures in the economic sectors of their choice.

The NEC Directive further requires Member States to regularly report information in order to monitor

Box 1.1 The NEC Directive's interim environmental objectives

The interim environmental objectives of the NEC Directive were set using scientific methodologies and data available until 2000 in the field of atmospheric dispersion and critical thresholds for the deposition of acidifying and eutrophying pollutants and for ambient concentrations of ground-level ozone.

Article 5 defines the interim environmental objectives of the NEC Directive as indicated below:

- **Acidification:** the areas where critical loads ([4]) of acid deposition are exceeded shall be reduced by at least 50 % (in each grid cell) compared with the 1990 situation.
- **Health-related ground-level ozone exposure:** the ground-level ozone load above the critical level ([5]) for human health (AOT60 = 0) shall be reduced by two-thirds in all grid cells compared with the 1990 situation. In addition, the ground-level ozone load shall not exceed an absolute limit of 2.9 ppm.h in any grid cell.
- **Vegetation ground-level ozone exposure:** the ground-level ozone load above the critical level for crops and semi-natural vegetation (AOT40 = 3 ppm.h) shall be reduced by one-third in all grid cells compared with the 1990 situation. In addition, the ground-level ozone load shall not exceed an absolute limit of 10 ppm.h, expressed as an exceedance of the critical level of 3 ppm.h in any grid cell.

Besides these interim objectives, footnote 1 of Annex I to the NEC Directive addresses eutrophication: 'These national emission ceilings are designed with the aim of broadly meeting the interim environmental objectives set out in Article 5. Meeting those objectives is expected to result in a reduction of soil eutrophication to such an extent that the Community area with depositions of nutrient nitrogen in excess of the critical loads will be reduced by about 30 % compared with the situation in 1990 …'

progress and verify compliance. These obligations included the development of national programmes, by 1 October 2002, that addressed the progressive reduction of their annual national emissions. These were updated and revised in 2006. In addition, Member States must prepare and report national emission inventories and emission projections for SO_2, NO_X, NMVOC and NH_3 to the Commission and the European Environment Agency (EEA) each year by 31 December at the latest.

1.1 Study objectives

The aim of the current assessment is to analyse the extent to which the NEC Directive's interim environmental and health objectives for the year 2010 have been achieved. The basis for the modelled assessment is the emission inventory data for the year 2010 as submitted by the EU Member States in the early months of 2012. This study also assesses the extent to which the reduction of soil eutrophication in accordance with the directive's Annex I footnote has been achieved.

To ensure objectivity, any assessment of the success of specific policy objectives should be based upon the same tools and approaches that were used in their original definition. However, scientific knowledge concerning air pollution and its impacts has developed significantly over the past decade since the NEC Directive was agreed. These developments mean that a more nuanced analysis is needed of whether the objectives of the directive have been met:

- more complete and improved emission inventories for the base year (1990) are now available;
- the scientific knowledge on environmental and health impacts has improved, e.g. development of ecosystem-specific critical loads;

([4]) A critical load in the NEC Directive is defined as 'a quantitative estimate of an exposure to one or more pollutants below which significant adverse effects on specified sensitive elements of the environment do not occur, according to present knowledge'. This definition applies to different receptors: terrestrial, 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 also been used extensively within the United Nations Economic Commission for Europe (UNECE) Long-range Transboundary Air Pollution Convention (UNECE, 1979), to take into account acidification of surface waters and soils, effects of eutrophication, and ground-level ozone. Technical details of critical loads are available in UNECE, 2004.

([5]) The NEC Directive defines a critical level as 'the concentration of pollutants in the atmosphere above which direct adverse effects on receptors, such as human beings, plants, ecosystems or materials, may occur, according to present knowledge'.

- the air pollution dispersion modelling approach used by the European Monitoring and Evaluation Programme (EMEP) ([6]) to calculate the impacts of air pollution has changed (from a Lagrangian regional air quality model to a Eulerian one (Box 1.2)); and,
- the level of detail of the air pollution modelling computations has improved, with results now available on a 50 x 50 km grid cell basis, as compared to the 150 x 150 km grid used at the time of determining the NEC Directive ceilings and interim objectives.

In performing an assessment of progress made in reducing harm caused by air pollution, such advances in scientific knowledge should clearly not be disregarded: these allow a more accurate picture to be obtained than by using the original techniques alone.

This report therefore employs two approaches in assessing the progress achieved toward meeting the interim environmental objectives of the NEC Directive, by performing assessments based as far as feasible upon:

- the year 2000 knowledge base, i.e. 'original' knowledge;
- the latest scientific knowledge, i.e. 'present' knowledge.

In addition, and as a verification of the presented modelling results for ozone, air quality monitoring data are used to inform upon the attainment of the NEC Directive's interim environmental objectives.

1.2 Assessment based upon 'original' knowledge

The original knowledge assessment was carried out based upon the state of scientific knowledge at the time of negotiating the NEC Directive. More specifically, the frame of reference expressed in the directive's text as 'the situation in 1990' was originally based on an integrated assessment of:

- 2001 estimates of historical emissions for 1990 and the-then projections for 2010;
- a dispersion model version available in 2001 that computed average depositions and

Box 1.2 Regional air quality models

Regional air quality models or chemical transport models (CTMs) describe the functional relation between emissions and concentration or deposition of air pollutants. The change over time of a concentration of species in a certain grid cell volume is described by the (changes in) mean wind speed, turbulent dispersion, chemical and physical transformation, dry and wet deposition, and emissions.

The required input for these models are the meteorological conditions, land use and land cover to determine the dry deposition of pollutants to the Earth's surface (i.e. the amount not deposited 'wet' via rain, snow, etc.). The anthropogenic, biogenic (e.g. isoprene) and — as far as possible — other and natural emissions (e.g. desert dust) also constitute important inputs. Furthermore, regional scale models, centred over Europe for example, need boundary conditions at the lateral and upper boundaries of the model domain. Thus, these models contain in principle the most relevant processes needed to calculate the concentration and deposition fields of pollutants regulated in the EU's legislation, i.e. in the NEC Directive and Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (the Air Quality Directive) (EC, 2008).

Most regional models are so-called 3D Eulerian grid models. The model applied in the current study to provide results based upon present knowledge is the Eulerian version of the EMEP model (Tarrasón et al., 2003). Eulerian grid models calculate concentrations and deposition based on a solution of advection diffusion equations and chemical equations. These models may have complex chemical schemes.

For the assessment based upon original knowledge, the older EMEP Lagrangian type model was applied, which does not allow distinctions between ecosystem area classifications (EMEP, 1998; EEA, 2011; Denby, 2012).

Today, the resolutions of regional air quality models are generally 50 x 50 km^2 or less. Currently around 10 x 10 km^2 is the highest feasible grid resolution for calculating concentrations and deposition across all of Europe for the time scale of (usually) a year.

([6]) Cooperative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe under the LRTAP Convention.

concentrations on 150 × 150 km^2 grid cells, focusing on 15 (instead of the current 27) EU Member States;

- the European critical load database of 1998 that addressed mostly terrestrial ecosystems, with an emphasis on forest soils as well as aquatic ecosystems (see Box 1.3).

This is the same knowledge base that was used in support of the 1999 Gothenburg Protocol 'to abate acidification, eutrophication and ground-level ozone' under the Convention on Long-range Transboundary Air Pollution (LRTAP) (UNECE, 1999).

In this present report, the original knowledge upon which the assessment is based comprises:

- the emission estimates for the year 1990 that were available in the year 2000, but with updated emissions inventory data recently reported for the year 2010;
- the previous Lagrangian EMEP air quality dispersion model that computed average depositions and concentrations;
- a 150 x 150 km^2 grid size; and,
- the critical loads and level approaches as applied in 2000.

On that basis, using the old emissions inventory data, the sulphur as well as the nitrogen (NO_X and NH_3) depositions have been calculated, as well as the critical loads exceedances and exceeded areas. The situation in 2010 was assessed using the original approaches, but with emissions inventory data for 2010 as reported recently by EU Member States. The results of this assessment show, based on the latest emission inventory data, the extent to which the interim targets have been met on the basis of the model knowledge base of the year 2000.

1.3 Assessment based upon 'present' knowledge

The 'present knowledge' assessment reflects the latest state of scientific knowledge. This includes:

- updated emissions inventory data reported in early 2012 for the years 1990 and 2010;
- the Eulerian EMEP air quality dispersion model that computes ecosystem-specific depositions;
- a 50 x 50 km^2 grid size; and,
- the current (ecosystems-based) critical loads approach that distinguishes between ecosystems following the European Nature Information System (EUNIS) (Davies, 1999) and improved critical loads for 2008, of nitrogen in particular (Box 1.3).

The sulphur and nitrogen (NO_X and NH_3) depositions have been calculated. Acidifying and eutrophying depositions were then compared to critical loads of acidity and nutrient nitrogen respectively. This establishes the location of grid cells and semi-natural areas in each Member State in which critical load values are exceeded, as well as the magnitude of these exceedances.

To minimise the impacts of varying meteorological conditions, for both the original as well as present

Box 1.3 Past and present critical loads

The European critical load database of 1998 was used to inform negotiations of the NEC Directive and the LRTAP Convention's Gothenburg Protocol, while the 2008 database is used for the review and revision of both policy agreements. The 1998 database of critical loads (de Smet and Posch, 1999) was improved in 2008 (Slootweg et al., 2008). These improvements reflected updated information submitted by 12 EU Member States, and first-time submissions by Romania and Slovenia. Critical loads for other Member States that did not submit critical loads data to the 2008 database were computed using European background information (Reinds et al., 2008). The update was necessary for a number of reasons, including the need to increase the resolution of mapped critical loads to 50 x 50 km^2 grid cells of EUNIS classes.

Compared to the European background information used in 1998, which only covered forest ecosystems (EUNIS class G), semi-natural vegetation (EUNIS classes D, E and F) is now also included. This leads to a broader range of critical loads for nitrogen in particular, based on a range of critical acceptable nitrogen concentration in the soil solution that varies between 0.2 g N m^{-3} and 0.3 g N m^{-3}, on the precautionary side. The European critical load database contains about 1.5 million critical load data points in both the 1998 and the 2008 database.

knowledge assessments, calculations have been based on the mean of the years 1996 through 1998, 2000 and 2003.

For ozone calculations, only results using the most recent EMEP Eulerian model are available. In contrast to the assessment for acidification, a slightly different approach is applied. AOT40 for crops and forests and AOT60 for human exposure have been calculated for 1990 as well as 2010 only on the basis of 'present knowledge' as defined above. However, results of calculations on the basis of original knowledge are available from older studies (e.g. Amann et al., 1999). These earlier results are therefore compared to the present knowledge calculations performed in this study. Updates of the response functions for the impact of ozone on vegetation (UNECE, 2010) have not been considered. In considering the latest scientific knowledge concerning vegetation ozone exposure, it should also be noted that, at present, ozone impacts on vegetation are better modelled by fluxes of ozone into stomatal openings of vegetation (Mills et al., 2011). Since such fluxes were not modelled with the original Lagrangian model, this approach was not considered here.

Another difference concerning the calculations for acidification is that the assessment could only be based on meteorological conditions for a single year — 2008. However, this is considered to be a rather representative weather year for Europe, not exhibiting extreme conditions.

2 Changes in knowledge about air pollutant emissions since 1990

2.1 Member State progress in meeting the 2010 NEC Directive emission ceilings

Under the NEC Directive, Member States are obliged, by 2010, to meet 'ceilings' for four important air pollutants, NO_X, NMVOC, SO_2 and NH_3 (Box ES.1). Each year, the EEA publishes an assessment of progress toward meeting these emission ceilings, based upon the information officially submitted by Member States under the requirements of the NEC Directive. The most recent report, summarising information reported at the end of 2011, was published in June 2012 (EEA, 2012a).

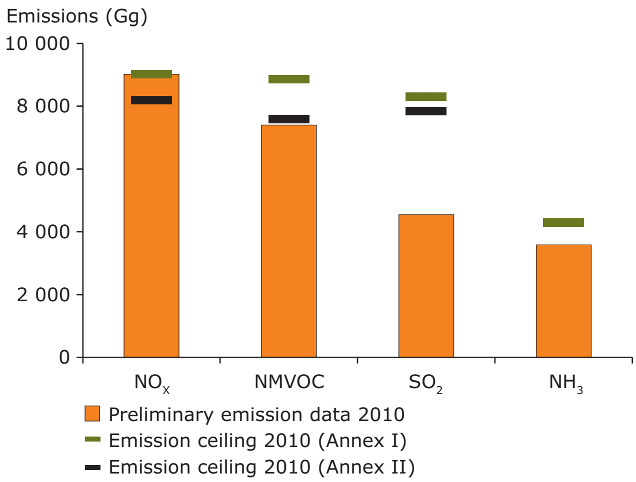
Based on the official preliminary data for 2010 reported by Member States for the first time, the annual NEC Status report showed 12 EU Member States exceeded one or more ceilings under the NEC Directive in 2010. Final emissions data for 2010 will be reported by countries at the end of 2012.

NO_X limits were exceeded most frequently, with 12 Member States failing to keep emissions below agreed ceilings (Table 2.1). These were Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Malta, the Netherlands, Spain and Sweden. In contrast, significant reductions of SO_2 emissions have occurred in the last decades. SO_2 emissions in the EU were more than 40 % below the EU's ceiling for this pollutant, and no Member States exceeded their SO_2 ceiling. Spain was the only Member State to report exceedances of three of its four emission ceilings (NO_X, NMVOC, NH_3), followed by Germany (NO_X, NMVOC) and Finland (NO_X, NH_3) with two exceedances each (EEA, 2012a).

The EU also has emissions ceilings under the NEC Directive: one is the sum of the individual Member States' ceilings for each pollutant, while the second is a stricter, specific ceiling for the EU as a whole. Of these, the two EU ceilings for NO_X were both exceeded, albeit the former by only a small margin (Figure 2.1).

Given that many Member States, and the EU as a whole, have not met the NEC Directive's emission ceilings on the basis of the preliminary emissions data reported for 2010, assessing the extent to which the interim environmental objectives of the directive have been met is therefore of high relevance.

Figure 2.1 Aggregated Member State preliminary 2010 emission data compared with EU-27 emission ceilings defined in the NEC Directive Annexes I and II ([a])



Note: ([a]) Annexes I and II to the NEC Directive define aggregated emission ceilings for the EU-27. The Annex I EU-27 ceilings represent the aggregation of individual Member State ceilings defined in that annex. The Annex II EU-27 ceilings are stricter than those of Annex I and are designed with the aim of attaining, by 2010, for the European Union as a whole, the interim environmental objectives set out in Article 5 of the NEC Directive (i.e. a reduction of acidification and health- and vegetation-related ground-level ozone exposure by 2010, compared with the 1990 situation). There is no separate ceiling for NH_3 defined in Annex II to the NEC Directive.

Source: EEA, 2012a.

Table 2.1 EU Member State progress in meeting EU NEC Directive 2010 emissions ceilings

Member State	NO_x	NMVOC	SO_2	NH_3
Austria	×	✓	✓	✓
Belgium	×	✓	✓	✓
Bulgaria	✓	✓	✓	✓
Cyprus	✓	✓	✓	✓
Czech Republic	✓	✓	✓	✓
Denmark	×	✓	✓	✓
Estonia	✓	✓	✓	✓
Finland	×	✓	✓	×
France	×	✓	✓	✓
Germany	×	×	✓	✓
Greece	✓	✓	✓	✓
Hungary	✓	✓	✓	✓
Ireland	×	✓	✓	✓
Italy	✓	✓	✓	✓
Latvia	✓	✓	✓	✓
Lithuania	✓	✓	✓	✓
Luxembourg	×	✓	✓	✓
Malta	×	✓	✓	✓
Netherlands	×	✓	✓	✓
Poland	✓	✓	✓	✓
Portugal	✓	✓	✓	✓
Romania	✓	✓	✓	✓
Slovakia	✓	✓	✓	✓
Slovenia	✓	✓	✓	✓
Spain	×	×	✓	×
Sweden	×	✓	✓	✓
United Kingdom	✓	✓	✓	✓
✓	**15**	**25**	**27**	**25**
×	**12**	**2**	**0**	**2**

Notes: '✓' indicates that the preliminary emission data reported by a Member State meet or lie below its respective emission ceiling. 'x' indicates that a ceiling is not met.

