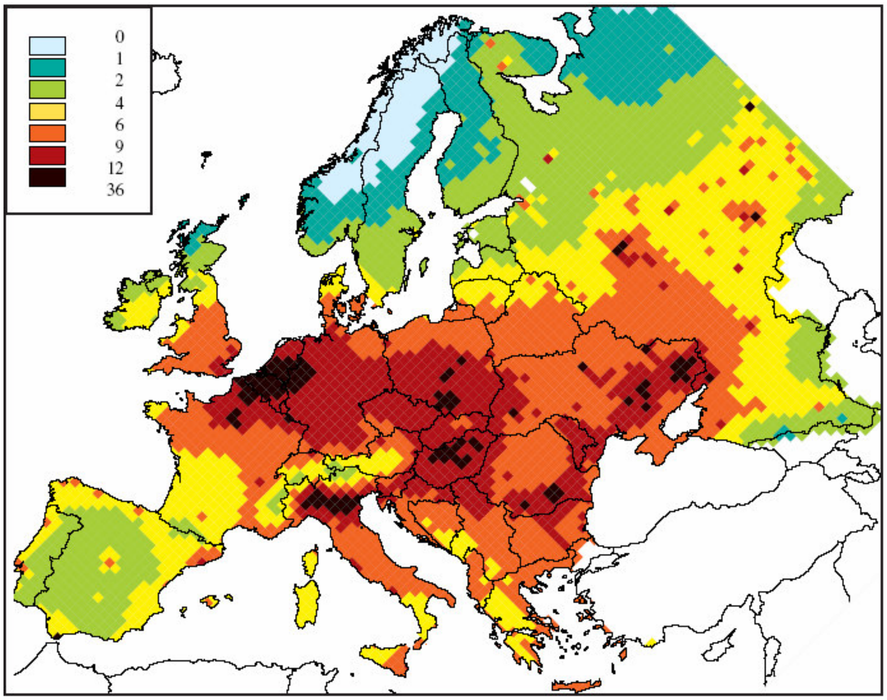
European Environmental Outlook 2005:

Background document air quality 1990-2030



ETC/ACC Technical Paper 2005/02
June 2005

Hans Eerens, Dora Petroula, Janusz Cofala, Liana Kalognomou, Steinar Larssen, Addo van Pul, Myrto Giannouli, Giorgos Mellios, Jan Eiof Jonson, Rob Swart, Leendert van Bree, Jean-Paul Hettelingh, Frank de Leeuw, Rafal Cabala, Zbigniew Klimont, Wolfgang Schoepp, Nicolas Moussiopoulos, Zissis Samaras, Sofia Eleftheriadou, Kevin Barret, Leonor Tarrason, Frank Dentener, Rita van Dingenen, Maarten Krol, Martin Adams

European Topic Centre on Air and Climate Change

The European Topic Centre on Air and Climate Change (ETC/ACC)
is a consortium of European institutes under contract of the European Environmental Agency
RIVM UBA-B UBA-V IIASA NILU AEAT AUTh CHMI DNMI NTUA ÖKO SHU TNO

Front page picture
Loss in statistical life expectancy that can be attributed to the identified anthropogenic contributions to PM2.5 (in months) for the emissions of the year 2000

Author affiliation
Hans Eerens, Dora Petroula, Addo van Pul, Rob Swart, Leendert van Bree, Jean-paul Hettelingh, Frank de Leeuw (RIVM/MNP), Janusz cofala, Rafal Cabala, Zbigniew Klimont, Wolfgang Schoepp (iiasa), Liana Kalognomou, Nicolas Moussiopoulos, Zissis Samaras, Myrto Giannouli,Sofia Eleftheriadou and Giorgos Mellios (auth), Steinar Larssen, Kevin Barret (nilu), Leonor Tarrason, Jan Eiof Jonson (metno), Frank Dentener, Rita van Dingenen, Maarten Krol (JRC-Ispra), Martin Adams (AEA-T)

EEA project managers
Andreas Barkman and Andre Jol

DISCLAIMER

ETC/ACC Technical paper 2005/2
European Topic Centre on Air and Climate Change
PO Box 303
3720 AH Bilthoven
The Netherlands
Phone +31 30 2743550
Fax +31 30 2744433
Email etcacc@mnp.nl
Website *http://air-climate.eionet.europa.eu/*

Summary

This report provides an overview and assessment of the air pollution situation in Europe from 1990-2030, based on indicators for underlying sectoral driving forces, emissions, air quality, deposition and the effectiveness of policies and measures.

The information presented in this report is to be used as background information for the State of the Environment and Outlook Report 2005 (SoEOR2005) of the European Environment Agency (EEA). In particular, the report provides the technical background information on the first set of scenario calculations performed by the European Topic Centre on Air and Climate Change (ETC/ACC) in support of the sub-reports 7 "European Environment Outlook" and 6 "Climate Change, Air Quality and transition pathways to a low-carbon European energy system" of the SoEOR2005.

The information is also to be expected to be of use for the Clean Air for Europe (CAFE)[1] programme, a thematic strategy under the EU sixth environmental action programme. The first part of the report on observed trends will also serve to satisfy the requirement of a regular European air quality assessment by the Exchange of Information Decision.

The report contains detailed background information on the trend and projection of the European air quality as well as an analysis of those calculations. Indicators are presented for Europe and occasionally for individual countries and when relevant for the global scale.

[1] For more information on the CAFE programme see: http://europa.eu.int/comm/environment/air/cafe/index.htm

Table of Contents

1. Introduction

1.1. Scope and coverage of the report

Scope of the report
The information presented in this report is to be used as background information for the State of the Environment and Outlook Report 2005 (SoEOR2005) of the European Environment Agency (EEA). In particular, the report provides the technical background information on the first set of scenario calculations performed by the European Topic Centre on Air and Climate Change (ETC/ACC) in support of the sub-reports 7 "European Environment Outlook" and 6 "Climate Change, Air Quality and transition pathways to a low-carbon European energy system" of the SoEOR2005. The information is also to be expected to be of use for the Clean Air for Europe (CAFE)[2] programme, a thematic strategy under the EU sixth environmental action programme. The first part of the report on observed trends will also serve to satisfy the requirement of a regular European air quality assessment by the Exchange of Information Decision.

The report contains detailed background information on the trend and projection of the European air quality as well as an analysis of those calculations. Indicators are presented for Europe and occasionally for individual countries and when relevant for the global scale in graphs, numbers and text.

Involved institutions
The scenarios described and analysed in this report are the result of a joint effort of several institutions working together in ETC/ACC. The institutions that contributed to this report are the Netherlands Environment Assessment Agency at the National Institute for Public Health and the Environment (MNP/RIVM, the Netherlands), the Norwegian air pollution institute (NILU, Norway), the Norwegian meteorological institute (DNMI, Norway), The Aristotle University of Thessaloniki (AUTH, Greece), the National Technical University of Athens (NTUA, Greece), AEA Technology (UK), the International Institute for Applied Systems Analysis (IIASA, Austria). Other institutes that contributed in this report and are not partners in the ETC/ACC consortium, are the Joint Research Centre (JRC)-Institute for Prospective Technological Studies (IPTS, Spain) and JRC-Institute for Environment and Sustainability (IES, Italy).

Coverage of air pollution problems addressed in the report
Transport (road, off-road and marine), power and heat production, industry and agriculture are the main sectors that cause emissions of air pollutants and are addressed in this report. They result in pollutant concentrations that vary strongly with location and time. Compounds like sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x and NO_2) typically occur in high concentrations locally, close to their sources (streets and industrial plants) and show low concentrations elsewhere.

---

[2] For more information on the CAFE programme see: http://europa.eu.int/comm/environment/air/cafe/index.htm

Compounds like ozone as well as the deposition of acid compounds occur over larger areas (both rural and urban), resulting in a 'regional background'. Particles in air (particulate matter [PM], such as $PM_{2.5}$ and PM_{10}) likewise show a rather high regional background level, to which the urban and local emissions can add significantly with high concentrations close to sources such as busy streets.

This report covers the issues relevant for the effects on human health and ecosystems and damage to crops. Pollutants and issues are:

- health-related: particulate matter (PM_{10}), ground-level ozone, nitrogen dioxide;
- Ecosystems-related: acidifying and eutrophying deposition, ground-level ozone;
- damage to crops: ground-level ozone.

No information is presented on carbon monoxide and benzene. Carbon monoxide is a rapidly diminishing problem related only to some remaining hotspots by traffic or industry locations. Benzene is also a largely hotspot-related problem. However, available data are still insufficient for a Europe-wide assessment of the problem it represents.

1.2. Objectives

The main policy questions addressed in the report are:

- Which progress is being made towards meeting the EU national emission ceiling directive (NEC) and the UNECE Long-range Transboundary Air Pollution (CLRTAP) emission targets?
- Which progress is being made towards meeting targets set in the air quality directives?
- What are trends in emissions of air pollution by the main socioeconomic sectors?
- What is the effectiveness of policies and measures for reducing air pollution?
- What are the trade-offs and benefits of climate change policy for air quality policies and vice versa.
- What will be the state and impact of air pollution by 2030 under a business as usual (baseline) scenario compared to (1) a variant of the baseline with less economic growth assumed, (2) a variant of the baseline with an increased share of renewable energy, (3) a main climate policy scenario, (4) a variant of the climate policy scenario with less economic growth assumed and (5) a variant of the climate policy scenario with strict air quality policies.

The focus is upon the local and regional air pollution issues in Europe. Effects of air pollution on ecosystems as well as on human health are addressed.

There is an increasing awareness in both science and policy communities of the importance of addressing the linkages between air pollutants and greenhouse gases. Many of the air pollutants and greenhouse gases have common sources and their emissions interact in the atmosphere and separately or jointly they cause a variety of environmental impacts on the local, regional and global scales. Linkages work in two directions: there can be synergies and negative trade-offs. Thus, emission control strategies that simultaneously address air pollutants and greenhouse gases may lead to a more efficient use of the resources on all scales. Chapter 8 will address this issue.

1.3. Approach and model framework used for the assessment

Baseline approach (LREM)

For the area of air pollution and climate change the EEA has chosen for a scenario approach which is consistent with the current use of scenarios by DG TREN (Transport & Energy) as well as DG Environment. This means that as a basis for the current scenario analysis some of the scenarios and scenario tools as applied for the Long Range Energy Modelling (LREM) work for DG TREN (EC, 2003b), the GRP project for DG Environment (GRP, 2002 and GRP, 2003) and the Clean Air For Europe (CAFE) programme for DG Environment are used. It should be noted here that the basis of the construction of the CAFE baseline scenario has also been the baseline developed in the context of the "Long Range Energy Modelling" framework contract for DG TREN and all socio-economic and development assumptions are identical to this study (EC, 2003b). The LREM study has been undertaken by one of the members of the ETC/ACC, NTUA as contractor to the commission. Both NTUA and RIVM (member of ETC/ACC as well) have been involved in the GRP project and both IIASA (member of ETC/ACC as well) and NTUA are contractors to the Commission in the CAFE programme. CAFE is a programme organised by the European Commission (DG Environment) to prepare a thematic strategy to reduce air pollution[3] and also makes use of the LREM projections.

Because of the dependency of the scenario results on the selection of the baseline, ideally a multi-scenario approach would provide more insight into the range of uncertainties, but such an approach would require considerably more resources. In order to put our results in perspective, we also compare our results with other scenario studies and explore a limited number of variants. For example, one variant addresses the uncertainty due to the assumed economic growth by calculating the air emissions and quality if the economic growth was assumed to be lower than in the baseline. A second variant explores the consequences of a more ambitious renewable target for Europe. The study focuses on the period up to 2030.

Low-greenhouse gas emission pathways (LGEP)

The low-greenhouse gas emission pathway should lead to "sustainable climate goals" and "sustainable air quality goals" (transboundary air pollution and urban air pollution). As sustainable climate goal in this study the political objective of the Council of Ministers of the European Union is used as the starting point. "Global average temperature should not exceed 2^{o}C above pre-industrial level and therefore concentration levels lower than 550 ppm (parts per million) CO_2 should guide global limitation and reduction efforts (6EAP)". However scientific analysis has shown that for medium to high estimates of the sensitivity of the climate system, the temperature target is consistent with 550 ppm CO_2-equivalents rather than CO_2, or roughly with 450 ppm CO_2 alone. Only for very low estimates of the climate sensitivity, 550 ppm CO_2 stabilisation would be compatible with the temperature objective. Therefore, the temperature objective is assumed to be leading for the SoEOR2005.

As sustainable air quality goals we take recommendations as formulated by WHO and UNECE for DG Environment as targets. In chapter 2 the various air quality goals are discussed further.

[3] For more information on the CAFE programme see: http://europa.eu.int/comm/environment/air/cafe/index.htm

For the purpose of the SoEOR2005 the LREM scenarios are extended, both in time and in scope to make the scenarios relevant for climate change issues and the long term (2050-2100) in addition to the air pollution focus and a time horizon till 2020 in CAFE. In Box 1-1 the extended scenarios are introduced.

The CAFE policy scenario (labelled CAFE CP, climate policy scenario) was at the outset of this study intended to coincide with the LGEP scenario up to 2020. However, the CAFE policy scenario in the course of the analysis changed over time and only became final around October 2004, therefore complete consistency of LGEP and LREM with the CAFE scenarios could in the short time available no longer be pursued. Compared to CAFE-CP, LGEP has to be considered as a stricter climate policy scenario which diverts from the CAFE policy case by 2010. As the analysis in this report shows, the price path assumed in the original CAFE policy scenario after 2020 resulted to be insufficient to bring GHG emissions down sufficiently to achieve the European emissions constraints related to the EU long-term climate objective.

Box 1-1: The scenarios in this report

In this report, the following scenarios and scenario variants are described:

- ***The baseline (LREM) scenario***. This scenario is used as the reference or baseline scenario, it is based on relatively optimistic assumptions with respect to economic growth in Europe with a roughly stable population in the medium term. For the purpose of the SoEOR2005 report, a global context up to 2100 has been provided to the original European 2030 LREM scenario and non-CO_2 greenhouse gas, non-CO_2 energy emissions and carbon sinks have been added. This extended LREM scenario we refer to in this report as **LREM-E.** The baseline scenario does not take into account climate policies, such as those related to the implementation of the Kyoto Protocol of the National Emission Ceiling (NEC) directive.

Variants

(1) To explore the implications of a less optimistic economic development in Europe a low-economic growth variant (**LREM-LE**) to the LREM-E scenario has been analysed for this report.

(2) To explore the effects of a stricter renewable target for Europe (**LREM-REN**). It assumes the implementation of the renewables electricity Directive 2001/77 of September 2001 as well as the Directive 2003/30 on renewable energy in transport and any additional follow-up Directives. Additional policies are introduced so that the share of renewable energy in total energy consumption meets the indicative target of 12 % in 2010 and future targets are set to increase this share to 16 % in 2020 and 20% in 2030. These shares are for illustrative purposes only and not meant as recommendations.

All LREM scenario variants assume only the current legislation **(CLE)** variant for air pollution policies (see LGEP-B scenario description).

- ***The Clean Air for Europe –Climate policy (CAFE-CP) scenario***. This scenario has the same assumptions for population and almost the same economic growth as LREM-E. Rather than taking the obligation of Kyoto as a point of departure and finding an optimal solution for climate policies in Europe, the scenario assumes the price of carbon to increase from 12 €/tCO_2 in 2010 up to €20/tCO_2 in 2020, and to remain at this level afterwards. If at this price level the Kyoto targets are not met through domestic measures in Europe, it is assumed that the gap is closed through usage of the Kyoto mechanisms such as Joint Implementation, the Clean Development Mechanism, and international emissions trading. The scenario takes into account adopted climate policies and measures in Europe. This scenario we refer to in this report as CAFE CP or as only **CP scenario.**

- ***The Low Greenhouse gas Emissions Pathways (LGEP) scenario***. This scenario was developed to assess whether longer-term sustainability objectives in the areas of air pollution and climate change address would be reached by the (extension of) the CP scenario. While the emphasis of CP scenario is on the period 2010-2020, the LGEP scenario puts developments at this time scale into a longer-term sustainability perspective and explores ways in which Europe can move towards a low-carbon energy system. It explicitly analyses policy options beyond those formally agreed today. Assumed is a carbon price development from €20/tCO_2 in 2020 to €65/tCO_2 in 2030. In this report we refer to this scenario as **LGEP** at the global level and **LGEP-Base** or short **LGEP-B** on the European level.

Variants

Two **LGEP** variants with respect to economic growth and the energy system have been explored:

(1) **LGEP-LE:** Economic assumption as in **LREM-LE**, this variant explores the consequences of slower economic growth, leaving other assumptions as in the LGEP-B case.

(2) **LGEP-SER:** Renewable assumptions as in **LREM-REN** and climate change policies as in **LGEP-B.**

In addition, our assessment of the main **LGEP-B** scenario on the European level includes two variants of air pollutants emission control policies:

- "current legislation" **(CLE)** where emission control policies according to the current legislation that have been implemented (or are in the pipeline) until the end of 2003 in each country are considered.
- "maximum feasible reductions" **(MFR)** where the effects of implementing in each economic sector the presently available most advanced technical emission control measures are considered.

1.3.1. Introduction to the DPSIR-approach

In this report, scenario results are presented and analysed according to the so-called DPSIR chain (see Box 1-2), covering the most important socio-economic and environmental aspects for the issues of air pollution and climate change, as it is presented in Figure 1-1. The assessment is based on *indicators*, aiming to describe **D**riving forces (e.g. population, GDP total) and **P**ressures (e.g. emissions of the various compounds), subsequently the **S**tate of the environment (regional and urban air quality, climate variables) and its **I**mpacts (e.g. exceedances of critical loads and climate change related impacts), and finally **R**esponses.

Box 1-2 Introduction DPSIR approach

The **Driving forces-Pressure-State-Impact-Response (DPSIR)** assessment framework is used to structure the main environmental cause-effect chains under the following definitions (EEA, 2001)

D: Driving forces or underlying causes describe the ultimate factors causing environmental change and include change in real income, population change, behavioural, sectoral and social change, market failure, policy failure and information failure.

P: Driving forces lead to **pressures** on the environment exerted by *proximate causes* (e.g. use of natural and biological resources and emissions).

S: Pressures affect the **state** of the various environmental sectors (air, water, and soil) in relation to their functions.
I: Changes in the state of the environment may have **impacts** on ecosystems, humans, materials and amenities, and resources.
R: Appraisal of different policy options as **response** to environmental problems**.**

This type of analysis is useful not only because it describes the relationships between the origins and consequences of environmental problems, but also because it helps the understanding of their dynamics by focusing on the links between DPSIR elements (EEA, 2003)

DRIVING FORCES, PRESSURE, STATE, IMPACTS AND RESPONSES IN SOEOR2005

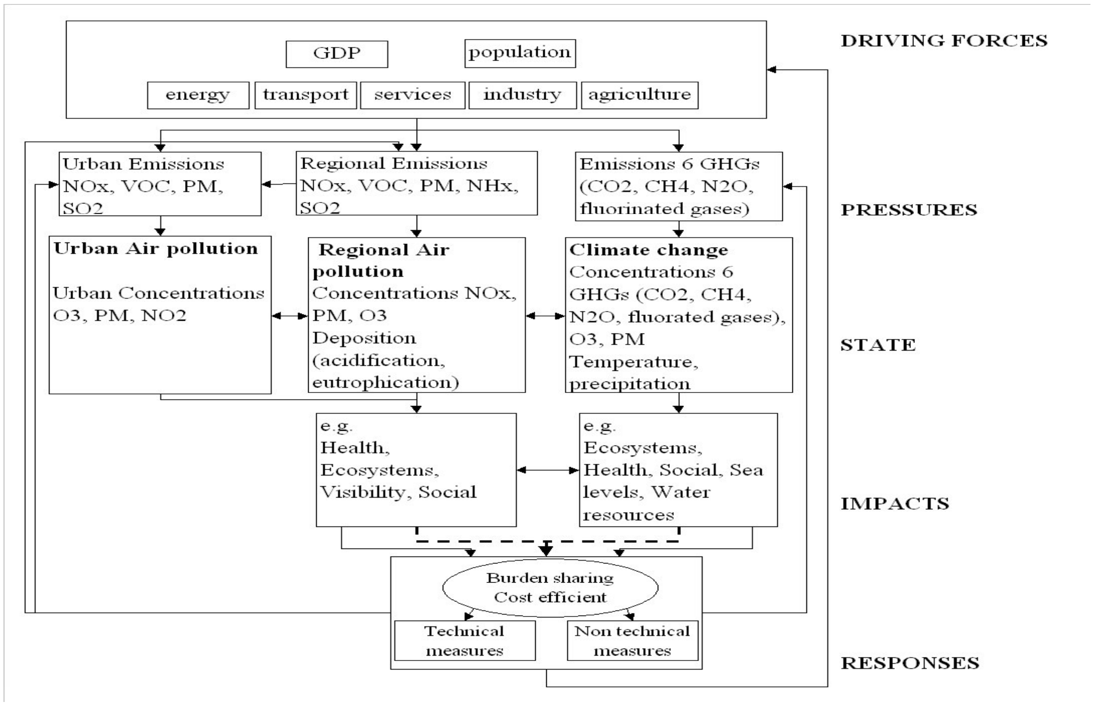


Figure 1-1 : DPSIR chain for air pollution and climate change

1.3.2. Selection of Indicators

Different criteria have been used to select the indicators for reporting the results of our scenario calculations (e.g. do they communicate meaningful political messages, are they comparable between countries, are they scientifically sound, are they transparent regarding the data used, can they be modelled?). This to optimise their relevance regarding the issues of air quality and climate change, including communicating information about progress towards agreed policy targets (so-called distance to target) and providing early warning signals.

In recent years ETC/ACC has been working on the development of a set of indicators. To a large extent the current scenario analysis uses these indicators. We refer to Eerens et al., (2002) for more details about their development. As the CAFE baseline scenario was the starting point for the further development of scenarios for SoEOR2005, the set of indicators was also made (to the extent possible) consistent with the preliminary list, discussed and developed within CAFE (EC, 2003a). The

Monitoring Mechanisms was a source of information for the development of our driving forces indicators concerning agriculture and waste production (Gugele and Roubaris, 2002), in order to facilitate the comparison between our results and the GHG trends and projections reported by member states. Finally, indicators from UNECE which present the critical loads on ecosystems were also considered (CCE, 2001, pp. 19-20)

All these indicators together formed a list, which was extended with new sub indicators, needed for the assessment of the results.

In the following chapters, most of the indicators in the scenarios will be assessed for the short, medium and long term. First in a global context and then in more detail in the European context.

1.3.3. An Integrated Assessment Framework

To make the scenario analysis for this study possible the ETC/ACC has developed an integrated assessment (IA) framework to enable the evaluation of the different scenarios, see Eerens, Amann, van Minnen (2002). The framework consists of a combination of existing models in a way that connections between the models have been ensured and data exchange needs are harmonised Figure 1-2 presents an overview of the models, their inputs and outputs.

- PRIMES developed by NTUA (European and national energy and related CO_2 emissions)
- RAINS developed by IIASA (national emissions of SO_2, NO_x, NH_3 and VOCs, exceedances of critical loads on sulphur, nitrogen and ozone)
- POLES developed by IPTS
- IMAGE, TIMER and FAIR developed by RIVM
- A model at AEA-T developed to calculate non-CO_2 emissions
- OFIS, developed by AUTH (urban air quality)
- EMEP, developed by DNMI (regional air quality and deposition)

The objective of the framework is to:

- Analyse the full causality chain (from economic activities and emissions to impacts) in order to evaluate the (cost-) effectiveness of different policies in the field of climate change and air pollution.
- Analyse co-benefits of environmental policies by integrating different environmental themes (i.e. climate change, air pollution, particulate matter, and ozone depletion).

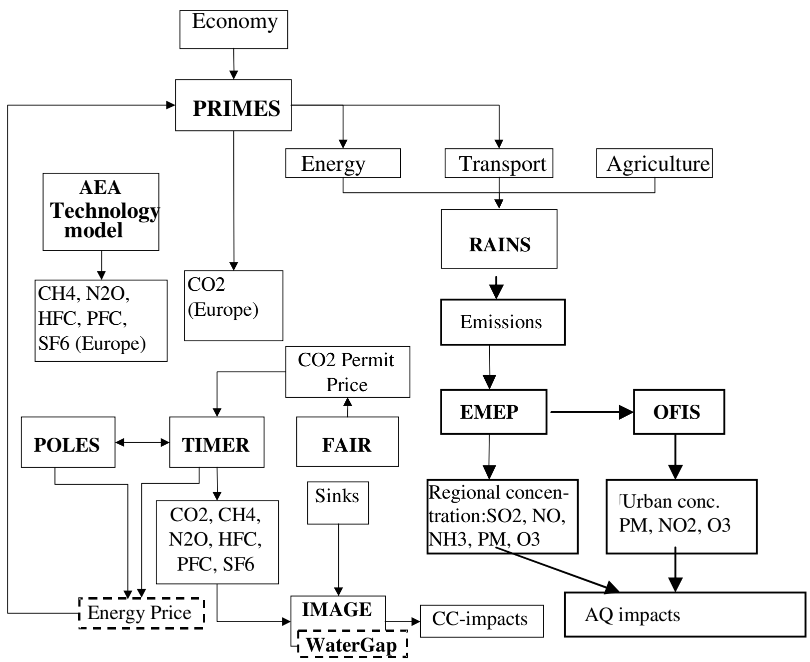


Figure 1-2 Overview of the model framework used for the scenarios analysis in this report

Certain aspects had to be added to or changed in the models in order to reach the mentioned objectives. New data sources, for example, have been added into the framework in order to develop more accurately future trends projections in non- CO_2 GHG emissions, see Bates and Klimont (2002).

More information on the models used can be found in Annex 7

Box 1-3 Country Coverage

In this report scenario analyses for the European scale cover in principle EEA 32: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
Results in this report are presented for:

EU15 Austria, Belgium, Denmark Finland France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, United Kingdom
EU10 Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia (acceding countries in 2004)
EFTA4 Iceland, Liechtenstein, Norway, Switzerland,
CC3 (Candidate Countries) Bulgaria, Romania, Turkey
EU25 EU15 plus EU10
EU30 EU 32 without Iceland and Liechtenstein

Country specific information is not presented in the main text but can be found in background documentation.

Not all models have the same coverage. PRIMES calculations do not cover Liechtenstein and Iceland, RAINS does not cover Turkey in its impact assessment. IMAGE TIMER and FAIR results for Europe as a region do include Romania and Bulgaria, but do not include Turkey

1.3.4. Limitations

The LGEP scenario is developed to show the transition to a low-carbon energy system in Europe. This doesn't guarantee that LGEP will automatically meet "sustainable climate goals" and "sustainable air quality goals". However, even reaching these goals does not guarantee that environmental goals in other areas, like e.g. biodiversity or water quality will automatically be met. For SoEOR2005 the LGEP scenario thus does not cover automatically the needs for these other areas..

Furthermore, it is important to notice that the LGEP scenario includes the assumption that if the Kyoto targets are not met through domestic measures with the given carbon price, the remaining gap is closed by usage of the Kyoto mechanisms, Joint Implementation, the Clean Development Mechanism (CDM), and international emissions trading. This means that the LGEP scenario does not imply that all reduction needed to meet the Kyoto targets will be achieved by domestic policies inside Europe. To a large extent reductions are gained outside Europe.

1.3.5. Uncertainties

It is important to recognise that the analysis presented in this report has many uncertainties. One could distinguish many types of uncertainties:

- *Assumptions about the future and human choice.* Ultimately, this report is about the future, which is not only inherently unknown, but also dependent on human choices. Which policies will be implemented in the future and how effective will they be? How fast will technology develop and in which direction? How will human preferences evolve? To what extent are the findings in this report for Europe dependent on the developments in the rest of the world?
- *Model-based assessment.* The results presented in this report are dependent on the way in which real-world dynamics are translated into model equations. How accurate do we model atmospheric chemistry of ozone precursors and transport of air pollutants?
- *Choice of indicators.* It is uncertain to what extent the indicators used are the right ones to represent what we really want to know. For example, are the air quality indicators adequately reflecting human health effects? And are the sustainability targets really preventing the impacts we would like to avoid?
- *Measuring and monitoring.* The statistical data on various socio-economic issues, data on the behaviour of natural systems, emission factors, all these sources of information which form the empirical basis of most of the models used are uncertain to a varying degree. For example, emission factors for CO_2 from energy have much lower uncertainties than those for nitrous oxide, or factors for carbon sequestration.

In the context of the report, the most relevant aspect of uncertainties appears to be how robust the findings are. If the basic data would be inaccurate, or if particular assumptions with respect to future would turn out to be wrong, are the conclusions still valid? And which factors influence the uncertainty in the results the most?

The choices made in designing the process leading to the scenarios in this report have influenced the extent to which something can be said about uncertainties.

It is evident that the models used are a simple representation of the real world, for both natural and socio-economic systems. For some variables, such as demographic development, the uncertainties in modelling future developments are relatively small because of the inertia in the population system. Technological change, and its relationship with economic growth is much more uncertain, which is reflected in the way it is incorporated in the models.

In this report, we have adopted and extended the one baseline scenario developed for the CAFE programme. The same assumptions with respect to demographics, economic growth and international fuel prices have been assumed for the LREM-E and CAFE-CP scenarios. These are the main sources of uncertainties in the analysis. Evidently, other socio-economic developments are possible or even likely. Higher or lower population or economic growth would lead to different outcomes in terms of emissions, environmental quality and costs of policies to achieve environmental goals. Ideally, a multi-scenario analysis should have been performed, but this was not done in the context of the CAFE project and insufficient time and resources were available to do this in the context of the SoEOR2005 report. In the report, we compare our results with a number of recent other analyses, and explore a low economic growth variant to provide some context to the results. For the Low Greenhouse gas Emissions Pathway, we explore different ways in which low air pollutant and GHG emissions can be achieved in Europe in line with longer-term air and climate change objectives (e.g., a renewable energy variant).

A type of uncertainty which is often forgotten is the issue of whether selected indicators or targets are representative for what they are aimed to express. It is assumed that if emissions of air pollutants are reduced and concentrations and deposition levels reduced to target levels, the impacts will be reduced or avoided. This is by no way certain, although one could of course say that the risks of impacts would become lower. For climate change, temperature is used as a surrogate for climate change impacts. However, other factors, such as precipitation or the occurrence of extreme events could be much more relevant, but we know less about those.

1.4. Report outline

Chapter 2 describes the air quality targets and the main air pollution issues of concern for Europe.

Chapter 3 and Chapter 4 continue with the emissions trends and state of air quality in Europe for the period 1990-in 2002 respectively.

Chapter 5 deals with the global and european emission assumptions and driving forces up to 2030. Subsequently, in Chapter 6 the resulting global and european emissions under these assumptions are presented.

Chapter 7 presents the air pollutant impact on human health and ecosystems. Chapter 8 focuses on urban air pollution and the impact on human health.

Chapter 9 discusses the co-benefits of a potentially sustainable GHG emission pathway for air pollution by 2030 through reduced emissions and reduced costs.

Chapter 10 finally concludes with a synthesis and discussion.

2. Air quality targets

2.1. Overview of main air pollution issues

Air pollution issues in Europe are addressed by:

- European Community legislation and strategies;
- The United Nations Economic Commission for Europe (UN-ECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP).

Air pollution is a transboundary, multi-pollutant, multi-effect environmental problem. Although significant and well directed efforts over more than two decades have led to a reduction in emissions, air pollution in Europe continues to pose risks and have adverse effects on human health and on natural and man-made environments (EEA, 2003). Box 2-1 summarises various important air pollution issues. These arise either from atmospheric deposition of pollutants or from direct exposure to ambient concentrations of pollutants i.e. from air quality.

The main deposition issues for this report are:

- acidification of soils and freshwater through the deposition of sulphur and nitrogen compounds;
- eutrophication of terrestrial, freshwater and marine ecosystems through the deposition of nitrogenous nutrients.

Box 2-1 Air pollution issues

1. Deposition of air pollutants

Ecosystem acidification and eutrophication: Emissions, atmospheric chemical reactions and subsequent deposition of nitrogen oxides (NO_x) sulphur dioxide (SO_2), and ammonia (NH_3) are causing acidification of terrestrial and freshwater ecosystems. Eutrophication is a consequence of excess input of nitrogen nutrients (nitrogen oxides and ammonia), that disturbs the structure and function of ecosystems e.g. excessive algae blooming in surface waters.

Materials damage: Acidifying pollutants also cause deterioration of structures and monuments.

2. Air quality

Ground-level ozone is a strong photochemical oxidant, which, in ambient air, can affect human health, and damage crops, vegetation and materials. Ozone is not emitted directly, but is formed in the lower atmosphere by reaction of volatile organic compounds and NO_x in the presence of sunlight.

Exposure of particulate matter, measured as concentrations of PM_{10} or $PM_{2.5}$ (particle diameter less than 10 and 2.5 µm respectively) in ambient air represents one of the largest human health risks from air pollution. Short-term inhalation of high concentrations may cause increased symptoms for asthmatics, respiratory symptoms, reduced lung capacity and even increased death rates. Harmful compounds in particulate form can damage materials.

Airborne particles can be emitted directly to air (primary particles) or can be produced in the atmosphere from precursor gases (secondary particles) such as SO_2, NO_x and ammonia.

Sulphur dioxide (SO_2) and nitrogen oxides (NO_x - combinations of nitrogen monoxide, NO, and nitrogen dioxide, NO_2) can have various adverse impacts on vegetation, human health, and materials.

The main air quality issues addressed are:

- human health effects resulting from ground-level (tropospheric) ozone, particulate matter and other pollutants, including nitrogen oxides, benzene and sulphur dioxide;
- adverse effects on vegetation and crops resulting from ground-level ozone, nitrogen oxides and sulphur dioxide.

Ground-level ozone, acidification and eutrophication are issues of European scale because of the atmospheric transboundary transport of pollutants. Air quality issues such as nitrogen dioxide and benzene are more sub-regional or local. Particulate matter and ozone have both local and transboundary aspects. Policy measures, therefore, must be targeted accordingly at European, national and local levels.
The issues of stratospheric ozone depletion and dispersion of chemicals such as organic compounds or heavy metals are not addressed in this report.

2.2. Review of Air Emission Targets

A key element of EU legislation on emissions is the national emission ceilings directive (NECD) (European Community, 2001a), which sets emission ceilings for sulphur dioxide (SO_2), nitrogen oxides (NO_X), ammonia (NH_3) and volatile organic compounds (VOCs). These have to be achieved through EU-wide and national policies and measures aimed at specific sectors. Member States are obliged to prepare a national programme presenting their approaches to achieve the emission ceilings.
EU sectoral emission legislation sets emission standards for specific source categories. There are a number of EU directives controlling emissions from vehicles (European Community, 1998), large combustion plants (European Community, 2001b) and industry (VOC directive — European Community, 1999 and integrated pollution prevention and control directive — European Community, 1996).

National emission ceilings for EU and non-EU countries have been agreed upon under the CLRTAP Gothenburg protocol (UNECE, 1999). Almost all European countries that are parties to CLRTAP have signed protocols under this convention. By March 2005, sixteen parties have ratified the 1999 Gothenburg protocol and will enter therfore into force. These ceilings represent cost-effective and simultaneous reductions of acidification, eutrophication and ground-level ozone, see Table 2.1. The EU NECD ceilings were developed using a similar approach.

Table 2.1: Emission reduction targets for 1990-2010 (%)

	Western Europe	Central and eastern Europe	Eastern Europe, Caucasus and Central Asia
Acidification (SO_2, NO_x and NH_3)	-56	-40	-40
Eutrophication (NO_x and NH_3)	-36	-10	-25
Ozon precursors (NO_x, VOC, CO and CH_4)	-53	-21	-36

2.3. Review of Air Quality targets

The air quality framework directive (96/62/EC) has a central aim; to avoid, prevent or reduce adverse effects on human health and the environment.

In the daughter directives (SO_2, NO_x/NO_2, PM_{10}, Pb, CO, C_6H_6 and O_3,) limit values (for ozone, target value and long-term objectives) for the protection of human health have been set for 2005 and 2010, see Table 2.2.

If these limit values are exceeded, Member States are obliged to set up, implement and report abatement plans. EU air policy will be evaluated and new policies developed under CAFE, the European Commission clean air for Europe programme, which is part of the sixth environmental action programme (6EAP). This should lead to a thematic strategy for air pollution in 2005.

Table 2.2: EU ambient air quality limit (LV) and target (T) values for the protection of human health and ecosystems (1999/30/EC, 2002/3/EC, 2001/81/EC).

Pollutant	Value (average time)	nr of exceedances allowed/ min exceedance area	To be met in
Human Health			
Ozone (T)	120 µg/m³ (8h average)	< 76 days/3 year	2010
PM_{10} (LV)	50 µg/m³ (24h average)	< 36 days/year	2005
PM_{10} (LV)	40 µg/m³ (annual mean)	None	2005
SO_2 (LV)	350 µg/m³ (1h average)	< 25 hours/year	2005
SO_2 (LV)	125 µg/m³ (24h average)	< 4 days /year	2005
NO_2 (LV)	200 µg/m³ (1h average)	< 19 hours/year	2010
NO_2 (LV)	40 µg/m³ (annual mean)	None	2010
Ecosystem protection			
Ozone(T)	$AOT40_c$ of 18 (mg/m³).h (5 year average)	Daylight hours May-July	2010
Ozone	$AOT40_c$ of 6 (mg/m³).h (5 year average over 22500 km²)	Reduction >33% compared to 1990	2010
Acidification	Critical load exceedances (year, averaged over 22500 km²)	Reduction >50% compared to 1990	2010
NO_x(LV)	30 µg/m³ (annual mean)	> 1000 km²	2001
SO_2(LV)	20 µg/m³ (annual mean)	> 1000 km²	2001
SO_2((LV)	20 µg/m³ (winter average)	> 1000 km²	2001

2.4. Review of Air quality impacts targets

Long-term environmental impact targets (see Table 2.3) within the EU and the CLRTAP policy frameworks are derived from an effect-oriented approach based on critical thresholds. These define the extent to which deposition and ambient concentrations should be reduced to maintain the structure and function of ecosystems.

Table 2.3: Long term air quality targets to protect human health and ecosystems

Pollutant	Value (average time)	nr of exceedances allowed/calculation period
PM_{10}	50 µg/m³ (24h average)	None
PM_{10}	20 µg/m³ (annual mean)	None
Ozone	120 µg/m³ (8h average)	None
Ozone	$AOT40_c$ of 6 (mg/m³).h (5 year average)	Daylight hours May-July
Acidification	Critical load exceedances (year)	None
Eutrophication	Critical load exceedances (year)	None

The level of protection afforded to ecosystems may therefore be expressed in terms of the fraction of total ecosystem areas where critical thresholds are not exceeded and hence protected from further impact (this does not reflect recovery from past damage, which typically only occurs over an extended period of time), see CCE, 2001; 1999). The emission targets set in the EU NECD and Gothenburg protocol correspond to interim environmental targets where ecosystem protection will be improved but critical thresholds will still be exceeded in some areas.

2.5. Air Quality targets in a sustainable context

2.5.1. Ecosystems

Critical loads

For the work under the Convention on Long-range Transboundary Air Pollution critical loads have been defined at the end of the 1980s (Nilsson and Grennfelt, 1988) as:
"the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur to present knowledge".

For the support of the 1999 multi-pollutant multi-effect Gothenburg Protocol and for the 2001 NEC-directive critical loads have been computed and mapped under the Convention on Long-range Transboundary Air Pollution by the Coordination Center for Effects[4] (CCE at RIVM) for nutrient nitrogen, to avoid eutrophication, and for acidity, defining the maximum depositions of S and N not leading to "harmful effects" due to acidification (Hettelingh et al., 2001). Emission reductions are considered successful if non-exceedance of critical loads is attained, i.e. when actual depositions do not exceed critical loads.

Critical loads are based on a steady-state concept; they are the constant depositions an ecosystem can tolerate in the long run, i.e. after it has equilibrated with these depositions. As such critical loads are a measure of sustainability of air quality.

However, many ecosystems are not in equilibrium with present or projected depositions, since there are processes ('buffer mechanisms') at work, which delay the reaching of an equilibrium (steady state) for years, decades or even centuries. By definition, critical loads do not provide any information on these time scales.

---

[4] The CCE (www.rivm.nl/cce) is a Programme Center under the International Co-operative Programme on Moddeling and Mapping of the Convention on Long-range Transboundary Air Pollution (http://www.unece.org/env/lrtap)

Dynamic modelling
With critical loads, i.e. in the steady-state situation, only two cases can be distinguished when comparing them to deposition: (1) the deposition is below critical load(s) i.e. does not exceed critical loads, and (2) the deposition is greater than critical load(s), i.e. there is critical load exceedance. In the first case there is no (apparent) problem, i.e. no reduction in deposition is deemed necessary. In the second case there is, by definition, an increased risk of damage to the ecosystem. Thus a critical load serves as a warning as long as there is exceedance, since it states that deposition should be reduced. However, it is often assumed that reducing deposition to (or below) critical loads immediately removes the risk of 'harmful effects', i.e. the chemical criterion (e.g. the Al/Bc-ratio[5]) that links the critical load to the (biological) effect(s), immediately attains a non-critical ('safe') value and that there is immediate biological recovery as well. But the reaction of soils, especially their solid phase, to changes in deposition is delayed by (finite) buffers, the most important being the cation exchange capacity (CEC). These buffer mechanisms can delay the attainment of a critical chemical parameter, and it might take decades or even centuries, before an equilibrium (steady state) is reached. These finite buffers are not included in the critical load formulation, since they do not influence the steady state, but only the time to reach it. Therefore, dynamic models are needed to estimate the times involved in attaining a certain chemical state in response to deposition scenarios, e.g. the consequences of 'gap closures' in emission reduction negotiations. In addition to the delay in chemical recovery, there is likely to be a further delay before the 'original' biological state is reached, i.e. even if the chemical criterion is met (e.g. Al/Bc<1), it will take time before biological recovery is achieved (Posch et al., 2003)

[5] In the Mapping Manual (www.icpmapping.org) the Bc/Al-ratio is used. However, this ratio becomes infinite when the Al concentration approaches zero. To avoid this inconvenience, its inverse, the Al/Bc-ratio, is used here.

Figure 2-1 shows a hypothetical evolution of acid deposition exceeding critical loads (at t_1) and its return to safety (t_4) (top graph), the corresponding (middle graph) development of the acidification indicator (Al/Bc ratio) with a delayed response both into risk (t_2) and safety (t_5) and, finally, the evolution of a biological indicator with again delays in t_3 and t_6 respectively.

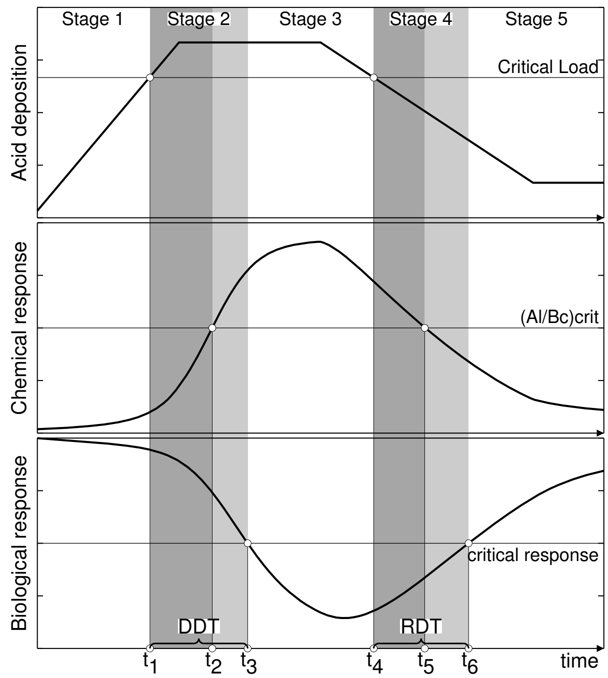


Figure 2-1: 'Typical' past and future development of the acid deposition effects on a soil chemical variable (Al/Bc-ratio) and the corresponding biological response in comparison to the critical values of those variables and the critical load derived from them. The delay between the (non)exceedance of the critical load, the (non)violation of the critical chemical criterion and the crossing of the critical biological response is indicated in grey shades, highlighting the Damage Delay Time (DDT) and the Recovery Delay Time (RDT) of the system.

Target loads

A target load is the deposition for which a pre-defined chemical or biological status is reached in the target year and maintained (or improved) thereafter. This implies, *inter alia*, that a target load has always to be smaller (or equal) to the corresponding critical load. If it exists at all, there exists an infinite variety of deposition paths, i.e. target loads. To bring order into this multitude and to make results comparable, a target load is a deposition path characterised by three numbers (years): (i) the protocol year, (ii) the implementation year, and (iii) the target year (see Figure 2).

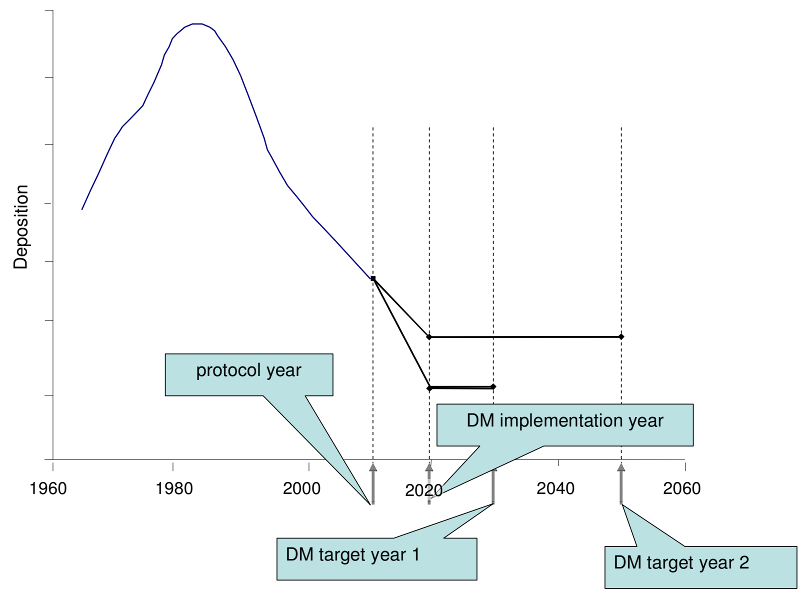


*Figure 2-2: Schematic representation of deposition paths leading to target loads by dynamic modelling (DM), characterised by three key years. (i) The year up to which the (historic) deposition is fixed (***protocol year***); (ii) the year in which the emission reductions leading to a target load are implemented (***DM implementation year***); and (iii) the years in which the chemical criterion is to be achieved (***DM target years***).*

The ***protocol year*** for dynamic modelling is the year up to which the deposition path is assumed to be known and cannot be changed. This can be the present year or a year in the (near) future, for which emission reductions are already agreed. An example is the year 2010, for which the Gothenburg Protocol, the EU NEC Directive and other (national) legislation is (soon expected to be) in place.

The ***implementation year*** for dynamic modelling is the year in which all reduction measures to reach the final deposition (the target load) are assumed to be implemented. Between the protocol year and the implementation year deposition are assumed to change linearly (see Figure 2-2).

Finally, the ***target year*** for dynamic modelling is the year in which the chemical criterion (e.g., the Al/Bc ratio) is met (for the first time).

A consistent database of target load functions for Europe's ecosystems and soil types is under construction at the Coordination Center for Effects. Preliminary analysis has shown (Posch, 2002) that a soil, which becomes non-exceeded with respect to acidity, may need decades or even centuries to recover its earlier (base cation) status.

The application of dynamic models for acidification as foreseen under the Convention on Long-range Transboundary Air Pollution and the EC-CAFE programme is to provide information on combinations of sulphur and nitrogen deposition which lead to recovery within pre-defined time horizons (e.g. 2030, if emission reductions are implemented in e.g. 2015).These deposition combinations are termed "target load functions".

Influence of climate change on critical loads and time delays of recovery
Information is lacking to provide robust information on the relationship between climate change and critical loads. The most important interactions related to climate change are changes in precipitation and temperature (weathering of base-cations and changing deposition patterns) and increasing CO_2 concentrations (increased carbon sequestration and with constant C:N ratio's also nitrogen storage). Models to calculate these complex interaction, with positive and negative effects on the critical load value, start to emerge. A preliminary scenario analysis of climate change and acidification combinations is described in Posch et al. (1996, 2002). Posch (2002) showed that the expected climate change in Europe in general increases critical loads, although decreases were observed in mountainous and arid regions.

2.5.2. Sustainable targets to protect human health

Short-term and long-term exposure to air pollution affects human health negatively. In general it is caused by emissions from mobile and point sources which are directly linked to for example energy consumption, industrial production, transport, and household activities. Often these emissions are transboundary, as air pollutants can travel a considerable distance away from their sources. In addition, emissions from sources in urban areas can have a significant local impact on human health, especially under stagnant weather conditions. Provisional estimates reveal that the extent of the health effects of the major air pollutants on life expectancy is in the order of several tens to hundreds of thousands of premature deaths per year in Europe (WHO, 2000).

As mentioned earlier in this chapter a framework of air quality guidelines (WHO Europe) and air quality standards and emission ceilings (European Union, member states) has been set in place to improve poor air quality and to reduce major adverse health impacts. In a number of cases (like PM_{10} or $PM_{2.5}$ and ground-level ozone) a safe concentration ("no-effect level or threshold"), below which health effects are unlikely to occur, does not seem to exist on a population level. Compliance with a standard can reduce the human health impact to a certain extent but can not prevent it. Furthermore, choices of air quality indicators like e.g. NO_2, being more an index of traffic-related air pollution rather than a causal agent by itself at low ambient concentrations, can undermine the credibility of an air management system from a health benefit perspective. Even if the current air quality targets set for 2005 and 2010 are met, considerable health impacts are still likely (WHO, 2003).

The long-term and sustainable goals for air pollution control are 1) preventing exposure to pollutants at concentrations likely to cause harm, and 2) achieving the highest level of human protection in the most cost-effective manner. Such sustainable targets are, however, not easy to formulate and require, in the longer term, an amending of the current framework and legislation strategy with new approaches like sustainable target setting and gap closure to achieve the greatest standard of overall exposure reduction and health protection (NSCA, 2003). An interim measure to start targeting these goals must use 1) prioritization of reducing exposure to those pollutants with the greatest health impact and 2) reduction of total population exposures. In addition, the current focus on compliance on the so-called "hot-spots" requires prudent weighing of "equity' versus "efficiency" principles. Quantitative exposure and health impact and cost-benefit and cost-efficiency assessment techniques are prerequisites to being able to implement such strategies.

Remarkably, other legislation areas like individual chemical substances (carcinogens) and industrial and transport safety have already developed long-term goals for human health protection. The maximum acceptable individual risk concept of $1*10^{-6}$ (for long-term mortality or morbidity, and one in a million people per year) is a frequently used (combined also with margin of safety approaches). However, on dealing with complex and difficult abatement measures, a risk of $1*10^{-5}$ is sometimes also accepted. Dealing with air pollution, however, this concept becomes even more difficult to apply because risks are usually in the order of 1 or more people in every hundred.

Based on approaches dealing more sensibly with air pollution control and setting sustainable long-term goals to protect human health, the following approaches may be suggested (based on the NSCA document, but others may also exist). The discussion could start from the principle that an effective air quality control strategy should focus on to reduce exposure to air pollutants which has the greatest health impact on the largest number of people.

- Prioritize in enforcement action in the current air quality management system based on health impact assessment and risk rating of critical (health effect causative) pollutants (or fractions as in ambient PM)
- Extend the air quality standards and emission ceiling approaches with critical components important for human health like the primary anthropogenic fraction for PM
- Use balanced weighing (in health-benefit and cost-benefit terms) of equity versus efficiency principles to improve hot-spots and/or overall air quality
- Develop a strategy to implement a tiered and more flexibilized air quality standard approach to be differentially implemented in urban, rural and roadside locations (the latter maybe less stringent)
- Use balanced weighing (in cost and benefit terms) of reducing background levels (transboundary approach, mandatory) versus regional/local levels (national/urban approach, flexible)
- Prioritize in overall population exposure reduction and maximizing health benefit actions and use the gap closure and cost benefit models as a sustainability assessment tool
- Develop new tools for evaluating health impacts of the total air pollution mixture
- Use these options and proposals as a starting point for broad international consultation to develop criteria and, ultimately, also to establish concrete sustainable exposure and health risk reduction targets and abatement strategies.
- Communicate the long term (sustainable) objectives and stimulate long-term (up to 2050/2100) visions (including emissions and technology pathways) that can lead to the realisation of the objectives.

3. Historical emissions in Europe 1990 – 2002

3.1. Introduction

In this chapter information on the emissions of ozone precursors, particulate matter and precursors of secondary aerosol and acidifying components from the period 1990-2002 are presented. The amounts, the sector split and trends in the emissions are given as well as an assessment of the distance to targets set in the NEC-directive.

3.2. Emissions of ozone precursors

Emissions of total non-methane volatile organic compounds, nitrogen oxides, carbon monoxide and methane, contribute to the formation of ground level (tropospheric) ozone. The relative impact of their combined contribution to ozone formation can be assessed based on their tropospheric ozone forming potential (TOFP): nitrogen oxides 1.22, non-methane volatile organic compounds 1.0, carbon monoxide 0.11 and methane 0.014 (de Leeuw 2002).

Transport is the dominant source of ozone precursors and contributed with 45% of the total emissions in 2002 in EEA32 countries. Other important emission sources in 2002 included commercial and domestic combustion and use of solvents in paint, glue and printing.

Non-methane volatile organic compounds (NMVOC) (38%/32% of total TOFP-weighted emissions for EU15/EU10) and nitrogen oxides (48%/51% for EU15/EU10) are the most significant pollutants contributing to the formation of tropospheric ozone in 2002. Carbon monoxide and methane contributed about 15% and 1% respectively. The emissions of NO_x and NMVOC, the two most important pollutants, were reduced with 28% and 35% respectively between 1990 and 2002, for EEA32 countries.

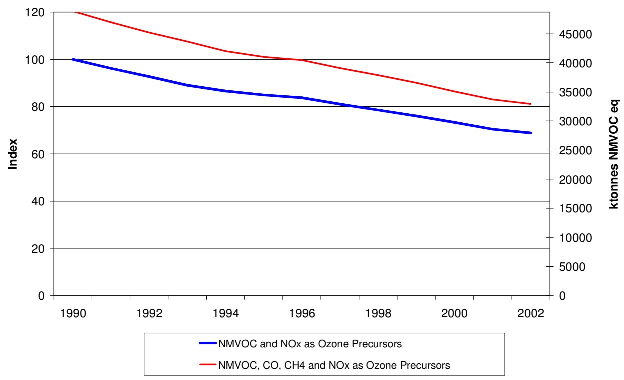
Total ozone precursor emissions have been reduced by 33% across the EEA32 region between 1990 and 2002. For EU15 countries, emissions have been reduced by 35%. For EU10 countries, the reduction was 40%. The decrease between 2000 and 2001 was 2.7% and 1.3% respectively for EU15 and EU10.

Emission reductions that have occurred since 1990 are mainly due to further introduction of catalytic converters for cars and increased penetration of diesel, but also as a result of the implementation of the Solvents Directive in industrial processes. Emissions in the transport sector have reduced by 39% between 1990 and 2002 (EEA32). This is also the largest reduction in absolute terms, and this reduction represents almost 60% of the total reduction in TOFP-weighted emissions in EEA32 countries. The sector responsible for the second largest absolute reduction was the energy industries sector, with 36% reduction in emissions, corresponding to a contribution of 12% to the total reduction of ozone precursor emissions.

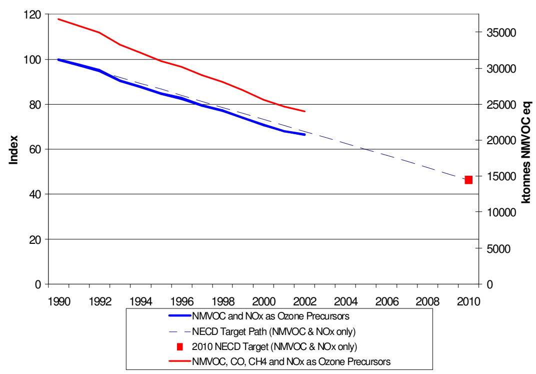
In EU10 countries, emission reductions in industrial sectors are as significant as the reductions in traffic emissions, in terms of reduction in TOFP-weighted emissions. Emissions in the industry (processes) sector have been reduced by 72% between 1990 and 2002, in energy-related sectors by between 50-66%, and in the transport sector by 28% since 1990. In terms of contributions to TOFP emissions reductions, these sectors all give about 25% contributions to this reduction. For non-EU member

countries, the TOFP emissions are not reduced since 1990. The TOFP emissions in these countries represent about 17% of the total EEA32 emissions.

a) EEA32



a) EU15



b) EU10

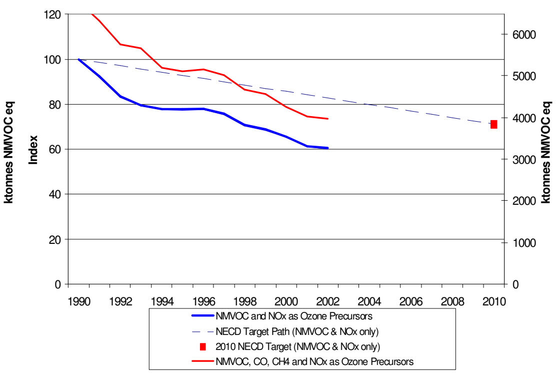
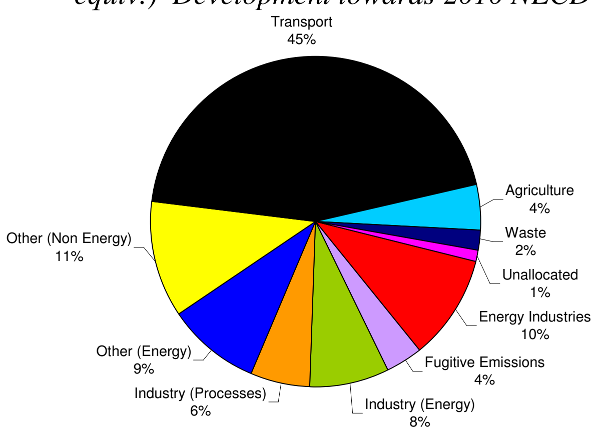


Figure 3-1: Emissions of ozone precursors between 1990 and 2002 (ktonnes NMVOC equiv.) Development towards 2010 NECD Target (for NO_x and NMVOC)



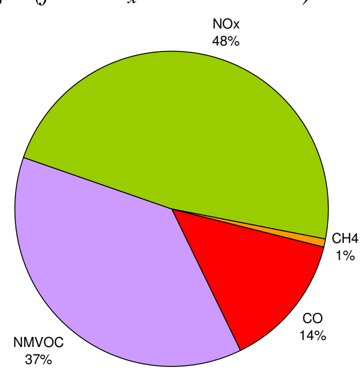


Figure 3-2: Sector split of emissions of ozone precursors in 2002 (%) for EEA32 (left), Pollutant split of emissions of ozone precursors in 2002 (%) for EEA32 (right).

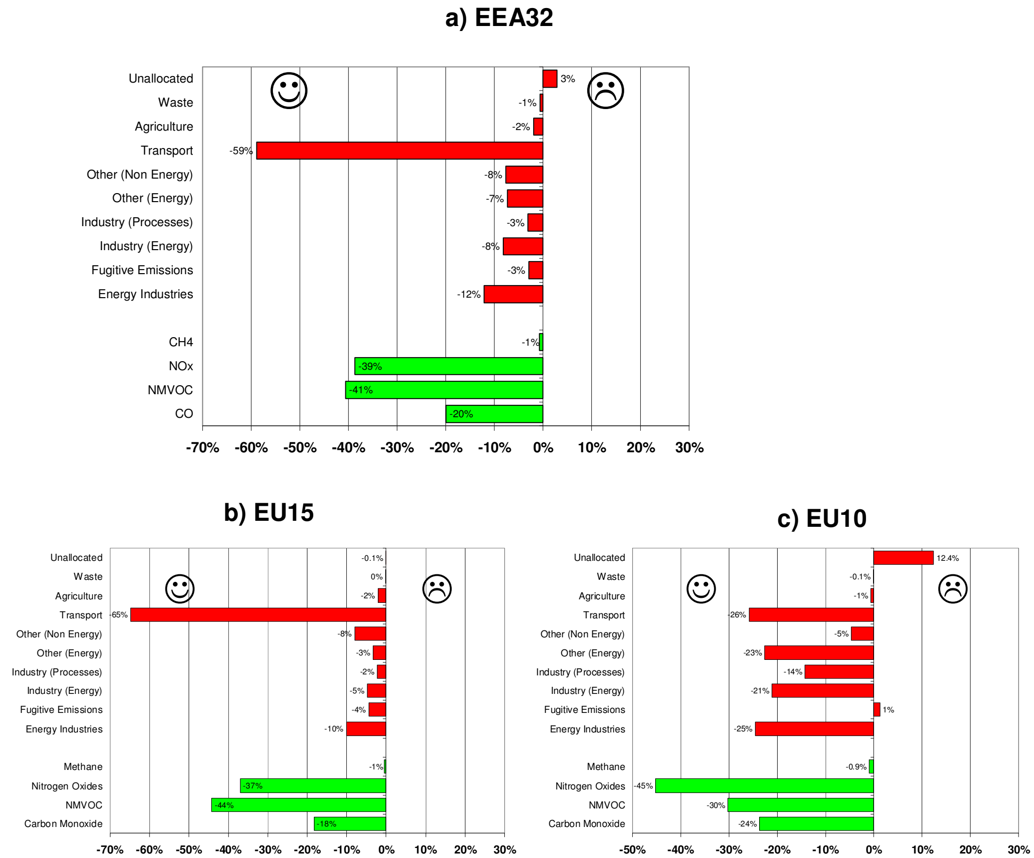


Figure 3-3: Contribution to change in ozone precursors emissions for each sector and pollutant 1990 – 2002, (%).

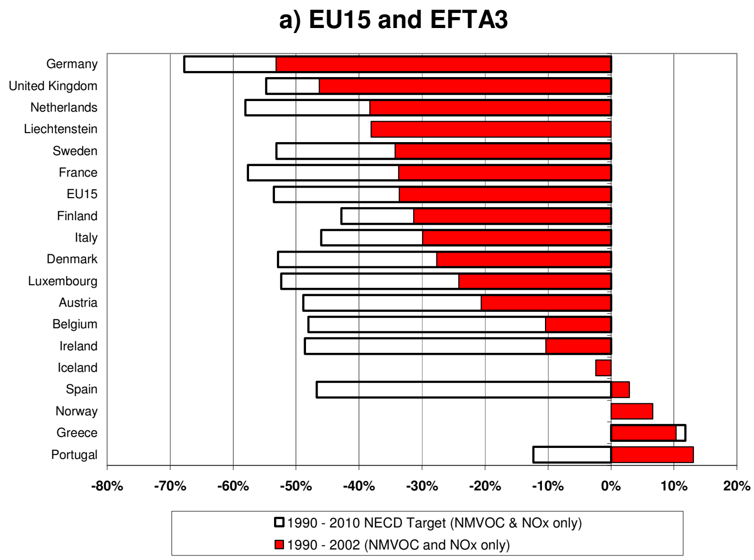
3.2.1. Assessment of distance –to– target

The EU15 is nearing two-thirds of the distance to its 2010 NECD target for NMVOCs and NO_x (TOFP-weighted). The largest emission reductions (in percentage terms) have taken place in Germany (-53%), the United Kingdom (-46%), Liechtenstein (-38%), the Netherlands (-38%) and Sweden (-34%). However, in contrast emissions in Spain (+3%), Norway (+7%), Greece (+10%), and Portugal (+13%) have increased since 1990. Most Member States still need to make substantial emission reductions to meet their targets.

In 2002, only six Member States were below a linear target path for the 2010 targets of the NECD. The emissions for four countries: Portugal, Spain, Belgium, and Ireland were more than 20 index points above their linear target paths.

In contrast to the EU15, countries in the EU10 have made substantial progress towards meeting the present temporary targets for NMVOC and NO_x set in the NECD. Six countries and the EU10 region as a whole have already met or exceeded their targets. The largest emission reductions have taken place in Slovakia (-59%), Lithuania (-55%), Estonia (-49%), the Czech Republic (-46%) and Latvia (-45%). Only Slovenia still needs to make substantial emission reductions to meet its target; Malta reported no data in 2004.

Of the Candidate countries, Bulgaria, Croatia and Romania have each already met their respective emissions targets set in the Gothenburg Protocol. Turkey has had a large increase (+51%) in TOFP-weighted emissions of NO_x and NMVOC between 1990 and 2002, but does not have an emissions target set under the Gothenburg protocol.



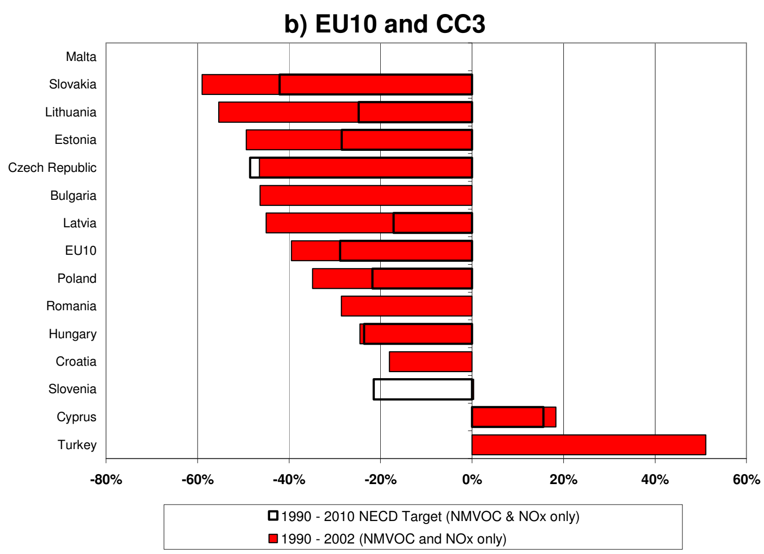
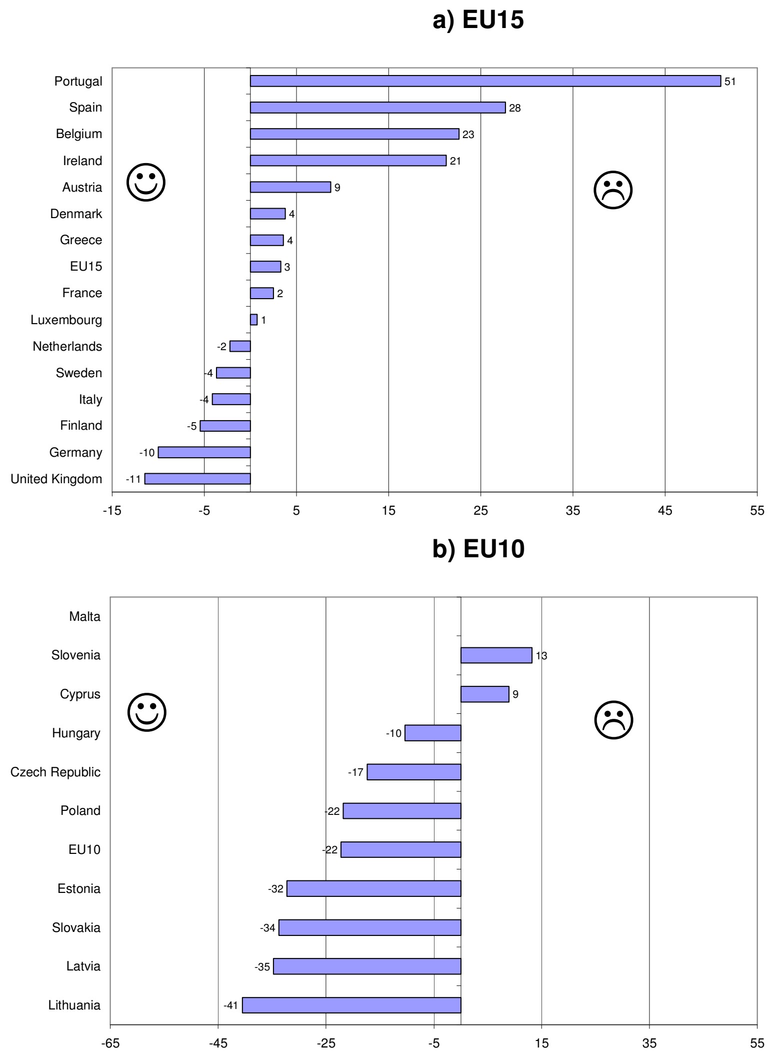


Figure 3-4: Change in emissions of ozone precursors (NMVOC and NO_x only) between 1990-2002 compared with the 2010 NECD targets (%)



Notes: The targets for 2010 are those set out in the National Emission Ceilings Directive, (NECD) and the UNECE Gothenburg Protocol. The NECD specifies Member State targets for non-methane volatile organic compounds and nitrogen oxides. Carbon monoxide and Methane have therefore been excluded, as there are no explicit targets for these pollutants. Targets for the EU10 Member States are temporary and are without prejudice to the review of the NEC Directive which is to be completed in 2004.

The distance-to-target indicator (DTI) is a measure for the deviation of actual emissions in 2000 from the (hypothetical) linear path between 1990 and 2010 (i.e. the target date for the EU national emissions ceiling directive) in order to evaluate progress of individual countries towards meeting their respective national targets..

Sources: Data from 2004 officially reported national total and sectoral emissions to UNECE/EMEP Convention on Long-Range Transboundary Atmospheric Pollution. Data not available for Malta

Figure 3-5: Distance-to-target indicators (in index points) to the 2010 targets of the NEC Directive.

3.3. Emissions of particulate matter and secondary particle precursors

Fine particles in this context refer to the sum of primary PM_{10} and the weighted emissions of secondary PM_{10}-precursor pollutants (de Leeuw, 2002). Primary PM_{10} refers to fine particles directly emitted into the atmosphere from emission sources while secondary emissions refer to emissions from pollutants which are (partly) transformed to particles by photo-chemical reactions in the atmosphere.

The emission data for primary PM_{10} is not as robust as that for other air pollutants and the factors used in the estimation of secondary PM_{10}- emission are based on assumptions about the deposition and reactions of the precursor pollutants.
Data are complete enough to support an assessment only for the EU15 and EFTA3 countries.

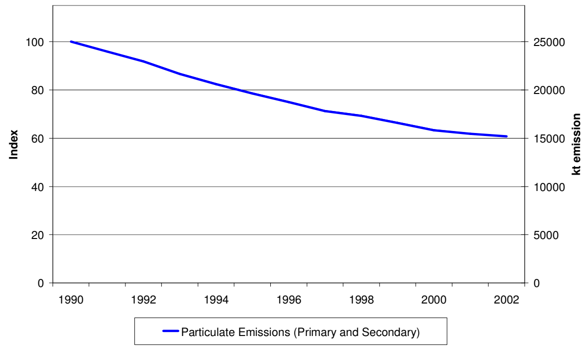


Figure 3-6: Emissions of primary and secondary fine particulates (kton) 1990-2002 for EU15

The most important sources of PM_{10} emissions in 2002 were road transport (28% of total emissions) followed by the energy industry sector (24%). Emissions of NO_x (55%) and SO_2 (20%) were the most important contributing pollutants to particulate formation in the EU15 in 2002. EU15 emissions of fine particles have been reduced by 39% between 1990 and 2002.

The emission reductions between 1990 and 2002 are due to abatement measures in many sectors: the energy industries (-55%), energy use by industry (-47%), road transport (-34%), and others. In terms of contribution to the total reduction in primary PM_{10} and secondary PM_{10} precursors, the main part of the reduction in emissions of energy-related particulate pollutants between 1990 and 2002 came from the energy supply sector which was responsible for 46% of the total reduction achieved. However, other sectors also decreased emissions significantly during this period as indicated above. Overall, the reduction in emissions of energy-related particulate pollutants was mainly achieved through a combination of the use of lower sulphur content fuels, fuel switching from coal and oil to natural gas, the deployment of emission abatement technologies in the energy supply (see EN09-EU for further details about emissions of SO_2 and NO_x from public electricity production) and industry sectors, and an increased market penetration of catalytic converters for road vehicles.

Emissions of primary PM_{10}, and secondary PM_{10} precursors are expected to decrease in the future as further improved vehicle engine technologies are adopted and stationary fuel combustion emissions are controlled through abatement or use of low sulphur fuels such as natural gas. Despite this it is expected that in the near future in the majority of the urban areas over the EU15 territory PM_{10} concentrations will still be well above the limit values, mainly as a result of the continued growth of road transport.

