Topic report 12/2001

The ShAIR scenario

Towards air and climate change outlooks, integrated assessment methodologies and tools applied to air pollution and greenhouse gases

A study undertaken by:
R. Albers (project leader), F. de Leeuw, J. van Woerden,
J. Bakkes (European topic centre on air quality (ETC-AQ),
Dutch Institute of Public Health and the Environment (RIVM))

N. Moussiopoulos, P. Sahm (European topic centre
on air quality (ETC-AQ), Aristotle University Thessaloniki (AUTh))

P. Capros, N. Kouvaritakis, L. Mantzos
(National Technical University of Athens (NTUA))

J. Cofala, C. Heyes, Z. Klimont, M. Amann
(International Institute for Applied System Analysis (IIASA))

T. Pullus, A. Visschedijk (European topic centre on air emissions (ETC-AE),
Netherlands Organisation for Applied Scientific Research (TNO))

Z. Samaras, P. Tourlou (European topic centre on air emissions (ETC-AE),
Aristotle University Thessaloniki (AUTh))

EEA project team:
Teresa Ribeiro (project manager), Roel van Aalst,
Andre Jol, Hans Vos, Hans Luiten

European Environment Agency

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European Environment Agency
Kongens Nytorv 6
DK-1050 Copenhagen K
Tel.: (45) 33 36 71 00
Fax: (45) 33 36 71 99
E-mail: eea@eea.eu.int
Internet: http://www.eea.eu.int

Preface

The European Environment Agency (EEA) report *Environment in the European Union at the turn of the century* (EEA, 1999a) considered past trends and future developments in the state of the environment under a baseline scenario defined in close coordination with the Directorate-General (DG) for the Environment. The report presents a consistent set of socio-economic, sectoral and environmental forecasts and makes use of various existing European and global models and assumptions. The study benefited by sharing parts of the baseline scenario with the so-called Priority Study (RIVM, 2001) prepared by a consortium led by the Dutch Institute of Public health and the Environment (RIVM) and commissioned by DG Environment.

Evaluating comments on *Environment in the European Union at the turn of the century* from stakeholders and from the European Forum on Integrated Environmental Assessment pointed to the need for the EEA to, amongst other things:

- improve its support to scenario-building in future integrated environmental assessments;
- improve its treatment of uncertainty in future analyses;
- take action to prepare scenarios for the next state of the environment and outlook report, to appear in 2004;
- consider stronger support through secondment of experts and stronger involvement of (new) European topic centres (ETCs) in the preparation of EEA reports.

In this context, the EEA commissioned, among others (EEA, 2000a; EEA, 2001a; EEA, 2001b), a study with a consortium of experts from the ETCs on air quality and air emissions and external experts led by an EEA team composed of Teresa Ribeiro (project manager), Roel van Aalst, Andre Jol, Hans Vos and Hans Luiten. The objective of the study was to evaluate and appraise past experience in environmental projections underpinning *Environment in the European Union at the turn of the century*, focusing primarily on air quality and climate change/greenhouse gas emissions and related issues. The study helped consolidate the experience gained and outlined a long-term strategy for integrated assessment and prospective analysis. Furthermore this study helped set the grounds for the establishment of the ETC on air and climate change, which started work in March 2001.

The main tasks of this study were to:

- test and evaluate the integrated assessment approach to air pollution and greenhouse gases;
- undertake sensitivity and uncertainty analysis of the so-called 'baseline scenario';
- further develop expertise and connections and interrelations among parties involved;
- identify relevant indicators, particularly for prospective analysis and policy evaluation;
- appraise, evaluate and further develop integrated assessment methodology;
- improve and further develop information flows and module interconnections.

The main effort in the study (called ShAIR) was learning, using and improving the integrated assessment methods and tools and producing an updated projection on air pollution and greenhouse gases based to a large extent on the Shared Analysis conventional wisdom energy scenario (EC, 1999b). The work on sensitivity analysis was limited to a number of partial sensitivity runs.

Besides this report, the study also produced five technical background reports, available from the EEA web site.

In the recently established ETC on air and climate change, assessments are planned of past and future air quality and emissions of air pollutants and greenhouse gases. Cross-benefits between greenhouse gas emission reduction measures and air quality at regional and urban level will be assessed. We expect the results to be useful in the upcoming Clean Air for Europe (CAFÉ) programme.

Gordon McInnes	David Stanners
Programme manager	Programme manager

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Summary

Main messages

Scope and goal of the study
The European Environment Agency (EEA) initiated this study to improve and appraise its past experience in the environmental projections underpinning the report *Environment in the European Union at the turn of the century* (EEA, 1999a, hereafter referred to as the EEUTC report). It should consolidate the experience gained and help to outline a long-term strategy for integrated assessment and prospective analysis. This study focuses primarily on issues related to air quality and climate change.
The main effort in the project was learning, using and improving the integrated assessment methods and tools and producing an updated projection (ShAIR) on air pollution and greenhouse gases based on the Shared Analysis scenario.
Five technical background reports were produced, underpinning this overall report.

Sectoral development
The Shared Analysis energy scenario has recently been updated on energy prices and taxes, transport volume and inclusion of the EU–ACEA (European Union–European Automobile Manufacturers Association) agreement. This results in about 2 % fewer carbon dioxide (CO_2) emissions in 2010 than in the ShAIR scenario. If the EU–ACEA agreement fails, CO_2 emissions might, however, be 2 % higher.
On the basis of the updated energy scenario, two variants have been considered: a further liberalisation of the electricity markets and more optimistic assumptions on renewables.
A further liberalisation of the electricity market beyond that assumed in the updated scenario results in important changes in the fuel mix. However, CO_2 emissions seem not to be significantly affected by liberalisation.
Assumptions more favourable for the performance of renewables (windpower) result in 1 % fewer emissions of CO_2 in 2010 and about 5 % in 2020 compared to the updated scenario.
A comparison of the transport emissions in ShAIR with the baseline Auto-Oil II scenario shows differences in 2010 of about 10 % for nitrogen oxides (NO_x) and 15 % for volatile organic compounds (VOCs) for nine EU countries, partly due to differences in the energy figures for the base year 1990. The ShAIR study has shown major discrepancies between transport, bottom-up scenarios and energy, top-down scenarios. These should be clarified further and as much as possible removed.
No long-term future agriculture trend information is available.

Greenhouse gas emissions
In the ShAIR scenario, emissions of the six greenhouse gases in 2010 for the EU as a whole are about 12 % above the Kyoto goal. The projected greenhouse gas emissions are lower than in the baseline projection of the EEUTC report.
There is a strong need for national information on future trends for the six greenhouse gases and for extension of the current approach for greenhouse gases to other European countries. Emission projection models are needed for CO_2 emissions from non-energy sources, methane (CH_4) and nitrous oxide (N_2O); dedicated studies are recommended for hydrofluorocarbons (HFCs), perfluorcarbons (PFCs) and sulphur hexafluoride (SF_6).

Transboundary air pollution
Emission reductions as foreseen in the ShAIR scenario result in a substantial improvement in the indicators for acidification and ozone. However, due to the limited controls put on ammonia emissions, eutrophication will remain a problem even after 2020. According to the ShAIR scenario, in 2020 more than 50 % of nitrogen deposition in Europe will originate from ammonia emissions, mainly from the agricultural sector.
The focus in air pollution policy is now on eutrophication and health effects (ozone and particulate matter (PM)) and less on acidification. Emissions of PM_{10} (respirable particulate matter with aerodynamic diameter less than 10 micrometres) are not well understood and not reported by all countries. Improvement of PM inventories and emission projections is now a major issue and the inclusion of PM in the RAINS model would be a great improvement.
Energy trends and climate change policies influencing the fuel mix (less coal, more gas) have a significant effect on the emission levels of long-range transboundary air pollutants. Moreover, CH_4 emission reductions in the northern hemisphere by about 25 %, as projected in the ShAIR study for the EU countries, are expected to lower the background concentration of ozone.

Urban air quality
Under the assumption of the ShAIR emission scenario, urban air quality is strongly improving but exceedance of (proposed) air quality guidelines is still expected in 2020. In a limited number of eastern European cities a major deterioration in air quality between 2010 and 2020 is projected by the models. The estimated number of excess deaths attributed to sulphur dioxide (SO_2) exposure decreases sharply. Compared to the calculations based on the emission scenarios developed for the EEUTC report and Auto-Oil II, the current results show more exceedances.
Sensitivity calculations show that the modelled concentrations are sensitive to meteorological conditions. The required reduction in urban emissions needed to meet the air quality guidelines may vary up to 50–60 % depending on the selected meteorological year.
In calculating exeedances of air quality guidelines in the urban area, hourly regional background concentrations are needed as input for those pollutants where the limit value is equivalent to a percentile. Such data are not calculated in the RAINS model.

Scope and goal of the study

The European Environment Agency (EEA) initiated this study to evaluate and appraise its experience in the environmental projections underpinning the report *Environment in the European Union at the turn of the century* (EEA, 1999a, hereafter referred to as the EEUTC report). This should consolidate the experience gained and help to outline a long-term strategy for integrated assessment and prospective analysis. This study focuses primarily on issues related to air quality and climate change.

The main objectives of this study were to:

- test and evaluate the integrated assessment approach to air pollution and greenhouse gases;
- undertake sensitivity and uncertainty analysis of the so-called baseline scenario;
- further develop expertise, connections and interrelations among parties involved;
- identify relevant indicators, particularly for prospective analysis and policy evaluation;
- improve and develop accessible methodologies, information flows and tools for integrated assessment;
- appraise, evaluate and further develop integrated assessment methodology.

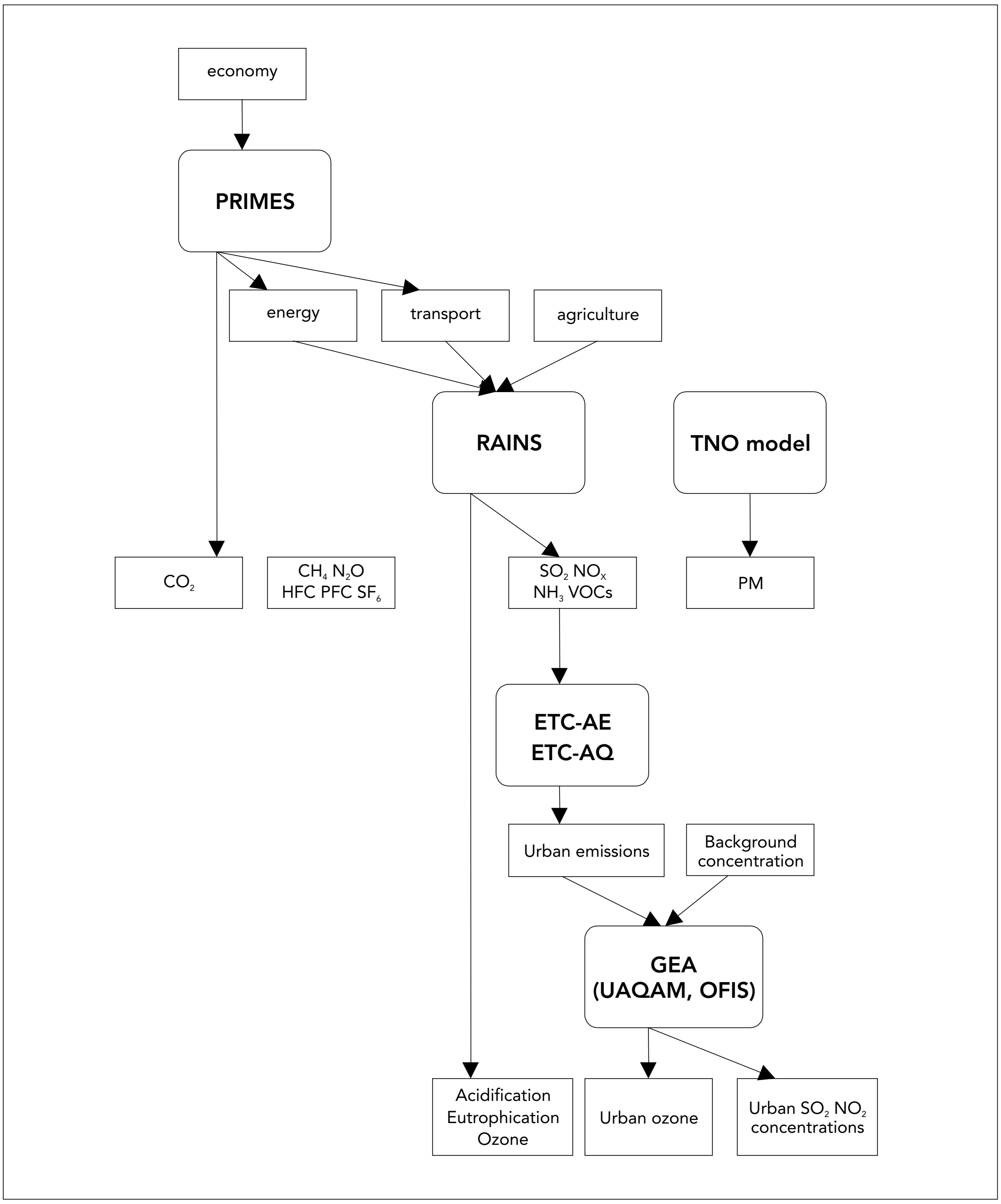
The main effort in the project was learning, using and improving the integrated assessment methods and tools and producing an updated projection (ShAIR) on air pollution and greenhouse gases based on the Shared Analysis scenario. The work on sensitivity analysis was limited to a number of partial sensitivity runs.