Source: EEA, 2012a.

2.2 Emissions data under 'original' and 'present' knowledge

The assessments performed in this report on the basis of original and present knowledge use different sources of reported emissions information:

1. original knowledge: historical emissions for 1990 as were available in 2001, based on UNECE (2001);

2. present knowledge: updated emissions inventory data reported in early 2012 for the years 1990 and 2010:

   (a) for the EU-27 Member States, 2010 emissions data as reported under the NEC Directive reported data, available as of February 2012 (EEA, 2012a);

   (b) for the EU-27 Member States, 1990 emissions data as reported in early 2012 under the UNECE LRTAP Convention (CEIP, 2012);

   (c) for non-EU countries, emissions data for 1990 and 2010 as reported in early 2012 under the UNECE LRTAP Convention (CEIP, 2012).

An overview of the emissions data set applied for the assessment is provided in Annex 1.

Between 1990 and 2010, there were significant reductions in the reported emissions of the air pollutants regulated under the NEC Directive. SO_2 emissions have decreased the most since 1990 in percentage terms (– 82 %), followed by NMVOC (– 56 %), NO_X (– 47 %) and NH_3 (– 28 %). There are many explanatory factors contributing to the reported decreases: the introduction of climate, energy and sectoral air quality policies; emission reductions driven by the economic transition of eastern European countries; fuel switching from more polluting fuels such as coal to gas and other fuels; and improved pollution abatement technologies for large industrial facilities and road vehicles.

In addition, improved scientific knowledge has changed the emission inventory estimates. Emission inventories are now more complete than they were when the NEC Directive was agreed. This reflects improved knowledge concerning the sources of the various air pollutants, as well as the availability of higher quality emission factors. Sources of methodological guidance for national emission inventory compilers are now also greatly improved (e.g. EMEP/EEA, 2009). Table 2.2 shows the differences in the reported emissions both for 1990 and 2010 (present knowledge) and the emissions according to the NEC Directive (original knowledge).

A number of assumptions concerning the future projected levels of key economic and societal parameters were made at the time the NEC Directive's emission ceilings were agreed. Several of these trends envisaged at the time did not transpire; such discrepancies explain some of the differences between the reported emissions for 2010 and the emission ceilings for that year.

Table 2.2 EU-27 emissions for 1990 and 2010, old and present knowledge (Gg)

	NO_X	NMVOC	SO_2	NH_3
EU-27 1990 (original knowledge)	17 028	19 315	27 139	5 270
EU-27 1990 (present knowledge)	17 120	17 248	26 331	5 016
EU-27 projected 2010 (original knowledge) ([a])	9 003	8 848	8 297	4 294
EU-27 realised 2010 (present knowledge)	9 020	7 389	4 536	3 588

Note: ([a]) The projected emissions for 2010 according to original knowledge are the aggregated Member State ceilings from Annex I of the NEC Directive.

Sources: EEA, 2012a; UNECE, 2001.

Table 2.3 provides an overview of the development of certain selected economic parameters for both the EU-15 and EU-27 regions, as were originally forecast and as occurred in reality. The values for the forecasted activities are derived from Amann et al. (1999). Realised activity rates are based on recent Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) and Eurostat data.

The following observations can be made concerning the difference between the assumed development of key economic parameters and what occurred in reality.

- Population growth by 2010 in the EU-15 was 4.3 % higher than had been assumed in 1999.
- GDP in the EU-15 grew by around 2 % a year (on average), while the projections used at the time for the NEC Directive (and for the Gothenburg Protocol to the LRTAP Convention) assumed an average growth of around 2.5 %. In the EU-12 Member States, GDP growth was 0.2 % higher than the expected 2 % growth.
- The use of fossil fuels in the EU-15 increased by 7.5 % between 1990 and 2010 (EEA, 2012f). This was significantly less than the expected increase of almost 20 % as applied for the NEC Directive calculations in 1999. Note that at the time the NEC Directive was agreed, projections did not yet include the co-benefits arising from the implementation of future climate and energy policies in the EU. This may partially explain the significant difference in projected energy use.
- Agricultural developments occurred broadly as originally estimated, although the use of synthetic nitrogenous fertilisers was significantly lower in reality than was forecast for both the EU-15 and EU-27. For the EU-27 region, livestock numbers were also lower than forecast.
- The number of road vehicles in the EU-15 developed more or less along the projected figures. 'Vehicles' in this study is linked to the assessment made by Amann et al. (1999), in which these are defined as the sum of the number of passenger cars, motorcycles and light- and heavy-duty vehicles.

In addition to differences in many of the driving forces described above, each of which may affect the extent to which emissions of air pollutants are released, new scientific insights also have led to significant changes in the estimate of emissions for various sources. A more thorough analysis,

Table 2.3 Comparison of development in selected parameters affecting emissions: originally forecast for 2010, and realised in actuality

Parameter		EU-15 (2010)	EU-27 (2010)
Population (million)	Forecast (a)	383.0	488.8
	Realised (b)	399.3	502.1
	% difference	4.3 %	2.7 %
Energy use (PJ)	Forecast (a)	65 141	79 815
	Realised (c)	44 802	54 150
	% difference	– 31.2 %	– 32.2 %
Vehicle numbers (million)	Forecast (a)	255 861	290 464
	Realised (d)	260 641	308 229
	% difference	1.9 %	6.1 %
Cattle numbers (million)	Forecast (a)	82.9	112.6
	Realised (c)	76.0	88.6
	% difference	– 8.3 %	– 21.3 %
Swine numbers (million)	Forecast (a)	106.9	167.8
	Realised (c)	118.2	143.8
	% difference	10.6 %	– 14.3 %
Poultry numbers (million)	Forecast (a)	1 054	1 524.3
	Realised (c)	1 177	1 485
	% difference	11.7 %	– 2.6 %
Synthetic fertiliser use (kt N)	Forecast (a)	9 515	13 633
	Realised (c)	7 490	9 647
	% difference	– 21.3 %	– 29.2 %

Sources: (a) Amann et al., 1999; (b) Eurostat; (c) EEA, 2012f; (d) European Commission, 2012.

which is outside the scope of this study, would be necessary to draw detailed conclusions regarding the development of original versus present emissions on the basis of insights in activity data and emission factors. Nevertheless, the following examples illustrate some key instances in which new knowledge has led to significant revision of emission estimates.

- **NO_X emissions from road transport higher than foreseen under real operating conditions:** In order to improve air quality, the pollutant exhaust emissions of road vehicles are limited by regulation. Regulatory limits apply to exhaust emission measurements during vehicle type approval procedures with the New European Driving Cycle (NEDC). Over the last three decades, limit values were lowered in steps from EURO 0 to EURO 5. Further steps have already been defined for the coming years (EURO 6). Air quality, however, has not improved as much as predicted on the basis of the tightening of emissions standards, especially with respect to nitrogen oxides (NO_X). One reason for this is the gap between the performance of emission control measures during type approval tests (NEDC) and their effectiveness under real-life urban driving conditions.

- **Inclusion of additional (new) sources, e.g. NO_X from agriculture:** In agriculture, new sources of NO_X were distinguished, such as NO_X emissions from manure on soils and in storage, and methods were developed to allow their estimation.

- **NMVOC cold-start emissions:** Engine emissions can be distinguished into those produced during thermally stabilised engine operation (so-called 'hot' emissions), and emissions occurring during engine start from ambient temperature (cold-start and warming-up effects). For the latter, NMVOC emissions have turned out to be different than originally estimated.

3 Achievement of the interim objective for acidification

NEC Directive, Article 5(a): 'Acidification: the areas where critical loads of acid deposition are exceeded shall be reduced by at least 50 % (in each grid cell) compared with the 1990 situation'.

3.1 Acidifying substances: differences between 'original' and 'present' dispersion modelling

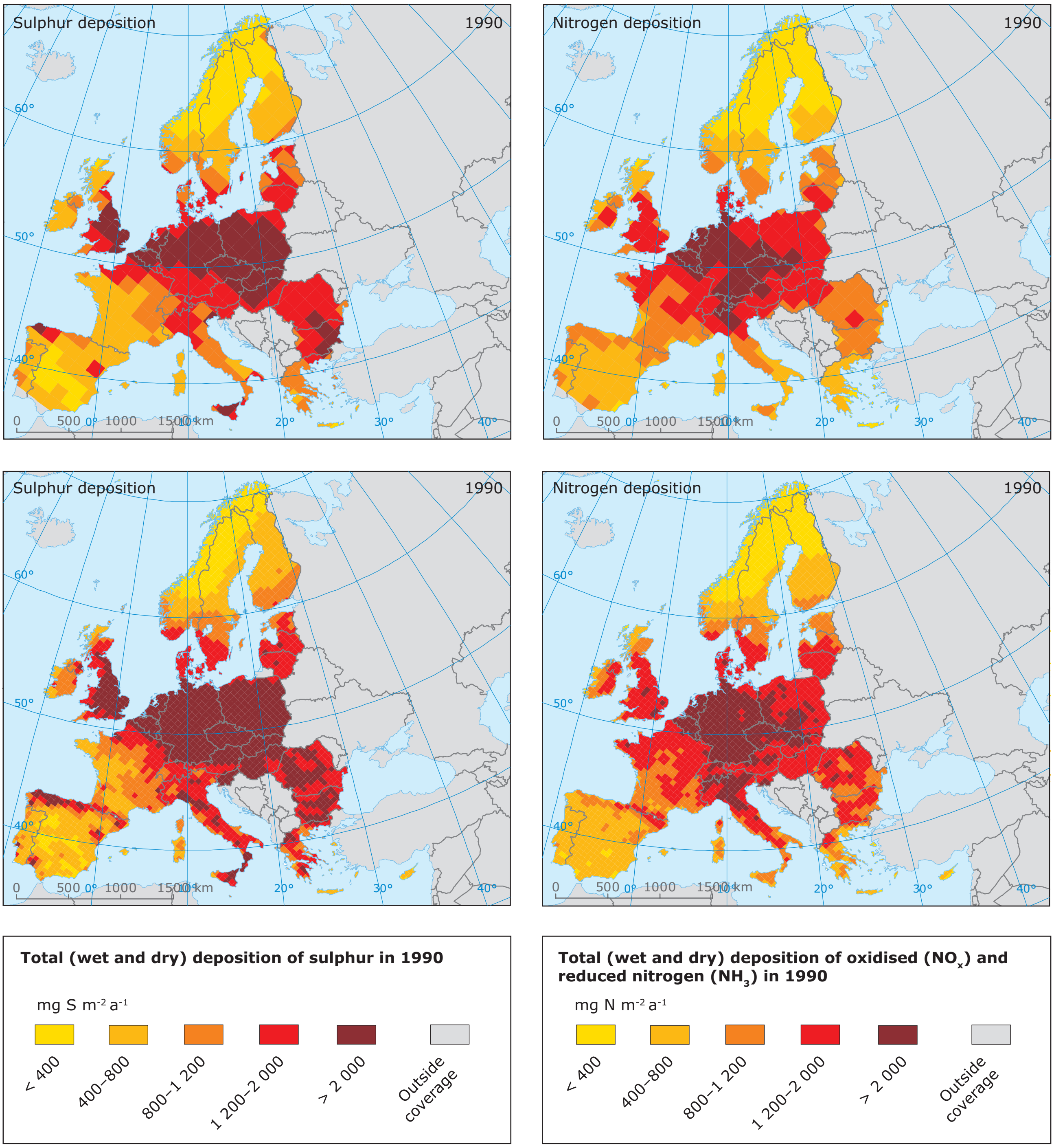
In 2000, the single layer Lagrangian model (EMEP, 1998) was used to calculate average depositions and ambient concentrations in grid cells of 150 x 150 km^2. This model did not allow distinctions between different ecosystem area classifications; deposition was then being computed as an average over the whole grid cell using a 12-year average meteorology (1980–1991). This has been replaced by the more sophisticated multilayer EMEP Eulerian (unified) model (Tarrasón et al., 2003), using a 5-year average meteorology (1996–1998, 2000, 2003). This model is used to establish relationships between European country emissions and specific ecosystems (forests, open land, etc.) in 50 x 50 km^2 grid cells covering Europe.

Map 3.1 compares the deposition in 1990 of sulphur and of reduced and oxidised nitrogen computed with both the Lagrangian model of 1998 and the present Eulerian model. It can be seen that higher resolution receptor grid cells and ecosystem-specific deposition as included in the Eulerian model reveal broader areas of high deposition, particularly for nitrogen, including northern Spain, Italy and eastern Europe.

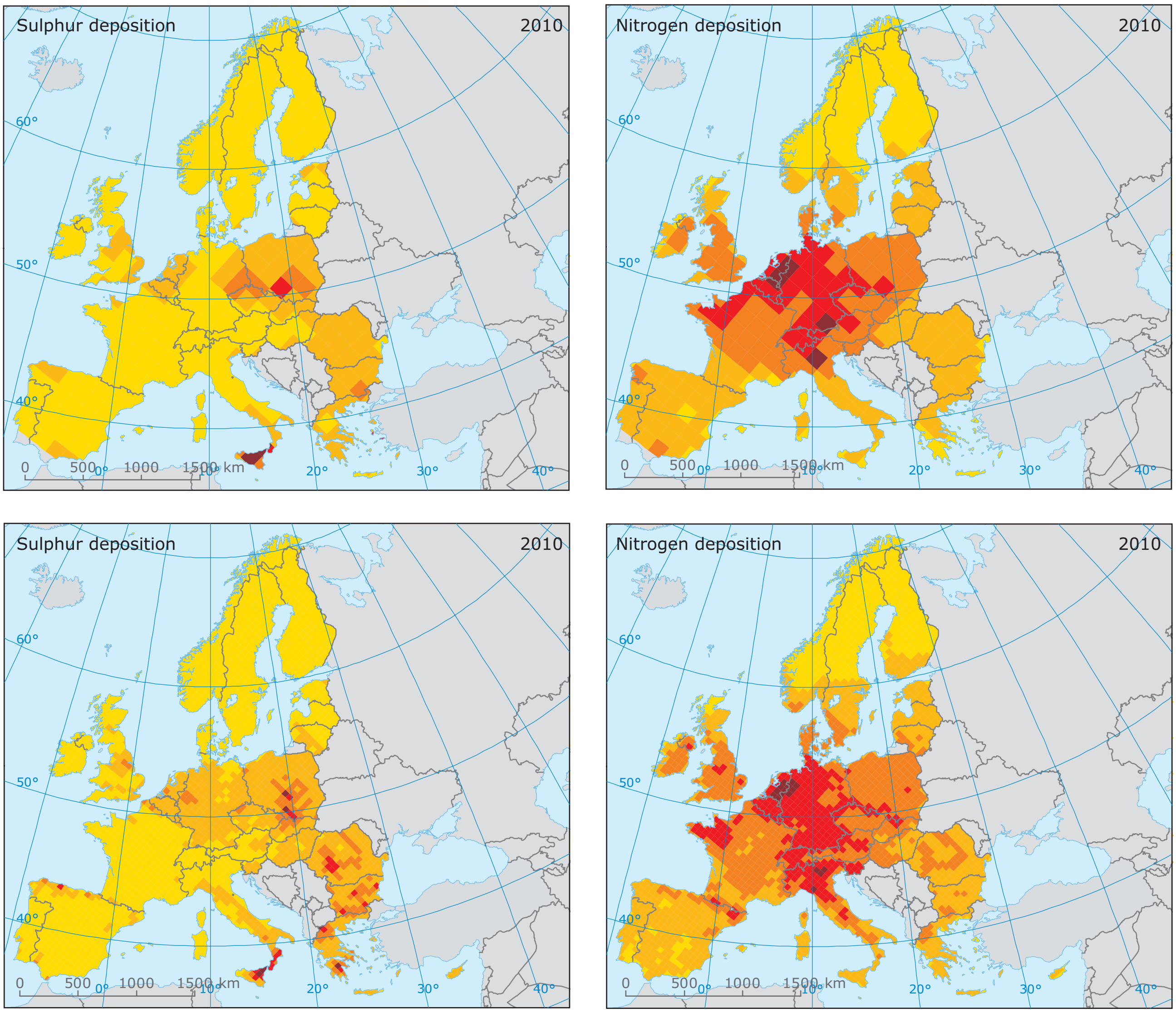
Map 3.2 shows a similar comparison for 2010. Compared to the results of the original Lagrangian model, the present Eulerian model computes depositions of sulphur in the range of 400 milligrams to 800 milligrams sulphur per square metre and year (mg S $m^{-2} a^{-1}$) (yellow) over Germany and Italy, while peaks are identified in the Balkan region and Romania.