Substantial further reductions in emissions are needed to reach the air quality limit values set in the EU First Daughter Directive to the Framework Directive on Ambient Air Quality.

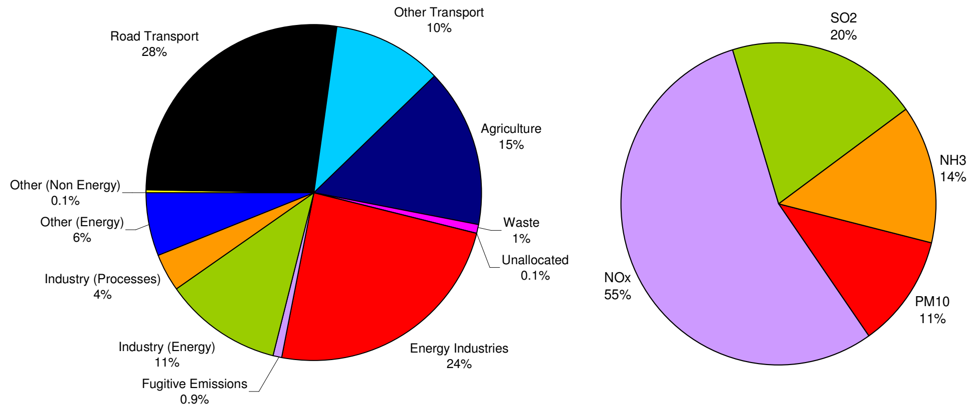


Figure 3-7: Sector split emissions of primary and secondary fine particulates (%)(left), Pollutant split of emissions of primary and secondary fine particulates in 2002 (%) for EU15 (right).

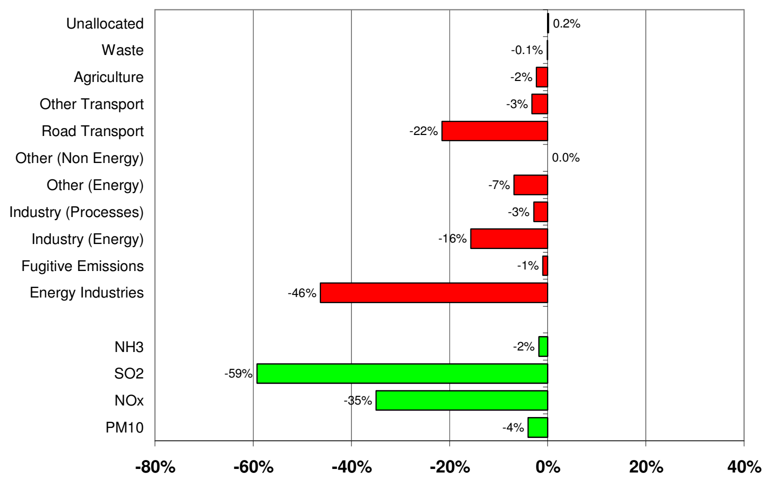


Figure 3-8: Contribution of the change in emissions of primary and secondary fine particulates (PM_{10}), per sector and per pollutant, relative to the total change in emissions between 1990 and 2002 (%) for EU15.

The total emission reduction between 2000 and 2001 was 1.7%. Two countries, the United Kingdom and Germany have reduced emissions by more than 50% since 1990, with six other Member States having made emission reductions of more than 30%. Greece (+0.3%), Portugal (+6%) and Iceland (+8%) are the only countries to have increased emissions since 1990.

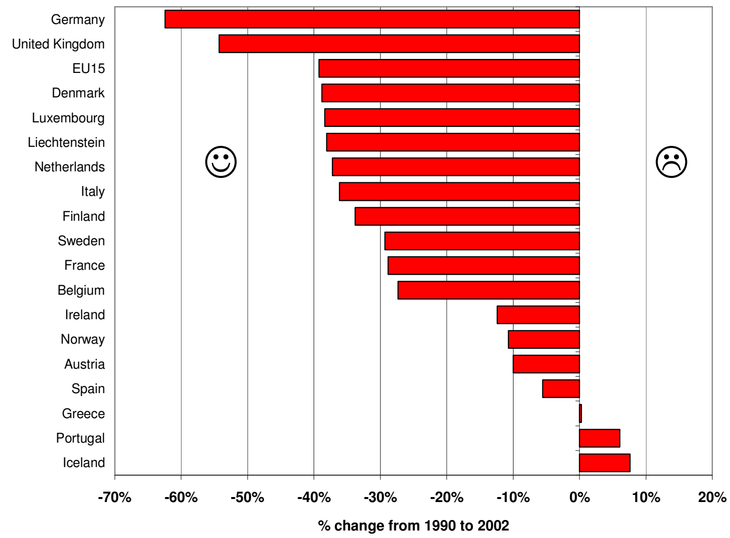


Figure 3-9: Change in emission of primary and secondary fine particles 1990-2002 (%) for EU15 and EFTA3 countries

3.4. Emissions of acidifying compounds

Acidification is caused by emissions of sulphur dioxide, nitrogen dioxide and ammonia into the atmosphere, their subsequent chemical reactions and deposition on ecosystems and materials. The emissions were aggregated acoording to (de Leeuw, 2002).

The most significant emission sources to acidifying emissions in EEA32 countries in 2002 were energy industries (32%), agriculture (25%), road transport (13%) and energy use in industry (11%). In 2002, the relative weighted contribution of sulphur dioxide emissions was 40%, NO_x emissions 32% and NH_3 emissions 28%.

Emissions of acidifying gases have decreased significantly in most EEA32 countries. Total weighted emissions decreased by 36% between 1990 and 2002 despite an increase in gross domestic product (GDP) during this time. The change in emissions between 2001 and 2002 was –2.0%. Since 1990, large and comparable decrease in emissions has occurred in many sectors: energy used in industry (58%), the industrial processes sector (57%), other energy (combustion) sectors (58%), and the energy industries sector (52%). Acidifying emissions from the road transport sector were reduced by 36%.

The substantial decrease in emissions of acidifying substances in the EEA32 is mainly due to the 59% reduction of sulphur dioxide emissions since 1990. This reduction is mainly due to a switch from high sulphur solid and liquid fuels to natural gas, in the energy industries, industry and domestic sectors, as well as economic restructuring of the new Länder in Germany, in the Czech Republic and other countries, and the introduction of flue gas desulphurisation in some power plants (EEA, 2004a).

The reduction in emissions of nitrogen oxides due to abatement measures in road transport and large combustion plants have to some extent been off set by increased road traffic, so the reduction in NO_x emissions amounted to 28%. Ammonia emissions are stabilising (18% reduction since 1990). Agriculture emissions, although a major

source, are very uncertain, and difficult to control. As emissions from the energy industry have decreased, the relative importance of agricultural emissions of acidifying pollutants has increased from 18% of total emissions in 1990 to 25% in 2002.

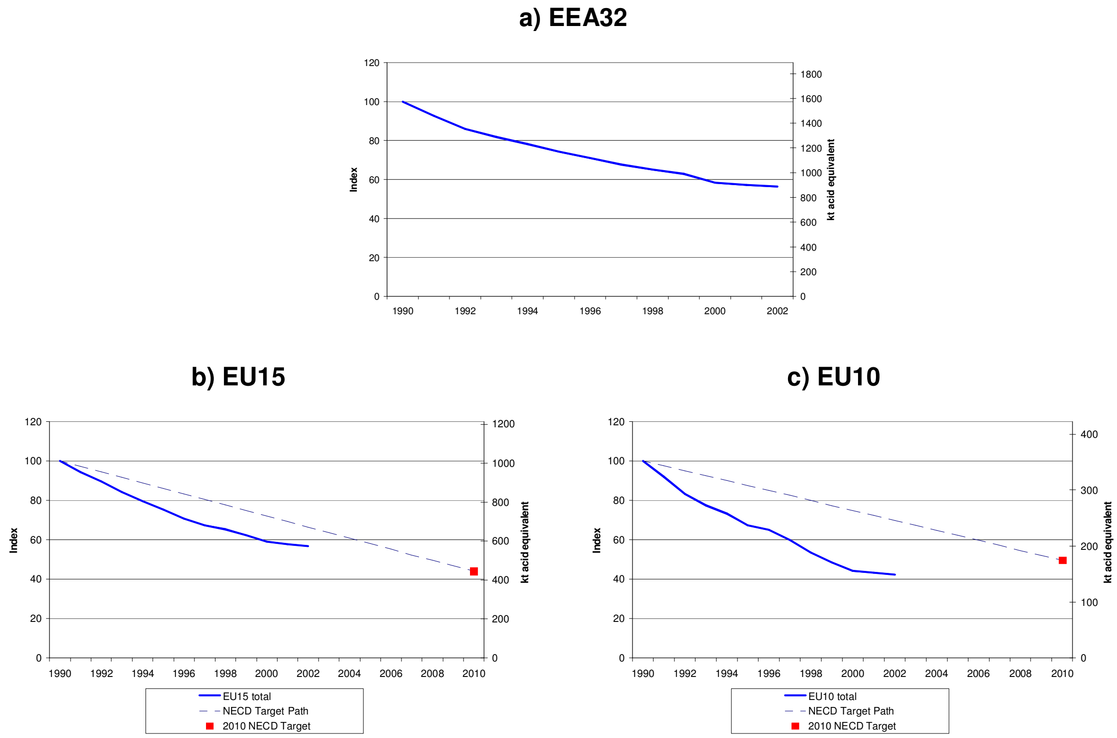


Figure 3-10: Emission trends of acidifying pollutants (ktonnes acid equivalent)

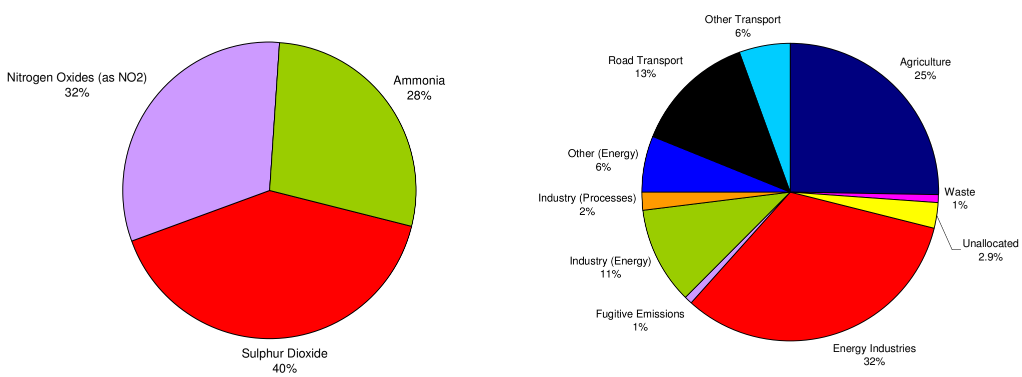


Figure 3-11: Sector split of EU15 emissions of acidifying pollutants in 2002 (%) for EEA32.

There is a certain difference between EU15 and EU10 countries in terms of major sectors and changes between 1990 and 2002. The industrial sector emissions, and thus sulphur, are more important in EU10 countries, while road transport and agriculture, and thus NO_x and ammonia, contribute more in EU15. The total emissions reductions were larger in EU10 than in EU15, respectively 58% and 43%. For non-EU member countries, the acidifying emissions are not reduced since 1990 and represent about 17% of the total EEA32 emissions.

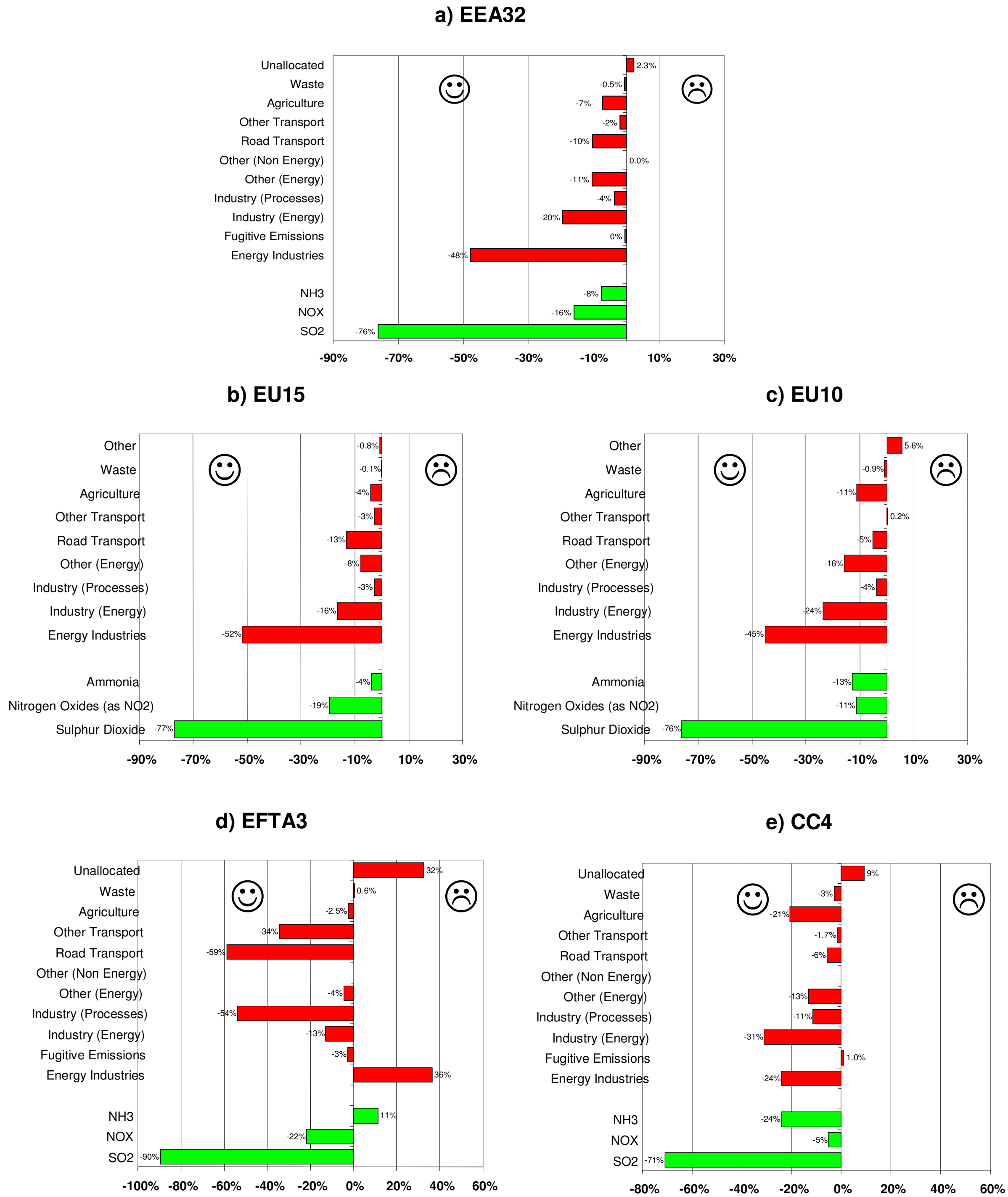


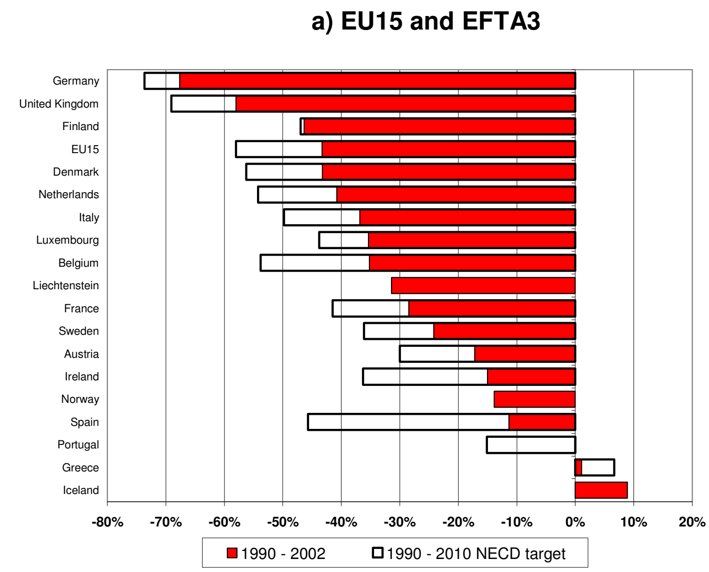
Figure 3-12: Contribution to total change in acidifying pollutant emissions for each sector and pollutant 1990 – 2002, (%).

3.4.1. Assessment of distance –to– target

The EU15 as a whole has made good progress towards the 2010 target but additional effort is still required in order that the target is met. The main contributions to the emissions reductions already achieved are from Germany (42% of the total EU15

reduction) and the UK (26% of the total EU reduction). Finland, Denmark, Luxembourg, Italy, Belgium and the Netherlands have also made good progress towards their targets having achieved more than a 35% emission reduction since 1990. Greece and Portugal are the only Member States that have increased their emissions during this time (by 1.1% and 0.1% respectively).

In 2002, three Member States were 10 or more index points below their linear path to the NECD target –Finland, United Kingdom and Germany. Three countries, Spain, Portugal and Ireland are substantially above the linear target path and therefore still need to make substantial emission reductions to meet the 2010 NECD target.



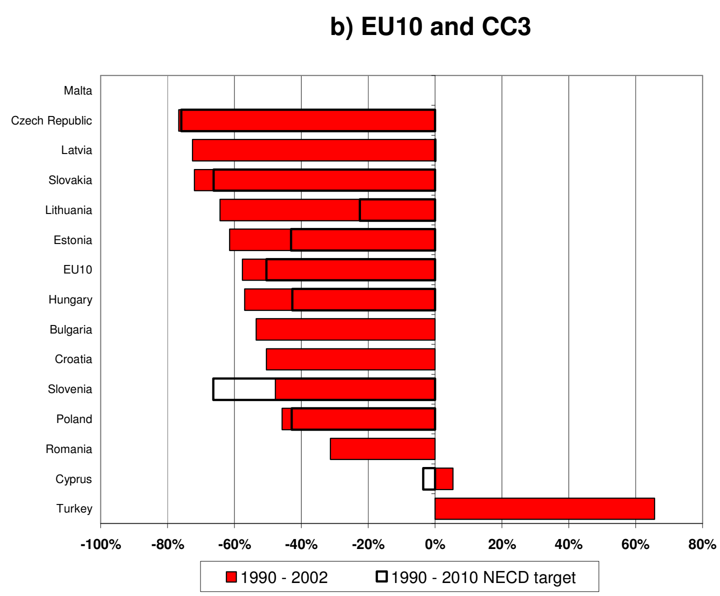
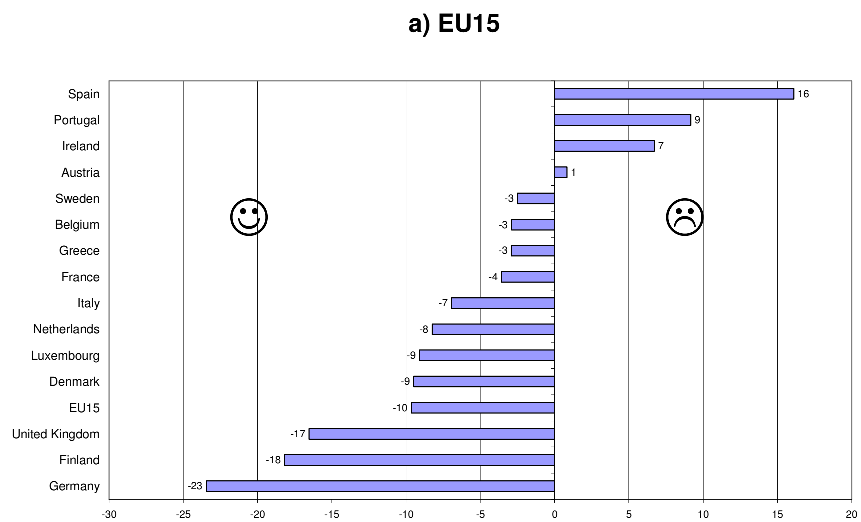
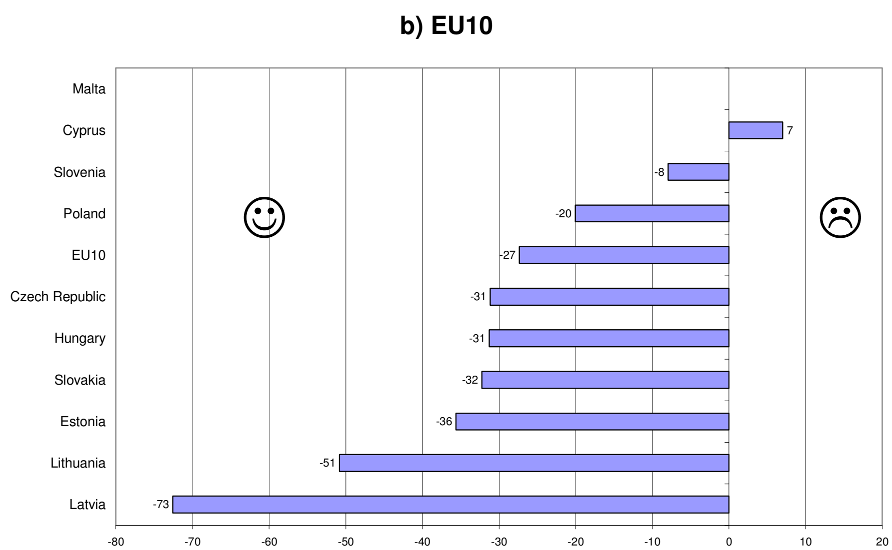


Figure 3-13: Change in emissions of acidifying substances since 1990 compared with the 2010 NECD targets (%).

EU10 countries have made excellent progress in terms of meeting their respective NEC Directive targets, with seven countries already having met their targets. Cyprus is the only EU10 country lying above a linear path to the NEC Directive target; emissions increased by 5% between 1990 and 2002. Only Slovenia and Cyprus still need to make further emission reductions; and Candidate country.





Notes: Emission targets are set through the National Emission Ceilings Directive – NECD. The distance-to-target indicator (DTI) is a measure for the deviation of actual emissions in 2000 from the (hypothetical) linear path between 1990 and 2010 (i.e. the target date for the EU national emissions ceiling directive) in order to evaluate progress of individual countries towards meeting their respective national targets. Targets for the EU10 Member States are temporary and are without prejudice to the review of the NEC Directive which is to be completed in 2004. Data not available for Malta.

Sources: Data from 2004 officially reported national total and sectoral emissions to UNECE/EMEP Convention on Long-Range Transboundary Atmospheric Pollution.

Figure 3-14: Distance-to-target indicators (in index points) to the 2010 targets of the NEC Directive.

4. State of Air Quality in Europe 1990-2002

This chapter provides information on concentrations and depositions of air pollutants from observations at a large number of monitoring stations across Europe. This summary concentrates on PM_{10}, O_3 and NO_2 in air, and on deposition of acidifying and eutrophying compounds. The state in 2002 is presented, as well as trends and tendencies since 1990.

The air quality data were all extracted from AirBase, the EU air quality data base. EEA member countries report time series annually to AirBase. The number of stations with data contained in AirBase has increased by an order of magnitude since before 1996, following the passing of the new Exchange of Information (EoI) Decision of the EC. To benefit from the substantially increased data coverage, and thus the improved representativity of the data ensemble, the report concentrates on showing air quality trends and tendencies since 1996 (since 1997 for PM_{10}, when the number of PM_{10} stations increased substantially.

4.1 Health related air pollution

The assessment of health related air pollution for 2002 is based on data from about 1500 stations in 28 European countries reporting data to AirBase. Most of the stations are located in EU-15. The 10 new EU Member States are not represented well enough by the existing stations to warrant a separate analysis on exceedances and trends in these countries, and their possible deviation from the EU-15 grouping.

This section is structured as follows:

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

For each of the compounds the state in 2002 (maps) is presented, as well as the change in average concentration year-by-year per station class, and distance-to-target in 2002 in terms of average and maximum extent of exceedances of limit and target values of the air quality directives (see Chapter 2).

4.1.1. Overview of trends and tendencies

The graphs in Figure 4-1 show the tendencies in concentrations, as an average for all types of stations. For each year, the plotted value represents the average of all stations in all countries (only stations with data covering at least 75% of the period shown). Annual means and short-term statistics are given.

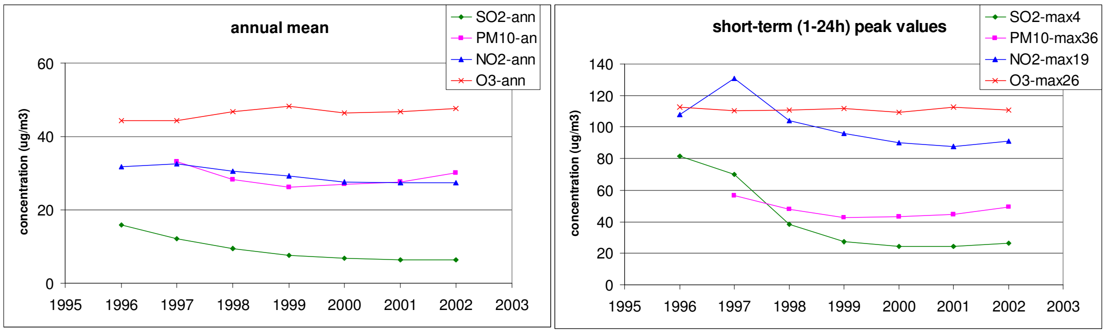
SO_2 shows a strong downward trend towards about 2000 and a flattening out after 2000 (even a small increase the last year for the short-term statistic).

NO_2 shows a similar behaviour (except for a peak in the short-term high percentile level in 1997), but the relative as well as absolute concentration reduction of NO_2 is much less than for SO_2.

For PM_{10}, however, the tendency is downwards until 1999-2000, and an upward tendency since then.

For all of SO_2, NO_2 and PM_{10}, there was an increase from 2001 to 2002 in the high percentile short-term concentrations. This may indicate that meteorological conditions could explain the increase[6].

For ground level ozone, the tendency is towards an increasing, or stable, concentration level (respectively for annual average and high short term concentrations).



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

The short-term values relate to the statistic of the short term limit values.

Figure 4-1: Summary of measured concentrations of SO_2, NO_2, PM_{10} and ozone in Europe, all stations.

Figure 4-2 gives, the fraction of stations which has a downward and upward tendency over the period 1997-2002 as a whole, based upon monthly average data (respectively with a significant or non-significant change). For SO_2, NO_2 and PM_{10} the majority of stations have a significant downward trend/tendency. For about 25-35% of the NO_2 and PM_{10} stations, this change over the period is not-significant. The stations showing upward tendencies are mainly hot-spot stations (traffic or industrial), dominated by local traffic or industrial plants which presumably are increasing in strength (e.g. streets with increasing amount of traffic). For ozone, the majority of stations have a (non-significant) upward tendency.

The spatial representativeness of these data for Europe as a whole, in terms of coverage of the population, is difficult to assess. Map 4.1–Map 4.6 later in this section show the coverage in 2002 in terms of cities included, as well as rural ozone stations. Within the urban scale, the representativeness of the reported concentrations depends upon the number and types of stations in each city, and their representativeness for population exposure. Most cities have only a few stations (1-3 stations of various types), but a number of cities report several monitoring stations in AirBase, such as for NO_2, where about 20 cities report 5 stations or more, and a few cities report up to 20 stations.

[6] Note that PM_{10} data **as stored in AirBase** is used here; some "trends" may be affected to some extent by an inconsistent use of correction factors over the years.

In the following subsections, tendencies in emissions and air pollutant concentrations are compared. It is found that:

1) The decrease of SO_2 and NO_2 concentrations is well in line with the emissions trends of SO_2 and NO_X.
2) For PM_{10}, the continuous downward trend in reported emissions is not reflected by the concentrations. Emissions of primary PM and precursor gas emissions were reported to decrease by about 15% between 1997 and 2002, while the concentrations are about at the same level in 2002 as in 1997.
   A detailed country-wise analysis showed that for the UK there was correspondence between emissions and concentrations. UK emissions data are considered to be of good quality. For other countries the emissions data were not complete enough to enable to check such correspondence. The quality of European PM emissions data should be checked.
3) For ozone, the substantial reductions in ozone precursor emissions (Figure 4-3) are not reflected by the measured ozone concentrations. To an extent this is expected in view of the chemistry of ozone, the slowly increasing hemispheric background, and the decreased scavenging by NO as a consequence of lower NO_x emissions.

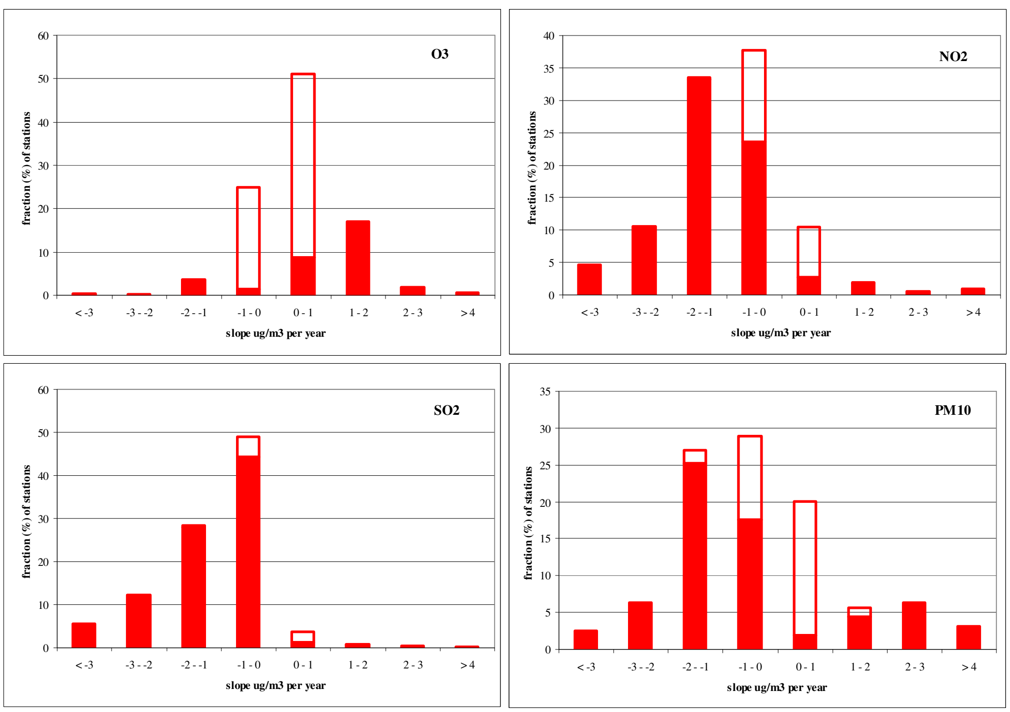


Figure 4-2: Number of stations with upward and downward tendency of annual mean concentrations (average µg/m³ change per year) for the period 1997-2002 [1]

(1) open bars refer to station with a non-significant trend, filled bars to station with a significant trend .

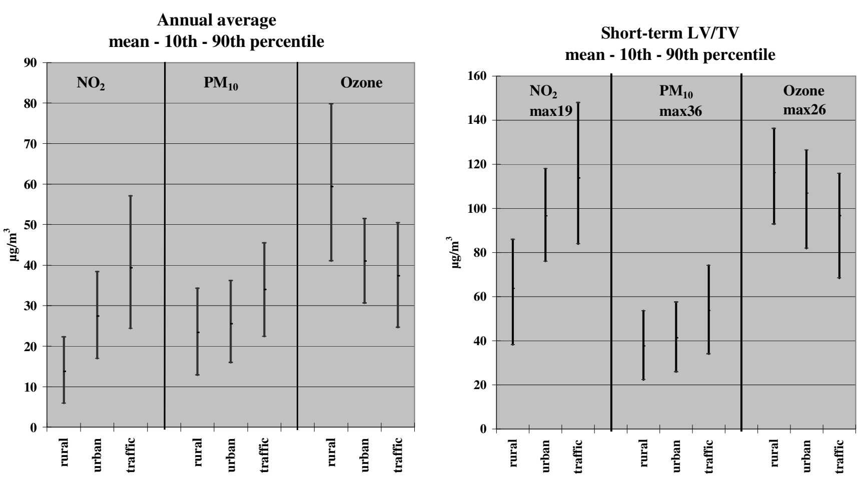
The tendency lines in Figure 4-1 are based on a large number of stations for O_3, SO_2 and NO_2, and less stations for PM_{10}. For O_3, SO_2 and NO_2 the tendency lines should be considered as being representative for the European situation as a whole, while the PM_{10} tendency line should be regarded with more caution. Possible regional

differences in the tendency lines are looked into in the subsequent sections, for each compound.

Box 1. Local urban and regional contributions to air pollution concentrations, for various compounds.

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

Ranges of concentrations at rural, urban and traffic stations in Air Base, 2001.



4.1.2. Ground level ozone

In 2002, the ozone data reported to AirBase included in total about 1450 monitoring stations in 26 countries with satisfactory data coverage, of which about 25% are in rural areas, and the rest distributed in about 800 cities and towns. The total population in those cities was about 109 million. Ozone data are available in AirBase from a substantial number of stations in many countries since 1996, the number increasing each year (levelling off in 2001-2002). Most of the stations are located in EU-15, with only 89 stations in the 10 new MS.

<u>*Tendencies in ozone 1996-2002*</u>

Figure 4-3 shows the change in ozone concentrations in Europe from 1996 to 2002. The graphs show that there is a tendency towards increasing ozone when looking at the *annual* average concentrations, while the health-related more short-term target level of the ozone directive (the 26th highest daily 8-hour average) show an almost unchanged averaged level since 1996, in all three area types (rural, urban, traffic hot-

spot). Most stations (about 78% of them) have a linear trend slope with coefficient within ±1 µg/m³ change in annual mean per year (Figure 4-2).

These tendencies are, for the average of stations, quite similar in all 4 regions (Northern, North-western, Central/Eastern and Southern Europe). There are regional differences in the ozone level in Europe: Northern and Southern Europe have on the average the highest concentrations, while North-western Europe has the lowest.

For the urban background and especially for the street stations, there is a slight predominance towards an upward concentration tendency, which fits with the effect of decreasing urban and traffic NOx concentrations (Summer ozone 2004 report, EEA 2004).

The highest 1-hour concentrations occurring in Europe, represented by the P99.9-1h plot in Figure 4-4 shows large variations from year-to-year, and no clear tendency can be seen in the data, although a downward tendency in indicated.

Another picture of the development tendency for ozone in Europe is provided by the number of exceedances of the EU information threshold value (120 µg/m³ as hourly average), see Figure 4-5 showing the average number of exceedance periods per station in 3 regions in Europe (North-western, Central and Southern Europe (EEA 2004). For region 1, Northern Europe, the number of exceedances was very small. The summers of 1995 and 2003 were very hot, resulting in increased number of exceedances. Between 1996 and 2003 the figure indicates an increasing tendency in exceedances of the information threshold in Southern Europe (EEA 2004).

Ozone concentrations are highest in rural areas and lower at urban traffic and industrial hotspots, because ozone is scavenged by freshly emitted NO (see Box 1).

The observed changes in ozone concentrations in Europe (looking at percentiles from annual average and to the 99.9th percentile of hourly) do not parallel the significant reduction in ground-level ozone precursor emissions (Figure 4-6). The precursor emissions, calculated as TOFP[7] , have been reduced between 1996 and 2002 by 19% for EEA32 countries in total (and by 21% and 24% in the EU15 and EU10 countries respectively).

Possible explanatory factors are:

- Increased hemispheric ozone background levels.
- Less ozone scavenging by NO because of reduced emissions of NO_X
- Increasing temperature may lead to increased photochemical activity. Most of the summers of the last years have been very warm.

The difference in concentration between urban and rural areas, show a slight decreasing tendency), especially for the “max26” statistic.

---

[7] Tropospheric ozone formation potential

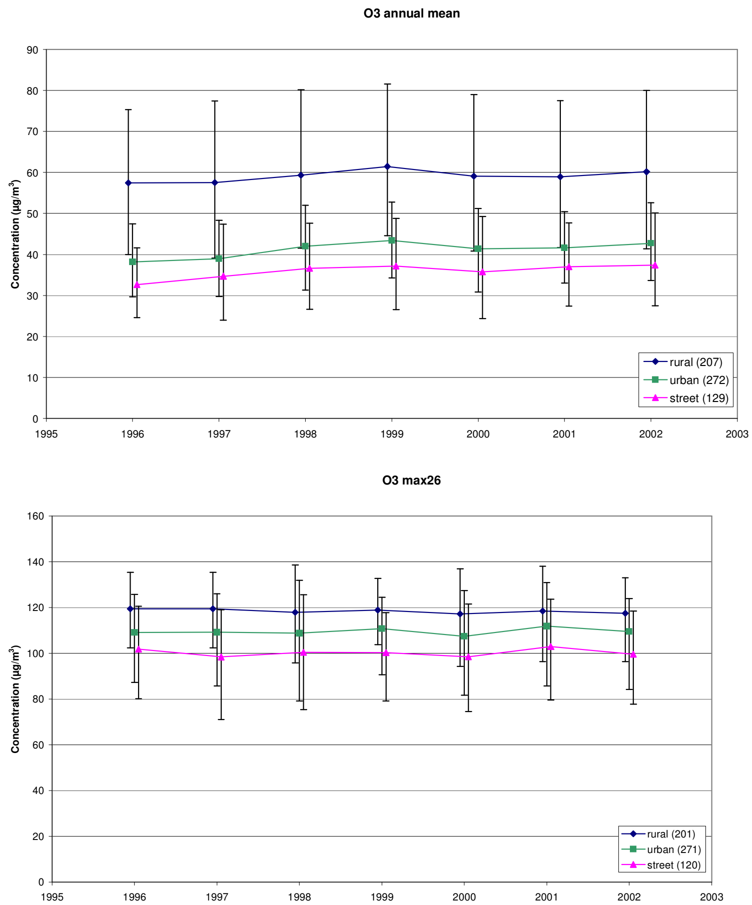


Figure 4-3: Ozone, interannual variations, 1996–2002. Indicators: Annual mean and the 26th highest daily 8-hour average per year (the EU Target Value indicator). All stations with 7 monitoring years. Vertical bars: 10th and 90th percentiles.

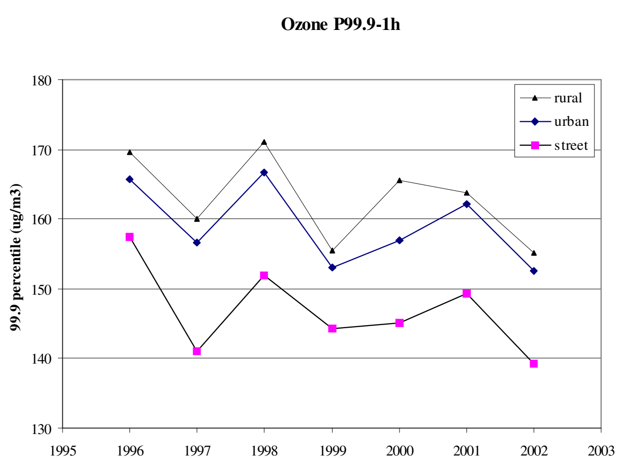
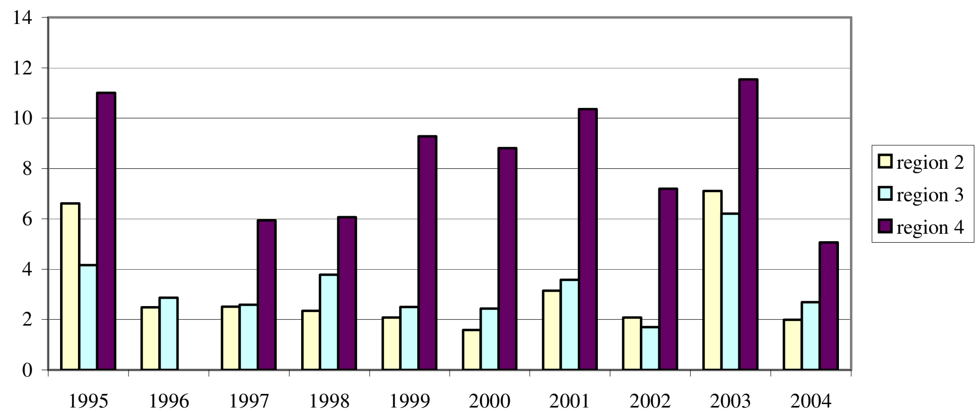


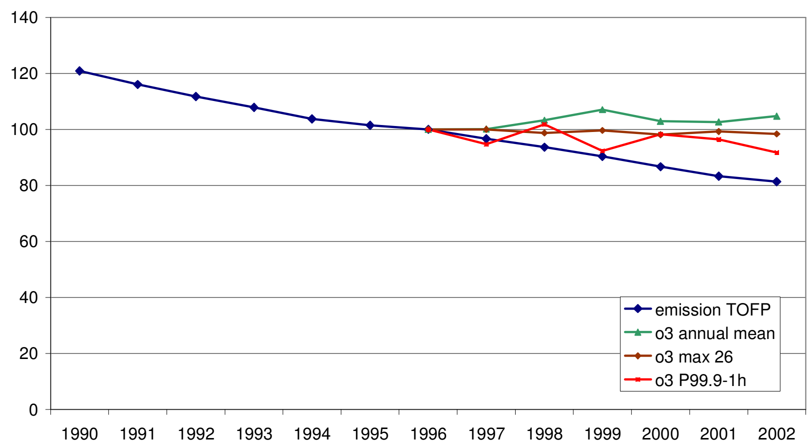
Figure 4-4: Ozone 99.9th percentilee of 1-hour average concentrations, 1996-2003.Average over all stations of each type (ug/m3)

average occurrence



Note: incomplete data were used for 2004 summer (only few data for August and September) Region 1 (N Europe) has not been included in this figure because of the low number of exceedances, Region 2: North-western, Region 3: Central/Eastern, Region 4: Southern.

Figure 4-5: Extent of exceedances of ozone Target values during Summers 1996-2003.
Average occurrence (the number of exceedance per station) per region for stations, which reported at least one exceedance, observed during the year.



Emissions TOFP: Total EEA32 emissions of equivalent ozone precursors, relative to emissions in 1996.
O_3 annual mean: Annual mean O_3 concentrations averaged over all urban background stations with full data coverage 1996-2002, relative to 1996 (272 stations).
O_3 max 26: As above, for the 26th highest daily maximum 8-hour average.
O_3 P99.9-1h: 99.9th percentile of 1 hour averages, averaged over all rural stations, relative to 1996 (201 stations).

Figure 4-6: Relative trend in emissions of ozone precursors between 1990 and 2002 for EEA32 countries total, and tendencies in measured concentrations

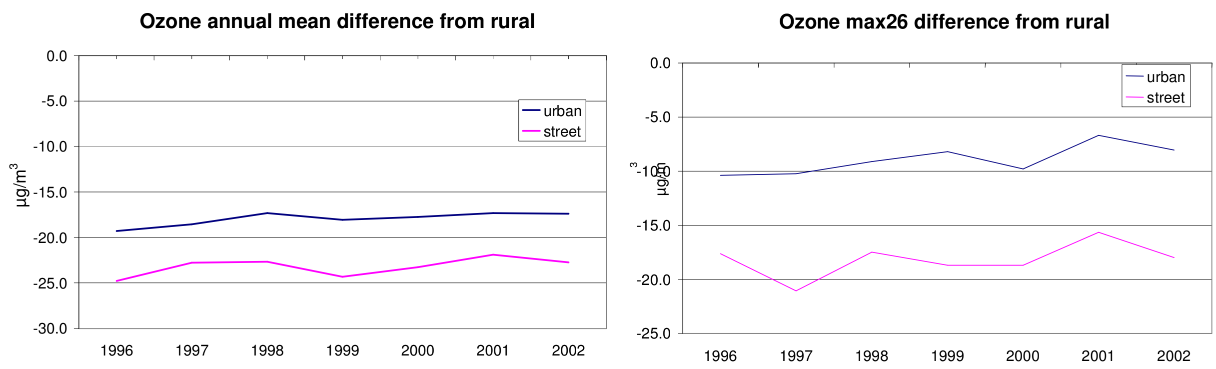


Figure 4-7: Ozone tendencies in urban areas relative to rural stations, 1996-2002

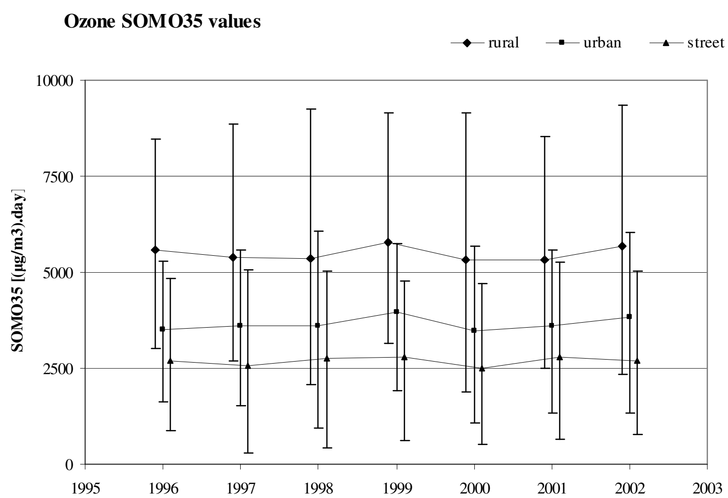


Figure 4-8: Annual variations of the SOMO35-values. Average values over all stations which reported data over at least six years in the period 1996-2002

<u>State, population exposure and distance-to-target, ozone, 2002</u>
The data for 2002 in Figure 4-3 show that the ozone target value (120 µg/m^3 as 26th highest daily 8-hour max value) is exceeded at more than 10% of the rural and urban background sites (as well as at some traffic sites). Map 4.1 and Map 4.2 (page 58-59) show the location of cities and rural sites with recorded exceedances in 2002. Of the 1459 stations, 426 stations in 13 countries measured levels in exceedance of the target value, and another 612 had levels above an upper classification level of 100 µg/m^3 (as 26th highest daily 8-hour value).

Maximum concentration measured (8-hour average) was 167 µg/m^3 at an Italian station, while 6 countries had maximum levels above 150 µg/m^3.

Target value exceedances were measured in about 165 cities and towns with a total population of about 25 million. Exceedances occur mainly in South European countries, as well as in Central and Eastern Europe (Switzerland, Austria, South and East Germany, Czech Republic, Slovakia and Poland).

20-30% of the urban population was exposed in 2002 to ambient ozone concentrations above the EU target value set for protection of human health (120 µg/m^3 daily maximum 8-hourly average, not to be exceeded more than 25 times during the calendar year). This percentage has been increasing somewhat since the mid-nineties.

Figure 4-8 shows the tendency in the recently proposed health-effects related exposure metric, the SOM35 ("Sum of means over 35 ppb" - average excess of daily maximum 8-h means over a cut-off level of 35 ppb). Similar to the other ozone metrics, no clear tendency is shown.

Figure 4-9 shows the extent of exceedances in Europe in 2002 (distance-to-target); the bars show the concentration averaged over all stations, the concentration averaged over all stations exceeding the target value and the maximum concentration for rural, urban background and traffic stations, respectively . Maximum concentrations recorded in 2002 were about 40 % above the target value. On the average, the concentrations at stations with exceedance of the target value were 9%, 7% and 6.5% above the target value respectively for rural, urban and traffic stations.

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

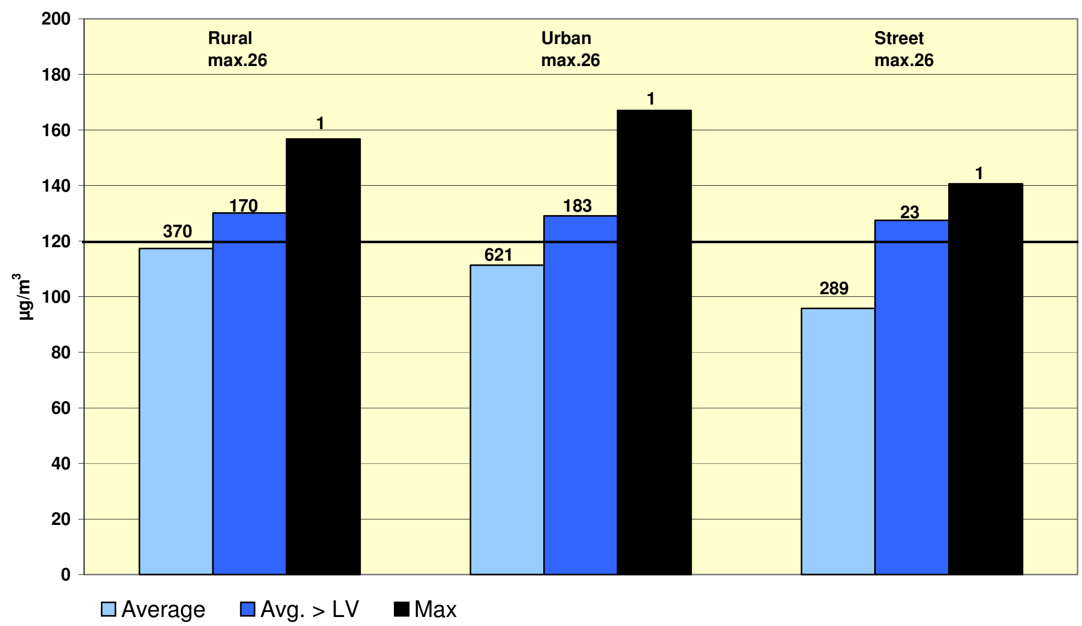


Figure 4-9: Distance-to-target, Ozone over EU Target Value, 2002 (number of stations on top of bars). The "Average" bar: all stations; the "Average>LV" bar: stations above the limit value;"Max" bar: the station with the highest concentration.

4.1.3. Particulate matter – PM_{10}

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

AirBase contains for 2002 about 1110 PM_{10} monitoring stations in 24 countries, and included stations in some 550 cities and towns. The amount of PM_{10} data in AirBase is substantial only from 1997 and onwards, so trend and tendency evaluations can only be made for that period. The new EU Member States are less well represented than EU-15 (111 of the stations are in EU10, and of these as many as 53 are in one country, the Czech Republic). About half of the monitoring stations use automatic monitors for which area-specific correction factors have to be established and used (see Box 2). Most countries have established such factors, but they have not always been applied consistently for all years. This fact influences the trend analysis from the data to some extent.

Tendencies in PM_{10}, 1997-2002

The number of PM_{10} monitoring stations has increased substantially, first in 1996-1997 as compared to earlier years, and then continuously since 1997. Thus, tendencies/trends for the whole period 1997-2002 is based on only about 135 stations with data for all the years, while for shorter, later periods the number of stations with data for all years increases quite substantially.

Figure 4-10 represents only the stations with data for all the years 1997-2002, (137 stations in 9 countries; Belgium, Czech Republic, Finland, the Netherlands, Poland, Portugal, Spain, Switzerland and UK).

Figure 4-10 shows that there was a downward tendency in PM_{10} concentrations in Europe from 1997 to 1999, and an upward tendency since then towards 2002. Similar plots for shorter, later periods, with many more stations confirm the upward tendency since 1999-2000.

Primary PM and precursor gas emissions in Europe are reported to be decreasing strongly since 1990. Precursor gas emissions are about 10 times the primary PM emissions. Precursor gas emissions (NO_X, SO_2, NH_3) have been reduced by about 16% between 1997 and 2002. Reported primary PM emissions have been reduced by about 6% over the same period. There are significant gaps, however, in the countries' reporting of primary PM emissions, so this reduction is uncertain, in terms of its representativeness for the entire EEA area, or even for EU15.

The tendency in measured PM_{10} concentrations do not reflect this significant decrease in emissions, which has been steady over the whole period.

Figure 4-10 shows clearly that the PM_{10} concentrations in Europe are dominated by the rural background concentrations. The averages for the three types of stations are not directly comparable, since they do not necessarily represent stations from the same areas. For the 135 stations in Figure 4-10, the difference between average rural and urban PM_{10} levels is small (about 4µg/m^3 in 2002, and this difference is confirmed by the larger set of stations for the shorter periods). The increase in PM_{10} on the average from urban to street stations is about 3µg/m^3, for the stations which have reported data.

The vertical bars show the large variability within each station class. Some rural stations have higher PM_{10} concentrations than many urban and even traffic stations.

An analysis of PM_{10} data from 16 station pairs (pairs of traffic and urban background stations in individual cities) of the AirBase for 2002, where the distance between the stations was less than 1 km, was carried out. It gave as a result that the PM_{10} concentration (annual average) at the traffic stations was on the average 6.9µg/m^3, or 25% higher than at the urban station of these pairs. The corresponding increase for the 36th highest day concentration was 11.7µg/m^3, or 26%. This result indicates that the added concentrations in streets, compared to the urban background, is generally larger than indicated by the lines in Figure 4-10.

The absolute and relative additions to PM_{10} from rural-to-urban-to-street locations vary, however, a lot between countries and regions. Figure 4-11 shows 3 examples, for countries with several stations in each class: Czech Republic, the Netherlands and UK. The very small additions from rural-to-urban-to-street in the densely populated Netherlands is apparent, while they are larger for CZ and UK.

The rural background is the result of natural PM sources, primary anthropogenic PM sources as well as formation of secondary particles (mainly inorganic particles formed from SO_2 and nitrogen compounds, while also secondary organic particles contribute). The absolute changes between years in PM_{10} concentrations are, for these 137 stations in 9 countries, almost identical for the rural and the urban stations. Thus, the changes from year to year occur mainly in the rural concentrations while the urban contribution on top of the rural concentration has stayed rather constant from 1997 to 2002. The contribution from the traffic in the streets represented have, however, been reduced steadily since 1997. This could reflect reduced traffic volume or changed vehicle composition in the represented streets, but more likely it reflects mainly the reductions in average emission factor from the vehicle fleet, as a result of the EU regulations of vehicle exhaust.

The PM_{10} tendency in urban areas as compared to the rural areas is better shown in Figure 4-12. It points to little difference in the urban and rural tendencies, although there is a slight downward tendency at urban background stations compared to the rural. For traffic hot-spot stations, however, the reduction compared to the rural is clearly shown.

Box 2. Correction factors for PM_{10} monitoring methods

The reference measurement method for PM_{10} is based upon gravimetric analysis, by weighing of filters through which a measured volume of air has been drawn. The reference sampler has a reference air intake which separates out particles larger than 10 μm (as equivalent aerodynamic diameter). The reference type samplers are described in CEN standard CE12341 (CEN, 1998).

Other PM_{10} monitoring instruments can be used, on the condition that their equivalence has been proven (see 1st Daughter Directive).CEN standard CEI2341 prescribes how to determine equivalences and how to determine a correction factor to be used. The standard prescribes that equivalence should be proven for various types of stations and locations/regions in the country.

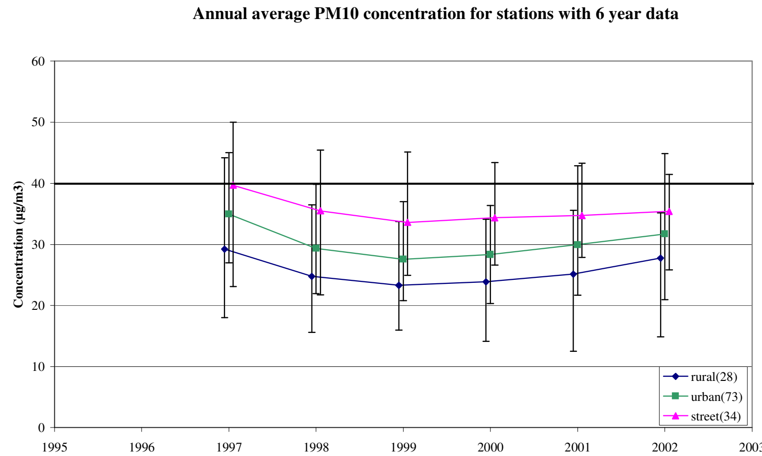
The status on the countries' determination of and application of correction factors for the PM_{10} monitors used in their networks has been investigated by ETC/ACC (Buijsman and de Leeuw, 2004)

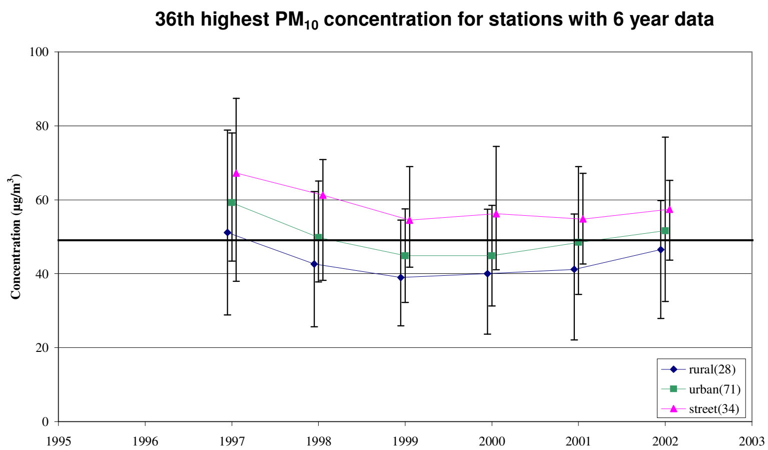
A summary of the status is as follows for countries using non-reference methods at stations reporting to AirBase:

Country	Method	CF	Applied on data for AirBase
Austria	BETA TEOM	1.18-1.30 1.16-1.30	Yes Yes
Belgium	BETA TEOM	1.37 1.47	Yes, after/ incl. 2002 Yes, after/ incl. 2002
Bulgaria		No CF	
Czech Rep.	BETA	1.0	NA
Estonia	BETA	1.15	Yes
Finland	BETA TEOM	1.0 1.0	NA NA
France	TEOM	1.0	NA
Germany	BETA TEOM	1.0-1.3 1.0-1.3	Yes Yes
Greece	BETA	No CF	
Hungary	BETA	No CF	
Iceland	BETA	No CF	
Italy	BETA/ TEOM	No info	No info

Country	Method	CF	Applied on data for AirBase
Latvia	BETA	1.0	NA
Lithuania	BETA	1.3	Yes, after, not incl.2002
Netherlands	BETA	1.33	Yes
Norway	TEOM	1.1	No
Poland	BETA/ TEOM	1.0	NA
Portugal	BETA	1.18 Traffic 1.11 Back-ground +Indus-trial	Yes Yes
Slovak Rep	TEOM	1.3	No
Slovenia	TEOM	1.3	Yes
Spain	BETA/ TEOM	Varies	No

BETA: beta absorption method
TEOM: oscillating microbalance method





Number of stations and countries per station class:

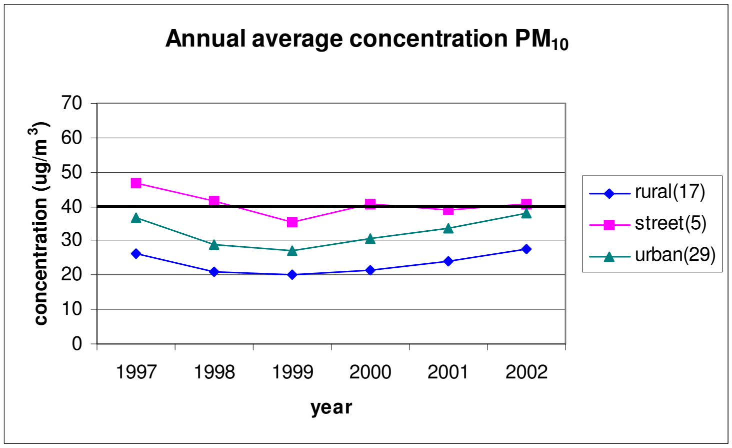
Rural: 28 stations in 4 countries: CH(1), CZ(17), GB(3), NL(7)
Urban: 73 stations in 7 countries: BE(3), CH(4), CZ(29), ES(1), GB(28), NL(5), PL(3)
Street: 34 stations in 9 countries: BE(4), CH(2), CZ(5), ES(10), GB(4), NL(5), PL(1), PT(1)

For PM_{10}, equivalent methods are used in many countries, and for these instruments, correction factors have to be determined and applied.

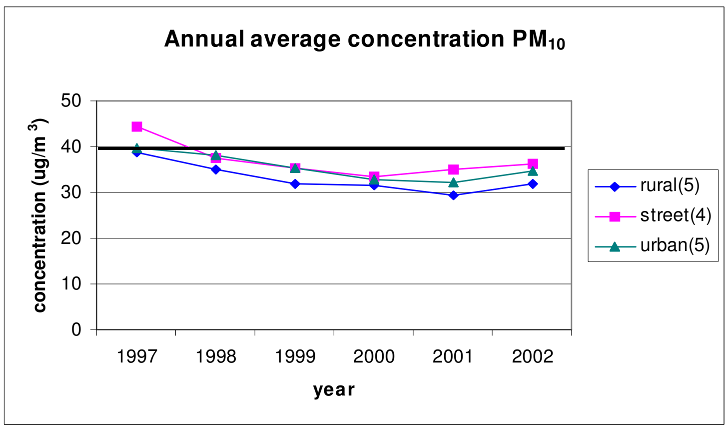
Correction factors related to measurement method is known for all the years with data This has been taken into account when producing the tendency lines, so that the tendencies shown are based upon consistent use of correction factor.

Figure 4-10: PM_{10}, interannual variations, 1997–2002 Indicators: Annual mean and the 36^{th} highest daily value per year. Vertical bars: 10^{th} and 90^{th} percentiles

Czech Republic: 6-year trend



Netherlands: 6-year trend



United Kingdom: 6-year trend

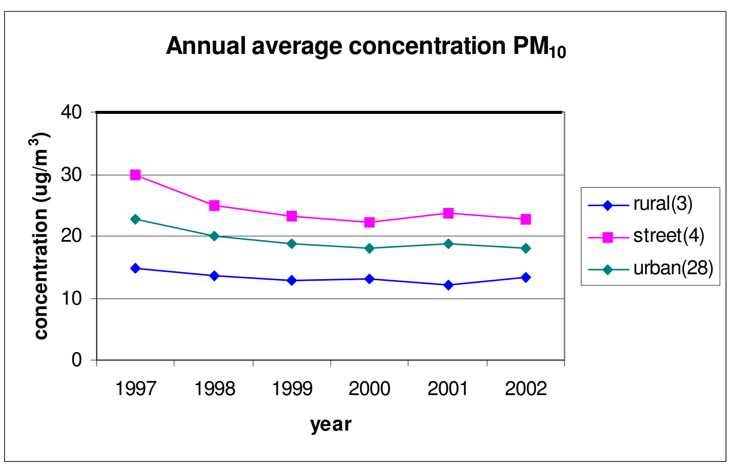


Figure 4-11: PM_{10} tendencies in the Czech republic, Netherlands and the UK

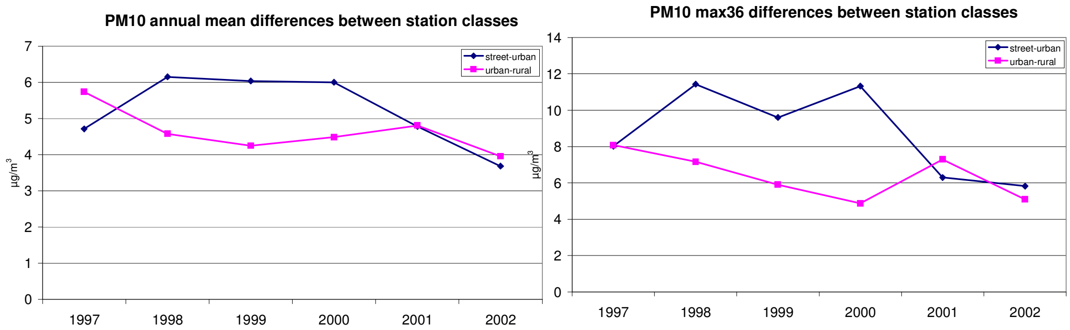


Figure 4-12:PM$_{10}$ tendencies in urban areas relative to rural stations, 1997-2002

The interannual changes in the rural PM$_{10}$ concentrations can be partly explained by changes in the rural sulphate concentrations, which shows a similar variation (Figure 4-13). SO_4 shows a slight increase after 2000 while the SO_2 reduction flattens off. Although the PM$_{10}$ and SO_4 lines in Figure 4-13 do not represent the same set of stations, the tendencies are similar. The SO_4 variations are, however, too small to account for all the PM$_{10}$ variation. Other contributing factors to rural PM$_{10}$ are also increasing.

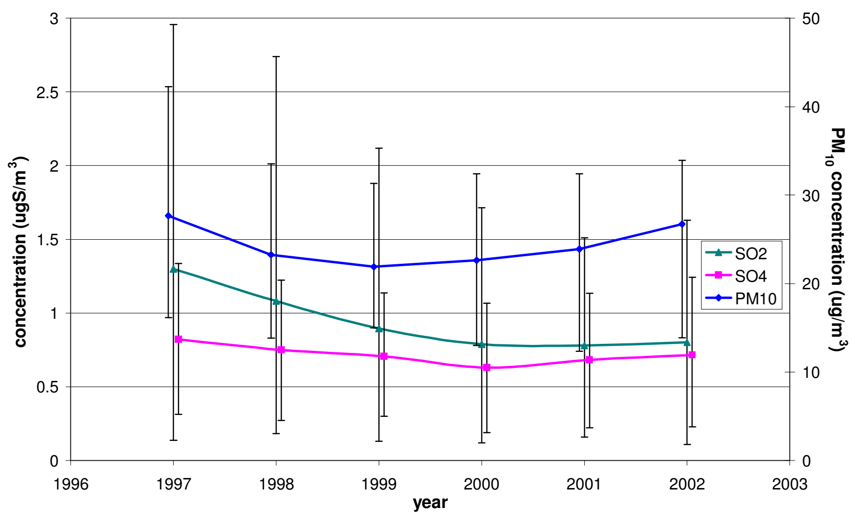


Figure 4-13: Annual concentrations of SO_2, SO_4 (EMEP data) and PM$_{10}$ for the period 1997-2002 for rural stations (respectively 72, 68 and 26 stations used). The vertical bars indicate respectively the 10th and 90th percentiles

An attempt was made to study whether there are regional differences in PM$_{10}$ tendencies in Europe (Snel, 2004). Due to the low number of stations with long time series of various types in each country, strong conclusions cannot be made. The results give the indication, however that the decreasing PM$_{10}$ tendency (annual average) from 1997 to 1999 and the increase after 1999 or 2000 showed up in most, if not all countries. Exceptions are Spain, where concentrations have stayed almost constant since 2000, while at 3 stations in Slovakia, concentrations have decreased steadily since 1999.

State, population exposure and distance-to-target, 2002

The limit values for PM_{10} were exceeded extensively in 2002 (see Table 4.1, Figure 4-10, Map 4.3 and Map 4.4). PM_{10} was reported to AirBase for a total of about 1100 stations. 141 stations were in rural areas, and the rest were urban traffic and industrial stations in about 550 cities.

Map 4.3 and Map 4.4 show the extent of the short term limit value ("max 36"). This was exceeded at 25 rural, 136 urban, 175 traffic and 45 industrial stations, covering more than 150 cities (Table 4.1). The highest concentrations are most pronounced in countries in Eastern and Southern Europe, but exceedances are extensive also in Central Europe as well as in Spain and Portugal. France, UK and the Nordic countries have very few exceedances at the reported stations. Stockholm and Uppsala in Sweden are exceptions, where the use of studded tyres on cars in the winter creates a significant PM_{10} problem (Hornsgatan in Stockholm has the 6th highest traffic stations "max 36" value (Table 4.1).

Table 4.1 Overview of exceedences of PM_{10} Limit Values, 2002

"Max36"	**Exceedances in:**	**Highest stations/cities**
Rural 141 stations	25 stations in 8 countries (7 in NL, 6 in DE)	CZ: 113; 69 µg/m^3 PL: 79 µg/m^3
Urban 488 stations	136 stations/ 104 cities in 15 countries (27 in DE, 22 in CZ)	BG: 128; 111 µg/m^3 PL: 119; 101 µg/m^3 11 stations over 80 µg/m^3, all in PL, BG.
Street 339 stations	175 stations/130 cities in 20 countries (52 in DE, 37 in ES, 21 in IT, 16 in AT)	PL: 160 µg/m^3 Krakow IT: 125 µg/m^3 Pescara IT: 121 µg/m^3 Torino IT: 110 µg/m^3 Parma GR: 110 µg/m^3 Thessaloniki SE: 102 µg/m^3 Stockholm
Other incl. Industrial	45 stations in 11 countries	ES: 123 µg/m^3 PL: 118 µg/m^3 GR: 115 µg/m^3
Annual Average	**Exceedances in:**	**Highest stations/cities**
Rural	3 stations in 2 countries	CZ: 70 µg/m^3
Urban	43 stations/37 cities in 8 countries (13 in CZ)	PL: 89 µg/m^3 IT: 75 µg/m^3 GR: 71 µg/m^3
Street	62 stations/48 cities in 12 countries (17 in ES, 15 in IT)	
Other incl. Industrial	19 stations in 5 countries (9 in ES)	ES: 82; 75 µg/m^3 GR: 67 µg/m^3 PL: 64 µg/m^3

PM_{10} is a significant pollution problem also in rural areas in Europe. Rural exceedances were experienced in 8 countries (Table 4.1), with "max36" concentrations up to and over 100µg/m^3 (2.5 times the LV). Even the LV for annual average was exceeded at stations in CZ and Poland.

The highest concentrations were more than 3 times the "max 36" limit value. Some street stations in Poland and Italy have very high values (Table 4.1), as have urban stations in Bulgaria and Poland.

About 50% of the urban population covered by monitoring stations is AirBase is potentially exposed to ambient concentrations of PM_{10} in excess of the EU limit value set for protection of human health (50µg/m^3 daily mean not to be exceeded more than 35 days during a calendar year). This percentage has been increasing since the mid-nineties.

The extent of exceedances is also indicated in Figure 4-14, which gives distance-to-target information. The highest average concentrations at the sites where it exceeds the limit value is up to 32% higher than their respective limit value. The maximum concentrations can reach as high as more than 3 times the limit value. The distance-to-target is largest at street stations for the "max36" statistic.

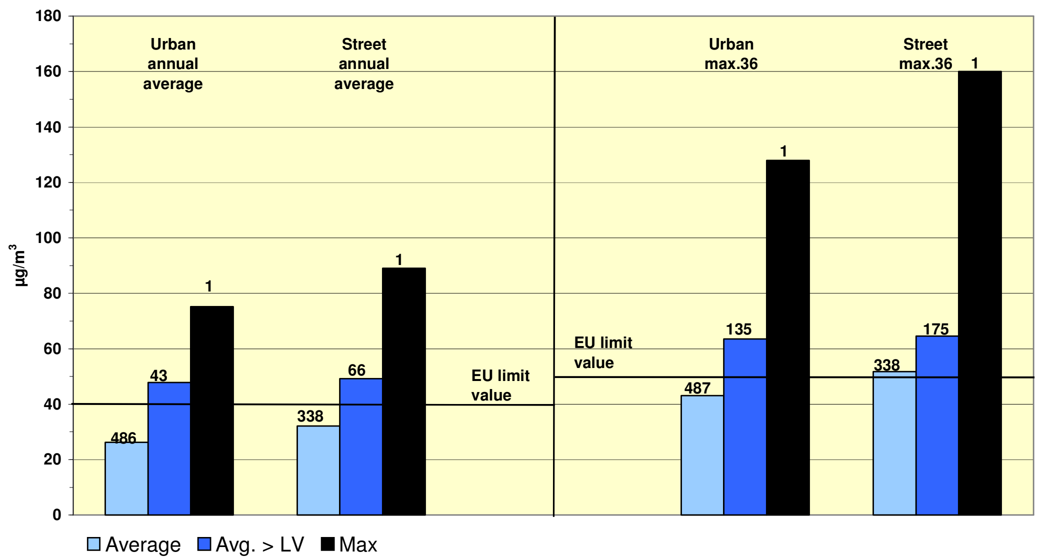


Figure 4-14: Distance-to-target, PM_{10} above EU limit value, 2002 (number of stations on top of bars). The "Average" bar: all stations; the "Average>LV" bar: the stations above the limit value; "Max" bar: the station with the highest concentration

Concluding, exceedances of PM_{10} limit values are widespread in urban areas in Europe, and they are exceeded also in rural areas in some countries. The concentrations averaged over a limited set of stations decreased between 1997 and 1999, and has increased since then. The inter-annual meteorological conditions can explain part of this variation, as can PM emission variations. The increase since 1999 seems, though, largely to be controlled by an increase in the rural PM_{10} concentration. This increase occurs simultaneous with an increase in secondary sulphate concentrations. The concentrations at street stations have been increased substantially

less than in rural and urban background, most probably due to the effect of control of vehicle exhaust emissions as a result of EU legislation.