Five technical background reports were produced, underpinning the main report.

Methods and models

This study made use of experiences gained in recent scenario studies in the context of policy processes in the European Union (EU). The economic and energy scenario used as a starting point in this study is the Shared Analysis scenario, which is a baseline scenario assuming existing agreed and adopted policies and measures. Various scenario assumptions have been updated, and the resulting scenario version, with a time horizon extended to 2020, is referred to as the ShAIR scenario. Based on these underlying trends, integrated projections have been made for emissions of greenhouse gases, long-range transboundary air pollution and urban air quality. The study used a model network that combined the models used in three policy fields. The model network is shown schematically in the figure below. The study shows that improvements of some of the elements in the model network are needed.

Figure I.



Greenhouse gases

Models

Two different methods have been used to make the projections of emissions of greenhouse gases in this study: the National Technical University of Athens (NTUA) PRIMES model for carbon dioxide (CO_2) emissions and information from scientific literature for the other greenhouse gases. The PRIMES model includes projections for all individual EU Member States (except Luxembourg) on energy-related carbon dioxide (CO_2) emissions. CO_2 emissions from non-energy sources (industrial processes and waste burning) are not included. No emission projections model was available for the other greenhouse gases. Projections have been based on the literature, and data for individual countries are sometimes lacking. Emissions and removals from land-use change and forestry (carbon sinks) were excluded.

For the non-EU countries in Europe only limited information is available. Energy projections can be collected from the literature but there is no way at the moment to deal with these countries in the same way as the EU Member States.

Results

In the ShAIR scenario emissions of the six greenhouse gases in 2010 for the EU as a whole are about 12 % above the Kyoto goal. This is mainly due to a projected rise of CO_2 emissions in the period 1990–2010 by about 7 %. The emissions of methane (CH_4) and nitrous oxide (N_2O) are projected to decline in the same period by 26 % and 14 %, respectively. Emissions of hydrofluorocarbons (HFCs), perfluorcarbons (PFCs) and sulphur hexafluoride (SF_6) rise about 75 % between 1995 and 2010.

The projected greenhouse gas emissions from the ShAIR scenario are lower than in the baseline projection of the EEUTC report. The CO_2 emission trend is about 1 % lower due to the use of a recently updated energy scenario. The discrepancies in CH_4 and N_2O emissions between the two scenarios are large because current policies and measures are included in the ShAIR scenario, while the EEUTC projection assumed no improvement in emission factors at all. The effect of changes in the trends of the underlying driving forces is almost negligible compared to the assumptions on policies and measures.

The Shared Analysis energy scenario has been updated on energy prices and taxes, transport volume and inclusion of the EU–ACEA (European Automobile Manufacturers Association) agreement (a voluntary agreement between the EU and car manufacturers). This results in about 2 % fewer CO_2 emissions in the year 2010 than in the ShAIR scenario. If the EU–ACEA agreement fails, CO_2 emissions might, however, be 2 % higher. On the basis of the updated energy scenario, two variants have been considered: a further liberalisation of electricity markets and more optimistic assumptions on renewables.

A further liberalisation of the electricity market beyond that assumed in the updated scenario results in important changes in the fuel mix: in 2010 the use of coal (–2 % compared with the updated scenario) and renewables (–6 %) decreases, while the use of gas (+ 4 %) and oil (+ 4 %) increases. CO_2 emissions are not affected by liberalisation since changing fuel mix compensates for the increase in total energy use. After the year 2010 the changes in the fuel mix become larger, but even then CO_2 emissions remain the same.

If the assumptions on the technical and economic performance of renewables are made more favourable, the share of wind energy in 2010 will be more than 50 % higher than in the updated scenario. The effect on the emissions of CO_2 is –1 % in 2010. In 2020 the effect of these changed assumptions on renewables results in a decrease of CO_2 emissions of about 5 % compared to the updated scenario.

Integration

There is a clear link between the effects of policy and measures in the fields of long-range air pollution and urban air quality on greenhouse gas emissions. Fossil energy use and transport are the main activities causing greenhouse gas emissions, but at the same time are the main sources of emissions of pollutants relevant for long-range air pollution and urban air quality. Regulations on large-scale combustion plants have a direct effect on the fuel mix, resulting in a change in CO_2 emissions. The same applies to low- and zero-emission vehicles.

Recommendations on methods and models

Since the policy goal of the EU aims at reducing the combination of the six greenhouse gases, there is a strong need for information at national level for all these gases. Lacking is information on future trends of CO_2 emissions from non-energy sources (about 5 % of the total of CO_2 emissions). The inclusion of models on CH_4 and N_2O is strongly recommended. There is also a need to include a model on emissions of HFCs, PFCs and SF_6. Because of the limited number and the specific character of the processes causing the fluorinated emissions, the link with the rest of the model network can remain weak. Dedicated studies on these substances appear to be the most efficient approach. Extension of the current approach for greenhouse gases to other European countries is strongly recommended.

Transboundary air pollution

Models
The projections for precursor emissions, concentrations of ground-level ozone and acidifying and eutrophicating depositions are made with the RAINS model. This model gives information for all individual European countries. A TNO (the Netherlands Organisation for Applied Scientific Research) model has been applied for PM_{10} (respirable particulate matter with aerodynamic diameter between 2.5 and 10 micrometres) emissions. PM_{10} concentrations were not projected as part of the ShAIR scenario. The energy scenario for EU Member States was calculated with the PRIMES model as an input to the RAINS model.

Results
The emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), ammonia (NH_3) and PM_{10} in 2010 decrease considerably compared with 1990. However, in the ShAIR scenario the ceilings of the Gothenburg protocol for these substances under current legislation are not met by a number of countries within and outside the EU. Main discrepancies between current legislation and the Gothenburg objectives occur in the emission of VOCs and SO_2 in EU Member States.

The emission projections in the ShAIR scenario show lower emission levels than the EEUTC baseline scenario. This is due to recent legislation, the inclusion of the Gothenburg protocol and, in small part, to lower energy projections.

The emission reductions result in a substantial improvement in the indicators for acidification and ozone. Eutrophication will, however, remain a problem even after 2020. This is due to the limited controls put on ammonia emissions. According to the ShAIR scenario, in 2020 more than 50 % of nitrogen deposition in Europe will originate from ammonia emissions. Trends in the agricultural sector are dominant for NH_3 emissions. Because there were no long-term trends on agriculture available it was assumed in the ShAIR scenario that livestock and the use of fertilisers after 2010 would remain constant.

The anticipated implementation of EU environmental legislation by the accession countries will play a decisive role in their future emission levels. This is of particular importance for emissions from road transport because of the large expected increase in private transport and the relatively liberal current emission standards for mobile sources in many of the accession countries. The reductions of emissions contributing to acidification, eutrophication and the formation of tropospheric ozone in the accession countries also have a positive impact on the present EU Member States.

A comparison of the transport emissions in ShAIR with the baseline Auto-Oil II scenario shows differences in 2010 of about 10 % for NO_x and 15 % for VOCs for nine EU countries. These differences are due to differences in the energy figures for the base year 1990 and to differences in sectors included. The ShAIR project has also shown major discrepancies between transport, bottom-up scenarios and energy, top-down scenarios. These should be clarified further and as much as possible removed.

Integration
Energy trends and climate change policies influencing the fuel mix (less coal, more gas) have a significant effect on the emission levels of long-range transboundary air pollutants. Another main link between greenhouse gases and air pollution, although not part of this study, is the link in the hemispheric background concentration of ozone, influenced by CH_4. If CH_4 emissions in the northern hemisphere decrease by about 25 %, as is the case in ShAIR for the EU countries, the background concentration of ozone might be significantly lower. Particulate matter (PM) emissions and concentrations are not integrated in the current model. However, as there are strong links with emissions of other pollutants, as well as with concentrations (by the production of secondary aerosols), better integration should be developed.

In the current studies the link with urban air quality is weak since only national emissions are used as input in the urban emission model. However, there is no link at present between the urban background concentration as already used, and the transboundary air quality as calculated with the RAINS model.

Recommendations on methods and models
The focus in air pollution policy is now on eutrophication and health effects (ozone and PM) and less on acidification. Eutrophication is becoming more and more dominated by NH_3 emissions since NO_x emissions are declining much faster. The transportation distance of NH_3 is low compared with SO_2 and NO_x and a grid of 150 x 150 kilometres (km) as used now is insufficient to deal with this. NH_3 emissions are not well understood and not reported by all countries and hence improvement should be made to these aspects. This applies also to PM_{10}. Improvement of PM inventories and emission projections is now a major issue and the inclusion of PM in the RAINS model would be a great improvement.

Urban air quality

Models
The model tools for assessment of urban air quality in the EEA's generalised exposure assessment (GEA) as applied in the Auto-Oil II Programme have been, specifically for this project, further extended for application to cities in central and eastern Europe. In the EEUTC report a different set of models was used. The difference is in the air quality models; the method used to estimate urban emissions remained the same. In the present study an updated and improved version of the OFIS model was applied to assess urban ozone levels in numerous large European cities. The UAQAM model for inert gases has been extended as well.

Results
Under the assumptions of the ShAIR emission scenario, urban air quality is strongly improving but violations of (proposed) air quality guidelines are still expected in 2020. Major problems with SO_2 exposure are found in eastern Europe; in a limited number of cities a major deterioration in air quality between 2010 and 2020 is predicted by the models. The estimated number of excess deaths attributed to SO_2 exposure shows a sharp decrease between 1990 and 2010; over the 2010–20 period a further decrease to about six excess deaths per 100 000 inhabitants is estimated. Compared with the calculations based on the emission scenarios developed for the EEUTC report and Auto-Oil II, the current results show more exceedances.

Sensitivity calculations show that the modelled concentrations are sensitive to meteorological conditions (for SO_2 concentration this is about 6 % for annual mean and 10 % for the 98-percentile concentration). However, in considering compliance with air quality guidelines, sensitivity will depend strongly on the ratio between threshold value and current concentrations. The required reduction in urban emissions needed to meet the air quality guidelines may vary up to 50–60 % depending on the selected meteorological year.

Integration
The regional background concentrations are an important factor in calculating exeedances of air quality guidelines in urban areas. Hourly background concentrations are needed as input for those pollutants where the limit value is equivalent to a percentile. Such data are not calculated in the RAINS model. Therefore background concentrations were taken from the cooperative programme for monitoring and evaluation of long-range transmission of air pollutants in Europe (EMEP) model runs performed for Auto-Oil II. Thus this is a missing link in the current model network.

Recommendations on methods and models
Improvement of city data, especially the improvement of the spatial distribution within cities, and the inclusion of carbon monoxide (CO) emission trends are important aspects to improve. However, the most important issue is the link to the background concentrations. If the choice is for a baseline, the use of RAINS within the model network might be revised.