Note that in both Map 3.1 and Map 3.2, the application of the present Eulerian model instead of the Lagrangian model does not diminish the magnitude of the depositions.

Map 3.1 **Total (wet & dry) depositions of sulphur (*left*) and total oxidised and reduced nitrogen (*right*) in 1990, computed using the EMEP Lagrangian model from 2000 (*top*) and the current EMEP Eulerian model (*bottom*)**



Map 3.2 **Total (wet & dry) depositions of sulphur (*left*) and total oxidised and reduced nitrogen (*right*) in 2010, computed using the original EMEP Lagrangian model (*top*) and the current EMEP Eulerian model (*bottom*)**



Total (wet and dry) deposition of sulphur in 2010

mg S m^{-2} a^{-1}

< 400 | 400–800 | 800–1 200 | 1 200–2 000 | > 2 000 | Outside coverage

Total (wet and dry) deposition of oxidised (NO_x) and reduced nitrogen (NH_3) in 2010

mg N m^{-2} a^{-1}

< 400 | 400–800 | 800–1 200 | 1 200–2 000 | > 2 000 | Outside coverage

3.2 Exceedances of critical loads for acidification

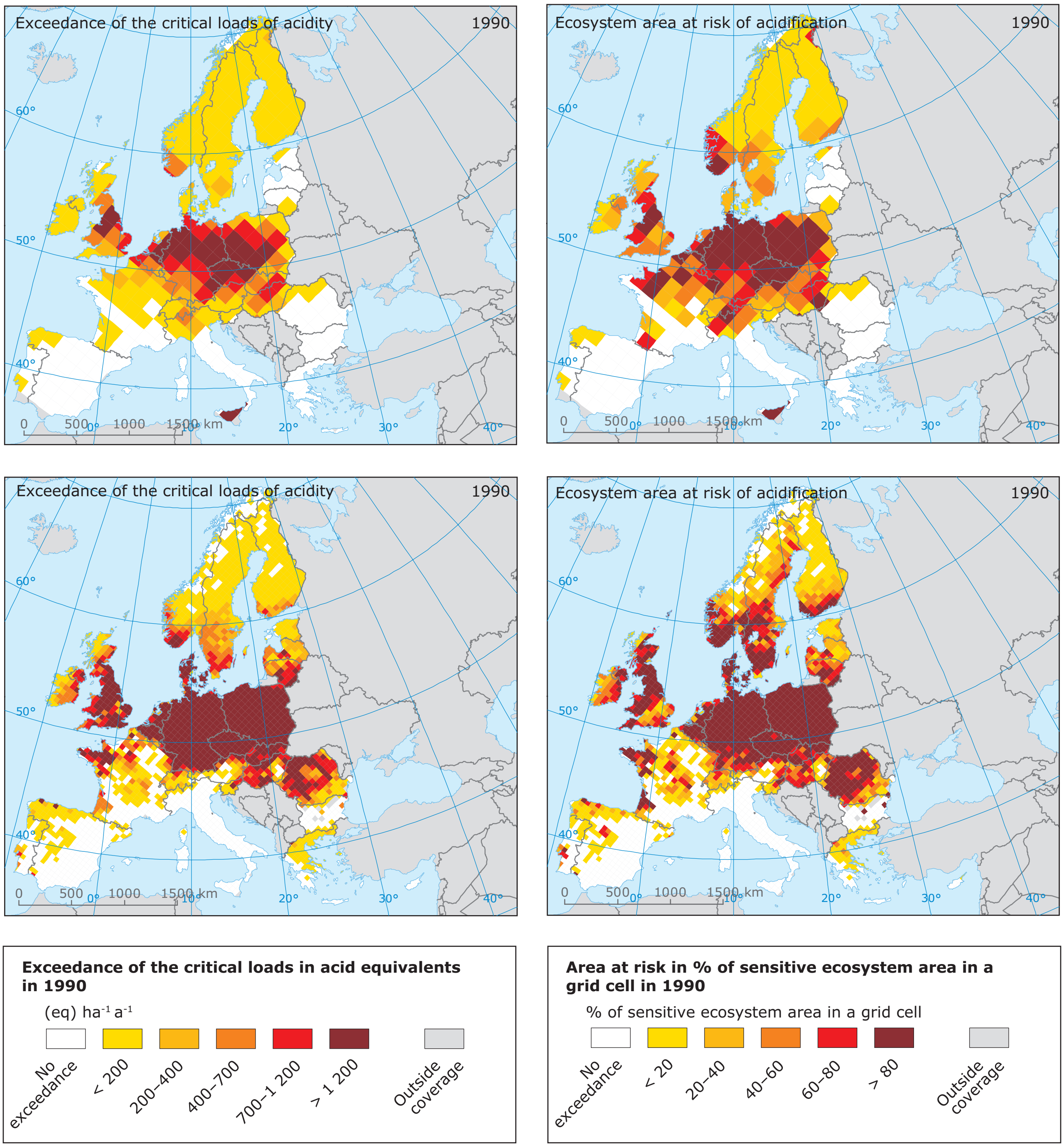
Deposition values higher than a critical load, as included in the 1998 and 2008 critical loads databases, are defined as an exceedance. Exceedances can be computed for each critical load data point in a grid cell. An 'average accumulated exceedance' (AAE) (Posch et al., 2001) can be computed for an ecosystem, grid cell and any region or country for which multiple critical loads and deposition values are available. In this study, the AAE is defined as the **area-weighted average** of exceedances (accumulated over all ecosystem points) in a grid cell. The AAE concept has been used for all previous modelling exercises in relation to the 2001 NEC Directive implementation and within the framework of its present review.

Map 3.3 (left) illustrates the distribution of the AAE magnitudes of the critical loads for acidification in acid equivalents per hectare and year (eq ha^{-1} a^{-1}). In addition, the area where critical loads are exceeded are shown as a percentage of the total natural (EUNIS) area in each grid cell (Map 3.3, right).

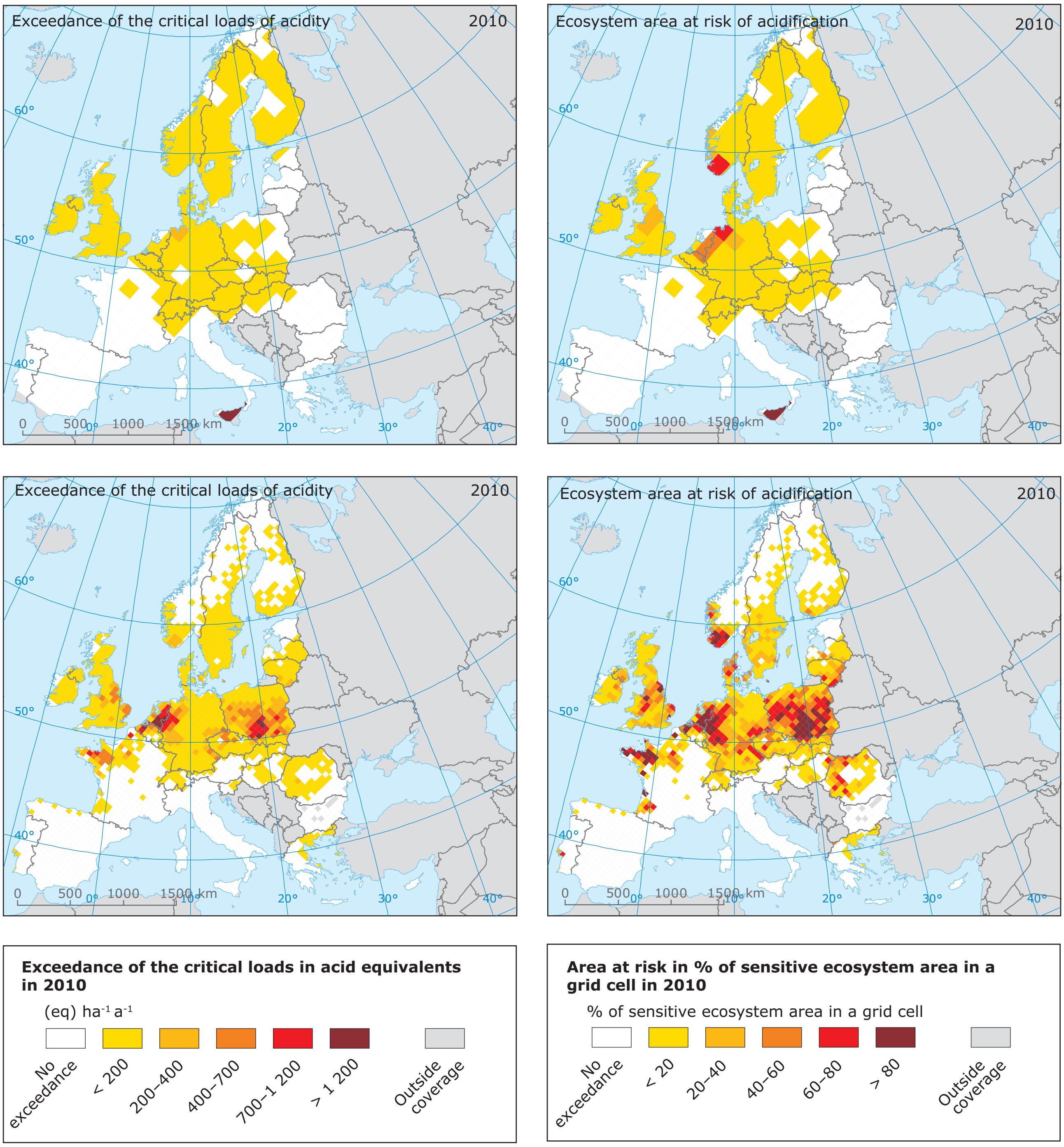
Map 3.3 further illustrates that exceedances computed for 1990 with the present Eulerian model combined with the 2008 critical loads database reveal a broader area at risk and with higher exceedances, extending to eastern Europe in particular, compared to the analysis performed using 'original' knowledge.

Map 3.4 shows results for the equivalent 2010 calculations on the basis of the original and present knowledge. A comparison with the respective 1990 results indicates that by 2010, the risk of acidification is markedly reduced, both in terms of magnitudes and areas at risk, as compared to 1990. However, grid cell locations where the area at risk of acidification (Map 3.4, bottom right) continue to exist (i.e. the non-grey shaded areas) are found in many of the western and central European Member States.

Map 3.3 Exceedance (eq ha^{-1}a^{-1}) of critical loads of acidity (*left*) and the area (% of sensitive ecosystem area in a grid cell) at risk of acidification (*right*) in 1990, computed using the original Lagrangian model combined with the 1998 critical load database (*top*) and the present Eulerian model combined with the 2008 critical load database (*bottom*)



Map 3.4 **Exceedance (eq ha^{-1}a^{-1}) of the critical loads of acidity (*left*) and the areas (% of sensitive ecosystem area in a grid cell) at risk of acidification (*right*) in 2010, computed using the original Lagrangian model combined with the original 1998 critical load database (*top*) and the present Eulerian model combined with the 2008 critical load database (*bottom*)**



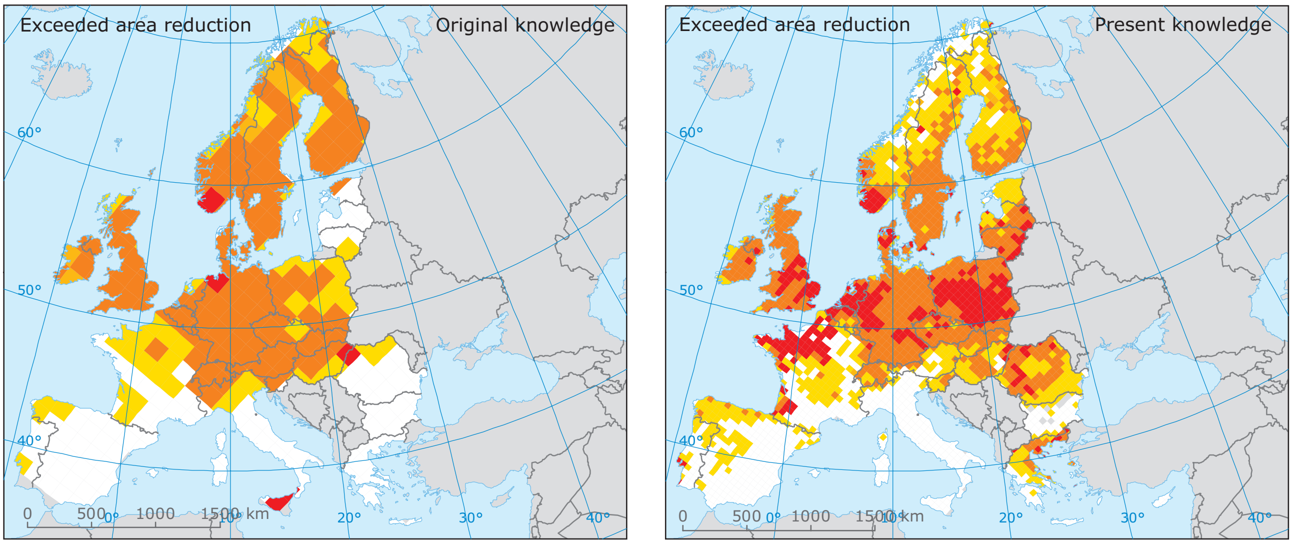
3.3 Has the 2010 acidification objective been met?

Map 3.5 shows the locations of the grid cells where the reduction of the areas at risk of acidification is reduced by more than 50 % (dark orange shading) as required under the NEC Directive. Yellow shading indicates grid cells where the critical loads are no longer exceeded. Light orange shading indicates that the percentage reduction is too small, relative to uncertainties, to allow an accurate comparison between 1990 and 2010.

Map 3.5 illustrates that the use of original knowledge to assess the NEC Directive's acidification target reveals only one grid cell which is in northern Germany where the area at risk of acidification is reduced less than 50 % in comparison to 1990. The grid cells in Sicily indicate a source of natural (volcanic) emissions which led to the exceedances illustrated. However, when present knowledge is applied, many grid cells across a large number of EU Member States indicate areas that do not meet the NEC Directive's interim objective for acidification.

When original knowledge on dispersion (Lagrangian model) is combined with present knowledge on critical loads (2008 critical load database), several additional grid cells do not meet the NEC Directive's target for acidification (Map 3.6, left). However, combining present knowledge on critical loads with *average* depositions computed with the Eulerian model (as opposed to ecosystem-specific depositions that the model normally utilises) diminishes the number of grid cells in excess of the NEC Directive's 2010 interim objective in comparison to Map 3.5. This is due to exceedances of critical loads in a grid cell being lower when average instead of ecosystem specific depositions are used. Computed ecosystem-specific depositions more closely reflect reality as deposition on forests is higher than on e.g. (semi-)natural grasslands.