4.1.4. Nitrogen Dioxide

For 2002, nitrogen dioxide (NO_2) monitoring data in AirBase include in total 1810 stations in 25 countries. 1255 of these stations are located in about 880 cities and towns. 148 of the stations are located in 9 of the new EU Member States, so these are not well enough represented to analyse the possible differences between the EU-15 and the new EU MS.

The number of NO_2 stations with data in AirBase is substantial from 1996 onwards, enabling an analysis of the tendency in air quality to be made for those years. The analysis of tendency/trend shown in Figure 4-15 is based upon a total of 677 monitoring stations in 16 countries, with data for all the years 1996-2002.

Tendencies in NO_2, 1996-2002

Figure 4-15 shows a downward tendency until 1999-2000 in NO_2 concentrations averaged over each of the three types of areas (rural, urban background, traffic hot-spot), both for annual average and the high short-term concentrations (the 19th highest hour, corresponding to the EU limit value). This slow downward tendency has taken place since 1990, as more and more data became available to allow for an indication of a tendency in concentrations. After 1999-2000, the concentration level for annual average has been rather unchanged, while for the short-term indicator, the concentration increased slightly from 2001 to 2002. The graphs show that it is the annual average limit value that is exceeded to the largest extent. The large difference in concentrations from rural to urban to hot-spot is clear from the graphs.

The downward and then flat trend in NO_2 concentrations in urban areas is experienced in most countries with long enough time series of measurements. Austria, Switzerland and Poland had increased concentration levels from 2001 to 2002 (Poland steadily since 1999). For Austria, this can be explained by reported increased NO_X emissions. At street stations the tendencies are more variable, undoubtedly due to various developments of the traffic volume in each of the individual street.

The year 1997 stand out as a year with high concentrations. A cold winter (especially January) with average wind speed fairly below average and the occurrence of days with stable meteorological conditions was higher than normal. An attempt has been made to correct for the effect of annual averaged meteorological conditions on the annual NO_2 concentration levels in AirBase. Corrections for the wind speed resulted in a reduction of the high 1997 concentrations compared to other years. Taking account of the corrections for wind speed, there is good correspondence between inter-annual variations in emissions of NO_x and annual average concentration levels of NO_2, in most countries.

The downward trend in NO_2 concentrations reflects the parallel reduction in NO_X emissions in Europe (Figure 4-16). The reported NO_X emissions show a reduction from 1996 to 2002 of 17%, for EU15 as well as for EU15+EU10 in total. The corresponding average reduction in NO_2 concentrations at the 318 urban background stations with data for 1996-2002 is also 17%.

The NO_2 concentration reduction has been somewhat more pronounced in urban areas than in rural areas (Figure 4-17), especially towards 2000.

Urban NO_2 is the sum of contributions from rural NO_2, from primary NO_2 emitted from local urban sources (mainly from vehicle exhaust) and from the reaction between urban NO and ozone in the urban air. There is a *reduction* in annual average ozone as one goes from the rural to the urban areas, of about 18µg/m^3, or 9 ppb, in 2002 (Figure 4-3 and Figure 4-7). The corresponding *increase* in NO_2 is about 14µg/m^3, or about 7.5 ppb (Figure 4-16 and Figure 4-17). Considering that some ozone in adsorbed on urban surfaces, and that primary exhaust NO_2 contributes to the urban NO_2 concentrations and the station set for O_3 and NO_2 are not identical, there is a fair correspondence between loss of ozone and increase in NO_2, as one moves from the rural to the urban setting.

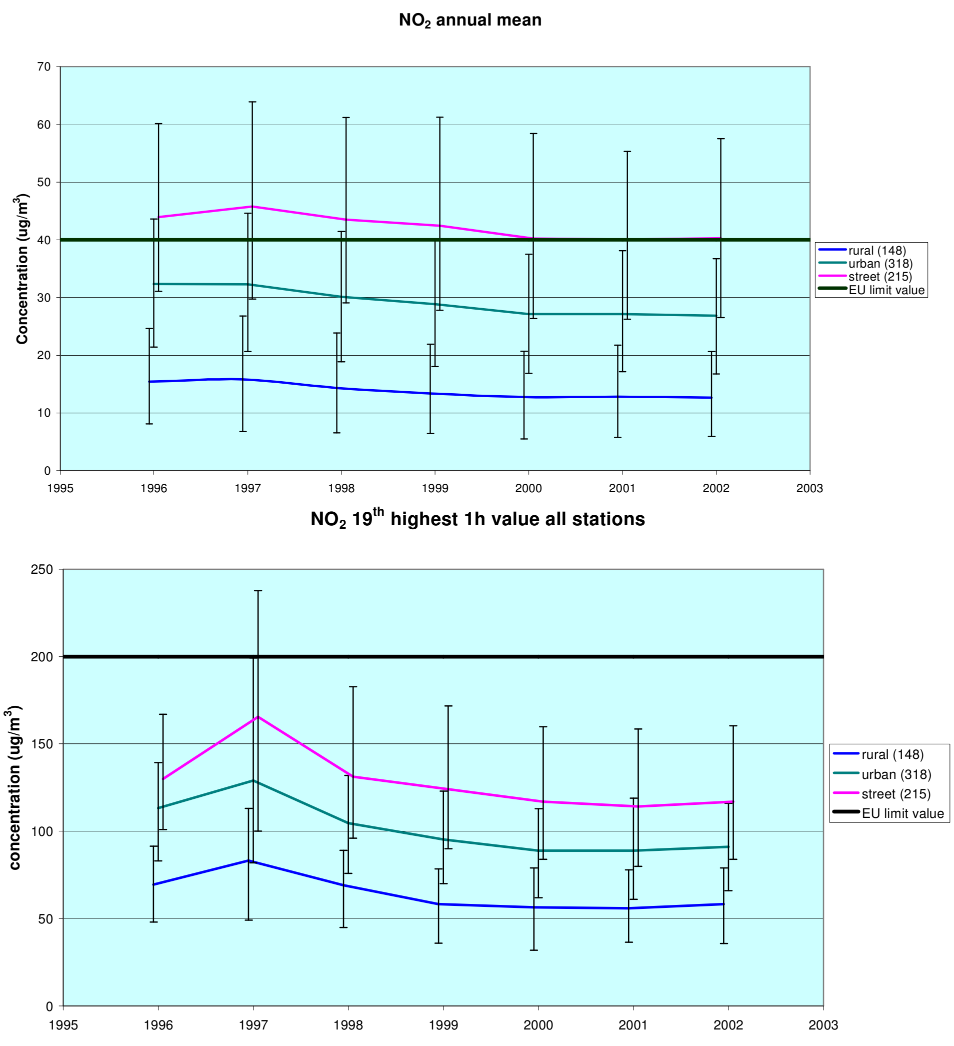


Figure 4-15: NO_2 interannual variations, 1996–2002 Indicators: Annual mean and the 19th highest 1-hour average value each year. All stations with 7 monitoring years. ertical bars: 10th and 90th percentiles

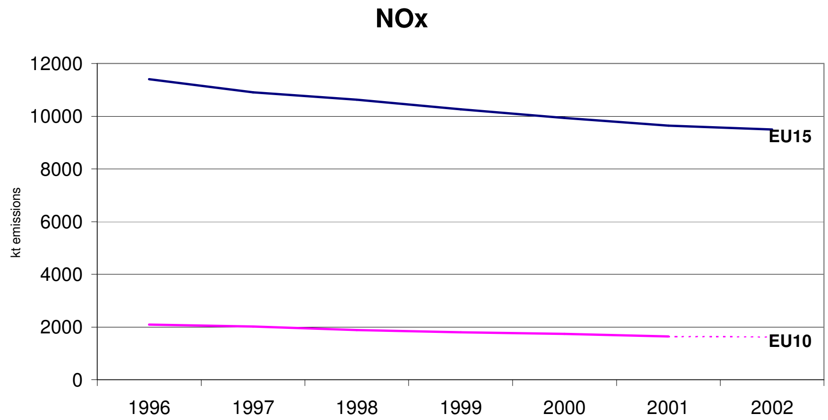


Figure 4-16: Emissions of NO_X for EU15 and EU10 countries, 1996-2002 (Ktonnes)

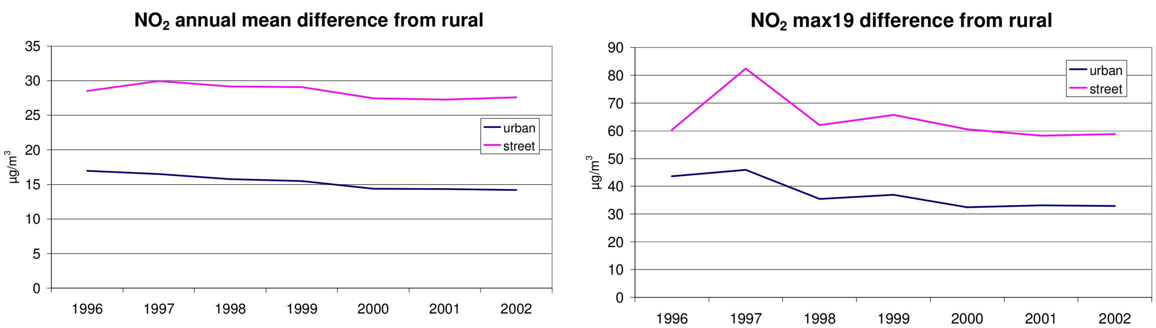


Figure 4-17: NO_2 tendencies in urban areas relative to rural areas, 1996-2002

<u>State, population exposure and distance-to-target, 2002</u>

Map 4.5 and Map 4.6 show locations of cities with sites in exceedance of the Limit Values of annual average, for 2002. Exceedances of the annual average LV are found at 345 stations in 16 countries. The cities with measured exceedances at urban background stations represent a total population of about 22 million inhabitants.

Somewhat more than 20% of the urban population was potentially exposed to ambient NO_2 concentrations above the EU limit value set for protection of human health (in this case 40µg/m^3 annual mean). This percentage has been decreasing since the mid-nineties.

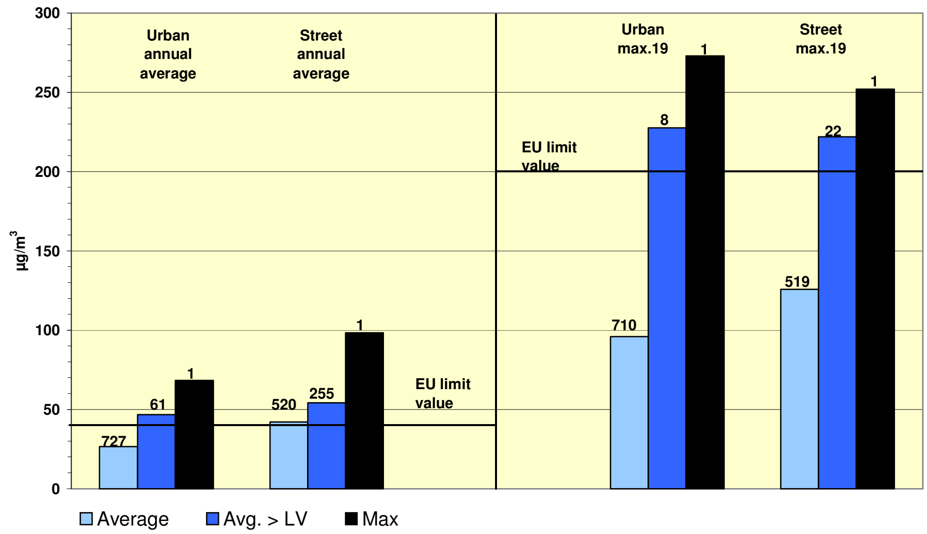


Figure 4-18: Distance-to-target, NO_2 2002 data. (nr of stations on top of bars). "Average" bar: all stations; the "Average>LV" bar: stations above the limit value; "Max" bar: the station with the highest concentration

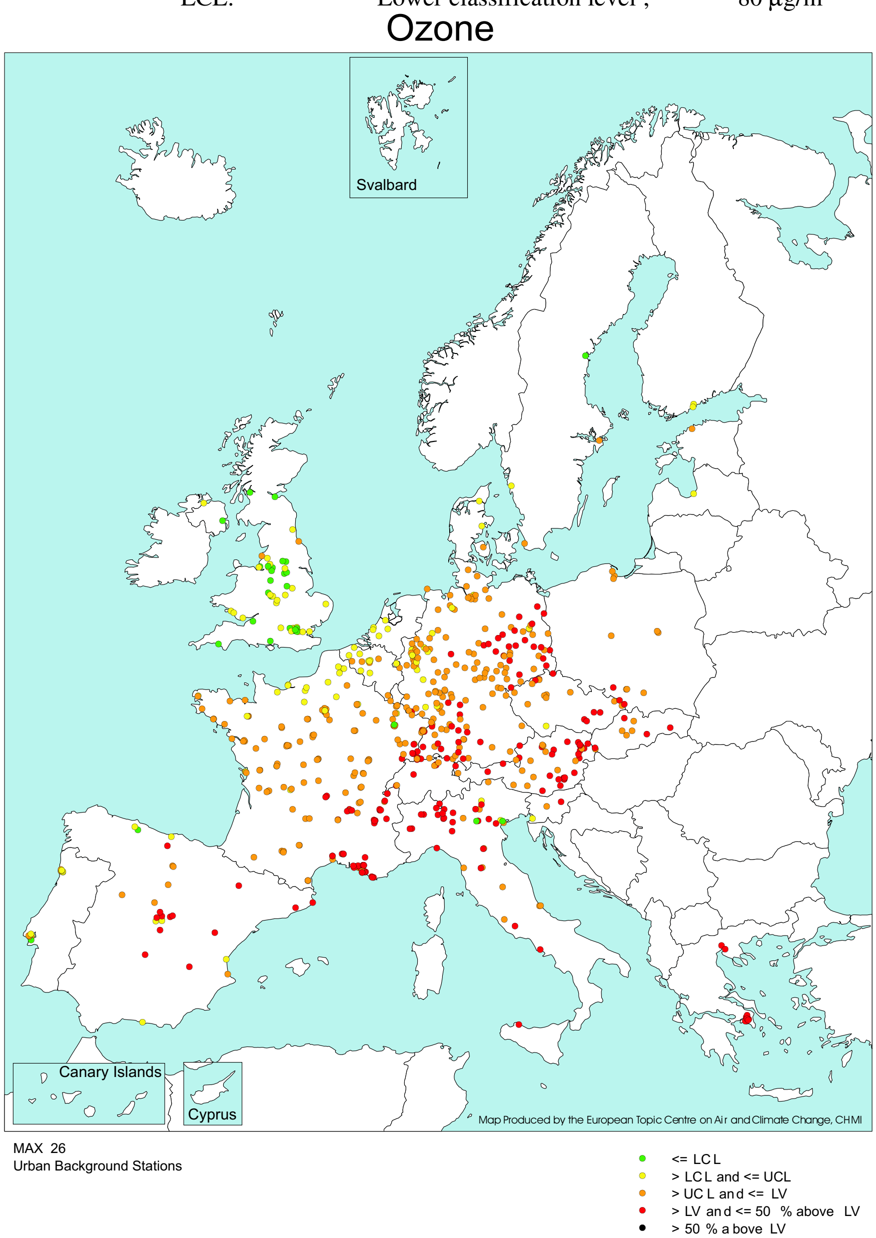
Figure 4-18 shows the extent of exceedances above the EU limit values in 2002. The annual average limit value was exceeded the most. For the stations in exceedance, the average annual concentration was 15% and 32% above the limit value, for urban background and traffic stations respectively. The most exposed stations had concentrations up to 2.5 times the limit value.

Thus, there are widespread exceedances of the EU limit values for NO_2 in cities in Europe. The concentrations tend to decrease, but have been rather unchanged since 2000, in most countries.

Map 4.1: Ozone in cities, 2002 Urban background stations, 26th highest daily 8-hour max value.

The maximum station in each city, relative to EU Target Value.

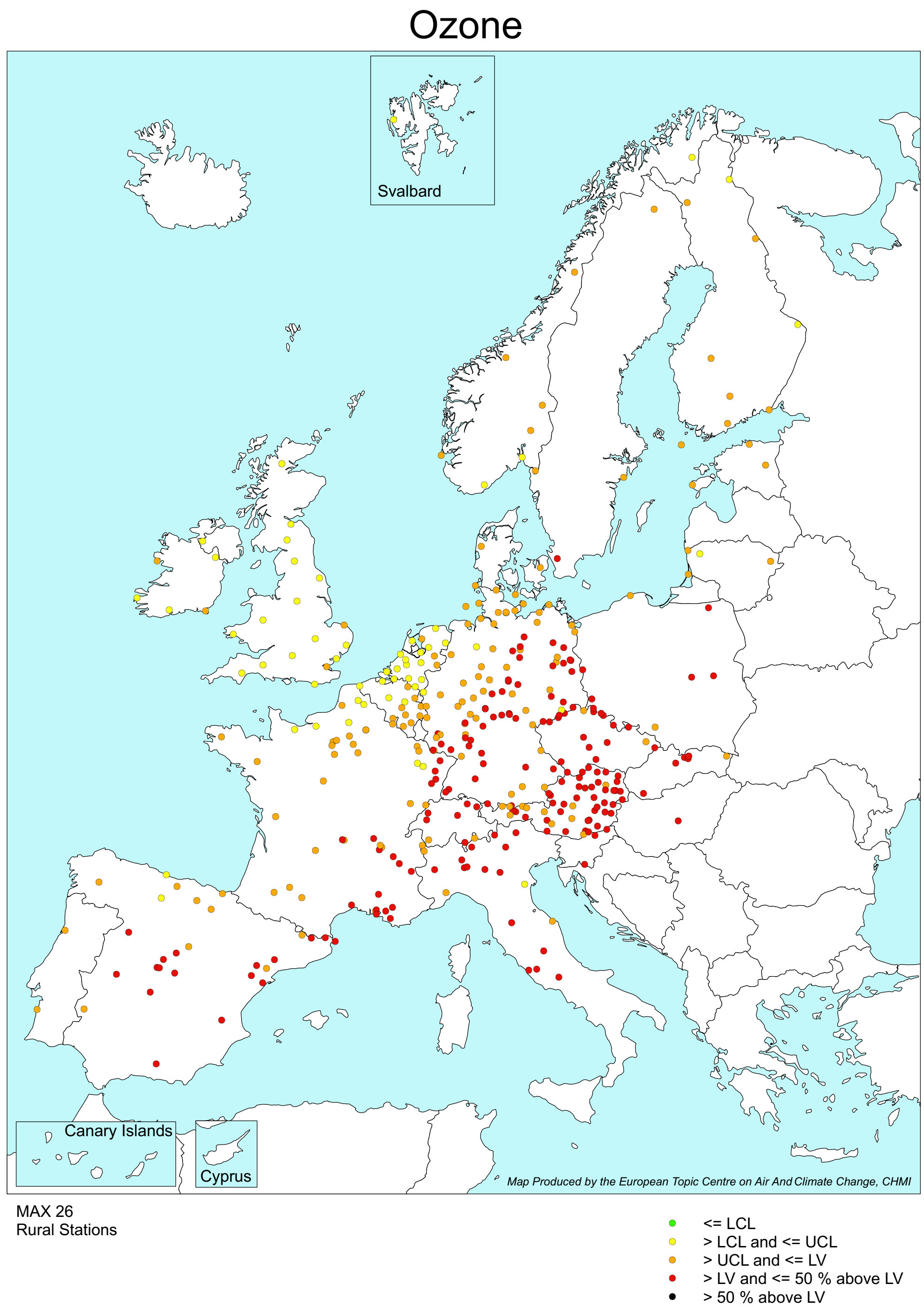
TV:	Target value:	120 µg/m^3
UCL[8]:	Upper classification level:	100 µg/m^3
LCL:	Lower classification level ;	80 µg/m^3



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

Map 4.2: Ozone at rural stations, 2002 26th highest daily 8-hour max value.

TV	Target value:	120 μg/m³
UCL[9]:	Upper classification level:	100 μg/m³
LCL:	Lower classification level ;	80 μg/m³



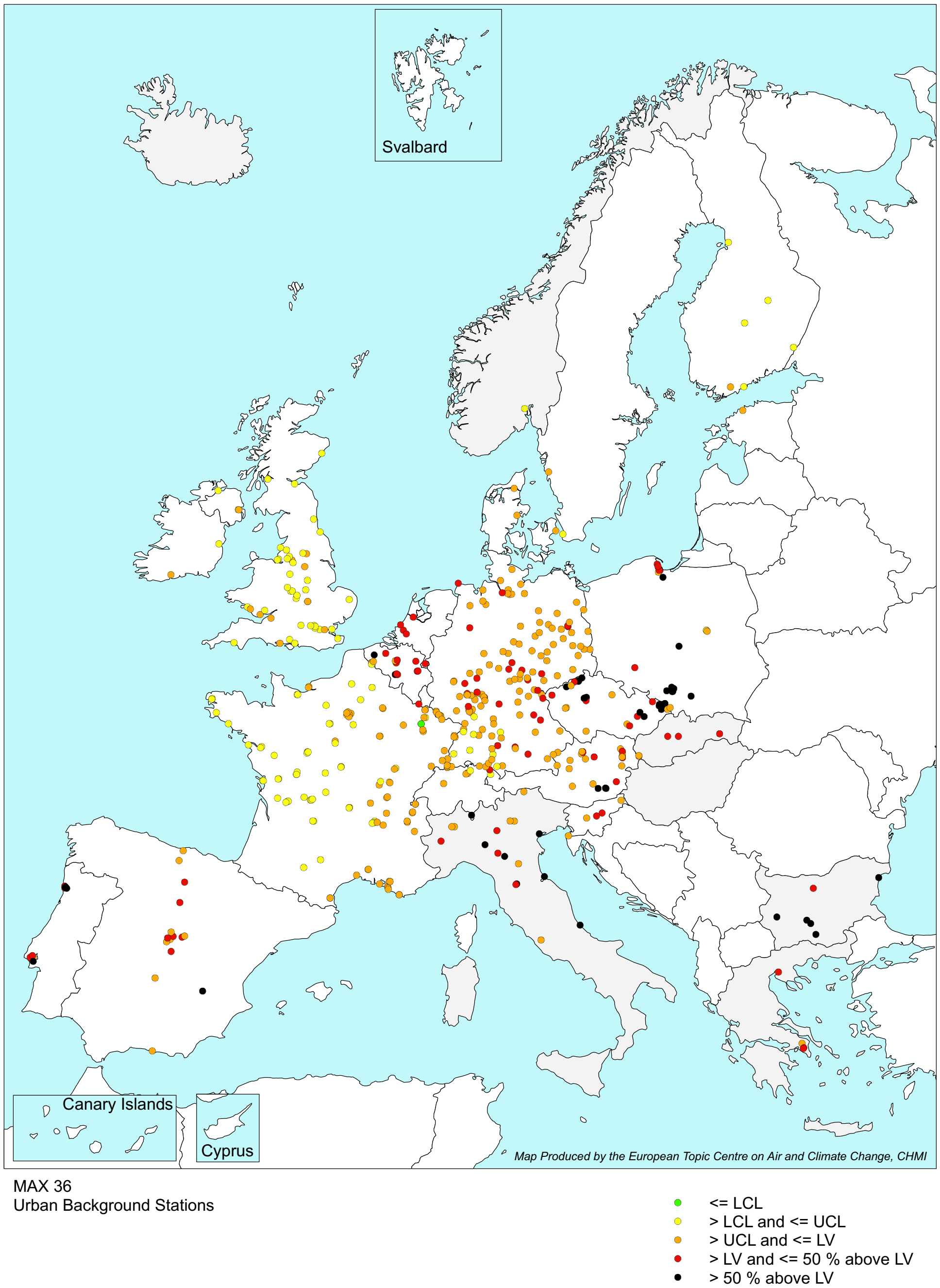
[9] UCL and LCL have been selected in order to visualise in the map the range in concentration levels measured. For ozone, upper and lower assessment levels have not been given, such as for PM_{10} and NO_2.

Map 4.3: PM_{10} in cities, 2002. Urban background (UB) stations, 36th highest daily value.

The maximum UB station in each city with data, relative to EU limit value (LV) and Upper and Lower Assessment Thresholds (UAT, LAT)[10].

LV: 50 µg/m³
UAT: 30 µg/m³
LAT: 20 µg/m³

Particulate Matter



---

10 The Assessment Thresholds for PM_{10} in the 1st Daughter Directive are connected to the indicative limit values for 2010, and those values should not be exceeded more than 7 times a year. In this map, the assessment threshold concentration value is used, but the colour coding is still linked to the 36th highest daily value, to show the range in concentration values measured.

Map 4.4: PM_{10} in cities, 2002

Hot-spot stations (traffic, industrial), 36th highest daily value.

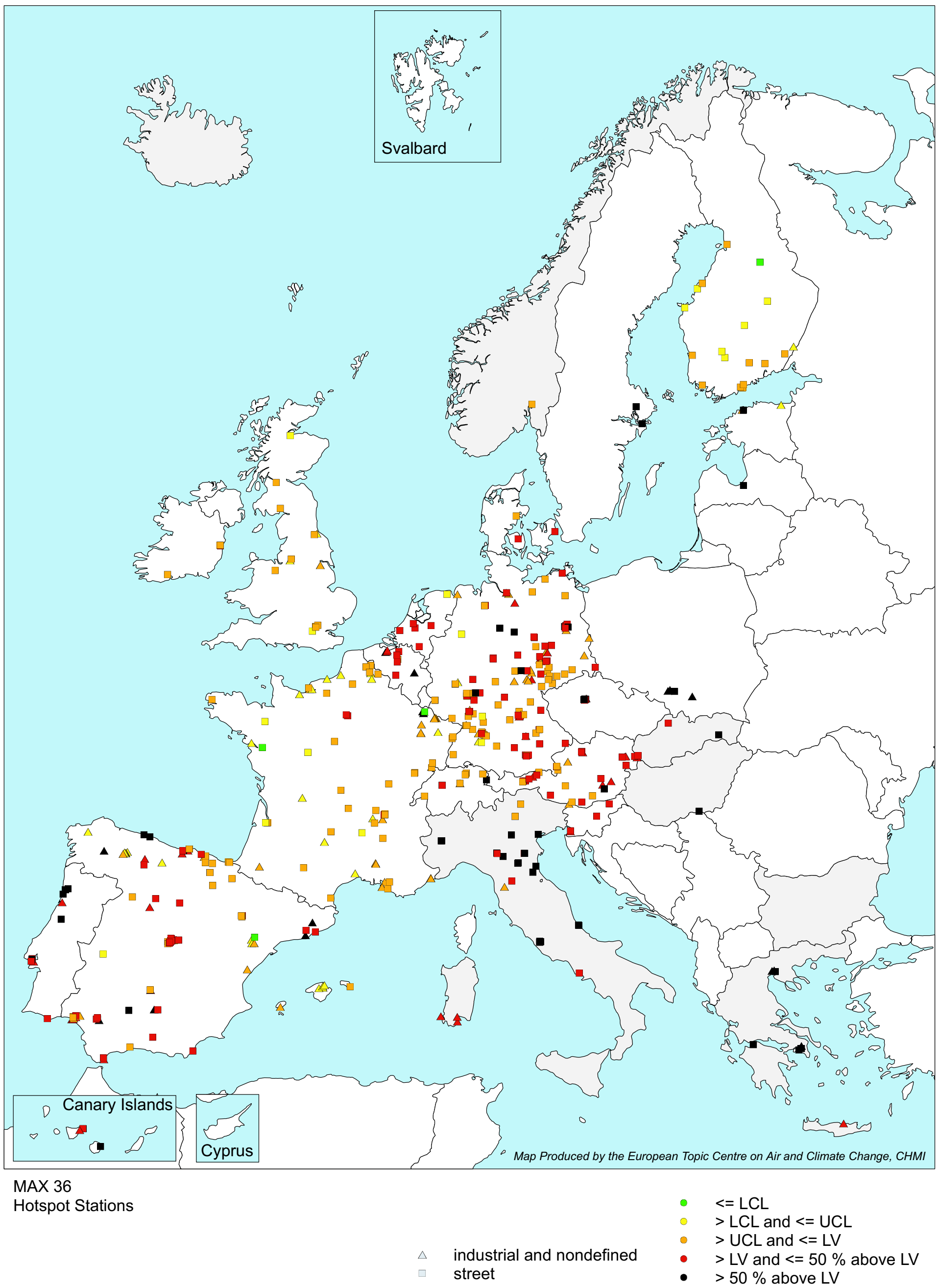
The maximum hot-spot station in each city, relative to EU limit value (LV) and Upper and Lower Assessment Thresholds (UAT, LAT)[11].

LV: 50 µg/m³

UAT: 30 µg/m³

LAT: 20 µg/m³

Particulate Matter



[11] The Assessment Thresholds for PM_{10} in the 1st Daughter Directive are connected to the indicative limit values for 2010, and those values should not be exceeded more than 7 times a year. In this map, the assessment threshold concentration value is used, but the colour coding is still linked to the 36th highest daily value, to show the range in concentration values measured.

Map 4.5: NO_2 in cities, 2002

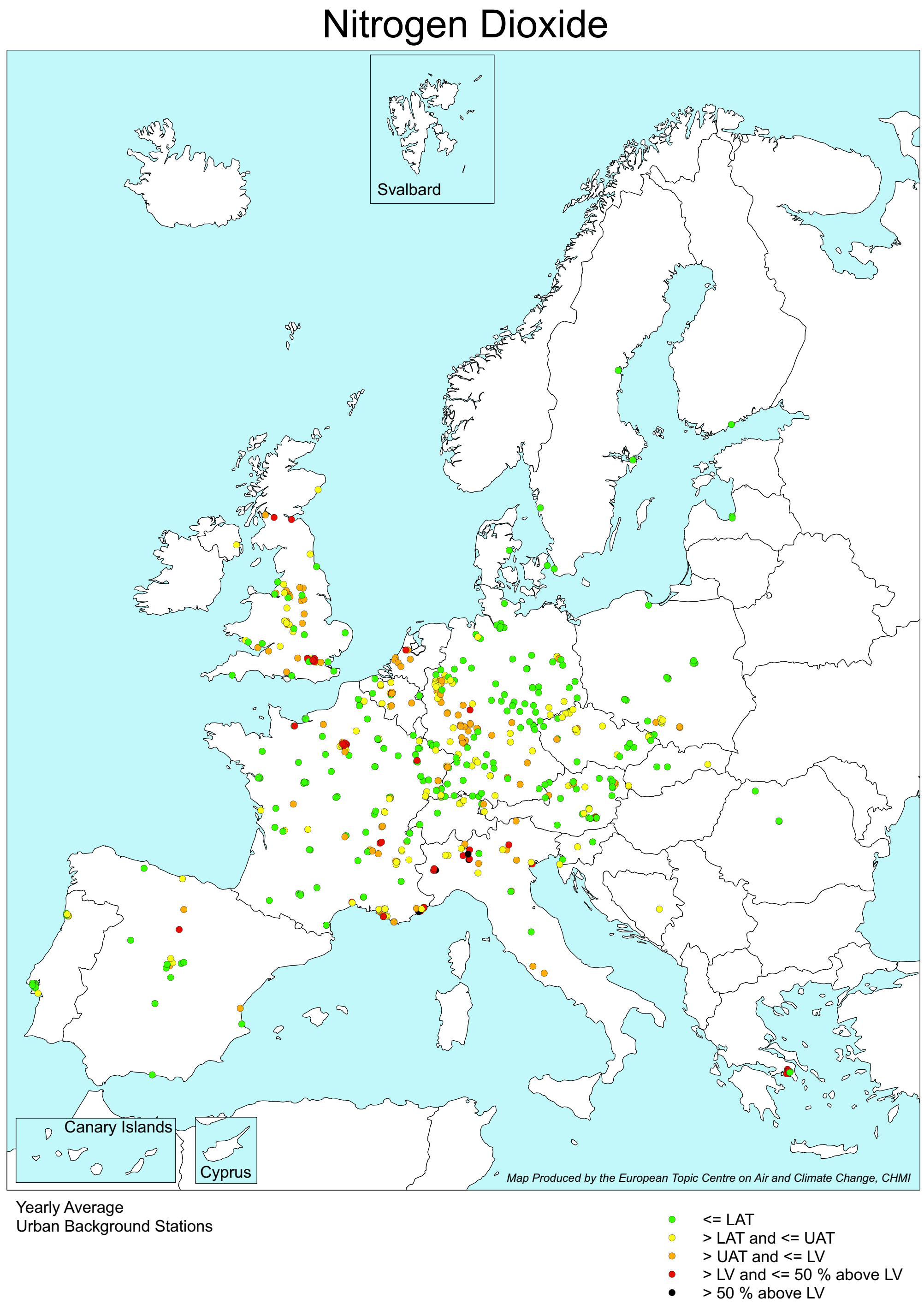
Urban background stations, annual average.

The maximum UB station in each city with data, relative to EU limit value (LV) and Upper and Lower Assessment Thresholds (UAT, LAT).

LV: 40 $\mu g/m^3$

UAT: 32 $\mu g/m^3$

LAT: 26 $\mu g/m^3$



Map 4.6: NO_2 in cities, 2002

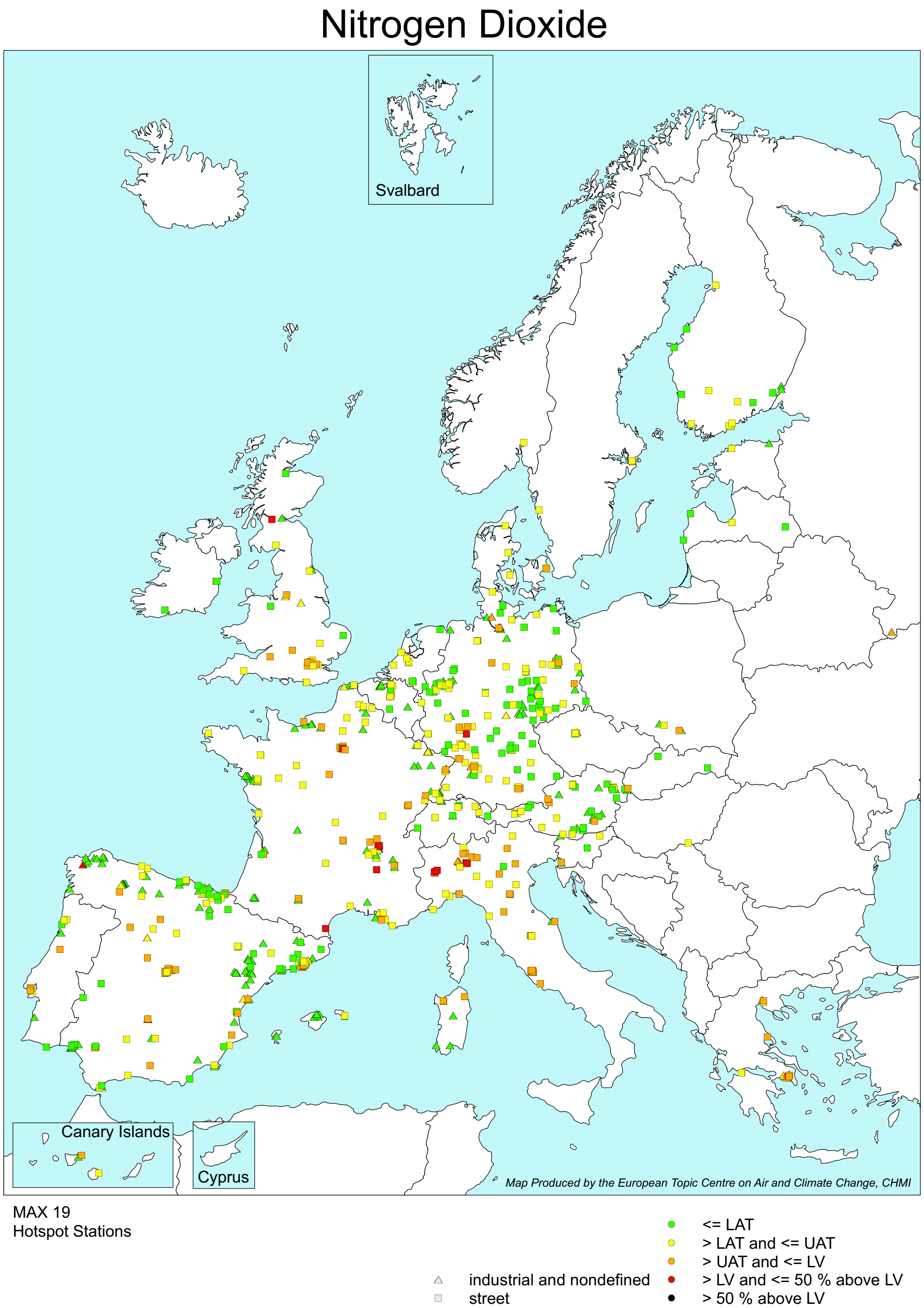
Hot-spot stations, 19^{th} highest hourly value.

The maximum UB station in each city with data, relative to EU limit value (LV) and Upper and Lower Assessment Thresholds (UAT, LAT).

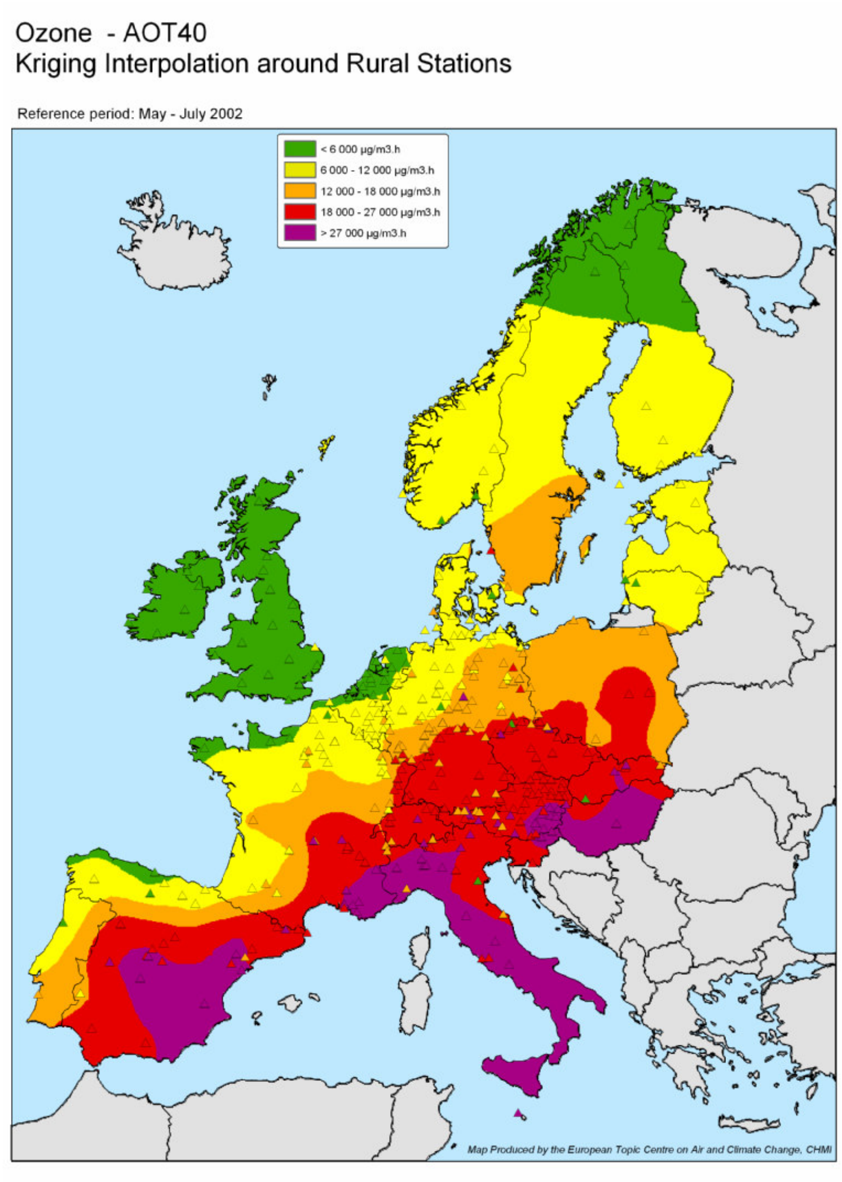
LV: 200 μg/m^3

UAT: 140 μg/m^3

LAT: 100 μg/m^3



Map 4.7 : Exposure above AOT40 target values for vegetation around rural ozone stations, 2000.



4.2 Ecosystem related air pollution

4.2.1 Ground level ozone

Ozone exposure of ecosystems and agricultural crops results in visible foliar injury and in the reduction in crop yield and seed production. For vegetation under European conditions, a long-term cumulative exposure during the growing season is of concern rather than an episodic exposure. The target level is expressed as AOT40 not to exceed 18 000 $\mu g/m^3 \cdot h$ and should be reached in 2010; the long-term objective is set at 6 000 $\mu g/m^3 \cdot h$. Map 4.7, Figure 4-19 and Figure 4-20 show that the long-term objective for vegetation and crops was exceeded in much of Europe, except in the UK, Ireland and Nordic countries. In 2002, the long-term objective was exceeded in more than 80 % of the EEA-31 area where data are available. The target value is already complied with in 60 % of the area with data, mainly in the northern part of Europe.

Large year-to-year fluctuations in crop exposure to ozone prevent firm conclusions on trends. The situation for EEA-31 countries as a whole is shown in Figure 4-19 for years since 1990. The area in Europe for which ozone data are available in AirBase has increased steadily since 1990. The area of exceedance of critical levels has varied considerably between years. The tendency is that for crops, the area of non-exceedance of the long-term objective (6 000 □g/m3•h) is small in all years, and as data for more areas become available, the areas with documented exceedance increases. There are, however, large variations from year to year in ozone due to meteorological variability, which may mask the real trend. The area with documented exceedance of the target value was in 1999 and 2000 about 20 % of the total arable land in EEA-31 countries.

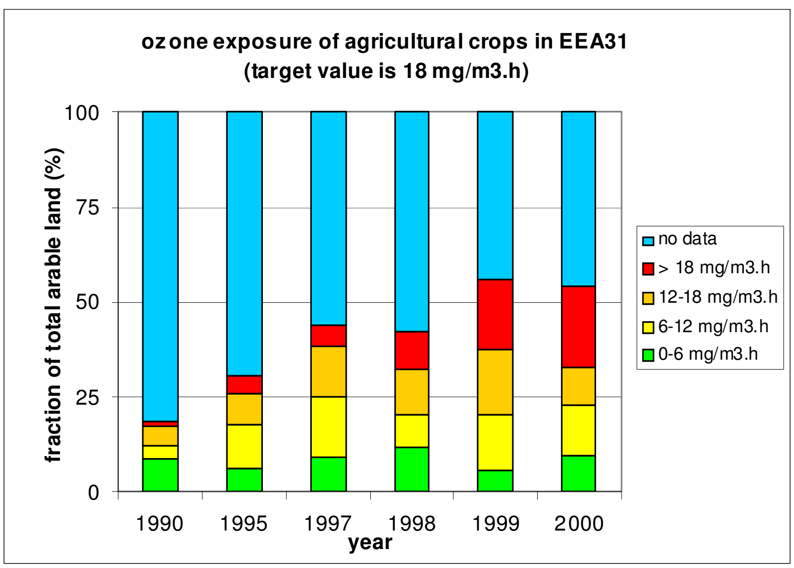


Figure 4-19: Exposure of agricultural crops to ozone (exposure expressed as AOT40 in mg/m3•h).

The changes in the average observed AOT40 value over the last five years is presented in Map 4.7, which shows the average AOT40 for all available data at rural stations in EEA-31 countries (about 200 stations). Although this figure is based on stations having at least 6 years of data during the period 1996–2002, the number of stations differs somewhat from year to year. Especially 1996 data is based on a relatively low number of stations. The data indicates over the years a somewhat increasing AOT40 average since 1997, and a flattening out after about 2000. The tendencies in Figure 4-3 for annual average is reflected in Figure 4-20, but the increase in AOT40 is enhanced compared to the annual average.

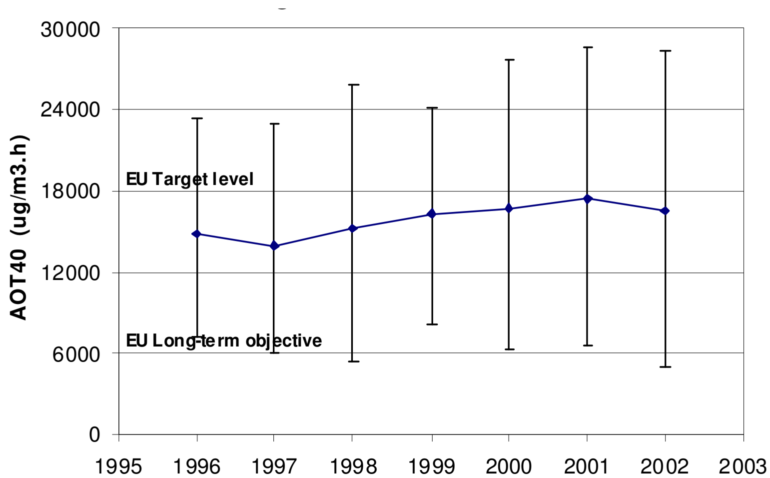
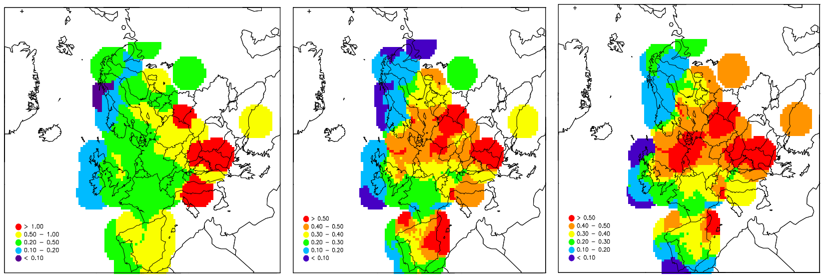


Figure 4-20: Average AOT40 for ozone at rural stations (May–July), EEA-31, 1996–2000. Average of about 200 rural stations. Vertical bars indicate 10th and 90th percentile values.

4.2.2 Acidification and eutrophication

In Map 4.8 a)-c) the observed supply in precipitation of sulphur and nitrogen compounds are shown for 2002. Observed concentrations of sulphur are highest in the south and east of Europe, whilst for oxidised and reduced nitrogen the area of greatest concentrations in precipitation extends into mid and north-west Europe. Deposition of these pollutants is attributed as resulting in acidification and eutrophication. Reaction of water with these compounds upon deposition to the earth’s surface results in acidifying conditions, with consequences including changes to the mineral balance of soils and waters, and whilst mechanisms are complex the increase in toxicity can affect vegetation and aquatic life. Eutrophication can arise as nitrogen is a fundamental plant nutrient. If sufficient, deposition can overcome nutrient limitations. Resulting enhanced growth can become detrimental to ecosystems.

Map 4.8: Observed concentrations of acidifying and eutrophying components in precipitation, 2002. Krieged. mg/l (a) SO_4-S; (b) NOx-N; (c) NHx-N



(a) sulphate (b) nitrate (c) ammonium

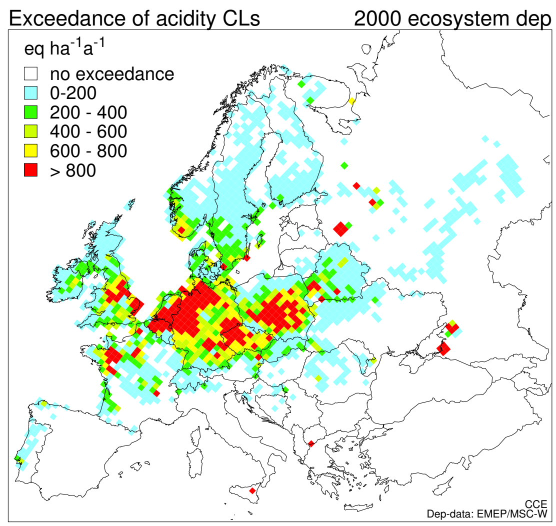
The risk of harm is measured through the concept of 'excess deposition', which is the expected deposition of acidifying or eutrophying pollutants in excess of a 'critical load', or threshold which should not be exceeded if ecosystems are to be protected from risk of damage. When evaluating the status of acidification and eutrophication in Europe the critical load values are compared with model estimates of pollutant deposition rather than observed values, as the distribution of monitoring is insufficient to provide full coverage. However, monitoring data is used to compare with the dispersion models used by EMEP compute pollution deposition.

Results from an entirely new pollutant dispersion model, along with revised estimates during 2004 of the critical loads, have provided a fresh evaluation of environmental status for key years. Map 4.9 shows the pattern of exceedence of acidity critical loads in 2000 (the most recent year assessed), showing that the problem continues to be focused in north-western and central Europe. The area of total ecosystem coverage receiving excess acidifying deposition is 11%, whilst the area expected to be in exceedence if NEC Directive and Gothenburg Protocol emission reductions are achieved will be 8%. Thus, over a quarter of the area in excess in 2000 will need to see depositions fall below critical loads in order to achieve protected status by 2010.

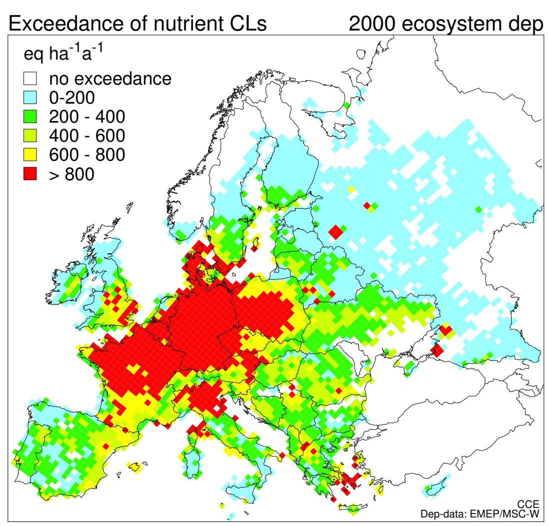
Map 4.10 shows that the exceedence of eutrophication critical loads poses a more widespread problem. Virtually the whole of north-west and central Europe was at risk of eutrophication in 2000 through exceedence of critical load thresholds. The area concerned is estimated at 35.1% of total ecosystem area. Although this is a substantial area, current reduction plans seek to bring little more than 1% of this under protection. Thus achievement of emission targets will not require dramatic changes within the remaining time.

Contending with acidification and eutrophication has been the objective of the Geneva Convention on Long-range Transboundary Air Pollution (CLRTAP), and most recently its Gothenburg protocol which tackles acidification, eutrophication and ground level ozone. The European Union has also addressed the issue via the EU National Emission Ceilings Directive (NECD).

Map 4.9: Ecosystems at risk of acidification, 2000. Units: Average accumulated exceedence of critical loads for acidity, as acid equivalents per hectare per year



Map 4.10: Ecosystems at risk of eutrophication, 2000. Units: Average accumulated exceedence of critical loads for acidity, as acid equivalents per hectare per year



These emission targets can be translated into to the anticipated consequences for acidification and eutrophication consequences utilising model estimates of the likely future deposition of pollutants. In Figure 4-21 the change in the area of ecosystems since 1990 which suffer exceedence of their critical loads is displayed. Particularly for acidification, there have been large improvements during the 1990s, this improvement slowing somewhat beyond 2000 and into the future. It is notable that a greater proportion of the ecosystem area of the EU25 is adversely affected than of the ecosystem area of the whole of Europe (defined here as the Parties to CLRTAP).

Review in the EMEP assessment report (Lovblad et al. 2004) describes overall decreases in European sulphur emissions since 1980 of nearly 70%. Western Europe

saw the earliest and largest reductions, the maximum decrease in national emissions being 90% (Denmark, Germany, the United Kingdom and Austria). At a subregional scale central-southeast Europe (Balkans to Kazakhstan) saw the smallest decrease of approximately 40%, whilst some individual Mediterranean countries saw an increase in sulphur emissions.

Whilst the development over time is broadly positive, the scale of the problem is greater than previously estimated. The EMEP assessment report uses the available model results and critical load estimates at the time of negotiation of the Gothenburg Protocol and NEC Directive to show the area which at that time had been expected to remain affected once emission reduction plans were implemented. This is displayed in Figure 4-21 as coloured dots.

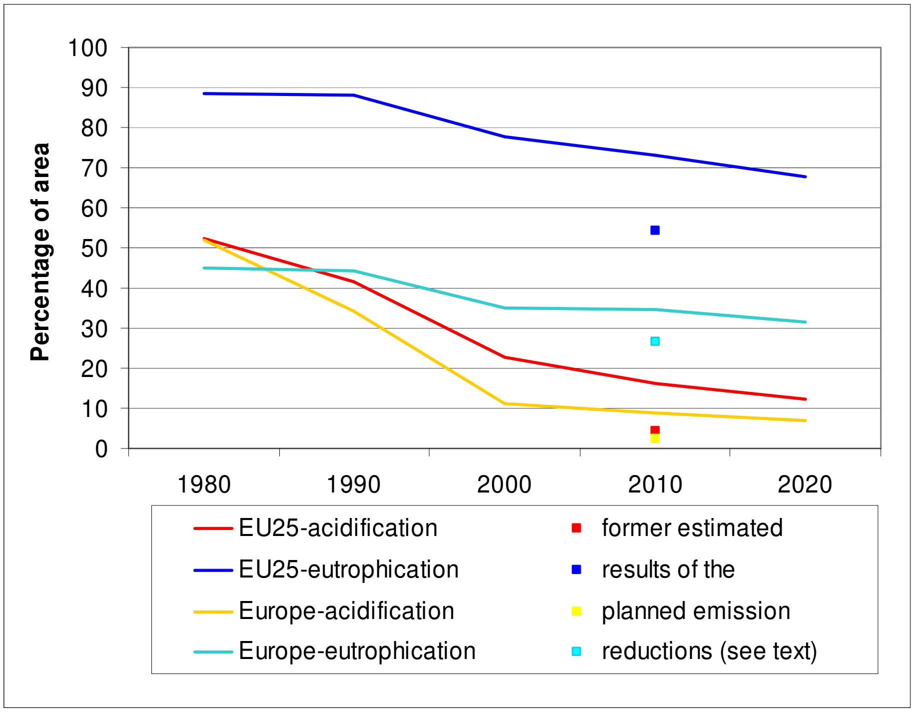


Figure 4-21 Ecosystems in the EU25 and the whole of Europe estimated at risk of acidification and eutrophication through excess deposition of pollutants. The estimated environmental quality target at Protocol agreement is also shown.

It is notable that the likely future status upon achievement of projected emission reductions will be poorer than anticipated during emission reduction negotiations. Improvement of the dispersion modelling since Gothenburg now permits estimates of ecosystem specific rather than grid averaged deposition. These can then be matched to ecosystem specific critical loads, enabling a closer approximation of expected environmental status. The poorer than anticipated situation is more striking for eutrophication. When the Protocol was agreed the area estimated to still be at risk once emission reductions were achieved in 2010 was 24.6% of all-Europe; the revised estimate with improved techniques is 34.7%. Within the EU25 the anticipated 2010 area of exceedence of 54.4% has been revised upwards to 73%.

5. Global and European emission assumptions and driving forces

5.1. Global key assumptions and driving forces

The assumptions for the drivers population and economic growth are equal for the LREM-E, the CAFE-CP and the LGEP scenario.

Spurred by further globalisation, economic growth is relatively fast in this scenario, although not as strong as assumed in the IPCC A1b scenario (IMAGE-team, 2001; Nakicenovic et al., 2000). Economic growth can therefore be described as medium (per capita yearly growth rate of 2 to 3%) in almost all regions. As growth is greater in low-income regions than in high-income regions, the relative gap between the regions will be reduced. However, for economic growth to occur, regions will need to have a sufficient level of institutional development and stability. In the scenario it is assumed that in the first 2-3 decades, these conditions will not be met in Sub-Saharan Africa; as a result this region will clearly lag behind in terms of income growth. However, the current barriers to economic development are gradually reduced in this same period– and from 2025/2035 onwards the region 'takes off' in terms of its development, similar to what we have seen for Asian countries in the past.

Table 5.1: Main driving forces of the LREM-E and LGEP scenario by region

	Population (in mill.)			Per Capita Income (in 1000PPP €1995 per year)[12]			Per Capita Income (growth rates)		Primary energy use (in TJ per year)		
	1995	2025	2050	1995	2025	2050	1995-2025	2025-2050	1995	2025	2050
Canada & USA	296	362	391	26	43	56	1.7%	1.1%	92	121	128
Enlarged EU	505	499	450	17	35	50	2.4%	1.5%	66	83	87
CIS	293	298	273	1,7	5,3	15	3.8%	4.2%	37	52	57
Oceania	28	40	46	15	30	43	2.2%	1.5%	4,8	8	9,7
Japan	125	121	111	41	65	90	1.6%	1.3%	19	23	22
Latin America	476	690	800	3,6	6,8	12	2.1%	2.4%	22	50	89
Africa	719	1346	1831	0,6	0,9	1,8	1.2%	2.8%	20	43	79
ME & Turkey	219	378	483	3,3	6,4	13	2.2%	2.8%	15	41	67
South Asia	1245	1865	2160	0,4	1,6	4,1	5.0%	3.9%	25	63	116
SE & E Asia	1798	2293	2439	1,4	7,4	17	5.7%	3.4%	72	169	252
World	5706	7891	8984	4,9	9,1	14	2.0%	1.9%	373	653	908

Source: IMAGE 2.2

The results of the most important driving forces by region are indicated in Table 5.1. The assumptions for population are based on the UN medium projections up to 2030 and the UN long-term medium projection afterwards. In this population scenario the global population stabilises at a level of 9.5 billion by 2100.

5.1.1. Change in energy use for the LREM-E scenario

In the LREM-E baseline, primary energy use will also continue to grow in almost all regions with the projected increase in population and income. World-wide, primary

[12] GDP levels of different countries are normally compared on the basis of conversion to a common currency (mostly US$) using Market Exchange Rates (MER). However, this is known to underestimate the real income levels of low-income countries. Therefore, an alternative conversion has been developed on the basis of purchasing power parity (PPP). In this article, we have usually used PPP-based GDP estimates, but where required, MER-based estimates for comparison are used.

energy use increases by about 75% in 1995-2025 and by another 40% in the period 2025-2050. As Figure 5-1 shows, the growth occurs largely in non-Annex I regions (Asia and rest of the world). The OECD and FSU region only slowly grow between 2000 and 2030, after which energy use stabilises as a result of saturation, stabilising population, further efficiency improvement (together outrunning the upward pressure from income growth).

Oil continues to be the most important energy carrier until 2040. After 2040 both natural gas and coal take over this position. This is partly due to the slowly increasing oil prices from 2010 onwards. In the period 2000-2025, a slowly increasing share of the world's oil supply will be produced in the Middle East as result of slow depletion of oil reserves (increasing production costs) in other parts of the world. Unconventional oil supplies from Canada and Latin America partly offset this trend, Important sectors for the use of coal include the electric power sector (depending on region; as it competes with natural gas) and industrial sectors. Natural gas is mainly applied in the electric power and buildings sectors.

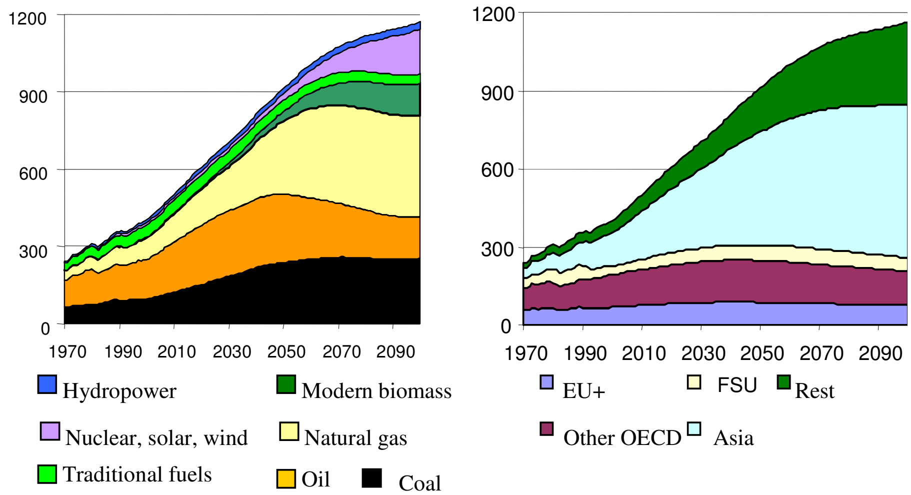


Figure 5-1: Development of global energy consumption under the LREM-E scenario

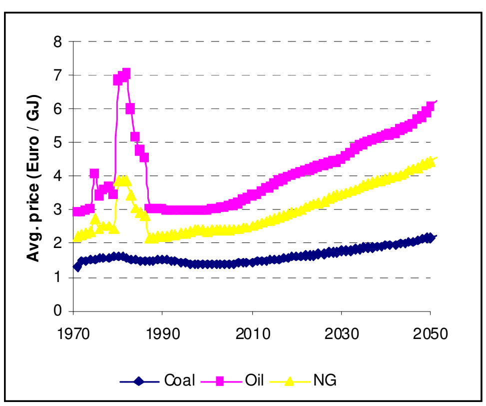


Figure 5-2: Development of global average prices of primary energy carriers

Over the whole period the natural gas price more-or-less follows a similar patterns as that of oil, although depletion impacts the natural gas price at a somewhat slower rate. The coal price remains fairly low during the whole period. In the buildings sector,

coal nevertheless looses market share even in the regions where it is currently used on the basis of the higher convenience and lower environmental impacts of alternatives.

Sustainable development has been adopted as an important policy goal for EU development. In the EU communication on sustainable development policy, it is defined as a development in which economic growth, social cohesion and environmental protection go hand-in-hand. More specifically, sustainable development is translated into a development that decouples economic and social development from environmental degradation and resource consumption. In the context of this report, the objective of sustainable development translates mainly into a long-term development of that would meet a set of specific targets for climate change and regional air pollution ensuring a long-term environmental quality in a cost-effective and socially acceptable way.

5.1.2. Change in energy use for the LGEP scenario

In the LGEP scenario the strong objective to limit global greenhouse gas emissions to a 550 ppmv CO_2-eq stabilisation profile leads to substantial changes in the energy system compared to the baseline.

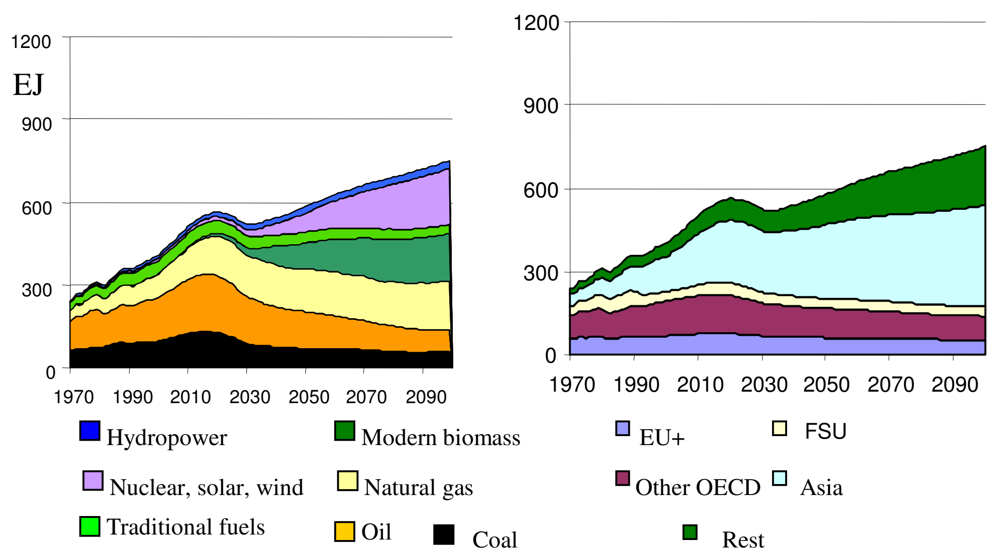


Figure 5-3: Development of global energy consumption under the LGEP scenario

In our analysis we have assumed that most of these changes are induced by attaching a high price to greenhouse gas emissions. Moreover, we also assume that with increasing permit prices, the unfavourable investment criteria for investments into energy efficiency in low-income regions can be reduced (in TIMER investments are simulated by a low accepted pay-back time). This low accepted pay-back time simulates investment barriers in these regions, resulting from a range of factors including large relative risks for long-term investments, lack of information and lack of capital. The emergence of a global emission trading market is likely to reduce these barriers. This is because investors from high-income countries (with stringent reduction objectives) are willing to invest in potentially low-cost reduction options in developing countries, thereby slowly reducing existing barriers as a function of an

increasing global permit price. This will open up a large potential for investments into energy efficiency world-wide.[13]

Under the LGEP scenario, global energy use still overall still slowly increases over the 2000-2050 period. However, as a result of rapid efficiency improvement between 2020 and 2030 global energy use actually declines. Compared to the LREM-E scenario global primary energy use is reduced by more than 35% in 2050. The largest reductions compared to LREM-E occur for coal (70% in 2050), with the remaining coal consumption being primarily used in electric power stations using carbon capture and storage. Instead of an increase compared to 2000 coal use now actually declines over the whole period. Reductions of oil and natural gas are 50 and 45%, respectively (compared to LREM-E). In absolute terms, oil use remains constant at first – and after 2030 starts to decline. Natural gas use increases. Other energy carriers gain market share, in particular solar, wind and nuclear-based electricity and modern biomass.[14]

5.2. European key assumptions and driving forces

For Europe, in all main scenarios (including baseline LREM-E and LGEP), the same assumptions for socio-economic developments (demographic and economic change) have been used, following the CAFE approach.

Population is assumed to be relatively stable in the EU-25, declining slightly over the longer term (to 2030). Uncertainties are much larger for economic growth. The economic growth assumptions for the medium term are within the range of other projections, although somewhat at the high end. This provides a rationale for also elaborating the low economic growth variant.

Enlargement of the EU is assumed to proceed successfully, boosting economic growth and enhancing convergence of incomes between the old and new member states. The economy of the EU-15 will grow throughout the period up to 2030 by an average of 2.3 % per year and GDP per capita by 2.2 %, which is similar to what happened over the past 30 years. The assumed growth rates may be modest compared with the ambitions of the Lisbon strategy, but also high compared with the current weak state of the EU economy. For the 10 new Member States, these percentage growth rates are 3.5 % and 3.7 %, with incomes gradually converging to EU-15 values. Furthermore, the EU economy is characterised by a further dematerialisation with stronger growth occurring in high value added industrial sectors and services.

5.2.1. Energy use assumptions for the LREM-E scenario

The baseline LREM-E scenario shows growing primary energy consumption, with fossil fuels continuing to dominate the fuel mix. Total energy consumption is expected to continue to rise, but the rate of increase is expected to progressively slow over the next 30 years, due to increasing efficiency in energy supply and consumption, combined with continued moves away from energy intensive industries towards lighter industries and services with lower energy intensity.

---

[13] We will look into the impact of this assumption in section 5.2.5 using an alternative set of TIMER-based cost curves

14 Modern biomass relates to gaseous or liquid fuels (commercially) produced from plants or trees. It differs from traditional biomass (gathered wood, straw, dung, charcoal, etc).

In the baseline scenario, however, many of the final energy sectors move away from oil and solids, the most carbon intensive fuels, in favour of electricity and gas. Thus, there is effectively very limited scope for further changes in the fuel mix and this is likely to make it much more difficult for the EU to attain further reductions after the first commitment period (2008-2012) of the Kyoto Protocol. Changes in individual fuels and the comparison of these with the corresponding changes in primary fuels also reflect the limited opportunity for substitution.

5.2.2. Energy use assumptions for the LGEP scenario

Under the LGEP scenario the increased global fuel prices mean that the European energy system undergoes some significant changes, all the way through to 2030 when compared to the baseline scenario.

Over the period to 2030, the contribution of energy intensity improvements is limited in 2030 to 34% of total emissions reduction compared to 48% in 2010. The remaining reductions are achieved through changing the mix of primary fuels to reduce CO_2 emissions.

On the demand side, the difference between the reduction in final energy demand and the corresponding reduction in emissions is much less than was the case for primary energy needs. Thus, in 2010, the reduction in demand accounts for about two thirds of the overall reduction in emissions originating from adjustments in final energy, further increasing to account for some 68% in 2020 and reaching at 71% in 2030. Largely, this is due to the projected shift away from carbon intensive fuels within final energy.

5.2.3. Assumptions on air pollutants emission control policies for the LGEP scenario

Our assessment on LGEP simulates two variants of air pollutants emission control policies:

- "current legislation" (CLE) and
- "maximum feasible reductions" (MFR).

The first variant includes emission control policies according to the current legislation in each country. We intended to include all known policies that have been implemented (or are in the pipeline) until the end of 2003. The assumption about penetration of emission control measures for individual countries have been verified by national experts during bilateral consultations carried out within the CAFE Programme. In order to be consistent with the CAFE work, we calculated the effects of implementation of all legally binding international and national emission and fuel standards in each country. In this way we explored only source-specific emission control legislation. Next, we compared the resulting emissions with internationally announced ceilings on national emissions that each country has committed itself to reach by 2010. The ceilings for the EU-15 were taken from the National Emission Ceilings Directive (OJ, 2001a). For other countries the ceilings from the Gothenburg Protocol (UN/ECE, 1999) were assumed.

The MFR case simulates the effects of implementing in each economic sector the presently available most advanced technical emission control measures. In many cases technology available depends on the vintage of capital stock in a given sector. We have included only those measures that do not require premature retirement of

existing equipment before the end of its technical life time. Emission control legislation for each pollutant included in our analysis is summarized Table 5.2 to Table 5.6.