RAINS clearly has a role in calculating emissions since it contains a good database on measures and policies. For the projections of concentrations and depositions, however, the full EMEP model or comparable models might be necessary. This ensures consistency between projections for the long-range transboundary pollutants and those for urban air quality. Because of the connection between RAINS and EMEP models, RAINS can still be used for evaluating policies against the baseline.

Options for the EEA

Scenario studies can be used in a number of ways. Options of interest for the EEA in its role of providing policy-relevant information are:

- providing an integrated baseline scenario which includes current policies, shows distances to targets and can be used as a starting point for policy analysis;
- evaluating (integrated) policy variants in interaction with the policy process;
- developing new scenarios and policy variants with the participation of stakeholders.

Projections under a baseline scenario might be presented in the five-year EEA state of the environment and outlook reports. In between the publication of these reports, partial updates could be made in order to show the effects of the latest policies. The greenhouse gas and air pollution projections should be based on EU-wide accepted economic and energy scenarios.

Improvement of models themselves is costly and time consuming, and not within reach of the EEA. However, the EEA could support model development by showing its interest and support. The efforts of the EEA might be focused on the consistency and coherence of the model and the institutional network, and the interconnections between the models used in the policy processes on climate change, long-range air pollution and urban air quality.

A baseline projection can be made along the lines of the ShAIR scenario. This study used a model network, which needs several improvements, such as:

- adding a model on agriculture scenarios;
- adding a model on non-CO_2 greenhouse gases;
- expanding the greenhouse gas models to all European countries;
- integrating PM in the model network;
- improving the link between transboundary and urban air quality;
- improving the link between the energy model and RAINS;
- improving the consistency between energy and transport models;
- improving the module on urban emissions;
- obtaining a better understanding of the state of current policies and measures.

Although the list of recommendations is long and contains several major topics, air and climate change is still a field in which assessment and scenario studies are most developed. In other fields methods, tools and models need much more development. The EEA, in broadening integrated assessment to other topics, could choose to focus on a number of priorities:

- help to develop a European scenario model on agriculture, as needed for assessment of land-use change (part of biodiversity) and soil degradation;
- help to develop a European model on water quality;
- continue and improve ETC activities in the field of waste and water quantity, in particular, improving the link to scenarios;
- enhance consensus on a biodiversity assessment methodology.

1. Introduction

1.1. Objectives

The European Environment Agency (EEA) mission is to provide targeted, objective and reliable information for those framing, further developing and implementing environmental policies at the European level. One of its key products to that end is the regular state of the environment and outlook report. Integrated environmental assessment (IEA) is a key methodology for reporting, since it provides policy-relevant information on current status and trends as well as potential future developments by prospective analysis.

Consequently, integrated assessment is a primary process for the EEA. In the recent report *Environment in the European Union at the turn of the century* (EEA, 1999a, hereafter referred to as the EEUTC report), the EEA showed substantial development in its experience in integrated assessment and prospective analysis. The EEA medium- to long-term strategy and work programme aims at improving the methodologies for integrated assessment and prospective analysis in order to produce more transparent, better documented and more scientifically sound results for the next integrated assessment report in five years' time.

The EEA initiated this study to evaluate and appraise its past experience in environmental projections underpinning the EEUTC report. This should consolidate the experience gained and help to outline a long-term strategy for integrated assessment and prospective analysis. This exercise focuses primarily on issues related to air quality and climate change.

The main objectives of this study are to:

- test and evaluate the integrated assessment infrastructure developed by undertaking sensitivity and uncertainty analysis of the so-called baseline scenario, with particular emphasis on air-related issues (air pollution and the interaction with climate change/greenhouse gases);
- build on expertise, connections and interrelations among parties involved;
- identify relevant indicators, particularly for prospective analysis and policy evaluation, and develop accessible methodologies, information flows and tools for their implementation;
- appraise, evaluate and further develop integrated assessment methodology.

During the study, discussion between the consortium and the EEA led to some changes in the definition of the objectives and products. In the end, the study had two main goals. One was to learn about and improve the integrated assessment methods and tools used and the other was to produce an updated projection (ShAIR) on air pollution and greenhouse gases based on the Shared Analysis scenario. The work on sensitivities was limited to a number of partial sensitivity runs.

1.2. Organisation of the project

The project team consisted of:

R. Albers (project leader), F. de Leeuw, J. van Woerden, J. Bakkes (European topic centre on air quality (ETC-AQ), Dutch Institute of Public health and the Environment (RIVM))
N. Moussiopoulos, P. Sahm (European topic centre on air quality (ETC-AQ), Aristotle University Thessaloniki (AUTh))
P. Capros, N. Kouvaritakis, L. Mantzos (National Technical University of Athens (NTUA))
J. Cofala, C. Heyes, Z. Klimont, M. Amann (International Institute for Applied System Analysis (IIASA))
T. Pullus, A. Visschedijk (European topic centre on air emissions (ETC-AE), Netherlands Organisation for Applied Scientific Research (TNO))

Z. Samaras, P. Tourlou (European topic centre on air emissions (ETC-AE), Aristotle University Thessaloniki (AUTh))

A number of technical background reports, underlying this overall report, were produced:

Cofala, J., Heyes, C., Klimont, Z. and Amann, M., 2000. *Integrated assessment of acidification, eutrophication and tropospheric ozone impacts in Europe*, IIASA, Laxenburg, Austria.
Capros, P., Kouvaritakis, N. and Mantzos, L., 2000. *Projections for energy related CO_2 emissions in the EU*, NTUA, Athens, Greece.
de Leeuw, F. and Moussiopoulos, N., 2000. *Partial sensitivity analysis of urban air quality*, ETC-AQ.
Tourlou, P. M. and Samaras, Z., 2000. *Task B.3 Partial sensitivity analysis,* ETC-AE, LAT/AUTh, Thessaloniki, Greece.
Woerden, J., 2000. *Mapping and documentation of information streams, data flows and models for climate change, acidification, urban air quality*, RIVM, Bilthoven, the Netherlands.

The study was supervised by an EEA team composed of T. Ribeiro (project manager), R. van Aalst, A. Jol, H. Vos and H. Luiten.

1.3. Structure of the report

First, a closer look will be taken at assessment methods and tools, with more specific attention on the use of scenarios (Chapter 2). This chapter provides an overview of recent European scenarios and describes the model network used in this study.

A projection is made of the air indicators for an updated scenario based on the energy scenario of the Shared Analysis project of the European Commission. This so-called ShAIR scenario is presented in four chapters on economic and energy developments (Chapter 3), climate change (Chapter 4), transboundary air pollution (Chapter 5) and urban air quality (Chapter 6). These chapters include a comparison with projections in previous studies, e.g. the EEUTC report and the Auto-Oil II Programme. Some partial sensitivity analyses are presented and discussed. Lessons learned about the process of designing scenarios in this study are presented and discussed and recommendations for future improvements are given (Chapter 7). The report is rounded off with recommendations for the development of assessment tools in fields outside air pollution and climate change (Chapter 8).

2. Methods and tools

2.1. Introduction

There are many definitions of integrated assessment, which are not analysed in detail for this report. Looking at this study the 'integration' part is in the interconnection of the policy fields of climate change, transboundary and urban air pollution, and describing the source-effect chain given an economic scenario.

The European Environment Agency (EEA) is required to support the policy process at the European level. The focus of this study is on how a prospective analysis can be used to help in policy processes. This is not necessarily the same as a pure scientific approach. Scientists focus primarily on improving knowledge and understanding, thereby reducing uncertainties, while politicians need to make decisions, despite the uncertainties. Supporting the policy process therefore requires a translation of the interconnection between pure science and the policy process. While, on the one hand, the approaches and methods may differ, on the other, there is a strong relationship between policy and science. Finding the right road between policy and pure science will always be a case for discussion.

Since supporting the policy process by means of scenario calculations is not new, there was no need to start from scratch. As the partners in this project have been involved in a number of assessment studies in the recent past, these experiences could be used as a starting point.

This chapter will first briefly describe the use of scenarios in prospective analysis, followed by an overview of a number of recent scenario studies that focused on policy support, without pretending to be complete. The model network used to design the ShAIR scenario is described in the last section.

2.2. Scenario building

Since it is impossible to predict the future, scenarios are constructed to give insight into possible future developments. A scenario is a storyline combined with a quantitative elaboration. Depending on the kind of questions to be answered there are different ways in which scenarios can be constructed. First of all, the goal of a scenario study has to be clear. A number of possible goals are:

- creating consensus;
- anticipating possible future policy questions;
- acquiring a feeling for policy robustness;
- becoming sensitised to current and future developments and policies for certain parameters (e.g. economic growth);
- comparing different policy options on costs and impacts;
- creating a baseline for negotiations;
- showing and developing different visions of the future.

Some of the functions might be combined in one study, others require quite different approaches. The use of scenarios to create consensus requires commitment and involvement from all parties in the consensus process. The construction of one or more scenarios, then, is a way to gain insight into each other's viewpoints and opinions and try to make the differences transparent and open to discussion.

Anticipating possible future policy questions needs one (or more) baseline scenario(s) that reflect current and future trends, and show the effect of policies and measures, and the distance to the policy targets. Consensus or transparency on measures and policies included is crucial. However, some independence from policy-makers is needed to reach an 'objective' picture of the effects of policies and measures. Comparing the effects of different policy options sometimes only needs a focus on a few driving forces and the use of just one baseline scenario; policy robustness assessment requires the use of more baselines or variants reflecting the sensitivities for the underlying assumptions in driving forces.

This variety of functions explains why different reports deal with scenarios in different ways. For instance, the Intergovernmental Panel on Climate Change (IPCC) presents a number of scenarios, while the Convention on Long-Range Transboundary Air Pollution (CLRTAP) chooses just one baseline. Indeed, IPCC wants to show the effects of trends in the long term, while the CLRTAP places the focus on the comparison of policy options to support negotiations on emissions goals.

Distinctions sometimes made between different types of scenarios are (EEA, 2000a):

- forecasting versus backcasting
- descriptive versus normative
- quantitative versus qualitative
- trend versus peripheral.

The EEA report *Environment in the European Union at the turn of the century* (EEA 1999a, hereafter referred to as the EEUTC report) used a forecasting, descriptive, quantitative, trend type of scenario. This study further focuses on the construction of baseline scenarios in this way. Important characteristics of such a baseline scenario are:

- causality: using the available knowledge on the mechanism;
- consistency: including the use of quantitative analysis much as possible;
- transparency: policy-makers should be able to follow the quantification;
- plausibility: being probable and realistic;
- instrumental approach: paying attention to the policy instruments.

Some other relevant aspects are the selection of relevant driving forces and the time horizon.

Driving forces
The state of the environment is related to the development of a large number of explanatory variables, such as economic trends (size, growth, structure, trade), energy consumption and production, mobility, agriculture, technological progress. Sometimes the focus can be on technological developments (e.g. ozone-depleting substances, or perfluorcarbons (PFCs) and hydrofluorocarbons (HFCs)), while sometimes the economic developments are dominant (e.g. carbon dioxide (CO_2)).

Time horizon
Scenarios focusing on the effects of environmental policies (e.g. CLRTAP: the use of one baseline to compare the effects of different policy options) usually have a time horizon of 10–15 years. Scenarios looking at environmental effects, for instance, of climate change, have a time horizon of 50–100 years and differences are usually in the underlying driving forces as there are economic, political, cultural and technological developments (e.g. the use of different storylines by IPCC).

One last aspect worth mentioning in this section is the difference in constructing a European scenario between:

- top-down: a consistent scenario is constructed in which the developments in all countries are treated the same way;
- bottom-up: the scenario is the sum of scenarios provided by the individual countries.

The latter improves the acceptance of the scenarios by countries, but consistency and transparency is more difficult to realise.

2.3. Integrated assessment

In general, five levels of integrated assessment can be distinguished:

- integration of results from various studies
- integrated assessment by models
- the integrated model
- involvement of stakeholders
- open model structure.

Integration of results from different studies
The easiest way to make an integrated assessment is to bring together information from all kind of sources and reports and try to connect them. In this approach there is (almost) no possibility of controlling consistency; showing co-benefits of policies from one level to another level is almost impossible. The first EEA assessment report (1995) was a clear example of this approach.

Integration by models
The use of a model network provides better possibilities of consistency and of showing co-benefits but is in general more complex than the integration of results from studies. The EEUTC was a first attempt at integration by models although it also made use of results from reports and studies whose content was outside the range of the EEA and therefore not totally consistent with the main results.