Map 3.5 Grid cells indicating where areas at risk of acidification are reduced by more than 50 % (*dark orange shading*) and where the NEC Directive objective has not been met (*red shading*), according to original (*left*) and present (*right*) knowledge

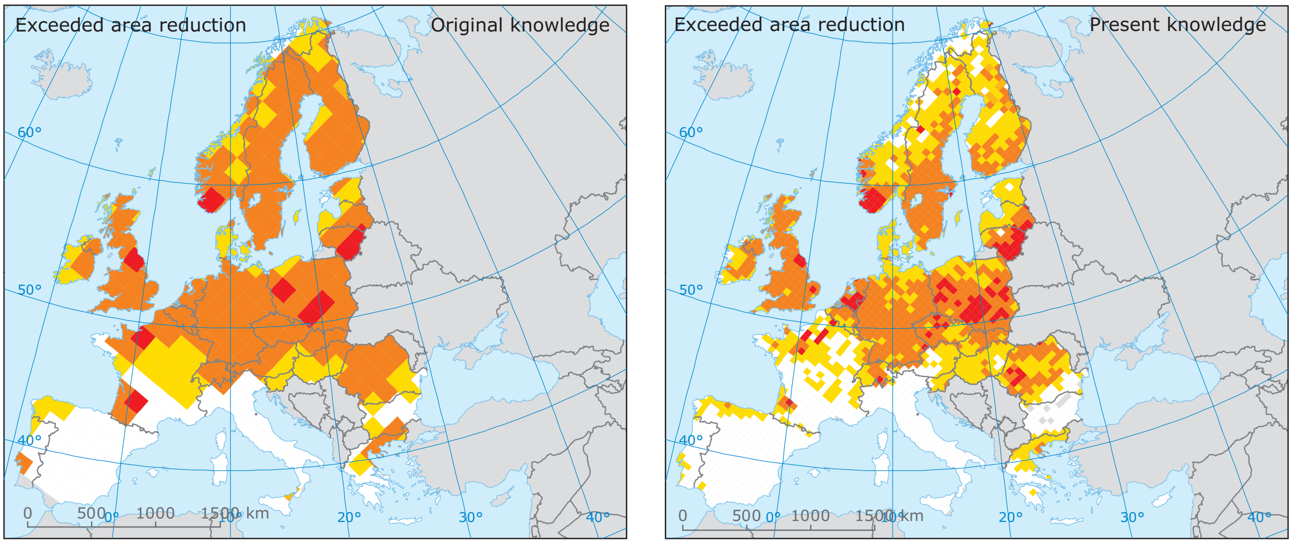


Grid cells indicating where areas at risk of acidification are reduced by more than 50% (dark orange shading) and where the NEC objective has not been met (red shading)

% reduction

Never exceeded	Not any more exceeded	Spurious exceeded	> = 50 % reduction	< 50 % reduction	Outside coverage

Map 3.6 Grid cells indicating where areas at risk of acidification are reduced by more than 50 % (*dark orange shading*) in comparison to the 1990 situation, and where the NEC Directive objective has not been met (*red shading*), when combining 2008 critical loads with the original Lagrangian model (*left*) and with average depositions computed with the present Eulerian model (*right*)



Grid cells indicating where areas at risk of acidification are reduced by more than 50% (dark orange shading) in comparison to the 1990 situation, and where the NEC Directive objective has not been met (red shading)

% reduction

Never exceeded	Not any more exceeded	Spurious exceeded	> = 50 % reduction	< 50 % reduction	Outside coverage

The general conclusion drawn from the results illustrated in Map 3.5 and Map 3.6 is that an assessment performed using original knowledge confirms that the NEC Directive target for acidification has been achieved in the vast majority of grid cells across the EU. However, this is only the case when the original average deposition approach is employed to assess attainment. Use of the present critical loads exceedances approach involving determination of ecosystem specific effects, which incorporates higher deposition rates to forests, increases the number of grid cells that do not meet the acidification objective.

Table 3.1 shows, for each Member State, the progress achieved in reducing the exceeded area for acidification. The table results show the area of exceedances in each country as a percentage of ecosystems. However, the table data do not provide information about the magnitude of the exceedance, nor of course its location. These details are provided in Map 3.4.

Table 3.1 The percentage 'exceeded area' for acidification for the EU-27 area, in 1990 and 2010, and the percentage change based on original knowledge

Member State	Total sensitive ecosystem area (km²)	Exceeded area in 1990 (%)	Exceeded area in 2010 (%)	Change (%)
Austria	35 746	41	3	– 93
Belgium	6 250	38	1	– 97
Bulgaria	48 330	0	0	–
Cyprus	2 461	53	1	– 98
Czech Republic	27 626	99	3	– 97
Denmark	3 584	19	0	– 99
Estonia	24 728	0	0	–
Finland	273 634	15	2	– 88
France	177 359	30	1	– 98
Germany	102 891	84	11	– 87
Greece	53 671	0	0	–
Hungary	20 805	60	2	– 96
Ireland	8 935	9	1	– 89
Italy	124 788	22	2	– 93
Latvia	35 823	0	0	–
Lithuania	19 018	6	0	– 100
Luxembourg	1 015	38	12	– 67
Malta	3 483	8	1	– 89
Netherlands	6 968	90	31	– 65
Poland	90 330	73	0	– 99
Portugal	31 121	0	0	– 100
Romania	97 964	1	0	– 100
Slovakia	20 532	56	8	– 86
Slovenia	–	0	0	–
Spain	187 115	1	0	– 100
Sweden	443 660	18	3	– 81
United Kingdom	81 815	46	7	– 85
EU-15	**1 538 552**	**26**	**3**	**– 89**
EU-27	**1 937 164**	**30**	**2**	**– 92**

Note: '–': not available.

4 Achievement of the eutrophication objective

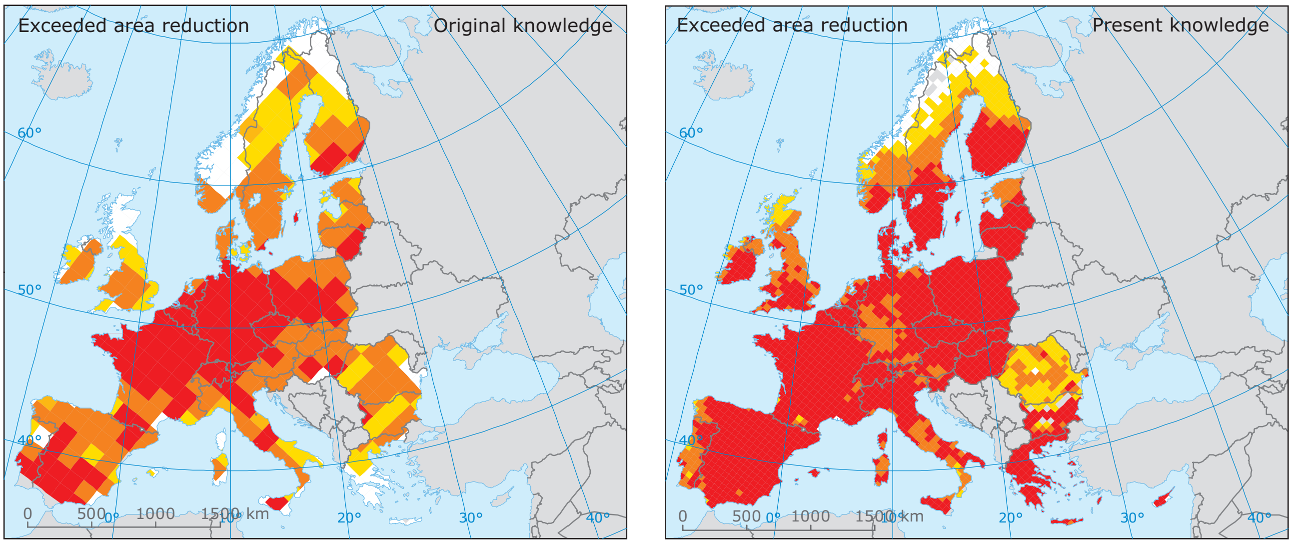
NEC Directive, Annex I (footnote 1): 'Meeting those [interim environmental] objectives is expected to result in a reduction of soil eutrophication to such an extent that the Community area with depositions of nutrient nitrogen in excess of the critical loads will be reduced by about 30 % compared with the situation in 1990'.

Footnote 1 of Annex I to the NEC Directive addresses eutrophication. To assess the risk of eutrophication, a grid-specific assessment was performed for reasons of completeness and comparability to the analysis of acidification. The assessment of the eutrophication objective in grid cells using both original and present knowledge indicates that the reduction of areas at risk of N deposition (i.e. exceeding critical loads for eutrophication) is less than 30 % in many EMEP grid cells within the EU-27 (Map 4.1). This also holds true when present knowledge on critical loads is combined with the original Lagrangian dispersion modelling, as well as when average nitrogen depositions are computed with the present Eulerian model (Map 4.2).

However, when considering the Community area as a whole as stipulated in the NEC Directive, an assessment performed on the basis of original knowledge indicates that the reduction of the area at risk of eutrophication (Table 4.1) is reduced by 34 % in the EU-27 as a whole (and by 30 % in the EU-15), thus meeting the directive's objective at European Union level. The distribution of the level of eutrophication protection naturally varies across the different Member States: in 11 EU-27 Member States, less than 30 % reduction of the area at risk of eutrophication has been achieved (Table 4.1).

However, when an assessment at EU level as a whole is performed using present knowledge, the NEC Directive eutrophication objective has not been met. In this case, the computed reduction of the area at risk turns out to be smaller than 30 % (22.5 % for the EU-27, and 22.8 % in the EU-15; this is not tabulated).

Map 4.1 Grid cells indicating where areas at risk of eutrophication in 2010 are reduced by more (*dark orange shading*) and less (*red shading*) than 30 % in comparison to the 1990 situation, when using original (*left*) and present (*right*) knowledge

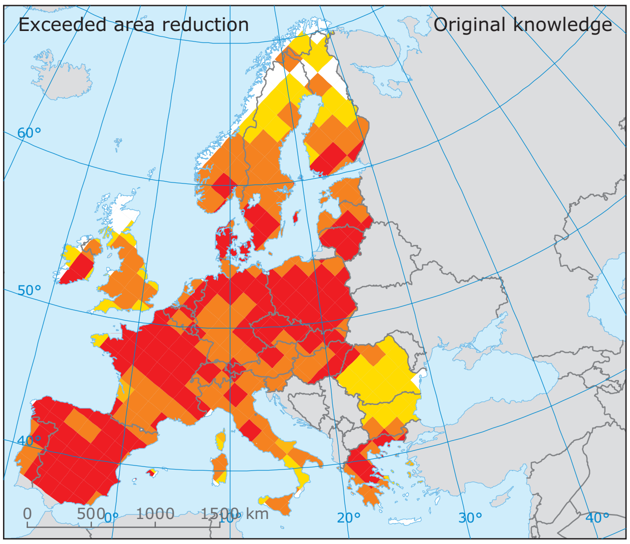


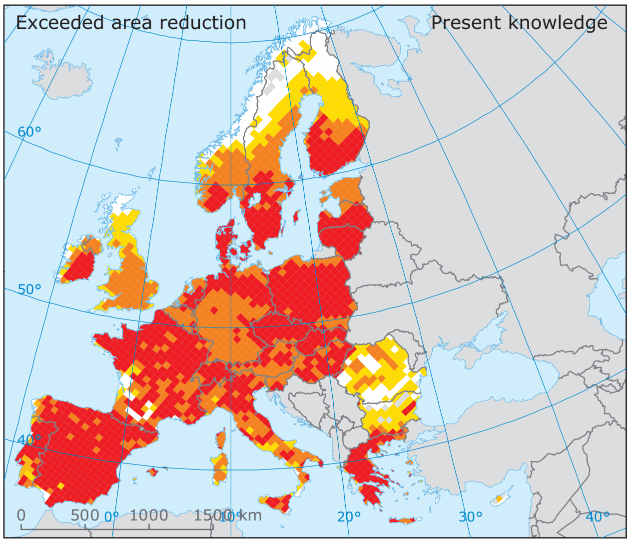
Grid cells indicating where areas at risk of eutrophication in 2010 are reduced by more (dark orange shading) and less (red shading) than 30 % in comparison to the 1990 situation

% reduction

Never exceeded	Not any more exceeded	Spurious exceeded	> = 30 % reduction	< 30 % reduction	Outside coverage

Map 4.2 Grid cells indicating where areas at risk of eutrophication are reduced by more (*dark orange shading*) and less (*red shading*) than 30 % in 2010, in comparison to the 1990 situation, when using present knowledge on critical loads in combination with original knowledge on dispersion (*left*) and with average N deposition computed with the Eulerian model (*right*)





Grid cells indicating where areas at risk of eutrophication are reduced by more (dark orange shading) and less (red shading) than 30 % in 2010, in comparison to the 1990 situation

% reduction

- Never exceeded
- Not any more exceeded
- Spurious exceeded
- > = 30 % reduction
- < 30 % reduction
- Outside coverage

Table 4.1 The percentage 'exceeded area' for eutrophication for the EU-27 area, in 1990 and 2010, and the computed change (SRMs) achieved in 2010 based on original knowledge

Member State	Total sensitive ecosystem area (km²)	Exceeded area in 1990 (%)	Exceeded area in 2010 (%)	Change (%)
Austria	40 255	87	49	– 44
Belgium	6 250	100	87	– 12
Bulgaria	48 330	73	14	– 81
Cyprus	2 461	–	–	–
Czech Republic	27 626	100	76	– 24
Denmark	3 584	69	36	– 48
Estonia	24 728	63	18	– 72
Finland	240 403	53	22	– 58
France	180 099	95	79	– 17
Germany	102 891	100	90	– 10
Greece	53 671	22	2	– 93
Hungary	20 805	38	38	– 2
Ireland	2 449	9	3	– 66
Italy	124 788	49	30	– 39
Latvia	35 823	100	21	– 79
Lithuania	19 018	100	75	– 25
Luxembourg	1 015	100	95	– 5
Malta	3 483	–	–	–
Netherlands	4 447	98	92	– 7
Poland	90 330	98	72	– 27
Portugal	31 121	50	38	– 24
Romania	97 964	41	9	– 79
Slovakia	20 532	100	46	– 54
Slovenia	–	43	31	– 26
Spain	187 115	57	34	– 41
Sweden	150 865	15	6	– 62
United Kingdom	92 244	14	1	– 93
EU-15	**1 221 197**	**60**	**42**	**– 30**
EU-27	**1 619 811**	**66**	**44**	**– 34**

Note: '-': not available.

5 Achievement of the interim objective for health-related ozone exposure

NEC Directive, Article 5(b): 'Health-related ground-level ozone exposure: the ground-level ozone load above the critical level (7) for human health (AOT60 = 0) shall be reduced by two-thirds in all grid cells compared with the 1990 situation. In addition, the ground-level ozone load shall not exceed an absolute limit of 2.9 ppm.h in any grid cell'.

The NEC Directive contains specific objectives addressing both human health- and vegetation-related exposure to ground-level ozone. This chapter discusses the extent to which the interim objective for health-related ozone in the NEC Directive has been achieved. Chapter 6 presents information related to the attainment of the interim objective addressing vegetation-related ozone exposure. Box 5.1 contains information on the different units used to express the ozone-related objectives.

Box 5.1 Measurement units relating to ozone exposure — human health

The AOT60, addressing human health, is defined as the accumulated amount of ozone over the threshold value of 60 parts per billion (ppb). More concretely, AOT60, commonly expressed in micrograms per cubic metre times hours (μg m^{-3}.h), is the sum of the difference between hourly concentrations of ground-level ozone greater than 120 μg m^{-3} (or 60 ppb) and 120 μg m^{-3} accumulated throughout the year.