Table 5.2: Current legislation and measures assumed for the maximum feasible reduction scenario for SO_2 emissions

Legislation considered in the Current Legislation (CLE) scenario	
Large combustion plant directive Directive on the sulphur content in liquid fuels Directives on quality of petrol and diesel fuels IPPC legislation on process sources National legislation and national practices (if stricter) Sea transport: 1.5% S marine fuel oil all ships in North Sea and Baltic Sea; 1.5% S fuel all passenger ships in other EU seas; low sulfur marine gas oil; 0.1% S fuel at berth in ports.	
Measures assumed for the Maximum Feasible Reduction (MFR) scenario	
Sector	**Technology**
Power plant boilers - coal, oil and waste fuels	High efficiency FGD
Power plants, biomass	Combustion modification on small biomass boilers
Residential/commercial boilers	Low sulphur coal and oil
Industrial boilers and furnaces	FGD on larger boilers, in-furnace controls for smaller boilers
Industrial processes	Stage 3 controls
Transport (land-based sources)	Sulphur-free gasoline and diesel
Sea transport	Low sulphur heavy fuel oil (0.5 % S)

Table 5.3: Current legislation and measures assumed for the maximum feasible reduction scenario for NOx emissions

Legislation considered in the Current Legislation (CLE) scenario	
Large combustion plant directive Auto/Oil EURO standards Emission standards for motorcycles and mopeds Legislation on non-road mobile machinery Implementation failure of EURO-II and Euro-III for heavy duty vehicles IPPC legislation for industrial processes National legislation and national practices (if stricter)	
Sea transport: MARPOL NO_x standards for ships built since 2000	
Large combustion plant directive	
Measures assumed for the Maximum Feasible Reduction (MFR) scenario	
Sector	**Technology**
Power plant boilers - coal, oil and gas	SCR
Power plants, biomass	Combustion modification on small biomass boilers, SCR on large boilers
Residential/commercial boilers	Combustion modification
Industrial boilers and furnaces	SCR on larger boilers, SNCR on smaller boilers
Industrial processes	Stage 3 controls
Non-road diesel vehicles (construction, agriculture, inland waterways, railways)	Equivalent to EURO VI on HDVs (post-stage III or IV, depending on a sector and rated power)
Non-road gasoline vehicles (construction, agriculture, inland waterways, railways)	3-way catalytic converters
Motorcycles	Stage 3 controls
Mopeds	Stage 3 controls
Heavy-duty trucks	Post-Euro V (possible Euro VI)
Light-duty vehicles (gasoline and diesel)	Post-EURO IV (possible Euro V)
Sea transport	SCR on all ships (retrofit and newbuilt)

Table 5.4: Current legislation and measures assumed for the maximum feasible reduction scenario for NMVOC emissions

Legislation considered in the Current Legislation (CLE) scenario	
Stage I directive Directive 91/441 (carbon canisters) Fuel directive (RVP of fuels) Legislation on mobile sources as for NO_x Solvents directive Product directive (paints) National legislation, e.g., Stage II	
Measures assumed for the Maximum Feasible Reduction (MFR) scenario	
Sector	**Technology**
Residential boilers and stoves, coal	New boilers or stoves, possibly equipped with oxidation catalysts
Residential stoves and fireplaces, wood	Catalytic inserts
Extraction and distribution of liquid fuels	Vapor balancing on tankers
Process emissions in oil refineries	Leak detection and repair program and covers on oil-water separators
Evaporative emissions from gasoline vehicles	Small carbon canister
Gasoline service stations	Stage I and II controls
Storage and distribution of gasoline	Internal floating covers and Stage I controls
Dry cleaning	New closed circuit machine, hydrocarbon machines and water-based cleaning
Degreasing	Closed (sealed) degreaser; use of chlorinated solvents (or use of A3 solvents and activated carbon filter), water based cleaning
Domestic (personal usage) use of solvents	Reformulation of products
Decorative paints	Simulation of possible developments beyond Product Directive
Vehicle refinishing	Primary measures and substitution
Wood coating	Very high solids systems (5 percent solvent content) (additionally small share of low [80 percent solvents], medium [55 percent], and high [20 percent] solid coating systems), application process with an efficiency of 75 percent
Coil coating	Powder coating system (solvent free), thermal oxidation
Automobile production	Process modification, substitution, end-of-pipe (adsorption, thermal oxidation)
Leather coating	Use of water based coating, bio-filtration
Winding wire coating	Primary (lower solvent content of enamel and reduced fugitive emissions) and secondary measures (increased efficiency of the oven)
Other industrial paint use (continuous processes, plastic, general)	Use of current standard solvent based paints (60 percent solvent content); Use of improved solvent based paints (55 percent) - application efficiency 65 percent; Use of water based paints (4-5 percent) - application efficiency 65 to 98 percent; Use of powder coatings; application efficiency 90 to 96 percent
Production of paints, inks and adhesives	Upgrade of the condensation units or carbon adsorption and solvent recovery
Industrial glue application	Emulsions, hot melts or UV cross-linking acrylates or electron beam curing systems, adsorption, incineration
Wood preservation	Use of water based preservatives (conventional application methods) and improved application technique (vacuum impregnation system)
Steam cracking (ethylene and propylene production) and downstream units - chem. ind.	Leak detection and repair program, stage IV

Measures assumed for the Maximum Feasible Reduction (MFR) scenario (continue table 5.4)	
Sector	**Technology**
Polystyrene processing	6 percent pentane expandable beads (85 percent) and recycled EPS waste (15 percent) and incineration
PVC production	Stripping and vent gas treatment plus optimization of emission treatment including leak and detection program
Pharmaceutical industry	Primary measures and high level employment of end-of-pipe measures (incl. thermal incineration, carbon adsorption, condensation, and other)
Storage and handling of chemical products	Internal floating covers/sec. seals, vapour recovery (double stage)
Synthetic rubber production	Use of 30 percent solvent based additives and 70 percent low solvent additives (90 percent vulcanized rubber and 10 percent thermoplastic rubber produced) and incineration
Food and drink industry	Thermal oxidation
Tyre production	New process
Manufacturing of shoes	Good housekeeping and substitution plus automatic application, biofiltration
Fat, edible and non-edible oil extraction	Schumacher type desolventiser-toaster-dryer-cooler plus "a new" hexane recovery section and process optimization
Other industrial sources	Good housekeeping in steel industry and switch to emulsion bitumen
Open burning of agricultural and municipal waste	Ban
Mobile sources	Legislation as for NO_x

Table 5.5: Current legislation and measures assumed for the maximum feasible reduction scenario for NH_3 emissions

Legislation considered in the Current Legislation (CLE) scenario	
No EU-wide legislation National legislations Current practice	
Measures assumed for the Maximum Feasible Reduction (MFR) scenario	
Sector	**Technology**
Cattle	Low nitrogen feed, housing adaptation, low nitrogen application (specifically distinguishing between options for liquid slurry and solid manure)
Pigs	Low nitrogen feed, housing adaptation and closed storage, low nitrogen application (specifically distinguishing between options for liquid slurry and solid manure)
Poultry	Low nitrogen feed, housing adaptation and closed storage, bio-filtration, low nitrogen application and incineration of poultry manure (limited number of countries)
Sheep	Low nitrogen application
N-fertilizer application	Substitution of urea with ammonium nitrate
Fertilizer production	BAT to control end-of-pipe emissions from fertilizer plants

Table 5.6: Current legislation and measures assumed for the maximum feasible reduction scenario for PM emissions

Legislation considered in the Current Legislation (CLE) scenario
Large combustion plant directive
Auto/Oil EURO standards for vehicles
Emission standards for motorcycles and mopeds
Legislation on non-road mobile machinery
IPPC legislation on process sources
National legislation and national practices (if stricter)
Mobile sources: legislation as for NO_x

Measures assumed for the Maximum Feasible Reduction (MFR) scenario	
Sector	**Technology**
Power plant boilers - coal, oil and gas	High efficiency de-dusters (ESP or fabric filters)
Power plants, biomass	Combustion modification on small biomass boilers
Power plants, oil	Fabric filters on large boilers, good housekeeping for smaller boilers
Commercial boilers, coal	High efficiency de-dusters (cyclones, fabric filters)
Residential boilers and stoves, coal	New boilers or stoves
Residential/commercial boilers (oil)	Good housekeeping
Residential stoves and fireplaces, wood	Catalytic inserts
Industrial processes	High efficiency de-dusters (ESP or fabric filters), good practices for fugitive emissions
Agriculture	Good practices, feed modifications, low till farming and alternative cereal harvesting
Construction	Spraying water at construction places
Flaring in oil and gas industry	Good practices
Mobile sources	Legislation as for NO_x

Table 5.7: Measures available to control emissions from ships. Reduction efficiency of each measure compared with "unabated" case is given in the parentesis.

Measures assumed for the Maximum Feasible Reduction (MFR) scenario	
SO_2	**NOx**
Low sulfur heavy fuel oil (original S content - 2.7%)	MARPOL emission standards (9 %)
- Desulfurization down to 1.5 %	Slide valve retrofit on slow speed engines (20 %)
- Desulfurization down to 0.5 %	Internal engine modifications (30 %)
Sea water scrubbing (85 % removal efficiency)	Humid air motors (70 %)
Low sulfur marine gas oil (0.2%, 0.1 % from 2008)	SCR (90 %)
Note: The use of low sulfur fuels simultaneously reduces the emissions of PM by 15 - 20 %	

5.2.4. Other assumptions for the LGEP scenario

Agricultural projections

The LREM-E scenario for agriculture (livestock production and application of mineral N fertilizers) assumes that the Common Agricultural Policy (CAP) reform is not implemented. Projections of animal numbers are based on results of a number of European and global models. For the EU-15, data for the years 2000 until 2010 are derived from the CAPRI model run at the University of Bonn (CEC, 2002). For the new EU10 countries, projections for the same time horizon originate from DG Agriculture. For other countries and for the period beyond 2010 the projection is based on trends derived from the study by FAO (Bruinsma, 2003). A scenario with CAP reform is under preparation. The forecast of fertilizer consumption until 2010 for EU-15, Switzerland and Norway is based on data by EFMA (European Fertilizer Manufacturers Association – EFMA, 2003). For other countries and for the period beyond 2010 the projection is based on trends derived from the FAO global study (Bruinsma, 2003).

NMVOC

The projections of the development of stationary sources of NMVOC not related to energy consumption were guided by the macroeconomic assumptions from the PRIMES model. Such first-order projections were discussed with a number of country and industrial experts during the CAFE bilateral consultations and further supplemented by additional data provided by these experts. Country-specific activity levels are available from RAINS WEB model.

6. Global and European emissions

6.1. Introduction

While emissions of greenhouse gases have steadily increased over the past decades, the emissions of acidifying pollutants have shown varying trends. Air quality problems vary from the local (nitrogen dioxides in streets, sulphur dioxide from industries) to the global scale (ozone) and effects can be very severe for both humans and ecosystems The urgency of regional and global environmental problems varies over the world, mostly as a result of economic development.. On one hand, in developing regions like Asia, emissions of SO_2 are rapidly increasing due to high economic growth and the recognition of the risks of acidification in the region is emerging. On the other hand, the introduction of abatement policies in developed regions like Europe, led to a rapid decrease of SO_2 emissions and at the same time in a turn of the focus also towards global environmental problems, like emissions of precursors of ozone and climate change (Alcamo et al., 1998).

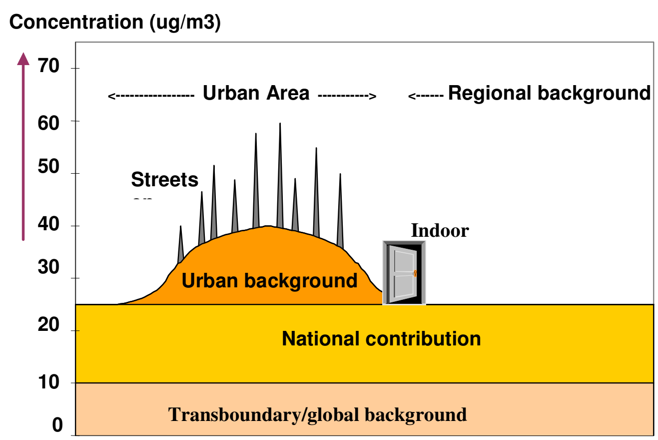


Figure 6-1: Air pollution concentration built-up from global to local scale

The objective of this chapter is to show the position of Europe regarding air pollutants emissions in a global perspective. For example, which air pollutants emissions are more relevant for Europe compared to other regions in the world. Therefore, we assess the global and continental emissions (incl. Europe) of using the baseline and mitigation scenarios that were developed under the ETC/ACC framework. More specifically, on the world regions scale, SO_2, NO_x and NMVOC emissions are estimated by the IMAGE model for the LREM-E, LREM-LE and LGEP scenarios up to the year 2100 and for the LREM-REN scenario up to 2030. On the European scale, emissions of SO_2, NO_x, NMVOC, NH_3 and PM (PM_{10} and $PM_{2.5}$) are estimated by the RAINS model for LREM -E, LGEP, LGEP-LE, LGEP-SER and LGEP-MFR scenarios up to the year 2030.

6.2. Global emissions 2000-2100

Global emissions of NO_x, SO_2 and NMVOC have been calculated through IMAGE model, which examines emissions divided in categories. The anthropogenic emissions, which include emissions from land use, industry and energy and the emissions coming from natural sources like lighting and ocean biota (Alcamo et al., 1998). Natural emissions are an important component of global NO_x emissions but

they remain relatively constant throughout the whole time period. As such, in this report we present only the anthropogenic emissions.

The differences in economic development status in the various world regions, lead in different patterns of air pollutants emissions. Therefore, in this section of the report, global emissions are described for two groups of regions, the developed regions (OECD Europe, Eastern Europe, USA, Canada, Oceania, Japan and Former Soviet Union) and the developing regions (South East Asia, South Asia, Africa, Central and South America, Middle East and Turkey).

6.2.1. Emissions in developed regions

The developed regions which start as the large emitters in 1990 will gradually become small emitters over the coming decades. For all scenarios and all the pollutants, the emissions have a similar decreasing trend. This trend can be seen partly as a result of rapid efficiency improvement, since all the scenarios describe a world in which technology development continues to play an important role for economic growth. Emissions control policies initiated by local air quality concerns assumed to be continued (e.g desulphurisation in power plants) also have an effect on air pollutants emissions, even though the environmental policies in the three baseline scenarios (LREM-E, LREM-LE and LREM-REN) are limited. The LGEP scenario presents the largest reductions of air pollutants emissions, especially after the second half of the 21st century, with VOCs, NO_x and SO_2 emissions being reduced by almost 80 percent, 95 percent and 98 percent respectively from the 1990 levels. The introduction of climate policies in the LGEP contributes also in the reduction of air pollutants emissions like SO_2 emissions.

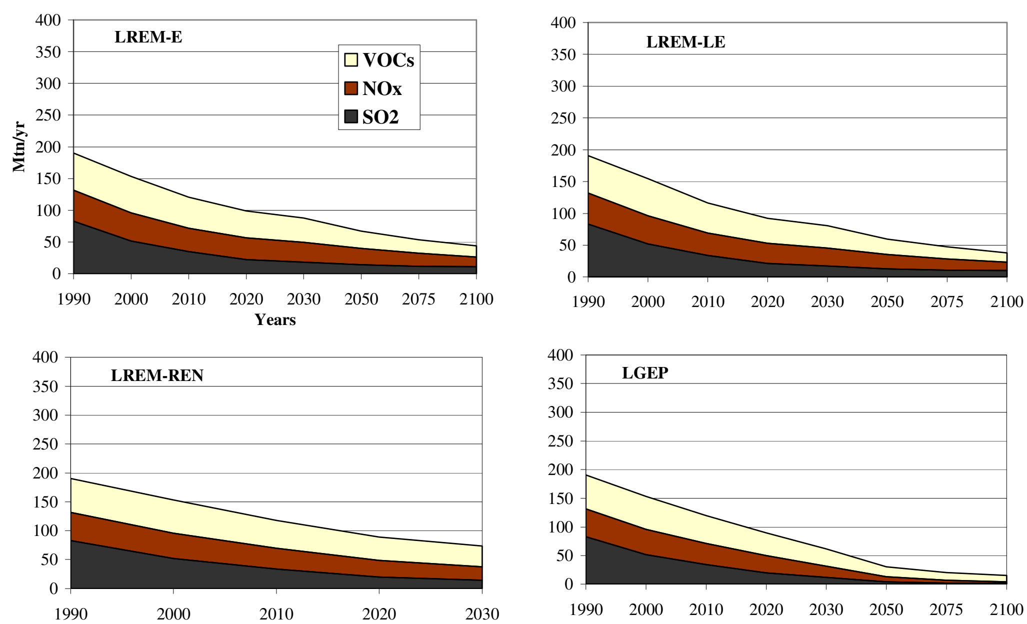


Figure 6-2: Air pollutants emissions in the developed regions under the LREM-E, LREM-LE, LREM-REN and LGEP scenarios (NO_x as Mtn NO_2, SO_2 as Mtn SO_2 and MNVOC as Mtn MNVOC)

6.2.2. Emissions in developing regions

The 1990 anthropogenic NO_x emissions in the 3 baseline scenarios (LREM-E, LREM-LE, LREM-REN) for the developing regions were about 18 Mtn as NO_2. Up

to 2020s, all scenarios project rising NO_x emissions[15]. LREM-REN scenario presents the lower NO_x emissions due to the introduction of targets in the use of renewables in 2030. The highest NO_x emissions are projected in the LREM- E scenario. Emissions continue to increase rapidly up to 2050, when they peak. They level off by 2100, as the fossil fuel technologies become more advanced. LREM-E NO_x emissions are estimated to be about 60 Mtn (as NO_2) in 2100, three times more than the 1990 emissions, while in LREM-LE emissions are estimated to be 23 percent lower than the emissions in LREM-E. The energy sector is the most important contributor in all scenarios, with emissions accounting for about 50 percent of the total anthropogenic emissions in 1990, reaching almost 80 percent in 2100 in the LREM-E scenario. In LGEP, NO_x emissions increase up to about 51 Mtn (as NO_2) in 2020, when they begin to decrease. In 2100, emissions are reduced almost 10% compared to the1990 levels. NOx per capita emissions of developing regions are equal to the NOx per capita emissions of the developed regions only in 2100 in the LGEP scenario.

In the case of NMVOC, the estimated emissions in developing regions are 78 Mtn in 1990. In all scenarios, NMVOC emissions show a steep increase (+70%), from 2000 onwards until 2020. They subsequently decline toward the end of the 21st century to almost 65 percent of the 1990 level in the LREM-E scenario. For NMVOCs emissions, the most important contributor in 1990 is land-use activities, followed by the energy sector and industrial activities. After 2010, up to 2050, the energy sector becomes more important than the land-use emissions. NMVOC emissions in LGEP peak in 2020, when they present similar trend to the emissions in the baseline scenarios (40 percent increase from the 1990 emissions) but then fall to more than half of the 1990 level by 2100. Emissions per capita of NMVOCs are during the whole time period well below the emissions per capita in developed regions.

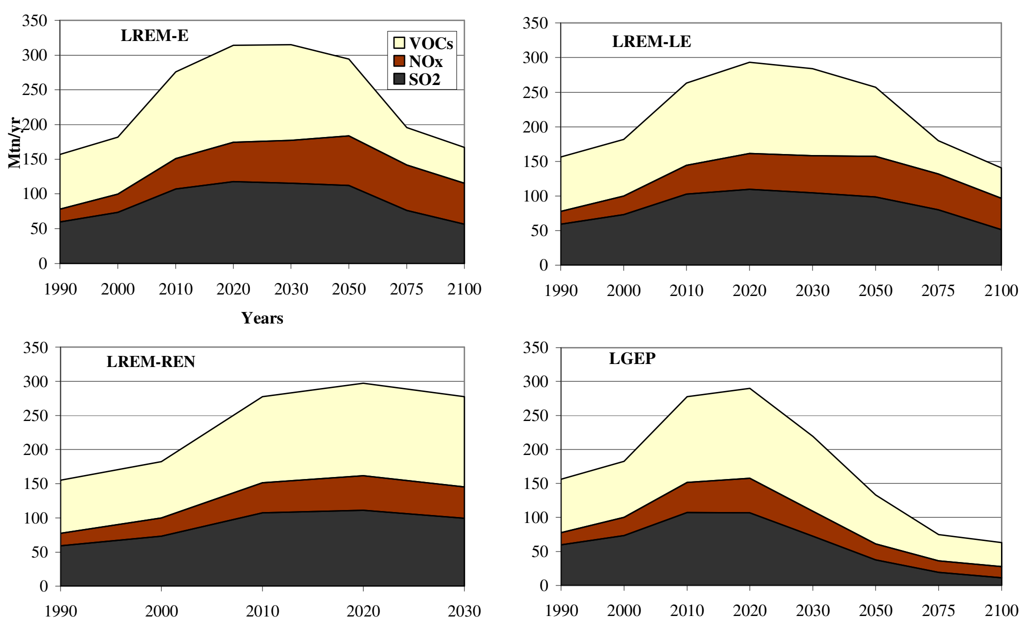


Figure 6-3: Air pollutants emissions in the developing regions under the LREM-E, LREM-LE, LREM-REN and LGEP scenarios (NO_x as Mtn NO_2, SO_2 as Mtn SO_2 and MNVOC as Mtn MNVOC)

[15] Recent (after 2000) changes in Current Legislation (CLE) such as the recently decided introduction of EURO road vehicles emission standards in China, India and Latin America are therefore not included.

In all scenarios, SO_2 emissions are the only emissions that around 2020 reach the same levels of per capita emissions as in developed regions. In the baseline scenarios, SO_2 emissions tend to increase from about 60 Mtn in 1990 to peak at about 110 – 120 Mtn (as SO_2) in 2020. Emissions remain relatively stable up to 2050, when they are gradually reduced by 2100 to about the 1990 levels in the LREM-E scenario and even more in the LREM-LE scenario. Emissions increase because of the growth of fossil fuel use driven by the economic development in combination with the limited environmental control policies. As the personal income in developing regions and the awareness on local air quality problems are increasing over the years, SO_2 becomes controlled as in the developed regions. In LGEP SO_2 emissions peak in 2010 at 107Mtn, when they start to decline, to be in 2100 about one fifth of the 1990 emissions. The greatest SO_2 emissions contribution in LREM-E and LREM-LE comes from the energy sector with almost 80 percent of the total anthropogenic emissions. In LREM-REN and LGEP most emissions come from both the energy sector and the land use sector. In LGEP by 2100, the land use sector even becomes the most important sector in terms of emissions.

6.3. European emissions 2000-2030

In this section we present the emissions of air pollutants covered by our study. As explained in Section 5.2.3, we discuss two emission control scenarios, namely:

- the "current legislation" (CLE) and
- the "maximum technically feasible reductions" (MFR).

As mentioned above, the calculations have been done with the RAINS WEB model. Out of 32 EEA countries RAINS does not cover Island and Liechtenstein. Historic and future emissions for Island have been taken from the EMEP's WEBDAB database. For Lichtenstein the assessment uses numbers from the Gothenburg Protocol to the Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-Level Ozone (UN/ECE, 1999). For each pollutant we present the emissions by country group (EEA32, EU-15, EU-10 (New Member States) and EFTA-4). Next, we discuss the emissions by CORINAIR sector (EEA, 2001). Emissions by country are presented in the Annex 1.

6.3.1. Emissions of NOx

In 1990 the emissions of NO_x in the EEA region were about 18 million tons. Until 2030, the emissions in the LREM-E scenario decrease by 59 percent of 1990 level. The highest contributor to NO_x emissions is EU 15 (75 percent in 1990 and 72 percent in 2030 – compare Table 6.1).

The greatest contributor to NO_x emissions in 1990 was road transport (44 percent), followed by the power plant and other fuel conversions sector (25 percent). Non-road sector contributed 13 percent and industrial combustion and processes another 11 percent. Till 2030 these proportions change. Industry and processes become responsible for 23 percent of the emissions, followed by road transport (23 percent), power plant and conversion (21 percent), road transport (21 percent), and non-road transport (19 percent). Within the EEA countries, the highest contributor to NO_x emissions is EU 15 (75 percent in 1990 and 71 percent in 2030), followed by EU 10 (14 and 10 percent respectively).

Table 6.1: Emissions of nitrogen oxides (NO_x), kilotons NO_x

a. Emissions by country group

Country group	1990	2000	LREM-E 2010	2020	2030
EEA 32	18022	13373	9861	7458	7474
EU 15	13590	9911	7145	5388	5348
EU 10	2514	1670	1171	774	777
EFTA 4	397	328	264	224	221

b. Emissions by SNAP sector

SNAP1 sector	1990	2000	LREM-E 2010	2020	2030
1:Combustion in energy industries	4737	2746	1837	1396	1400
2:Non-industrial combustion plants	792	711	726	722	728
3:Combustion in manufacturing industry	1992	1535	1370	1405	1473
4:Production processes	371	328	328	339	352
5: Extraction and distribution	0	0	0	0	0
6: Solvent use	0	0	0	0	0
7:Road transport	7800	5882	3770	2078	2149
8:Other mobile sources and machinery	2290	2116	1801	1492	1347
9:Waste treatment and disposal	22	25	21	17	17
10:Agriculture	18	9	10	10	10
Total	18022	13352	9861	7458	7474

In 2000 about 13.4 million ton of NO_x was emitted in the EEA countries (Table 6.1). Till 2030 these emissions in the LGEP-B-CLE scenario decrease to 6.8 million tons, i.e., by 49 percent. The reduction in the LGEP-LE-CLE case is about five percentage points higher (minus 54 percent). Relative reductions for the EU-15 are similar – minus 51 and 56 percent respectively. The reductions for the New Member States (EU-10) are higher (minus 62 percent for the LGEP-B-CLE case). However, the difference between the base case and the low growth scenario (LGEP-LE-CLE) is small, which is mainly due to a smaller difference in the assumed economic growth for this country group compared with the difference for the EU-15. Emissions for the scenario with renewable energy targets (LGEP-SER-CLE) are practically the same as in the base case (LGEP-B-CLE). Implementation of the best available control technology in the EEA region (LGEP-B-MFR) reduces the emissions in 2030 by half to 3.5 million tons.

Within the EEA countries, the highest contributor to NO_x emissions is EU-15 (74 percent in 2000), followed by EU-10 (13 percent). In 2030 these contributions decrease to about 72 and 9 percent respectively (for the LGEP-B-CLE scenario). Simultaneously the contributions of candidate countries (Bulgaria, Romania, Turkey), in which phasing-in of emission controls occurs with some delay, increases.

In the EEA region the greatest contributor to NO_x emissions in 2000 was road transport (44 percent –Table 6.3), followed by combustion in energy industries (21 percent). Non-road sector contributed 16 percent, and industrial combustion another 12 percent. Structural changes in fuel consumption patterns (as in the LGEP-B-CLE scenario), together with implementation of stricter controls, cause an over-proportional decrease of emissions in the road transport and combustion in energy industries sectors. Thus the contribution of these two sectors to the total EEA NO_x emissions decreases to 30 and 17 percent, respectively. Changes in the structures of sectoral emissions in the EU-25 are similar as for the whole EEA region (Table 6.4).

Out of about 690 kilotons NO_x reduced in the EEA region in the LGEP-LE-CLE scenario compared with LGEP-B-CLE, 37 percent occurs in road transport (of which 95 percent in the EU-25), 22 percent in the energy sector and about 17 percent in manufacturing industries (both: combustion-related and process emissions).

Although some countries (Austria, Luxembourg, Sweden) will not reach the national emission ceilings with the "current legislation" measures in the LGEP-B scenario even in 2030 (compare Annex 1), aggregated national emissions are much lower than the sum of the ceilings. This difference is 1.6 million tons for EU-15 and 1.2 million tons for EU-10 (25 percent and 67 percent of the corresponding ceiling). In the LGEP-LE scenario only one country (Luxembourg) does not comply with the NEC ceiling[16].

Compared with the CAFE CP-CLE emissions for 2020, the 2030 NO_x emissions in the "sustainable emission pathway" scenario (LGEP-B-CLE) are 350 kilotons lower. In the CP_CLE scenario six countries: Austria, Belgium, France, Luxembourg, Sweden, and Norway do not comply with ceilings. As mentioned above, implementation of more stringent climate policies (higher CO_2 taxes) reduces the number of non-complying countries to three. The results of our scenarios clearly demonstrate that measures aimed at CO_2 reduction and longer period available for implementation of structural changes in the energy system and for phasing-in of emission controls help in achieving air pollution targets.

Table 6.2: Emissions of nitrogen oxides by country group, kilotons NO_x

Country	2000	NEC ceiling	2020, CP		2030, LGEP			
			CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
EEA 32	13373	n.a.	7153	4186	6806	6126	6833	3460
EU 15	*9911*	*6519*	*5164*	*3131*	*4890*	*4361*	*4914*	*2532*
EU 10	*1670*	*1800*	*724*	*405*	*634*	*611*	*636*	*317*
EFTA 4	*328*	*n.a.*	*249*	*142*	*239*	*229*	*239*	*114*

Table 6.3: Emissions of nitrogen oxides in the EEA countries by CORINAIR sector, kilotons NO_x (Iceland and Lichtenstein not included)

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	2746	1243	518	1121	966	1178	513
2: Non-industrial combustion plants	711	687	484	641	599	621	449
3: Combustion in manufacturing industry	1535	1357	439	1369	1203	1349	437
4: Production processes	328	337	207	346	335	345	210
5: Extraction and distribution	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	5882	2006	1449	2018	1766	2018	1220
8: Other mobile sources and machinery	2116	1471	1078	1258	1202	1268	622
9: Waste treatment	25	16	10	15	15	15	9
10: Agriculture	9	9	0	9	9	9	0
Total	13353	7125	4186	6777	6097	6804	3460

[16] In case of Luxembourg a high relative difference between calculated emissions and the ceiling is caused by the fact that the emissions in RAINS are calculated based on fuel sales. Because of the so-called "fill-up tourism" a large proportion of fuel sold in Luxembourg is used on territories of neighbouring countries.

Table 6.4: Emissions of nitrogen oxides in EU-25 by CORINAIR sector, kilotons NO_x

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	2336	995	448	923	794	980	437
2: Non-industrial combustion plants	637	596	424	543	505	524	390
3: Combustion in manufacturing industry	1304	1083	371	1052	966	1032	360
4: Production processes	189	186	93	186	178	185	94
5: Extraction and distribution	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	5304	1809	1320	1790	1553	1790	1092
8: Other mobile sources and machinery	1793	1204	875	1014	962	1024	474
9: Waste treatment	10	7	3	6	6	6	2
10: Agriculture	8	8	0	8	8	8	0
Total	11581	5888	3535	5524	4972	5550	2849

6.3.2. Emissions of NMVOC

In 1990 the emissions of NMVOC in the EEA region were about 18.7 million tons. In the LREM-E scenario they decrease till 2030 to 6.9 million tons, i.e., by 56 percent. In 1990, the greatest contributor was road transport (45 percent), followed by solvent use sector (28 %). Because of stringent controls required by the legislation on mobile sources, the emissions from road transport are likely to be reduced by about 90 percent. Thus, by 2030, the contribution of that sector to total EEA emissions decreases to only 15 percent. Although in absolute terms the emissions from other sectors also decrease, their relative contribution increases. For instance, compared with 1990, the share of emissions from solvent use increases to 41 percent.

Also for NMVOC the EU 15 plays a dominant role as a contributor to total EEA emissions. In 1990 78 percent of VOC originated from sources located in the “old” EU Member States. Till 2030, this proportion becomes slightly lower (71 percent). Till 2030, this proportion becomes slightly lower (71 percent). This is because the emissions form the accession countries (Bulgaria, Romania) decrease slower than in other countries and in case of Turkey even an increase of emissions is expected. Also the New Member states (EU 10) will gain their relative share (increase from 10 to 12 percent of total EEA emissions). .

Table 6.5: Emissions of non-methane volatile organic compounds (VOC)in the LREM-E scenario, kilotons

a. Emissions by country group

			LREM-E		
Country group	1990	2000	2010	2020	2030
EEA 32	18652	12481	8374	6920	6878
EU 15	14548	9344	6129	5197	5156
EU 10	2106	1310	902	718	707
EFTA 4	594	532	220	171	170

b. Emissions by CORINAIR sector

SNAP1 sector	1990	2000	LREM-E 2010	2020	2030
1:Combustion in energy industries	134	118	105	86	71
2:Non-industrial combustion plants	1188	1065	854	677	488
3:Combustion in manufacturing industry	80	57	49	52	54
4:Production processes	1350	1240	1230	1250	1274
5: Extraction and distribution	1138	1050	684	641	638
6: Solvent use	5150	4020	3086	2771	2812
7:Road transport	8415	3788	1460	824	884
8:Other mobile sources and machinery	922	902	676	390	428
9:Waste treatment and disposal	138	141	142	142	142
10:Agriculture	137	86	88	88	88
Total	18652	12467	8374	6920	6878

Already in 2000 the emissions of NMVOC decreased to about 12.5 million tons, i.e., to about two thirds of the 1990 level (Table 6.6).). In our scenarios (LGEP-B-CLE and LGEP -SER-CLE) they further decrease. By 2030 the emission level is 6.9 million tons, 45 percent lower than in 2000. Implementation of the best available control technology (LGEP-B-MFR case) additionally reduces the emissions by one third to 4.7 million tons. The reduction in the LGEP-LE-CLE case is only marginally (three percent) higher than in the LGEP-B-CLE scenario. Relative reductions by country group (EU-15, EU-10) are similar. In spite of much higher use of biomass in the scenario with the renewable energy targets (LGEP-SER-CLE) the emissions are only by 0.5 % higher than in the base case. This is because in that scenario biomass is used first of all in large boilers in the power plant and industrial sector, where the combustion is well controlled, as well as for production of liquid biofuels. The consumption in the residential sector does not increase

In the EEA the greatest contributor to NMVOC emissions in 2000 was solvent use (32 percent), followed by road transport (30 percent) and production processes (10 percent – Table 6.7). Implementation of strict controls on transport emissions reduces the share of that sector in 2030 to only 12 percent. Simultaneously relative contributions of the solvent use and process sectors increase to 40 and 18 percent, respectively (all values for the LGEP-B-CLE scenario).

In all LGEP-B-CLE scenarios only three countries: Belgium, the Netherlands, and Spain do not comply in 2030 with national emission ceilings. Similarly as for NO_x, aggregated national emissions are much lower than the sum of the ceilings. This difference for the LGEP-B-CLE scenario is about 1.3 million tons for EU-15 and 0.9 million tons for EU-10 (20 percent and 57 percent of the corresponding ceiling).

The EEA region's NMVOC emissions for the CAFE CP-CLE scenario are in 2020 only 36 kilotons higher than the LGEP-B-CLE emissions. This is because for NMVOC a large proportion of emissions originates from non-energy sources (solvents and paints use) and the activity levels as well as penetration of control technologies for these sources in the two scenarios and years are similar.

Table 6.6: Emissions of non-methane volatile organic compounds (NMVOC) by country group, kilotons

Country	2000	NEC ceiling	2020, CP		2030, LGEP			
			CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
EEA 32	12481	n.a.	6927	4638	6891	6675	6925	4659
EU 15	*9344*	*6510*	*5207*	*3701*	*5183*	*5016*	*5212*	*3698*
EU 10	*1310*	*1640*	*708*	*414*	*694*	*685*	*700*	*403*
EFTA 4	*532*	*n.a.*	*180*	*114*	*175*	*172*	*175*	*112*

Table 6.7: Emissions of non-methane volatile organic compounds (NMVOC) in the EEA countries by CORINAIR sectors, kilotons (Iceland and Lichtenstein not included)

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	118	93	93	115	92	171	115
2: Non-industrial combustion plants	1065	719	377	557	492	552	343
3: Combustion in manufacturing industry	57	50	50	47	43	35	47
4: Production processes	1240	1254	762	1268	1242	1264	770
5: Extraction and distribution	1050	640	478	632	617	631	466
6: Solvent use	4020	2739	1691	2779	2779	2779	1769
7: Road transport	3788	808	689	841	765	841	664
8: Other mobile sources and machinery	902	387	356	417	410	417	342
9: Waste treatment	141	142	131	142	142	142	131
10: Agriculture	86	86	11	86	86	86	11
Total	12468	6917	4638	6884	6668	6918	4659

Table 6.8: Emissions of non-methane volatile organic compounds (NMVOC) in EU-25 by CORINAIR sectors, kilotons

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	100	79	79	99	79	154	99
2: Non-industrial combustion plants	772	531	304	439	385	434	292
3: Combustion in manufacturing industry	49	41	41	38	36	26	38
4: Production processes	1089	1070	680	1062	1042	1058	678
5: Extraction and distribution	736	567	431	549	538	548	413
6: Solvent use	3585	2409	1520	2445	2445	2445	1573
7: Road transport	3302	691	612	688	622	688	570
8: Other mobile sources and machinery	841	345	324	377	372	377	314
9: Waste treatment	125	126	117	126	126	126	117
10: Agriculture	56	56	8	56	56	56	8
Total	10654	5916	4115	5878	5701	5912	4101

6.3.3. Emissions of SO_2

Dramatic changes occur in the emissions of sulphur dioxide in the EEA region. In the LREM-E scenario they decrease from about 27 million tons in 1990 to only 4.1 million tons in 2030, i.e., by 85 percent. This is mainly due to stringent controls in the energy sector, which will decrease its share from 74 percent in 1990 to 47 percent in 2030. It is worth mentioning that important reductions occurred in the period 1990 –

2000 (decrease by 52 percent), which was due to introduction of tighter emission standards in the power plant sector as well as due to lowering sulphur content in heavy fuel oil. In the EU 10 and in eastern Germany the economic restructuring played an important role, in addition to emission and fuel standards.

Also for SO_2 the EU 15 has the highest contribution to total EEA emissions (59 percent in 1990 and 53 percent in 2030). The EU 10 contribute 23 and 16 percent respectively. The contribution of other EEA countries increases, which is mainly due to the increase of emissions from Turkey.

Table 6.9: Emissions of sulphur dioxide (SO_2) in the LREM-E sceanrio, kilotons SO_2

a. Emissions by country group

Country group	1990	2000	LREM-E 2010	2020	2030
EEA 32	26929	13080	7671	5746	4137
EU 15	15933	6040	2656	2208	2187
EU 10	6325	2696	1622	997	664
EFTA 4	88	71	37	34	29

b. Emissions by CORINAIR sector

SNAP1 sector	1990	2000	LREM-E 2010	2020	2030
1:Combustion in energy industries	19794	9068	4935	3347	1946
2:Non-industrial combustion plants	2179	767	401	277	231
3:Combustion in manufacturing industry	2970	2014	1405	1179	986
4:Production processes	809	730	666	677	703
5: Extraction and distribution	0	0	0	0	0
6: Solvent use	0	0	0	0	0
7:Road transport	667	185	29	26	28
8:Other mobile sources and machinery	497	282	225	232	234
9:Waste treatment and disposal	5	5	5	4	4
10:Agriculture	8	5	5	5	5
Total	26929	13056	7671	5746	4137

Compared with 2000, the emissions in the LGEP-B-CLE scenario decrease by further 75 percent. The reduction in the EU-10 reaches even 81 percent. On a contrary, the reduction in the EFTA-4 group of countries is relatively modest (22 percent), which is due to already clean production structures in the base year (2000) in the latter group of countries. In spite of very high reductions achieved with the "current legislation" measures, there is still a high potential to reduce the emissions through implementation of the best available techniques. Thus in the LGEP-B-MFR scenario the emissions are reduced by another 55 percent down to 1.5 million tons.

Also for SO_2 the EU-15 has the highest contribution to total EEA emissions (46 percent in 2000). The EU-10 contributes 21 percent, and the candidate countries are responsible for 32 percent of total emissions. Implementation of controls on major emission sources in EU-10 and in the candidate countries will cause a decrease of their shares till 2030 in total EEA emissions to 15 percent and 27 percent respectively.

Changes in sectoral composition of SO_2 emissions are shown in Table 6.11. Whereas in 2000 combustion in energy industries (power plants) was responsible for about 69 percent of emissions, followed by combustion in industry (15 percent), non-industrial combustion plants and production processes (about 6 percent each), in 2030 the

emissions from power plants decrease to only 38 percent of total, with simultaneous increase of the shares of manufacturing industries and processes (27 and 21 percent).

The LGEP-LE scenario results in lower SO_2 emissions by about 280 kilotons compared with LGEP-B. This reduction occurs mainly in combustion sectors (energy and manufacturing industries Table 6.11) because of lower energy demand. The emissions in the LGEP-SER-CLE scenario differ only marginally from the Baseline.

For SO_2, only the Netherlands does not achieve the NEC ceiling in 2030. Although the Dutch pollution control legislation belongs to the most stringent in Europe, and structural changes in the LGEP-B scenario are quite profound, the resulting emissions are still higher than a very ambitious Dutch ceiling. Thus additional measures will be necessary in this country to comply with the NEC Directive.

Higher tax on CO_2 emissions in the LGEP-B-CLE scenario in 2030 and longer time available for implementation of structural changes and emission controls compared with the CAFE CP-CLE scenario results in additional structural changes in European energy supply and consumption and higher penetration of control measures. This reduces the SO_2 emissions in 2030 by more than 1.5 million tons compared with the CP-CLE 2020 emissions.

Table 6.10: Emissions of sulphur dioxide, kilotons SO_2

Country group	2000	NEC ceiling	2020, CP		2030, LGEP			
			CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
EEA 32	13080	n.a.	4850	1625	3333	3062	3304	1525
EU 15	*6040*	*3850*	*2013*	*1043*	*1867*	*1672*	*1865*	*978*
EU 10	*2696*	*2693*	*793*	*241*	*504*	*478*	*477*	*152*
EFTA 4	*71*	*n.a.*	*58*	*20*	*56*	*54*	*56*	*19*

Table 6.11: Emissions of sulphur dioxide in the EEA countries by CORINAIR sectors, kilotons SO_2 (Iceland and Lichtenstein not included)

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	9068	2486	618	1251	1193	1253	605
2: Non-industrial combustion plants	767	258	159	207	189	182	126
3: Combustion in manufacturing industry	2014	1130	418	895	743	881	350
4: Production processes	730	681	370	688	653	684	378
5: Extraction and distribution	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	185	26	16	27	25	27	22
8: Other mobile sources and machinery	282	234	43	230	225	242	43
9: Waste treatment	5	4	2	3	3	3	1
10: Agriculture	5	5	0	5	5	5	0
Total	13056	4823	1625	3306	3035	3277	1525

Table 6.12: Emissions of sulphur dioxide in EU-25 by CORINAIR sectors, kilotons SO_2

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	5679	1006	448	752	632	754	359
2: Non-industrial combustion plants	665	202	129	157	141	132	102
3: Combustion in manufacturing industry	1337	777	327	647	600	633	280
4: Production processes	647	596	327	592	560	588	331
5: Extraction and distribution	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	152	18	12	17	16	17	17
8: Other mobile sources and machinery	246	199	39	199	194	210	39
9: Waste treatment	5	3	1	3	3	3	1
10: Agriculture	4	4	0	4	4	4	0
Total	8735	2805	1284	2371	2150	2343	1130

6.3.4. Emissions of NH_3

The EEA 1990 emissions of ammonia were about 5.3 million tons. The current Member States (EU 15) are responsible for about two thirds of emissions in the region. The contribution of the new Member States (EU 10) was in 1990 17 percent. It decreased in 2000 to less than 13 percent but is expected to increase to 14 percent by 2030.

It is characteristic that the use of some emission control technologies causes an increase of the emissions of ammonia. This is a case for transport, where the first generation of catalytic converters had much higher NH_3 emission factors than the uncontrolled vehicles. Thus, according to our calculations, the emissions of ammonia from transport increased between 1990 and 2000 by a factor of 3.5, and reached two percent of national emissions. After the year 2000 these emissions decrease, which is due to phasing-in of new generations of catalytic converters with much lower ammonia emissions. The increase of ammonia emissions from industrial combustion (which for ammonia includes the power plant sector) is caused by the requirement of using the SCR and SNCR technologies to reduce the emissions of NO_x.

Table 6.13: Emissions of ammonia (NH_3) in the LREM-E scenario, kilotons NH_3

a. Emissions by country group

			LREM-E		
Country group	1990	2000	2010	2020	2030
EEA 32	5294	4641	4727	4654	4599
EU 15	3542	3234	3184	3064	2952
EU 10	874	590	618	632	645
EFTA 4	93	95	86	84	83

b. Emissions by CORINAIR sector

SNAP1 sector	1990	2000	LREM-E 2010	2020	2030
1:Combustion in energy industries	12	16	19	35	39
2:Non-industrial combustion plants	30	31	28	27	25
3:Combustion in manufacturing industry	4	4	3	4	4
4:Production processes	83	68	65	65	65
5: Extraction and distribution	0	0	0	0	0
6: Solvent use	0	0	0	0	0
7:Road transport	23	82	53	24	24
8:Other mobile sources and machinery	1	1	1	1	1
9:Waste treatment and disposal	206	212	197	194	194
10:Agriculture	4936	4224	4361	4304	4247
Total	5294	4638	4727	4654	4599

In the decade 1990 – 2000 the emissions of ammonia (NH_3) decreased in the EEA region by 13 percent from about 5.3 million tons to 4.6 million tons. This was due to reduction of livestock farming and fertilizer use in central and eastern Europe (EU-10) and (to a certain extend) also in eastern Germany. Besides, some countries (e.g., the Netherlands and Denmark) implemented measures to reduce the emissions, and in some countries the outbreak of animal diseases had reduced the livestock numbers.

Agricultural sector dominates the national emissions. Its share in total ammonia emissions is about 91 - 93 percent over the whole period. In agriculture, about 82 percent of emissions originate from livestock farming; the balance is due to nitrogen fertilizer use. Since the scenarios analyzed in our study differ only in terms of activity levels for energy-related sectors and the contribution of those sectors to total national ammonia emissions is small, the differences among our scenarios are marginal.

Until 2030 the emissions stabilize at approximately current level. Although the emissions of the EU-15 decrease by less than ten percent, the emissions from the "new" member states and also from the candidate countries increase. Implementation of the best available technology (LGEP-B-MFR case) reduces the emissions by 40 percent from 2000 values, down to 2.7 million tons.

For ammonia, several countries do not achieve the NEC and the Gothenburg Protocol ceilings even in 2030. These are: Denmark, Germany, Netherlands, Spain, UK, Norway, Bulgaria and Romania. However, at an aggregated level (country groups) the ceilings are met with a wide margin (170 kilotons for EU-15 and more than 220 kilotons for EU-10). It remains to be seen to what extent the CAP reform will help individual countries to comply with the ceilings.

Table 6.14: Emissions of ammonia, kilotons NH_3

Country group	2000	NEC ceiling	2020, CP		2030, LGEP			
			CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
EEA 32	4641	n.a.	4646	2783	4585	4574	4586	2714
EU 15	*3234*	*3110*	*3057*	*1957*	*2940*	*2931*	*2941*	*1866*
EU 10	*590*	*866*	*629*	*306*	*642*	*642*	*643*	*308*
EFTA 4	*95*	*n.a.*	*86*	*54*	*86*	*86*	*86*	*53*

Table 6.15: Emissions of ammonia in the EEA countries by CORINAIR sectors, kilotons NH_3 (Iceland and Lichtenstein not included)

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	16	25	69	24	18	27	61
2: Non-industrial combustion plants	31	26	46	24	21	23	42
3: Combustion in manufacturing industry	4	4	36	4	3	3	35
4: Production processes	68	65	23	65	65	65	23
5: Extraction and distribution	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	82	23	24	23	22	23	24
8: Other mobile sources and machinery	1	1	1	1	1	1	2
9: Waste treatment	212	194	194	194	194	194	194
10: Agriculture	4224	4304	2389	4247	4247	4247	2334
Total	4638	4643	2783	4582	4571	4583	2714

Table 6.16: Emissions of ammonia (NH_3) in EU-25 by CORINAIR sectors, kilotons NH_3

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	16	24	59	21	15	24	51
2: Non-industrial combustion plants	25	22	39	21	19	20	36
3: Combustion in manufacturing industry	3	3	32	3	3	2	31
4: Production processes	58	54	21	54	54	54	21
5: Extraction and distribution	0	0	0	0	0	0	0
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	77	20	20	19	17	19	19
8: Other mobile sources and machinery	1	1	1	1	1	1	2
9: Waste treatment	164	145	145	144	144	144	144
10: Agriculture	3480	3417	1944	3320	3320	3320	1871
Total	3824	3686	2263	3582	3573	3583	2174

6.3.5. Emissions of PM

Emission of particulate matter (PM) is an important indicator of air pollution situation in Europe. In this report we present two indicators: emissions of PM_{10} and $PM_{2.5}$.

In the decade 1990 – 2000 the emissions of PM_{10} decreased in the EEA region from 7.5 million tons to 3.2 million tons, i.e., by 57 percent. The emissions of $PM_{2.5}$ decreased by 50 percent. The most important drivers were:

- economic restructuring in central and eastern Europe (EU-10) and in eastern Germany, which has caused a drastic decrease of emissions from the power plant, industry and process sectors,
- switch from coal to other fuels in the household sector,
- implementation of more efficient control technologies, especially on large combustion sources,

- enforcement of stringent standards on exhaust emissions from road transport sources.

Future emissions of PM_{10} in the LREM-E scenario further decrease, although at much lower rate than in the last decade. By 2030, the PM_{10} emissions will be 70 percent lower than in 1990. Whereas in 1990 the PM 10 emissions were dominated by combustion sectors and industrial processes (82 percent of total) the contribution those sectors will decrease till 2030 to only 65 percent. The emissions from waste disposal and from agriculture gain relative importance (from five percent of total in 1990 to 18 percent in 2030). Although strict standards have been imposed on exhaust PM emissions from transport sources, the total emissions from transport will not decrease proportionally to the stringency of the standards. This is because non-exhaust emissions (tyre and brake wear, which in our scenario remain uncontrolled) will increase proportionally to traffic volume.

Table 6.17: Emissions of PM_{10} in the LREM-E scenario, kilotons

a. Emissions by country group

			LREM-E		
Country group	1990	2000	2010	2020	2030
EEA 32	7475	3199	2430	2213	2161
EU 15	4302	1830	1403	1273	1234
EU 10	1792	625	383	304	278
EFTA 4	60	53	39	35	33

b. Emissions by CORINAIR sector

			LREM-E		
SNAP1 sector	1990	2000	2010	2020	2030
1:Combustion in energy industries	1734	429	330	324	340
2:Non-industrial combustion plants	2625	879	575	436	339
3:Combustion in manufacturing industry	930	322	234	261	293
4:Production processes	832	498	420	430	438
5: Extraction and distribution	120	69	50	43	37
6: Solvent use	0	0	0	0	0
7:Road transport	628	420	278	243	276
8:Other mobile sources and machinery	228	224	168	98	58
9:Waste treatment and disposal	100	105	105	105	104
10:Agriculture	278	249	269	273	277
Total	7475	3195	2430	2213	2161

Although strict standards have been implemented on exhaust PM emissions from transport sources, the total emissions from transport will not decrease proportionally to the stringency of the standards. This is because non-exhaust emissions (tyre and brake wear, which in our scenario remain uncontrolled) will increase proportionally to traffic volume.

Table 6.18: Emissions of $PM_{2.5}$ for the LREM-E scenario, kilotons

a. Emissions by country group

			LREM-E		
Country group	1990	2000	2010	2020	2030
EEA 32	4509	2268	1650	1427	1343
EU 15	2718	1323	955	812	761
EU 10	987	425	267	200	176
EFTA 4	48	42	28	23	22

b. Emissions by CORINAIR sector

SNAP1 sector	1990	2000	LREM-E 2010	LREM-E 2020	LREM-E 2030
1:Combustion in energy industries	670	246	193	183	187
2:Non-industrial combustion plants	1896	777	528	408	319
3:Combustion in manufacturing industry	489	211	162	181	203
4:Production processes	516	284	229	234	238
5: Extraction and distribution	12	8	6	5	4
6: Solvent use	0	0	0	0	0
7:Road transport	513	351	191	140	154
8:Other mobile sources and machinery	215	212	159	93	55
9:Waste treatment and disposal	94	99	99	98	98
10:Agriculture	104	79	83	84	85
Total	4509	2267	1650	1427	1343

In 1990 the EU 15 was responsible for 58 percent of total PM_{10} emissions from the EEA region, followed by EU 10 (24 percent). Till 2030 the share of EU 15 decreases to 57 percent and the share of EU 10 even to 13 percent (data for the LREM-E scenario). Simultaneously contribution of the candidate countries to total emissions increases. This is first of all due to a relatively faster increase in energy demand in Turkey and less stringent emission control legislation compared with the current EU Member countries.

Future emissions of PM_{10} in the LGEP-B-CLE scenario further decrease, although at lower rate than in the last decade (Table 6.19). By 2030, the emissions are about 1.9 million tons, 40 percent lower than in 2000. Implementation of the MFR measures (scenario LGEP-B-MFR) reduces the emissions down to about 1.0 million tons (68 percent reduction from 2000 levels).

In 2000 the old Member States (EU-15) were responsible for 57 percent of total PM_{10} emissions from the EEA region, followed by EU-10 (20 percent). Candidate countries (Bulgaria, Romania, Turkey) contributed 21 percent, and the balance was emitted in the EFTA-4 group of countries. The shares of the current EU Member States decrease (EU-15 to 59 percent and EU-10 to 12 percent) and the share of the candidate countries increase to 26 percent. This is first of all due to a relatively faster increase in energy demand in Turkey and less stringent emission control legislation compared with the current EU Member countries.

In 2000 more than 70 percent of the EEA emissions originated from four sectors: non-industrial combustion (28 percent), road transport (13 percent), production processes (16 percent), and combustion in energy industries (14 percent-Table 6.21). Till 2030 the emissions from all those sectors decrease, although at a different pace. Thus the contribution of individual emission sources changes. The share of energy industries, non-industrial combustion and non-road mobile sources decreases. The shares of other sectors increase. In particular, the emissions from production processes as well as from agricultural sources and waste treatment become more important. Although strict standards have been implemented on exhaust PM emissions from road transport sources, the total emissions from transport will not decrease proportionally to the stringency of the standards. This is because non-exhaust emissions (tyre and brake wear, which in our scenario remain uncontrolled) will increase proportionally to the increase in traffic volume.

Compared with LGEP-B-CLE, the LGEP-LE-CLE scenario results in four percent lower emissions in 2030. The reductions occur first of all in the non-industrial combustion plants sector (residential/ commercial) but also in the road transport and the power plant (combustion in energy industries) sectors. Similarly as for other pollutants, the difference between the LGEP-B and LGEP-SER scenarios is marginal. Also for PM the LGEP-B emissions are lower than the corresponding emissions in the CAFE CP scenario. The difference is four percent for EEA-32 and three percent for EU-25.

Reduction of $PM_{2.5}$ follows similar patterns as those for PM_{10} (compare Table 6.20, Table 6.23 and Table 6.24). However, total reductions are higher (46 percent instead of 40 percent for PM_{10}), which is due to a lesser contribution to $PM_{2.5}$ emissions of sectors with no (or limited number of) control options. To these sectors belong: fugitive emissions from production processes, non-exhaust emissions from transport, and agriculture.

Table 6.19: Emissions of PM_{10}, kilotons

Country	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
EEA 32	3199	2081	1101	1917	1803	1904	1004
EU 15	*1830*	*1205*	*768*	*1126*	*1033*	*1115*	*699*
EU 10	*625*	*285*	*143*	*231*	*225*	*229*	*118*
EFTA 4	*53*	*37*	*22*	*35*	*34*	*35*	*20*

Table 6.20: Emissions of $PM_{2.5}$, kilotons

Country	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
EEA 32	2268	1360	680	1229	1147	1225	592
EU 15	*1323*	*778*	*466*	*713*	*647*	*710*	*405*
EU 10	*425*	*187*	*83*	*147*	*143*	*147*	*63*
EFTA 4	*42*	*26*	*14*	*23*	*23*	*23*	*13*

Table 6.21: Emissions of PM_{10} in the EEA countries by CORINAIR sectors, kilotons (Iceland and Lichtenstein not included)

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	429	218	57	152	130	146	38
2: Non-industrial combustion plants	879	435	154	353	312	349	125
3: Combustion in manufacturing industry	322	252	116	277	264	274	124
4: Production processes	498	427	211	408	398	409	199
5: Extraction and distribution	69	38	38	30	29	29	30
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	420	237	198	261	235	261	206
8: Other mobile sources and machinery	224	95	86	53	51	53	40
9: Waste treatment	105	105	75	104	104	104	74
10: Agriculture	249	272	166	276	276	276	169
Total	3195	2078	1101	1914	1799	1901	1004

Table 6.22: Emissions of PM $_{10}$ in EU-25 by CORINAIR sectors, kilotons

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	262	94	36	65	47	59	24
2: Non-industrial combustion plants	699	339	120	292	256	288	102
3: Combustion in manufacturing industry	207	118	87	113	104	111	89
4: Production processes	361	319	193	302	293	303	180
5: Extraction and distribution	61	35	35	27	26	26	27
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	383	209	174	223	200	223	174
8: Other mobile sources and machinery	196	77	71	37	35	38	28
9: Waste treatment	86	84	59	83	83	83	58
10: Agriculture	201	214	136	215	215	215	136
Total	2455	1490	911	1357	1258	1344	817

Table 6.23: Emissions of PM $_{2.5}$ in the EEA countries by CORINAIR sectors, kilotons(Iceland and Lichtenstein not included)

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	246	127	46	93	80	94	31
2: Non-industrial combustion plants	777	409	146	334	294	331	119
3: Combustion in manufacturing industry	211	174	95	194	185	192	104
4: Production processes	284	234	94	223	218	223	88
5: Extraction and distribution	8	4	4	3	3	3	3
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	351	136	98	147	134	147	94
8: Other mobile sources and machinery	212	90	81	50	48	50	37
9: Waste treatment	99	98	75	98	98	98	74
10: Agriculture	79	84	40	85	85	85	41
Total	2265	1357	680	1226	1144	1223	592

Table 6.24: Emissions of PM $_{2.5}$ in EU-25 by CORINAIR sectors, kilotons

SNAP Sector	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
1: Combustion in energy industries	156	61	29	44	34	46	20
2: Non-industrial combustion plants	618	319	115	277	242	273	98
3: Combustion in manufacturing industry	141	90	71	89	82	87	74
4: Production processes	183	157	85	147	142	147	79
5: Extraction and distribution	7	4	4	3	3	3	3
6: Solvent use	0	0	0	0	0	0	0
7: Road transport	320	121	87	126	115	126	79
8: Other mobile sources and machinery	185	73	67	35	33	35	26
9: Waste treatment	80	79	59	78	78	78	58
10: Agriculture	58	61	32	61	61	61	32
Total	1748	964	549	860	790	857	469

Summary of relative changes in the emissions of air pollutants for the scenarios included in our report is shown in Figure 6-4.

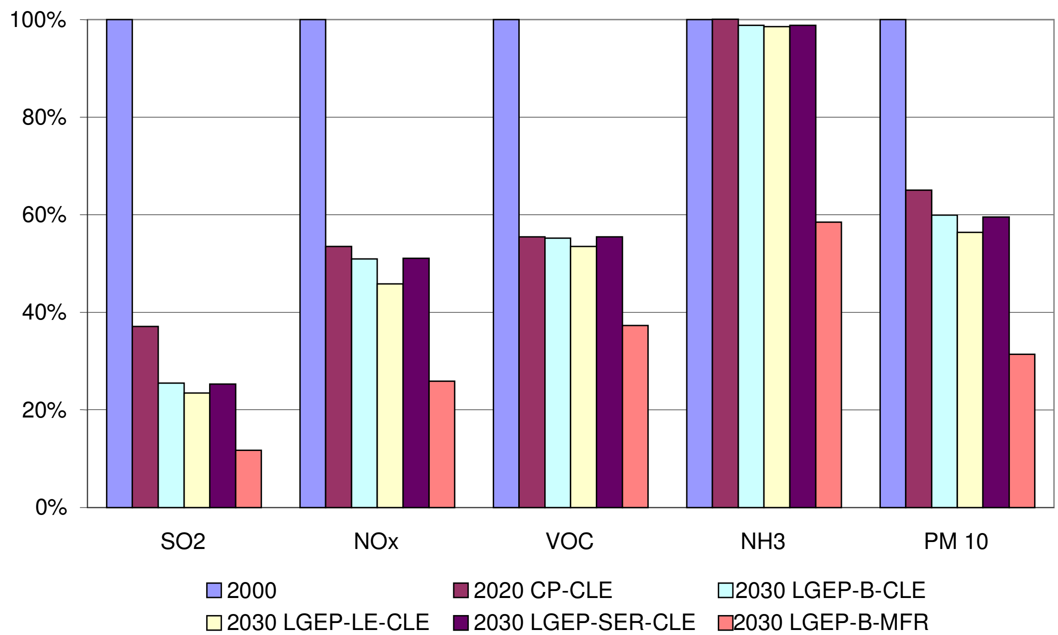


Figure 6-4: Change in emissions of air pollutants in the EEA region relative to 2000

6.3.6. Shipping emissions

Within CAFE programme new scenarios of emissions from international shipping have been elaborated. The scenarios are based on studies by ENTEC (ENTEC, 2002, ENTEC, 2005). ENTEC identified several emission control options for seagoing vessels and estimated their efficiency and costs. The most important options are listed in Table 5.7.

The CLE scenario is a kind of a “business as usual”. It includes measures already decided, as well as measures that are the state of the art technology for newly built ships (e.g., slide valve modification for slow speed engines). The MFR scenario assumes a full implementation of the best available emission control technology on all existing and new ships.

Table 6.25. Emissions of air pollutants from international shipping by sea region, kilotons

a. NO_x:

			2010	2020		2030	
Region	1990	2000	CLE	CLE	MFR	CLE	MFR
Atlantic Ocean	444	566	686	834	95	1045	123
Baltic Sea	273	349	424	517	59	649	76
Black Sea	93	118	143	174	20	218	26
Mediterranean Sea	1415	1808	2211	2711	310	3400	400
North Sea	518	659	800	971	111	1218	144
Total sea regions	2743	3501	4265	5207	595	6530	769

b. NMVOC:

			2010	2020		2030	
Region	1990	2000	CLE	CLE	MFR	CLE	MFR
Atlantic Ocean	16	21	27	35	35	45	45
Baltic Sea	10	13	17	22	22	28	28
Black Sea	3	4	6	7	7	9	9
Mediterranean Sea	52	68	88	114	114	148	148
North Sea	19	25	32	41	41	53	53
Total sea regions	101	131	170	219	219	284	284

c. SO_2:

			2010	2020		2030	
Region	1990	2000	CLE	CLE	MFR	CLE	MFR
Atlantic Ocean	307	396	494	632	122	815	158
Baltic Sea	188	242	174	225	75	290	97
Black Sea	65	83	104	133	26	171	33
Mediterranean Sea	958	1237	1552	2003	388	2583	502
North Sea	357	460	328	423	141	547	183
Total sea regions	1874	2418	2652	3415	752	4406	972

d. PM_{10}:

			2010	2020		2030	
Region	1990	2000	CLE	CLE	MFR	CLE	MFR
Atlantic Ocean	28	36	46	59	48	77	62
Baltic Sea	17	22	24	30	30	39	38
Black Sea	6	8	10	12	10	16	13
Mediterranean Sea	88	114	146	189	154	244	199
North Sea	33	42	45	57	56	74	72
Total sea regions	171	222	270	348	298	450	385

e. $PM_{2.5}$:

			2010	2020		2030	
Region	1990	2000	CLE	CLE	MFR	CLE	MFR
Atlantic Ocean	27	34	44	56	46	72	59
Baltic Sea	16	21	22	29	28	37	36
Black Sea	6	7	9	12	10	15	12
Mediterranean Sea	83	108	138	179	146	231	188
North Sea	31	40	42	54	53	70	69
Total sea regions	162	210	255	330	282	426	364

Table 6.26. Emission control costs by sea region and scenario, million €/year; constant prices of 2000

		2010	2020		2030	
Region	2000	CLE	CLE	MFR	CLE	MFR
Atlantic Ocean	6	42	63	1287	85	1646
Baltic Sea	4	291	376	720	486	920
Black Sea	1	8	13	270	17	345
Mediterranean Sea	29	147	220	4122	297	5272
North Sea	7	549	707	1353	914	1729
Total sea regions	47	1037	1378	7752	1798	9912

7. Projection of air pollutant impacts on health and ecosystems for 2000-2030

7.1. Introduction

This section analyzes the impacts of the emission reductions outlined in Section 3 on a range of health and environmental indicators. It uses the results of calculations performed by the EMEP model for emission fields as specified for each of the scenarios by the RAINS model. The analysis was carried out for the meteorological conditions of a single year (1997).

With decreasing emissions from European sources, European air quality is increasingly influenced by hemispheric background pollution. The atmospheric computations of the EMEP model conducted for the CAFE analysis consider present background levels as boundary conditions to their calculations. For ozone, however, a wide range of scientific literature hints at increasing background concentrations resulting from intercontinental and hemispheric transport, essentially caused by global increases in methane emissions and steep growth in Asian emissions of NO_x and VOC. Thus, any considerations of future environmental air quality targets for Europe should not forget the ongoing increases in background pollution, in order to set European emission control efforts into a realistic context. For this purpose, the analysis presented in this paper assumes for the years 2020- 2030 a 3 ppb increase in hemispheric background levels of ozone compared to the year 2000 (see also section 7.10).

7.2. Loss in life expectancy attributable to the exposure to fine particulate matter

With the methodology described in Amann *et al.* (2004), the RAINS model estimates changes in the loss in statistical life expectancy that can be attributed to changes in anthropogenic emissions (ignoring the role of secondary organic aerosols). This calculation is based on the assumption that health impacts can be associated with changes in PM2.5 concentrations. Following the advice of the joint World Health Organization/UNECE Task Force on Health (http://www.unece.org/env/documents/2004/eb/wg1/eb.air.wg1.2004.11.e.pdf), RAINS applies a linear concentration-response function and associates all changes in the identified anthropogenic fraction of PM2.5 with health impacts. Thereby, no health impacts are calculated for PM from natural sources and for secondary organic aerosols. It transfers the rate of relative risk for PM2.5 identified by Pope *et al.* (2002) for 500.000 individuals in the United States to the European situation and calculates mortality for the population older than 30 years. Thus, the assessment in RAINS does not quantify infant mortality and thus underestimates overall effects. Awaiting results from the City-Delta project, the provisional estimates presented in this report assume PM2.5 concentrations originating from primary emissions in urban areas to be 25 percent higher than in the surrounding rural areas.

The loss of life expectancy in 2000 is estimated at approximately 9 months for the EEA countries, for which the estimates are available (compare Figure 7-2). The "current legislation" controls decrease those losses to below 6 months. Implementation of the MFR measures further decreases the expected loss in life

expectancy to less than 2 months. presents the spatial distribution of the indicator. Results by country are to be found in Annex 2.

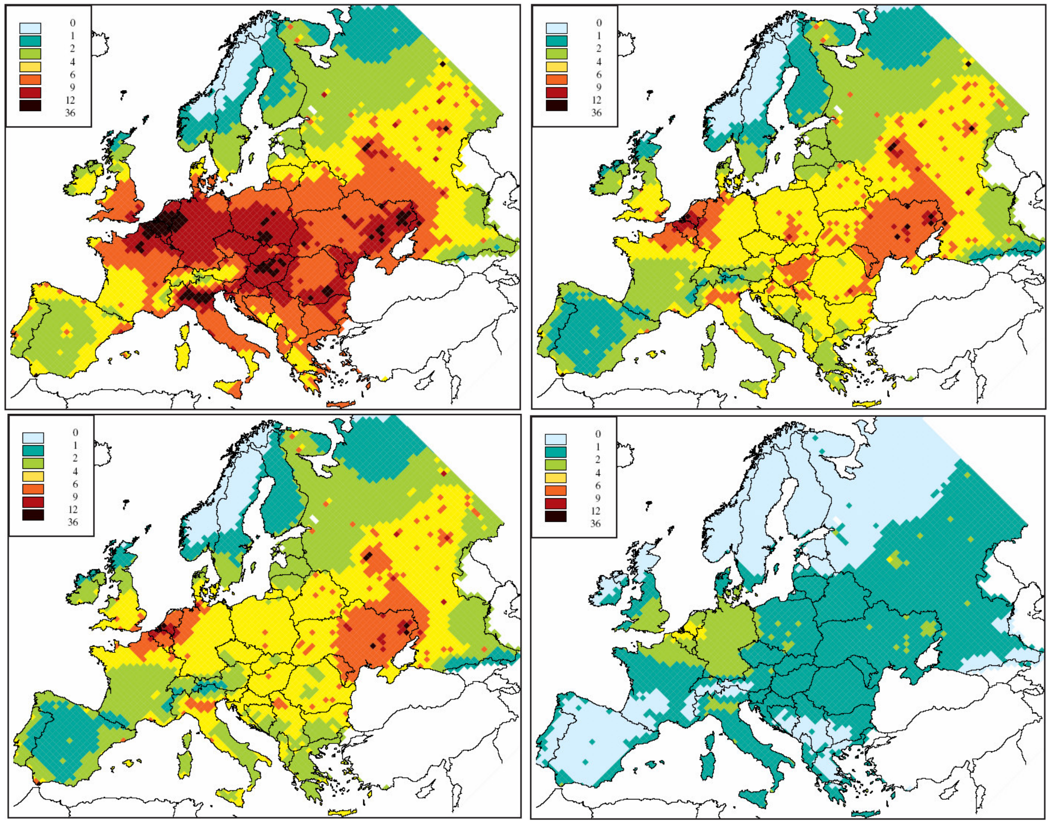


Figure 7-1: Loss in statistical life expectancy that can be attributed to the identified anthropogenic contributions to $PM_{2.5}$ (in months) for the emissions of the year 2000 (top left panel), the current legislation case of the CAFE "Baseline with climate policies" (CP-CLE) for 2020 (top right), the "Low Greenhouse Emissions Pathway – Base" scenario in 2030 (LGEP-B-CLE – bottom left) and the maximum feasible reduction case for 2030 (LGEP-B-MFR – bottom right panel). Calculation results for the meteorological conditions of 1997. Provisional calculations based on generic assumptions on urban increments in $PM_{2.5}$, awaiting City-Delta results.

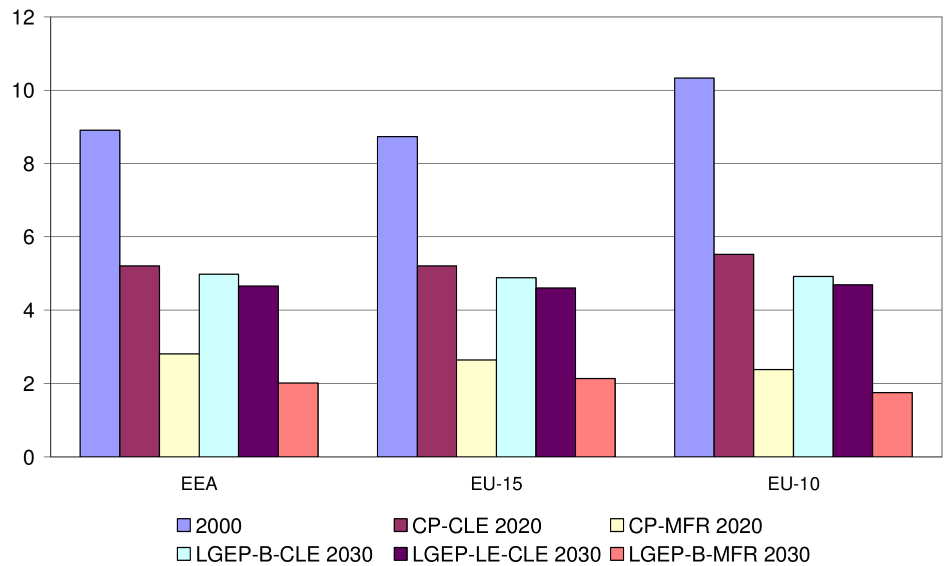


Figure 7-2: Loss in statistical life expectancy that can be attributed to the identified anthropogenic contributions to $PM_{2.5}$ (in months) by country group and scenario

7.3. Premature deaths attributable to the exposure to ground-level ozone

The joint WHO/UNECE Task Force at its 7th Meeting developed specific recommendations concerning the inclusion of ozone-related mortality into RAINS. Key points of these recommendations are summarized below:

- The relevant health endpoint is mortality, even though several effects of ozone on morbidity are also well documented and causality established; however, available input data (e.g., on base rates) to calculate the latter on a European scale are often either lacking or not comparable.
- The relative risk for all-cause mortality is taken from the recent meta-analysis of European time-series studies, which was commissioned by WHO and performed by a group of experts of St. George's Hospital in London, UK (WHO, 2004). The relative risk taken from this study is 1.003 for a 10 µg/m^3 increase in the daily maximum 8-hour mean (CI 1.001 and 1.004).
- In agreement with the recent findings of the WHO Systematic Review, a linear concentration-response function is applied.
- The effects of ozone on mortality are calculated from the daily maximum 8-hour mean. This is in line with the health studies used to derive the summary estimate used for the meta-analysis mentioned above.

Even though current evidence was insufficient to derive a level below which ozone has no effect on mortality, a cut-off at 35 ppb, considered as a daily maximum 8-hour mean ozone concentration, is used. This means that for days with ozone concentration above 35 ppb as maximum 8-hour mean, only the increment exceeding 35 ppb is used to calculate effects. No effects of ozone on health are calculated on days below 35 ppb as maximum 8-hour mean. This exposure parameter is called SOMO35 (sum of means over 35) and is the sum of excess of daily maximum 8-h means over the cut-off of 35 ppb calculated for all days in a year.

The Eulerian EMEP model has been used to calculate the SOMO35 exposure indicator for the baseline emission projections. RAINS applies the SOMO35 based methodology to quantify the changes in premature mortality that are attributable to the projected reductions in ozone precursor emissions. However, these estimates are loaded with considerable uncertainties of different types, and further analysis is necessary to explore the robustness of these figures. In particular, these numbers are derived from time series studies assessing the impacts of daily changes in ozone levels on daily mortality rates. By their nature, such studies cannot provide any indication on how much the deaths have been brought forward, and some of these deaths are considered as "harvesting effects" followed by reduced mortality few days later. At present it is not possible to quantify the importance of this effect for these estimates. Also the influence of the selected cut-off value (35 ppb) on the outcome needs to be further explored in the future.