When assessing environmental issues at different levels more models are usually included and more scientific disciplines and groups are involved. To come to an integrated approach extra communication is needed. The integration of the results is often overlooked. An integrator is required who is able to overview all the levels in order to reach consistency and interpret the overall results. Many of the problems in scenario studies that include a number of institutes can be related to integration problems. The essence is that overall results or an overall data analysis are only in the interest of the project leader and the user of the assessment, but not of all the partners in the project.

The integrated model
The extreme form of coordination in a model network is to bring all the models together as modules of an overall model. Most of the integrated assessment studies just make use of one model (see EEA, 2000a). The reason is clear: one model is relatively easy to deal with. The other side of the coin is, however, that to bring all the models together in one model the information has to be condensed for running and handling the model. Experience has taught us that models dealing with more than one topic, illustrative as they might be, are not able to give direct support to the policy process as that requires more detailed information.

Involvement of stakeholders
The most advanced integrated assessment method is the participatory approach. Interaction with stakeholders is also essential to reach consensus, especially on the process, and to a lesser extent on the results. The participatory approach requires flexibility in order to react on the wishes and proposals of the stakeholder. On the other hand, a basic system (model) has to be available, because adding main subjects might cost too much time to incorporate in the assessment process.

Good examples are seen in the way the United Nations Economic Commission for Europe (UNECE) uses the RAINS model in preparing protocols and the use of IMAGE in the field of climate change. Both cases involve just one model as a basic framework. In general, this approach is more time consuming than the others and requires an available model framework.

Open model structure
A different approach is to allow the use and development of more models to help solve policy questions. This clearly increases uncertainties in outcome since a greater number of approaches will be used in parallel. It is clear that the number of resources needed for an

open model structure is much greater than for one of the other levels. IPCC uses this method, and the Auto-Oil II study also used a number of different models at the same time.

2.4. Recent European policy-oriented studies in air pollution

Recent years showed a boom in scenario analyses on European air pollution, covering such themes as:

- CO_2 emissions from future energy use (Shared Analysis project);
- Regional air quality (RAINS calculations for CLRTAP Gothenburg protocol and EC national emission ceilings directive);
- Urban air quality (Auto-Oil II);
- Economic impacts of environmental policies (the Priority Study);
- Overall environmental scenario (EEUTC).

A short characterisation of these scenarios is given below.

- *Environment in the European Union at the turn of the century (EEUTC report).*
  A comprehensive assessment report produced by the EEA, this document describes the present and future state of the environment in the 18 EEA member countries and some accession countries, focusing on distance-to-target analyses. Only one scenario, called 'baseline', was used. It comprised existing and proposed policies prior to August 1997 and reflected a kind of business-as-usual economic scenario. The time horizon of the EEUTC report is 2010.

- *Shared Analysis*
  The Shared Analysis project was funded by the European Commission (Directorate-General (DG) for Energy). The project was intended to provide a common framework on energy analysis involving experts from all Member States, as well as from academic institutes, industry and non-governmental organisations (NGOs). The project concentrated on several specific core issues, e.g. future world energy demand, the progress and implications of liberalisation of electricity and gas supply on the European Union (EU) energy system and the wider economy, and strategic policy responses to the Kyoto protocol, taking into consideration energy- and non-energy-related greenhouse gas emissions.

- *CLRTAP Gothenburg protocol*
  During the negotiations on the protocol to abate 'acidification, eutrophication and ground-level ozone' (the Gothenburg protocol) the IIASA (International Institute for Applied System Analysis) RAINS model played a central role. First, a reference scenario was constructed, and measures and critical loads were produced in consultation with the countries (bottom up). The model was used to explore the possible range for environmental improvements between what is expected to be achieved through current legislation and what could be achieved if technical emission controls were utilised to the maximum extent. Later during the negotiations, the model was used to identify cost-minimal distributions of emission reductions across national borders so as to realise environmental targets specified by the negotiating parties and vice versa, and to illustrate the environmental impacts of emission reductions proposed by the negotiators. However, it must be noted that while the model guided the negotiations, the commitments made by the parties in the end were mainly influenced by domestic considerations. The extra emission reduction of the protocol was about 50 % of the emission reduction given in the scenario (G5/2) used as starting point for the negotiations.

- *Draft EU national emission ceilings directive (and the ozone directive)*
  The IIASA RAINS model was used to support the policy process within the EU on the draft national emission ceilings directive and the ozone directive. A number of scenario runs were performed by IIASA parallel to the runs for the Gothenburg protocol. The basic scenario was identical in both processes (Gothenburg protocol and EU).

- *Auto-Oil II*
  The Second European Auto-Oil Programme (AOP II) was established in 1997 to provide the technical input for the European Commission's work on future vehicle and fuel quality standards and related measures. The intention was to relate transport emissions to the air quality directive of the EU. The work programme of AOP II was based on seven work groups, with members drawn from Member States, the oil and auto industries, environmental NGOs and the European Commission. As part of this programme a baseline transport and emission scenario was developed by Standard & Poor's Research Services (DRI) for road transport and a baseline emission scenario for stationary sources by Sustainable Environment Consultants Ltd (Senco,1999). The baseline emission scenario for the stationary sources was, to a large extent, similar to the RAINS baseline (end 1998). An approach for evaluating urban air quality was also developed.

  The base-case scenario covers the 1990–2020 period (road transport scenario data and emissions) for the 15 EU Member States and Estonia, Poland and Switzerland. A detailed analysis for 10 cities was performed by the Joint Research Council (JRC) using complex air quality models. The goal of the generalised exposure assessment (GEA) of the EEA (European topic centres on air quality (ETC-AQ) and air emissions (ETC-AE)) was to:

  - estimate the size of the urban population living in cities in the European Union which will not be in compliance with air quality guidelines in future years;
  - estimate additional emission reductions needed to reach compliance.

  It worked complementary to the JRC model. As part of the Auto-Oil study air quality in 200 urban agglomerations within the EU was calculated for a reference year (1990 or 1995) and for the year 2010. Pollutants considered were sulphur dioxide (SO_2), nitrogen dioxide (NO_2), PM_{10} (respirable particulate matter with aerodynamic diameter between 2.5 and 10 micrometres), lead (Pb), ozone (O_3), carbon monoxide (CO) and benzene. Some results are also reported for Benzo(a)Pyrene (B(a)P).

- *Priority Study*
  The Priority Study was funded by the European Commission (DG Environment). The primary objective of this study was to provide an economic assessment of priorities for European environmental policy planning. The analysis is based on an examination of the cost of avoided damage, environmental expenditures, risk assessment, public opinion and sustainability. The study incorporates information on targets, scenario results and policy options and measures, including their costs and benefits. Three principal scenarios, generally using a 1990–2010 time frame, were employed by the study. The baseline scenario is based on projected changes to basic socio-economic parameters such as population and gross domestic product (GDP) growth and energy consumption; and continued implementation of existing and proposed EU policies as at August 1997. Thus, the urban waste water treatment directive, issued in 1993, is reflected in the baseline scenario, while the provisions of the Kyoto protocol are not. This scenario has been constructed in close cooperation with the EEA and is, therefore, largely consistent with the latest EU state of the environment report (EEA, 1999a).

  A scenario has also been developed to assess the maximum feasible reduction of environmental pressures using a set of measures based on the full application of available technology. Finally, an accelerated policy scenario uses new targets to assess a set of measures, which go beyond existing policies, but which generally fall short of maximum technology. This scenario aims to identify the circumstances where benefits and costs are optimised. It is best applied to issues which have well-defined emission targets and impact indicators, and where credible economic values can be computed. Such is the case with climate change, for example, where the targets of the Kyoto protocol are taken into account.

Table 1

	Number of themes	Integrated assessment	Number of baselines	Integrated assessment	Area
EU 98	> 3	Model network and studies integration	1	Top down	EEA 18 + accession countries
Priority Study	> 3	Model network	1	Top down	EU-15
Shared Analysis	1	1 model	1	Top down	EU-14
CLRTAP	1	1 model	1	Bottom up	Whole Europe
National emission ceilings directive	1	1 model	1	Bottom up	Whole Europe
Auto-Oil II	1	Open model structure	1	Top down	EU-15

Although mostly the same institutes and models were involved in the above-mentioned studies there are a number of differences in:

- methodology (goals and approaches)
- involvement of Member States and other stakeholders
- inclusion of policy
- data for base year
- assumptions
- choice of models.

All in all, the conclusion is that there is no generally accepted combined set of models at the moment to make scenarios in the field of air and climate change.

2.5. Data flows and models used

2.5.1. The DPSIR chain

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

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).

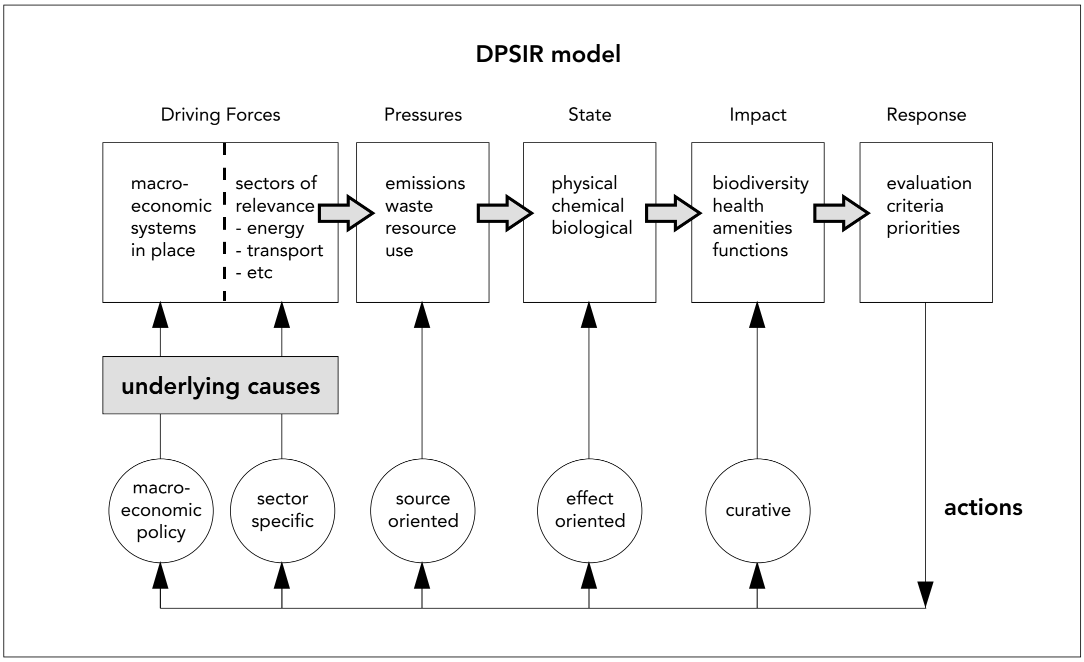
S: Pressures affect the **state** of the various environmental sectors (air, water, and soil) in relation to their functions.

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.

Figure 2.1 reflects DPSIR in a way that is tailored to this study. Policy response can be assigned to any of the five kinds of actions (macro-economic policy, sector specific, source oriented, effect oriented and curative) given in Figure 2.1. In some cases, the underlying causes may not be amenable to policy influence, e.g. population change. In this study we seek policy actions that remove or ameliorate the underlying causes of the environmental problems.

Figure 2.1. **The Driving forces-Pressure-State-Impact-Response (DPSIR) chain (source: RIVM et al., 2001)**



2.5.2. The model network

The information flow in this scenario study follows the DPSIR chain, starting with the driving forces and following with pressures (emissions of the various compounds), state (regional and urban air quality) and ending in proxy indicators on impacts (exceedances of critical loads and exposure of population). The responses influence mainly the driving forces and the pressures.

The Shared Analysis scenario was used for the socio-economic scenario. This scenario includes data on investment, consumption, and demographic and employment trends. The energy supply and demand and CO_2 emissions were derived with the National Technical University of Athens (NTUA)'s modular PRIMES model. Designed for the medium to long term, the PRIMES model simulates a market equilibrium solution for energy supply and demand in the European Union Member States, reflecting considerations about market economics, industry structure, energy/environmental policies and regulation. CO_2 emissions from non-energy sources are not included in PRIMES; these emissions, from the cement industry, for example, contribute to about 5 % of total CO_2 emissions. Furthermore, CO_2 sinks are excluded.