Over more recent years, the so-called SOMO35 metric has been used in assessment of policy options for estimating ozone effects on human health, instead of the AOT60. This metric was recommended by the World Health Organization (WHO) in 2004 because new findings had shown that the risk of effects increases in proportion to the ozone level, with a significant increase in mortality observed above 50–70 μg m^{-3} (measured as a one- or eight- hour average) (70 μg m^{-3} corresponds to 35 ppb). The SOMO35 is defined as the sum of the amounts by which maximum daily 8-hour concentrations exceed 70 μg m^{-3} (cut-off value) on each day in a calendar year. SOMO35 levels are generally expressed in micrograms per cubic metre times days (μg m^{-3}.day).

The EU Air Quality Directive requires standardisation of concentrations of gaseous pollutants at a temperature of 20 °C and at an atmospheric pressure of 101.3 kilopascals (kPa). Under these conditions, one ppb ozone corresponds to a mass concentration of 2.0 μg m^{-3}.

In accordance with the definitions in the NEC Directive, the unit ppm.h is used in the maps presented in this report. When viewing Table 5.2, it should be considered that for calculating the AOT, ozone concentrations are multiplied with hours over a certain period (= accumulated concentrations).

Table 5.1 Conversion of volumetric (ppb) into mass (μg m^{-3}) ozone concentrations

ppb	μg m^{-3}
35	70
40	80
60	120

Table 5.2 Conversion for AOT, i.e. accumulated ozone concentrations (ppb and ppm.h) into mass (μg m^{-3}.h)

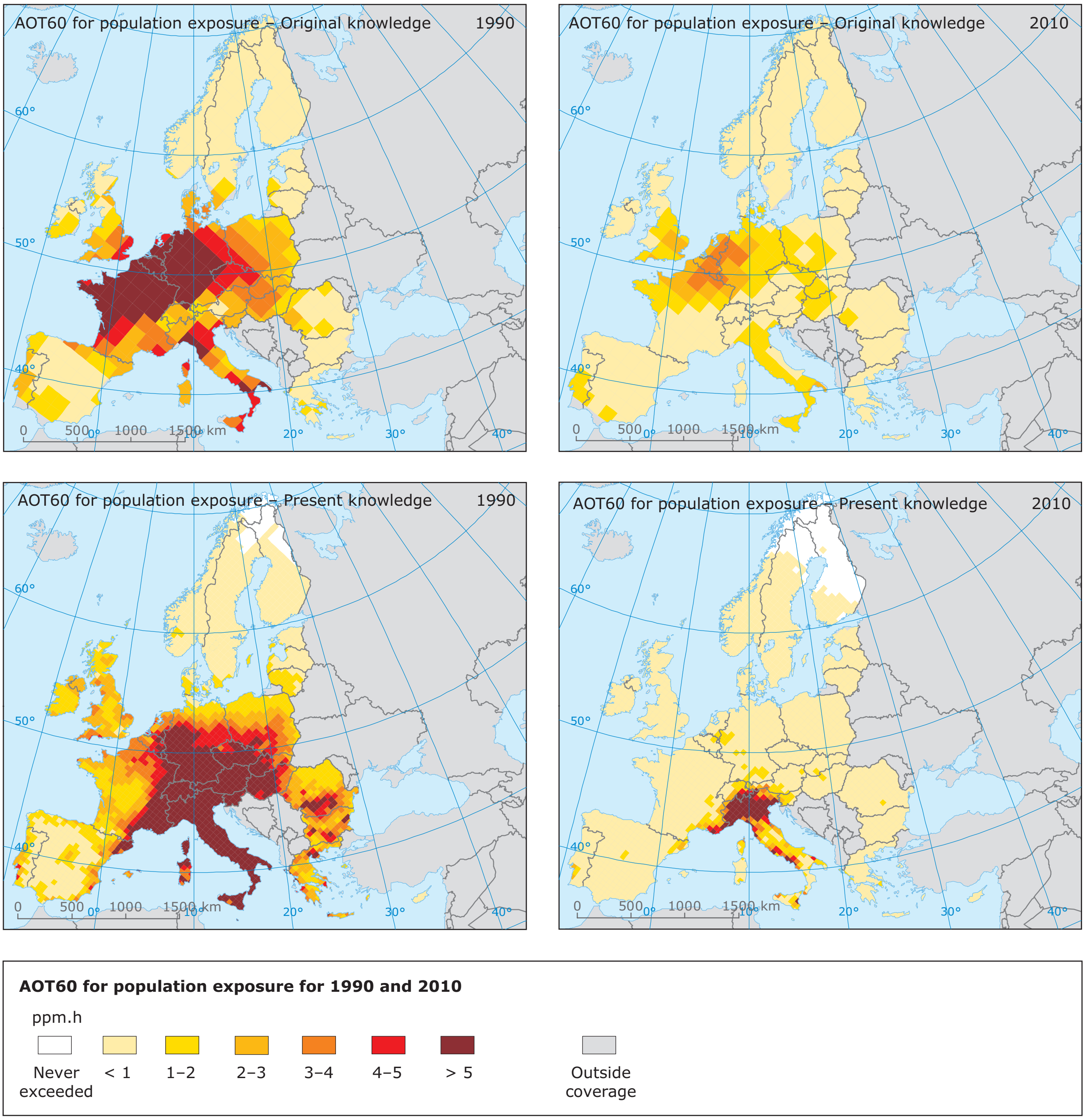
ppb.h	ppm.h	μg m^{-3}.h
1 000	1	2 000
3 000	3	6 000
6 000	6	12 000
9 000	9	18 000
12 000	12	24 000
15 000	15	30 000
18 000	18	36 000

(7) The NEC Directive defines a critical level as 'the concentration of pollutants in the atmosphere above which direct adverse effects on receptors, such as human beings, plants, ecosystems or materials, may occur, according to present knowledge'.

5.1 Ozone dispersion and concentrations

Ozone concentrations for both the human health and vegetation–related assessments were calculated with the present Eulerian EMEP model (Open Source EMEP/MSC-W model, version v.2011-06) (Simpson et al., 2011) and meteorological input fields for the year 2008. The calculations were performed with reported emissions from Member States for NO_X, SO_X, NMVOC and NH_3 (the NEC Directive pollutants, see Annex 1) and CO. As CO emissions are not reported under the EU NEC Directive, emissions reported under the LRTAP Convention

Map 5.1 AOT60 for area-weighted population exposure for 1990 (*left*) and 2010 (*right*) based on the original Lagrangian model on a 150 x 150 km² grid (*top*) ([a]) and the present Eulerian EMEP model on a 50 x 50 km² grid (*bottom*)



Note: ([a]) Amann et al., 1999.

were used (CEIP, 2012) for both 1990 ('new' emissions are not distinguished from 'original' ones) and 2010. The spatial distribution of the emissions was the same for 1990 and 2010, and was taken from the distribution used in the EMEP model for 2008. In the calculations, a trend from 1990 to 2010 is taken into account in the background concentrations for ozone (at the western boundary of the model domain) and for methane.

The AOT60 for human health is shown in Map 5.1 calculated on the basis of both original and present knowledge. The highest AOT60 values occur for the central and southern parts of western Europe in 1990. Using present knowledge, the area with high AOT60 values is much larger than the result calculated using original knowledge. For both assessments, the calculated AOT60 values are significantly lower in 2010, with values above 2 ppm.h confined almost entirely to Italy on the basis of present knowledge.

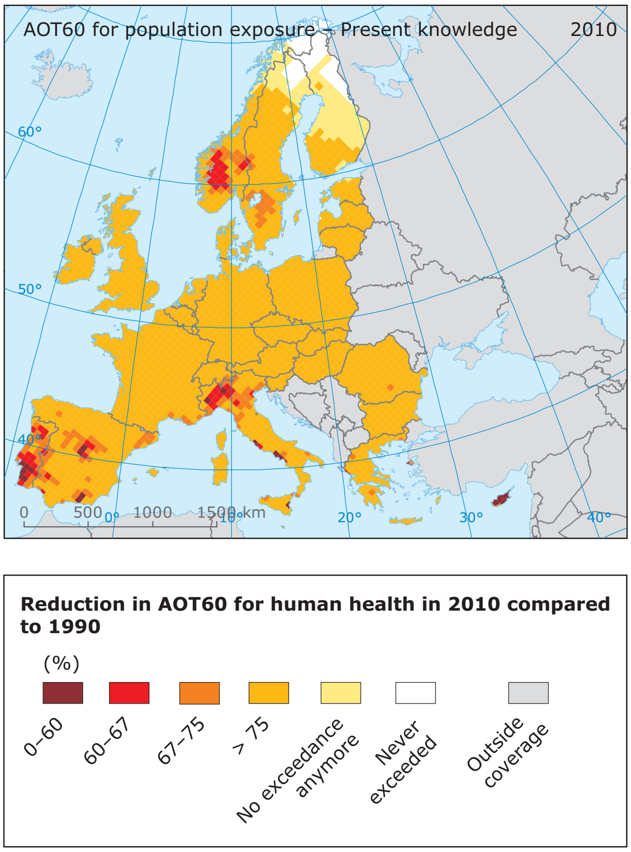
5.2 Have the 2010 objectives for health-related ozone exposure been met?

There are two objectives in the NEC Directive for ozone-related human health. Firstly, AOT60 shall be reduced by two-thirds in all grid cells in 2010 compared to the 1990 situation. This objective has been achieved in almost the whole of Europe, except for a few grid cells in northern Italy, Portugal and Spain (Map 5.2). Secondly, the AOT60 shall not exceed 2.9 ppm.h in any grid cell in 2010 (Map 5.1). This objective is achieved in most of Europe with the exception of northern Italy and some grid cells in the rest of Italy (see also Table 5.3).

The ozone-related objectives are calculated using present knowledge, i.e. the present Eulerian EMEP model and emissions for 1990 and 2010 as available in 2012, but using a single year of meteorological data only (i.e. 2008). AOT data from the AirBase air quality database (EEA, 2012c) reveal that 2008 is not an outlier of the AOT40 and AOT60 trends between 2005 and 2010, excluding 2006 which was an extreme ozone year (see Annex 2). Therefore it seems unlikely that the choice of the meteorological year affects the general conclusions presented here with respect to achieving the NEC Directive's objectives.

The emissions used for the ozone calculations for 1990 are based on present knowledge. If the original emission estimates for this year were used as available in 1999, the calculated ozone levels for

Map 5.2 Reduction (%) in AOT60 for human health in 2010 compared to 1990, calculated with present knowledge (Eulerian EMEP model)



1990 would have been higher. Consequently, the calculated reductions in AOT levels from 1990 to 2010 would likewise have been higher. In terms of the impacts of the differing grid cell size used in the original (150 x 150 km^2) and current (50 × 50 km^2) models, the smaller grid cells as used in the present EMEP model will probably not affect the calculated ozone concentrations significantly, considering the spatially large scale changes in ozone concentrations as presented here.

In addition to the targets for health-related ozone exposure set in the NEC Directive, the EU's Air Quality Directive (EC, 2008) sets long-term objectives and target values for ground-level ozone (Table 5.4).

There have been many efforts to mitigate ozone pollution since 1990, and the general air quality situation has improved as a result. Nevertheless, the health-related threshold of the target value (applicable from year 2010), was exceeded more than

Table 5.3 Country averages of AOT60 for human health for 1990 and 2010, and the change in AOTs in 2010 relative to 1990

	AOT60 health (ppm.h)		
	1990	**2010**	**Change**
Austria	9.5	1.0	– 89 %
Belgium	4.4	0.5	– 89 %
Bulgaria	3.1	0.2	– 94 %
Cyprus	0.6	0.3	– 50 %
Czech Republic	5.5	0.4	– 92 %
Denmark	1.0	0.1	– 87 %
Estonia	0.5	0.0	– 94 %
Finland	0.1	0.0	– 98 %
France	4.2	0.6	– 87 %
Germany	5.4	0.6	– 90 %
Greece	2.7	0.4	– 84 %
Hungary	5.0	0.5	– 91 %
Ireland	1.8	0.1	– 93 %
Italy	17.5	4.4	– 75 %
Latvia	0.7	0.0	– 94 %
Lithuania	1.1	0.1	– 90 %
Luxembourg	5.7	0.5	– 91 %
Malta	5.5	0.9	– 84 %
Netherlands	3.7	0.5	– 87 %
Poland	2.9	0.3	– 89 %
Portugal	1.3	0.5	– 66 %
Romania	2.9	0.2	– 94 %
Slovakia	5.2	0.4	– 92 %
Slovenia	9.4	1.2	– 87 %
Spain	1.4	0.2	– 82 %
Sweden	0.3	0.0	– 85 %
United Kingdom	2.1	0.2	– 92 %
EU-15	**4.0**	**0.7**	**– 82 %**
EU-27	**3.8**	**0.6**	**– 84 %**

Table 5.4 Ground-level ozone objectives of the Air Quality Directive — human health

	Objective	Level	Averaging time
Human health	Long-term objective	120 (µg m^{-3})	8-hour average, maximum daily
	Target value	120 (µg m^{-3}) (*)	8-hour average, maximum daily

Note: (*) Not to be exceeded on more than 25 days per calendar year, averaged over 3 years; 2010 is be the first reporting year for which the data are used in calculating compliance over the following 3 years.

25 times in 2010 at 40 % of the rural background measurement stations, but only at 27 % of urban background stations, 27 % of industrial sites and 12 % of traffic sites (EEA, 2012d). Provisional data show that this threshold was also exceeded in 17 EU Member States during the summer months of 2011 (EEA, 2012e). As in previous years, the most widespread concentrations occurred in the Mediterranean area.

It should also be noted that the WHO has meanwhile updated its air quality guideline for ozone. The 8-hour mean concentration limit has been lowered from 120 µg m^{-3} to 100 µg m^{-3} (WHO, 2006). The WHO (2011) explains the rationale for the guideline as follows: 'The previously recommended limit, which was fixed at 120 µg m^{-3} 8-hour mean, has been reduced to 100 µg m^{-3} based on recent conclusive associations between daily mortality and ozone levels occurring at ozone concentrations below 120 µg m^{-3}.

6 Achievement of the interim objective for vegetation-related ozone exposure

NEC Directive, Article 5(c): 'Vegetation-related ground-level ozone exposure: the ground-level ozone load above the critical level for crops and semi-natural vegetation (AOT40 = 3 ppm.h) shall be reduced by one third in all grid cells compared with the 1990 situation. In addition, the ground-level ozone load shall not exceed an absolute limit of 10 ppm.h, expressed as an exceedance of the critical level of 3 ppm.h in any grid cell'.

As for health-related ozone exposure, the NEC Directive contains two interim objectives concerning vegetation-related ozone exposure. The first of these is a percentage reduction objective for 2010 in all grid cells compared to the 1990 situation, while the second addresses the absolute concentration limits to be attained by 2010. With respect to the first objective, assessment is based upon AOT40. Critical AOT40 values are 3 ppm.h for crops and semi-natural vegetation, and 10 ppm.h for forests.