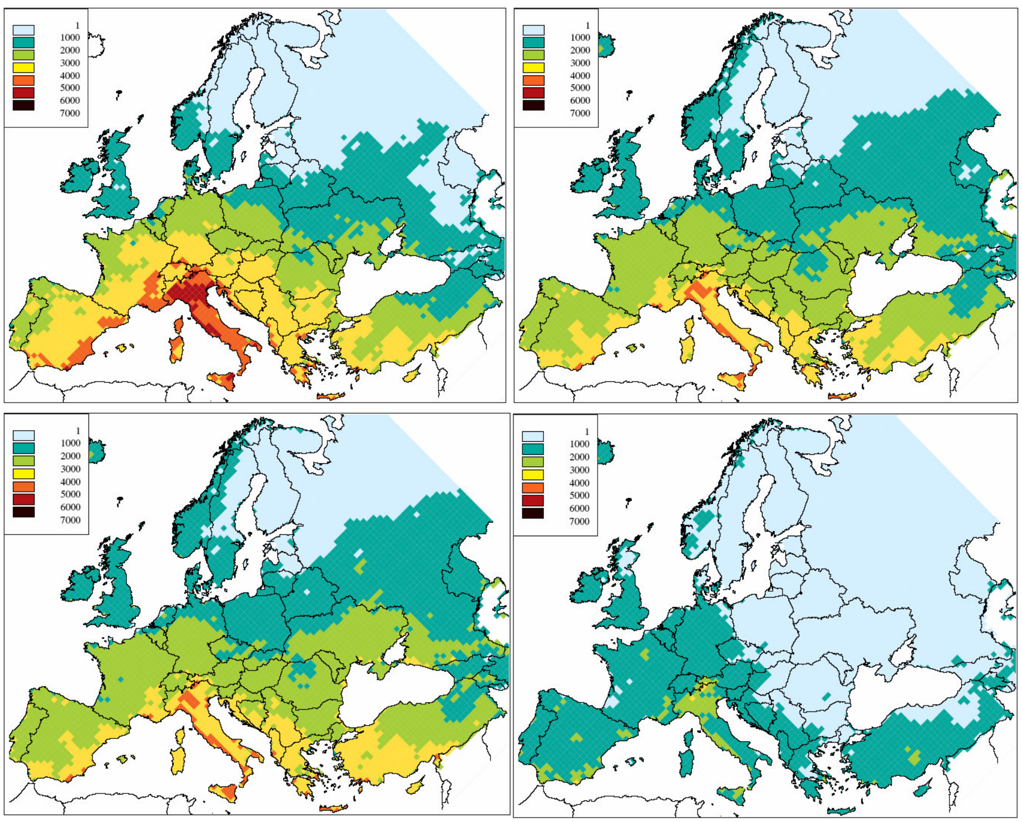


Figure 7-3: Grid-average ozone concentrations in ppb.days expressed as SOMO35 for the emissions of the year 2000 (top left panel), the current legislation case of the CAFE "Baseline with climate policies" (CP-CLE) for 2020 (top right), the "Low Greenhouse Emissions Pathway – Base" scenario in 2030 (LGEP-B-CLE – bottom left) and the maximum feasible reduction case for 2030 (LGEP-B-MFR – bottom right panel,. Calculation results for the meteorological conditions of 1997.

Figure 7-4 shows the estimates of premature mortality due to elevated ozone levels by country group. Whereas in 2000 about 49 cases per million inhabitants occurred on average in the EEA region, the number decreases to 41 in 2020 (CAFE baseline scenario CP-CLE) and remains the same for the LGEP-B_CLE scenario in 2030. In

the LGEP-B-MFR scenario the value of that indicator decreases to 26. On average, the mortality indicators for the CLE scenarios are for the EU-15 15 to 18 percent lower. The MFR values are for the EU-15 40 percent lower than the EEA average.

Spatial distribution of SOMO35 is shown in Figure 7-3. The highest values are for southern European countries (Italy, Greece, Bulgaria). However, hot spots occur also in Luxembourg and in Switzerland. Consequently, also premature mortality indicators for those countries are above the averages (compare Annex 2).

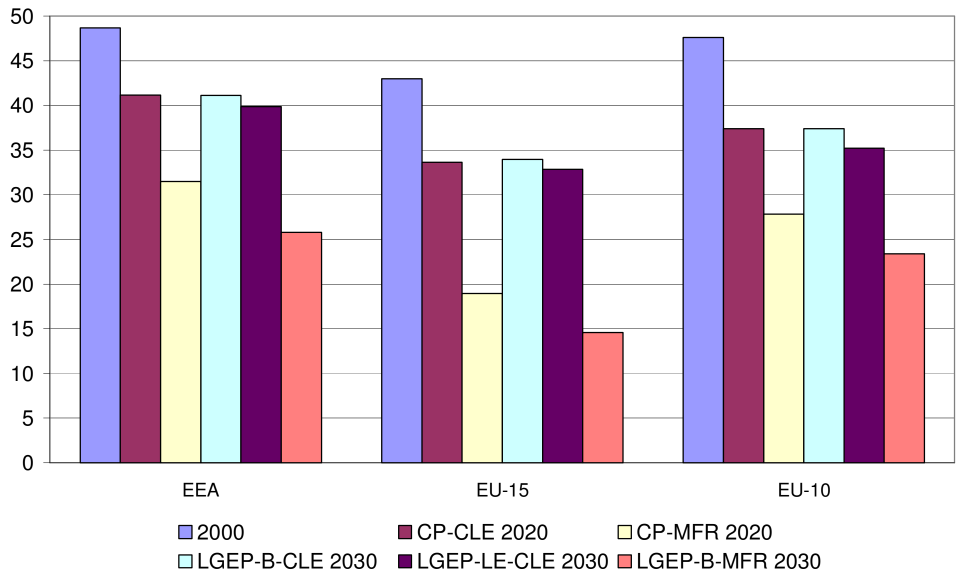


Figure 7-4: Provisional estimates of premature mortality attributable to ozone (cases of premature deaths per million inhabitants per year).

7.4. Vegetation damage from ground-level ozone

The RAINS model applies the concept of critical levels to quantify progress towards the environmental long-term target of full protection of vegetation from ozone damage. At the UNECE workshop in Gothenburg in November 2002 (Karlsson *et al.*, 2003) it was concluded that the effective ozone dose, based on the flux of ozone into the leaves through the stomatal pores, represents the most appropriate approach for setting future ozone critical levels for forest trees. However, uncertainties in the development and application of flux-based approaches to setting critical levels for forest trees are at present too large to justify their application as a standard risk assessment method at a European scale.

Consequently, the UNECE Working Group on Effects retains in its Mapping Manual the AOT40 (accumulated ozone over a threshold of 40 ppb) approach as the recommended method for integrated risk assessment for forest trees, until the ozone flux approach will be sufficiently refined. However, such AOT40 measures are not considered suitable for quantifying vegetation damage, but can only be used as indicators for quantifying progress towards the environmental long-term targets.

The Mapping Manual defines critical levels for crops, forests and semi-natural vegetation in terms of different levels of AOT40, measured over different time spans. From earlier analysis of ozone time series for various parts of Europe, the critical

level for forest trees (5 ppm.hours over the full vegetation period, April 1- September 30 is recommended as default) appears as the most stringent constraint. For most parts of Europe, the other critical levels will be automatically achieved if the 5 ppm.hours over six months condition is satisfied. Thus, if used for setting environmental targets for emission reduction strategies, the critical levels for forest trees would imply protection of the other receptors.

Figure 7-5 presents the evolution of the excess ozone that is considered harmful for forest trees, using the AOT40 (accumulated ozone over a threshold of 40 ppb) as a metric. The updated manual for critical levels (UNECE, 2004) specifies a no-effect critical level of 5 ppm.hours for trees. Related to this quantity, significant excess ozone is calculated for 2000 for large parts of the European Union. Emission reductions till 2030 as in the LGEP-B-CLE scenario will improve the situation, but will not be sufficient to fully eliminate the risk. Implementation of the MFR measures limits the area affected to a limited number of hot spots, mainly in Italy.

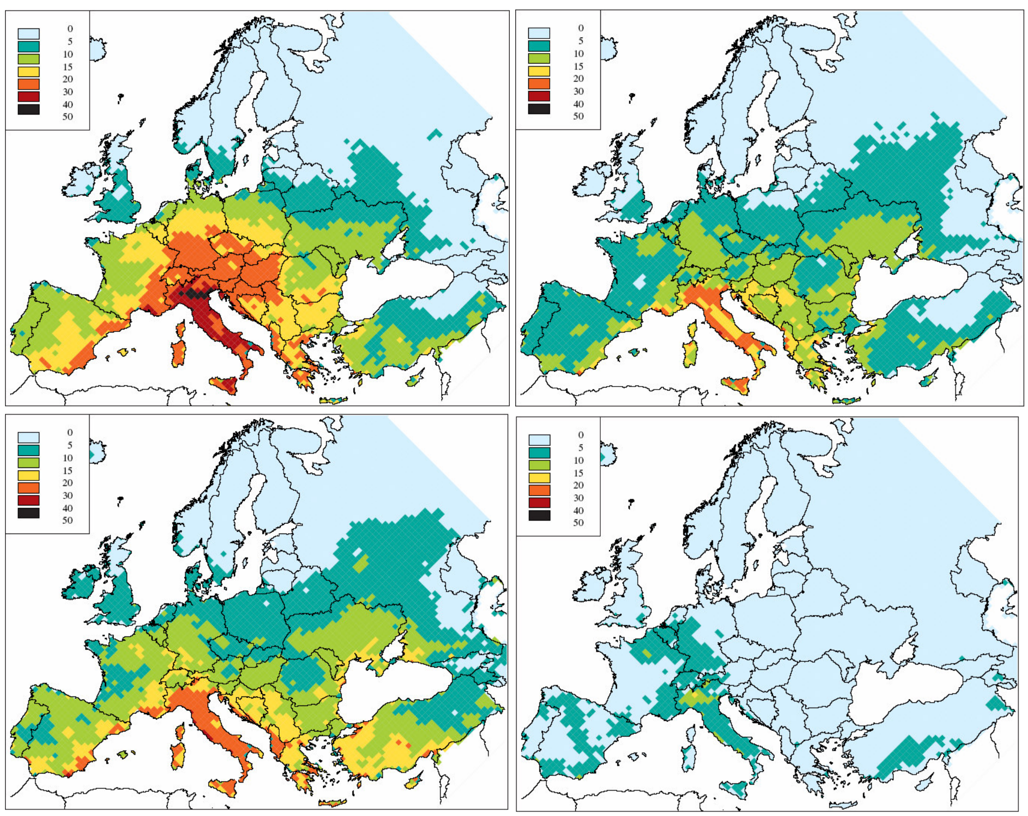


Figure 7-5: AOT40 (in ppm.hours) for the emissions of the year 2000 (top left panel), the current legislation case of the CAFE "Baseline with climate policies" (CP-CLE) for 2020 (top right), the "Low Greenhouse Emissions Pathway – Base" scenario in 2030 (LGEP-B-CLE – bottom left) and the maximum feasible reduction case for 2030 (LGEP-B-MFR – bottom right panel). Calculation results for the meteorological conditions of 1997. The critical level for forests is set at 5 ppm.hours.

7.5. Acid deposition to forest ecosystems

RAINS used the concept of critical loads as a quantitative indicator for sustainable levels of sulphur and nitrogen deposition. The analysis using is based on the critical loads databases compiled by the Coordination Centre on Effects under the UNECE

Working Group on Effects. This database combines quality-controlled critical loads estimates of the national focal centers for more than 1.6 million ecosystems (Posch *et al*., 2004). National focal centres have selected a variety of ecosystem types as receptors for calculating and mapping critical loads. For most ecosystem types (e.g., forests), critical loads are calculated for both acidity and eutrophication. Other receptor types, such as streams and lakes, have only critical loads for acidity, on the assumption that eutrophication does not occur in these ecosystems. The RAINS analysis groups ecosystems into three classes (forests, semi-natural vegetation such as nature protection areas and freshwater bodies) and performs separate analyses for each class. The RAINS analysis compares for a given emission scenario the resulting deposition to these ecosystems with the critical loads and thus provides an indication to what extent the various types of ecosystems are still at risk of acidification. This indicator cannot be directly interpreted as the actual damage occurring at such ecosystems. To derive damage estimates, the historic rate of acid deposition as well as dynamic chemical processes in soils and lakes need to be considered, which can lead to substantial delays in the occurrence of acidification as well as in the recovery from acidification.

According to the new estimates using the critical loads database of 2004, about 18 percent of forests in the EEA countries were endangered by acidification (data for the year 2000, compare Figure 7-7). For the New Member States (EU-10) this share is twice as high. Implementation of the “current legislation” measures reduces the risk to about eight percent of forest area in the EEA region (eU-15 – ten percent, EU-10 – eight percent). Further improvement is possible through implementation of the MFR measures. In this case the forest area at risk is reduced to about two percent (three percent for EU-15, close to zero for EU-10). However, one should stress, that country group averages do not reflect the situation in individual countries (compare Annex 2). For instance, in Belgium, Netherlands, Germany, Ireland, UK and Czech Republic the relative share of ecosystems affected is much higher than region averages.

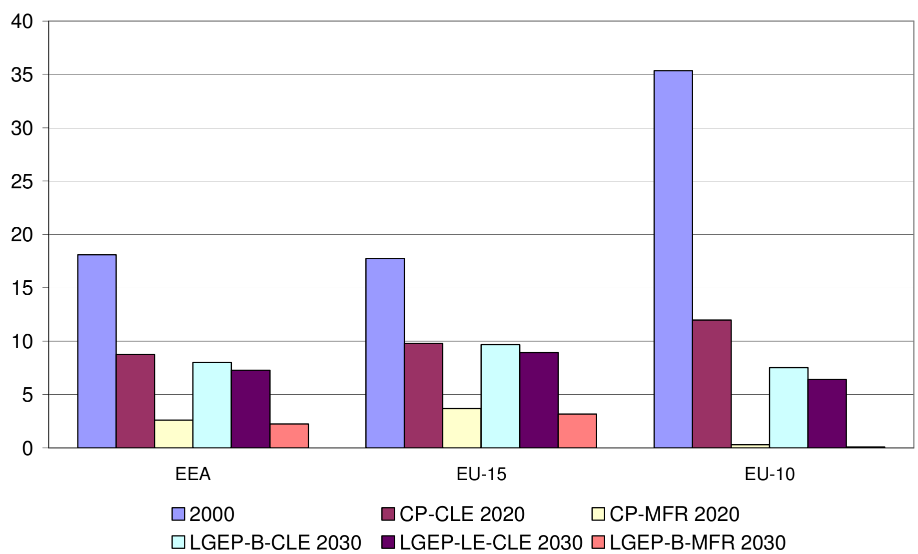


Figure 7-6: Percentage of forest area receiving acid deposition above the critical loads by country group and scenario

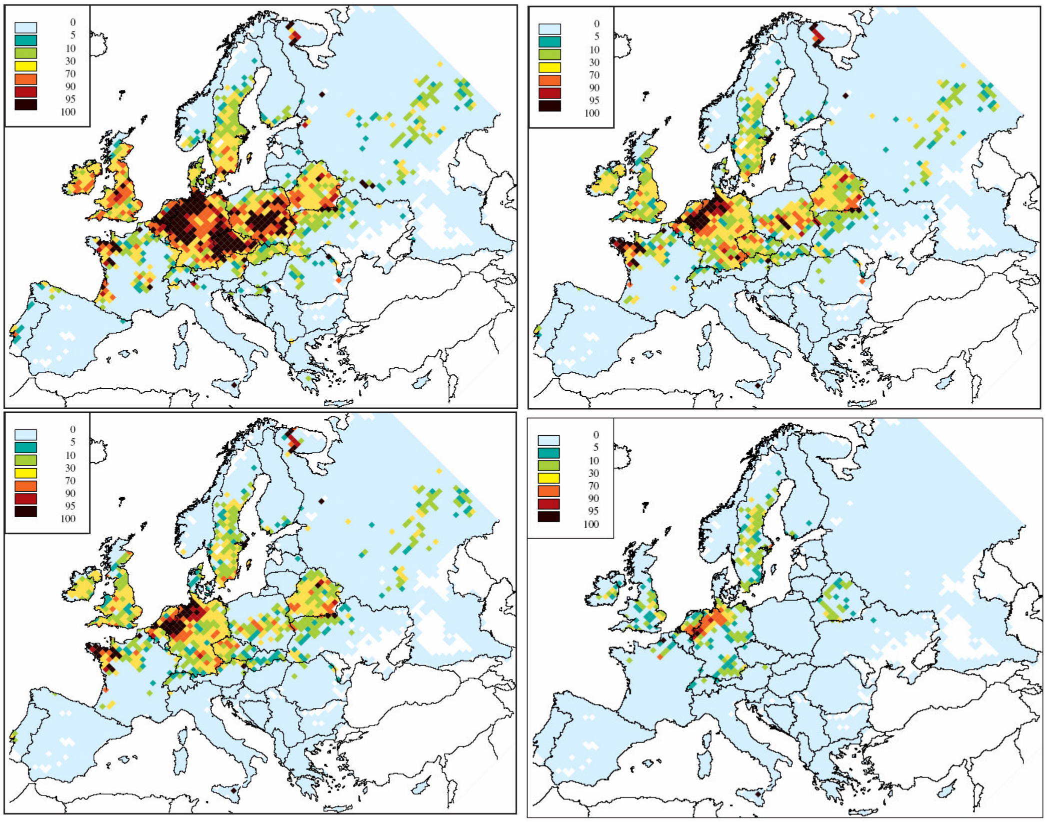


Figure 7-7: Percentage of forest area receiving acid deposition above the critical loads for the emissions of the year 2000 (top left), the CAFE CP-CLE case for 2020 (top right), the LGEP-B-CLE scenario in 2030 (bottom left) and the LGEP-B-MFR case for 2030 (bottom right). Calculation results for the meteorological conditions of 1997, using ecosystem-specific deposition for forests. Critical loads data base of 2004.

7.6. Acid deposition to semi-natural ecosystems

A number of countries have provided estimates of critical loads for so-called "semi-natural" ecosystems. This group typically contains nature and landscape protection areas, many of them designated as "Natura2000" areas of the EU Habitat directive. While this group of ecosystems includes open land and forest areas, RAINS uses as a conservative estimate grid-average deposition rates for the comparison with critical loads, which systematically underestimates deposition for forested land. Available indicators are presented in Table 7.1. Spatial distribution of ecosystems with exceedances is shown in Figure 7-8.

Table 7.1: Percentage of area with semi-natural ecosystems with acid deposition above critical loads by scenario and country. The analysis reflects average meteorological conditions of 1997

Country	2000	2020, CP		2030, LGEP		
		CLE	MFR	B-CLE	LE-CLE	B-MFR
France	49.6	9.0	0.6	9.0	8.2	0.4
Germany	69.2	40.9	11.3	38.7	33.5	10.2
Italy	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	64.3	47.8	17.8	45.9	43.8	17.2
UK	28.3	9.3	1.3	9.4	8.6	0.8
Average	24.8	8.5	1.5	8.4	7.7	1.2

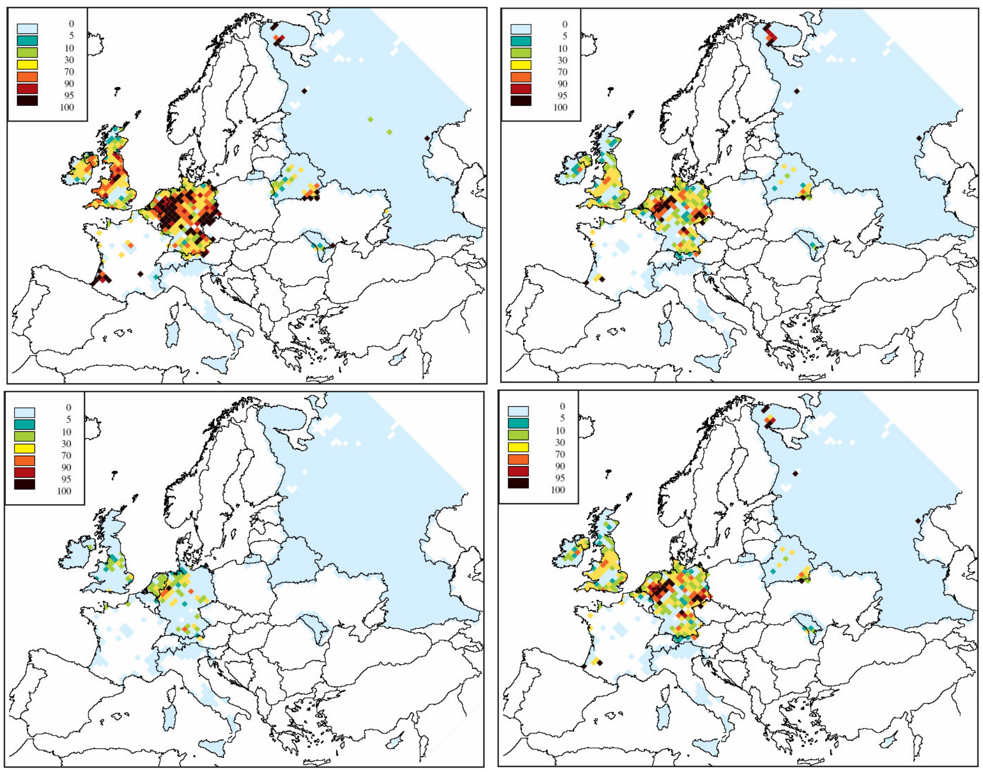


Figure 7-8: Percentage of the area of semi-natural ecosystems receiving acid deposition above the critical loads, for the baseline emissions for 2000 (left panel), the current legislation case of the "Climate policy" scenario in 2020 (centre panel) and the maximum feasible reduction case for 2020 (right panel). Calculation results for the meteorological conditions of 1997, using grid-average deposition. Critical loads data base of 2004. For areas shown in white no critical loads estimates have been provided.

7.7. Acid deposition to freshwater bodies

In a number of countries critical loads have been estimated for the catchments areas of freshwater bodies (lakes and streams), which experienced significant acidification in the past. The baseline emission projections suggest a significant decline of acid deposition at many of these catchments areas, in many cases even below their critical loads. As indicated above, recovery from acidification requires acid deposition to stay

some time below the critical loads. Available country values and their spatial distribution are shown in Table 7.2 and Figure 7-8.

Table 7.2: Percentage of freshwater ecosystems area receiving acid deposition above the critical loads for by scenario and country. Calculation results for the meteorological conditions of 1997, using grid-average deposition. Critical loads data base of 2004.

Country	2000	2020, CP		2030, LGEP		
		CLE	MFR	B-CLE	LE-CLE	B-MFR
Finland	0.7	0.7	0.2	0.7	0.7	0.2
Sweden	14.9	10.5	5.2	10.9	10.5	5.1
UK	8.1	3.7	1.3	3.8	3.5	0.8
Norway	28.6	19.3	9.1	19.9	19.6	6.9
Switzerland	79.8	56.9	18.2	53.2	52.7	9.7
Average	22.6	15.4	7.3	15.8	15.5	5.9

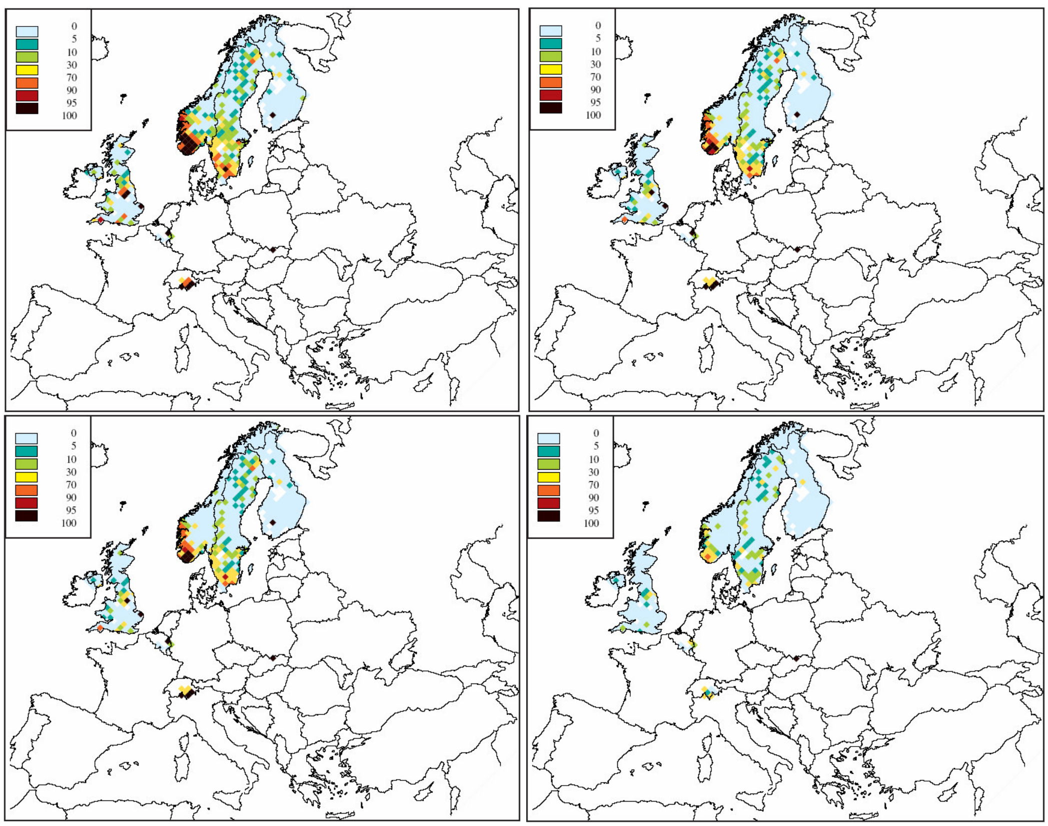


Figure 7-9: Percentage of freshwater ecosystems area receiving acid deposition above the critical loads for the emissions of the year 2000 (top left panel), the current legislation case of the CAFE "Baseline with climate policies" (CP-CLE) for 2020 (top right), the "Low Greenhouse Emissions Pathway – Base" scenario in 2030 (LGEP-B-CLE – bottom left) and the maximum feasible reduction case for 2030 (LGEP-B-MFR – bottom right panel). Calculation results for the meteorological conditions of 1997, using grid-average deposition. Critical loads data base of 2004. For areas shown in white no critical loads estimates have been provided.

7.8. Excess nitrogen deposition

Excess nitrogen deposition poses a threat to a wide range of ecosystems endangering their bio-diversities through changes in the plant communities. Critical loads indicating the maximum level of nitrogen deposition that can be absorbed by ecosystems without eutrophication have been estimated throughout Europe. As a conservative estimate, the assessment presented in this report uses grid-average deposition for all ecosystems, resulting in a systematic underestimate of nitrogen deposition to forests.

Eutrophication is a wide-spread phenomenon in the EEA region. In 2000 more than 52 percent of ecosystems were endangered (54 percent for EU-15, 71 percent for EU-10 – compare Figure 7-11). Although emission reduction in the LGEP scenarios is quite significant, the eutrophication indicator improves only about eight to ten percentage points. A more significant improvement occurs in the MFR scenario, where the share of ecosystems endangered is reduced to below ten percent. Geographical distribution of ecosystems with excess nitrogen deposition is shown in Figure 7-10.

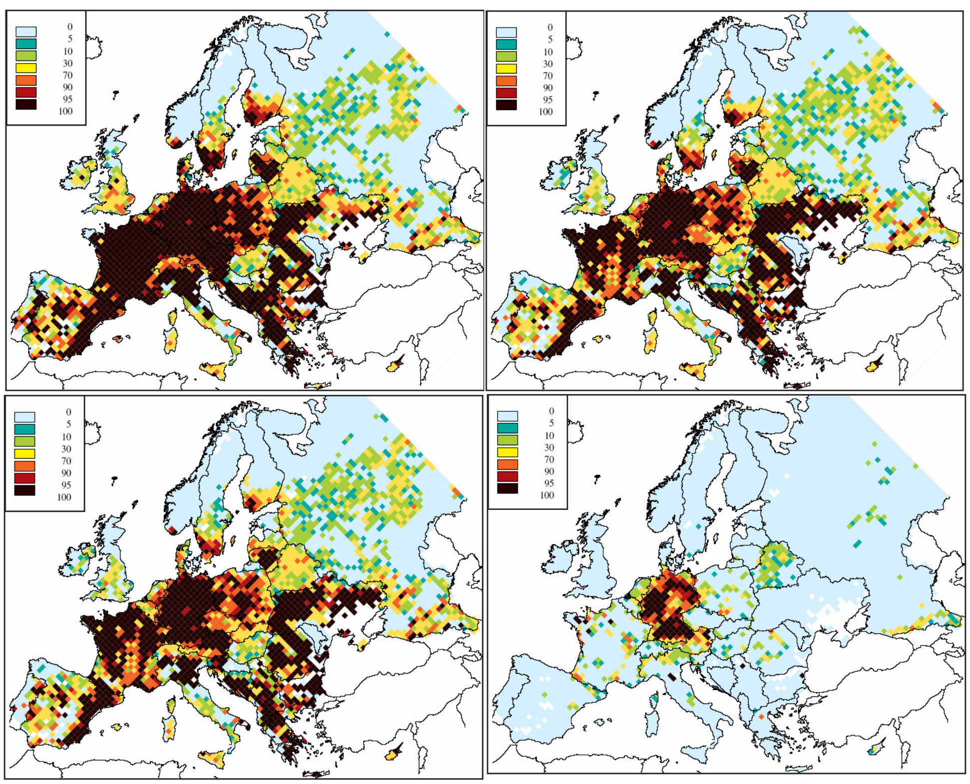


Figure 7-10: Percentage of total ecosystems area receiving nitrogen deposition above the critical loads for the emissions of the year 2000 (top left panel), the current legislation case of the CAFE "Baseline with climate policies" (CP-CLE) for 2020 (top right), the "Low Greenhouse Emissions Pathway – Base" scenario in 2030 (LGEP-B-CLE – bottom left) and the maximum feasible reduction case for 2030 (LGEP-B-MFR – bottom right panel). Calculation results for the meteorological conditions of 1997, using grid-average deposition. Critical loads data base of 2004. For areas shown in white no critical loads estimates have been provided.

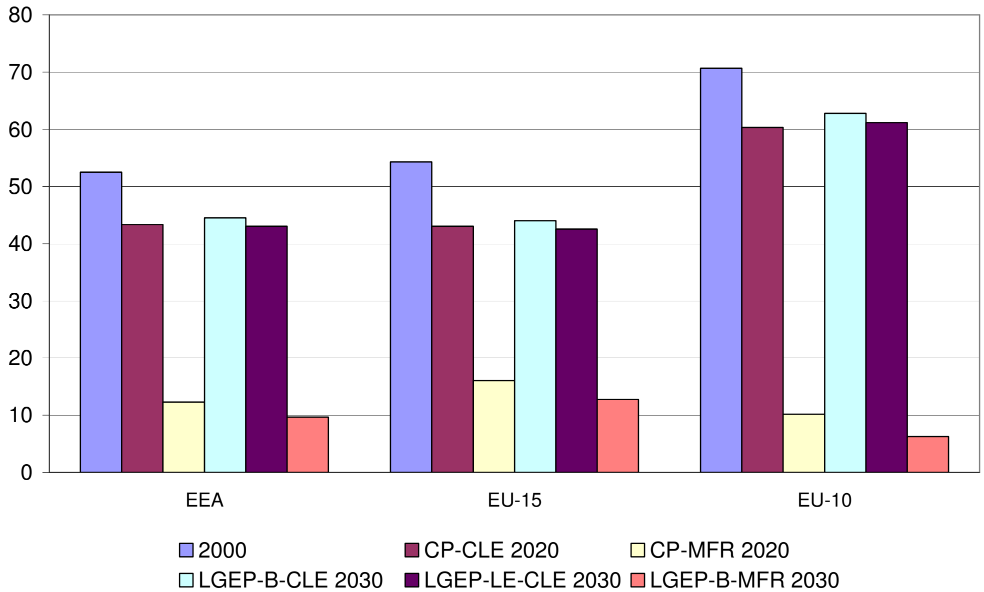


Figure 7-11: Percentage of total ecosystems area receiving nitrogen deposition above the critical loads for eutrophication by country group and scenario

7.9. Consequences for assessment of ambient $PM_{2.5}$ concentrations

As has been mentioned before, all present state-of-the-art models underestimate PM concentrations. This will affect to a certain extent assessments for e.g. $PM_{2.5}$ when using current model calculations. The main question is to which extent the gap between observed and modelled PM concentrations is to be attributed to natural processes or anthropogenic sources. Presently, the main uncertainties are:

- Secondary organic aerosols (SOA). A certain fraction of SOA is caused by anthropogenic emissions, though some estimates suggest that the contribution from natural sources may dominate total SOA. Clarification of this question is urgent to judge whether the inability of contemporary atmospheric chemistry models to quantify SOA is a serious deficiency for modelling the anthropogenic fraction of total PM mass.
- The contributions of sea salt and (wind blown) mineral dust
- Aerosol water. There are indications that particle bound water may explain a substantial part of the gap between observed and modelled $PM_{2.5}$ concentrations.
- Primary anthropogenic emissions. There are indications that current estimates are too low, based on comparison between modelled and measured elemental carbon content of PM.

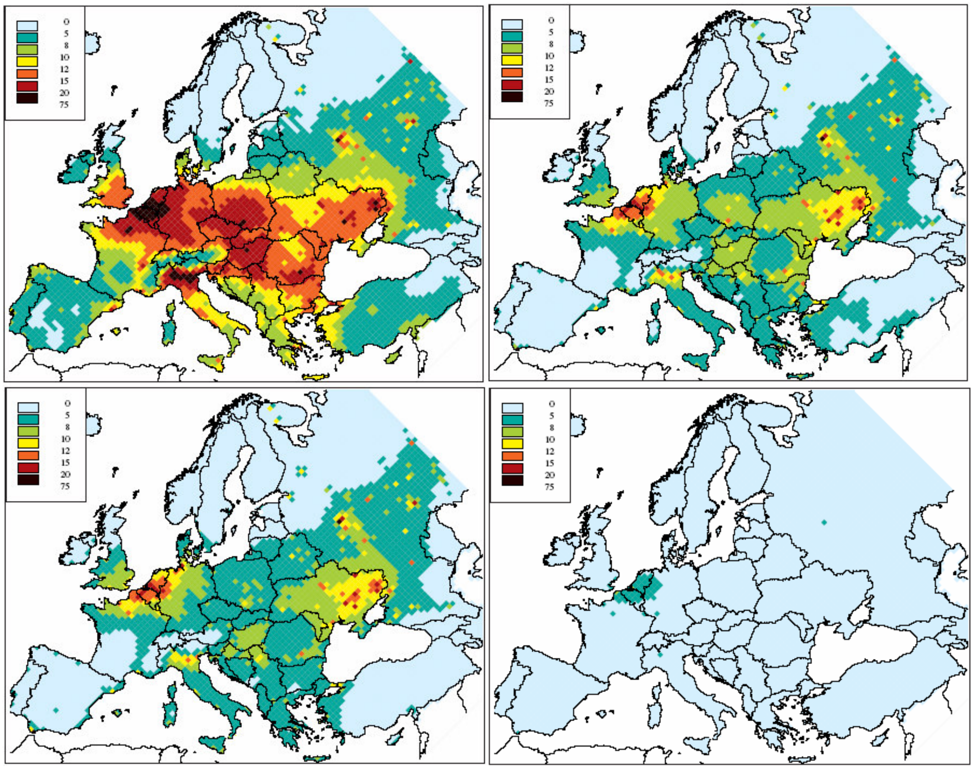


Figure 7-12: Identified anthropogenic contribution to modelled grid-average PM2.5 concentrations (annual mean, µg/m^3) for the emissions of the year 2000 (top left panel), the current legislation case of the CAFE "Baseline with climate policies" (CP-CLE) for 2020 (top right), the "Low Greenhouse Emissions Pathway – Base" scenario in 2030 (LGEP-B-CLE – bottom left) and the maximum feasible reduction case for 2030 (LGEP-B-MFR – bottom right panel). Calculation results for the meteorological conditions of 1997.

In contrast, the modelling of secondary inorganic aerosols is considered reliable within acceptable uncertainty ranges. This applies especially to sulphate, validation for nitrate and ammonium is hampered by a lack of insufficient monitoring data with known accuracy, though the model performs reasonably well for other nitrogen-related compounds. Figure 7-12 presents the model estimates of the identified anthropogenic fraction of $PM_{2.5}$ for the discussed scenarios and years.

7.10. Trend in Hemispheric background of ozone

In the EMEP-calculations the hemispheric background concentration of ozone is taken into account by setting a boundary condition. However, it is expected that the hemispheric ozone levels will increase due to the global increase of the methane emissions and steep growth of the NOx and VOC emissions in Asia. In the calculations by EMEP this is taken into account by assuming an increase in the hemispheric background concentration of ozone to 2020-2030 of 3 ppb.

Dentener et al., (2004) showed that the northern hemispheric ozone levels for the Current LEgislation CLE-emission projections will increase by 3-5 ppb from the period 1990-2000 to the period 2020-2030. Dentener et al (2004) used the TM5 model and a 1990 emissions distribution based on the EDGAR database (see e.g. the methane spatial distribution for Methane, figure 7.13).

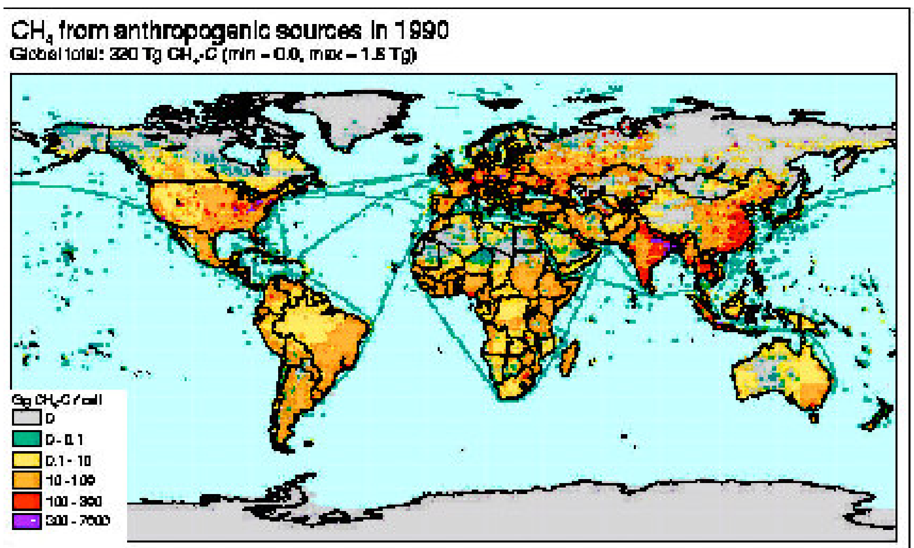


Figure 7-13:1990 (EDGAR) Methane emissions from anthropogenic sources (Gg CH4.C/cell)

In figure 7.14 the 2000 and 2030 baseline results for the SOMO-35 ozone levels are shown. In 2030, compared to 2000, the SOMO-35 ozone levels show an increase in most parts of Europe.

Following an MFR-emission projection the northern hemispheric concentration in 2020-2030 will decrease about 5 ppb below the 1990- 2000 ozone levels. A reduction in the NMVOC, NOx, CO emissions alone following MFR and assuming methane emissions of the CLE scenario, results in a decrease of the northern hemispheric concentration of 2-4 ppb. This shows that the main effect in the ozone reduction is due to air pollution emission reductions. If the methane emissions are reduced following the MFR scenario and the other ozone precursor emissions kept constant at baseline level, the decrease in ozone concentration is 1-2 ppb.

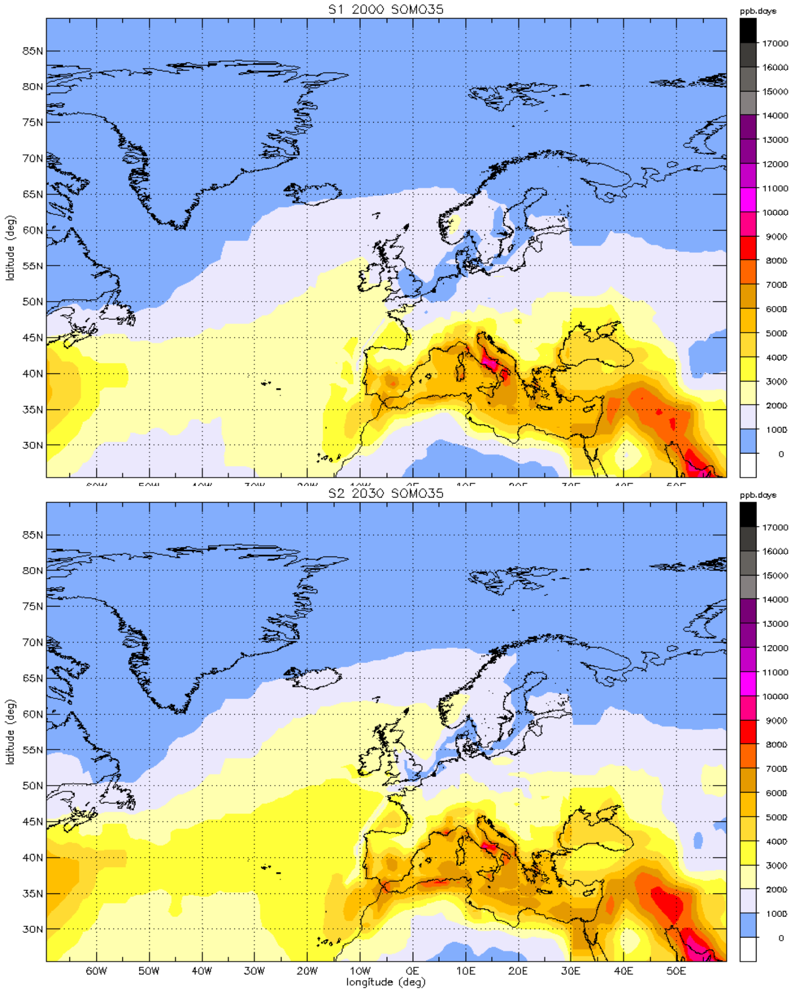


Figure 7-14: TM5 Ozone SOMO-35 concentration calculations for the European region 2000 and 2030 baseline

Source:TM5 model JRC-Ispra

The above assumption in the EMEP-calculations coincides with the baseline CLE-projection of Dentener et al., (2004). In this CLE-baseline-projection it is assumed somewhat less growth in emissions than the LREM-baseline scenario in this study. The trend in the hemispheric ozone concentration in the LREM-scenario therefore would be somewhat higher than the assumed 3 ppb.

With an MFR-scenario Dentener et al., (2004) calculated a decrease in hemispheric ozone, compared to baseline, of about 5 ppb. In this study the LGEP-scenario reached a comparable methane emission a few years earlier then in the MFR –scenario, while for the other air pollutant emissions a comparable reduction is reached a few years later, with the exception of NO_x where LGEP reaches a similar reduction only by 2075. It is not clear how these differences between in scenarios will lead to another trend in hemispheric ozone levels.

In the LGEP-MFR scenario of this study, however, additional reductions on emissions of NMVOC, NOx en CO are assumed. Under the assumption that other parts of the world would also implement additional air pollution measures a comparable picture in expected emissions emerges, it is therefore suggested that the LGEP-MFR scenario compares closest to the MFR-scenario of Dentener et al., (2004).

In conclusion it can be stated that the assumption of an increase of 3 ppb by 2030 is in approximation valid for the LREM-scenario but an overestimation of the hemispheric ozone concentration for the scenarios with additional climate policy measures (LGEP-scenarios). This results subsequently in an overestimation of the ozone indicators calculated for 2030 in these scenarios. How much the indicators are overestimated has not been analysed, although it can be expected that the ozone SOMO-35 target of zero by 2030 will still not be met in any of the scenario's.

8. Urban air pollution impact on human health

8.1. Introduction

In urban and suburban areas all over Europe, population is exposed to conditions that exceed air quality standards set by the EU and the World Health Organisation (WHO). Studies of long-term exposure to air pollution, especially to particulate matter, suggest an increased mortality, increased risk of chronic respiratory illness and of developing various types of cancer. For exposure estimates it is necessary to include air pollution at the urban scale. In this chapter an assessment of urban air pollution under LGEP-CLE condition is presented and the consequences of a maximum feasible reduction scenario by 2030 is explored and compared with the LGEP scenario with Current Legislation (CLE) on air pollution only. The urban areas, inhabiting 53 million people (12% of the EU-25 population) covered are: Antwerp, Athens, Barcelona, Brussels, Budapest, Gdansk, Graz, Lisbon, Helsinki, Rome, Stuttgart, Thessaloniki, Copenhagen, Marseilles, Berlin, Katowice, London, Milan, Paris and Prague.

8.2. Driving forces and emission projections

In the framework of the present study urban emissions were calculated according to two emission control scenarios, namely **LGEP-CLE** and **LGEP-MFR** (as defined in previous chapters) (Cofala et al., 2005).

- The **CLE** (or Current Legislation) scenario includes all known policies that have been implemented until the end of 2003 (or are in pipeline).
- The **MFR** (or Maximum Feasible Reductions) scenario only those measures that do not require premature retirement of existing equipment before the end of its technical life time were included.

Emission estimates were produced for a base year (2000) and projections (2030) according to the aforementioned emission control scenarios, on urban and local (street) level.

Due to the diverse nature of the available data (MERLIN, TREMOVE, etc.) it was not feasible to estimate emissions on urban and local scale using a common data source. For that reason, two different approaches were followed in order to estimate air pollutant emissions at urban and street level, respectively, which are elaborated in the following sections.

8.2.1. Urban scale

Outline of methodology

Sectoral emissions (in kt) were obtained for the two scenarios (LGEP-CLE and LGEP-MFR) and for the years 2000, 2010, 2020 and 2030 (personal communication J. Cofala, IIASA). The emissions per country obtained from IIASA summed over all sectors are shown in Annex 1 of this report. Emission reductions were then calculated for each country (AT, BE, CZ, DK, FI, FR, DE, GR, HU, IT, PL, PT, ES, UK), year (2010, 2020 and 2030), SNAP category (SNAP 1 to 10 as described in chapter 6) and pollutant (NO_x, VOC, SO_2, NH_3, PM_{10} and $PM_{2.5}$).

In order to obtain emission reductions at urban level, it was considered that for each country emission reductions at city level are equal to the emission reductions at country level. In addition, urban emission inventories for the reference year 2000 were provided by Stuttgart University, Institute of Energy Economics and the Rational Use of Energy (IER), through the MERLIN project for all cities considered. To derive future urban emissions for the 20 urban areas, the aforementioned reduction factors were applied to the gridded city emissions (5*5 km^2, MERLIN emissions) and thus the projected (2030) emissions for each city were produced for each of the two emission control scenarios (LGEP-CLE and LGEP-MFR) considered. The resulting emissions were then divided by the estimated city area (see Annex 9) in order to obtain emissions per km^2 for each city considered in this study.

It should be mentioned that in order to predict the future urban growth it was assumed that city growth rates correspond to national population growth rates. However, since the emission results of IIASA became available only recently, it is not known whether the results provided by IIASA follow this assumption as well.

Figure 8-1 shows an example of the overall (aggregated for all sectors) NOx emissions per city area [kg/km^2] for the reference year (2000), as well as for the two emission control scenarios (CLE and MFR) considered for the year 2030. Similar results for all pollutants considered are presented in Annex 4 of this report. From these results it is apparent that calculated emissions according to the emission control scenarios and especially those for the LGEP-MFR scenario are considerably reduced compared to the Reference year (2000) emissions.

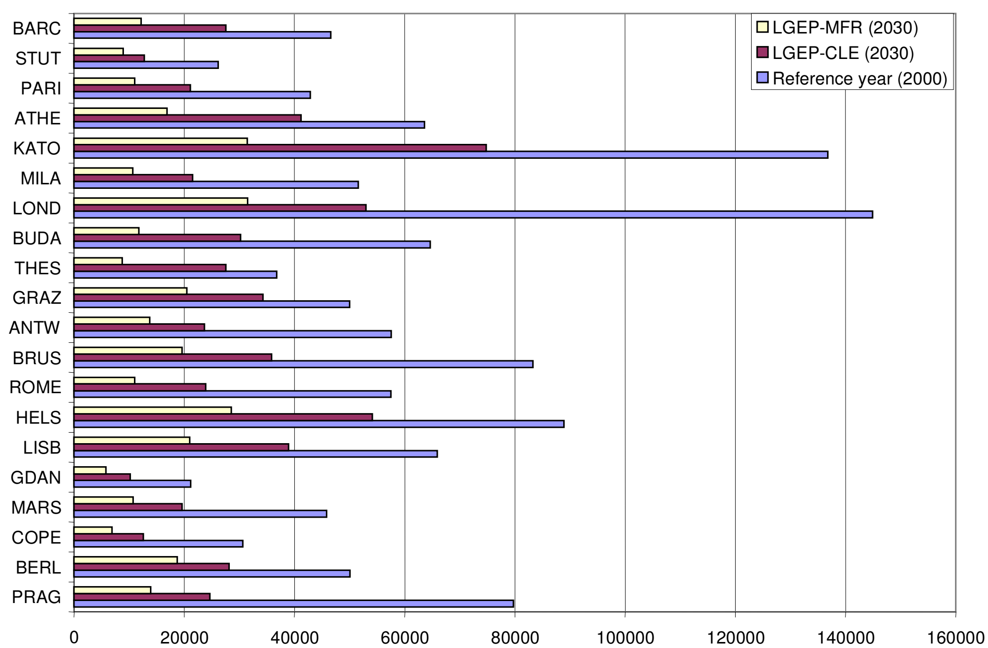


Figure 8-1: NOx emissions per city area [kg/km^2], according to the Reference year (2000), the LGEP-CLE scenario (2030) and the LGEP-MFR scenario (2030).

Figure 8-2 to Figure 8-4 present NOx emissions per city area [kg/km^2] and SNAP category for the reference year (2000) and for each of the two emission control scenarios (CLE and MFR) considered for the year 2030. From these figures it can be

observed that the contribution of each sector towards the overall emissions produced varies appreciably depending on the city and the pollutant considered. For example, in the case of NOx emissions, the predominant sources of these emissions are “Combustion in energy and transformation industries”, “Non-industrial combustion plants”, “Combustion in manufacturing industry” and “Road transport” (i.e. SNAP 1, 2, 3 and 7 respectively). Similar data for all pollutants considered in this study can be found in Annex 4 in the form of tables.

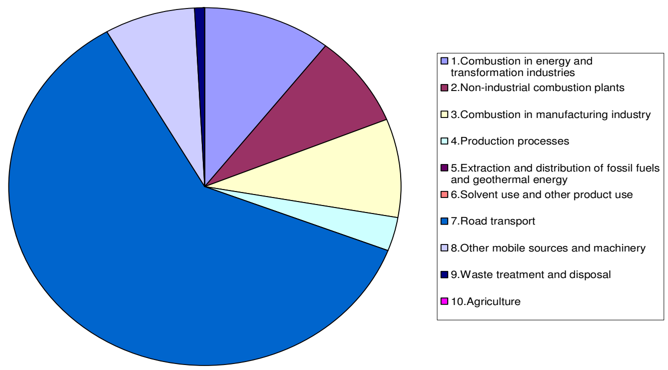


Figure 8-2: NOx emissions per total urban area [kg/km^2], and SNAP category for the reference year (2000).

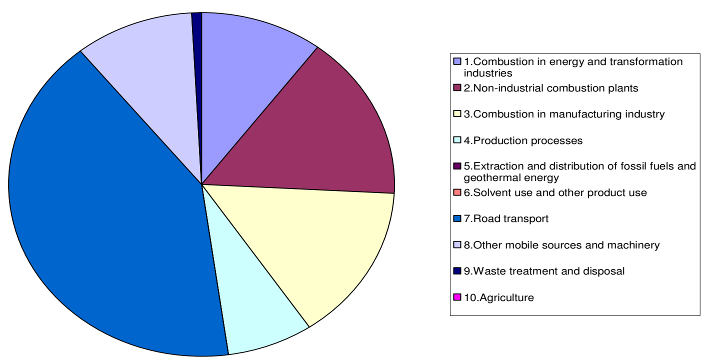


Figure 8-3: NOx emissions per total urban area [kg/km^2], and SNAP category for the year 2030 according to the LGEP-CLE scenario.

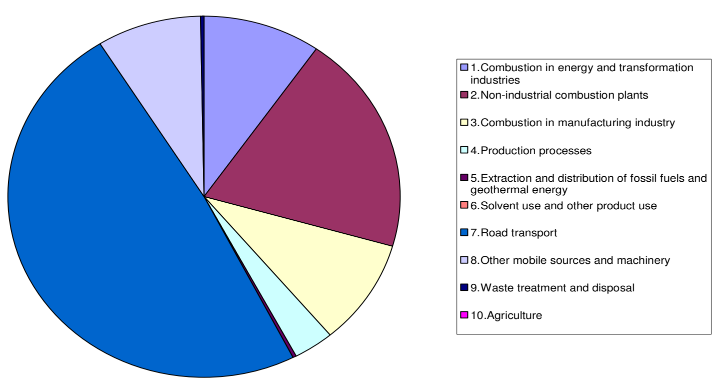


Figure 8-4: NOx emissions per total urban area [kg/km^2], and SNAP category for the year 2030 according to the LGEP-MFR scenario.

8.2.2. Local scale

Outline of methodology

Vehicle fleets originating from the TRENDS model (LAT, 2002) for each EU15 country were used in order to calculate emissions for the reference year (2000) with the COPERT model (Ntziachristos et al, 2000) for a narrow street canyon assumed to have an average daily traffic of 20,000 vehicles per day. For the three non-EU15 countries (i.e. HU, PL and CZ) vehicle fleets extracted from the TREMOVE model (De Ceuster et al, 2005) were used. Moreover, in the case of two-wheelers, updated NO_x and PM emission factors were used, which were produced by LAT (LAT, 2004). Both the updated emission factors for 2-wheelers and the COPERT methodology only account for exhaust $PM_{2.5}$ emissions. To account for PM_{10} emissions the European Phenomenology report was used (JRC, 2003) for calculating an approximate value of the $PM_{2.5}$/ PM_{10} mass concentration ratio in order to convert the aforementioned $PM_{2.5}$ emissions to PM_{10}. This factor was differentiated from city to city wherever possible and for cities which were not included in the aforementioned report, the assumption was made that the factor of the city located closest was valid. Generic values were used for the remaining parameters (vehicle speed, percentage of heavy duty vehicles in the fleet (henceforth: HDV %), street canyon geometry etc.). These values were assumed to coincide with those defined in the typology methodology for urban canyons (van den Hout and Teeuwisse, 2004). Generalised attenuation factors were then calculated according to the two scenarios (LGEP-CLE and LGEP-MFR) for NO_x and PM emissions.

These attenuation factors were obtained by the following method:
Vehicle activity data (1995-2020) from the TREMOVE model version 2.23[17] were inserted in the TRENDS model. Then, emission results were calculated using the COPERT III model at country level. A short description of the TRENDS and TREMOVE methodologies can be found in Annex 6.

In order to produce emission estimates for the two scenarios considered, suitable emission reductions based on the introduction of EURO V and EURO VI vehicles (for LDVs and HDVs respectively) were applied to the emissions calculated by COPERT. The emission estimates produced according to each scenario were then extrapolated up to the year 2030 and attenuation factors were calculated for each scenario. A more detailed description of the methodology used for the evaluation of emissions is given in the following section.

New street emissions up to the year 2030 for the street canyons located in the 20 urban areas considered were calculated by applying the above attenuation factors to the reference year (2000) emissions. The temporal distribution of the emissions assumed to be valid for the year 2000 was also applied to the year 2030. The new street emissions for the LGEP-CLE and LGEP-MFR projections for the hypothetical street with average daily traffic of 20, 000 vehicles resulting from the application of the aforementioned attenuation factors for the year 2030 will be used to project local

[17] The TREMOVE model was considered in this study in order to ensure compatibility with the scenarios of CAFE. However, at the time when the COPERT runs described in the text were conducted, the TREMOVE model was not finalised and the results of the final version may vary from those presented here, which were extracted from the latest available version (v 2.23).

air quality in the report “Air pollution levels at hotspot areas of selected European cities” (EEA, 2005).

Emission control scenarios

The scenarios currently under discussion at EU level are considered here for Euro V and Euro VI emission standards for light and heavy duty vehicles respectively. Several different scenarios were run using data estimated by TRENDS with input traffic activity data originating from TREMOVE. The scenarios focus on NOx and PM emissions and are suggested on the basis of the discussions on Euro V and Euro VI held at EU level (European Commission, 2004). Table 8.1 and Table 8.2 show the emission standards adopted according to each scenario, for NOx and PM emissions respectively. With regard to PM the cases suggested with DPF as the technical measure, the actual reduction used was 90%. This can be justified by the fact that if a DPF is used to satisfy a legal limit its reduction effect in real life might go far beyond the legal limit.

Table 8.1: Reduction percentage of NOx emissions with respect to Euro IV (for PC and LDV) and to Euro V (for HDV) for Euro V (for PC and LDV) and Euro VI (for HDV) compliant vehicles, according to the various scenarios.

	PC - LDV Gasoline	PC - LDV Diesel	HDV
Package 1	-	-20%	-50%
Package 2	-	-20%	-85%
Package 3	-	-40%	-85%
Package 4	-40%	-20%	-85%
Package 5	-40%	-40%	-85%

Table 8.2: Reduction percentage of PM emissions with respect to Euro IV (for PC and LDV) and to Euro V (for HDV) for Euro V (for PC and LDV) and Euro VI (for HDV) compliant vehicles, according to the various scenarios.

	PC - LDV Gasoline	PC - LDV Diesel	HDV
Package 1		-50%	-0%
Package 2	-	DPF	-0%
Package 3	DPF (GDI)	DPF	DPF

For the purpose of this study, only the results of the base case scenario as well as of the more “strict” of the aforementioned packages (package 5 for NOx emissions and package 3 for PM emissions) were used. It was considered that the base case scenario of TREMOVE v2.23 approximates a “business as usual” scenario corresponding to the LGEP-CLE scenario as defined in previous chapters (chapters 1 and 5). In addition, package 5 and package 3 for NOx and PM emissions respectively, represent the maximum reductions that can be achieved through emission control measures and are consistent with the specifications set for NOx and PM emissions in the LGEP-MFR scenario. Finally, emission results according to the two scenarios for the time period 2011-2020 were extrapolated up to the year 2030.

Results

Table 8.3 and Table 8.4 present an example of the development of NOx and PM emissions factors respectively, which were calculated for the main vehicle categories considered by TRENDS in Germany. These factors were derived for urban road traffic according to the LGEP-CLE (base case) and the LGEP-MFR scenarios, for the time period 2010 – 2030 in five-year intervals, considering the year 2000 as the reference year. It should be noted that the results for the two scenarios for the year

2010 are identical, since the restrictions set for the LGEP-MFR scenario are enforced after the year 2011 as mentioned above.

From Table 8.3 it can be observed that NOx reductions for each vehicle category are in agreement with the requirements set in Table 8.1. The most significant reductions with respect to the reference year are found in the case of diesel passenger cars and light-duty vehicles. This is due to the high reduction factors (Table 8.1) defined for these vehicle categories as well as to the high replacement rates of passenger cars and light-duty vehicles. For diesel passenger cars, a decrease of the order of 70% with respect to the LGEP-CLE scenario is expected according to the LGEP-MFR scenario.

From Table 8.4 it can be observed that, as in the case of PM emissions, the most marked reductions can be observed for diesel passenger cars and light-duty vehicles. More specifically in the case of diesel passenger cars, a decrease of the order of 60% with respect to the LGEP-CLE scenario is predicted if the limitations set by the LGEP-MFR scenario are enforced.

Overall, the results presented in Table 8.3 and Table 8.4, indicate that considerable reductions can be achieved in future air emissions by introducing "cleaner" vehicles in the vehicle fleet. Introducing new vehicle technologies in the vehicle fleet is expected to produce a more notable effect in the case of passenger cars and especially diesel passenger cars, which have the highest renewal rates.

Table 8.3: Development of NOx emission factor (%) for the two scenarios in Germany (reference year: 2000)

NOx emission factor (%)	2010		2015		2020		2025		2030	
	CLE	MFR	CLE	MFR	CLE	MFR	CLE	MFR	CLE	MFR
PC Gasoline	36	36	22	20	17	13	16	12	17	12
PC Diesel	108	108	105	78	102	54	98	38	100	30
LDV	81	81	74	58	74	45	79	42	83	42
HDV	67	67	46	42	34	25	32	15	36	11
Buses	70	70	44	42	26	21	22	12	21	10

Table 8.4: Development of PM emission factor (%) for the two scenarios in Germany (reference year: 2000)

PM emission factor (%)	2010		2015		2020		2025		2030	
	CLE	MFR	CLE	MFR	CLE	MFR	CLE	MFR	CLE	MFR
PC Diesel	69	69	69	44	70	26	69	15	70	11
LDV	58	58	47	34	42	20	45	15	47	15
HDV	54	54	30	29	17	13	12	6	13	5
Buses	64	64	35	34	16	13	10	6	9	5

8.3. Urban air quality projection results

In this section, current and future air quality at urban and street scale is assessed in terms of the mean annual concentration of PM_{10}, $PM_{2.5}$, NO_2 and O_3 for 20 European cities (see Section 8.2.1 for a list of the cities considered). The model simulations were performed using the urban scale model OFIS (Arvanitis and Moussiopoulos, 2003) and the street scale model OSPM (Hertel and Berkowicz, 1989), both described in Annexes 7 and 8. For all model runs (reference year, LGEP-CLE and LGEP-MFR scenarios), the OFIS model was driven by results of the regional scale model EMEP which is assumed to describe adequately the regional air quality around the city.

Urban background conditions required by the street scale model OSPM were derived from OFIS results. The street level concentrations were estimated on the basis of appropriate assumptions concerning the street level emissions. This approach allows a complete analysis of both the reference year situation and scenario projections, as the impact of air pollution control strategies and measures are accounted for at all relevant scales (regional, urban and street scale).

Table 8.5, figure 8.4 and 8.5 presents the mean annual urban scale model results for NO_2 and PM_{10} as well as the SOMO35 index for the reference year (2000), the scenario LGEP-CLE and the LGEP-MFR scenario (projections in the year 2030) assuming 1997 meteorology.

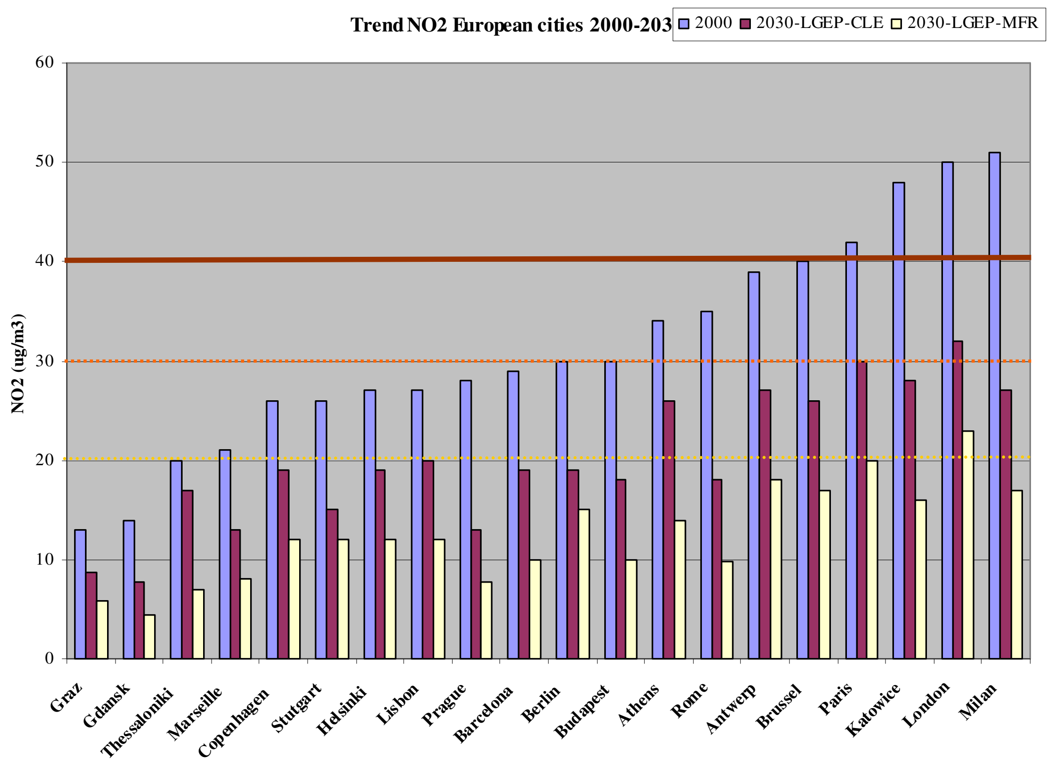


Figure 8.4 Trend annual average NO_2 concentration in European cities 2000-2030

The modelled concentrations follow closely the trend assumed in the emission projections for each case (see also Annex 4 for details), with reductions predicted in 2030 for both the LGEP-CLE and the MFR scenario. The reductions in the mean annual concentrations are largest according to the LGEP-MFR scenario, but significant air quality improvements in all cities are also observed for the LGEP-CLE projection.

Regarding NO_2, it is expected that even in the LGEP-CLE scenario the limit value currently valid for 2010 ($40 \mu g/m^3$) will be met in 2030, since all cities except London show mean annual concentrations of less than $30 \mu g/m^3$. With further decreases found in the LGEP-MFR scenario, where the concentrations reach mean annual values of less than 20µg/m3 in all cities except London, with an annual mean of 23µg/m3.

Similarly to NO_2, a reduction is observed in the PM_{10} concentrations for both the LGEP and the LGEP-MFR scenarios. According to the concentrations presented in Table 8.6 there is an average reduction of 6 µg/m3 in LGEP, with maximum reduction in Katowice and Budapest, and a minimum in reduction of 2 µg/m3 observed in a number of cities. In the LGEP-MFR scenario, in line with the additional emission reductions, the average reduction increases in 2030 to 10µg/m3, with the maximum reduction observed for Katowice (23 µg/m3). A similar reduction is observed in the $PM_{2.5}$ concentrations. An average reduction of 5 µg/m3 is calculated for the LGEP scenario, with the maximum (10µg/m3) observed in Budapest, Katowice and Milan and a minimum reduction of 2 µg/m3 observed across most cities. A larger reduction is observed in the LGEP-MFR scenario, where the average reduction increases to 8µg/m3 and the maximum reduction is observed in Katowice, Budapest, Milano and Paris (14 µg/m3).

The trend towards a general underprediction (see Annex 8) of the reference year mean annual PM_{10} concentrations due to missing PM_{10} sources affects also the projections for 2030, i.e. the results for both the LGEP-CLE and LGEP-MFR scenarios, which are most probably both underestimated. Therefore, definite conclusions as to how many cities will meet the indicative 2010 limit value (20µg/m^3) in the year 2030 cannot be made. However, it appears likely that the cities with the highest concentration estimates for 2030 in the LGEP-CLE projection, like Antwerp and Paris, may not avoid exceedances by 2030. All cities are found to be in compliance with the indicative 2010 limit value in 2030 according to the MFR scenario – an obvious consequence of significant reductions of primary PM and PM precursor emissions. Similarly to PM_{10}, the general underprediction in the $PM_{2.5}$ concentrations (see Annex 8), also affects the projected values. Therefore, no definte conclusions can be drawn concerning the exceedance of the suggested concentration cap of 25 µg/m^3 [18] set to apply from 2015 onwards.

[18] Proposal for a Directive on ambient air quality and cleaner air in Europe (COM(2005) 447, advanced preliminary version).

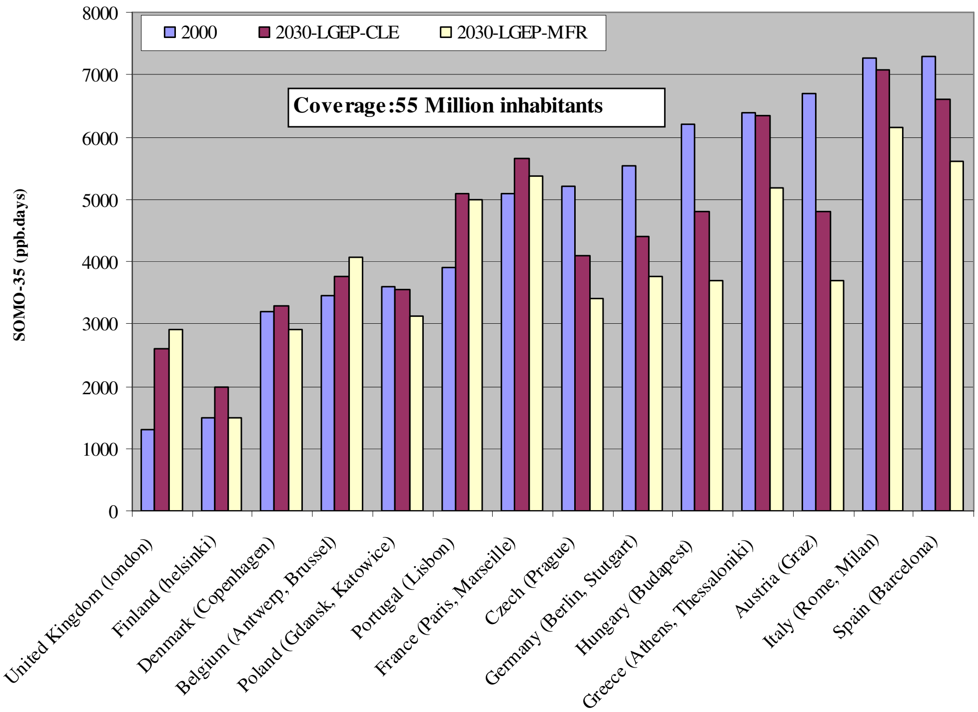


Figure 8.5: Trend SOMO-35 Ozone concentration in European cities 2000-2030

For ozone, a mixed picture appears in the LGEP case with 10 cities (with an average SOMO35 of 3800 ppb.days in 2000) show an increase of 13% (490 ppb.days), in SOMO35 concentration and 10 cities (with an average SOMO35 of 6300 ppb.days in 2000) show a decrease of 15% (970 ppb.days). Ozone concentrations will decrease if large scale reduction in VOCs, Methane, CO and NO_x are realized. At the local scale, however, high NO_x concentrations will reduce ozone concentrations, if these local NO_x concentration go down, the relatively low ozone concentrations (compare the average of 3800 ppb.days for increasing cities with an average of 6300 ppb.days for cities with decreasing ozone values) will go up. In the LGEP-MFR case the number of cities with decreasing ozone concentrations increases to 14 (with an average ozone SOMO35 of 5900 ppb.days in 2000) and the average reduction increases to 27% (1600 ppb.days). The 6 cities with increasing or constant ozone SOMO35 levels (with an average value of 3100 ppb.days in 2000) go up with 25% (750 ppb.days). For certain cities like Copenhagen and Katowice the SOMO35 index remains virtually the same between the reference year and the LGEP-CLE scenario.

Table 8.5: Mean annual NO_2 , PM_{10} and $PM_{2.5}$ concentrations ($\mu g/m^3$) and SOMO35 index over all the cities computed using OFIS for the reference year (2000), the LGEP-CLE and the LGEP-MFR scenario for the year 2030.