Scenario estimates from AEA Technology and Ecofys were used as the starting point for greenhouse gas emissions other than CO_2. Uncertainties in these non-CO_2 emissions scenarios are relatively large. Whether the underlying socio-economic scenarios correspond with the NTUA baseline scenario for 2010 could not be quantified, but the differences with scenarios used to assess other environmental issues are relatively small or usually not relevant; in any case they have little effect on the emission scenarios. Differences have been observed with respect to waste production, animal numbers, coal mining and fertilisers, since they underlie the environmental scenarios (i.e. climate, acidification, waste etc). The Dutch Institute of Public health and the Environment (RIVM) has slightly adjusted these scenarios in order to improve consistency.

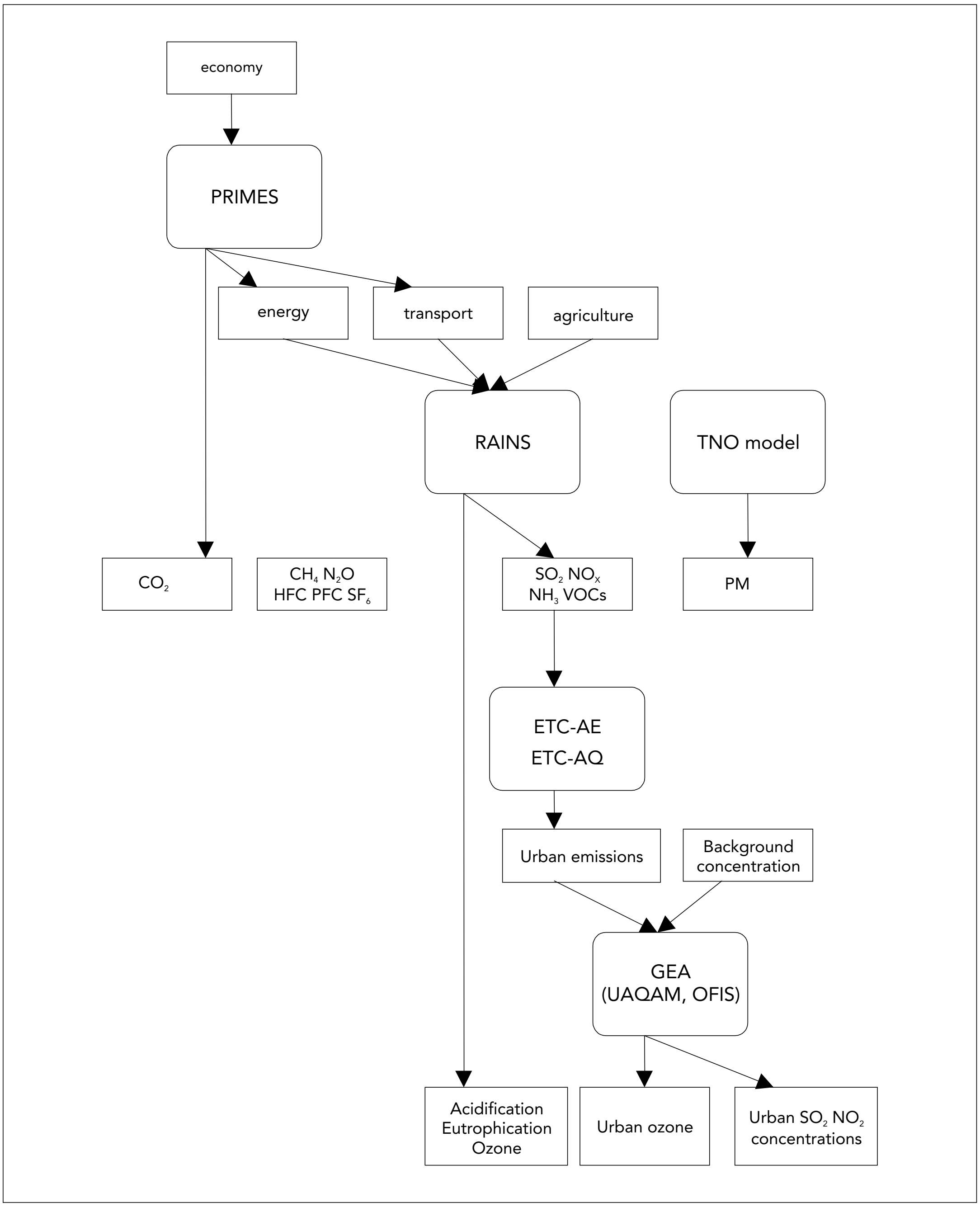
For acidification and eutrophication, IIASA's RAINS model was used. For the emissions scenarios of SO_2, nitrogen oxides (NO_x), ammonia (NH_3) and volatile organic compounds (VOCs), RAINS used its own transport and agricultural scenario on the basis of national communications, while energy consumption data was taken from PRIMES and emission factors from the *EMEP/Corinair Guidebook* and Corinair inventory. National report information came from national experts. The emission scenarios were used to derive acidification, eutrophication and ozone effects on natural ecosystems and human health in terms of exceedance of critical loads. The energy consumption data from PRIMES needed adjustments before they could be used as input in RAINS, such as the breakdown of fuel consumption by transport categories (e.g. cars, trucks, light/heavy duty) or the division of data for Germany into the former west and east parts.

Models developed for the Auto-Oil II Programme were used for the urban stress assessment.

The model chain as used in this study is presented schematically in Figure 2.2, showing the five models used:

- the NTUA PRIMES model (energy and related CO_2 emissions);
- the IIASA RAINS model (national emissions of SO_2, NO_x, NH_3 and VOCs, exceedances of critical loads on sulphur, nitrogen and ozone);
- a TNO model to calculate the emission of PM_{10};
- RIVM's UAQAM on urban concentrations of NO_2, SO_2;
- AUTh's OFIS on urban ozone concentrations.

The model network Figure 2.2.



3. Economic developments

3.1. Introduction

The air quality and climate change projections as described in this study are based on the economic baseline scenario of the Shared Analysis project of the European Commission (EC, 1999a). This scenario follows the philosophy of conventional wisdom, describing recent trends of the major drivers for the period up to 2020. This chapter describes the demographic and economic outlook that forms the basis of the Shared Analysis scenario including transport and energy trends for the 15 European Union (EU) Member States. Assumptions made on energy trends for the other European countries are also given, as constructed by the International Institute for Applied System Analysis (IIASA). The relevant agricultural developments (livestock and fertiliser consumption) are given as assumed by IIASA.

3.2. Demographic and macro-economic assumptions

3.2.1. Demographic issues

Population is an important determinant both of overall economic performance and energy trends, especially in the transportation, household and services sectors. For the period from 1995 to 2010, population in the EU is assumed to rise very modestly by some 12 million people. After 2010, total EU population is effectively stable and its level of 384 million people in 2020 is only marginally higher than in 2010. Household size in the EU (i.e. number of inhabitants per household) is assumed to decrease from 2.62 inhabitants per household in 1995 to 2.47 in 2010, and 2.36 in 2020, reflecting the changing age structure of the population as well as changes in lifestyles.

3.2.2. Economic growth

The present Shared Analysis scenario draws on the macro-economic and sectoral projections available for the short term (up to 2000) from DGII (Economic and Financial Affairs) of the European Commission and, to a lesser extent, from other sources. For the period beyond 2000 it uses the aggregate assumptions for the world economy derived from the OECD (Organisation for Economic Co-operation and Development) Linkages project.

Unfortunately, there are few sources for long-term projections on sectoral trends for individual European countries, essential for the discussion of detailed energy projections. As past experience has shown, these changes can often be dramatic and can move in different directions in different countries. No study is available at the level of disaggregation needed for long-term energy models. Thus an attempt has been made here to build a separate 'story' describing the evolution in each EU country. The projections were made in three steps:

- First, gradual conditional convergence of the EU economies by 2030 in terms of per capita income was assumed. The gross domestic product (GDP) of each EU country for the period 2000–2030 was derived on this basis.
- Second, the starting situation of each country, along with clearly identifiable trends and the identifiable driving forces of growth for each economy, were used to determine the growth rate in each industrial sector.
- Third, the GEM-E3 ([1]) general equilibrium model of the EU economy has been used to ensure consistency of sectoral and macro-economic projections.

The baseline scenario simulates a dynamic path of the EU economy up to 2030. It is derived from exogenous assumptions on the evolution of technological progress associated with production factors, changes in the global economic and environmental context and the continuation of the current pattern of public finance policy.

(1) The GEM-E3 model was constructed within collaborative projects coordinated by NTUA.

The baseline scenario assumes that the 1999 economic crisis in a number of Asian economies and Russia is not expected to have a significant impact on European economies. In this sense, the recovery of the EU economies observed beyond 1997 is expected to continue in the short term. The observed increase of gross domestic product (GDP) in the EU for 1990–95 was 1.4 % per year while the assumed growth for 1995–2000, following recent trends, indicates a significant boost at 2.6 % per year. In the medium to long term GDP is assumed to increase by 2.4 % a year from 2000 to 2010 and by 1.85 % a year in the following decade.

Macro-economic assumptions for the EU in the baseline scenario Table 3.1.

	1995	2000	2010	2020	1995-2020 % per year
Gross domestic product (GDP) (million 1999 euro)	7374	8394	10649	12767	2.2
Share per sector (%)					
Energy intensive manufacturing	6.0	5.8	5.6	5.4	1.8
Non energy intensive manufacturing	20.5	20.1	19.6	19.2	2.0
Services	63.3	64.1	65.3	66.1	2.4
Population (million)	372	377	383	384	0.1

In the short term the process of monetary union and continued fiscal prudence are expected to favour investment over private consumption. Growth in fixed capital formation in the EU is expected to be especially rapid and to exceed 6 % in the 1998–2000 period. Investment prospects in accession countries are likely to prove especially buoyant due to the continued flow of EU funds for large infrastructure programmes. After 2000, economic growth is expected to be more balanced, with private consumption following GDP trends closely. Fiscal prudence is expected to continue but become gradually less stringent, thus reducing its negative impact on activity somewhat.

Overall, the growth of private consumption in the EU is assumed to be somewhat lower than average GDP growth. Following a growth of private consumption by 1.2 % per year from 1990 to 1995, the assumed growth for the period 1995–2000 reaches 2.3 % a year. The annual growth rates for the decades 2000–10 and 2010–20 are 2.3 % and 1.8 %, respectively.

The long-established trend of the restructuring of EU economies away from the primary and secondary sectors and towards services is assumed to continue, although the pace of change is expected to decelerate. Thus, following the period of substantial restructuring of the past 20 years, the industrial sector's share in GDP is assumed to decline only modestly. New industrial activities with high added value and a lower material base are projected to emerge in most countries. For the EU as a whole, the share of industrial value added in the economy is assumed to decline from just over 28 % in 1995 to 26 % in 2020. Agricultural added value declines by one percentage point over the same period and is limited to just 2 % of GDP by 2020.

Considerable differences are assumed in the evolution of the economic structure in different EU countries, with some further specialisation taking place. In Denmark, France and Greece, the service sector will exceed 70 % of GDP by 2020. This sector accounts for less than 60 % by 2020 in Austria and Ireland only. Within the industrial sector, energy-intensive industries tend to lose their share, while high value-added specialised sectors increase in importance. For example, the value-added share of the engineering sector increases as a proportion of the total industry in all EU countries except Portugal. Agricultural added value declines in almost all countries and by 2020 it accounts for more than 4 % of GDP only in Finland, Greece and the Netherlands.

3.3. Projections on transport

The main indicators on transport in the Shared Analysis scenario are given in Tables 3.2 and 3.3.