Box 6.1 Measurement units relating to ozone exposure — vegetation

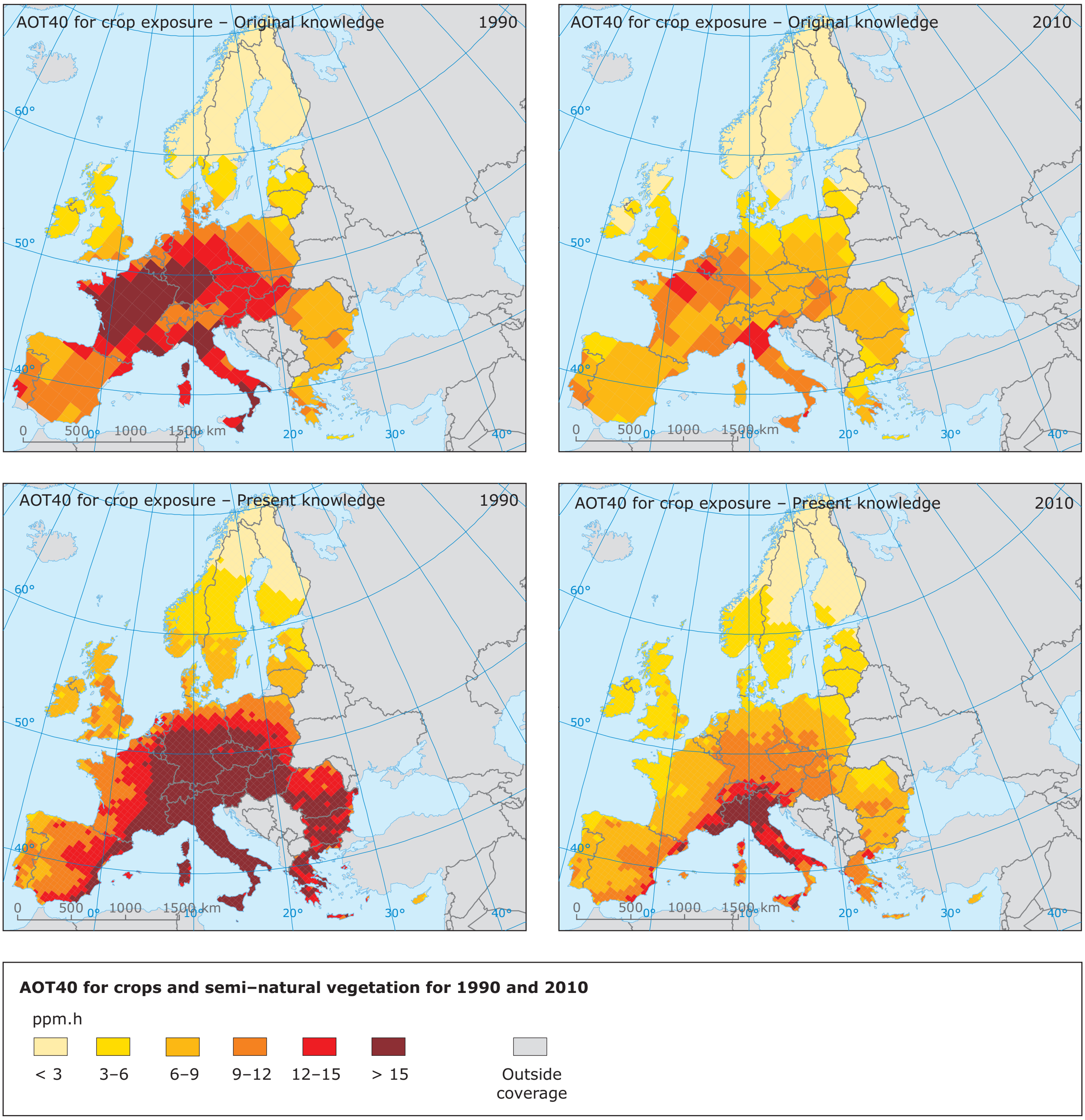
The AOT40, addressing crops and semi-natural vegetation, is defined as the accumulated ozone exposure over the threshold of 40 ppb. More concrete, AOT40 (commonly expressed in $\mu g\ m^{-3}.h$) is the sum of the amounts by which hourly mean ozone concentrations exceed 80 $\mu g\ m^{-3}$ (or 40 ppb). AOT40 is measured during daylight hours, for crops over three months (May–July) and for forests over six months (April–September). Note that the modelled AOT40 is based on ozone at crop height (normally 1 m) or tree height (normally 20 m) and is thus not directly comparable to AOT40 values based on measured ozone concentrations (for which the air sample intake is typically at 2 m height). Both the AOT40 measured and modelled results refer to daylight hours only.

6.1 Vegetation-related ozone exposure

Map 6.1 presents the modelled AOT40 for 1990 and 2010 based on the original Lagrangian model and the current Eulerian EMEP model. With present knowledge, the calculated AOT40 for crops and semi-natural vegetation in 1990 (Map 6.1; bottom left) shows the highest values in the central and southern part of western Europe e.g. Austria, the Czech Republic, western France, southern Germany, Hungary, Italy, Slovakia, and Slovenia. This is somewhat different than the situation based on the original knowledge for 1990, in which the highest AOT40 values were confined to a smaller area including France, southern Germany and northern and southern Italy. The calculated AOT40 values are significantly lower in 2010. In both assessments, it is clear that substantial improvements in the exposure of crops and semi-natural vegetation to ozone have been made since 1990. According to present knowledge, relatively high values are confined just to Italy in 2010.

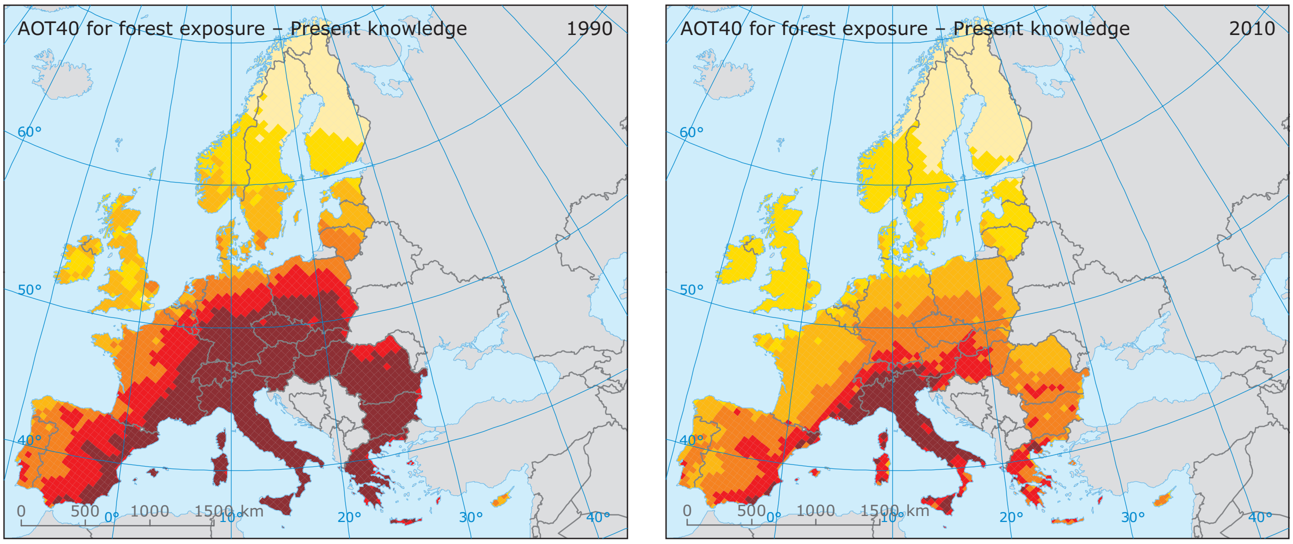
The calculated AOT40 values for forests according to present knowledge (Map 6.2) show a similar pattern as illustrated in Map 6.1 for crops, both for 1990 and 2010.

Map 6.1 **AOT40 for crops and semi-natural vegetation for 1990 (*left*) and 2010 (*right*) based on the original knowledge Lagrangian model on a 150 x 150 km² grid (*top*) ([a]) and the present knowledge Eulerian EMEP model on a 50 x 50 km² grid (*bottom*)**



Note: ([a]) Based on Amann et al., 1999.

Map 6.2 AOT40 forests for 1990 (*left*) and 2010 (*right*) based on the Eulerian EMEP model on a 50 x 50 km² grid (only assessed for present knowledge)



AOT40 forests for 1990 and 2010

ppm.h

< 5 | 5–10 | 10–15 | 15–20 | 20–25 | > 25 | Outside coverage

6.2 Have the 2010 objectives for vegetation-related ozone exposure been met?

According to the NEC Directive, the AOT40 above the critical level for crops and semi-natural vegetation (3 ppm.h) shall be reduced by one-third in all grid cells in 2010 compared to 1990. This objective has been achieved in most of the EU-27, except in Spain and Portugal, based on the calculations with the Eulerian EMEP model (Map 6.3, left). The AOT40 for crops above the critical level was reduced by more than 40 % in large parts of Europe in 2010 compared with 1990. In parts of Italy and Greece, reductions between 33 % and 40 % were modelled. Only in parts of Spain and Portugal is the calculated reduction in AOT40 less than 33 %.

Map 6.3 Percentage reduction in AOT40 for crops and semi-natural vegetation above 3 ppm.h in 2010 (*left*) and percentage reduction in AOT40 for forests above 10 ppm.h in 2010 (*right*); both compared to 1990 calculated with the present Eulerian EMEP model on a 50 x 50 km² grid

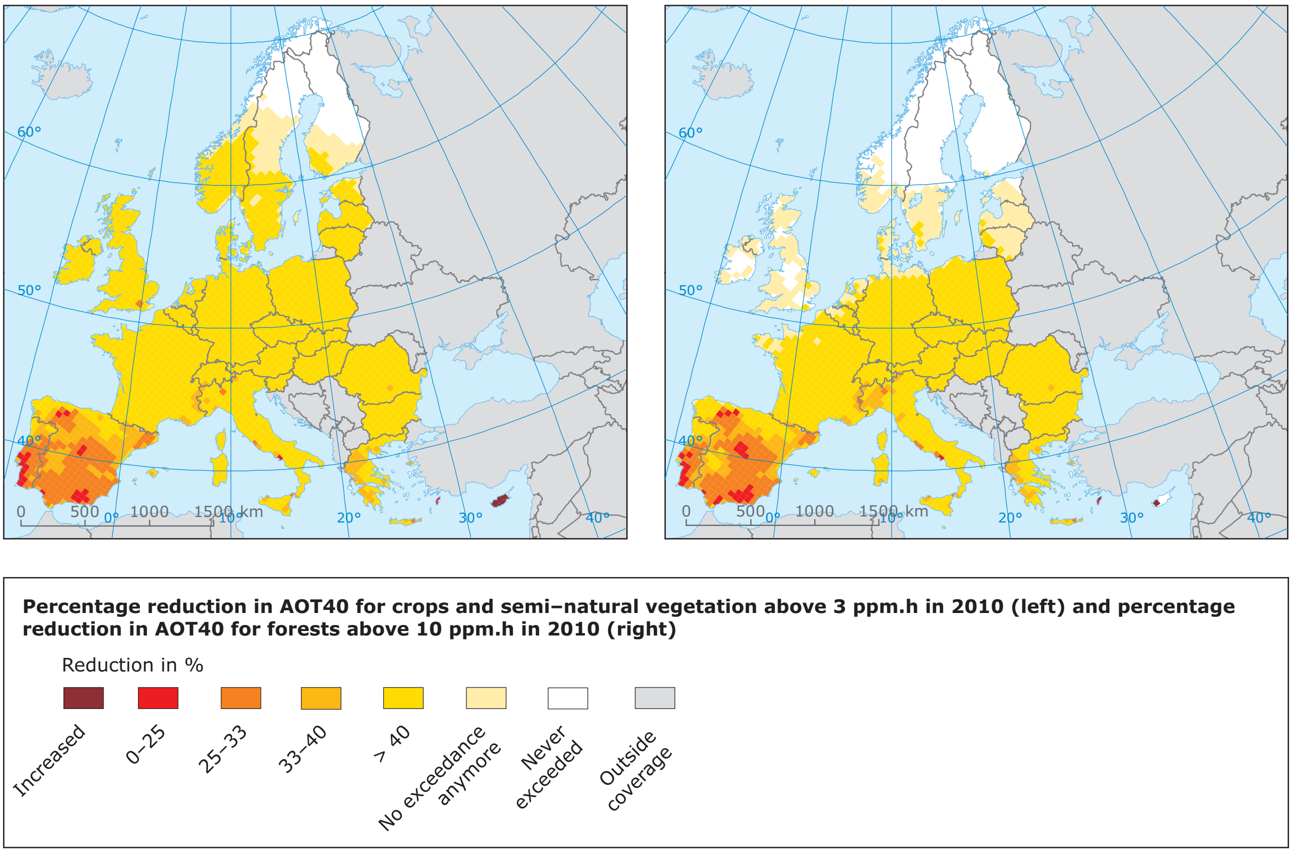


Table 6.1 shows the average AOT40 per Member State, as well as the change above the critical levels in 2010 relative to 1990. The average AOT40 for Spain was reduced from 11.7 ppm.h in 1990 to 8.8 ppm.h in 2010, which corresponds to a reduction of 34 % in AOT40 above the critical level of 3 ppm.h. Thus, based on these calculations, the reduction is very close to the objective for the Spanish average. This also holds true for Portugal (30 % for the country average).

Table 6.1 Country averages of AOT40 for crops/semi-natural vegetation and forests, for 1990 and 2010, and the change in AOTs above the critical level ([a]) in 2010 relative to 1990

	AOT40 Crops (ppm.h)			AOT40 Forests (ppm.h)		
	1990	**2010**	**Change**	**1990**	**2010**	**Change**
Austria	21.2	11.5	– 53 %	37.5	22.1	– 56 %
Belgium	14.0	7.8	– 56 %	19.1	11.8	– 80 %
Bulgaria	15.7	7.9	– 62 %	30.4	16.9	– 66 %
Cyprus	7.2	7.6	12 %	14.2	15.4	30 %
Czech Republic	17.5	9.6	– 54 %	30.8	18.2	– 60 %
Denmark	7.7	4.9	– 60 %	13.1	8.6	– 100 %
Estonia	5.4	3.2	– 92 %	10.5	6.6	– 100 %
Finland	2.5	1.4	NE	4.2	2.9	NE
France	14.6	8.2	– 55 %	24.1	15.3	– 62 %
Germany	16.5	9.3	– 54 %	25.2	15.2	– 66 %
Greece	15.1	9.9	– 43 %	29.0	20.3	– 46 %
Hungary	17.7	9.5	– 56 %	32.9	19.6	– 58 %
Ireland	6.5	4.2	– 65 %	10.0	7.8	NE
Italy	26.4	15.8	– 45 %	47.2	30.7	– 44 %
Latvia	6.3	3.5	– 85 %	13.4	8.1	– 100 %
Lithuania	7.6	4.0	– 77 %	16.2	9.5	– 100 %
Luxembourg	17.0	9.3	– 55 %	24.4	14.6	– 68 %
Malta	15.2	9.3	– 48 %	30.3	20.3	– 49 %
Netherlands	11.9	6.7	– 59 %	15.6	9.8	– 100 %
Poland	12.4	7.1	– 57 %	23.5	14.2	– 69 %
Portugal	9.0	7.2	– 30 %	17.4	14.9	– 34 %
Romania	14.6	7.2	– 64 %	28.4	15.7	– 69 %
Slovakia	17.1	8.9	– 58 %	32.0	18.6	– 61 %
Slovenia	21.3	11.9	– 51 %	38.5	23.4	– 53 %
Spain	11.7	8.8	– 34 %	22.8	18.5	– 34 %
Sweden	4.4	2.8	– 100 %	7.2	5.2	NE
United Kingdom	8.2	5.0	– 61 %	11.3	8.2	– 100 %
EU-15	**12.1**	**7.4**	**– 51 %**	**20.6**	**14.1**	**– 62 %**
EU-27	**12.4**	**7.4**	**– 54 %**	**21.9**	**14.3**	**– 64 %**

Note: ([a]) The critical level for crops and semi-natural vegetation is 3 ppm.h, and for forests it is 10 ppm.h.

NE = Critical level not exceeded in 1990.

In the assessments undertaken in this work, the observed increases in methane (Sussmann et al., 2012) and tropospheric background levels of ozone (Derwent et al., 2007) concentrations, as measured in air masses advected across the North Atlantic Ocean, are taken into account. Those measurements are used to set the boundary conditions for the EMEP model used, which is centred over Europe. Both the increases in methane and in background ozone result in higher AOT levels in 2010 and slightly reduced reductions in 2010 relative to 1990. These increases in background concentrations change the reduction in AOT40 for crops for the average of the EU-15 Member States, for example, from 56 % to 51 % from 1990 to 2010. If these changes in background levels are not taken into account, the objective for the reduction in AOT40 for crops would almost be achieved at most locations in Spain and Portugal. Without the changes in background concentrations, the calculated reduction in Spain and Portugal is on average 41 %; including these background changes brings the calculated reduction down to between 30 % and 34 %.