	Reference year (2000)				LGEP-CLE 2030				LGEP-MFR 2030			
	NO_2	**PM_{10}**	**$PM_{2.5}$**	**SOMO-35**	**NO_2**	**PM_{10}**	**$PM_{2.5}$**	**SOMO-35**	**NO_2**	**PM_{10}**	**$PM_{2.5}$**	
ANTW	38.5	25.9	18.3	3444	27.3	16.4	12.3	3611	17.7	10.4	7.9	
ATHE	33.8	12.3	10.5	6287	26.4	9.0	7.4	6384	13.8	5.1	3.9	
BARC	29.2	15.5	13.5	7271	19.1	9.5	8.1	6562	10.3	5.4	4.2	

BERL	30.3	10.0	8.9	4328	19.4	6.7	5.8	3525	14.5	4.3	3.6
BRUS	40.1	21.3	17.4	3514	25.9	13.1	10.9	3867	17.2	8.2	6.5
BUDA	29.7	21.3	15.8	6197	18.1	7.8	6.5	4766	10.1	4.2	3.3
COPE	25.9	9.0	7.7	3229	18.8	6.7	5.8	3236	11.5	3.7	2.9
GDAN	13.9	10.1	7.5	4037	7.7	5.3	4.4	3443	4.5	2.5	2.1
GRAZ	13.2	8.2	7.0	6692	8.7	5.8	4.7	4767	5.8	3.7	2.9
HELS	26.7	8.8	7.5	1496	18.9	5.9	5.1	1956	11.6	3.0	2.4
KATO	47.7	29.7	19.2	3508	28.4	13.1	9.3	3550	16.4	6.9	5.0
LISB	27.3	10.5	9.3	3858	19.6	9.0	7.7	5102	11.6	4.5	3.6
LOND	49.6	12.3	10.3	1348	31.6	9.3	7.7	2613	22.5	5.9	4.5
MARS	20.7	11.4	9.1	7758	12.9	7.9	6.4	7352	8.1	4.2	3.1
MILA	51.3	19.3	17.6	7945	27.3	9.8	8.5	7363	16.8	6.1	5.1
PARI	42.1	24.0	20.7	4689	29.7	15.5	13.2	5392	19.8	8.1	6.6
PRAG	28.6	13.0	10.7	5196	12.7	5.4	4.6	4131	7.7	3.4	2.8
ROME	34.7	11.5	10.5	6338	17.8	7.2	6.4	6562	9.8	3.7	3.1
STUT	26.4	9.5	8.5	7061	15.1	6.4	5.2	5505	11.8	4.3	3.4
THES	19.8	10.0	8.5	6834	16.8	7.7	6.4	6064	6.9	4.0	3.1

Concerning the influence of meteorology on the actual concentrations, an attempt was made to evaluate, with the OFIS model, how urban concentrations are affected by increasing mean annual temperatures and 'extreme' weather conditions observed in recent years. The model was run for the LGEP-CLE using two different sets of meteorological data and corresponding regional air quality model results (EMEP) for the year 2030. Thus the results are independent of the increase/decrease in the emissions and the concentrations should be purely influenced by the meteorological conditions. The year 1997 was assumed to represent average meteorology observed in the '90s, whereas the year 2003 was assumed to represent more 'extreme' conditions observed in recent years. The results are shown in Table 8.6.

Table 8.6: Mean annual NO_2 and PM_{10} concentrations ($\mu g/m^3$) and SOMO35 index for all cities according to the LGEP-CLE scenario in 2030 using 1997 and 2003 meteorology.

	NO_2		**PM_{10}**		**O_3 (SOMO)**	
City	**1997**	**2003**	**1997**	**2003**	**1997**	**2003**
ANTW	27.3	27.0	16.4	17.1	3611	4246
ATHE	26.4	25.0	9.0	8.9	6384	6509
BARC	19.1	18.3	9.5	8.5	6562	6602
BERL	19.4	20.1	6.7	7.0	3525	3674
BRUS	25.9	25.4	13.1	13.3	3867	4453
BUDA	18.1	18.0	7.8	8.0	4766	5447
COPE	18.8	18.5	6.7	7.1	3236	3227
GDAN	7.7	7.4	5.3	5.9	3443	3697
GRAZ	8.7	7.7	5.8	5.6	4767	5409
HELS	18.9	19.3	5.9	6.8	1956	1868
KATO	28.4	29.7	13.1	13.5	3550	3929
LISB	19.6	18.3	9.0	7.8	5102	5361
LOND	31.6	31.6	9.3	9.7	2613	2682
MARS	12.9	11.7	7.9	7.2	7352	7629
MILA	27.3	27.3	9.8	10.1	7363	7865
PARI	29.7	29.8	15.5	14.7	5392	5869
PRAG	12.7	12.4	5.4	5.6	4131	4492
ROME	17.8	16.5	7.2	6.5	6562	7418
STUT	15.1	14.2	6.4	6.2	5505	5923
THES	16.8	18.6	7.7	8.1	6064	6547

The meteorological conditions during the year 2003 generally led to higher mean annual temperatures across Europe, which as a consequence leads to higher mean annual O_3 concentrations in all cities compared to the 1997 meteorology, except Helsinki and Copenhagen where the O_3 concentrations remain almost unchanged. The enhanced O_3 production from the dissociation of NO_2 in the presence of sunlight leads to reduced mean annual NO_2 concentrations in 17 cities, compared to the 1997 meteorology. Finally, the 2003 meteorology led to higher PM_{10} mean annual concentrations in 12 cities, compared to the 1997 meteorology. It should be noted that for all pollutants the urban concentration changes for each year follows closely the corresponding changes in the regional air quality model results. Nevertheless, there are cases where different meteorologies lead to different urban concentration levels between the cities, indicating that the climatological influence up to a certain extent depends on the particular characteristics of each city.

Table 8.7 summarises in a compact manner the results of the scenario analysis. The table shows model results for the reference year, two alternative scenarios accounting for average (1997) and extreme (2003) meteorological conditions and the MFR scenario (1997 meteorology). Table 8-9 shows the same end-point as a population weighted average.

Table 8.7: Minimum, maximum, average mean annual urban background concentrations for NO_2, PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) and SOMO35 index over all cities for the reference year (2000), LGEP--CLE and MFR scenario (LGEP-MFR).

	NO_2				**PM_{10}**			**$PM_{2.5}$**			**O_3 (SOMO35)**		
Scenario	**MIN**	**AVE**	**MAX**	**EXC ***	**MIN**	**AVE**	**MAX**	**MIN**	**AVE**	**MAX**	**MIN**	**AVE**	**MA**
Reference year (2000)	13.2	31.5	49.6	5	8.2	14.7	29.7	7.0	11.9	20.7	1348	5052	794
LGEP-B-CLE_2030 (1997 met)	7.7	20.1	31.6	0	5.3	8.9	16.4	4.4	7.3	13.2	1956	4788	736
LGEP-B-CLE_2030 (2003 met)	7.4	19.8	31.6	0	5.6	8.9	17.1	-	-	-	1868	5128	786
LGEP-B-MFR_2030	4.5	12.4	22.5	0	2.5	5.1	10.4	2.1	4.0	7.9	1487	4170	656

*Number of cities in excess of $40\mu g/m^3$.

Table 8.8: Minimum, maximum, average mean annual urban background concentrations for NO_2, PM_{10} and O_3 over all cities for the reference year (2000), LGEP-CLE (2030) and LGEP-MFR (2030).

	Population weighted average									
	NO_2				**PM_{10}**			**O_3 (SOMO35)**		
Scenario	**MIN**	**AVE**	**MAX**	**EXC****	**MIN**	**AVE**	**MAX**	**MIN**	**AVE**	**MAX**
Reference year (2000)	13	37	51	5	8.2	16	30	1300	4890	8000
LGEP-CLE	7.7	24	32	0	5.3	10	16	2000	4950	7400
LGEP-MFR	4.5	15	23	0	2.5	6	10	1500	4480	6600

**Number of cities in excess of $40\mu g/m^3$.

8.4. Air Quality at the Local (street) scale

As presented earlier in chapter 4, the NO_2 , PM_{10} and $PM_{2.5}$ concentrations measured at urban traffic stations across Europe are higher than those at urban background stations, due to the increased local emissions from road traffic (see also EEA Fact Sheet TERM 04, 2004). The concentrations measured at traffic stations largely depend on the specific street configuration, orientation with respect to the prevailing wind direction and location (also the location of the traffic station in the street itself), hence it is difficult to define a representative range of values. For the same reasons, the concentrations modelled will largely depend on the specific street configurations considered and also the heavy duty vehicles percentage (HDV%) as well as the average vehicle speed assumed, since these are the most important parameters governing the street emissions. For quantifying the hotspot contributions, it is convenient to introduce street increments, i.e. the difference between the street and the urban background concentrations.

Figure 8.6, 8.7 and 8.8 show the street increments for NO_2 , PM_{10} and $PM_{2.5}$ calculated with the OSPM model for a narrow canyon configuration with a traffic volume of 20,000 vehicles per day. The street orientation was assumed to be East to West. Wind speed and direction for each city were derived from the EMEP data. By applying the logarithmic law the wind speeds were scaled down to represent realistic values at building height. The resulting wind roses and yearly average wind speeds for each city can be found in Annex 6. The streets were assumed to be centrally located, i.e. the urban background concentrations were assumed to be properly described by the maximum concentrations computed by the OFIS model. Details concerning the calculations of the street emission can be found in Section 8.2.2 where the methodology is analysed, and Annex 4 where the emissions assumed in the narrow canyon for each city are presented, according to the specific fleet composition and contribution of each vehicle category in each city.

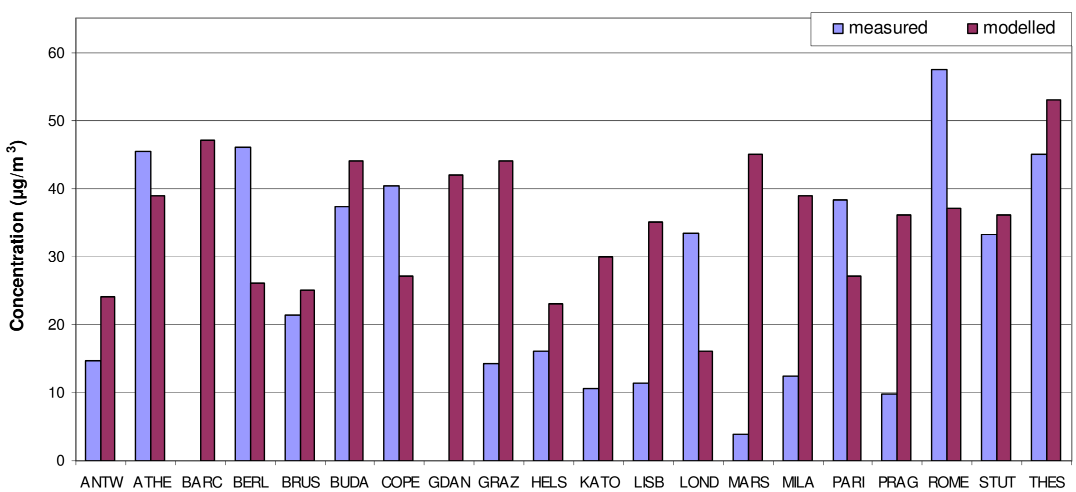


Figure 8.6: Mean annual NO_2 street increments ($\mu g/m^3$) in 20 European cities: OSPM model results compared with observations.

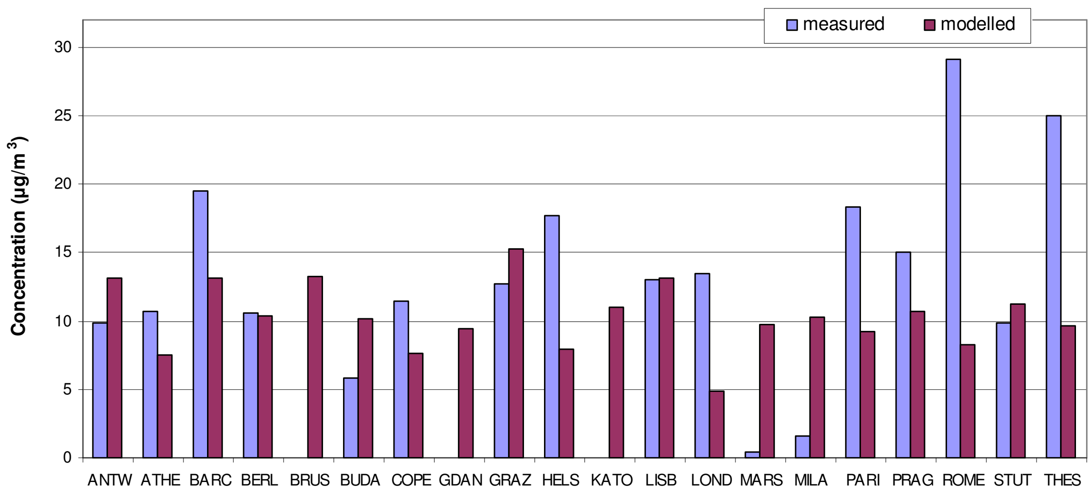


Figure 8.7: Mean annual PM_{10} street increments ($\mu g/m^3$) in 20 European cities: OSPM model results compared with observations.

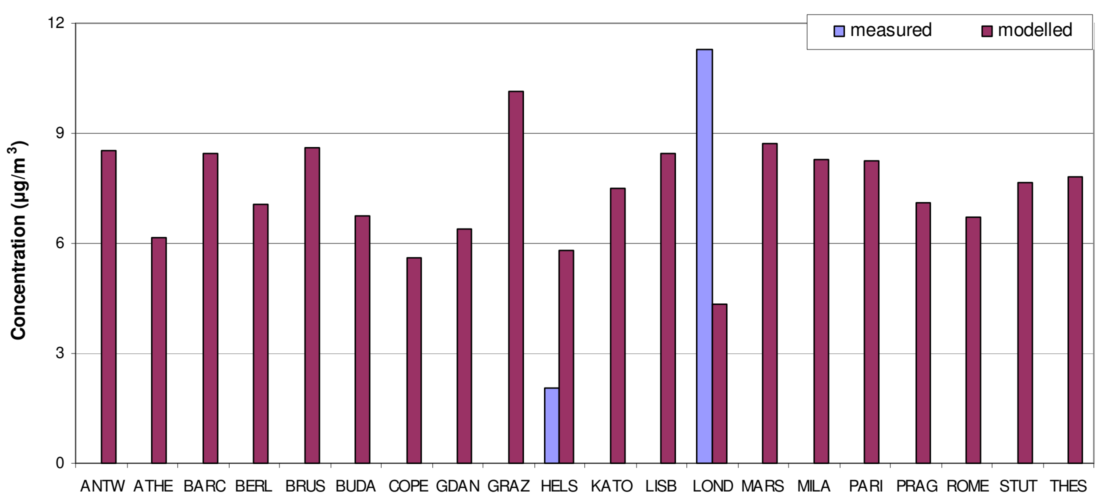


Figure 8.8: Mean annual $PM_{2.5}$ street increments ($\mu g/m^3$) in 20 European cities: OSPM model results compared with observations.

The measured street increments shown in Figures 8.6, 8.7 and 8.8 were calculated using the maximum measured street and background concentrations in each city. Inevitably, this introduces an uncertainty, as the increment depends critically on the locations of the respective urban background and traffic stations, which are often not close to each other. This can lead to either an overestimation or an underestimation depending on whether the street station is located in the city centre and the urban background station far from the centre or vice-versa. Moreover, agreement or disagreement between measured and modelled street increments will be strongly affected by the question of how similar the actual street geometry, orientation, etc. is compared to the hypothetical streets studied. Answering this question, however, would have required a detailed analysis of the characteristics of the street canyons where the traffic stations are operating, a task beyond the scope of the present study.

The aim results presented in Figures 8.6, 8.7 and 8.8 is not to show an ideal comparison with measurements, but rather to provide an order of magnitude for the NO_2,. PM_{10} and $PM_{2.5}$ street increments across European cities.

From the figures it is clear that large variations in street increments are apparent in the case of NO_2. For PM_{10} the range of the modelled street increment values is 5-15 µg/m^3, the average value being 10 µg/m^3. The average value of the measured street increments from Airbase (as many station pairs as possible, not considering their proximity) is 11 µg/m^3, not including the exceptionally large street increments for Rome and Thessaloniki. In Chapter 4, it is mentioned that the average measured PM_{10} street increment from 16 station pairs (traffic and urban background station pairs) for 2002 and for stations located close to each other (i.e. less than 1 km apart) was 6.9 µg/m^3. Given that the modelled street increment may be slightly overestimated due to the lower than actual vehicle speed assumed, the modelling approach seems to reproduce fairly well the observed PM_{10} street increments.

For $PM_{2.5}$ the range of the modelled street increments is 4-10 µg/m^3. From the few data available, the measured increment is found to range between 2 µg/m^3 in Helsinki to 11.3 µg/m^3 in London.

Overall, the selection of the specific street configurations (fleet composition, traffic volume etc.) has led to reasonable results. However, the precise HDV% and average vehicle speed per day play the most important role in the emission calculations. Both quantities can vary significantly from street to street affecting strongly the NO_x and PM emissions and thus also the range in the modelled concentrations.

9. Cost of combating air pollution and the possible co-benefits from climate change policies

9.1. Introduction

The assessment of costs of environmental policies needs to be based on comparable methodologies. Depending on the purpose of the assessment, a wide variety of methodologies and cost definitions can be used. These definitions are not always clearly specified in the reports describing the costs of policies.

The purpose in this section is to define the minimum requirements for achieving comparability of costs calculated by the integrated assessment models used by the ETC/ACC in the area of air pollution and climate change. This is of particular importance when the models are "softly" linked, i.e., when the output of one model (aimed at the analysis of CO_2 mitigation) is linked with other models that look at the reduction of emissions of non-CO_2 greenhouse gases (GHGs) or at the mitigation of emissions of air pollutants, like SO_2 or PM. Such linking has been recently applied to determine the ancillary benefits of climate policies for air pollution, compare van Vuuren et al. (2003).

In the first part of this chapter (9.2) a short overview of different cost concepts is presented.

It needs to be stressed that this chapter does not include a complete presentation of costing methodologies used in integrated assessment. It concentrates on those issues that are important for the comparison of costs calculated by energy models and air pollution control models at an international level, as available within the ETC/ACC. In different contexts, other methods of costs (and benefits) assessments may be appropriate. For these other methods we do not provide detailed description nor do we make recommendations with regard to their usefulness in policy applications.

9.2. Basic cost concepts used in environmental policy analysis – an overview[19]

Actions to abate air pollution or GHGs will divert the resources from other, alternative uses. A mitigation cost assessment should consider all changes in resources demanded and supplied by a given abatement option in relation to a specific non-policy case (the so-called reference or baseline case). This implies that both the benefits and the cost of a mitigation option (relative to the baseline situation) should be included and, as far as possible, all relevant costs should be covered. Some examples of cost-representation can be found in the textbox.

[19] This part borrows from Sijm et al. (2002).

Textbox: Representation of costs in scenarios

The assessment of costs of environmental policies needs to be based on comparable methodologies. Depending on the purpose of the assessment, a wide variety of methodologies and cost definitions can be used. Actions to abate air pollution or GHGs will divert the resources from other, alternative uses. A mitigation cost assessment should consider all changes in resources demanded and supplied by a given abatement option in relation to a specific non-policy case (the so-called reference or baseline case).

Major distinctions in costs can be made between **economic** versus **financial/production** costs on the one hand and between **private** versus **social** costs on the other hand. An assessment of mitigation costs in terms of financial costs is based on actual payments and market prices of the resources involved. For a variety of reasons, however, these actual prices and payments may not reflect the true scarcity value or opportunity cost of the resources used. The reasons may be taxes, subsidies, trade and exchange rate controls, other policy-induced market distortions, and market imperfections such as lack of competition or imperfect information. A monetary analysis of a mitigation option based on the true scarcity values is called economic cost assessment. It implies that, if market prices are distorted, corrections have to be made. These corrected prices, which should be equal to the opportunity costs of the resources involved, are called **shadow prices**.

Private versus social costs reflect the perspective from which the costs are considered. Costs that influence an individual's decision-making are called private costs. Social costs, on the other side, are usually defined as all relevant costs of an activity considered from either the national or global perspective. The major distinction between social and individual costs is the so-called "**external costs**" and the **discount rate**. Used.

External costs refer to the costs or impacts arising from any human activity that are inflicted upon one or more members of a society, but that are not accounted for in the decision-making process of the agent or entity causing these impacts. They can be positive or negative. An example of an externality is global warming. Global warming causes damage costs for some individuals (e.g., costs of using air conditioners). This is an externality in as far as those economic actors who cause global warming do not take into account this impact when making decisions on emissions and do not provide financial compensation to the ones damaged. Another example is the negative health impact associated with air emissions from fossil fuels use. Hence, these external costs should be explicitly accounted for in a social cost assessment, which can be conducted in both financial and economic terms.

Certain mitigation policies may have significant **macroeconomic** effects, i.e., impacts on GDP, income distribution, employment and trade. Through changes in prices and quantities, such policies may bring about a variety of dynamic feedback effects at the (inter-) sectoral or national level. These effects might be particularly strong if a set of mitigation options is implemented more or less simultaneously during a short time interval. In such cases, macroeconomic impacts have to be included in a mitigation cost assessment. Such an exercise, however, requires complex macroeconomic modelling and a large amount of reliable, aggregated data that may be hard to generate for countries or regions involved.

Finally costs calculation in scenario's require the choice of a **discount rate,** to allow economic effects occurring at different times to be compared. There is a wide literature about the methodologies for determining the discount rate. Within the climate policy, an overview of issues and problems involved is presented in Arrow et al. (1995).

The CO_{2eq} **permit price** describes the **highest** costs expected to be made to reduce GHG's, the **Effort rate** (as percentage of GDP) desribes the expected average costs to be made to reduce GHG's.

9.3. Requirements for costs comparability

Structural changes in energy systems induced by climate policies (switch to gas, biomass, and renewable energy forms) change the costs of controlling traditional air pollutants. When measuring co-benefits of climate policies for air pollution it is

important to identify not only the reductions in emissions of air pollutants but also to calculate the change in emission control costs for these pollutants. These costs may be further compared with the total costs of climate policies. Currently air pollution and climate policies are analysed by different models[20]. When combining the estimates of costs of climate policies with those of controlling air pollution it is important that the estimates are comparable.

As mentioned, the costs definition and the parameters used by individual models depend on the scope and purpose of the analysis. A single energy user (household, a car owner) bases his decisions on market prices, including taxes. When making investment decisions that involve borrowing of capital, he uses the interest rate that is available for him for a particular type of loan. Similarly, a power generation company prepares its expansion plans using expected market prices for inputs (capital, labour, fuels) and expected prices of electricity and heat. National or regional energy models used in the climate policy debate may look for cost-efficient solutions from the point of view of the whole economy. Then a discount rate, unified across all sectors, and undistorted prices (net of taxes and subsidies) should be used. Other models (like PRIMES) simulate the behaviour of energy producers and consumers on the energy market and thus use market prices and sector specific interest rates[21]. Air pollution control policies are usually analysed with the models that take the perspective of the whole economy. Before costs calculated by different models are added, they need to be recalculated to a comparable basis. Below, the requirements for such comparability are discussed.

It is proposed that the comparison of costs of air pollution and climate policies is limited to the private economic cost. This means that the outcome of models used for evaluation of climate polices and air pollution control should be recalculated, taking into account costs from the point of view of the whole economy.

It needs to be stressed that each model used in the analysis can (and even should) use its own cost definition to determine the optimal structure of the system covered. Only for comparison of costs with other models these costs should be re-calculated (ex-post) using consistent and unified definitions and assumptions. The most important assumptions are discussed below.

9.3.1. Price level

Cost estimates of models used in the analysis need to be recalculated to the same price level. It is proposed that models involved use constant prices of the base year. As a base year we suggest to use the year 2000.

9.3.2. Removal of price distortions

All price distortions should be removed. The distortions are introduced through various types of taxes and subsidies, as well as through market imperfections. For comparing costs of policies at international level, international prices should be used for tradable goods and local prices for non-tradable goods. Since investment goods are traded internationally, the prices of investment equipment (boilers, generators,

---

[20] Up-to-now, within the ETC/ACC, TIMER and PRIMES energy models were used. These models have been linked to the pollution control model RAINS.

[21] Because of different assumptions, the resulting structure of the energy system calculated by the two types of models may be different.

scrubbers etc.) should be determined based on world market prices. The same is true for fossil fuels, where world prices should be included. This means that for the exporting country the FOB (Free on Board) price is the appropriate one for the assessment of fuel cost. For imports, the CIF (Costs, Insurance Freight) prices should be used. In addition, prices of energy carriers should be adjusted to reflect the local (in-country) average transportation, and/or transmission and distribution costs. Since the models used for studying environmental policies at international level do not explicitly include the spatial distribution of energy demand within the country, it is usually a sufficient approximation if national average transmission and distribution costs are used. For local cost components, like labour, local raw materials, or costs of waste disposal, country-specific costs and prices should be used. Once more it needs to be stressed that for the purpose of our analysis all taxes and subsidies should be eliminated.

9.3.3. Inclusion of "learning"

If the models include change in investment costs of technologies involved due to the so-called "learning" effect, i.e., a decrease of investments because of wide-scale implementation of the technology, the actual investment cost will be calculated endogenously by the model used. For models in which learning is not explicitly included, the parameters of technologies (costs, conversion efficiencies, pollutant removal efficiencies) should be specified at a level, which is expected for the year relevant for the analysis. For instance, if the air pollution control model includes a sulphur scrubber to be installed around the year 2015, the technological characteristic of the scrubber should include its cost and efficiency as expected for 2015, and not of the scrubbers installed in the late 1980s.

9.3.4. Use of unified discount rate

The discount rate allows economic effects occurring at different times to be compared. It plays an important role in analysis of actions with varying time paths of costs and benefits. There is a wide literature about the methodologies for determining the discount rate. Within the climate policy, an overview of issues and problems involved is presented in Arrow et al. (1995).

In practice, different models use different rates. This is usually justified by a different purpose of analysis. For cost comparison, it is important that the costs are recalculated using unified social interest rate. For the purpose of defining co-benefits of climate policies for air pollution at the international level it is proposed that a four percent real interest rate is used for all economic sectors in all countries. This value has been used in the work on protocols to the CLRTAP as well as for preparation of the EU National Emission Ceilings (NEC) Directive.

9.3.5. Presentation of costs

Depending on the design and the purpose of the model, different cost calculation methods may be used. If year-by-year flows of inputs and outputs are available, models may calculate the net present value (NPV) of all costs. Other models concentrate on "snapshot" information for particular years, e.g., on values for the ends of five-year periods. These models calculate the annual costs of policies in the years under study. It is straightforward to recalculate the NPV result into the annual costs. Conversely, calculating the NPV of annual costs with the models that use information on activities for particular years only requires additional assumptions. Thus it is

proposed that the costs are compared based on annual cost concept and recalculate NPV values into annual costs.

9.4. Costs of combating air pollution

This section discusses the costs of controlling emissions of pollutants as assessed by RAINS. All costs are calculated according to the methodology adopted by the ETC/ACC (compare Cofala and Klaassen, 2003). The most important elements of that methodology are as follows:

- Only direct costs of technical measures oriented towards reducing the emissions are included. Costs of implementing structural changes in the energy system (enhanced efficiency of energy production and use, fuel switching, structural changes in the demand for goods and services) are calculated by the PRIMES energy model used for preparation of scenarios of activity levels.
- All costs are in constant prices or 2000
- Annual cost method is used with uniform (the same for all countries and sectors) interest rate of four percent.

Table 9.1 and Figure 9-1 present the costs by country group and cost category. The following categories have been included:

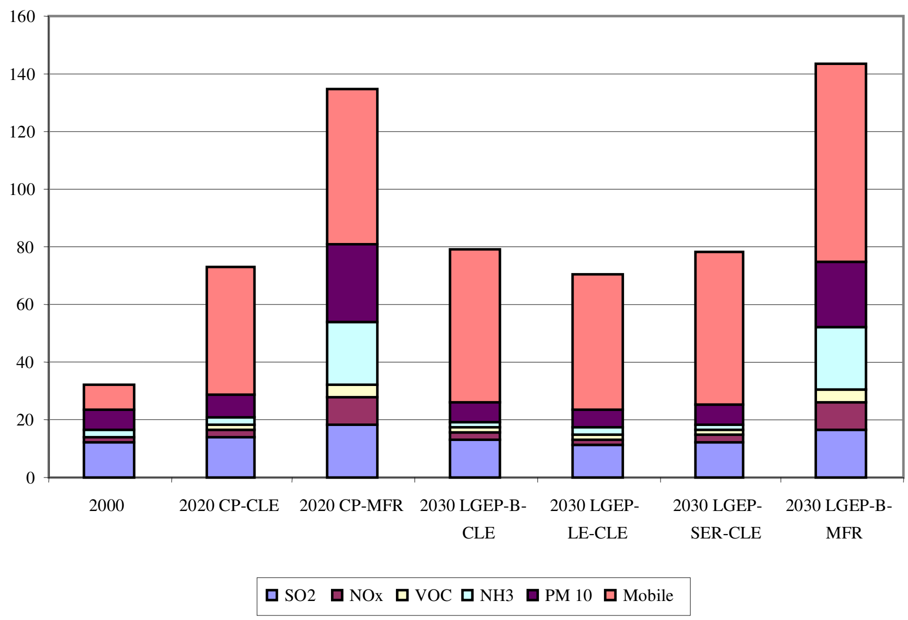
- Controls of SO_2 emissions
- Controls on stationary sources of NO_x
- Controls on stationary sources of NMVOC
- Costs of controlling emissions of ammonia
- Controls on mobile sources in the road and non-road sector.

Controls on mobile sources are treated separately, because the emission control technologies simultaneously affect the emissions of more than one pollutant and thus it is not possible to attribute costs separately to each of them.

In 2000, the “current legislation” costs in the EEA region were about 32 billion € (about 65 €/capita), of which 95 percent were costs for the EU-25. About 37 percent of total expenditures went on sulfur controls, 26 percent on mobile sources and 23 percent on PM abatement from stationary sources. Till 2030 the control costs increase by a factor 2.5 to about 79 billion € or 160 €/capita (scenario LGEP-B-CLE). The increase is mainly due to more stringent legislation on mobile sources.

The MFR costs are more than 80 percent higher than the cost of “current legislation”. In this case the highest cost increase occurs for ammonia, stationary sources of PM and transport. Lower economic growth scenario results in cost savings of about 8 billion €. Increased implementation of renewable energy forms causes a decrease of emission control costs by 1.1 billion €, or 1.4 percent.

Details on emission control costs by country are to be found in Annex 3.



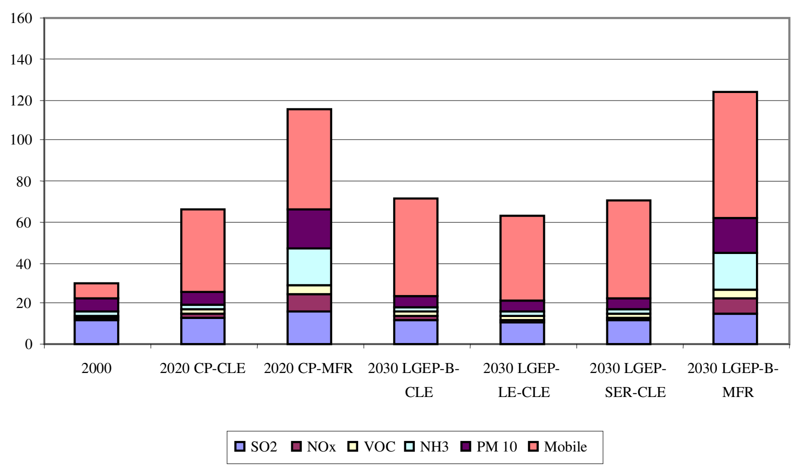


Figure 9-1: Emission control costs by pollutant and scenario for the EEA region (upper panel and EU-25 (lower panel), billion Euro/year

Table 9.1: Emission control costs by pollutant and scenario for the EEA region, billion Euro/year

EEA:

Pollutant	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
SO_2	11.8	14.2	18.1	13.3	11.4	12.6	17.0
NO_x	2.0	2.5	9.9	2.2	1.9	2.0	9.2
VOC	0.5	1.8	4.6	1.9	1.8	1.9	4.6
NH_3	2.0	2.2	21.6	2.1	2.1	2.1	21.5
PM 10	7.4	7.7	26.3	6.5	6.0	6.4	22.2
Mobile	8.1	44.6	54.2	53.1	47.5	53.1	68.8
Total	31.7	72.9	134.7	79.2	70.8	78.1	143.3

EU-25:

Pollutant	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
SO_2	11.4	12.9	15.9	12.0	10.2	11.3	15.0
NO_x	2.0	2.4	8.6	2.0	1.8	1.8	7.9
VOC	0.4	1.7	4.0	1.8	1.8	1.8	4.0
NH_3	2.0	2.2	18.0	2.1	2.1	2.1	17.6
PM 10	6.4	6.5	19.7	5.5	5.0	5.4	17.6
Mobile	7.7	40.2	48.6	47.7	42.5	47.7	61.4
Total	29.8	65.8	114.8	71.2	63.4	70.1	123.4

9.5. Co-benefits from climate change policies

Many of the traditional air pollutants and greenhouse gases have common sources, their emissions interact in the atmosphere, and separately or jointly they cause a variety of environmental impacts on the local, regional and global scales. Linkages work in two directions: there can be synergies and negative trade-offs. Emission control strategies that simultaneously address air pollutants and greenhouse gases may lead to a more efficient use of the resources on all scales: they have so-called co-benefits.

The environmental issues of which linkages are known to exist between climate change and air pollution are acidification, eutrophication, tropospheric ozone formation and urban air pollution, see for a more in depth description e.g. EEA (2003b). Table 9.2 illustrates how the linkages between air pollution and climate change can be seen as a multi-pollutant/multi-effect problem extended towards radiating forcing.

In political as well as in modeling practice, greenhouse gas emissions and air pollutants emissions reductions policies are usually not fully integrated yet [22]. Therefore, a full assessment of the co-benefits is beyond the scope of this report. However, the scenarios analysed for this report provide some insights into the

[22] During the course of the SoEOR2005 development, the RAINS model was expanded into the so-called GAINS model, allowing for simultaneous evaluation of GHG and AP policies. This model was not yet available for the assessments reported here.

ancillary benefits of climate policies on air pollution. Not all types of ancillary benefits are evaluated. Neither have the ancillary effects of air pollution abatement on greenhouse gas emissions been analyzed.

Table 9.2:Illustration of the linkages between climate change and air pollution

	SO_2	NO_x	NH_3	VOC	CO	Primary PM+BC	CH_4	CO_2+ GHGs
Ecosystems								
• Acidification	√	√	√					
• Eutrophication		√	√					
• Ground level ozone		√		√	√		√	
Health impacts								
• Direct	√	√		√	√	√		
• Indirect by sec. aerosols and ozone	√	√	√	√	√		√	
Radiative forcing								
• Direct		√					√	√
• Via aerosols	√	√	√	√		√		
• Via OH		√		√	√		√	

First, Table 9.3 compares the costs of abating air pollution in the EU25 across scenarios. By 2020, in the CAFE (moderate) Climate Policy scenario, with current legislation for air pollution, the estimated costs are more than 5 billion € lower (more than 7 %) than in the baseline scenario (LREM-E).] In the stringent climate policy LGEP scenario, by 2030 the costs are almost 10 billion € (more than 12 %) lower than in the baseline. In the renewable variant of LGEP (SRE-CLE) this increases to almost 11 billion€ (more than 13 %) by 2030. The largest cost reduction, compared to the baseline, are found in the stringent climate policy scenario with moderate low economic growth assumptions (LGEP-LE), more than 17 billion € lower (or 22%). The costs savings are primarily achieved in the mobile sources (all pollutants) and stationary sources of SO_2 and PM_{10}. Only marginal ancillary benefits are achieved for VOC and NH_3, because the sources of these substances are largely independent on the major source of greenhouse gases: fossil fuel combustion. The type of (mainly technical) measures assumed in LGEP to combat emissions of nitrous oxide and methane have little impacts on ammonia and VOC emissions. A scenario with more structural economic policies in the agricultural sector (such as those associated with the Common Agricultural Policy) might lead to additional ancillary benefits for emissions of ammonia and VOCs.

Second, in addition to the reduced abatement costs for air pollutants, the emissions of these pollutants under the climate policy scenarios are lower than in the baseline. While the baseline emissions already meet the NEC ceilings, the CP and LGEP scenarios lead to significantly lower emissions in the years after 2010. In Table 9.4 the projected air pollutant emissions are summarized for the EU25 under baseline and LGEP conditions. The table clearly demonstrated additional ancillary benefits of climate policies on air pollution policies, with SO_2 more then 16% lower compared to baseline and PM and NO_x emissions approximately 10% below baseline values. Much lower benefits are found again for NMVOC and ammonia emissions. In the renewable variant SER-CLE, these additional emissions reductions are further amplified by

policies not directly addressing greenhouse gases or air pollutants, but the fuel mix of the European energy system.

Table 9.3: Air pollutant abatement cost; baseline compared to CP and LGEP

EU 25 — costs in billion €/year

Pollutant	2000	2020	2030	2020, CP	2030, LGEP			
		LREM-E		CLE	B-CLE	LE-CLE	SER-CLE	B-MFR
SO2	11,4	15,1	16,0	12,9	12	10,2	11,3	15
NOx	2	3,0	3,1	2,4	2	1,8	1,8	7,9
VOC	0,4	1,7	1,8	1,7	1,8	1,8	1,8	4
NH3	2	2,3	2,2	2,2	2,1	2,1	2,1	17,6
PM 10	6,4	7,3	7,4	6,5	5,5	5	5,4	17,6
Mobile	7,7	41,5	50,5	40,2	47,7	42,5	47,7	61,4
Total	30	71	81	66	71	63	70	123

% cost change

Pollutant	2020, CP	2030, LGEP			
	CLE	B-CLE	LE-CLE	SER-CLE	B-MFR
SO2	-14,5	-25,0	-36,3	-29,4	-6,3
NOx	-18,7	-35,6	-42,1	-42,1	150
VOC	0,0	1,2	1,2	1,2	125
NH3	-4,4	-6,1	-6,1	-6,1	690
PM 10	-11,4	-25,4	-32,2	-26,7	140
Mobile	-3,2	-5,5	-15,8	-5,5	22
Total	-7,2	-12	-22	-13	52

cost changes in billion/year

Pollutant	2020, CP	2030, LGEP			
	CLE	B-CLE	LE-CLE	SER-CLE	B-MFR
SO2	-2,2	-4,0	-5,8	-4,7	-1,0
NOx	-0,6	-1,1	-1,3	-1,3	4,8
VOC	0,0	0,0	0,0	0,0	2,2
NH3	-0,1	-0,1	-0,1	-0,1	15,4
PM 10	-0,8	-1,9	-2,4	-2,0	10,2
Mobile	-1,3	-2,8	-8,0	-2,8	10,9
Total	-5,1	-9,8	-17,6	-10,9	42,4

The additional emissions reductions lead to reduced impacts. The impacts on statistical life expectancy due to $PM_{2.5}$, on premature mortality due to ozone (with precursors VOCs and NO_x), on forest area with acid deposition above critical loads (SO_2 and NO_x) and on the percentage of ecosystems receiving nitrogen deposition above critical loads for eutrophication (NO_x and NH_3) reported in chapter 7 and Annex 2) would all be reduced further as compared to the baseline. The costs that would be needed to reaching the same impact levels with air pollution abatement measures can be roughly estimated by multiplying the annual costs in 2030 by the percentage additional emissions reductions for the various substances, adding up to almost 4 billion €, excluding measures to abate emissions from mobile sources. If the latter would be added these benefits may be significantly higher.

Under the Maximum Feasible Reductions (MFR) scenario, more than 50 % further reductions are achieved (from 30 % for VOC to more than 60 % for $SO_{2)}$ by 2030, but at a cost of more than 40 billion € higher (more than 50 %, see Table 9.3). The air pollution abatement costs saved by reducing greenhouse gas emissions would thus allow covering a significant part of the options associated with the maximum feasible reductions and thus help further improving European air quality.

Table 9.4: Air pollutant emissions; baseline compared to CP and LGEP

EU25 emissions	kton						% change			
		LREM-E	2030, LGEP				2030, LGEP			
air pollutant	2000	2030	B-CLE	LE-CLE	SER-CLE	B-MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
SO2	8736	2851	2371	2150	2342	1130	-16,8	-24,6	-17,9	-60,4
NOx	11581	6125	5524	4972	5550	2849	-9,8	-18,8	-9,4	-53,5
VOC	10654	5863	5877	5701	5912	4101	0,2	-2,8	0,8	-30,1
NH3	3824	3597	3582	3573	3584	2174	-0,4	-0,7	-0,4	-39,6
PM10	2455	1512	1357	1258	1344	817	-10,3	-16,8	-11,1	-46,0
PM2.5	1748	937	860	790	857	468	-8,2	-15,7	-8,5	-50,1

Thirdly, it should be noted that various dimensions of the ancillary benefits have not been analyzed. For example, the above considerations do not address the higher-scale improvements in the background air pollution levels in the LGEP scenarios, notably for ozone. Also, ancillary effects beyond air pollution abatement are not addressed, such as those in terms of improved energy security, level and composition of economic growth, employment effects and other environmental implications such as for waste.

10. Synthesis and discussion

We will present and discuss the answer to the questions as given in the objectives of this report in section 1.2. We will start with the key messages with respect to the developments in emissions and air quality over the period 1990-2002. Subsequently we will discuss the results on the outlook for 2030.

1. **Key messages on meeting the EU national emission ceiling directive (NEC) and the UNECE Long-range Transboundary Air Pollution (CLRTAP) emission targets**
   - Emissions of ozone forming gases (ground level ozone precursors) have been reduced by 33% across the EEA32 between 1990 and 2002. The emission reductions are mainly due to introduction of catalysts on new cars.
   - While good progress has been made in some EU15 countries towards meeting the NEC Directive emission targets for NO_x and NMVOC, most Member States still need to make substantial emission reductions to meet their targets. In contrast to the EU15, countries in the EU10 have made substantial progress towards meeting the present temporary targets for NMVOC and NO_x set in the NEC Directive. Six countries and the EU10 region as a whole have already met or exceeded their targets.
   - Total EU15 emissions of fine particulates (PM_{10}) have been reduced by 39% between 1990 and 2002. This is mainly due to reduction in emissions of the secondary particulate precursors SO_2 and NO_x, but also to reductions of primary PM_{10} from energy industries.
   - Across the EU15, emissions have decreased by 39% since 1990. Two countries, the United Kingdom and Germany have reduced emissions by more than 50% since 1990, with six other Member States having made emission reductions of more than 30%.
   - Emissions of acidifying gases have decreased significantly in most EEA32 countries. Between 1990 and 2002 emissions decreased by 43% in the EU15 and by 58% in the EU10 despite increased economic activity (GDP) across both regions during this period.
   - The EU15 as a whole has made good progress towards meeting the 2010 targets of the NEC Directive but additional effort is still required in order that the respective targets are met. EU10 countries have made excellent progress in terms of meeting their respective NEC Directive targets, with seven countries already having met their NEC Directive targets.
2. **Key messages on air quality and meeting targets set in the air quality directives**

   In general

   Tendencies in air pollutant concentrations since 1996**:**
   - **SO2** concentrations strongly reduced till 2000 and flattened thereafter;
   - **Ozone**, long-term average has increased since 1996, health-related ozone Indicators remained almost constant, and maximum (hourly) concentrations showed a downward tendency;
   - **PM_{10}** concentrations showed a downward tendency towards 2000, and an increase thereafter;
   - **NO_2** concentrations have decreased steadily since 1996.

- There were widespread exceedances of target and limit values at monitoring stations in Europe in 2002, for ozone, NO_2 and especially for PM_{10}.

Health related Air Quality directives:

- *Ozone* precursor emissions decreased substantially (by about 20%) since 1996, but is not reflected in ozone concentrations trends, especially for the health-relevant indicators (8-hour averages). Hemispheric ozone background is increasing, and reduced NO_X emissions leads to increased urban ozone.

  The highest recorded ozone concentration at an urban station in 2002 was 40% higher than the AQ target value. AQ target value exceedance occurred at more than 10% of the rural and urban background stations in Europe. On the average, these stations were about 8% higher than the target value.

- *Reported PM* primary and precursor gas emissions decreased steadily by about 15% since 1997, while PM_{10} concentrations were reduced up until 1999-2000 and has increased since then, but the levels in 2002 were still a bit lower than in 1997. Sulphate in PM show a similar variation. Reasons for the discrepancy could be sought in variations between years in meteorological/dispersion conditions, uncertainty in emissions data and inconsistent use of correction factors over the years.

  The highest recorded daily (36^{th} highest) PM_{10} concentration in 2002 was more than 3 times the AQ limit value, recorded at a street station. The stations in exceedance had concentrations on the average up to 32% higher than the limit value, dependent upon the type of station.
  The rural PM10 concentrations dominate the PM10 levels in Europe.

- *NO_2* emissions decreased on average 17% between 1996 and 2002, the same decrease was observed at urban background stations.

  The highest concentration recorded in 2002 was about 2.5 times the limit value for annual average recorded at a street station. On the average, the stations in exceedance had concentrations up to 32% higher than the limit value, dependent upon statistic and type of station.

Ecosystems related Air Quality directives:

- Ground level ozone continues to exert pressure on European vegetation and crop production. The long-term objective level for ozone (AOT40) was exceeded in 2002 in more than 80% of the EEA31 area with data available. The average AOT40 value (averaged over about 200 rural stations) has been steadily increasing since 1997, but was reduced in 2002 compared to 2001

3. **What are the trade-offs and benefits of climate change policy for air quality policies and vice versa.**
   - The main synergies for air quality policies are found for SO_2, with an additional 16% reduction in 2030 in LGEP compared to the baseline or a cost reduction of approximately 2 billion/year.
   - Significant synergies are also found for NO_x and PM_{10}, with each an 10% reduction in 2030 in LGEP compared to the baseline or a cost reduction of at least 800 million/year.

- Ammonia and NMVOC emission are not significant changes if LGEP is compared to the baseline emissions.
- For air pollution and climate change policies fuel swift and energy effiency options reduces are highly synergistic
- Climate change measures outside Europe have in general no co-benefits for European air pollution policies, with the exception of methane measures, resulting in a decrease of hemispheric ozone leading to European health benefits.

4. **Outlook for the emissions and air quality in 2030**

In this study the development of European air pollution emissions up to 2030 for three variants of the Low Greenhouse gas Emissions Pathways (LGEP) scenario are discussed. These variants (Baseline – LGEP-B, Low Growth – LGEP-LE, and Renewable Energy Targets - LGEP-SER) demonstrate the longer-term effects of the likely changes in European energy production and consumption structures induced by policies to mitigate climate change. Scenario results clearly demonstrate that implementation of such policies may result in cleaner and less energy-intensive economic structures, which – together with the enforcement of the already adopted emission control legislation - will radically mitigate the European air pollution. Despite continued economic growth, emissions of many traditional air pollutants will significantly decline up to 2030. The LGEP baseline (LGEP-B) energy and economic projections, combined with current legislation on pollution control, suggest for the EEA countries the following reductions of air pollutants' emissions compared with 2000:

- NO_x – 49 percent,
- NMVOC – 45 percent,
- SO_2 – 75 percent
- NH_3 – 1 percent
- PM 10 – 40 percent
- PM 2.5 - 46 percent.

Emission reductions of some pollutants for the current EU Member States are even higher. The "low economic growth" scenario (LGEP-LE) results in further moderate reductions of emissions compared with the LGEP-B: minus two to five percentage points for NO_x, SO_2, and NMVOC, up to four percentage points for PM. Differences for the emissions of ammonia are small. Additional reductions of air pollutants emissions in case of implementation of renewable energy targets are rather small.

As a consequence, air quality in Europe will significantly improve, and impacts on human health and vegetation attributable to air pollution will diminish. The LGEP-B scenario in 2030 implies for the EEA region the following improvement of impact indicators compared with 2000:

- Loss of statistical life expectancy minus 44 percent,
- Premature mortality due to ozone minus 16 percent
- Forest area at risk of acidification minus 56 percent,
- Ecosystems' area endangered by eutrophication minus 15 percent.

In a variant on the LGEP-B scenario in which it is assumed that the best available control technology is implemented, the LGEP-B-MFR scenario, it is shown that it is possible to further reduce the emissions. Compared with 2000 levels the achievable reductions are:

- 74 percent for NO_x ,
- 63 percent for NMVOC,
- 88 percent for SO_2,
- 42 percent for NH_3,
- 69 percent for PM_{10}.

Although the current legislation brings substantial improvement of impact indicators, it does not assure sustainable conditions. The scenario with the best available emission controls is much closer to sustainability targets. However, even in this scenario environmental damage is likely to occur at least in some parts of Europe.

The “current legislation” air pollution control costs increase in the EEA region from about 65 €/capita in 2000 to 160 €/capita in 2030 (scenario LGEP-B). The increase is mainly due to more stringent legislation on mobile sources. The costs in the LGEP-B-MFR scenario are 80 percent higher than the cost of “current legislation” of the LGEP-B scenario.

The projections presented in this report clearly indicate that in the future the relevance of different pollution sources will change. Traditionally large polluting sectors will drastically reduce their shares in total emissions, because of enforcement of stringent control measures. In turn, other sources, which have received less attention in the past, will become dominating contributors. In 2030, the major contributions to land-based SO_2 emissions will come from industrial combustion and process sources. NO_x emissions will predominantly originate from diesel heavy duty vehicles and off-road machinery. Solvents will become the major source of VOC emissions, and wood burning and industrial processes will be responsible for the majority of emissions of fine particulate matter. Risk to ecosystems by acidification and eutrophication will be dominated by ammonia emissions from the agricultural sector.

References

Chapter 1

Bates, J., and Z., Klimont (2002) ETC/ACC framework for agricultural base-line scenario development in the context of integrated assessment for air pollution and climate change. ETC/ACC Technical Paper 2003/3

CCE (2001) Modelling and Mapping of Critical Thresholds in Europe, Status Report 2001, edited by: M. Posch; P.A.M. de Smet; J.-P. Hettelingh; R. J. Downing. National Institute of Public Health and Environmental Protection, Bilthoven, The Netherlands

EC (2003a) Selection of indicators for the CAFE programme. A note to the CAFE Steering group. Brussels.

EC (2003b) Mantzos, L., Capros, P., Kouvaritakis, N., Zeka-Paschou M. (2003): European Energy and Transport: Trends to 2030. European Commission – Directorate General for Energy and Transport, ISBN 92-894-4444-4, Office for Official Publications of the European Communities, Luxembourg

EEA (2003) Europe's water: An indicator based assessment. EEA topic report 1/2003. Copenhagen

EEA (2001) The ShAIR scenario: Towards air and climate change outlooks, integrated assessment methodologies and tools applied to air pollution and greenhouse gases. Topic report 12/2001

Eerens H., Amann M., Minnen J.van. (2002) The ETC-ACC framework for base-line scenario development in the context of integrated assessment for air pollution and climate change. Internal note. ETC/ACC.

Gugele, B. and N. Roubaris. September (2002) State-of-play of the work on CO2 and other greenhouse gas indicators. Paper prepared for the Committee under the Monitoring Mechanism of Community and other Greenhouse Gas Emissions (Council Decision 99/296/EC). ETC/ACC and Eurostat. Draft 6.

GRP (2002) P. Criqui, A. Kitous, M. Berk, M. den Elzen, B. Eickhout, P. Lucas, D. van Vuuren, N. Kouvaritakis, D. Vanregemorter, B. de Vries, H. Eerens, R. Oostenrijk and L. Paroussos, Greenhouse gas Reduction Pathways in the UNFCCC process up to 2025, Study Contract B4-3040/2001/325703/MAR/E.1 for DG Environment. Policy makers Summary: europa.eu.int/comm/environment/ climat/studies.htm

GRP (2003) D.P. van Vuuren, M.G.J. den Elzen, M.M. Berk, P. Lucas, B. Eickhout, H. Eerens, R. Oostenrijk, Regional costs and benefits of alternative post Kyoto climate regimes, Bilthoven, RIVM report 728001025/2003.

Chapter 2

CCE (1999) Posch, M., Smet, P.A.M. de, Hettelingh, J-P., Downing, R.J., Calculation and mapping of critical thresholds in Europe, Bilthoven, Coordination Center for Effects, RIVM report 259101010, ISBN 90-96900927, 2001

CCE (2001) Posch, M., Smet, P.A.M. de, Hettelingh, J-P., Downing, R.J., Calculation and mapping of critical thresholds in Europe,Bilthoven, Coordination Center for Effects, RIVM report 259101009, ISBN 90-69600838, 1999

EC (1996) European Parliament and Council, 1996. Directive 1996/61/EC concerning integrated pollution prevention and control, September 1996

EC (1998) Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Council Directive 70/220/EEC, Brussels, 13 October 1998, Official Journal L 350 28/12/1998 P. 0001 – 0057.

EC (1999) Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain activities and installations, Brussel, Official Journal L 085 , 29/03/1999 P. 0001 – 0022.

EC (2001a) Directive 2001/81/EC of the European Parliament and of the Council on national emission ceilings for certain atmospheric pollutants, Brussels, 23 October 2001

EC (2001b) Directive 2001/80/EC of the European Parliament and of the Council on the limitation of emissions of certain pollutants into the air from large combustion plants, 23 October 2001

Hettelingh J-P, Posch M, De Smet PAM (2001) Multi-effect critical loads used in multi-pollutant reduction agreements in Europe. Water, Air and Soil Pollution 130: 1133-1138.

Nilsson, J and Grennfelt, P (eds) (1988) Critical Loads for Sulphur and Nitrogen. Nord 1988:97, Nordic Council of Ministers, Copenhagen, Denmark, 418 pp.

NSCA (2003). National Society for Clean Air and Environmental Protection, report Air Quality Limit Values - is there a better way?

Posch M, Hettelingh J-P, Slootweg J (2003) Manual for the dynamic modeling of soils in Europe, RIVM report

Posch M, Hettelingh J-P, Alcamo J, Krol M (1996) Integrated scenarios of acidification and climate change in Asia and Europe, Global Environmental Change, 6:375-395.

Posch, M. (2002) Impacts of climate change on critical loads and their exceedances in Europe, Environmental Science & Policy, volume 5, number 4, 2002, pp 307-317

WHO (2000) WHO Air Quality Guidelines for Europe, 2nd Edition, WHO Regional Publications, European Series, No. 91.

WHO (2003) Health aspects of air pollution with particulate matter, ozone, and nitrogen dioxide, Report on WHO working group, Bonn, 13-15 January.

UN/ECE (1999) Protocol to the 1979 Convention on Long-range Transboundary Air Pollution to Abate Acidification, Eutrophication, and Ground-level Ozone, United Nations Economic Commission for Europe, Geneva, Switzerland. (http://www.unece.org/env/lrtap/protocol/)

Chapter 3 and 4

Buijsman, Ed. and de Leeuw, Frank (2004) Correction factors and PM10 measurements. ETC/ACC Technical paper 2004/4. November 2004 (Final Draft).

CEN (1988) Air quality - Determination of the PM 10 fraction of suspended particulate matter - Reference method and field test procedure to demonstrate reference equivalence of measurement methods. CEN Standard EN 12341:1998. (EN 12341:1998)

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

EEA (2004a) Greenhouse gas emission trends and projections in Europe 2004. Progress by the EU and its Member States towards achieving their Kyoto Protocol targets. EEA report No5/2004.

EEA (2004b) Air Pollution by ozone in Europe in Summer 2004. Provisional overview of exceedances of EC ozone threshold values during April–August 2004. (Final Draft Report, 6 October, 2004).

Lövblad, G., L. Tarrasón, Kjetil Torseth and S. Dutchak (2004). EMEP Assessment Part I European Perspective. EMEP, Oslo Norway, ISBN 82-7144-032-2.

S. Snel (2004) Trends in PM10 concentrations for European countries (1997 – 2002). Eliminating the influence of emissions and meteorology. Thesis report. Wageningen University

Chapter 5

Bruinsma, J. (ed.) (2003) World agriculture: towards 2015/2030, An FAO Perspective, Earthscan, London and FAO, Rome

CEC (2002) Prospects for agricultural Markets 2002-2009. June 2002, Directorate General for Agriculture, Brussels

EFMA (2003) Forecast of Food, Farming and Fertilizer Use in the European Union, 2002 to 2012. European Fertilizer Manufacturers Association (EFMA), Brussels

IPCC Special Report on Emissions Scenarios (SRES), Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A. et al. (2000) Special Report on Emissions Scenarios, Working Group III, Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, 595 pp.

IMAGE team (2001) The IMAGE 2.2 implementation of the SRES scenarios: A comprehensive analysis of emissions, climate change and impacts in the 21st century, RIVM CD-ROM Publication 481508018, Bilthoven: National Institute of Public Health and the Environment, 2001.

OJ (2001a) Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants. Official Journal of the European Communities, L309/22, November 27, 2001.

RAINS WEB (2003) The RAINS WEB model. IIASA, Laxenburg, Austria. (http://www.iiasa.ac.at/web-apps/tap/RainsWeb).

UN/ECE (1999) Protocol to the 1979 Convention on Long-range Transboundary Air Pollution to Abate Acidification, Eutrophication, and Ground-level Ozone, United Nations Economic Commission for Europe, Geneva, Switzerland. (http://www.unece.org/env/lrtap/protocol/)

Chapter 6

Alcamo, J., E. Kreileman, M. Krol, R. Leemans, J. Bollen, J. van Minnen, M. Schaefer, S. Toet, and B. de Vries (1998) Global modelling of environmental change: an overview of IMAGE 2.1. In Global change scenarios of the 21 st century. Results from the IMAGE 2.1 Model. J. Alcamo, R. Leemans, E. Kreileman (eds.), Elsevier Science, Kidlington, Oxford, pp. 128-130.

CEC (2003) European energy and transport. Trends to 2030. KO-AC-02-001-EN-C, European Commission, Directorate General for Energy and Transport, Luxembourg.

EEA (2001) Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook. Copenhagen, European Environment Agency.

EMEP (2004) UNECE/EMEP activity and emission database WebDab. Oslo, Norway. (http://www.webdab.emep.int/).

ENTEC (2005) Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. Report for the European Commission Directorate General Environment . February 2005, ENTEC UK Limited.

ENTEC (2002) Quantification of emissions from ships associated with ship movements between ports in the European Community. Report for the European Commission Directorate General Environment. July 2002, ENTEC UK Limited.

RAINS WEB (2004) The RAINS WEB model. IIASA, Laxenburg, Austria. (http://www.iiasa.ac.at/web-apps/tap/RainsWeb).

UN/ECE (1999) Protocol to the 1979 Convention on Long-range Transboundary Air Pollution to Abate Acidification, Eutrophication, and Ground-level Ozone, United Nations Economic Commission for Europe, Geneva, Switzerland. (http://www.unece.org/env/lrtap/protocol/)

Chapter 7

Dentener, F., D. Stevenson, J. Cofala, R. Mechler, M. Amann, P. Bergamaschi, F. Raes, and R. Derwent (2004) The impact of air pollutant and methane emission controls on tropospheric ozone and radiative forcing: CTM calculations for the period 1990–2030.Atmos. Chem. Phys., 4, 1–68, 2004

Chapter 8

Arvanitis A. and N. Moussiopoulos, Coupling an aerosol module to a deterministic long term ozone exposure model. 26th NATO/CCMS ITM, Istanbul, 2003

Cofala J., Cabala R., Klimont Z. Heyes C. and Schoepp W. (2005) Emissions of air pollutants in the EEA countries and their environmental impacts for the SEP scenarios - IIASA's contribution to the SEOR2005 Report, International Institute for Applied Systems Analysis (IIASA), February 2005

De Ceuster G., Van Herbruggen B., Logghe S. and Proost S., (2004) TREMOVE 2.2 model description, Report to the European Commission DG ENV, December 2004.

European Commission, DG Enterprise (2004) Euro 5 Questionnaire, Brussels, 16-02-2004 URL: http://www.tremove.org/

Hertel, O. and Berkowicz, R. (1989) Operational Street Pollution Model (OSPM), evaluation of the model on data from St. Olavs street in Oslo, DMU Luft A-135

JRC :Joint Research Center. A European aerosol phenomenology. Joint Research Center - European Commission. Institute for Environment and Sustainability, ISPRA. 2003

LAT, DTU, PSIAMTK, INFRAS (2002) Development of a Database System for the Calculation of Indicators of Environmental Pressure Caused by Transport. TRENDS main report to the European Commission, October 2002. URL: http://forum.europa.eu.int/Public/irc/dsis/pip/library?l=/

Ntziachristos L. and Samaras Z., COPERT III: Computer programme to calculate emissions from road transport, Methodology and emission factors (Version 2.1), Technical report No 49, 2000. URL: http://vergina.eng.auth.gr/mech/lat/copert/copert.htm

Chapter 9

Arrow K. J., Clinke W.R., Maler K-G., Munasinghe M., Squittieri R., Stiglitz J.E. (1995) Intertemporal equity, Discounting, and Economic Efficiency. In: Bruce J.P. et al. (eds.): Climate change 1995. Economic and Social Dimensions of Climate Change.

Intergovernmental Panel for Climate Change, Cambridge University Press, Cambridge, UK.

Cofala J., and Klaassen G. (2003) Assuring comparability of cost assessments in defining co-benefits of climate policies for air pollution. A note for ETC ACC. IIASA, Laxenburg, Austria.

EEA (2003a) Van Vuuren, D. P., J. Cofala, H. C. Eerens, R. Oostenrijk, M. G. J. den Elzen, C. Heyes, Z. Klimont, M. Amann. Exploring the ancillary benefits of the Kyoto Protocol for air pollution in Europe. EEA, Copenhagen, Denmark.

EEA, (2003b) W. Tuinstra, R. Swart, J. van Minnen, D. Petroula, C. Brink, L. van Bree, H.C. Eerens*, E.-A.Kalognomou , N. Moussiopoulos , J. Cofala, Z. Klimont , M. Amann, F. Dentener, F. Raes Air Quality and Climate Change Policies in Europe: Exploring linkages and the added value of an Integrated approach , EEA, Copenhagen, first draft march 2003-03-03

Annexes

RAINS model

Amann M., Bertok I., Cabala R., Cofala J., Gyarfas F., Heyes C., Klimont Z., Schöpp W.Wagner F. (2005) First results from the RAINS Multi-Pollutant, Multi-effects Optimization including Fine Particulate Matter. International Institute for Applied Systems Analysis (IIASA), January 2005

Amann, M., Cofala, J., Heyes, C., Klimont, Z., Mechler, R., Posch, M. and Schoepp, W. (2004) The RAINS model. Documentation of the model approach prepared for the RAINS review. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria (http://www.iiasa.ac.at/rains/review/review-full.pdf)

Amann, M., J. Cofala, C. Heyes, Z. Klimont and W. Schöpp (1999) "The RAINS model: a tool for assessing regional emission control strategies in Europe."Pollution Atmospherique (December 1999): 41-63.

EEA (2001) Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook. Copenhagen, European Environment Agency.

EMEP (2004) UNECE/EMEP activity and emission database WebDab. Oslo, Norway. (http://www.webdab.emep.int/).

Hettelingh, J-P., M. Posch and J. Slootweg, (2004) Critical loads and Dynamic modelling results. CCE Status Report. RIVM 259101014/2004.

Mechler, R., M. Amann, W. Schoepp and Z. Klimont (2002). Preliminary estimates of changes in statistical life expectancy due to control of particulate matter air pollution in Europe. Oslo, Norway, EMEP: pp. 61 - 89.

RAINS WEB (2004) The RAINS WEB model. IIASA, Laxenburg, Austria. (http://www.iiasa.ac.at/web-apps/tap/RainsWeb).

Simpson D., Fagerli H., Jonson J. E., 21003: Tsyro S., Wind P. (2003) Unified EMEP Model Description. EMEP Report 1/2003, Oslo, Norway.

EMEP model

Fagerli, H., Simpson, D., Tsyro, S., Solberg, S., Aas, W. and Tarrasón, L. (editor). (2003) Transboundary Acidification and Eutrophication and Ground Level Ozone in Europe. Part II. Unified EMEP Model Performance. EMEP Status Report 1/2003, Part II.

Simpson D., Fagerli H., Jonson J. E., 21003: Tsyro S., Wind P. (2003) Unified EMEP Model Description. EMEP Report 1/2003, Oslo, Norway.

Tarrasón, L., Benedictow, B., Benestad, R., Jonson, J.E., Hanssen-Bauer , I., Langner, J., Andersson, C. and Bergström, R. Meteorological years available for use in Integrated Assessment Modelling for the review of the National Emission Ceilings Directive (NECD). Note prepared for the CAFE Steering Group under request by the European Commission. In preparation. 2005

Tarrasón, L., Fagerli, H., Jonson, J.E., Klein, H., van Loon, M., Simpson, D., Tsyro, S., Vestreng, V., Wind, P., Posch, M., Solberg, S., Spranger, T., Thunis, P. and White, L. (2004) Transboundary Acidification and Eutrophication and Ground Level Ozone in Europe. Unified EMEP Model Description. EMEP Status Report 1/2004.

Van Loon, M., Roemer, M,.G.M. and Builtjes, P.J.H. (2004) "MODEL INTER-COMPARISON In the framework of the review of the Unified EMEP model" TNO Report R2004/282, Apeldoorn, The Netherlands.

IMAGE model and TIMER model

Alcamo, J., Leemans, R., Kreileman, G. J. J., Global change scenarios of the 21st century, Results From the IMAGE 2.1 Model, London: Pergamon & Elseviers Science, 1998.

De Vries (2002) Vries, B. de, H.J.M., van Vuuren, D.P., den Elzen, M.G.J. and Janssen, M.A., 2002. The Targets Image Energy model regional (TIMER) - Technical documentation, RIVM report 461502024, National Institute of Public Health and the Environment (RIVM), Bilthoven, the Netherlands

IMAGE team (2001a) The IMAGE 2.2 implementation of the SRES scenarios: A comprehensive analysis of emissions, climate change and impacts in the 21st century, RIVM CD-ROM Publication 481508018, Bilthoven: National Institute of Public Health and the Environment, 2001.

IMAGE team (2001b) The IMAGE 2.2 implementation of the SRES scenarios: Climate change scenarios resulting from runs with several GCMs, RIVM CD-ROM Publication 481508019, Bilthoven: National Institute of Public Health and the Environment, 2001.

TRENDS model, TREMOVE model and OFIS model

Arvanitis A. and N. Moussiopoulos (2003) Coupling an aerosol module to a deterministic long term ozone exposure model. 26th NATO/CCMS ITM, Istanbul, 2003

Borrego C., Tchepel, O. (1999) General requirements for Quality Assurance Project Plan, EURO-TRAC-2-Symposium and 3rd SATURN Workshop, 23-24 Agosto, Aveiro, Portugal. pp.47-60, 1999

De Ceuster G., Van Herbruggen B., Logghe S. and Proost S. (2004) TREMOVE 2.2 model description, Report to the European Commission DG ENV, December 2004.

EMEP/CORINAIR, Emission inventory Guidebook, Group 7: Road transport, 3rd edition, October 2002. URL: http://reports.eea.eu.int/EMEPCORINAIR3/en/

Kunz R. and N. Moussiopoulos (1997) Implementation and assessment of one-way nesting technique for high resolution wind flow simulations. Atmospheric Environment 1997, 31, 3167-3176.

LAT, DTU, PSIAMTK, INFRAS (2002) Development of a Database System for the Calculation of Indicators of Environmental Pressure Caused by Transport. TRENDS main report to the European Commission, October 2002.

Marchial Echenique & Partners (2000) SCENES European Transport Forecasting model and Appended Module: Technical Description. SCENES Deliverable 4 to the European Commission, April 2000.

Moussiopoulos N. (1995) The EUMAC Zooming Model, a tool for local-to-regional air quality studies. Meteorology and Atmospheric Physics 1995, 57, 115-133.

Moussiopoulos N., P. Sahm and Ch. Kessler (1995) Numerical simulation of photochemical smog formation in Athens, Greece - a case study. Atmospheric Environment 1995, 29, 3619-3632.

Moussiopoulos N. and I. Douros (2004) Application and development of the OFIS model within the framework of CITY-DELTA, HELECO '05 - 5th International Exhibition and Conference on Environmental Technology, Athens, Greece, 2004.

Ntziachristos L. and Samaras Z. (2000) COPERT III: Computer programme to calculate emissions from road transport, Methodology and emission factors (Version 2.1), Technical report No 49, 2000. URL: http://vergina.eng.auth.gr/mech/lat/copert/copert.htm

Scott, B. C. (1979) Parameterization of sulphate removal by precipitation. J. Appl. Met. 1979, 17, 11375-11389.

Schwarz, U. (2002) Methoden und Modelle zur multiskalig hoch aufgeloesten Bestimmung von luftverunreinigenden Emissionen in Europa. Dissertation am Institut fuer Energiewirtschaft und Rationelle Energieanwendung, Universitaet Stuttgart. (doctoral thesis at the Intitute of Energy Economics and the Rational Use of Energy, University of Stuttgart) (in German)

van den Hout, D. and Teeuwisse, S. (2004) Street typology, ETC/ACC SEC deliverable to EEA.