Table 3.2. **Distance travelled in the Shared Analysis scenario in 10^3 km driven per capita**

Country	1995	2010	2020	Annual growth rate 1995–2020
Austria	12.9	15.4	17.5	1.2
Belgium	10.8	14.1	16.9	1.8
Denmark	13.9	14.6	15.5	0.4
Finland	12.5	15.1	16.9	1.2
France	13.4	15.8	17.8	1.1
Germany	11.2	13.7	16.7	1.6
Greece	10.8	17.1	19.7	2.4
Ireland	12.9	17.0	18.5	1.4
Italy	13.0	16.2	18.5	1.4
Netherlands	11.2	13.9	16.5	1.5
Portugal	8.9	12.0	15.2	2.1
Spain	13.5	17.5	19.4	1.5
Sweden	13.8	16.6	18.1	1.1
UK	12.1	14.7	16.7	1.3
Total EU-14	**12.3**	**15.2**	**17.5**	**1.4**

Table 3.3. **Passenger travel by mode**

Country	% public road transport			% private cars and motorcycles			% air			% train		
	1990	1995	2020	1990	1995	2020	1990	1995	2020	1990	1995	2020
Austria	13.2	13.6	9.3	74.9	73.5	66.9	2.2	2.8	6.5	9.6	10.1	17.3
Belgium	14.9	12.5	8.9	75.9	77.8	73.5	2.1	2.7	5.5	6.6	6.2	11.4
Denmark	13.5	14.6	9.8	74.0	73.8	71.1	3.6	3.7	6.0	7.0	6.9	12.4
Finland	13.4	12.5	9.1	73.7	74.6	70.3	7.3	7.5	12.0	5.3	5.0	8.3
France	5.8	5.2	3.7	82.7	84.4	81.2	1.9	2.5	4.8	9.0	7.1	9.7
Germany	8.9	7.9	5.1	79.4	79.6	68.9	4.9	5.2	13.1	6.7	7.2	12.9
Greece	10.5	10.3	6.4	75.0	75.7	64.5	7.8	7.5	15.8	1.9	2.2	10.0
Ireland	12.2	12.1	8.8	81.6	81.4	79.4	3.3	3.5	6.9	2.8	2.9	4.8
Italy	12.8	10.6	7.9	79.1	81.1	78.0	1.6	1.7	3.5	6.3	6.5	10.6
Netherlands	11.7	10.5	7.4	77.1	76.8	71.8	2.0	3.4	8.5	6.7	7.0	10.2
Portugal	20.9	22.2	14.8	57.4	59.0	53.3	10.7	8.3	13.7	10.8	10.3	18.0
Spain	10.2	10.1	7.2	78.6	77.9	74.7	6.9	7.5	11.4	3.3	3.6	5.9
Sweden	10.4	7.8	5.4	78.7	76.7	70.4	5.1	10.2	16.0	5.3	5.1	8.0
UK	7.1	7.1	6.5	84.5	84.1	77.1	3.2	3.6	8.4	4.9	5.1	7.8
Total EU-14	**9.6**	**8.9**	**6.5**	**79.8**	**80.2**	**74.1**	**3.8**	**4.3**	**8.8**	**6.2**	**6.2**	**10.1**

3.4. Energy projections

3.4.1. Policy assumptions

The Shared Analysis scenario is based on the assumption that EU policies currently in place and in the pipeline, at least as known at the end of 1997, will be continued. The Shared Analysis scenario includes the following assumptions.

- The liberalisation of electricity and gas markets proceeds in line with EC directives and is assumed to develop fully in the years to 2010.
- The restructuring in power and steam generation is made possible by mature gas-based power generation technologies that are efficient, involve low capital costs and are flexible regarding plant size, co-generation and independent power production.

- Energy policies that aim at promoting renewable energy (wind, small hydro, solar energy, biomass and waste) are assumed to continue involving subsidies on capital costs and preferential electricity selling prices.
- Ongoing infrastructure projects in some Member States involving the introduction of natural gas are assumed to gain full maturity in the first half of the first decade of the projection period.
- The Shared Analysis scenario takes into account the different policies in place in the different EU Member States as regards nuclear capacity. It is assumed that Finland (with ongoing construction of 250 megawatts (MW) of new nuclear capacity), Germany, the Netherlands, Spain, Sweden and the United Kingdom will not expand further their nuclear capacity. In France (with ongoing construction of new nuclear plants of the order of 6.4 gigawatts (GW)) and Belgium further nuclear expansion, based on economic criteria, is assumed for the period beyond 2010. Decommissioning of existing nuclear capacity occurs on the basis of technical lifetime (40 years) with the exception of Sweden for which a much stricter decommissioning programme exists (based on political decisions).
- The Shared Analysis scenario did not incorporate the effects from the ACEA/KAMA/JAMA negotiated agreements of 1999 and 2000 (see http://europa.eu.int/comm/environment/co2/co2_agreements), as they had not yet been finalised by the end of 1997.
- Since specific policies and measures aiming at meeting the Kyoto targets were not announced in many countries and had not been finalised in others, by the end of 1997, these policy targets were not integrated in the Shared Analysis scenario.
- The emission limit values for new plants from the large combustion plant directive (88/609/EEC) regarding sulphur dioxide (SO_2) and nitrogen oxide (NO_x) emissions are taken into account in the technical and economic characteristics of technologies.

3.4.2. Fuel prices

Energy prices in the baseline scenario were assumed to gradually increase from the low level they had in March 1999, when oil prices were on average about US$ 12–15 per barrel, following a smooth ascending path (see Table 3.4).

International fuel prices in the Shared Analysis scenario up to 2020 (in 1999 euro per tonne oil equivalent) Table 3.4

	Average boarder prices in the EU (1999 euro per toe)				Average % change per year		
	1995	2000	2010	2020	1995-2000	2000-2010	2010-2020
Crude oil	106	91	112	133	-3.1	2.1	1.8
Natural gas	101	82	104	126	-4.0	2.3	1.9
Coal	67	65	66	68	-0.6	0.2	0.3

Oil prices were assumed to recover their 1995 price level by 2005 and then grow gradually. Natural gas prices increase at lower rates in the first half of the period but then grow slightly faster than oil as a result of pressures from the supply side. Coal prices remain almost stable in real terms.

In general, energy taxes are assumed to remain unchanged in real terms, as determined by legislation in March 1999. Thus, nominal changes in the price of energy products are the result of two different effects. The fuel cost component increases in line with the nominal price of the relevant primary fuel, which includes increases in both the real cost and an inflation effect, while the tax component of the energy price rises in line with inflation.

3.4.3. Other assumptions

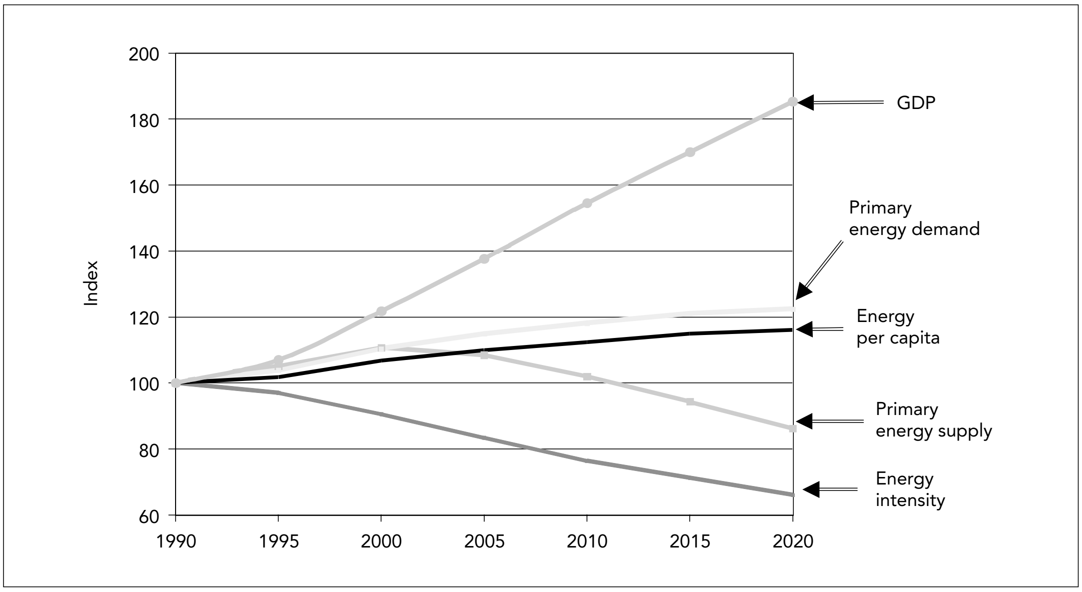
Outdoor temperature levels determine part of the energy use for heating. It was assumed that the degree-days during the outlook period would be constant at 1995 levels. Assuming a future level of degree-days closer to the historical average would ignore the evidence that the degree-days are falling. It is important to note, however, that should the weather in 2000 be closer to its historical average rather than to its level in 1995 the demand for energy for heating purposes would be above that projected.

The **discount rate** plays an important role within the PRIMES model. It is partly responsible for the determination of investment decisions by economic agents regarding energy-using equipment. Three rates are currently used within the model: the first, used mostly for large utilities, is set at 8 %; the second, used for large industrial and commercial concerns, is set at 12 %; the third, used for households in determining their spending on transport and household equipment, is set at 17.5 %. The 'subjective' nature of the discount rate used by households is discussed in the relevant chapter.

3.4.4. Energy projections for EU-15

The results of the Shared Analysis scenario show that despite the evidence of saturation for some energy uses in the EU, energy demand is expected to continue to grow, albeit at rates that are significantly lower than those experienced in the recent past. Thus, while significant economic growth can take place with only a small increase in energy use, there is no complete de-linking between energy and the economy. The Shared Analysis scenario shows an increase in energy demand by 10.5 % from 1990 to 2000, 7 % from 2000 to 2010 and 3.6 % from 2010 to 2020. Figure 3.1 shows the relative change of some key indicators of the energy system compared to their 1990 level indexed at 100.

Figure 3.1. **EU primary energy indicators, 1990–2020**



The implied energy intensity improvement (expressed as primary energy demand per unit of GDP) is expected to continue to improve albeit at a decelerating pace, averaging 0.9 % pa between 1990 and 2020 (see Table 3.5). This is partly due to the sectoral restructuring and dematerialisation of economic growth of the EU, but also to the fact that new capital goods (for industry, buildings and appliances) incorporate technological progress corresponding to zero or negative costs of energy efficiency improvement.

Production of fossil primary energy within the EU, after peaking in the period 2000–05, is expected to decline through to 2020. In contrast, renewable energy sources are expected to receive a significant boost as a result of policy and technological progress. The average annual growth rate in primary energy consumption is expected to be close to 0.7 % over the period to 2020. Fossil fuels will continue to dominate the EU energy system, their share remaining rather stable at 1990 levels (just above 80 %) over the projection period. Import dependency will increase from around 48.7 % in 1990 to 65.5 % in 2020.

Primary energy demand, baseline scenario — Table 3.5.

	Mtoe				Annual growth rate (%)			Share (%)			
	1990	2000	2010	2020	90-00	00-10	10-20	1990	2000	2010	2020
Solid fuels	301	207	182	218	- 3.7	- 1.3	1.8	22.9	14.3	11.7	13.6
Liquid fuels	544	604	653	660	1.1	0.8	0.1	41.4	41.7	42.1	41.1
Natual gas	222	337	400	430	4.3	1.7	0.7	16.9	23.2	25.8	26.7
Nuclear	181	223	227	199	2.1	0.2	- 1.3	13.8	15.4	14.6	12.3
Electricity (trade outside EU)	2	1	2	2	- 9.4	9.5	1.3	0.2	0.1	0.1	0.1
Renewable	64	79	88	100	2.1	1.1	1.2	4.9	5.4	5.7	6.2
Total	1314	1451	1552	1609	1.0	0.7	0.4				
Energy intensity (toe/mln 1999 euro)	191	173	159	146	- 1.0	- 0.8	- 0.9				
					0.7	0.3	0.2				
Energy per capita (toe/capita)	3.6	3.9	4.0	4.1							

The use of solid fuels is expected to continue to fall until 2010 both in absolute terms and as a proportion of total energy demand. Beyond 2015, however, the demand for solid fuels is projected to increase modestly due to the power generation problems that will ensue from the decommissioning of a number of nuclear plants, and a certain loss of competitiveness of gas-based generation due to higher natural gas import prices.