In addition to the targets for vegetation-related ozone exposure set in the NEC Directive, the EU's Air Quality Directive (EC, 2008) sets long-term objectives and target values for ground-level ozone (AOT40 for crops), to be met by 2010 (Table 6.2).

A substantial part of the agricultural area in the EU-27 is still exceeding the target value (e.g. approximately 20 % in 2009).

According to the NEC Directive, the AOT40 for forests shall not exceed 10 ppm.h in any grid cell. This objective has clearly not been achieved, as Map 6.2 indicates. Only in northern and eastern Europe and in the United Kingdom was the calculated AOT40 below 10 ppm.h in 2010. In the rest of Europe, much higher values are calculated, as high as 40 ppm.h in northern Italy. Although the objective for forests has not been met for a large area of the EU-27, the calculated AOT40 for forests above the critical level of 10 ppm.h was reduced significantly in Europe from 1990 to 2010 (Map 6.3, right). Reductions of more than 33 % are evident in almost all of Europe (Table 6.1).

Table 6.2 Ground-level ozone objectives of the Air Quality Directive — vegetation

Vegetation (crops)	Long-term objective	6 000 (µg m^{-3}.h) or 3 (ppm.h)	Accumulated over May through July
	Target value	18 000 (µg m^{-3}.h) or 9 (ppm.h)	Accumulated over May through July, averaged over 5 years

7 Verification of study results with measured air quality data

7.1 Comparison between modelled and measured data

The findings from the modelling assessments presented here can be confirmed by other studies where ground-level ozone measurement data were used to improve the modelling results. One such example is the analysis of 2009 data by de Smet et al. (2012), who used information derived from European rural background station measurements from the AirBase air quality database (EEA, 2012c) with supplementary data sources such as the EMEP model output, altitude and surface solar radiation. In this study, the highest values for the AOT40 for crops (accumulated concentrations from May to July) were calculated for Italy, particularly for the northern part of the country (levels exceeding 13 ppm.h). Similarly, the regional results for the forest AOT40 (accumulated concentrations from April to September) were similar, with highest levels exceeding 25 ppm.h.

A second example is provided by the ensemble application of several European chemical transport models (i.e. not only the EMEP model used in this present study) within the Global Monitoring for Environment and Security (GMES) atmosphere activities. The GMES programme is an EU initiative dedicated to implementing integrated observation and modelling systems to monitor the state of the environment. One component developed in the Monitoring Atmospheric Composition and Climate (MACC) project (MACC, 2012) aims at delivering global and regional (European) forecasts and also historical maps and figures of air pollutant concentrations and air quality. Results relevant in the context of the present report are the so-called air quality analyses of past years. The most recent calculations are available for year 2009 (Rouil, 2011). The methodological approach used for these MACC analyses is to assimilate, as far as feasible, observational results from AirBase measurement stations directly into the model calculations in order to improve the modelling assessments.

The MACC results show again the highest values calculated for northern and parts of southern Italy, some regions in France, Greece and Spain (values exceeding 13 ppm.h for the AOT40 for crops). It is interesting to note that the summer of 2009 was warmer than the long-term average. However, the heat waves affecting particularly Italy and Spain, as well as Belgium, France, Germany and the United Kingdom, did not have the same severe impacts on ozone levels as occurred in the extreme warm year 2003. For estimating ozone effects on human health, the SOMO35, instead of the AOT60, was used in both studies mentioned above (see Box 5.1).

In terms of verifying the modelling results of this study with measurement data for ozone, when evaluating the latest available ozone measurement results at rural background stations (for the year 2009) submitted to the EMEP Chemical Coordination Centre (CCC), it is clear that there is a spatial bias concerning the reporting of different European countries (which is also reflected in the national reporting to the AirBase air quality database). In Spain, for example, 11 measurement stations have been established, while there are only two stations reporting data from Greece and only 1 reporting data from Italy (Hjellbrekke et al., 2011). Concerning the AOT40 for crops in Spain in 2009 (compare with Map 6.1):

- two stations were below 3 ppm.h;
- two stations were in the range of 3 ppm.h to 6 ppm.h;
- three stations were in the range of 6 ppm.h to 9 ppm.h;
- three stations were in the range of 9 ppm.h to 12 ppm.h;
- no stations were in the range of 12 ppm.h to 15 ppm.h;
- one station was above 15 ppm.h (15 corresponds to 34 000 $\mu g/m^3$.h; the target value in the Air Quality Directive is 18 000 $\mu g/m^3$.h, averaged over 5 years).

For Greece the two EMEP stations reported about 2.9 ppm.h (Aliartos) and approximately 15 ppm.h (Finokalia), respectively. Italy reported only data for one station, and here the measured levels exceeded 15 ppm.h (17 ppm at Montelibretti) in 2009.

7.2 Evaluation of environmental objectives for ozone based on monitoring data

Air quality monitoring data from EMEP and from the AirBase air quality database (EEA, 2012c), have also been used as a verification of the modelling results from this work. To allow for the influence of meteorological variability two three-year periods were compared: 1990–1992 and 2008–2010 for AirBase data, or 2007–2009 for EMEP data (2010 EMEP data were not available at time of writing). Stations operational during at least two years in the start- and end periods and with a minimum of 75 % data coverage were selected. Rural stations were used to assess improvement in vegetation exposure (AOT40) and (sub)urban background stations were used to evaluate progress in population exposure (AOT60). It should be noted that the density of networks in the reference period (1990–1992) is lower than the current density. There is also strong geographical bias in the selected set of monitoring stations (Table 7.1) which are situated in only a small number of predominantly western Member States. While AirBase data for recent years is considerably more representative, monitoring data for early years, such as the period 1990–1992, is limited.

The observations show that the objective for protection of crops and semi-natural vegetation has been met at 47 of the 79 rural background stations included in the analysis. At three stations the AOT40 was below the target value in both 1990 and 2010. At 29 stations the objective was not met while at eleven of these stations a higher level was observed for the period 2008 to 2010. Stations where the objective has not been met are located in Austria and Germany. In total 29 high-altitude stations (at an altitude of more than 500 m) are included in the analysis. At 18 of these, the objective was not met. Concentrations at high altitudes are sensitive to the tropospheric background concentrations. Increased tropospheric ozone concentration might be a possible explanation for the relatively large number of non-compliance stations at high altitudes.

Table 7.1 Number of rural and (sub)urban background stations used to evaluate ecosystem and health related NEC objectives

Member State	Rural stations	Urban stations
Austria	19	12
Belgium	2	1
Germany	27	63
Finland	1	–
Greece	–	2
Netherlands	15	4
Sweden	3	1
United Kingdom	12	2
Total	**79**	**85**

Source: AirBase air quality database (EEA, 2012c).

The EMEP data largely overlap with the Airbase data (i.e. the same monitoring stations used for reporting to both databases). The only differences are that one additional EMEP station in Portugal showed higher concentrations for the period 2008 to 2010 and that the objective at one EMEP station in Slovenia has not been met.

The reduction target of more than 33 % for the AOT40 for forests was met at 65 stations. The target was not met at 13 stations located in Austria and Germany. The EMEP data shows less than 33 % reduction at one station in Slovenia. Notwithstanding the observed reductions, current concentrations (averaged 2008–2010) are still above the critical level of 10 ppm.h at more than 60 % of the rural background stations. Concentrations below the critical level are mainly observed in the Baltic States, Belgium, Ireland, the Netherlands, Scandinavia and the United Kingdom.

In general, the observations lead to a similar conclusion as the model calculations, in that the interim objectives to reduce the excess concentration of ozone above the critical levels for crops and forests are largely met in the Member States considered in the presented analysis. However, the observations indicate slightly lower reductions than the model calculations and the remaining problem areas are not only confined to Southern Europe but include also more northern regions (Austria and Germany).

The objective for the reduction in the critical level for human health (67 % reduction in AOT60) is, according to the observations, met at a quarter of the (sub) urban background stations. In contrast to this finding, the model calculations showed that this objective is achieved in almost the whole of EU-15 area. Note that model data refer to an averaged concentration in grid cells of 50 x 50 km^2. With the exception of mega-cities such as London and Paris, the urban conditions are generally not resolved in grid cells of this size.

It is well known that in urban areas trends in ozone concentration tend to behave differently compared to rural areas. Close to NO_x sources, there is a quenching of ozone due to the chemical interaction between ozone and the freshly emitted nitrogen monoxide (NO). This generally leads to lower ozone concentrations at traffic and urban locations, than in nearby rural areas. This so-called ozone 'titration' effect has become less important due to the strong decrease in NO_x emissions since 1990.

The reduction in rural ozone concentrations, as a result of European-wide reductions in precursor emissions, is largely counterbalanced in urban areas by the increasing effect of reduced titration. The absolute limit value of 2.9 ppm.h (5 800 $\mu g/m^3$.h) was still exceeded in 2010 at 12.5 % of the urban background stations, in particular in Italy.

8 Conclusion

The objective of this report was to assess to what extent the NEC Directive's environmental and health objectives concerning acidification, eutrophication and ground-level ozone exposure for the year 2010 have been achieved. The main basis for the assessment is the emission inventory data officially reported by Member States.

The analysis was conducted by using the same scientific methods of 2001 (original knowledge) and 2010 (present knowledge) that support European air pollution abatement policies. The original knowledge consisted of modelling concentrations and exposure using the older Lagrangian EMEP model (utilising a 150 × 150 km^2 grid for the computation of grid-average S and N depositions and ground-level ozone concentrations, together with the 1998 European critical load database for assessing the risk of acidification and eutrophication). The assessment performed on the basis of present knowledge used the current Eulerian EMEP model on a 50 × 50 km^2 grid for the computation of ecosystem-specific depositions and ground-level ozone concentrations, in combination with the 2008 European critical loads database.

When assessing progress using original knowledge, the NEC Directive's interim environmental acidification objective has been met in almost all grid cells, while the eutrophication objective — provided in a footnote within the NEC Directive and which was formulated on the European Union area as a whole — has been met both for the EU-15 and the EU-27 regions as a whole. If, in contrast, the eutrophication objective had been required to be met in individual grid cells (as for acidification) or in individual Member States, it would be exceeded in many grid cells and in 11 Member States. While acidification has been markedly reduced, eutrophication is now recognised as a major environmental problem in Europe, especially in the context of its potential adverse impacts on biodiversity. An assessment using present knowledge indicates that neither the acidification nor eutrophication objective have been met.

The health- and vegetation-related interim environmental ozone objectives have been achieved using present knowledge, across most of the EU-27 area. For forests, however, the objective of no exceedance of the critical limit has been violated in most Member States. This analysis also shows that model results are more optimistic than the observations about the achieved reductions in ozone concentrations between 1990 and 2010.

The European Commission is currently reviewing the EU's air policy, and, amongst other initiatives, is expected to propose a revised NEC Directive by 2013 at the latest. A revised directive would build on the findings of the policy review, and is likely to set objectives addressing human health and the environment for 2020 and beyond, for relevant air pollutants. In the absence of new legislation, however, the NEC Directive remains in force and requires countries to keep emissions below national ceilings also in the years beyond 2010.

9 Units, acronyms and abbreviations

6EAP	Sixth Environment Action Programme of the European Union
AAE	average accumulated exceedance
AOT40	Accumulated ozone exposure over a threshold of 40 parts per billion. For the purposes of the NEC Directive, AOT40 means the sum of the difference between hourly concentrations of ground-level ozone greater than 80 $\mu g\ m^{-3}$ (= 40 ppb) and 80 $\mu g\ m^{-3}$ during daylight hours accumulated from May to July each year
AOT60	Accumulated ozone exposure over a threshold of 60 parts per billion. For the purposes of the NEC Directive, AOT60 means the sum of the difference between hourly concentrations of ground-level ozone greater than 120 $\mu g\ m^{-3}$ (= 60 ppb) and 120 $\mu g\ m^{-3}$ accumulated throughout the year
C_6H_6	benzene
CCC	Chemical Coordination Centre under the UNECE Convention on Long-range Transboundary Air Pollution
CCE	Coordination Centre for Effects under the UNECE Convention on Long-range Transboundary Air Pollution
CO_2	carbon dioxide
CTM	chemical transport model
EEA	European Environment Agency
Eionet	European Environmental Information and Observation Network of the EEA
EMEP	European Monitoring and Evaluation Programme: Cooperative programme for monitoring and evaluation of the long-range transmissions of air pollutants in Europe under the UNECE LRTAP Convention
ETC/ACM	European Topic Centre for Air Pollution and Climate Change Mitigation
EU	European Union
EUNIS	European Nature Information System
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
GDP	gross domestic product
Gg	1 gigagram = 10^9 g = 1 kilotonne (kt)
GMES	Global Monitoring for Environment and Security
LRTAP Convention	UNECE Convention on Long-range Transboundary Air Pollution
MACC	Monitoring Atmospheric Composition and Climate service under GMES

NEC	National Emission Ceilings (Directive)
NEDC	New European Driving Cycle
NFR	nomenclature for reporting (UNECE)
NH_3	ammonia
NMVOC(s)	non-methane volatile organic compound(s)
NO_2	nitrogen dioxide
NO_X	nitrogen oxides
O_3	ozone
PJ	petajoule
PM	particulate matter
ppb	part(s) per billion
ppm	part(s) per million
ppm.h	part(s) per million per hour
SO_2	sulphur dioxide
SOMO35	the sum of the amounts by which maximum daily 8-hour concentrations exceed 70 µg m^{-3} (cut-off value) on each day in a calendar year
SO_X	sulphur oxides
SRM	source receptor matrices (of the EMEP air quality model)
UNECE	United Nations Economic Commission for Europe
VOCs	volatile organic compounds (non-methane)
WHO	World Health Organization
µg	microgram

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Annex 1 Emissions data

Table A1.1 Data sets 1990 (old and new) and 2010: NMVOC and SO_2/SO_x

Unit: Gg	1990 officially reported data from 2001 (1990, old)		1990 officially reported data from 2012 (1990, new)		2010 officially reported data from 2012		Reporting year reference for 2010 data
	NMVOC	SO_2/SO_x	NMVOC	SO_2/SO_x	NMVOC	SO_2/SO_x	
Albania ([a])	31	72	42.8	78.0	32.1	36.6	CEIP, 2008
Armenia	81	72	81.0	72.0	35.2	25.7	CEIP, 2007
Austria	344.7	91	276.0	74.5	131.5	18.8	NECD, 2010
Belarus	533	637	533.0	637.0	307.6	58.6	CEIP, 2010
Belgium	354	372	314.9	361.8	104.8	67.2	NECD, 2010
Bosnia and Herzegovina		480		480.0			NR
Bulgaria	217	2 008	620.1	1 099.5	93.0	387.2	NECD, 2010
Canada	2 880	3 236	2 785.4	3 202.4	2 078.8	1 366.0	CEIP, 2010
Croatia	105	180	113.4	173.5	76.3	41.5	CEIP, 2010
Cyprus		46	17.1	30.9	11.3	22.1	NECD, 2010
Czech Republic	435	1 876	441.0	1 881.0	153.9	169.5	NECD, 2010
Denmark	169.3	182.6	165.8	176.4	84.2	13.9	NECD, 2010
Estonia	88.4	252.1	70.3	273.6	38.0	83.2	NECD, 2010
Finland	209	260	238.9	262.5	115.0	66.7	NECD, 2010
France	2 459	1 278	2 589.4	1 353.9	852.4	261.6	NECD, 2010
Georgia	46.4	248.3	46.4	248.3	109.1	19.3	CEIP, 2010
Germany	3 221	5 321	3 128.1	5 292.0	1 053.0	449.3	NECD, 2010
Greece	334	506	268.2	473.4	183.4	265.6	NECD, 2010
Hungary	205	1010	205.0	1 010.0	109.0	29.1	NECD, 2010
Iceland	12.8	24	12.6	20.4	5.4	76.6	CEIP, 2009
Ireland	110	186	93.2	182.3	44.0	25.9	NECD, 2010
Italy	2 213	1 651	2 014.6	1 794.2	1 102.5	210.2	NECD, 2010
Kazakhstan in the former official EMEP domain			0.4	1 156.3	NR	948.0	CEIP, 2000
Kyrgyzstan			25.0	97.0	17.2	25.9	CEIP, 2005
Latvia	179	119	101.5	104.8	65.0	7.4	NECD, 2010
Liechtenstein	1.56	0.149	0.9	0.1	0.4	0.0	CEIP, 2010
Lithuania	108	222	108.0	222.0	69.0	38.1	NECD, 2010
Luxembourg	19	15	18.9	14.6	8.8	1.7	NECD, 2010
former Yugoslav republic of Macedonia					25.2	83.2	CEIP, 2010
Malta ([b])					2.5	8.1	NECD, 2010
Montenegro					10.5	9.7	CEIP, 2009
Monaco	0.7	0.073	0.7	0.1	0.3	0.0	CEIP, 2010
Netherlands	502	202	477.3	191.6	150.6	33.9	NECD, 2010
Norway	301.7	52.7	289.3	52.2	140.2	19.4	CEIP, 2010
Poland	831	3 210	831.0	3 210.0	652.8	969.6	NECD, 2010
Portugal	379.9	359.4	294.2	294.1	169.1	67.8	NECD, 2010
Republic of Moldova	157	265	123.7	175.0	36.4	6.7	CEIP, 2009

Table A1.1 Data sets 1990 (old and new) and 2010: NMVOC and SO_2/SO_x (cont.)