Wickert, B. (2001) Berechnung anthropogener Emissionen in Deutschland für Ozonvorlaeufersubstanzen - Modellentwicklung und Sensitivitaetsstudien. Dissertation am Institut fuer Energiewirtschaft und Rationelle Energieanwendung, Universitaet Stuttgart. (in German)

Annex 1: Emissions of pollutants by country

Emissions of NO_x, kilotons:

Country	2000	NEC ceiling	2020, CP		2030, LGEP			
			CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	192	103	***127***	91	***109***	96	***109***	66
Belgium	333	176	***190***	112	172	155	174	84
Denmark	207	127	105	65	95	91	95	48
Finland	212	170	117	63	103	95	103	48
France	1447	810	***819***	460	767	685	781	370
Germany	1645	1051	808	599	799	679	791	517
Greece	322	344	209	120	202	187	204	90
Ireland	129	65	63	39	55	49	57	30
Italy	1389	990	663	363	616	541	625	286
Luxembourg	33	11	***18***	***11***	***17***	***14***	***17***	10
Netherlands	399	260	240	166	235	197	233	134
Portugal	263	250	156	97	159	130	154	81
Spain	1335	847	681	397	634	577	648	314
Sweden	251	148	***150***	75	***151***	***152***	***159***	71
UK	1753	1167	817	473	775	712	764	384
Cyprus	26	23	18	10	18	17	18	10
Czech Rep.	318	286	113	60	89	82	90	43
Estonia	37	60	15	8	12	11	11	6
Hungary	188	198	83	42	77	73	79	35
Latvia	35	61	15	9	14	14	15	8
Lithuania	49	110	27	15	24	24	25	13
Malta	9	8	4	2	4	3	4	2
Poland	843	879	364	209	332	324	327	166
Slovakia	106	130	60	34	48	47	50	26
Slovenia	58	45	24	16	16	15	16	9
Iceland	20	n.a	28	n.a.	29	29	29	n.a.
Liechtenstein	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	211	156	***166***	109	155	151	155	83
Switzerland	97	79	55	33	55	50	55	30
Bulgaria	191	266	102	45	81	76	81	35
Romania	331	437	186	94	191	172	191	91
Turkey	942	n.a.	729	369	771	675	771	372
EEA 32	13373	n.a.	7153	4186	6806	6126	6833	3460
EU 15	*9911*	*6519*	*5164*	*3131*	*4890*	*4361*	*4914*	*2532*
EU 10	*1670*	*1800*	*724*	*405*	*634*	*611*	*636*	*317*
EFTA 4	*328*	*n.a.*	*249*	*142*	*239*	*229*	*239*	*114*

Emissions higher than the NEC ceiling are shown in red

Emissions of NMVOC, kilotons:

Country	2000	NEC ceiling	2020, CP		2030, LGEP			
			CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	190	159	138	92	133	129	133	88
Belgium	238	139	***144***	106	***149***	***146***	***150***	108
Denmark	128	85	58	39	56	55	56	37
Finland	171	130	97	61	89	87	90	58
France	1541	1050	923	659	913	881	923	669
Germany	1553	995	809	637	787	747	789	641
Greece	280	261	144	79	147	139	147	78
Ireland	88	55	46	30	45	43	46	30
Italy	1735	1159	731	540	717	698	723	527
Luxembourg	13	9	8	6	8	7	8	6
Netherlands	264	185	***203***	144	***203***	***193***	***203***	142
Portugal	259	180	162	108	169	157	169	112
Spain	1114	662	***692***	431	***676***	659	***682***	430
Sweden	298	241	174	118	206	204	206	118
UK	1472	1200	878	651	886	870	887	655
Cyprus	13	14	6	4	6	6	6	4
Czech Rep.	241	220	119	69	120	119	121	69
Estonia	34	49	17	11	15	15	15	9
Hungary	168	137	90	51	84	82	84	47
Latvia	52	136	28	13	28	28	29	13
Lithuania	74	92	43	20	40	40	41	19
Malta	5	12	2	1	2	2	2	1
Poland	581	800	320	202	313	309	316	198
Slovakia	88	140	64	31	68	67	68	32
Slovenia	54	40	20	12	18	17	18	10
Iceland	13	n.a	10	n.a.	7	7	7	n.a.
Liechtenstein	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	374	195	82	60	78	77	78	58
Switzerland	145	144	88	54	90	88	90	54
Bulgaria	134	185	79	33	73	71	73	32
Romania	378	523	241	102	227	220	227	105
Turkey	783	n.a.	512	274	538	510	538	309
EEA 32	12481	n.a.	6927	4638	6891	6675	6925	4659
EU 15	*9344*	*6510*	*5207*	*3701*	*5183*	*5016*	*5212*	*3698*
EU 10	*1310*	*1640*	*708*	*414*	*694*	*685*	*700*	*403*
EFTA 4	*532*	*n.a.*	*180*	*114*	*175*	*172*	*175*	*112*

Emissions higher than the NEC ceiling are shown in red

Emissions of NH_3, kilotons:

Country	2000	NEC ceiling	2020, CP CLE	2020, CP MFR	2030, LGEP B-CLE	2030, LGEP LE-CLE	2030, LGEP SER-CLE	2030, LGEP B-MFR
Austria	54	66	54	28	52	52	52	26
Belgium	81	74	***76***	47	74	74	74	45
Denmark	91	69	***78***	40	***76***	***76***	***76***	39
Finland	35	31	***32***	22	31	31	31	21
France	728	780	702	387	671	670	672	364
Germany	638	550	***603***	481	***584***	***580***	***582***	470
Greece	55	73	52	35	49	49	49	32
Ireland	127	116	***121***	84	112	112	112	77
Italy	432	419	399	248	383	382	383	235
Luxembourg	7	7	6	4	5	5	5	4
Netherlands	157	128	***140***	103	***135***	***134***	***135***	99
Portugal	68	90	67	40	65	65	65	39
Spain	394	353	***370***	198	***357***	***357***	***358***	189
Sweden	53	57	49	33	47	47	47	32
UK	315	297	***310***	206	***299***	***298***	***299***	195
Cyprus	6	9	6	3	6	6	6	3
Czech Rep.	74	80	65	36	65	65	65	36
Estonia	10	29	12	5	15	15	15	5
Hungary	78	90	85	39	88	88	88	39
Latvia	12	44	16	7	18	18	18	8
Lithuania	50	84	57	39	60	60	60	41
Malta	1	3	1	1	1	1	1	1
Poland	309	468	333	150	336	336	336	149
Slovakia	32	39	33	17	33	33	33	16
Slovenia	18	20	20	9	19	19	19	9
Iceland	3	n.a	3	n.a.	3	3	3	n.a.
Liechtenstein	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	26	23	***23***	15	***23***	***23***	***23***	15
Switzerland	66	63	60	39	59	59	59	38
Bulgaria	92	108	***124***	72	***124***	***124***	***124***	72
Romania	223	210	***285***	143	***285***	***285***	***285***	143
Turkey	407	n.a.	466	251	508	508	508	272
EEA 32	4641	n.a.	4646	2783	4585	4574	4586	2714
EU 15	*3234*	*3110*	*3057*	*1957*	*2940*	*2931*	*2941*	*1866*
EU 10	*590*	*866*	*629*	*306*	*642*	*642*	*643*	*308*
EFTA 4	*95*	*n.a.*	*86*	*54*	*86*	*86*	*86*	*53*

Emissions higher than the NEC ceiling are shown in red

Emissions of SO_2:

Country	2000	NEC ceiling	2020, CP		2030, LGEP			
			CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	38	39	26	22	23	21	22	19
Belgium	187	99	83	51	70	64	71	47
Denmark	28	55	13	10	12	11	11	8
Finland	77	110	62	46	53	49	53	41
France	654	375	345	148	306	275	307	144
Germany	643	520	332	214	295	242	262	190
Greece	481	523	110	40	103	92	104	32
Ireland	132	42	19	10	15	14	17	8
Italy	747	475	281	117	241	219	258	100
Luxembourg	4	4	2	1	2	2	2	1
Netherlands	84	50	***64***	41	***65***	***57***	***64***	42
Portugal	230	160	81	33	85	75	84	34
Spain	1489	746	335	155	344	315	350	162
Sweden	58	67	50	39	50	50	53	38
UK	1186	585	209	115	203	185	209	111
Cyprus	46	39	8	3	7	6	7	2
Czech Rep.	250	265	53	26	32	30	33	14
Estonia	91	100	10	3	7	6	6	2
Hungary	487	500	88	19	67	55	57	15
Latvia	16	101	8	2	6	6	7	2
Lithuania	43	145	22	5	21	21	20	5
Malta	26	9	2	1	2	2	2	1
Poland	1515	1397	554	167	328	318	310	101
Slovakia	124	110	33	11	23	21	23	7
Slovenia	97	27	16	5	14	13	13	4
Iceland	24	n.a	27	n.a.	27	27	27	n.a.
Liechtenstein	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	27	22	18	13	16	15	16	12
Switzerland	20	26	13	7	13	11	13	7
Bulgaria	1313	856	651	59	117	185	117	43
Romania	838	918	182	32	115	105	115	35
Turkey	2122	n.a.	1154	230	674	569	674	298
EEA 32	13080	n.a.	4850	1625	3333	3062	3304	1525
EU 15	*6040*	*3850*	*2013*	*1043*	*1867*	*1672*	*1865*	*978*
EU 10	*2696*	*2693*	*793*	*241*	*504*	*478*	*477*	*152*
EFTA 4	*71*	*n.a.*	*58*	*20*	*56*	*54*	*56*	*19*

Emissions higher than the NEC ceiling are shown in red

Emissions of PM_{10}:

Country	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	49	39	27	36	34	36	24
Belgium	70	41	26	37	35	37	24
Denmark	33	23	16	22	21	22	14
Finland	44	34	17	29	27	29	15
France	375	245	136	229	204	221	123
Germany	261	191	147	182	168	181	135
Greece	66	57	31	51	44	50	26
Ireland	22	16	10	15	14	15	10
Italy	273	151	100	133	123	134	89
Luxembourg	4	3	3	3	3	3	3
Netherlands	58	49	37	49	45	49	35
Portugal	59	48	25	50	42	50	25
Spain	235	142	88	131	122	131	79
Sweden	79	49	24	47	46	47	23
UK	202	116	82	110	105	110	76
Cyprus	3	3	2	3	3	3	2
Czech Rep.	104	33	20	21	20	21	14
Estonia	42	9	3	6	6	6	2
Hungary	87	34	14	32	32	33	13
Latvia	10	6	3	5	5	5	3
Lithuania	21	15	6	12	12	12	5
Malta	1	1	0	1	1	1	0
Poland	307	155	81	128	124	125	68
Slovakia	29	22	10	18	17	18	8
Slovenia	21	8	4	5	5	6	3
Iceland	3	3	n.a.	3	3	3	n.a.
Liechtenstein	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	35	22	14	20	20	20	12
Switzerland	15	12	8	12	12	12	8
Bulgaria	94	68	18	56	55	56	15
Romania	171	99	31	88	85	88	29
Turkey	424	387	120	381	369	381	122
EEA 32	3199	2081	1101	1917	1803	1904	1004
EU 15	*1830*	*1205*	*768*	*1126*	*1033*	*1115*	*699*
EU 10	*625*	*285*	*143*	*231*	*225*	*229*	*118*
EFTA 4	*53*	*37*	*22*	*35*	*34*	*35*	*20*

Emissions of $PM_{2.5}$:

Country	2000	2020, CP		2030, LGEP			
		CLE	MFR	B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	37	27	18	25	23	25	15
Belgium	43	24	16	21	20	21	13
Denmark	22	13	8	12	11	12	7
Finland	36	27	12	22	21	22	10
France	290	165	84	151	134	149	73
Germany	171	111	82	105	95	103	73
Greece	49	41	21	36	30	36	18
Ireland	14	9	6	9	9	9	5
Italy	209	99	64	84	78	85	55
Luxembourg	3	2	2	2	2	2	2
Netherlands	36	26	19	25	23	25	17
Portugal	46	37	18	39	31	39	18
Spain	169	90	53	80	73	80	44
Sweden	67	39	16	37	36	37	15
UK	129	67	46	63	60	63	41
Cyprus	2	2	1	2	2	2	1
Czech Rep.	66	18	11	11	11	11	7
Estonia	22	6	2	4	4	4	1
Hungary	60	22	7	21	21	21	7
Latvia	7	4	2	3	3	3	1
Lithuania	17	12	4	9	9	9	3
Malta	1	0	0	0	0	0	0
Poland	215	102	47	81	78	80	37
Slovakia	18	14	5	11	11	11	4
Slovenia	15	6	3	4	4	4	2
Iceland	3	3	n.a.	3	3	3	n.a.
Liechtenstein	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Norway	29	16	10	14	14	14	8
Switzerland	10	6	5	6	6	6	4
Bulgaria	59	40	12	33	32	33	10
Romania	115	66	18	59	57	59	17
Turkey	305	264	87	254	245	254	85
EEA 32	2268	1360	680	1229	1147	1225	592
EU 15	*1323*	*778*	*466*	*713*	*647*	*710*	*405*
EU 10	*425*	*187*	*83*	*147*	*143*	*147*	*63*
EFTA 4	*42*	*26*	*14*	*23*	*23*	*23*	*13*

Annex 2: Impact indicators by country

Loss in statistical life expectancy that can be attributed to the identified anthropogenic contributions to $PM_{2.5}$ (in months)

Country	2000	2020, CP		2030, SEP		
		CLE	MFR	B-CLE	LE-CLE	B-MFR
Austria	8.1	4.4	2.4	3.9	3.6	1.8
Belgium	14.9	9.3	5.5	8.7	8.2	4.2
Denmark	6.8	4.6	2.5	4.7	4.6	2.0
Finland	2.6	2.0	0.9	1.9	1.9	0.8
France	9.3	5.3	2.7	5.0	4.6	2.1
Germany	10.7	6.3	3.6	5.9	5.4	2.8
Greece	7.0	4.5	1.6	4.1	4.0	1.3
Ireland	4.6	3.0	1.8	3.1	2.9	1.0
Italy	9.1	5.0	2.2	4.8	4.5	1.7
Luxembourg	11.0	6.4	3.5	6.1	5.6	2.9
Netherlands	13.4	9.2	5.7	8.8	8.3	4.1
Portugal	5.4	3.3	1.8	3.2	2.9	1.3
Spain	5.4	3.1	1.6	3.1	2.9	1.1
Sweden	3.9	2.8	1.5	2.7	2.6	1.1
UK	7.6	4.9	2.8	4.8	4.6	2.2
Czech Rep.	10.4	5.0	2.5	4.4	4.1	1.9
Estonia	3.7	2.9	1.3	2.8	2.8	1.0
Hungary	12.5	6.4	2.3	5.7	5.5	1.7
Latvia	4.4	3.1	1.2	3.1	3.0	1.0
Lithuania	6.2	4.3	1.7	4.0	3.9	1.2
Malta	7.4	6.7	3.9	7.2	7.2	2.2
Poland	10.8	5.8	2.6	5.2	4.9	1.9
Slovakia	10.6	5.4	2.2	4.8	4.5	1.7
Slovenia	9.5	5.1	2.1	4.6	4.4	1.5
Norway	2.0	1.4	0.9	1.4	1.4	0.6
Switzerland	7.0	3.3	1.7	3.1	2.8	1.4
Bulgaria	8.6	5.1	1.3	4.2	4.1	1.1
Romania	9.6	5.6	1.6	5.0	4.8	1.3
EEA	8.9	5.2	2.6	4.9	4.6	2.0
EU-15	*8.7*	*5.2*	*2.8*	*5.0*	*4.7*	*2.1*
EU-10	*10.3*	*5.5*	*2.4*	*4.9*	*4.7*	*1.8*
EFTA	*5.1*	*2.6*	*1.4*	*2.5*	*2.2*	*1.1*
EU-25	9.0	5.3	2.7	5.0	4.7	2.1

Data for Cyprus, Iceland, Liechtenstein, and Turkey are not available

Provisional estimates of premature mortality attributable to ozone (cases of premature deaths per million inhabitants per year).

Country	2000	2020, CP		2030, LGEP		
		CLE	MFR	B-CLE	LE-CLE	B-MFR
Austria	52	39	27	39	37	21
Belgium	37	33	30	33	33	29
Denmark	34	30	24	30	29	19
Finland	11	12	8	12	12	6
France	45	37	28	37	36	23
Germany	52	40	31	40	38	26
Greece	60	54	32	56	55	22
Ireland	20	22	19	22	22	16
Italy	78	62	45	63	61	34
Luxembourg	74	61	48	60	58	41
Netherlands	27	23	22	22	23	20
Portugal	46	46	36	47	46	30
Spain	53	45	34	45	44	27
Sweden	22	21	15	22	21	12
UK	24	29	26	29	29	24
Czech Rep.	52	38	25	37	35	20
Estonia	15	15	9	16	16	8
Hungary	73	56	29	57	55	22
Latvia	17	18	9	19	19	8
Lithuania	27	26	11	28	28	9
Malta	34	31	24	31	30	16
Poland	36	29	16	29	29	12
Slovakia	44	33	18	33	31	14
Slovenia	56	41	26	41	39	19
Norway	20	22	18	22	22	16
Switzerland	64	46	34	46	43	28
Bulgaria	72	62	27	64	62	21
Romania	55	47	20	50	48	16
EEA	49	41	30	41	40	24
EU-15	*49*	*41*	*31*	*41*	*40*	*26*
EU-10	*43*	*34*	*19*	*34*	*33*	*15*
EU-25	*48*	*40*	*29*	*40*	*39*	*24*
EFTA	*48*	*37*	*28*	*37*	*35*	*23*

Data for Cyprus, Iceland, Liechtenstein, and Turkey are not available

Percentage of forest area receiving acid deposition above the critical loads

Country	2000	2020, CP		2030, LGEP		
		CLE	MFR	B-CLE	LE-CLE	B-MFR
Austria	15.2	4.7	0.5	3.8	3.2	0.4
Belgium	55.4	25.2	13.3	23.8	22.1	13.0
Denmark	31.8	5.7	0.3	7.8	6.8	0.3
Finland	1.6	0.9	0.4	1.0	1.0	0.4
France	12.4	4.2	0.7	4.1	3.8	0.3
Germany	72.3	43.0	12.9	40.1	35.5	10.7
Greece	0.6	0.0	0.0	0.0	0.0	0.0
Ireland	47.0	23.0	9.1	22.9	21.9	4.2
Italy	2.3	0.7	0.3	0.7	0.3	0.3
Luxembourg	35.1	13.7	0.0	9.9	9.6	0.0
Netherlands	88.3	80.6	52.3	80.7	80.2	33.2
Portugal	2.6	0.5	0.0	0.5	0.5	0.0
Spain	1.0	0.0	0.0	0.0	0.0	0.0
Sweden	23.7	15.3	8.4	16.5	16.0	8.1
UK	49.0	23.4	6.0	24.9	23.1	4.2
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0
Czech Rep.	80.8	29.9	1.8	23.4	20.2	0.6
Estonia	0.3	0.0	0.0	0.0	0.0	0.0
Hungary	3.9	1.1	0.0	1.0	0.6	0.0
Latvia	0.6	0.5	0.0	0.4	0.4	0.0
Lithuania	2.9	1.0	0.0	1.0	0.9	0.0
Poland	59.0	19.7	0.2	10.9	9.1	0.1
Slovakia	22.7	6.9	0.4	6.0	5.4	0.1
Slovenia	2.8	0.0	0.0	0.0	0.0	0.0
Norway	2.3	0.5	0.0	0.5	0.5	0.0
Switzerland	7.4	3.8	1.4	3.6	2.8	1.4
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0
Romania	4.2	1.0	0.0	0.8	0.7	0.0
EEA	18.1	8.7	2.6	8.0	7.3	2.2
EU-15	*17.7*	*9.8*	*3.7*	*9.7*	*8.9*	*3.2*
EU-10	*35.3*	*12.0*	*0.3*	*7.5*	*6.4*	*0.1*
EU-25	*20.8*	*10.2*	*3.1*	*9.3*	*8.5*	*2.6*
EFTA	*3.0*	*1.0*	*0.2*	*1.0*	*0.8*	*0.2*

Data for Cyprus, Iceland, Liechtenstein, Malta and Turkey are not available

Percentage of total ecosystems receiving nitrogen deposition above the critical loads for eutrophication.

Country	2000	2020, CP		2030, LGEP		
		CLE	MFR	B-CLE	LE-CLE	B-MFR
Austria	96.0	86.4	52.9	84.3	82.4	41.5
Belgium	92.7	60.8	23.3	58.5	54.8	18.4
Denmark	52.7	37.2	0.8	40.0	37.8	0.7
Finland	25.1	14.4	0.0	17.5	16.0	0.0
France	95.8	79.1	20.2	77.3	75.6	9.1
Germany	96.2	94.4	85.5	94.2	93.9	82.9
Greece	75.8	72.9	2.0	78.8	77.9	0.7
Ireland	11.6	3.3	0.0	2.4	2.2	0.0
Italy	62.3	47.7	12.8	49.1	47.2	10.4
Luxembourg	96.4	82.1	39.6	80.3	77.8	37.3
Netherlands	66.5	60.8	26.7	60.5	60.0	24.3
Portugal	29.7	12.0	0.0	13.2	7.8	0.0
Spain	64.6	50.1	6.7	49.7	47.6	1.6
Sweden	26.1	16.1	0.6	18.9	17.4	0.3
UK	13.3	5.5	0.0	6.2	5.1	0.0
Cyprus	47.8	63.6	13.2	64.9	64.7	8.5
Czech Rep.	95.2	76.6	11.9	75.4	71.8	9.1
Estonia	11.7	5.8	0.0	9.7	9.6	0.0
Hungary	30.7	24.4	4.6	24.7	24.5	3.4
Latvia	54.3	38.0	0.5	49.1	45.4	0.5
Lithuania	85.0	80.8	4.4	83.9	82.5	2.1
Poland	86.0	78.8	17.8	79.6	78.6	10.6
Slovakia	88.8	60.2	4.4	60.4	57.8	2.5
Slovenia	94.3	88.0	20.8	88.0	85.9	11.4
Norway	5.8	2.8	0.0	3.9	2.8	0.0
Switzerland	81.5	55.5	5.6	50.4	48.5	5.1
Bulgaria	80.8	84.4	3.1	85.6	84.7	3.0
Romania	87.1	88.1	10.5	90.2	89.0	10.1
EEA	52.5	43.3	12.3	44.5	43.1	9.7
EU-15	*54.3*	*43.0*	*16.0*	*44.0*	*42.5*	*12.7*
EU-10	*70.7*	*60.3*	*10.2*	*62.8*	*61.2*	*6.3*
EU-25	*57.0*	*45.9*	*15.0*	*47.2*	*45.7*	*11.7*
EFTA	*12.4*	*7.4*	*0.5*	*8.0*	*6.8*	*0.5*

Data for Iceland, Liechtenstein, Malta and Turkey are not available

Annex 3: Emission control costs by country

NO_x, million €$_{2000}$/year

Country	2000	2020, CP		2020	2030	2030, LGEP			
		CLE	MFR	LREM-E		B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	40	30	147	45	50	29	29	28	124
Belgium	55	43	269	62	101	43	40	42	271
Denmark	10	12	82	14	13	8	8	3	68
Finland	17	25	154	37	42	18	14	13	126
France	26	58	1,125	116	132	58	29	31	987
Germany	1,368	1,130	1,775	1314	1356	1,075	913	988	1,772
Greece	3	49	195	81	72	37	29	35	178
Ireland	4	21	97	24	22	12	13	8	75
Italy	107	188	971	216	259	149	127	140	902
Luxembourg	0	2	16	2	5	2	1	2	16
Netherlands	180	285	503	294	329	254	235	258	457
Portugal	5	32	140	36	34	6	6	6	127
Spain	9	83	593	100	126	75	65	57	555
Sweden	25	18	186	46	84	23	22	24	191
UK	56	65	1,229	137	106	33	31	31	1,039
Cyprus	0	1	11	1	1	1	1	1	9
Czech Rep.	21	46	184	55	41	30	26	27	170
Estonia	0	5	19	7	8	5	4	3	18
Hungary	4	20	142	25	38	11	12	13	116
Latvia	0	1	15	3	4	1	0	1	14
Lithuania	1	6	41	9	17	6	7	4	35
Malta	0	1	4	1	1	1	1	1	4
Poland	29	199	620	290	223	139	133	115	557
Slovakia	3	27	99	30	32	14	14	13	64
Slovenia	1	5	30	6	9	3	3	3	21
Norway	5	12	82	13	12	10	10	10	72
Switzerland	34	24	100	27	31	21	21	21	96
Bulgaria	0	9	97	13	29	13	13	13	75
Romania	1	22	232	28	48	24	22	24	217
Turkey	1	49	700	58	172	117	97	117	886
EEA	2,003	2,469	9,857	3090	3401	2,219	1,922	2,031	9,240
EU 15	*1,902*	*2,042*	*7,482*	*2525*	*2733*	*1,824*	*1,558*	*1,665*	*6,887*
EU 10	*59*	*310*	*1,164*	*427*	*375*	*210*	*202*	*180*	*1,007*
EFTA	*40*	*36*	*182*	*39*	*43*	*32*	*30*	*32*	*168*

NMVOC, million €$_{2000}$/year

Country	2000	2020, CP		2020	2030	2030, LGEP			
		CLE	MFR	LREM-E		B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	10	43	99	43	45	45	45	46	100
Belgium	30	75	95	74	79	80	80	80	99
Denmark	1	7	42	6	6	6	6	6	42
Finland	-5	4	54	3	3	4	4	4	53
France	185	515	783	511	513	517	514	516	780
Germany	87	327	568	318	363	372	366	371	582
Greece	-4	14	67	13	14	15	14	15	69
Ireland	3	23	33	22	24	24	24	24	34
Italy	37	257	421	250	256	262	260	262	415
Luxembourg	1	2	3	2	2	2	2	2	3
Netherlands	6	42	89	40	41	43	42	43	91
Portugal	-1	13	73	12	13	14	13	14	79
Spain	1	109	340	105	114	118	117	118	344
Sweden	22	46	107	45	47	48	48	48	109
UK	80	200	779	196	199	202	202	202	782
Cyprus	0	1	2	1	1	1	1	1	2
Czech Rep.	6	22	59	21	24	24	24	24	59
Estonia	0	1	7	1	1	1	1	1	5
Hungary	2	13	37	12	12	13	13	13	36
Latvia	-1	1	16	1	1	1	1	1	16
Lithuania	-1	2	32	1	1	2	2	2	30
Malta	0	0	1	0	0	0	0	0	1
Poland	-2	21	204	17	17	21	20	20	193
Slovakia	-15	-13	44	1	1	-15	-15	-15	46
Slovenia	-1	1	15	1	1	1	2	1	14
Iceland	4	17	106	17	18	18	18	18	105
Switzerland	17	39	68	38	40	40	40	40	70
Bulgaria	0	2	23	2	1	1	1	1	21
Romania	-4	2	141	2	2	2	2	2	144
Turkey	1	0	272	7	9	-5	-6	-5	268
EEA	462	1787	4577	1766	1848	1857	1839	1856	4590
EU 15	*455*	*1675*	*3552*	*1642*	*1719*	*1752*	*1736*	*1752*	*3581*
EU 10	*-12*	*50*	*416*	*57*	*59*	*49*	*48*	*48*	*402*
EFTA	*22*	*57*	*174*	*56*	*58*	*59*	*58*	*59*	*174*

NH_3, million €$_{2000}$/year

Country	2000	2020, CP		2020	2030	2030, LGEP			
		CLE	MFR	LREM-E		B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	23	28	561	31	30	27	27	27	547
Belgium	120	146	752	159	155	142	142	142	750
Denmark	134	233	924	300	294	229	229	229	917
Finland	37	49	221	58	54	47	47	47	215
France	87	111	2830	57	57	111	111	111	2795
Germany	746	712	1812	688	661	677	677	677	1672
Greece	0	0	257	0	0	0	0	0	246
Ireland	0	0	381	0	0	0	0	0	363
Italy	166	156	1385	185	175	147	147	147	1346
Luxembourg	0	0	22	0	0	0	0	0	20
Netherlands	493	589	1571	588	576	577	577	577	1541
Portugal	0	0	566	0	0	0	0	0	563
Spain	0	0	2510	0	0	0	0	0	2487
Sweden	39	59	339	67	64	56	56	56	327
UK	52	51	1155	78	74	48	48	48	1128
Cyprus	0	0	44	0	0	0	0	0	43
Czech Rep.	15	42	350	48	55	48	48	48	349
Estonia	0	0	47	0	0	0	0	0	47
Hungary	36	29	310	29	29	29	29	29	312
Latvia	0	0	56	0	0	0	0	0	56
Lithuania	0	0	201	0	0	0	0	0	199
Malta	0	0	8	0	0	0	0	0	8
Poland	0	0	1408	0	0	0	0	0	1409
Slovakia	0	0	161	0	0	0	0	0	160
Slovenia	13	13	100	13	13	12	12	12	98
Norway	0	0	208	0	0	0	0	0	212
Switzerland	0	0	68	0	0	0	0	0	66
Bulgaria	0	0	424	0	0	0	0	0	424
Romania	0	0	1283	0	0	0	0	0	1283
Turkey	0	0	1689	0	0	0	0	0	1900
EEA	1960	2217	21639	2301	2236	2150	2150	2150	21484
EU 15	*1896*	*2133*	*15286*	*2211*	*2139*	*2061*	*2061*	*2061*	*14918*
EU 10	*63*	*84*	*2682*	*90*	*96*	*89*	*89*	*89*	*2680*
EFTA	*0*	*0*	*276*	*0*	*0*	*0*	*0*	*0*	*279*

SO_2, million €$_{2000}$/year

Country	2000	2020, CP		2020	2030	2030, LGEP			
		CLE	MFR	LREM-E		B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	292	316	326	345	371	291	259	285	304
Belgium	373	463	521	524	667	436	391	435	478
Denmark	319	144	158	150	152	128	119	112	142
Finland	296	320	377	332	343	280	256	269	329
France	1378	1920	2393	2152	2256	1884	1583	1729	2327
Germany	2623	2142	2700	2833	2805	2087	1541	1799	2710
Greece	182	459	593	547	539	412	347	404	582
Ireland	86	179	204	191	196	148	130	146	172
Italy	1913	1611	1823	1839	1911	1484	1249	1448	1708
Luxembourg	29	58	63	61	77	57	45	57	61
Netherlands	327	360	422	396	512	384	294	374	443
Portugal	86	305	385	330	384	278	229	272	364
Spain	693	1364	1627	1448	1653	1386	1210	1348	1635
Sweden	477	436	487	536	640	455	438	464	525
UK	1052	1088	1245	1332	1232	926	828	891	1101
Cyprus	4	63	83	65	73	59	54	59	77
Czech Rep.	407	275	387	326	314	141	123	136	179
Estonia	9	36	51	42	42	24	23	19	35
Hungary	92	155	201	201	256	149	135	148	193
Latvia	7	33	41	42	46	32	31	32	39
Lithuania	15	59	76	70	86	53	54	49	69
Malta	0	17	24	19	21	18	15	18	26
Poland	600	895	1453	1067	1185	794	759	697	1288
Slovakia	50	143	196	151	172	97	92	94	124
Slovenia	47	57	71	85	75	40	38	38	53
Norway	64	102	126	109	105	93	87	93	114
Switzerland	109	110	166	114	114	104	92	104	161
Bulgaria	32	79	221	93	148	98	86	98	156
Romania	67	185	364	216	317	191	171	191	352
Turkey	196	805	1359	884	1070	770	753	770	1207
EEA	11824	14180	18143	16504	17764	13300	11430	12575	16954
EU 15	*10124*	*11165*	*13325*	*13020*	*13738*	*10637*	*8919*	*10031*	*12881*
EU 10	*1232*	*1733*	*2583*	*2068*	*2270*	*1408*	*1323*	*1289*	*2082*
EFTA	*173*	*212*	*292*	*223*	*220*	*197*	*179*	*197*	*275*

PM, million €$_{2000}$/year

Country	2000	2020, CP		2020	2030	2030, LGEP			
		CLE	MFR	LREM-E		B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	121	214	873	223	216	207	191	209	847
Belgium	156	130	310	161	200	109	104	110	283
Denmark	78	80	338	82	82	77	74	66	328
Finland	135	249	871	246	222	199	187	197	709
France	614	972	4077	1048	978	876	765	856	3721
Germany	1660	1396	2594	1738	1690	1241	1055	1151	2468
Greece	303	245	677	329	297	173	137	160	602
Ireland	45	63	195	64	68	61	58	65	201
Italy	297	497	1463	495	517	400	360	406	1241
Luxembourg	6	8	13	9	13	7	7	7	13
Netherlands	160	118	482	121	158	113	101	114	469
Portugal	57	115	760	121	133	109	93	111	841
Spain	387	368	1176	408	472	338	303	342	1105
Sweden	182	329	1245	365	359	292	288	294	1066
UK	640	484	1002	547	564	456	435	456	967
Cyprus	4	5	18	5	5	5	5	5	17
Czech Rep.	400	227	350	268	283	100	93	97	199
Estonia	66	22	115	26	25	15	13	12	69
Hungary	95	90	251	117	145	81	79	79	222
Latvia	14	16	73	21	23	16	16	17	53
Lithuania	15	23	224	30	36	20	21	20	156
Malta	1	2	3	2	2	2	2	2	3
Poland	789	696	2313	785	754	563	538	520	1822
Slovakia	96	94	147	96	98	66	64	67	109
Slovenia	38	19	89	34	33	11	11	12	58
Norway	61	87	224	90	65	63	62	63	147
Switzerland	56	41	128	41	34	36	34	36	113
Bulgaria	211	191	444	212	158	141	139	141	269
Romania	216	131	934	202	209	107	99	107	497
Turkey	492	742	4909	812	820	643	624	643	3618
EEA	7396	7651	26299	8696	8657	6526	5955	6362	22211
EU 15	*4841*	*5267*	*16076*	*5955*	*5969*	*4659*	*4157*	*4543*	*14860*
EU 10	*1519*	*1193*	*3583*	*1383*	*1403*	*878*	*841*	*830*	*2708*
EFTA	*117*	*128*	*352*	*131*	*99*	*98*	*96*	*98*	*260*

Mobile sources, million €$_{2000}$/year

Country	2000	2020, CP		2020	2030	2030, LGEP			
		CLE	MFR	LREM-E		B-CLE	LE-CLE	SER-CLE	B-MFR
Austria	164	769	924	791	1039	963	860	961	1,258
Belgium	187	1,102	1,313	1127	1329	1,238	1,064	1,237	1,629
Denmark	115	539	664	547	688	646	617	646	826
Finland	68	444	544	439	497	467	423	467	604
France	941	4,220	5,350	4298	5004	4,733	4,199	4,732	6,285
Germany	2,182	8,231	9,600	8880	10541	9,986	8,713	9,984	12,671
Greece	116	1,174	1,366	1201	1631	1,558	1,437	1,560	1,892
Ireland	96	749	884	770	872	764	652	764	946
Italy	908	4,757	5,843	5015	5797	5,515	4,882	5,515	7,097
Luxembourg	54	235	273	241	273	249	199	248	304
Netherlands	319	1,947	2,319	2045	2607	2,456	1,848	2,454	3,066
Portugal	143	1,164	1,444	1202	1706	1,581	1,320	1,580	2,012
Spain	501	3,801	4,850	3796	4890	4,765	4,363	4,773	6,322
Sweden	228	769	947	836	833	782	702	761	1,164
UK	1,214	5,434	6,423	5475	6493	6,211	5,679	6,205	7,962
Cyprus	8	58	73	60	63	59	55	59	77
Czech Rep.	57	712	862	727	877	814	755	817	1,028
Estonia	7	123	148	120	128	118	119	118	149
Hungary	57	710	855	723	834	773	705	777	971
Latvia	0	166	197	165	189	175	170	175	219
Lithuania	14	294	348	278	336	312	310	313	392
Malta	3	21	25	22	22	21	19	21	26
Poland	269	2,155	2,628	2199	3086	2,781	2,750	2,804	3,597
Slovakia	30	446	546	387	503	466	451	467	603
Slovenia	33	175	219	180	234	221	208	222	292
Norway	117	530	674	542	591	536	476	536	734
Switzerland	270	675	832	690	757	708	626	708	929
Bulgaria	0	315	399	320	359	334	319	334	456
Romania	0	935	1,190	947	1230	1,175	1,075	1,175	1,580
Turkey	0	1,968	2,468	2001	2949	2,694	2,535	2,694	3,706
EEA	8,104	44,620	54,209	46022	56359	53,101	47,531	53,108	68,798
EU 15	*7,238*	*35,337*	*42,745*	*36662*	*44200*	*41,914*	*36,958*	*41,888*	*54,038*
EU 10	*479*	*4,860*	*5,901*	*4860*	*6271*	*5,740*	*5,542*	*5,773*	*7,354*
EFTA	*388*	*1,205*	*1,505*	*1232*	*1348*	*1,243*	*1,102*	*1,243*	*1,663*

Annex 4: Emission projections per city and sector

Emissions per city

SO_2 emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
Reference year (2000)	39.939	21.975	11.828	17.266	44.464	21.961	52.433	16.164	31.957	20.057	36.786	26.787	197.340	19.522	29.434	264.464	48.758	17.232	2.883	80.174
LGEP-B-CLE (2030)	1.854	8.961	4.882	6.166	11.782	15.203	27.689	6.035	8.312	4.622	21.658	10.173	84.172	7.024	11.007	94.837	25.893	6.111	1.101	30.718
LGEP-B-MFR (2030)	1.204	5.051	3.983	3.029	4.855	5.921	16.559	2.911	4.752	3.078	15.427	4.943	20.180	4.794	5.736	26.975	9.061	3.213	723	15.854

PM_{10} emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
Reference year (2000)	10.207	3.890	4.522	8.379	9.054	10.311	14.656	5.013	19.036	18.277	17.157	6.694	16.189	9.701	6.038	40.492	9.365	11.522	1.776	11.497
LGEP-B-CLE (2030)	1.685	2.370	2.248	3.997	3.028	9.031	9.584	1.979	7.474	8.603	15.145	6.262	3.908	5.202	2.661	14.580	8.167	6.110	1.196	5.661
LGEP-B-MFR (2030)	1.166	1.650	1.599	2.180	1.095	4.392	4.727	1.581	4.406	5.544	9.965	3.854	1.800	3.777	1.833	6.463	5.017	2.920	826	4.059

$PM_{2.5}$ emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
Reference year (2000)	6.790	2.932	2.835	6.744	4.466	8.880	11.983	4.192	14.654	12.149	11.004	4.603	8.210	7.370	4.829	20.071	6.927	9.713	1.437	9.173
LGEP-B-CLE (2030)	933	1.621	1.231	2.815	1.560	7.485	7.926	1.386	5.183	5.045	9.568	4.167	1.890	3.278	1.756	8.081	5.809	4.745	835	3.987
LGEP-B-MFR (2030)	579	1.061	665	1.224	569	3.209	3.438	1.037	2.593	2.910	5.858	2.491	889	2.036	1.126	3.879	3.415	2.095	516	2.648

NOx emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
Reference year (2000)	79.744	50.056	30.655	45.836	21.197	65.896	88.891	57.531	83.278	57.593	50.045	36.764	64.625	144.913	51.535	136.744	63.578	42.892	26.148	46.568
LGEP-B-CLE (2030)	24.633	28.075	12.606	19.561	10.207	38.912	54.096	23.887	35.843	23.644	34.277	27.526	30.207	52.945	21.508	74.777	41.157	21.086	12.729	27.543
LGEP-B-MFR (2030)	13.896	18.751	6.869	10.707	5.773	20.981	28.497	11.015	19.565	13.682	20.445	8.733	11.773	31.487	10.619	31.465	16.862	11.019	8.939	12.196

VOC emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
Reference year (2000)	85.926	51.997	51.486	88.305	37.759	150.787	81.531	104.694	101.159	80.234	238.292	85.809	76.116	135.390	122.818	52.611	123.579	92.916	46.401	113.449
LGEP-B-CLE (2030)	50.625	26.468	20.219	39.343	17.363	88.830	40.850	31.731	32.200	34.048	159.816	54.608	29.718	56.570	55.375	27.722	61.462	44.045	21.522	50.508
LGEP-B-MFR (2030)	26.134	22.244	12.915	29.157	11.129	58.796	25.618	24.954	23.868	24.301	102.373	26.736	20.253	42.104	38.654	18.172	32.774	32.796	16.942	33.757

NH_3 emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
Reference year (2000)	1.423	112	223	358	844	878	341	787	1.081	1.596	455	3.673	2.008	451	63	1.498	1.530	954	843	1.245
LGEP-B-CLE (2030)	1.349	105	149	280	881	777	293	676	640	1.254	432	3.058	2.265	405	29	1.739	1.215	882	793	1.091
LGEP-B-MFR (2030)	361	103	80	172	362	555	181	485	436	736	294	844	916	279	49	1.222	183	758	661	529

Emissions per city and sector

Reference year (2000)

SO_2 emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	19.413	9.827	6.906	4.189	4.777	2	42.388	86	0	0	1.582	0	32.683	0	0	94.598	0	6.899	370	0
SNAP 2	20.057	5.122	2.906	1.769	27.940	1.907	3.863	5.873	9.129	6.906	12.309	15.711	67.307	6.886	12.694	40.912	25.028	4.144	925	15.381
SNAP 3	428	5.667	1.308	7.095	7.219	15.585	5.206	5.123	12.902	2.249	21.606	9.033	77.932	7.409	10.678	112.657	10.837	2.797	851	53.857
SNAP 4	0	379	0	0	3.591	0	0	1.353	1	2.043	133	4	17.466	582	3.107	15.250	2.010	0	30	0
SNAP 5	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
SNAP 6	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0
SNAP 7	0	325	520	4.151	660	4.302	475	2.636	6.859	4.515	1.157	1.540	1.867	4.489	2.355	795	3.109	2.539	363	9.240
SNAP 8	40	494	188	48	277	166	500	1.085	126	86	0	498	38	157	600	252	7.773	312	267	1.666
SNAP 9	1	138	0	15	0	0	0	7	2.941	4.259	0	0	47	0	0	0	0	543	64	30
SNAP 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PM_{10} emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	3.337	1.119	78	79	462	1	2.168	17	10	14	66	0	3.813	0	22	3.984	0	584	44	0
SNAP 2	3.475	644	761	3.544	7.160	4.480	8.237	796	6.503	4.155	5.159	2.217	7.835	2.951	1.690	20.534	3.563	6.406	413	1.922
SNAP 3	427	251	55	255	334	1.419	1.662	1.046	1.303	712	3.290	1.855	2.400	551	959	10.243	2.301	143	109	4.308
SNAP 4	38	730	0	0	650	0	0	0	0	5.646	7.557	1.818	0	881	837	5.145	1.658	0	120	438
SNAP 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 7	1.862	705	3.320	4.335	393	3.782	1.190	2.043	8.440	5.611	1.085	723	2.021	5.079	1.897	542	1.518	2.755	727	4.204
SNAP 8	894	441	308	149	55	629	1.399	1.075	2.482	1.704	0	42	120	220	632	44	323	553	364	486
SNAP 9	45	1	0	18	0	0	0	13	299	435	0	0	0	17	0	0	0	1.080	0	121
SNAP 10	128	0	0	0	0	0	0	24	0	0	0	39	0	0	0	0	4	0	0	17

$PM_{2.5}$ emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	2.086	890	96	45	151	0	886	10	6	8	53	0	901	0	13	1.302	0	328	35	0
SNAP 2	2.021	529	1.078	3.385	3.335	4.167	7.793	739	4.960	3.169	4.680	1.895	4.590	1.824	1.570	9.564	3.045	6.119	352	1.666
SNAP 3	236	188	68	136	185	1.072	1.048	775	683	373	2.773	1.422	1.324	322	710	5.686	1.764	76	82	3.212
SNAP 4	19	360	0	0	376	0	0	0	0	2.356	2.708	663	0	336	418	2.974	605	0	59	212
SNAP 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 7	1.518	548	1.155	3.023	363	3.052	952	1.639	6.650	4.421	790	575	1.281	4.671	1.522	500	1.208	1.922	565	3.508
SNAP 8	846	416	438	144	56	588	1.305	1.011	2.091	1.436	0	40	114	199	595	44	305	536	343	460
SNAP 9	41	1	0	12	0	0	0	13	265	386	0	0	0	19	0	0	0	733	0	112
SNAP 10	24	0	0	0	0	0	0	5	0	0	0	7	0	0	0	0	1	0	0	3

NOx emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	15.624	18.371	6.183	809	4.113	10	46.503	423	70	97	597	0	28.884	0	564	35.459	0	5.954	721	0
SNAP 2	13.463	5.523	2.041	3.210	5.114	2.361	10.031	1.995	11.351	7.147	7.345	949	8.624	7.332	4.237	14.667	1.525	5.803	3.847	1.933
SNAP 3	3.636	3.606	971	2.345	2.242	4.809	5.845	7.653	5.658	1.517	27.890	1.429	9.444	4.436	7.019	68.814	1.773	1.310	1.560	14.479
SNAP 4	20	698	0	0	774	0	0	0	0	1.421	999	15.736	2.049	98	207	6.120	14.350	0	115	69
SNAP 5	0	222	0	0	0	0	0	4	0	0	0	0	0	101	14	0	0	71	3	0
SNAP 6	0	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	0
SNAP 7	45.068	12.797	16.218	38.380	7.855	55.917	19.525	34.085	62.036	42.448	13.214	17.192	15.333	129.440	31.645	10.832	36.092	24.395	13.189	27.646
SNAP 8	1.928	7.780	5.242	1.070	989	2.799	6.987	13.341	1.407	966	0	1.289	234	3.407	7.848	777	9.822	3.986	6.423	2.384
SNAP 9	4	1.014	0	22	110	0	0	29	2.756	3.997	0	0	56	98	0	75	0	1.375	212	56
SNAP 10	0	0	0	0	0	0	0	1	0	0	0	168	0	0	0	0	17	0	0	1

VOC emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	432	174	179	109	84	0	0	3	2	2	407	0	609	0	4	845	0	87	18	0
SNAP 2	10.236	4.975	7.466	7.274	9.348	7.489	0	722	2.154	1.585	133.142	16	15.296	2.345	466	10.707	26	4.748	621	4.070
SNAP 3	1.476	171	40	86	654	162	0	95	131	135	1.160	22	2.783	234	383	3.438	27	79	144	1.215
SNAP 4	8.232	2.036	0	3.684	1.697	7.360	10.820	951	1.994	5.119	11.104	4.772	712	9.278	2.856	5.846	6.911	982	1.036	2.567
SNAP 5	439	3.499	1.746	3.362	1.537	4.950	4.850	6.277	2.238	2.344	9.490	2.133	9.112	4.713	4.994	2.766	3.207	3.490	1.473	5.522
SNAP 6	51.229	24.958	10.880	22.402	10.343	58.137	26.339	17.179	15.010	18.994	45.320	44.489	21.650	40.885	51.264	12.133	42.531	31.676	33.409	42.757
SNAP 7	10.223	14.757	20.192	49.151	12.135	66.749	38.227	66.421	79.421	51.888	37.455	33.620	25.839	76.332	61.445	15.867	68.219	45.224	8.515	56.643
SNAP 8	3.320	1.413	10.980	1.896	1.643	5.923	1.229	12.763	173	120	0	270	102	1.420	1.405	728	2.593	6.292	1.186	425
SNAP 9	339	14	0	340	282	9	65	105	31	46	130	5	11	184	0	246	9	333	0	212
SNAP 10	0	0	4	1	35	9	0	179	5	1	84	483	0	0	0	35	55	5	0	38

NH_3 emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	7	0	0	0	0
SNAP 2	0	0	0	0	9	0	0	18	0	0	16	0	0	0	16	15	0	0	0	0
SNAP 3	0	3	0	0	2	0	0	5	0	0	10	0	0	0	0	14	0	0	6	2
SNAP 4	710	2	0	108	427	118	0	0	0	0	0	2.238	0	219	0	1.041	1.252	9	1	82
SNAP 5	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 7	57	0	61	71	17	104	15	50	587	345	29	29	63	0	46	26	64	45	0	77
SNAP 8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 9	0	0	0	31	14	328	0	40	0	0	10	0	0	7	0	41	0	633	0	0
SNAP 10	656	95	161	148	374	328	326	673	494	1.251	389	1.406	1.946	224	0	354	214	267	835	1.084

LGEP-CLE (2030)

SO_2 emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	872	4.060	3.088	1.449	591	0	20.041	8	0	0	910	0	2.683	0	0	11.711	0	2.387	153	0
SNAP 2	862	2.000	1.225	760	3.931	968	2.484	1.402	2.110	1.596	5.557	5.631	2.988	766	3.031	5.756	8.970	1.779	361	4.657
SNAP 3	118	2.288	349	3.746	4.107	13.983	4.520	2.442	5.313	926	14.848	3.862	60.116	2.732	5.090	64.091	4.633	1.477	344	23.417
SNAP 4	0	298	0	0	3.120	0	0	931	1	1.482	134	5	18.224	534	2.139	13.247	2.340	0	24	0
SNAP 5	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
SNAP 6	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0
SNAP 7	0	93	88	180	7	148	496	176	777	512	209	44	105	2.884	157	8	88	110	104	1.243
SNAP 8	1	125	133	27	26	104	148	1.067	73	50	0	632	7	107	590	24	9.861	173	67	1.371
SNAP 9	1	77	0	5	0	0	0	7	39	56	0	0	47	0	0	0	0	185	35	30
SNAP 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PM_{10} emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	62	285	28	74	163	0	1.170	3	2	2	25	0	1.315	0	4	1.408	0	544	11	0
SNAP 2	249	680	451	1.627	2.083	6.020	6.280	206	1.795	1.147	3.621	1.941	1.011	544	437	5.973	3.120	2.942	436	817
SNAP 3	156	234	40	201	124	741	1.415	439	590	322	3.501	1.562	513	310	402	3.811	1.938	112	101	1.801
SNAP 4	30	636	0	0	380	0	0	0	0	3.519	7.350	2.260	0	742	714	3.005	2.061	0	105	442
SNAP 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 7	994	498	1.675	2.044	275	2.222	485	1.007	4.093	2.721	648	443	1.066	3.529	935	379	930	1.299	513	2.418
SNAP 8	15	35	54	34	4	49	234	288	724	497	0	15	3	61	169	3	115	127	29	44
SNAP 9	43	1	0	18	0	0	0	13	271	394	0	0	0	16	0	0	0	1.086	0	121
SNAP 10	136	0	0	0	0	0	0	24	0	0	0	41	0	0	0	0	4	0	0	18

$PM_{2.5}$ emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	52	235	42	40	62	0	537	2	2	2	21	0	320	0	3	530	0	298	9	0
SNAP 2	158	585	652	1.589	1.045	5.607	5.987	191	1.642	1.049	3.395	1.732	776	490	406	2.998	2.783	2.872	389	716
SNAP 3	115	186	57	126	89	630	925	359	375	205	3.140	1.373	361	209	329	2.742	1.703	70	81	1.538
SNAP 4	16	313	0	0	201	0	0	0	0	1.482	2.671	819	0	275	352	1.588	747	0	52	214
SNAP 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 7	515	269	404	1.015	159	1.203	261	545	2.314	1.539	340	223	431	2.233	506	220	467	645	277	1.363
SNAP 8	14	33	77	33	4	45	217	271	610	419	0	14	2	55	159	3	109	123	27	41
SNAP 9	38	1	0	12	0	0	0	13	240	349	0	0	0	17	0	0	0	737	0	112
SNAP 10	26	0	0	0	0	0	0	5	0	0	0	7	0	0	0	0	1	0	0	3

NO_x emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	2.290	11.089	2.912	417	1.198	3	32.198	243	38	52	663	0	5.312	0	324	10.329	0	3.072	435	0
SNAP 2	8.894	5.143	1.634	2.682	3.763	3.357	9.902	1.480	9.390	5.913	6.000	1.032	7.334	6.528	3.144	10.792	1.658	4.848	3.582	1.968
SNAP 3	2.165	2.669	867	2.141	1.467	6.346	4.696	5.677	3.903	1.047	20.307	1.550	10.450	3.680	5.207	45.011	1.923	1.196	1.155	13.794
SNAP 4	28	637	0	0	561	0	0	0	0	1.223	994	18.728	2.258	73	169	4.437	17.078	0	105	72
SNAP 5	0	222	0	0	0	0	0	4	0	0	0	0	0	101	14	0	0	71	3	0
SNAP 6	0	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	0
SNAP 7	10.911	4.617	4.037	13.640	2.848	27.657	4.764	8.733	21.539	14.738	6.312	4.637	4.743	40.049	8.108	3.928	9.734	8.670	4.759	10.461
SNAP 8	340	2.999	3.157	668	260	1.549	2.536	7.720	968	665	0	1.411	55	2.453	4.542	205	10.747	2.487	2.476	1.190
SNAP 9	4	652	0	12	110	0	0	29	4	6	0	0	56	62	0	75	0	743	137	56
SNAP 10	0	0	0	0	0	0	0	1	0	0	0	168	0	0	0	0	17	0	0	1

VOC emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	168	425	152	180	34	0	0	3	2	2	453	0	108	0	4	343	0	145	44	0
SNAP 2	1.295	5.551	5.962	3.654	2.916	10.869	0	187	1.116	821	91.988	17	3.781	922	121	3.339	28	2.385	693	1.553
SNAP 3	895	92	38	77	499	98	0	64	66	68	813	29	1.123	167	256	2.624	36	71	78	1.435
SNAP 4	9.174	1.588	0	3.920	1.931	8.537	9.718	863	2.008	5.154	11.592	5.230	692	7.949	2.592	6.652	7.573	1.045	808	2.375
SNAP 5	186	1.641	1.056	2.916	1.072	2.868	2.575	4.194	1.403	1.469	6.553	1.078	3.122	4.196	3.337	1.928	1.622	3.027	691	3.875
SNAP 6	36.301	12.040	7.195	15.785	7.240	48.434	21.574	13.005	13.830	17.501	35.884	42.371	16.711	28.787	38.807	8.493	40.506	22.319	16.116	28.032
SNAP 7	1.196	4.585	2.708	11.118	2.978	14.237	6.675	10.813	13.525	8.837	12.319	5.305	4.108	13.793	10.003	3.894	10.765	10.230	2.646	12.580
SNAP 8	1.071	532	3.103	1.352	376	3.768	244	2.320	214	149	0	90	61	564	255	167	866	4.486	447	410
SNAP 9	339	14	0	340	282	9	65	105	31	46	130	5	11	192	0	246	9	333	0	212
SNAP 10	0	0	4	1	35	9	0	179	5	1	84	483	0	0	0	35	55	5	0	38

NH_3 emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	0	0	0	0	28	0	0	0	0	0	1	0	0	0	0	282	0	0	0	0
SNAP 2	0	0	0	0	3	0	0	18	0	0	17	0	0	0	16	5	0	0	0	0
SNAP 3	0	1	0	0	2	0	0	3	0	0	8	0	0	0	0	18	0	0	2	2
SNAP 4	742	2	0	93	409	86	0	0	0	0	0	1.799	0	176	0	998	1.007	7	1	82
SNAP 5	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 7	30	0	9	20	6	50	3	14	188	111	6	8	27	0	13	10	19	13	0	37
SNAP 8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 9	0	0	0	30	9	325	0	32	0	0	10	0	0	5	0	25	0	615	0	0
SNAP 10	576	90	139	138	422	317	290	609	452	1.144	391	1.251	2.238	224	0	400	190	248	790	970

LGEP-MFR (2030)

SO_2 emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	445	1.849	2.402	731	175	0	9.686	7	0	0	875	0	569	0	0	3.472	0	1.204	70	0
SNAP 2	712	1.065	1.205	531	2.752	854	2.481	1.042	1.028	778	4.249	3.544	1.366	403	2.252	4.030	5.646	1.243	192	2.722
SNAP 3	46	1.573	244	1.583	1.001	4.909	3.800	1.139	2.924	510	9.960	1.268	14.464	987	2.375	15.626	1.522	624	236	11.649
SNAP 4	0	285	0	0	900	0	0	373	1	1.264	134	1	3.645	493	856	3.822	468	0	23	0
SNAP 5	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
SNAP 6	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0
SNAP 7	0	93	88	180	7	148	496	176	777	512	209	44	105	2.884	157	8	88	110	104	1.243
SNAP 8	1	125	44	5	20	9	96	175	22	15	0	86	1	28	97	18	1.336	32	67	239
SNAP 9	0	40	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	18	0
SNAP 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PM_{10} emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	24	233	14	9	101	0	1.158	1	0	1	15	0	278	0	1	867	0	65	9	0
SNAP 2	47	344	190	588	488	2.057	2.095	88	776	496	1.262	666	265	223	187	1.398	1.071	1.063	221	279
SNAP 3	102	208	34	159	77	645	966	379	298	163	2.273	1.497	399	191	348	2.357	1.856	89	90	1.600
SNAP 4	17	441	0	0	191	0	0	0	0	2.469	5.968	1.274	0	431	380	1.515	1.162	0	73	223
SNAP 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 7	838	405	1.317	1.395	235	1.656	368	812	2.749	1.828	448	391	856	2.881	754	324	822	887	418	1.824
SNAP 8	14	19	44	17	3	34	141	276	340	233	0	14	2	37	162	3	105	63	15	40
SNAP 9	25	0	0	12	0	0	0	8	244	355	0	0	0	13	0	0	0	754	0	83
SNAP 10	99	0	0	0	0	0	0	17	0	0	0	12	0	0	0	0	1	0	0	10

$PM_{2.5}$ emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	21	198	21	9	41	0	533	1	0	1	14	0	88	0	1	352	0	64	8	0
SNAP 2	33	308	276	575	258	1.923	1.990	82	717	458	1.182	596	212	207	174	740	958	1.040	205	246
SNAP 3	86	164	49	103	63	557	630	319	237	129	2.207	1.325	305	141	293	1.942	1.643	58	71	1.381
SNAP 4	7	192	0	0	86	0	0	0	0	1.053	2.280	383	0	131	167	680	349	0	32	97
SNAP 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 7	370	181	256	511	118	697	156	364	1.135	754	175	174	282	1.509	338	162	366	325	186	803
SNAP 8	13	17	63	16	3	32	129	259	286	197	0	13	2	33	153	3	99	61	14	38
SNAP 9	25	0	0	9	0	0	0	8	218	318	0	0	0	15	0	0	0	548	0	82
SNAP 10	23	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	1

NOx emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	1.039	6.941	1.754	208	543	2	13.723	104	13	18	410	0	1.713	0	138	4.684	0	1.531	272	0
SNAP 2	4.677	4.962	1.216	1.697	2.564	2.771	9.346	1.022	5.787	3.644	4.398	713	3.944	3.480	2.169	7.354	1.146	3.067	3.456	1.309
SNAP 3	723	1.156	244	699	498	2.206	1.545	2.030	1.498	402	11.139	388	2.509	1.146	1.861	15.297	481	390	500	4.244
SNAP 4	7	482	0	0	187	0	0	0	0	1.223	850	3.745	452	18	56	1.479	3.415	0	79	39
SNAP 5	0	222	0	0	0	0	0	4	0	0	0	0	0	101	14	0	0	71	3	0
SNAP 6	0	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	0
SNAP 7	7.265	2.996	2.361	7.841	1.845	15.226	2.878	5.167	11.793	8.069	3.647	3.224	3.094	25.422	4.797	2.544	6.767	4.984	3.088	5.999
SNAP 8	185	1.712	1.294	262	135	776	1.005	2.689	475	326	0	663	35	1.276	1.582	106	5.052	976	1.414	605
SNAP 9	0	233	0	0	0	0	0	0	0	0	0	0	27	45	0	0	0	0	49	0
SNAP 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

VOC emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	168	424	153	180	34	0	0	3	2	2	447	0	106	0	4	343	0	144	44	0
SNAP 2	730	5.727	2.735	2.174	1.359	4.939	0	120	809	595	54.295	8	1.857	717	78	1.557	13	1.419	715	950
SNAP 3	915	92	41	77	499	102	0	64	65	67	838	31	1.084	167	256	2.622	39	71	78	1.434
SNAP 4	5.854	936	0	2.701	1.039	4.865	6.332	554	1.277	3.278	8.157	2.471	338	7.122	1.664	3.578	3.578	720	476	1.269
SNAP 5	174	1.554	895	2.606	741	2.442	1.544	4.124	1.333	1.396	6.168	634	3.062	2.584	3.281	1.334	953	2.706	654	3.164
SNAP 6	15.994	9.265	4.124	10.451	4.635	30.691	11.629	8.119	9.171	11.605	21.917	18.859	10.444	20.082	24.228	5.437	18.029	14.777	12.401	15.423
SNAP 7	953	3.730	2.140	9.466	2.275	12.328	5.876	9.618	10.976	7.171	10.420	4.596	3.294	10.748	8.897	2.975	9.326	8.710	2.153	10.921
SNAP 8	1.017	502	2.822	1.186	353	3.419	178	2.236	207	144	0	86	59	509	246	156	823	3.937	421	394
SNAP 9	330	14	0	314	190	9	61	99	29	43	121	4	10	174	0	166	8	308	0	195
SNAP 10	0	0	4	1	4	1	0	18	1	0	10	48	0	0	0	4	6	5	0	7

NH_3 emissions [kg/km^2]	PRAG	BERL	COPE	MARS	GDAN	LISB	HELS	ROME	BRUS	ANTW	GRAZ	THES	BUDA	LOND	MILA	KATO	ATHE	PARI	STUT	BARC
SNAP 1	0	0	0	0	57	0	0	0	0	0	3	0	0	0	0	566	0	0	0	0
SNAP 2	0	0	0	0	7	0	0	40	0	0	25	0	0	0	35	12	0	0	0	0
SNAP 3	0	20	0	0	32	0	0	56	0	0	82	0	0	0	1	247	0	0	47	15
SNAP 4	37	2	0	52	84	21	0	0	0	0	0	90	0	145	0	205	51	4	1	4
SNAP 5	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 7	30	0	9	20	6	48	3	14	189	111	6	9	27	0	13	10	19	13	0	37
SNAP 8	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNAP 9	0	0	0	30	9	325	0	32	0	0	10	0	0	5	0	25	0	615	0	0
SNAP 10	294	70	68	70	166	160	178	344	247	624	170	745	889	129	0	157	113	127	612	473

Local scale (street) emissions per city for the reference year (2000) for a narrow canyon (20000 vehicles/day)

	PM_{10} [g/km/day]	NO_x [g/km/day]
ANTW	2993	20420
ATHE	1629	26066
BARC	2469	27096
BERL	2247	18883
BRUS	2993	20420
BUDA	1912	30146
COPE	1955	26110
GDAN	2256	33866
GRAZ	3058	20856
HELS	1827	23606
KATO	2256	33866
LISB	3059	24856
LOND	1247	23542
MARS	1993	25287
MILA	1653	21949
PARI	1993	25287
PRAG	2175	24179
ROME	1653	21949
STUT	2247	18883
THES	1629	26066

Annex 5: Monitoring stations used in validation of urban and local air quality calculations

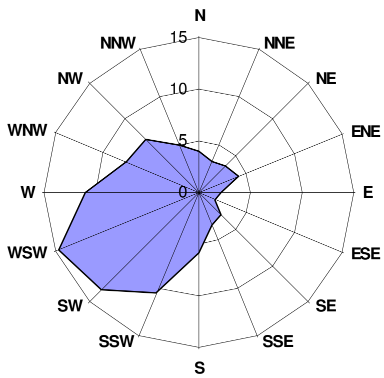
(The station codes correspond to the EU-codes in Airbase).

City Name	NO_2	O_3	PM_{10}
ANTW	BE0227A BE0232A BE0228A	-	BE0432A BE0204A
ATHE	GR0037A GR0031A GR0032A	GR0028A GR0035A	GR0037A GR0039A GR0030A
BARC	-	-	ES1024A ES1438A
BERL	DE1091A DE0742A DE1188A	DE0742A DE1091A	DE1091A DE0742A DE1115A
BRUS	BE0185A BE0186A BE0308A	BE0185A BE0186A	BE0185A BE0309A BE0402A
BUDA	HU0022A HU0021A	-	HU0022A HU0021A
COPE	DK0045A DK0034A	DK0045A	DK0045A DK0030A
GDAN	PL0045A PL0047A	PL0047A	PL0046A PL0052A
GRAZ	AT0085A AT0112A AT0205A	AT0022A AT0119A	AT0022A AT0109A AT0205A
HELS	FI0124A FI0142A	FI0124A	FI0124A FI0142A
KATO	PL0008A PL0022A PL0041A	PL0022A PL0008A	PL0022A PL0040A PL0041A
LISB	PT0091A PT0109A PT0093A	PT0091A	PT0087A PT0112A PT0093A

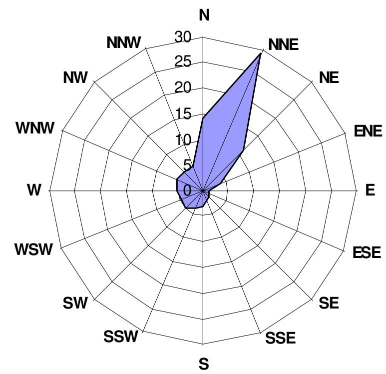
LOND	GB0566A GB0644A GB0682A	GB0586A GB0642A	GB0586A GB0566A GB0682A
MARS	FR1117A FR1115A FR0177A	FR1116A FR1117A	FR1108A FR1116A FR0177A
MILA	IT1017A IT0466A IT0477A	IT0466A IT1034A	IT0706A IT1034A IT0770A
PARI	FR0913A FR0331A FR0335A	FR0900A FR1181A	FR0351A FR0331A FR0335A
PRAG	CZ0020A CZ0010A CZ0065A	CZ0009A CZ0020A	CZ0009A CZ0020A CZ0012A
ROME	IT0953A IT0826A	IT0953A	IT0953A IT0828A
STUT	DE0749A DE0637A DE1171A	DE0640A DE0748A	DE0644A DE0900A DE1171A
THES	GR0045A EPTAPYRGIO (Municipality Network station) VENIZELOU (as above)	GR0047A EPTAPYRGIO	GR0047A

Annex 6: Wind roses and wind speeds assumed in the various cities for the local scale air quality analysis

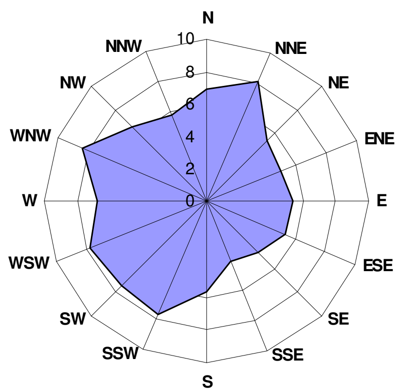
Wind direction Frequency for ANTW



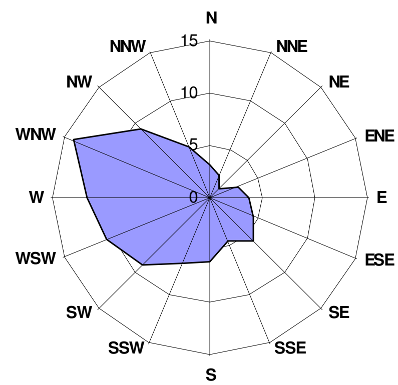
Wind direction Frequency for ATHE



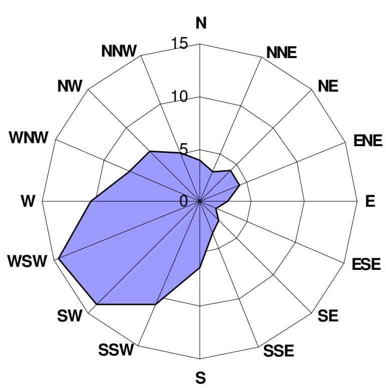
Wind direction Frequency for BARC



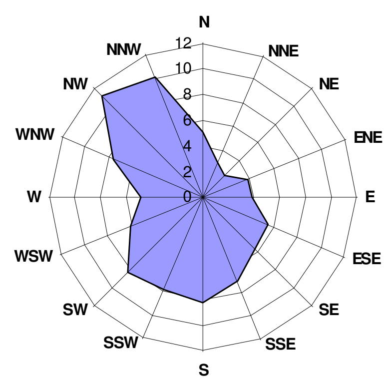
Wind direction Frequency for BERL

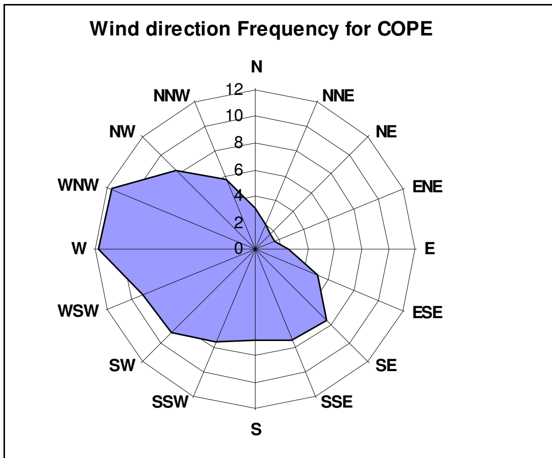


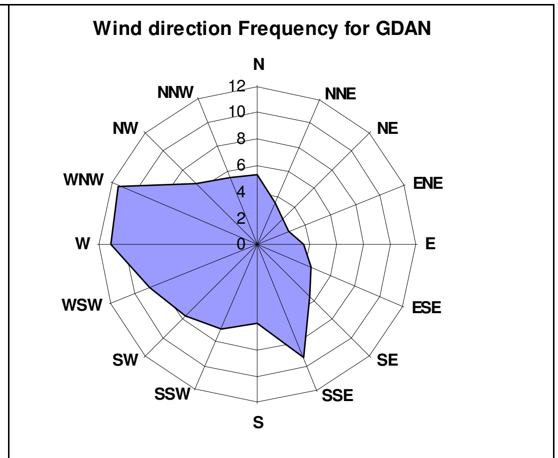
Wind direction Frequency for BRUS

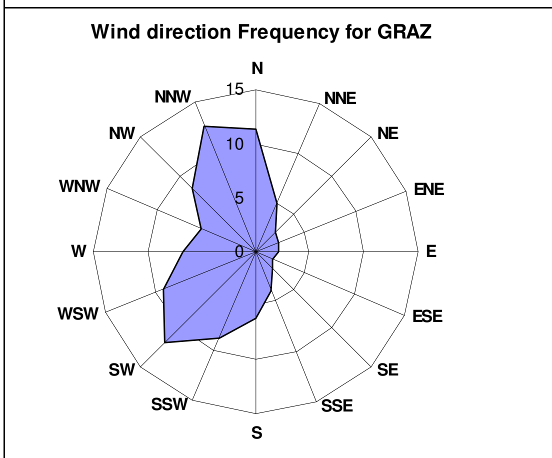


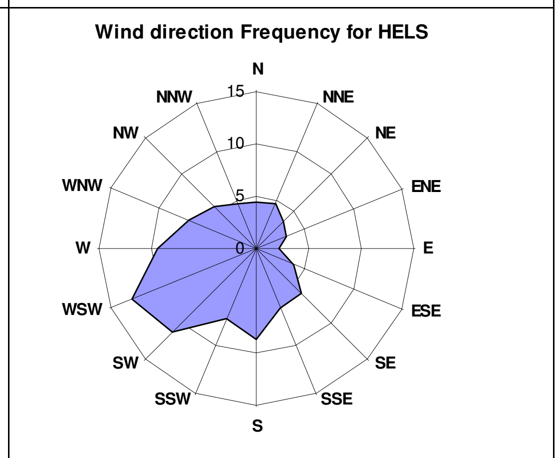
Wind direction Frequency for BUDA

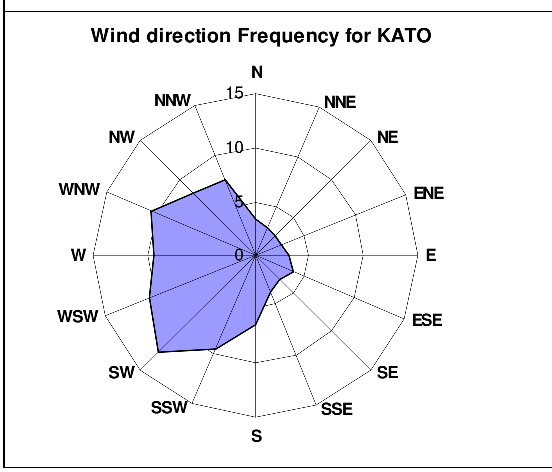


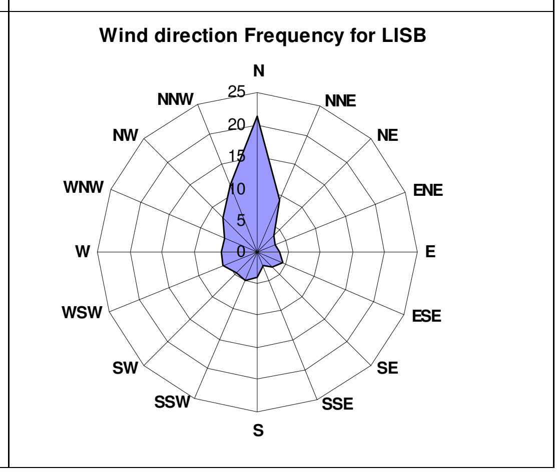

Wind direction Frequency for COPE
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0
2
4
6
8
10
12


Wind direction Frequency for GDAN
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0
2
4
6
8
10
12

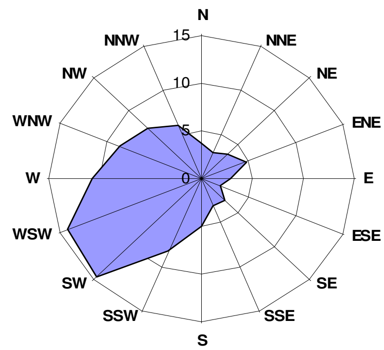

Wind direction Frequency for GRAZ
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0
5
10
15


Wind direction Frequency for HELS
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0
5
10
15

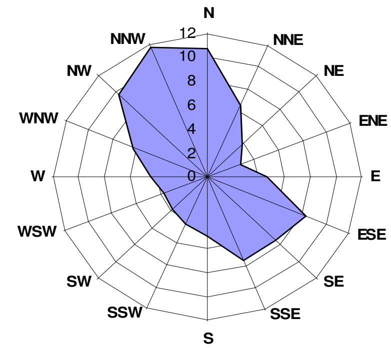

Wind direction Frequency for KATO
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0
5
10
15


Wind direction Frequency for LISB
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
0
5
10
15
20
25

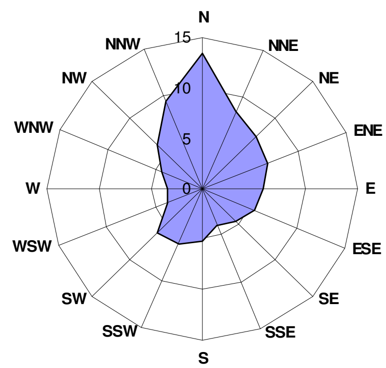
Wind direction Frequency for LOND



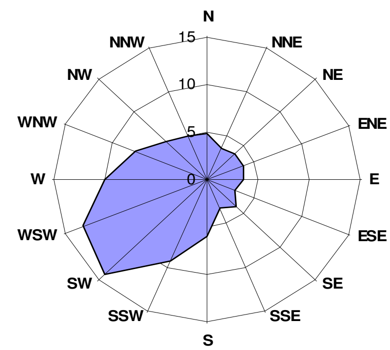
Wind direction Frequency for MARS



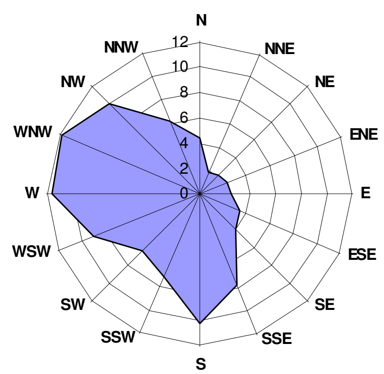
Wind direction Frequency for MILA



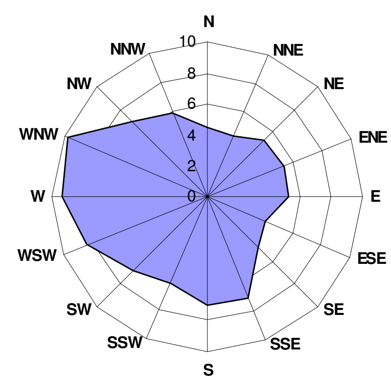
Wind direction Frequency for PARI



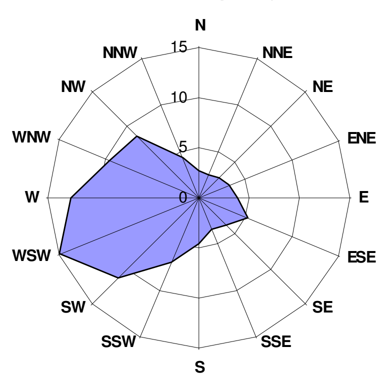
Wind direction Frequency for PRAG



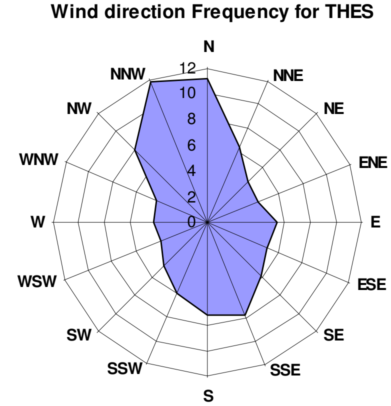
Wind direction Frequency for ROME



Wind direction Frequency for STUT



Wind direction Frequency for THES



Average yearly windspeeds considered in each city.