Spurred on by its very rapid penetration in new power generation plant and co-generation, gas is by far the fastest growing primary fuel. Its share in primary energy consumption is projected to increase further to 26.7 % by 2020. The share of oil in primary consumption is projected to be relatively stable over the period to 2020; its annual growth rate is projected to decelerate from 0.8 % in the period to 2010 to 0.1 % during 2010–20. Under the Shared Analysis technology assumptions, novel energy forms, such as hydrogen and methanol, do not make significant inroads, primarily due to cost considerations. Final energy demand is expected to grow marginally faster than primary energy (because of improved rates of conversion efficiency in power generation), rising by 0.9 % per year over the projection period. As can be seen from Table 3.6 there are relatively modest changes in fuel shares over the coming years.

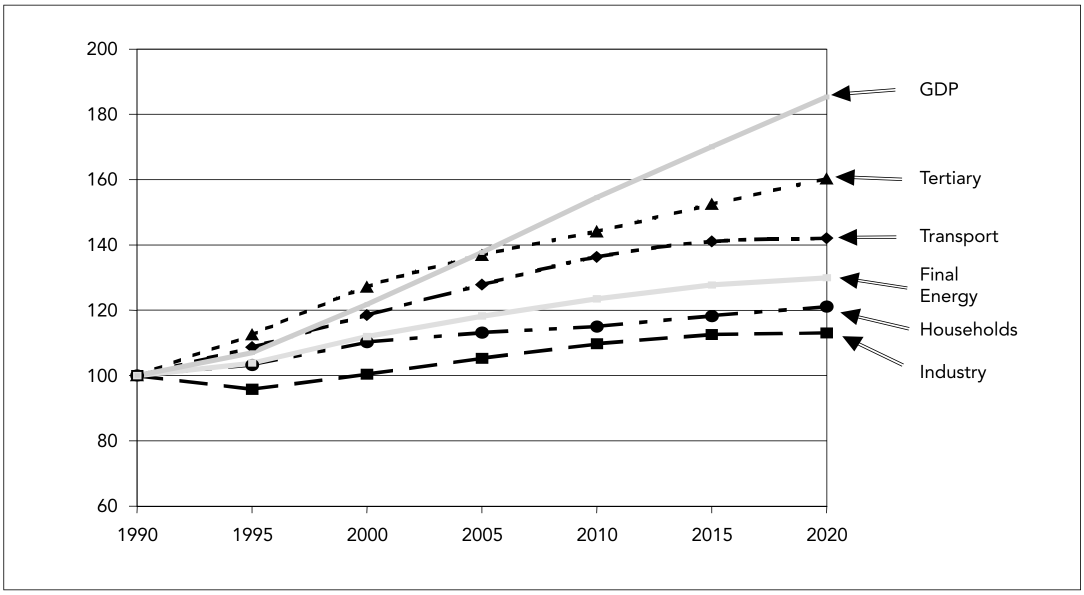
Final energy demand by sector and fuel, Shared Analysis scenario — Table 3.6.

	Mtoe				Annual growth rate (%)			Share (%)			
	1990	2000	2010	2020	90-00	00-10	10-20	1990	2000	2010	2020
Total	852	954	1053	1108	1.1	1.0	0.5				
By sector											
Industry	257	258	282	290	0.1	0.9	0.3	30.1	27.0	26.8	26.2
Residential	232	256	267	282	1.0	0.4	0.5	27.3	26.9	25.4	25.4
Tertiary	110	140	159	177	2.4	1.3	1.1	12.9	14.7	15.1	16.0
Transport	253	299	344	359	1.7	1.4	0.4	29.6	31.4	32.7	32.4
By fuel											
Solid fuels	71	36	27	20	- 6.5	- 2.9	- 2.7	8.3	3.8	2.5	1.8
Liquid fuel	378	435	477	487	1.4	0.9	0.2	44.4	45.6	45.3	43.9
Natural gas	157	198	211	212	2.3	0.7	0.0	18.4	20.7	20.1	19.1
Steam	68	74	89	101	0.9	1.9	1.3	8.0	7.8	8.5	9.2
Electricity	156	189	226	265	1.9	1.8	1.6	18.3	19.8	21.5	24.0
Renewable energy	22	22	22	21	- 0.1	0.2	- 0.4	2.6	2.3	2.1	1.9

Energy demand in the tertiary sector is the fastest growing segment of final demand, reflecting the expected restructuring of the economy towards services. The modest growth in residential energy demand reflects the lack of growth in EU population and the small increase in the number of households. By 2020, transport accounts for almost a third of EU final energy consumption, followed by the industrial and the residential sector, which account for around 26 % of consumption each.

The increase in transport energy demand is actually greater than the increase in the demand for liquid fuels over the 1990–2020 period, reflecting a decline in oil consumption in the other sectors. By the end of the forecast period oil becomes almost exclusively a fuel for transportation and a feedstock for petrochemicals. The use of electricity is expected to expand by 1.8 % per year over the projection period and its growth is expected to be especially rapid in the tertiary sector. Steam demand is projected to grow by 1.3 % a year in the period up to 2020. The industrial sector is projected to remain the dominant user of steam. Figure 3.2 illustrates the different trends in the evolution of final energy demand relative to the evolution of gross domestic product.

Figure 3.2. **Final energy demand and GDP, 1990–2020 (1990 = 100)**



The technology of electricity and steam generation improves, leading to higher thermal efficiency, lower capital costs and greater market availability of new generation technologies. The assumed improvement, however, is not spectacular and no major technological breakthrough occurs during the projection period in the baseline scenario. Table 3.7 demonstrates that total power capacity for the EU increases by some 300 GW in the 1995–2020 period (2) and a similar amount of new capacity will be required for the replacement of decommissioned plants. Thus the EU is projected to build 594 GW of new plants over the 1995–2020 period in order to cover its growing needs and replace the decommissioned plants.

Table 3.7. **Power generation capacity by type of plant, Shared Analysis scenario**

	Installed GW				Annual growth rate (%)			Share (%)		
	1995	**2000**	**2010**	**2020**	**95-00**	**00-10**	**10-20**	**1995**	**2010**	**2020**
Nuclear	132	136	135	117	0.7	- 0.1	- 1.4	23.1	18.8	13.4
Coal and lignite	179	166	101	37	- 1.6	- 4.8	- 9.6	31.5	14.1	4.2
Open cycle multi-fired	66	69	60	122	0.9	- 1.3	7.3	11.5	8.4	14.0
Open cycle of IPP	33	33	25	21	0.1	- 2.8	- 2.0	5.8	3.5	2.4
GTCC and small GT	46	84	254	384	12.7	11.7	4.2	8.1	35.4	44.1
Clean coal and lignite	1	1	3	27	0.0	22.5	22.7	0.1	0.5	3.1
Biomass and waste	4	4	5	6	2.5	0.6	2.5	0.7	0.7	0.7
Hydro and renewables	109	119	134	158	1.7	1.2	1.7	19.2	18.6	18.1
Total capacity	**570**	**613**	**717**	**872**	**1.4**	**1.6**	**2.0**			
Power generation efficiency										
Total electricity & steam	0.54	0.56	0.60	0.64	1.0	0.6	0.6			
Normalised for electricity only	0.35	0.38	0.41	0.44	1.5	0.7	0.7			

The use of conventional coal and oil plants declines very rapidly. Due to the decommissioning of older plants, there is a modest decline in the capacity of nuclear plants, while nearly half of

(2) The detailed breakdown of power generation by type of technology was not available for 1990 in the PRIMES database.

the thermal plants currently utilised by independent producers are also expected to be scrapped. This decline in capacity is more than compensated for by the dramatic increase in gas turbine combined cycle (GTCC) plants and small gas turbines (GTs). Their capacity increases by nearly nine times over the projection period to exceed 380 GW, or almost 45 % of the total installed capacity by 2020. A significant growth in generation by clean coal plants and biomass generation is also expected to occur over the next few years, in particular towards the end of the projection period. However, these forms of power generation will still only account for less than 5 % of total generation capacity by 2010.

Growth in hydroelectricity and other renewable forms of electricity generation is projected to be more than 50 GW of new capacity, the increase in these capacities representing about one sixth of total net capacity additions. Wind power will dominate this increase. A significant improvement is expected to occur in the efficiency of power generation. The efficiency of the overall power and steam generation system is expected to increase by around 10 percentage points and to reach 64 % by 2020. The efficiency of generation of electricity, excluding steam, improves from 35 % to 44 % between 1995 and 2020. This is due to the combined effect of the adoption of more efficient technologies (like GTCC) and of co-generation.

3.4.5. Energy trends in other European countries

Following the collapse of most centrally planned economies in the late 1980s, central and eastern European countries are still currently undergoing substantial restructuring and reforms towards a market economy. The region as a whole experienced a sharp recession until 1993 after which a process of slow recovery began.

In the context of the Shared Analysis scenario the evolution of the energy system for seven accession countries ([3]), namely the Czech Republic, Hungary, Poland, Slovenia and the three Baltic States (Estonia, Latvia, Lithuania — for which separate historical data have not always been available for this analysis) was examined. In response to the negative economic conditions gross domestic energy consumption and indigenous energy production in these seven countries followed a downward trend, declining in 1996 to 86 % and 81 % of their 1988 levels, respectively. The biggest share in the demand decline was that of solid fuels, followed by oil, while primary energy consumption of natural gas increased by about 30 % between 1988 and 1996. However, by 1996, solid fuels still dominated consumption, although their share fell from 60 % in 1980 to 53 %. Oil and gas accounted for 21 % and 16 % of primary energy consumption in 1996. Production from all fossil fuels has also fallen substantially since 1985 as a result of economic restructuring. With a limited oil and gas resource base, the countries of the region are net importers of crude oil and natural gas, which they import mainly from Russia. In 1996, almost 95 % of oil demand was covered by imports. Net imports of natural gas increased by 60 % between 1988 and 1996, from 15.8 million tonnes of oil equivalent (Mtoe) to 25.4 Mtoe.

As regards the future evolution of the energy system in the seven accession countries, primary energy consumption is expected to grow by 1.1 % a year in the 1995–2010 period and by slightly more (1.4 %) between 2010 and 2020. The implied energy intensity improvement is expected to reach an annual rate of more than 2.9 % per year in 1995–2020 (see Table 3.8). This is due to economic recovery after 1993, industrial restructuring, the opening up to competition and the ‘rationalisation’ of the energy system begun by the advent of economic reforms, as well as the accelerated substitution of solid fuels with natural gas. The significant decrease of primary production, especially with regard to solid fuels, will result in a growth of import dependency from 17.5 % in 1995 to more than 55 % in 2020.

(3) The discussion of recent trends in this section is based on the *1998 Annual Energy Review* of the European Commission.

Table 3.8. **Primary energy demand, baseline scenario for seven accession countries**

	Mtoe				Annual growth rate (%)			Share (%)		
	1995	2000	2010	2020	95-10	10-20	95-20	1995	2010	2020
Gross inland consumption	187	193	221	255	1.1	1.4	1.2			
Solid fuels	100	93	85	77	- 1.1	- 1.0	- 1.1	53.6	38.3	30.1
Liquid fuels	39	41	48	61	1.4	2.4	1.8	21.0	21.9	24.1
Naturel gas	29	38	66	92	5.6	3.4	4.7	15.5	29.7	36.1
Nuclear	11	12	12	12	0.5	0.1	0.4	6.0	5.5	4.8
Electricity	0	0	- 1	- 1	6.9	- 0.6	3.8	-0.1	-0.3	-0.2
Renewable energy	8	9	11	13	2.5	1.7	2.2	4.0	4.9	5.1
Energy intensity (toe/mln 1990 euro)	1494	1243	910	718	- 3.2	- 2.3	- 2.9			
Import dependency (%)	17.5	28.3	44.2	55.5						

The use of solid fuels is expected to decrease substantially in the projection period, both in absolute terms and as a proportion of total energy demand. The share of solid fuels drops from 54 % in 1995 to around 30 % in 2030. This occurs to the advantage of natural gas, which experiences very rapid penetration in new power generation plants and in many categories of final demand, increasing its market share by more than 20 percentage points between 1995 and 2020. The shares of oil and renewable energy forms in primary consumption exhibit a moderate increase over the projection period.