Unit: Gg	1990 officially reported data from 2001 (1990, old)		1990 officially reported data from 2012 (1990, new)		2010 officially reported data from 2012		Reporting year reference for 2010 data
	NMVOC	SO_2/SO_x	NMVOC	SO_2/SO_x	NMVOC	SO_2/SO_x	
Romania	772	1311	616.0	1 311.0	440.8	372.0	NECD, 2010
Russian Federation	3 566	4 460	3 668.0	4 671.0	2 257.6	1 340.3	CEIP, 2009
Serbia					137.6	276.7	CEIP, 2010
Slovakia	148	543	142.0	526.0	62.4	69.4	NECD, 2010
Slovenia	44	196	55.2	198.1	34.0	10.4	NECD, 2010
Spain	2 790	2 049	1 040.5	2 180.5	672.3	443.6	NECD, 2010
Sweden	526	119	359.0	105.0	197.1	34.5	NECD, 2010
Switzerland	279	42	289.3	40.8	89.0	12.9	CEIP, 2010
Turkey	462.2	764.7	462.9	764.6	723.7	1 661.0	CEIP, 2010
Ukraine	1 369	3 782	1 369.0	2 783.0	357.4	1 215.9	CEIP, 2010
United Kingdom	2 657	3 754	2 761.6	3 707.2	788.8	406.0	NECD, 2010
United States	19 099	21 481	21 871.0	20 935.0	11 909.4	8 599.7	CEIP, 2009
Yugoslavia ([c])	142	508					

Notes: ([a]) Amann, 1999.
([b]) NMVOC: Amann, 1999.
([c]) NH_3 and NMVOC based on Amann, 1999.
NR — not reported.

Table A1.2 Data sets 1990 (old and new) and 2010: NO_x and NH_3

Unit: Gg	1990 officially reported data from 2001 (1990, old)		1990 officially reported data from 2012 (1990, new)		2010 officially reported data from 2012		Reporting year reference for 2010 data
	NO_x	NH_3	NO_x	NH_3	NO_x	NH_3	
Albania ([a])	24	32	22.1	28.7	28.9	23.7	CEIP, 2008
Armenia	40	25	46.2	25.0	23.5	16.7	CEIP, 2007
Austria	192.6	79	195.4	65.5	144.0	62.1	NECD, 2010
Belarus	285	4	285.0	214.9	170.1	151.1	CEIP, 2010
Belgium	339	107	401.4	120.2	220.6	69.1	NECD, 2010
Bosnia and Herzegovina		0					NR
Bulgaria	361	144	248.5	132.8	120.3	50.7	NECD, 2010
Canada	2 104	0	2 477.0	423.3	1 996.1	467.1	CEIP, 2010
Croatia	87.6	37.10	95.4	50.9	70.5	37.5	CEIP, 2010
Cyprus	18	9	16.7	5.1	18.0	5.3	NECD, 2010
Czech Republic	742	156	544.0	156.0	238.9	68.7	NECD, 2010
Denmark	271.7	127.90	274.6	114.4	128.8	68.9	NECD, 2010
Estonia	67.7	24.25	73.6	24.6	36.7	10.3	NECD, 2010
Finland	300	38	323.3	38.1	165.5	37.1	NECD, 2010
France	1 865	790	1 864.5	703.6	1 080.2	645.1	NECD, 2010
Georgia	129.5	0	129.5		35.7	26.7	CEIP, 2010
Germany	2 706	765	2 889.1	691.5	1 322.9	547.8	NECD, 2010
Greece	326	79	329.3	84.7	315.4	64.6	NECD, 2010
Hungary	238	124	238.0	124.0	162.0	64.9	NECD, 2010
Iceland	26.3	0	27.2	NR	23.8	NR	CEIP, 2009
Ireland	118	112	120.8	106.6	73.0	106.2	NECD, 2010
Italy	1 938	466.00	2 013.8	468.0	965.9	378.9	NECD, 2010
Kazakhstan in the former official EMEP domain		0	355.7	0.5	200.9	0.3	CEIP, 2000
Kyrgyzstan		0	115.2		62.8	NR	CEIP, 2005
Latvia	102	44	65.1	48.2	35.3	17.3	NECD, 2010
Liechtenstein	0.628	0.15	0.8	0.3	0.6	0.3	CEIP, 2010
Lithuania	158	84	158.0	84.0	57.8	30.0	NECD, 2010
Luxembourg	23	7	23.8	5.0	20.6	4.0	NECD, 2010
former Yugoslav Republic of Macedonia		0			29.0	9.8	CEIP, 2010
Malta ([b])		0			8.1	1.5	NECD, 2010
Montenegro		0			7.8	3.0	CEIP, 2009
Monaco	0.523	0	0.5	0.0	0.3	0.0	CEIP, 2010
Netherlands	580	226	566.3	355.1	275.9	121.8	NECD, 2010
Norway	219.2	22.90	190.1	20.8	184.3	22.7	CEIP, 2010
Poland	1 280	508	1 280.0	508.0	876.8	277.4	NECD, 2010
Portugal	317	104.60	224.7	63.2	180.1	47.9	NECD, 2010
Republic of Moldova	100	49	130.7	63.0	29.2	26.6	CEIP, 2009
Romania	546	300	546.0	300.0	272.2	160.8	NECD, 2010
Russian Federation	2 553	1 258	3 600.0	1 191.0	3 426.2	770.5	CEIP, 2009
Serbia		0			199.6	81.9	CEIP, 2010
Slovakia	226	62.90	222.0	65.0	88.6	24.4	NECD, 2010
Slovenia	63	24	59.8	19.9	44.6	17.3	NECD, 2010
Spain	1 156	472	1 286.3	317.7	899.9	368.3	NECD, 2010

Table A1.2 Data sets 1990 (old and new) and 2010: NO_x and NH_3 (cont.)

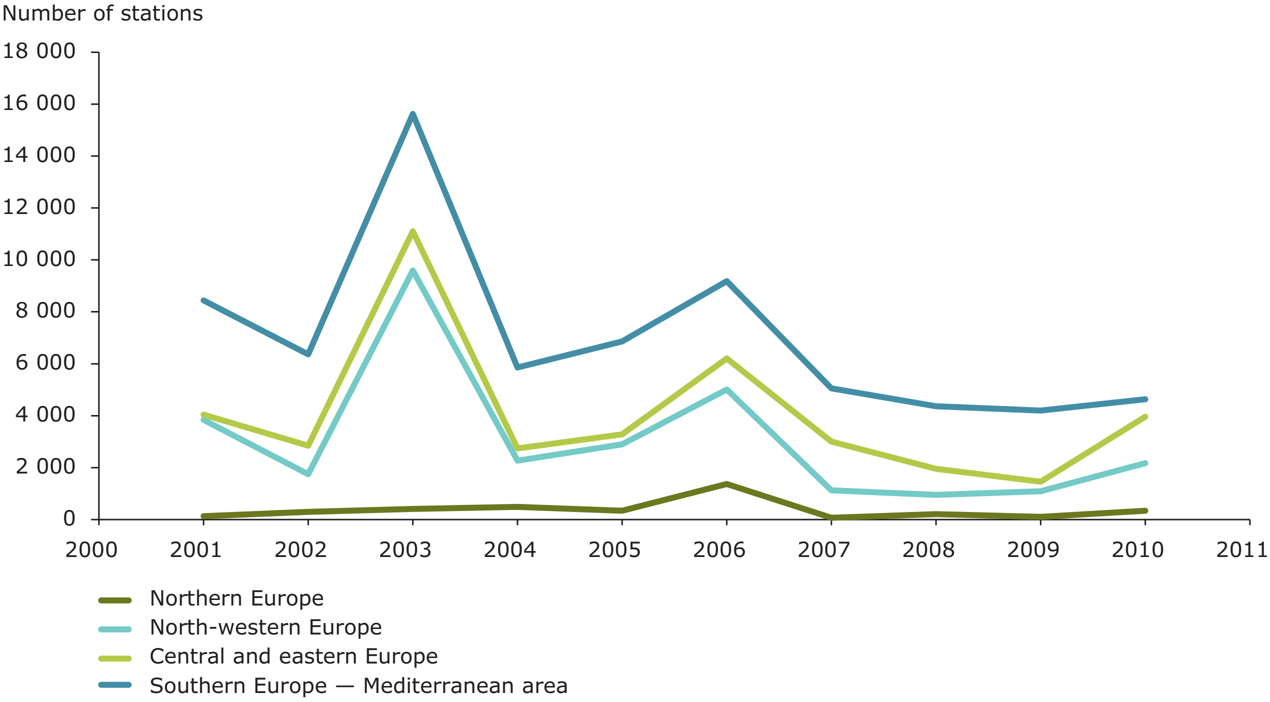
Unit: Gg	1990 officially reported data from 2001 (1990, old)		1990 officially reported data from 2012 (1990, new)		2010 officially reported data from 2012		Reporting year reference for 2010 data
	NO_x	NH_3	NO_x	NH_3	NO_x	NH_3	
Sweden	338	51	269.3	54.9	161.4	51.7	NECD, 2010
Switzerland	154	71.50	145.1	73.0	78.7	62.6	CEIP, 2010
Turkey	628	602	643.7		1 084.9	514.8	CEIP, 2010
Ukraine	1 097	23	1 097.0	729.0	603.2	25.2	CEIP, 2010
United Kingdom	2 756	365.30	2 885.3	359.9	1 105.8	284.4	NECD, 2010
United States	21 927	3 926	23 161.0	3 918.0	12 439.3	3 698.6	CEIP, 2009
Yugoslavia ([c])	66	90					

Notes: ([a]) Amann, 1999.
([b]) NH_3 Cyprus: EEA dataset ap3a_2003.
([c]) NH_3 and NMVOC based on Amann, 1999.
NR — not reported.

Annex 2 Representativeness of 2008 for ozone calculations

Figures in this annex are derived from the AirBase air quality database (EEA, 2012c) (including measurement data up to 2010).

Figure A2.1 AOT60 (sub)urban stations, data coverage 75 %, operational over 8 to 10 years



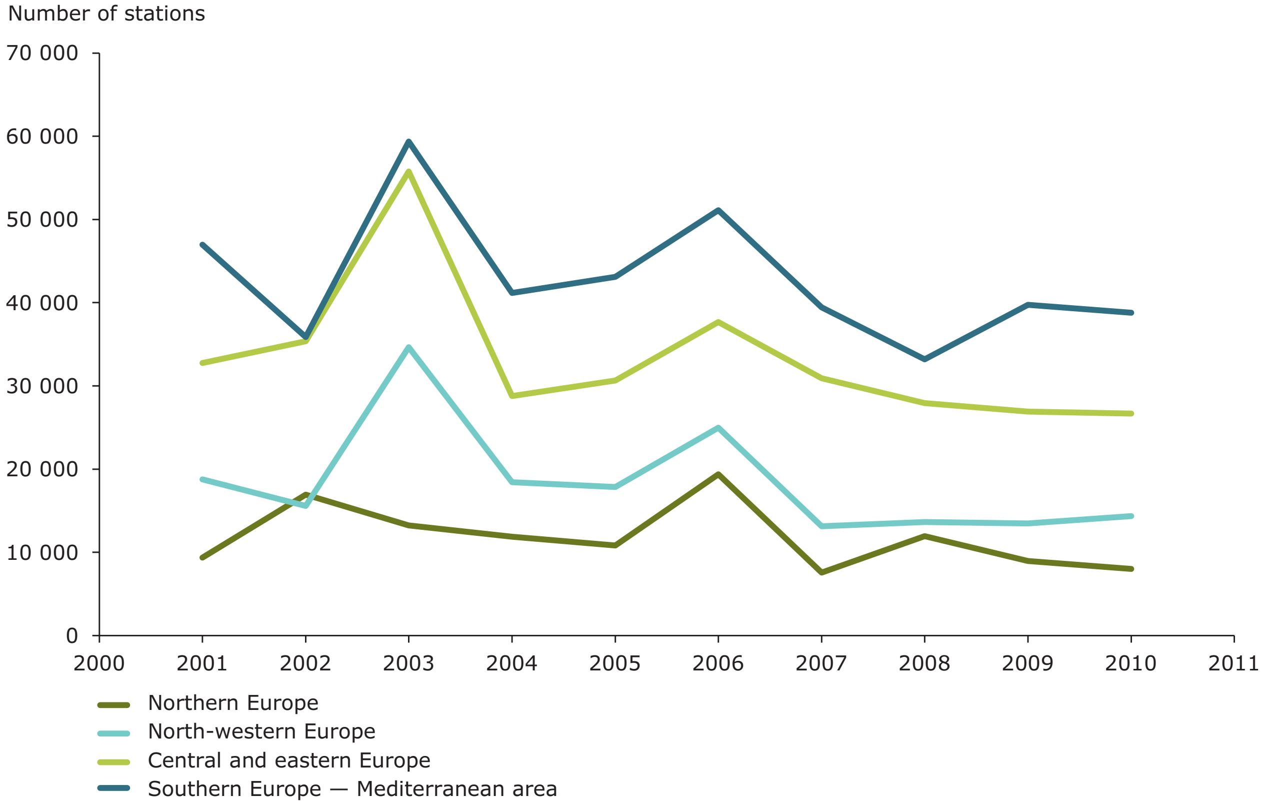
Notes: Northern Europe: Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Norway and Sweden.

North western Europe: Belgium, France (north of 45 ° latitude), Ireland, Luxembourg, the Netherlands and United Kingdom.

Central and eastern Europe: Austria, Bulgaria, Czech Republic, Liechtenstein, Poland, Romania, Slovakia and Switzerland.

Southern Europe and Mediterranean area: Albania, Andorra, Bosnia-Herzegovina, Croatia, Cyprus, France (south of 45 ° latitude), Greece, Italy, Kosovo under UNSCR 1244, Malta, Monaco, Montenegro, Portugal, San Marino, Serbia, Slovenia, Spain and the former Yugoslav Republic of Macedonia.

Figure A2.2 AOT40-forest rural stations, data coverage 75 %, operational over 8 to 10 years



Notes: Northern Europe: Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Norway and Sweden.

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