City	Wind speed (m/s)	City	Wind speed (m/s)
ANTW	3.10	KATO	2.62
ATHE	3.07	LISB	3.13
BARC	2.29	LOND	3.74
BERL	2.83	MARS	2.70
BRUS	3.06	MILA	1.66
BUDA	2.27	PARI	2.88
COPE	3.68	PRAG	2.63
GDAN	3.44	ROME	2.50
GRAZ	2.67	STUT	2.48
HELS	3.15	THES	1.90

Annex 7: Background information on models used

Models and uncertainties related to emission calculations

RAINS model

The Regional Air Pollution INformation and Simulation (RAINS) model provides a tool for analysis of reduction strategies for air pollutants (Amman et al., 1999). The model considers emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), non-methane volatile organic compounds (NMVOC) and particulate matter (PM). RAINS consists of several modules, which contain information on:

(i) economic activities causing emissions (energy production and consumption, passenger and freight transport, industrial and agricultural production, solvent use etc.)
(ii) emission control options and costs,
(iii) atmospheric dispersion of pollutants and
(iv) sensitivities of ecosystems and humans to air pollution.

It simultaneously addresses health and ecosystems' impacts of particulate pollution, acidification, eutrophication and tropospheric ozone. Thus it creates a consistent framework for multi-pollutant, multi-effect air pollution management. Historic emissions of air pollutants are estimated for each country in Europe based on information collected by international emission inventories (EEA 2001) and on national information (EMEP, 2004). The model also includes projections until 2030. Options and costs for controlling emissions are represented by several emission reduction technologies. Atmospheric dispersion processes over Europe for all pollutants are modeled based on results of the European EMEP model developed at the Norwegian Meteorological Institute (Simpson et al., 2003). The RAINS model incorporates databases on critical loads and critical levels compiled at the Coordination Center for Effects (CCE) at the National Institute for Public Health and Environmental Protection (RIVM) in the Netherlands (e.g. Hettelingh et al, 2004). For acidification and eutrophication the model estimates the area of ecosystems not protected for each country by comparing deposition on a grid-level against critical loads. For ozone, an estimate is made of the exceedance of critical (damage) thresholds for vegetation (natural ecosystems, agricultural crops) and human health. RAINS contains also a methodology that links air pollution scenarios with changes of statistical life expectancy (Mechler et al. 2002). The present structure of the RAINS model is illustrated in Table A7.1.

Table A7.1: Air quality management as a multi-pollutant, multi-effect problem.

	SO_2	NO_x	NH_3	VOC	Primary PM emissions
Acidification	√	√	√		
Eutrophication		√	√		
Ground-level ozone		√		√	
Health damage due to fine particles	√	√	√	√	
	via secondary aerosols				√

The model can be operated in the 'scenario analysis' mode, i.e., following the pathways of the emissions from their sources to their impacts. In this case the model provides estimates of regional costs and environmental benefits of alternative emission control strategies. An 'optimization mode' is also available to identify cost-optimal allocations of emission reductions in order to simultaneously achieve specified deposition and concentration targets.

In this way all four environmental problems from Table A7.1 can be addressed simultaneously. The formulation of the optimization problem in RAINS can be found in Amann et al., 2005.

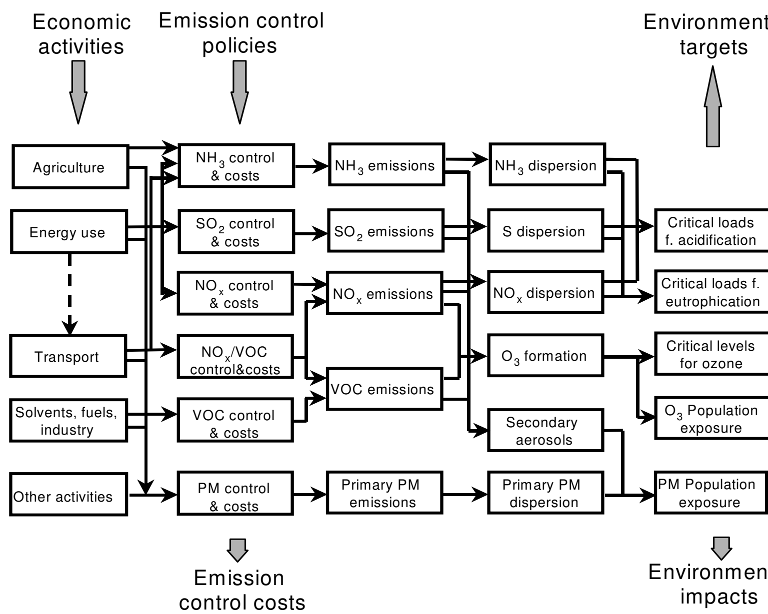


Figure A7.1: Flowchart of the RAINS model.

The model covers almost all European countries, including the European part of Russia. RAINS incorporates data on energy consumption for 42 regions in Europe, distinguishing about two dozens of categories of fuel use in six major economic sectors. The RAINS database also covers scenarios of non-energy economic activities responsible for air pollution (agricultural production, industrial processes, solvent use etc.). Activity scenarios are an exogenous input to the model.

RAINS calculates emission reductions for control strategies reflecting the current pollution control legislation in Europe. Emission reductions are assumed to be achieved exclusively by technical measures; any feedback of emission controls on economic and energy system is not included. Options and costs for controlling emissions for the various substances are represented in the model by reflecting characteristic technical and economic features of the most important emission control

technologies. The model covers several hundreds of technologies. For example, emissions of SO_2 can be controlled through the use of fuels with lower sulfur content or through desulfurization of flue gases. Reduction of the emissions from transport can be achieved through implementation of catalytic converters, engine modifications, particulate traps etc. For the reduction of NMVOC a wide range of measures (for instance, recovery of gasoline vapors, use of water-based paints, incineration or recovery of solvents) is available. The model assumes that all control technologies are generally available in every country. However, their actual implementation, and future technical potential and cost takes into account a number of country-specific circumstances like level of technological advancement, installation size distribution, operation regimes, labor costs, etc. Inclusion of those country-specific factors makes it possible to look for optimal cross-country allocation of emission control measures. Information on activities and emission sectors covered by RAINS as well as methodology for emissions and control costs calculation can be found in model technical documentation (http://www.iiasa.ac.at/rains/databases.html). Currently a WEB-based interface for emissions, control costs and environmental effects calculations is available (compare RAINS WEB, 2004). New functions and updates of input data to that interface are under development. More information about the model can be found in Amann et al., 2004.

EMEP model
The Unified EMEP model is an Eulerian model that has been developed at EMEP/MSC-W (Meteorological Synthesizing Centre – West of EMEP) for simulating atmospheric transport and deposition of acidifying and euthrophying compounds as well as photo-oxidants and $PM_{2.5}$ and PM_{10} in Europe. The latest model version has been documented in the EMEP Status Report I, Part I (Simpson *et. al.,* 2003) and the EMEP Status Report 2004 (Tarrasón et al., 2004) where a few updates are described. Model details and its applications can be also found on the EMEP web site: http://www.emep.int. Therefore, here only a short description of the basic features of the model is given.

The model domain covers Europe and the Atlantic Ocean. The model grid (of the size 170×133) has a horizontal resolution of 50 km at 60^oN, which is consistent with the resolution of emission data reported to CLRTAP. In the vertical, the model has 20 sigma layers reaching up to 100 hPa. Approximately 10 of these layers are placed below 2 km to obtain a high resolution within the boundary layer which is of special importance to the long range transport of air pollution. The Unified Model uses 3-hourly resolution meteorological data from the PARLAM-PS model, a dedicated version of the HIRLAM (HIgh Resolution Limited Area Model) Numerical Weather Prediction model.

The emissions consist of gridded annual national emissions of sulphur dioxide, nitrogen oxides, ammonia, non-methane volatile organic compounds and carbon monoxide. They are available in each cell of the 50×50 km^2 model grid anddistributed temporally according to monthly and daily factors derived from data provided by the University of Stuttgart (IER). Concentrations of 71 species are computed in the latest version of the Unified EMEP model (56 are advected and 15 are short-lived and not advected). Four secondary and two primary PM compounds are included in the model. The sulphur and nitrogen chemistry is coupled to the photo-chemistry, which allows a more sophisticated description of e.g. the oxidation of sulphur dioxide to sulphate, including also oxidant limitations.

Dry deposition is calculated using the resistance analogy and is a function of the pollutant type, meteorological conditions and surface properties. Parametrization of wet deposition processes includes both in-cloud and sub-cloud scavenging of gases and particles using scavenging coefficients.

Performance of the EMEP model
Recently, the performance of the EMEP model has been compared with five other air quality models (van Loon et al., 2004), with the main aim to establish the performance of the EMEP model amongst other state-of-the-art models. In this study the model were compared against measurements of various compounds at 162 locations, covering large parts of the EMEP model domain, for the years 1999 and 2001. Hence, the inter-comparison dealt with a broad range of different weather conditions and chemical regimes. A general conclusion in van Loon et al. (2004) is that all models have a good performance for ozone and oxidant, an intermediate performance for sulphate, nitrate, ammonium and precursors (NO_x, NO_2, SO_2), and a poor performance in NO and in wet concentrations and wet fluxes. PM_{10} and NO_x are substantially underestimated by all models. Partly, this is due to a poor representation of the vertical (and horizontal) gradients near the surface, which is a common problem

for all primary components. In the case of PM_{10} missing sources and components also contribute to the underestimation of the measurements. Therefore, integrated assessment can only deal with the identified part of PM, based on identified sources. The modelled concentration levels of the secondary inorganic contributions to PM_{10} agree generally quite well with observed levels. In a separate paragraph below the consequences for $PM_{2.5}$ are discussed further.

In general, the models show similar spatial patterns: the models perform usually better/worse compared to their average performance at the same stations, pointing in the direction of a common deficiency in regions with relatively poor general performance, either in the models themselves or in their input. Generally, the models perform best in central and north-west Europe, in a stretch of land north of the Alps and south of southern Scandinavia, from Great Britain to Poland.

With respect to the EMEP model, the study by van Loon et al. (2004) concludes that the EMEP model is a state-of-the-art model and that it is among the best performing models. The results also show that the relatively good performance of the EMEP model is seen throughout the whole domain, as is illustrated by Figure A7.2, where the correlation coefficients between modelled and observed times series of daily maximum ozone for the stations considered are plotted for the EMEP model together with the range of per station provided by the other models in the intercomparison.

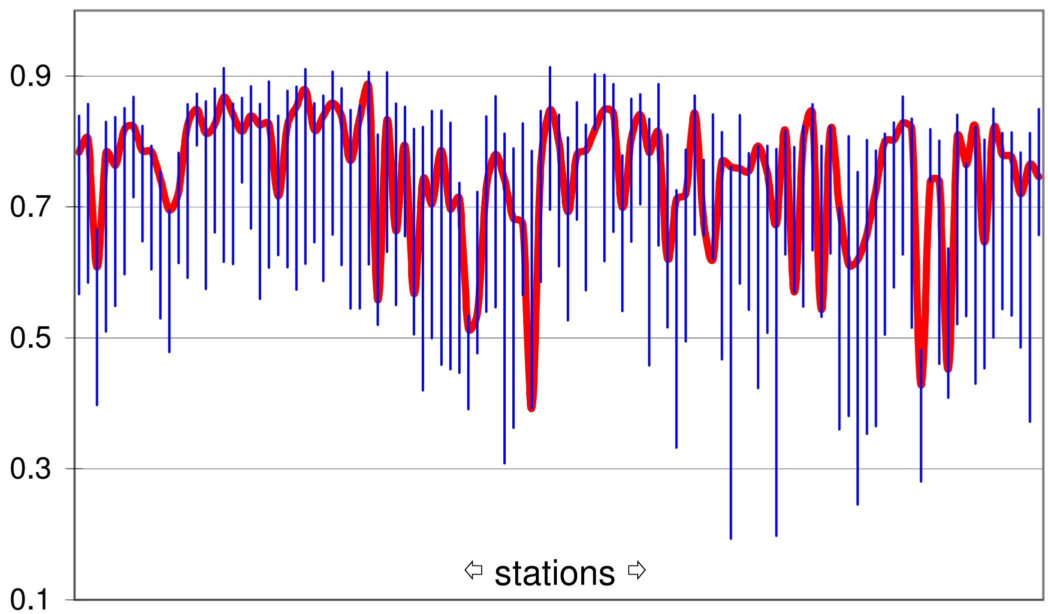


Figure A7.2: Correlation coefficients of daily maximum ozone in 1999 for the EMEP model (red line) and the range provided by the other models considered in van Loon et al. (2004). Reproduced from Appendix C in van Loon et al. (2004).

In the EMEP status reports of the year 2003 (Fagerli et al., 2003) and the year 2004 (Tarrasón et al., 2004) various comparisons are made between observed and modelled concentrations and depositions from the EMEP, showing similar performance of the EMEP model as in van Loon et al. (2004). In addition, the two EMEP status reports show that the EMEP model is quite well able to follow observed trends over a period of more than 20 years. This is another indication that the model is able to deal with a

broad range of meteorological and chemical regimes. In illustration of this is given in Figure A7.3 for sulphate in air.

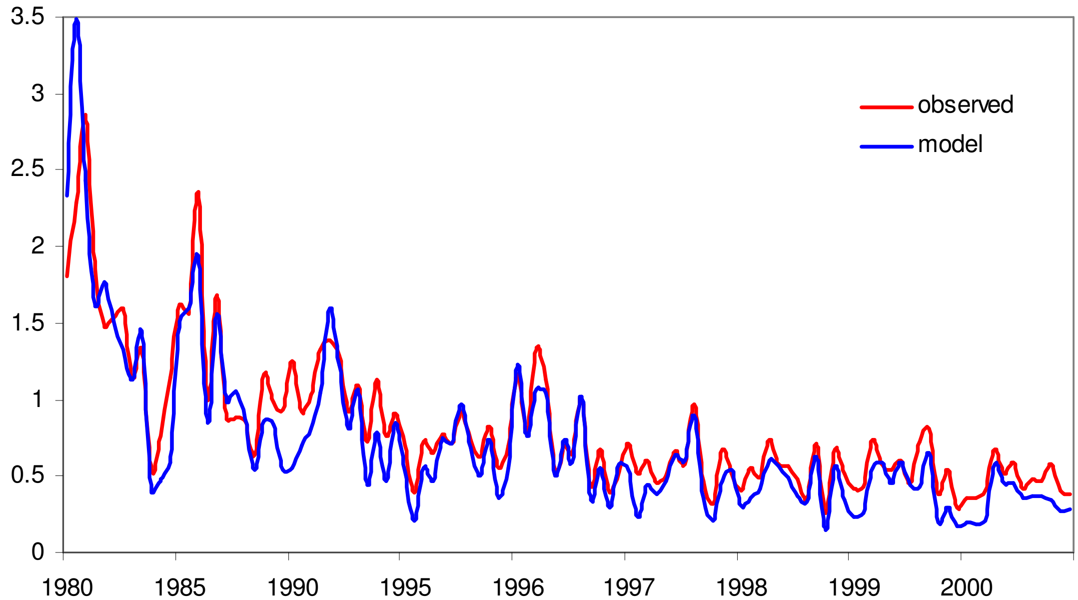


Figure A7.3: Modelled versus observed times-series (monthly)for sulphate in air (µg(S) m^{-3}) averaged over 12 stations in Europe. Reproduced from Figure 1.12 in Fagerli et al. (2004).

Impact of inter-annual meteorological variability

Recently, EMEP has carried out a pilot study on meteorological variability. The results of this study are currently under discussion in the CAFE steering group (Tarrasón et al., 2005). In this study the effect of meteorological variability on O_3 and $PM_{2.5}$ air concentration and sulphur and nitrogen depositions is investigated, by examining results for individual meteorological years with the 8-year average over the period 1995-2002 with the EMEP model using the same emissions for each of these years. The inter-annual differences are thus only driven by differences in meteorology. The magnitude of the inter-annual variations is dependent on the specific pollutant and indicator.

For ozone, yearly air concentrations over Europe may change by 5-10% due to changes in meteorology only. The summer ozone mean (April to September) is usually more robust to meteorological variations (below 5%), whereas the sum of ozone means over 35ppb (SOMO35) shows a slightly larger variability (between 5-15%). This is to be expected as any statistic based on the exceedance of a threshold value is more sensitive to meteorological variability than a non-threshold indicator. In fact, the higher the threshold is, the closer we get to the tail of the statistical distribution of ozone, and the larger is the sensitivity of the indicator to meteorological changes. These results for ozone are confirmed by calculations by the MATCH model in the framework of the EU-NEPAP project (Network for the support of European Policies on Air Pollution).

Similarly, inter-annual meteorological variability can impose changes in particulate matter concentrations (e.g. $PM_{2.5}$) up to 10-20%. The situation is similar for deposition of acidifying and eutrophying compounds.

For both ozone and PM, the changes in yearly air concentrations over Europe due to meteorology are comparable to those expected from reductions in emissions over the next decade. Therefore changes in meteorological conditions need to be considered when future air quality scenarios are analysed.

In Tarrasón et al. (2005) also the meteorological year 2003 is examined because of the extreme meteorological conditions by which this year was characterised: strong summer temperature increases and changes in the precipitation patterns in large parts of Europe. Both for ozone and PM extreme variations in the air quality indicators occur for 2003, considerably larger than for any of the previous years calculated either with the Unified EMEP model or the MATCH model. Current understanding on future climate situations indicates that such meteorological conditions would be more probable in the next 20-30 years and are expected to be within the statistical normal variability by 2070-2100.

With respect to the individual meteorological years in the period 1995-2002, it is concluded in Tarrasón et al. (2005) that the year 1997 together with 1998 is the closest to averaged conditions for most air quality indicators. In particular, the results for 1997 show relative low bias from the 8 year averaged $PM_{2.5}$ air concentrations and depositions of acidifying and eutrophying compounds in most European regions. It can therefore be concluded that for a first analysis the meteorological year 1997 is a reasonable choice. This conclusion agrees quite well the findings from the assessment of the CAFE baseline scenario, which considered the meteorological conditions of four years (1997, 1999, 2000 and 2003), finding that at least for particulate matter 1997 did not represent extreme conditions.

Thus, for full assessment, the calculations should include inter-annual meteorological variability, which was not possible because of resource (computer time) constraints. For the present purposes, the choice of the year 1997 seems to be reasonable. In addition, the selected year is consistent with the year used for setting environmental targets for the first round of the RAINS optimization analyses (compare Amann et al., 2004d). In the future, when refining the assessment, the inter-annual meteorological variability needs to be taken into account.

IMAGE model
IMAGE 2 (Integrated Model to Assess the Global Environment) is a so-called 'Integrated Assessment Model (IAM). IAM's are in general developed to assess human impacts on the environment and earth system. IMAGE 2 is a multi-disciplinary IAM, designed to simulate the dynamics of the global society-biosphere-climate system. The objectives of the model are both science and policy related. Scientific goals of the model are:

- to simulate future trends of greenhouse gas emissions.
- to investigate linkages and feedbacks in the society-biosphere-climate system.
- To assess the most important sources of uncertainty in such society-biosphere-climate linked system.
- To help identify gaps of knowledge about the system in order to help set the agenda for global change research.

On the other hand, policy-related goals of IMAGE 2 are:

- to support decision making by linking important scientific and policy aspects of global change
- to provide a dynamic and long-term (30-100 years) perspective about the consequences of global change.
- to evaluate the consequences of different policy options, and economic and technological scenarios, including costs and benefits.
- to provide insights in cross-linkages of various policy measures.

The combination of scientific and policy goals has steered the design and development of the model. Therefore the model is in general process-oriented but also contains several (global) parameterisations (e.g. in order to limit the computational and data requirements). Furthermore, although IMAGE 2 is global in application, calculations range from a 0.5^{o} longitude x 0.5^{o} latitude grid (for terrestrial issue) to world region level, depending on the type of calculations. The advantage of the geographic explicit calculations is that it greatly increases model testability against observations, allows an improved representation of feedbacks and enables more detailed information for climate change impact analysis. These characteristics increase the scientific credibility of the model.

IMAGE 2 consists of three systems of models (II-3): The Energy model TIMER, Terrestrial Environment System (TES), and Atmosphere Ocean System (AOS). Interactions and several feedbacks between these systems and underlying model are modelled explicitly. TIMER uses information on economic and demographic trends in the 18 regions to compute human activities, energy related variables (e.g. consumption, efficiency improvement, supply and trade of fossil fuel and renewables), industrial production and the emissions of greenhouse gases, ozone precursors and sulphur.

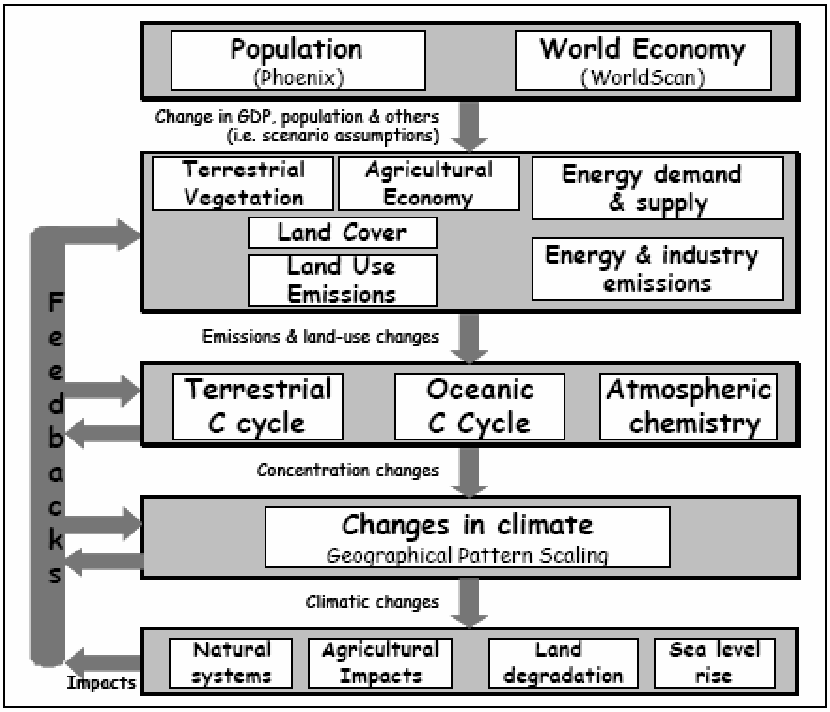


Figure A7.4: The structure of the IMAGE model

TES consists of various models computing food, fodder and wood demand, crop and animal production, trading of food and timber, the distribution of natural ecosystem, greenhouse gas emissions from land-use change, natural ecosystems and agricultural production systems, and the C storage pools within the terrestrial biosphere and exchange between biosphere and atmosphere. Models in the AOS compute changes in atmospheric composition by employing the emissions from TIMER and TES and by taking the oceanic and terrestrial CO_2 uptake and atmospheric chemistry into consideration. Subsequently, changes in climatic properties are computed by resolving oceanic heat transport and the changes in radiative forcing by GHGs and aerosols. Finally, IMAGE 2 contains specific impact models for sea-level rise and land degradation risk.

TIMER model
The energy system model, TIMER (Targets IMage Energy Regional Model), has been developed to simulate long-term energy baseline and mitigation scenarios and explore the long-term dynamics of the energy system. The model describes the investments in, and the use of, different types of energy options influenced by technology development (learning-by-doing) and depletion. Inputs to the model are macro-economic scenarios and assumptions on technology development, preference levels and fuel trade. The output of the model demonstrates how energy intensity, fuel costs and competing non-fossil supply technologies develop over time. The model recognises 17 world regions, 5 different end-use sectors, several different energy-producing sectors and about 10 energy carriers. The electricity generation sub-model includes production options based on hydropower, nuclear energy, renewables and different fossil fuels. The model is linked to an emission module that relates energy use to emissions of various greenhouse gases. The TIMER model has been described in detail in Vries et al. (2001). TIMER is incorporated into the IMAGE integrated assessment framework to study global change. Figure A7.5 provides an overview of the model.

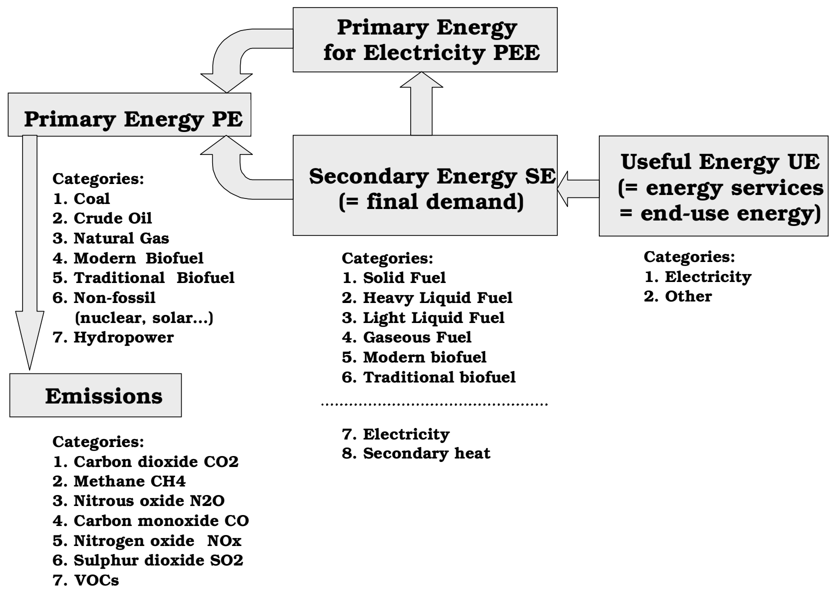


Figure A7.5: Overview of the sub-models of the TIMER-model. Regional population and per capita activity levels are from exogenous inputs. The TIMER Emissions Model connects the TIMER-model with the other parts of the IMAGE-model.

Implementation of CO_2 mitigation is generally modelled on the basis of price signals. A tax on carbon dioxide (carbon tax) is applied to bring down carbon emissions from the energy system. It should be noted that TIMER does not account for any feedback from the energy system to economic drivers. In response to the carbon tax, the model generates several responses:

1. Price-induced investments in energy-efficiency, which, in turn, affect the energy-efficiency supply cost curve as a result of learning-by-doing (economies of scale, innovation).
2. Price-induced fossil fuel substitution.
3. Changes in the trade patterns of (fossil) fuels as a consequence of changing demand patterns and regional fuel prices.

4. Price-induced acceleration of investments in non-fossil options such as wind/solar energy, nuclear energy and biofuels, bringing down their specific investment costs in the process of learning-by-doing.
5. A decrease in the use of fossil fuels (as result of the responses discussed above), leading to slower depletion rates and consequently lower prices but also to a lower rate of innovation in the production of these fuels (slowing down learning-by-doing).

TIMER simulates a variety of technological and economic changes in the energy system in response to the requirement to reduce CO_2 emissions. Differences in energy system costs between scenarios are used as a measure for costs of CO_2 mitigation, defined as the product of energy consumption, and the costs of energy production and consumption, plus the annuitised expenditures for energy efficiency. Costs of (aggregated) energy technologies used by the model are calibrated for the base year using historical data (see Vries et al. (2001)). It should be stressed that total system costs are not directly related to the costs of a single measure because each option induces changes in the costs of other parts of the system. Investing in energy efficiency, for instance, reduces the costs of energy production and also accelerates the learning of energy-efficiency technology. Costs of air pollution control equipment are not included in the energy system costs of TIMER.

Uncertainties
In 2001, a large uncertainty project has been performed for the TIMER model to determine the main uncertainties and how these are dealt with (van der Sluijs et al, 2002). The study included different methods, including formal sensitivity analysis, the qualitative NUSAP methodology and comparison with other models. The study found that the main modelling uncertainties included, 1) drivers of energy demand such as economic growth and energy demand, 2) structural changes determining energy demand, 3) assumed technological changes for non-fossil fuels, 4) resources of fossil fuels, in particular natural gas and oil.

TRENDS model

TRENDS is an MS-Access software that calculates a range of environmental pressures due to transport. The final aim of the TRENDS study was to produce a range of transparent, consistent and comparable environmental pressure indicators caused by transport. These indicators were calculated directly from the activity levels and reflect the potential change in the state of the environment, or the risk of specific environmental impacts which any changes in policy might have. The road transport module yields vehicle activity data during a time interval of 50 years (1970-2020) for EU 15 countries (LAT, 2002). More specifically, the software produces estimates of the vehicle population and age as well as the annual mileage for 113 vehicle categories, depending on the vehicle type, the vehicle technology and the type of fuel used. The TRENDS/Road Transport module also generates data tables, which are used as input in the COPERT model (Ntziachristos and Samaras, 2000) in order to calculate vehicle emissions from road transport.

TREMOVE model

TREMOVE deals with a large set of pollutants and covers all EU-15 countries, Switzerland, Norway, Czech Republic, Hungary, Poland and Slovenia for the main transport modes (road, rail, air and shipping). A transport model becomes available that can be applied for environmental and economic analysis of different policies and measures to reduce atmospheric emissions from all modes of transport in the enlarged European Union. (De Ceuster et al, 2005). The transport demand module represents, for a given year, the number of passenger-kilometres (pkm) or ton-kilometres (tkm) that will be used on each mode in each model region of the country considered. With this demand module, the impact of policy measures on the transport quantity of all transport modes is calculated. A reference scenario is therefore incorporated in the TREMOVE demand module. This reference is based on output of the European transport model SCENES (SCENES, 2000).

Uncertainties in emission modelling

As in all cases of the application of estimation methodologies, results obtained through modeling of vehicle emissions are subject to uncertainties. Since the true emissions are unknown it is impossible to calculate the accuracy of the estimates. However, an estimate of their precision can be obtained. This estimate also provides an impression of the accuracy if the methodology used for estimating road traffic emissions represents a reliable image of reality. In the case of an emission calculation model such as COPERT, the aforementioned uncertainties are the results of errors, which can be divided into random and systematic ones (EMEP/CORINAIR, 2002).
Random errors are those caused by:

- The inaccuracy of the measurement devices and techniques
- The lack of a sufficient number of representative measurements, e.g., for heavy duty vehicles, cold starts, and evaporative emissions
- Erroneous data with regard to vehicle usage.

In principle, systematic errors may be distinguished into two categories:

- Errors concerning emission factors and measurements:
  - Errors in the patterns used to simulate actual road traffic; this means that driving cycles may not be representative of real-life road traffic, e.g., typical speed and acceleration of real driving conditions may be considerably different

from those used in off-road dynamometer tests, thus systematically underestimating vehicle emissions

  - Errors in the emission factors used for the calculations. Sufficient emission measurements are not available in all countries. Thus, average values derived from measurements in other countries have to be used. This can lead to significant variations because in some countries vehicles are undergoing periodic emission tests, so measured emission factors may not be representative of the vehicle fleets of other countries. This can bias the emission factor measurements and the evaluation of the effects of Inspection/Maintenance programmes and degradation of emission control equipment.

- Errors concerning assessment of vehicle park and usage:
  - Erroneous assumptions of vehicle usage. In many countries the actual vehicle usage is not known, in some others, data from only a few statistical investigations are available. Most important are errors in total kilometres travelled and in the average trip length. However, the fuel balance (i.e., the comparison of the calculated fuel consumption with the statistically known one), is a valuable means to check the validity of the various assumptions made and to avoid major errors.
  - Erroneous estimates of the vehicle park. Not all the vehicle sub-categories considered appear in the statistics and, therefore, they have to be estimated. For example, assessing the number of gasoline and diesel vehicles >2.5 t which belong to the category "Light Duty Trucks" and those which belong to the category "Heavy Duty Vehicles", involves considerable uncertainty since the exact numbers are not available. The same may apply for splitting a certain category into different age and technology groups, as the real numbers are not always known.

Models and uncertainties related to air quality calculations

OFIS model

The OFIS model belongs to the European Zooming Model (EZM) system, a comprehensive model system for simulations of wind flow and pollutant transport and transformation (Moussiopoulos, 1995) and was developed to serve a twofold aim; (i) allowing authorities to assess urban air quality by means of a fast, simple and still reliable model and (ii) refining a regional model simulation by estimating the urban subgrid effect on pollution levels.

OFIS was derived from the more sophisticated EZM core models. Being closely related to the 3D photochemical dispersion model MARS/MUSE (Moussiopoulos et al., 1995), OFIS simulates concentration changes due to the advection of species and chemical reactions in each cell of the computational domain. The concentration values outside this domain are assumed to coincide with the regional background concentrations used for the calculation of the boundary conditions.

The computational domain of the model consists of a two-layer gridded strip with a length of 240 km and a width defined by the city size, with the city in the centre. The strip is oriented along the prevailing wind direction, altering direction when the meteorological input is modified (every 3 hours). Thus, the core region lies always inside the OFIS computational domain and defines the urban area. Areas outside this region are affected to a lesser degree, depending on their distance from the centre,

defining suburban and rural regions. The computational domain of the model for a specific time frame with a prevailing wind from SW is illustrated in Figure A7.6. The first vertical layer extends up to 90m (in accordance with the EMEP model, which provides the boundary conditions), while the second one extends up to the mixing height, thus varying with time. The restriction to this computational domain results in a high computational speed and a low output file size. For prescribing the time evolution of the mixing height as well as of the turbulent exchange coefficient between the two layers, a 1D version of the non-hydrostatic meteorological model MEMO (Kunz and Moussiopoulos, 1997) is utilised. Emission data are inserted into the model in the form of gridded emission inventories. Emissions are calculated for each OFIS cell by properly taking into account the emission density of the underlying fine-scale inventory. Biogenic emissions are also taken into account for rural areas. Due to the modular structure of OFIS, chemical transformations can be treated by any suitable chemical reaction mechanism, the default being the EMEP MSC-W chemistry (Arvanitis and Moussiopoulos, 2003).

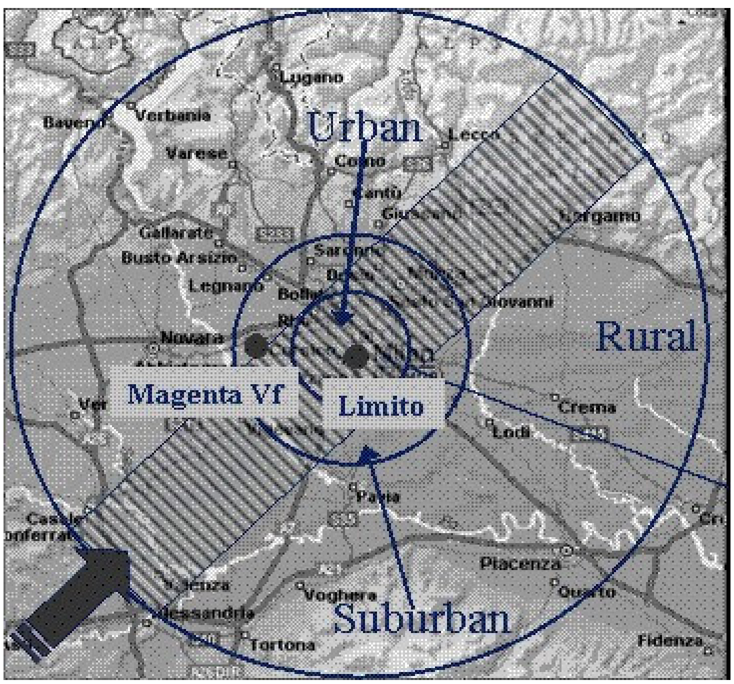


Figure A7.6: OFIS computational domain (gridded strip) and geographic distribution of urban, suburban and rural areas.

Pollutant transport and transformation is calculated by solving the following equations for each grid cell of the computational domain and each species of the chemical mechanism in use:

$$\Delta c_i^1 / \Delta t = K_z (c_i^2 - c_i^1) / {dz_1}^2 + q_i / dz_1 + R_i (c_1^1, ..., c_n^1) + u (c_i^{u1} - c_i^1) / \Delta x \quad (1)$$

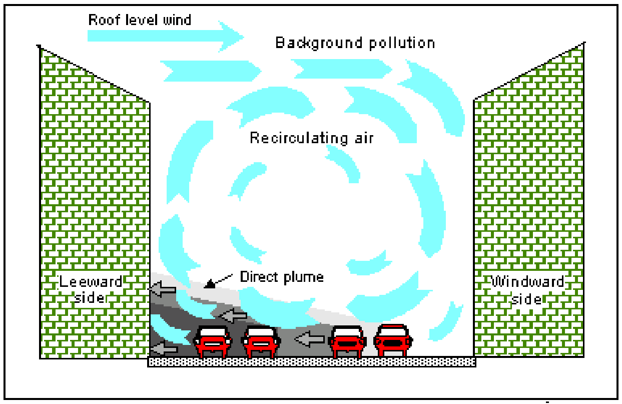
$$\Delta c_i^2 / \Delta t = K_z (c_i^1 - c_i^2)/(dz_2 dz_1) + R_i(c_1^2,...,c_n^2) + u\,(c_i^{u2} - c_i^2)/\Delta x + (c_i^{bc} - c_i^2)\max\left[0, \Delta H_t/(\Delta t \cdot H_t)\right] \quad (2)$$

where
c_i is the concentration of chemical species i of the mechanism,
K_z is the vertical turbulent exchange coefficient
q_i is the emission rate for species i
R_i is the chemical formation or destruction rate for species i
H_t is the mixing height

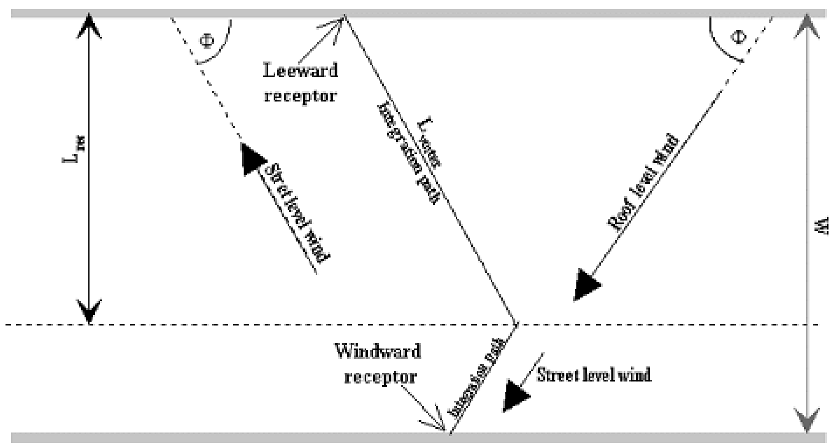
Error! Objects cannot be created from editing field codes. in the two equations is defined by the chemical mechanism in use. The third term on the right hand side of the equation refers to the advection discretised using a simple upwind scheme. **Error! Objects cannot be created from editing field codes.** and inflow boundary conditions can be derived from available monitoring data or, preferably, taken from results of a regional scale model. Meteorological input may be derived and fed into the model from either available measurements or the output of a larger scale model. The numerical solution of the equation system is based on a variable step, second order BDF formula and a Gauss-Seidel iterative technique.

The OFIS model can take advantage of the frequency (3-hourly values) by which boundary conditions and meteorological data from larger scale models usually become available. More specifically, OFIS performs a 5-hour run for each 3-hour frame, utilising one hour as a pre-run and reserving the last hour for purposes of blending (i.e. averaging) with the calculated concentrations at the beginning of the next 3-hour frame. An appropriate parameterisation for wet removal (Scott, 1979), an important physical process especially with regard to particulate matter, is also part of the model. Parameterisation of the wet deposition processes includes both in-cloud and sub-cloud scavenging of particles, including $PM_{2.5}$ and PM_{10}. While sub-cloud scavenging is taken into account in both layers, in-cloud scavenging is only applied on the model's second layer.The model simulates separately each day of, typically, one year. From the overall concept of OFIS it is apparent that the model aim is not to accurately reproduce concentration patterns in any location over the whole year, but rather to correctly report when and to what extent high concentration levels or a regulated threshold exceedance occur at an urban location or a spot downwind the city (Moussiopoulos and Douros, 2004).

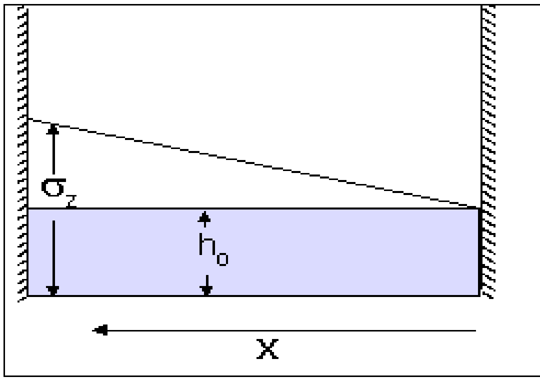
OSPM model
OSPM is a practical street pollution model, developed by the National Environmental Research Institute, Department of Atmospheric Environment. Concentrations of exhaust gases are calculated using a combination of a plume model for the direct contribution and a box model for the recirculating part of the pollutants in the street.



The direct contribution is calculated using a simple plume model. It is assumed that both the traffic and emissions are uniformly distributed across the canyon. The emission field is treated as a number of infinitesimal line sources aligned perpendicular to the wind direction at the street level. The cross wind diffusion is disregarded. The wind direction at the street level is assumed to be mirror reflected with respect to the roof level wind. The plume expression for a line source is integrated along the path defined by the street level wind. The length of the integration path depends on the extension of the recirculation zone.



- The length of the vortex, calculated along the wind direction, is 2 x the upwind building height. For roof-level wind speeds below 2 m/s, the length of the vortex decreases linearly with the wind speed. The buildings along the street may have different heights, affecting thereby the length of the vortex and subsequently the modelled concentrations.
- The upwind receptor (lee-side) receives contribution from the traffic emissions within the area occupied by the vortex (the recirculation zone), the recirculated pollution and a portion of the emissions from outside of the vortex area.
- The downwind receptor (wind-side) receives contributions from the recirculated pollution and the traffic emissions from outside of the recirculation zone only.
- As the wind speed approaches zero or is parallel with the street, concentrations on the both sides of the street became equal.
- The vertical dispersion is modelled assuming a linear growth of the plume with the distance from the source.



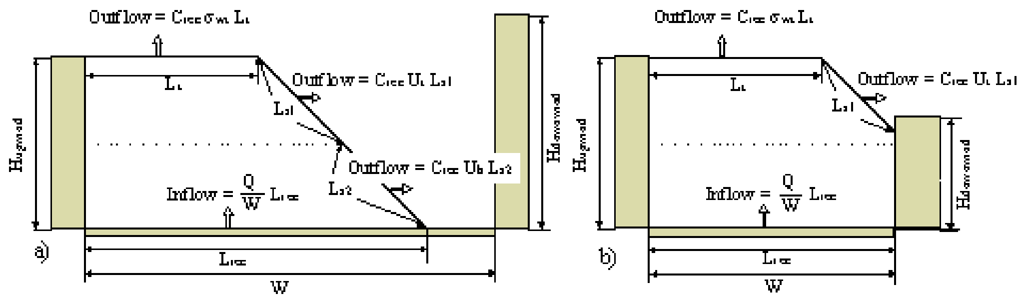
- vertical dispersion

$$\sigma_z(x) = \sigma_w \frac{x}{u_b} + h_o$$

- the direct contribution

$$C_d = \sqrt{\frac{2}{\pi}} \frac{Q}{W \sigma_w} \ln\left[\frac{h_o + (\sigma_w / u_b) W}{h_o}\right]$$

ho = 2~4 m (depends on wind speed) - initial dispersion



The contribution from the recirculation part is calculated using a simple box model. It is assumed that the canyon vortex has the shape of a trapeze, with the maximum length of the upper edge being half of the vortex length. The ventilation of the recirculation zone takes place through the edges of the trapeze but the ventilation can be limited by the presence of a downwind building if the building intercepts one of the edges. The concentration in the recirculation zone is calculated assuming that the inflow rate of the pollutants into the recirculation zone is equal to the outflow rate and that the pollutants are well mixed inside the zone.

Traffic Created Turbulence

The turbulence within the canyon is calculated taking into account the traffic created turbulence. The traffic induced turbulence plays a crucial role in determination of pollution levels in street canyons. During windless conditions the ambient turbulence vanishes and the only dispersion mechanism is due to the turbulence created by traffic. Thereby, the traffic created turbulence becomes the critical factor determining the highest pollution levels in a street canyon.

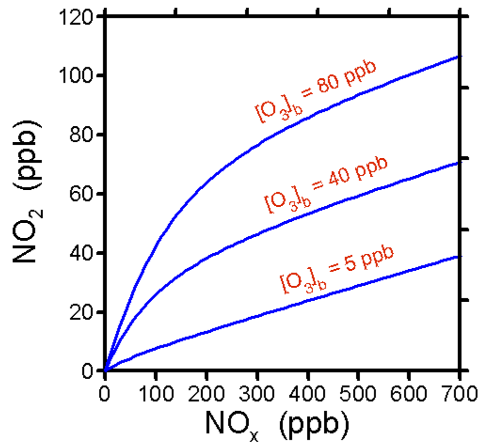
Street geometry

The model can be used for streets with irregular buildings or even buildings on one side only but it is best suited for regular street-canyon configurations. The model should not be used for crossings or for locations far away from the traffic lanes.

Wind meandering

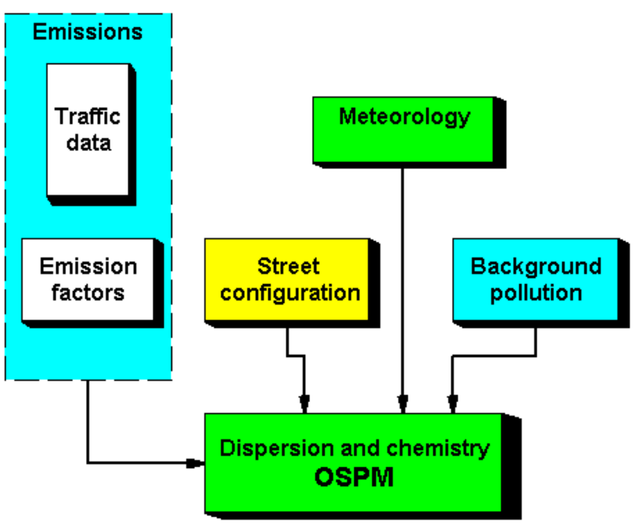
Concentration distribution of pollutants in the street is calculated taking into account wind direction fluctuations. For each calculation hour, the resulting concentrations are averaged over a wind direction sector centered arround the hourly mean wind direction. The width of the averaging wind sector depends on the roof level wind speed and increases with the decreasing wind speed. For calm conditions the averaging sector approaches 360^o, which results in uniform concentration distribution accross the street.

NO_2 chemistry
The NO_2 concentrations are calculated taking into account NO-NO_2-O_3 chemistry and the residence time of pollutants in the street.
The presence of NO_2 in ambient air is mainly due to the chemical oxidation of the emitted NO by background ozone. Under sunlight conditions, photodissociation of NO_2 leads to partial reproduction of NO and O_3.
$NO + O_3 <=> NO_2 + O_2$



The relationship between NO_2 and NO_x concentrations in the ambient air is non-linear and depends on the concentrations of ozone. The time scales characterising these reactions are of the order of tens of seconds, thus comparable with residence time of pollutants in a street canyon. Consequently, the chemical transformations and exchange of street canyon air with the ambient air are of importance for NO_2 formation.

Model structure
The model is designed to work with input and output in the form of one-hour averages.



The required input data are hourly values of wind speed, wind direction, temperature and global radiation. The two last parameters are used for calculation of chemical transformation of NO-NO_2-O_3. The model requires also hourly values of urban background concentrations of the modelled pollutants. Beside the hourly input parameters, the model requires also the data on the street geometry and the traffic in the street.
More details (and references) can be found in: http://www2.dmu.dk/1_Viden/2_Miljoe-tilstand/3_luft/4_spredningsmodeller/5_OSPM/5_description/default_en.asp

Uncertainties in air quality models
Uncertainty is a parameter generally associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measured quantity. In other words, uncertainty is numerical information that complements a result, indicating the magnitude of the doubt about this result.
Uncertainties specifically for air quality models typically originate from a number of different causes.
Model uncertainty comes from the modelling approach itself, as it assumes to describe the real process by using several assumptions and may be based on incomplete knowledge about the emission process itself. Such sources include input data errors, insufficient meteorological or/and emission data, atmospheric turbulence, model simplifications, future weather forecasting, spatial and temporal averaging. Also, natural variability in the process can significantly contribute to the total uncertainty (Borrego and Tchepel, 1999).
The major categories of uncertainty in air quality models are classified as follows:

- Scenario (Future) Uncertainty
- Parameter Uncertainty
- Conceptual Model Uncertainty
- Variability (Turbulence)

However, the relationship between meteorological and air quality data is dependent on the time and spatial scale of the data used. Meteorological data on an hour by hour basis is much more uncertain than long term, or climatological, meteorological fields. Also, when diagnostic meteorological models are used then the meteorological fields they produce become more uncertain the further removed they are from the observations. These uncertainties will be reflected in the air quality modelling.

Annex 8: Comparison of the OFIS model results to measurements on urban scale

Urban scale air quality analysis - reference year (2000)

In Figure A8.1, Figure A8.2, Figure A8.3 and Figure A8.4, the OFIS model results for the mean annual levels of NO_2, PM_{10} and O_3 are compared to urban background station measurements from AirBase. EMEP model results for the cell in which each city is located are also shown for comparison. It should be noted that the EMEP values appearing in the figures do not correspond to the regional background used for the boundary conditions of the OFIS model, as the influx of pollutants into the computational domain of the model is provided by EMEP cells adjacent to the cell that contains the city.

To account for the variability of the urban background levels in each city, the figures show the ranges for both observations and model results. As expected, the model predicts maximum values for NO_2 and PM_{10} in the city centre, whereas maximum O_3 values are observed at the outskirts of the urban area (cf. Chapter 4). For cities where there is only one station available, it is not possible to define such a range and the concentration observed at the particular location should be treated as indicative. The appropriateness of the reported urban background concentrations depends upon the number and types of stations in each city, bearing in mind also their representativeness for population exposure. Moreover, the observed concentrations presented in Figure A8.1, Figure A8.2, Figure A8.3 and Figure A8.4, were not all measured in 2000, as this would lead to very few measurement data available and seriously inhibit comparison with the modelled estimate. For these reasons, also measurements from the years 2001, 2002 and 2003 were used as they are undoubtedly good approximations for the approximate level of the concentrations measured in 2000.

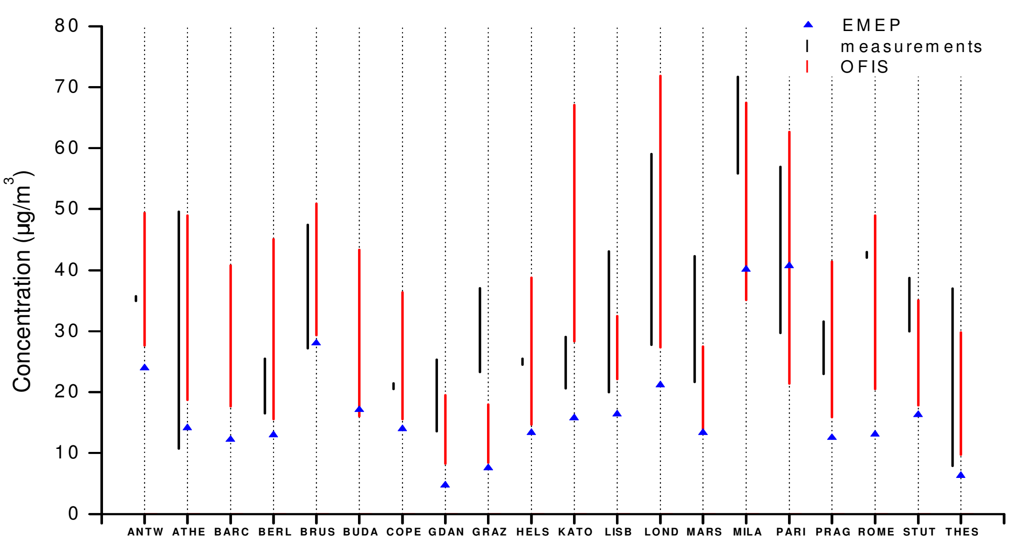


Figure A8.1: Mean annual NO_2 urban background concentrations ($\mu g/m^3$) in 20 European cities: Range of OFIS model results compared with the range of observations. The EMEP results for the cell in which each city is located are also presented.

For the NO_2 concentrations, there is good agreement between the OFIS model results and the urban background measurements, with the spread of the OFIS values mostly overlapping with the spread in the measured data, though in some cases the maximum value is overestimated by the model. This finding confirms that OFIS generally refines the EMEP model results, thus leading to a good estimate of the urban background NO_2 concentrations. Somehow as an exception to this very satisfactory general agreement, a large discrepancy between model results and observations is detected for Graz and Marseille. A possible reason for this could be that the stations in these cities do not fully reflect what one would expect under the term 'urban background'. The station characterisation in AirBase is in some cases problematic but a station-by-station analysis would be required to study this in detail for each city. A possible underestimation of the urban NO_x emissions is another potential reason for the disagreement in these two cities. The use of gridded emission inventories resulting from the application of a top-down approach (from NUTS 3 down to the domain of interest) using the European emission model (Schwarz, 2002; Wickert, 2001) instead of an emission inventory that would result from a bottom-up approach (emission inventory using local data) may have led to different estimates for the emissions of the various pollutants and thus possibly to an underestimation.

Another interesting feature of these results is the fact that the EMEP value in cases like Paris and Milan appears to be relatively high, even higher than the lowest urban background value calculated using the OFIS model. As a fine scale model, OFIS allows for a better description of spatial inhomogeneities in the concentration field by taking into account a high resolution emission inventory, which can actually lead to low values in larger distances from major emission sources. In the case of Milan, this elevated EMEP value is mostly due to the large number of point sources found in the greater city area which are located inside the EMEP cell containing the city. In the case of Paris, the greater city area is very large and thus much of the EMEP cell is occupied by the city and its suburbs, leading to computed concentrations in the particular cell clearly above the actual regional background level.

Figure A8.2 illustrates the correlation between the modelled and observed mean annual NO_2 urban background concentrations (observed: average over all stations considered) for each city. All cities were considered for which measurements have been available. Also on the basis of this illustration, the model results are generally found to be in good agreement with the measurements.

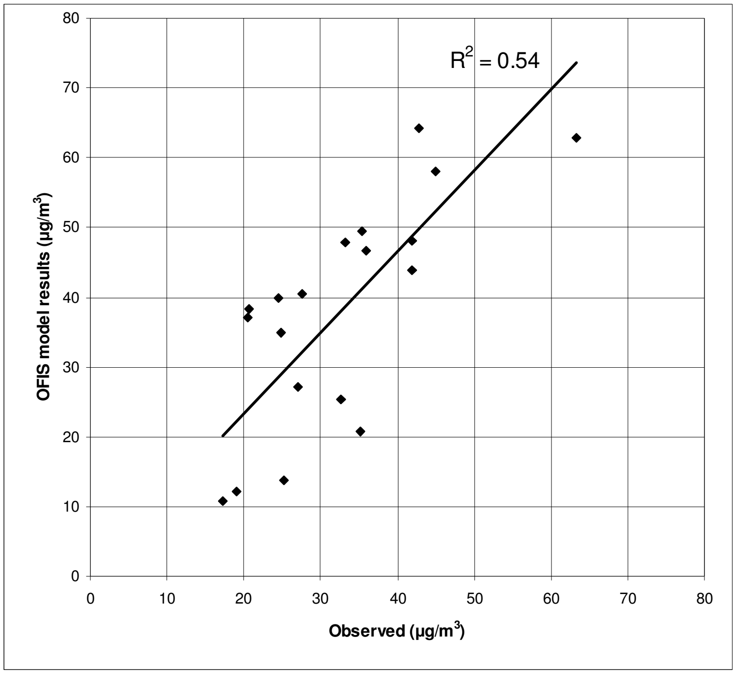


Figure A8.2: Scatter plot of modelled vs. observed NO_2 mean annual urban background concentrations (µg/m^3).

As can be seen in Figure A8.3, OFIS systematically underpredicts PM_{10} compared to the measurements. An obvious explanation for this is missing sources in the emission inventories used by the urban scale model. As is also mentioned in Chapter 4, the primary PM_{10} emission data is not as robust as for other air pollutants and this fact combined with the complex formation, deposition and resuspension processes lead to uncertainties concerning PM_{10} emissions. Moreover, the OFIS model, like many urban scale models, does not yet account for the formation of secondary organic particulates, an omission that could have led to a further underestimation of the modelled PM_{10} concentrations. Furthermore, natural primary PM sources such as windblown dust and sea salt are not accounted for in the emission inventories used for both the regional (EMEP) and the urban scale (OFIS) models.
Similarly to PM_{10}, an underprediction is also expected in the $PM_{2.5}$ model results. $PM_{2.5}$ comprise a large proportion of the secondary particulates, organic and inorganic and state-of-the-art modelling techniques for simulating the complex formation processes tend to lead to an underestimation of the actual concentrations. Considering also that the formation of secondary organic particulates is not considered in the version of the OFIS model used in the present study l, the particles formed from natural VOC sources are also not considered, leading to a further underestimation.

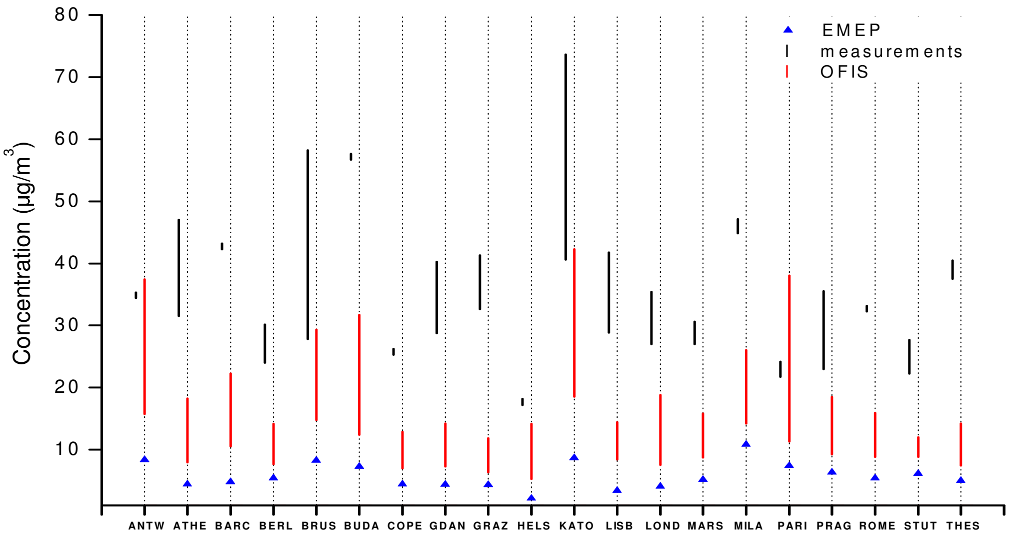


Figure A8.3: Mean annual PM_{10} urban background concentrations (µg/m^3) in 20 European cities: Range of OFIS model results compared with the range of observations. The EMEP results for the cell in which each city is located are also presented.

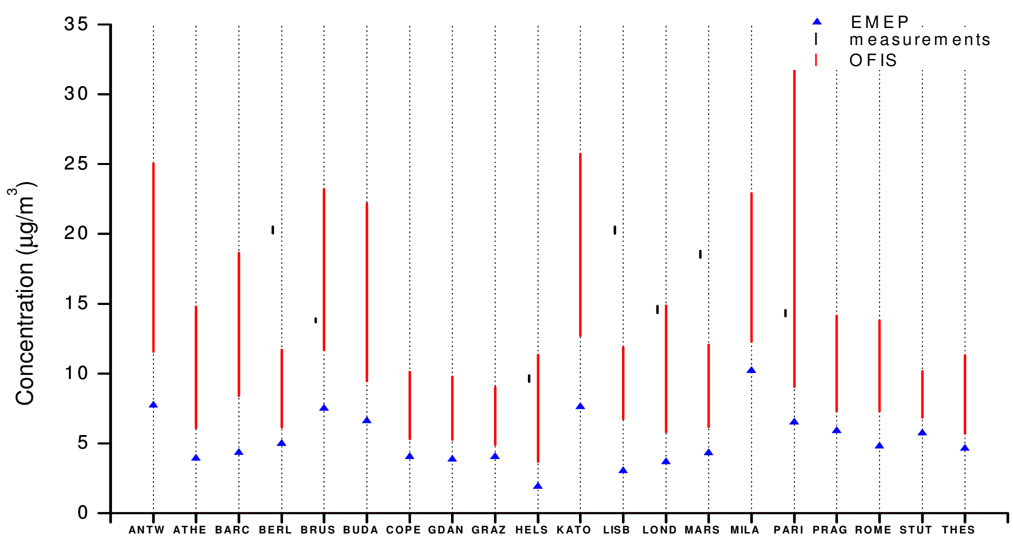


Figure A8.4: Mean annual $PM_{2.5}$ urban background concentrations (µg/m^3) in 20 European cities: Range of OFIS model results compared with the range of observations. The EMEP results for the cell in which each city is located are also presented.

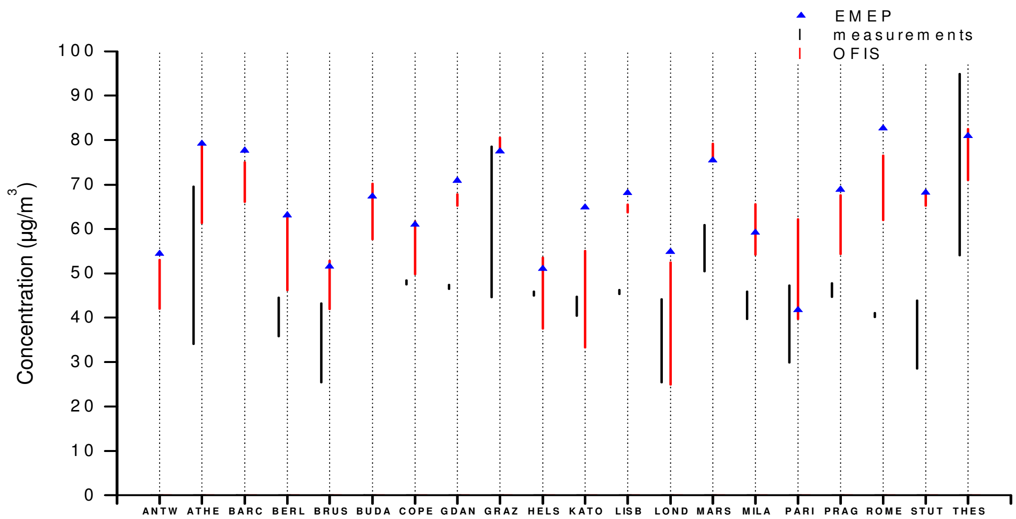


Figure A8.5: Mean annual O_3 urban background concentrations (µg/m^3) in 20 European cities: Range of OFIS model results compared with the range of observations. The EMEP results for the cell in which each city is located are also presented.

From A8.5, it can be concluded that the range of the OFIS model results for O_3 is generally higher than the range observed in the urban background stations. However, compared with the EMEP model results, the combination EMEP/OFIS reproduces much better the urban ozone levels close to the city centre accounting for the ozone titration due to the high NO_x emission levels. Moreover, even the observed ozone levels at measuring stations characterised as 'urban background' are usually influenced by neighbouring NO_x emission sources and thus may not accurately reflect the true urban background ozone levels. The above behaviour is consistent with corresponding findings from the CityDelta intercomparison exercise (URL1), where one of the main conclusions was that using urban/fine scale models is more important for assessing urban NO_2 and PM levels compared to ozone. It is also interesting to note the relatively low EMEP ozone concentration value for the cell containing Paris. Apparently, large pollution sources with relatively high NO_x emission densities are on the respective EMEP cell, this leading to a much higher ozone depletion compared with one would have expected for a situation charactersing the regional background.

Annex 9: Methodology for estimating city areas

As mentioned in section 8.2.1, gridded city emissions were obtained from the MERLIN project for each of the 20 urban areas considered in the study. For each urban area MERLIN provides emissions for a grid with a total of 30*30 (i.e. 900) cells with grid cell dimensions equal to 5*5 km^2. The city center is located near the center of the grid, or in the cell with (x, y) components equal to (15, 15). The overall area covered by each city grid is equal to 22500 km^2, which greatly exceeds actual city dimensions (see Table A9.1 estimated city areas obtained through personal communication with H. Eerens).

In order to calculate city emissions per km^2, the cells corresponding to the actual city area were identified. This was achieved using the following methodology:

The levels of CO emissions were used as a criterion in order to determine which cells belong to city areas in each MERLIN urban area considered. CO emissions were chosen since high levels of CO emissions usually correspond to areas with increased road traffic. Figure A9.1 shows the contribution of each grid cell (total no. of cells equal to 900) towards the total CO emissions in the city of Athens. Line 1 of Figure A9.1 represents the percentage of the cumulative sum of CO emissions per grid cell. In addition, the gradient of line 1 was evaluated (line 2 of Figure A9.1), which shows the rate of the contribution of each cell towards the overall CO emissions in decreasing order. From Figure A9.1 it can be observed that line 2 decreases very steeply at first and then gradually levels off. The cells that exhibit the steepest decline correspond to the cells with the highest contribution to the total CO emissions and therefore can be considered as the cells that constitute the city area.

Apart from the rate of CO emissions in each cell, an additional criterion was considered in order to determine the grid cells that correspond to each city area: the proximity of each grid cell to the city center. The necessity to introduce this condition is displayed in Figure *A9.2*, which shows the distribution of the MERLIN CO emissions for the city of Athens per grid cell. From this figure it is apparent that high values of CO emissions do not originate solely from the central area (Athens city center) but from neighboring urban areas as well. In order to determine the grid cells that correspond to each city area, the cells that exhibit the highest levels of CO were filtered according to their distance from the city center (distance from the cell with (15, 15) coordinates) and only those cells that were found to be close to the city center were considered as city cells. The resulting city areas (calculated) are shown in Table A9.1 together with estimates of the respective areas obtained through personal communication with H. Eerens.

Finally, emissions per km^2 were calculated by summing over the emission values of all cells corresponding to a city area and dividing that sum with the overall area of the respective cells.

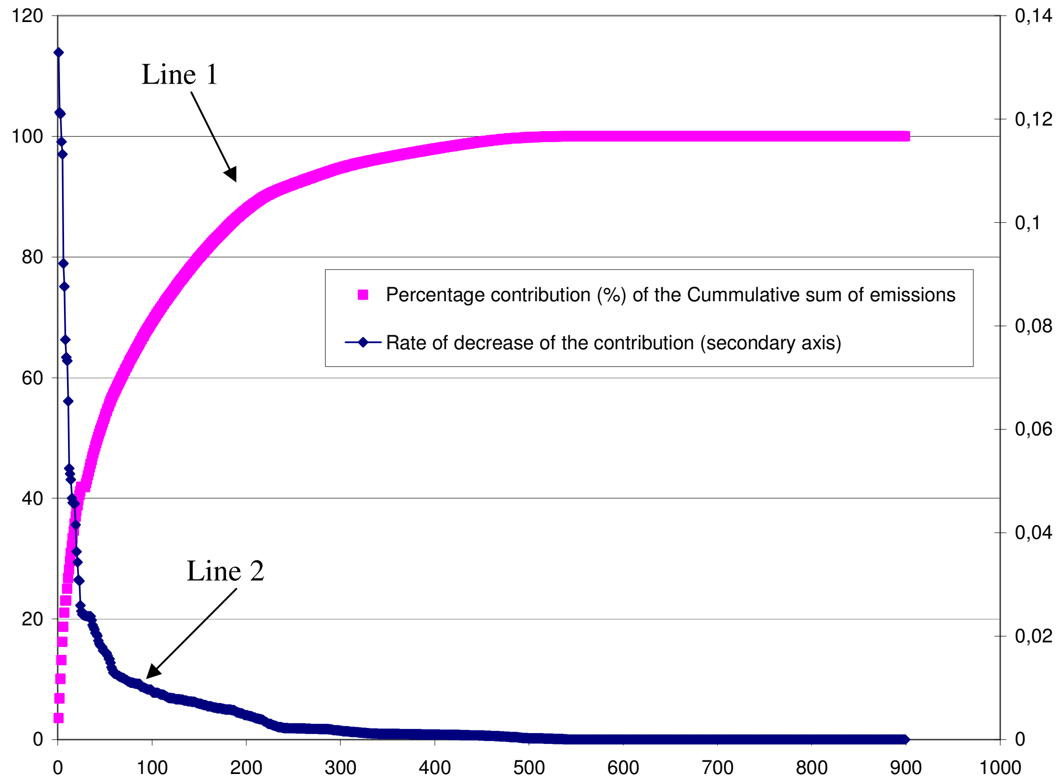


Figure A9.1: Contribution of each grid cell to the overall CO emissions in Athens

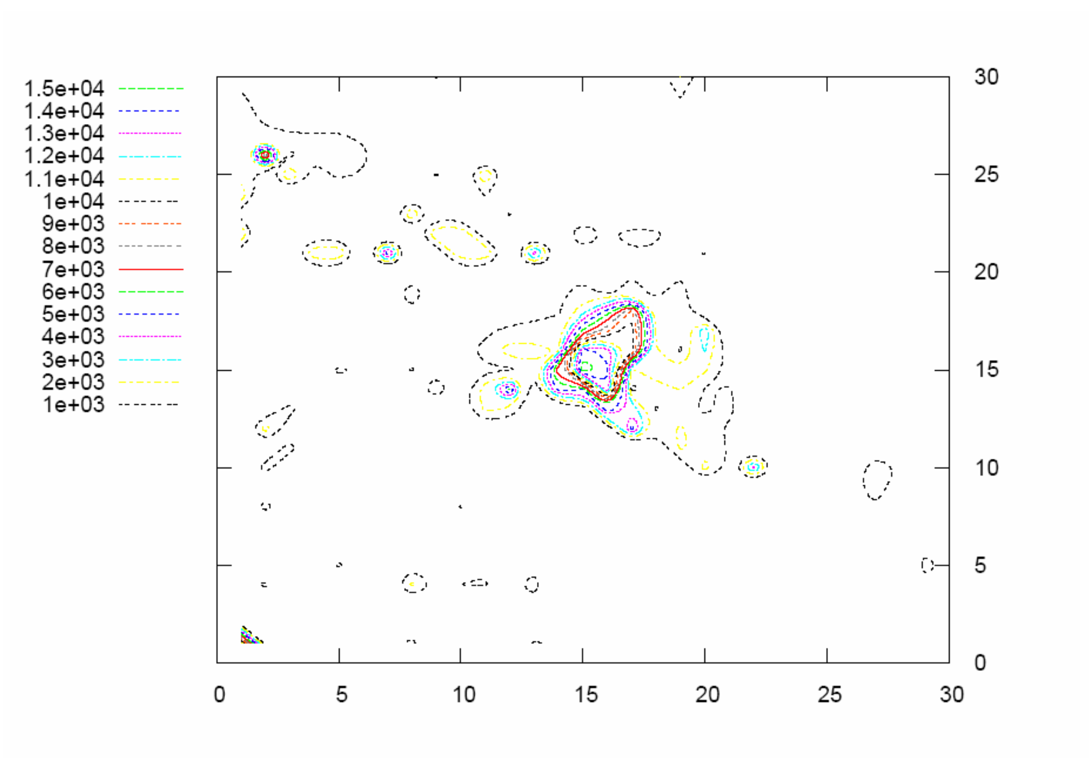


Figure A9.2: Distribution of annual (2000) CO emissions [t] in Athens (Source: MERLIN)

Table A9.1: Calculated and estimated values of the area [km^2] of each city

City	Estimated city area [km^2]	Calculated city area [km^2]
Barcelona	218	250
Berlin	590	600
Brussels	133	150
Budapest	372	375
Copenhagen	424	425
Graz	30	50
Helsinki	287	275
Lisbon	100	100
London	1294	1300
Marseille	227	250
Milan	573	575
Paris	1997	2000
Prague	245	250
Rome	511	500
Stuttgart	438	450
Gdansk		300
Antwerp	299	300
Thessaloniki		250
Athens	808	750
Katowice		275