Final energy demand in central and eastern European accession countries peaked in 1985 at close to 154 Mtoe and then declined sharply to reach 116 Mtoe in 1994. There was a moderate increase of about 2 % with respect to final energy demand in 1995 and a sharper increase of 5.6 % in 1996. The main contribution to the decline up to 1994 came from solid fuels, the consumption of which fell by 45 % between 1985 and 1996 due to the slowdown in the output of the steel industry and to reductions in the use of coal for heating and cooking purposes. Oil, being mainly a transport fuel, exhibited a decline in consumption of ‘only’ 3 % due to increases in the number of private cars. On the other hand, natural gas consumption increased by 35 % in the 1985–96 period due to its rapid penetration in the tertiary and household sector, which occurred at the expense of district heat. For the latter a decrease of more than 30 % was observed between 1985 and 1996. Finally, electricity demand remained fairly stable in the 1985–96 period. Final energy demand is expected to grow marginally faster than primary energy (because of improved rates of conversion efficiency in power generation), rising by 1.3 % per year and 1.8 % per year in the 1995–2010 and 2010–20 periods, respectively. The decline of solid fuels in final use (–2.6 % per year between 1995 and 2020) is more pronounced here than at the primary energy level. This is because there is substitution of solid fuels by natural gas and electricity, which rise by 3.4 % per year and 3 % per year, respectively, in the same period. Oil becomes primarily a fuel for transportation.

By 2020, the residential and tertiary sector accounts for almost half of final energy consumption, followed by industry and the transport sectors, which account for respective consumptions of around 30 % and 22 %. Energy demand in the transport sector is the fastest growing segment of final demand.

Electricity generation in central and eastern European accession countries after a peak of 303 TWh in 1989 followed a downward trend reaching a minimum of 261 TWh in 1994 before recovering with increases of 3.5 % in 1995 and 4 % in 1996. Thermal production is still dominant, with 80 % of total generation in 1996, having declined from 88 % in 1985. Thermal production in 1996 relied mainly on solid fuels (90 %) followed by gas (5.5 %) and oil (5 %), a fuel mix that has not changed significantly during the 1985–95 decade. Nuclear and hydro generation increased both in absolute terms and as a share in total generation. The use of electricity in final demand is expected to expand by 3 % per year over the projection period. District heat demand is projected to remain rather stable at its 1995 levels. Table 3.9 shows the trends projected for the power and heat generation systems of the central and eastern accession European countries. As this analysis does not include assumptions on policy shifts in the framework of these accession countries becoming members of the EU, there are no assumptions on the decommissioning of nuclear plants not meeting EU safety standards. Therefore nuclear production is projected in this analysis to remain relatively stable. Renewable energy forms are expected to gain some market share but remain below 5 % of total electricity generation in 2020.

Power generation, baseline scenario for seven accession countries Table 3.9.

					Annual growth rate (%)			Share (%)		
	1995	2000	2010	2020	95-10	10-20	95-20	1995	2010	2020
Electricity generation (TWh)	**271**	**291**	**355**	**449**	**1.8**	**2.4**	**2.0**			
Nuclear	43	45	47	47	0.6	0.1	0.4	15.8	13.2	10.5
Hydro/renewables	11	13	18	21	3.5	1.7	2.8	3.9	5.0	4.7
Thermal (incl. biomass)	217	233	291	381	2.0	2.7	2.3	80.2	81.8	84.8
Fuel input (Mtoe)	**77**	**81**	**96**	**112**	**1.5**	**1.5**	**1.5**			
Solids	62.0	60.4	60.1	57.6	- 0.2	- 0.4	- 0.3	80.3	62.6	51.5
Oil	6.5	7.0	5.4	6.4	- 1.2	1.7	0.0	8.4	5.7	5.7
Gas	8.5	12.7	29.8	47.2	8.7	4.7	7.1	11.1	31.1	42.2
Biomass/waste	0.2	0.5	0.6	0.7	9.5	0.8	5.9	0.2	0.6	0.6

The use of traditional coal and oil plants declines very rapidly. Significant investment in GTCC plants is expected to occur in the 1995–2020 period. As a result, consumption of natural gas in power and steam generation is expected to increase at an annual growth rate of 7 % per year.

For the non-EU countries, except for the seven accession countries mentioned above, energy projections are based on data submitted by the governments to the United Nations Economic Commission for Europe (UNECE) and published in the UNECE Energy Database (UNECE, 1996). For the year 2010, these projections were updated at IIASA by national experts in the process of reviewing the input data to the scenario calculations conducted for the negotiations on the Gothenburg protocol (UNECE, 1999a). IIASA extrapolated the sectoral trends to the year 2020, preserving physical consistency of the energy flows within each country.

Between 1990 and 2020, the scenario is expected to see an increase in total energy demand in the 10 accession countries (the seven plus Bulgaria, Romania and Slovakia) by 17 % (Table 3.10). The demand for coal decreases by 34 % and the demand for gas increases by 100 % compared to the 1990 level. Fuel demand for mobile sources is projected to increase by 58 %, mainly due to the rapid growth in private car use.

For the other non-accession and non-EU countries, the energy projections imply an 8 % drop in total primary energy consumption (Table 3.10), mainly due to the sharp decrease in energy use that occurred in the last 10 years in the countries of the former Soviet Union. Continued economic restructuring should allow further economic development while keeping the energy demand up to 2020 below the 1990 level. The consumption of coal and oil by stationary sources is predicted to decrease by about 40 and 42 %, respectively. Consumption of natural gas increases by 8 %. Similar to the two previous groups of countries, the demand for transport fuels increases 26 % over the period 1990–2020. This increase is particularly rapid after the year 2010. In spite of a rapid increase in car ownership, the increase in the demand for motor fuels until 2010 is very limited because of a decrease in material and transport intensities in the former 'planned economy' countries. Thus the demand for goods transport up to 2010 remains below the 1990 level.

Table 3.10. **Projections of total primary energy consumption by country (in petajoules, PJ)**

Country	1990	2010	2020	Change 1990–2020
Austria	1 059	1 186	1 297	22 %
Belgium	1 966	2 421	2 528	29 %
Denmark	731	837	879	20 %
Finland	1 196	1 519	1 580	32 %
France	9 260	11 053	12 096	31 %
Germany	14 658	13 869	13 676	– 7 %
Greece	911	1 415	1 666	83 %
Ireland	405	646	731	81 %
Italy	6 492	7 436	7 738	19 %
Luxembourg	121	128	159	31 %
Netherlands	2 741	3 434	3 893	42 %
Portugal	707	1 098	1 374	94 %
Spain	3 542	5 123	5 544	57 %
Sweden	2 106	2 232	1 853	– 12 %
UK	8 610	9 981	10 307	20 %
Total EU-15	**54 505**	**62 380**	**65 322**	**20 %**
Bulgaria	1 319	1 280	1 434	9 %
Czech Rep.	1 959	1 957	2 233	14 %
Estonia	423	290	327	– 23 %
Hungary	1 128	1 245	1 504	33 %
Latvia	380	294	385	1 %
Lithuania	700	483	652	– 7 %
Poland	4 242	4 820	5 390	27 %
Romania	2 361	2 454	2 735	16 %
Slovakia	993	984	1 083	9 %
Slovenia	241	307	378	57 %
Total accession	**13 746**	**14 114**	**16 120**	**17 %**
Albania	108	122	127	18 %
Belarus	1 762	1 553	1 608	– 9 %
Bosnia-H.	290	277	316	9 %
Croatia	393	424	455	16 %
FYR Macedonia	146	134	144	– 2 %
Moldova	390	323	296	– 24 %
Norway	850	1 173	1 266	49 %
Russia	18 138	16 520	16 412	– 10 %
Switzerland	980	1 025	1 036	6 %
Ukraine	10 011	8 595	8 624	– 14 %
Yugoslavia	741	679	774	5 %
Total other	**33 809**	**30 825**	**31 058**	**– 8 %**
Total Europe	**102 060**	**107 319**	**112 500**	**+10 %**

3.4.6. European energy projection

Table 3.10 presents aggregated national energy consumption for all European countries for 2010 and 2020. For Europe as a whole the ShAIR scenario shows an increase in total energy demand of 10 % between 1990 and 2020. The demand for coal and oil decreases by – 30 and –16 %, respectively (Table 3.11). This decline is compensated by a rapid increase in the demand for natural gas (+ 46 % until 2020) and other fuels (nuclear, hydropower, renewable energy (+ 18 %)). Despite a continued improvement in the fuel economy of new cars and trucks, a 32 % increase in total fuel demand is expected.

Energy projections by source category for all European countries (in petajoules, PJ) Table 3.11.

Source Category/fuel	1990	2010	2020	Change 1990–2020
Stationary sources:				
Total	87 170	89 320	92 892	7 %
Coal	23 116	15 111	16 207	- 30 %
Liquid fuels	20 280	16 461	17 010	- 16 %
Gaseous fuels	28 845	39 575	42 128	46 %
Other, of which:	14 929	18 175	17 547	18 %
Nuclear	10 974	12 845	11 690	7 %
Hydro	1 750	2 097	2 256	29 %
Mobile sources — total	14 890	17 999	19 607	32 %
Total	**102 060**	**107 319**	**112 500**	**10 %**

3.4.7. Comparison with the EEUTC scenario

The ShAIR scenario and the *Environment in the European Union at the turn of the century* (EEA 1999a, hereafter referred to as the EEUTC report) scenario differ in the assumed levels of future economic activities (represented by different energy demand) as well as in the degree to which emission control measures are implemented. Whereas the EEUTC scenario includes the 'business as usual' energy pathways for the EU-15 (Capros *et al.*, 1997) and the 'official energy pathways' for the accession countries (UNECE, 1996), the current ShAIR scenario is based on the results of the Shared Analysis project.

Tables 3.12 and 3.13 present the energy demand projected for 2010 using the two scenarios. Compared with the EEUTC scenario, the Shared Analysis case for EU-15 is characterised by a 3 % lower demand for primary energy. The demand for natural gas and for liquid fuels in transport is 4 % lower. In turn, the demand for coal increases 5 % above BAU level. The demand for oil by stationary sources is 13 % lower.

Modified assumptions about energy development in the accession countries cause a 4 % drop in the demand for primary energy. There are also important structural changes in the composition of fuels. Compared with the official energy pathways included in the EEUTC, the Shared Analysis scenario assumes 19 % lower demand for coal, which is compensated by a 23 % increase in natural gas. There is also an important difference in the demand for liquid fuels in the transport sector. In the new ShAIR scenario it is 18 % lower than in the EEUTC.

Differences in energy consumption in 2010 between the EEUTC and the ShAIR scenarios — EU-15 (in petajoules (PJ)) Table 3.12.

Source Category/fuel	EEUTC	ShAIR	Difference
Stationary sources:			
Total	50 940	49 217	- 3 %
Coal	6 805	7 149	5 %
Liquid fuels	12 518	10 934	- 13 %
Gaseous fuels	19 029	18 246	- 4 %
Other, of which:	12 589	12 888	2 %
Nuclear	8 981	9 505	6 %
Hydro	1 248	1 112	- 11 %
Mobile sources — total	13 695	13 163	- 4 %
Total	**64 635**	**62 380**	**- 3 %**

Table 3.13. **Differences in energy consumption in 2010 between the EEUTC and the ShAIR scenarios — accession countries (in petajoules, PJ)**

Source Category/fuel	EEUTC	ShAIR	Difference
Stationary sources:			
Total	12 677	12 496	- 1 %
Coal	5 253	4 234	- 19 %
Liquid fuels	1 814	1 717	- 5 %
Gaseous fuels	4 066	5 002	23 %
Other, of which:	1 545	1 544	0 %
Nuclear	1 114	971	- 13 %
Hydro	128	141	10 %
Mobile sources — total	1 962	1 618	- 18 %
Total	**14 639**	**14 114**	**- 4 %**

3.4.8. Comparison with Auto-Oil II

Table 3.14 compares the demand for liquid fuels from the transport sector of the Shared Analysis energy scenario with the demand implied by the Auto-Oil II (AOP II) baseline scenario. The comparison has been performed for the nine countries covered by the Auto-Oil II study (EU-9). Even for the historical base year (1990) significant differences can be observed. Compared to the ShAIR scenario, which is calibrated against available energy statistics, the Auto-Oil II study assumes a 6 % lower consumption of diesel and 3 % lower gasoline consumption for the EU-9. Disagreement can lead to a difference as high as +17 % for diesel use in Greece and as low as –36 % for gasoline and LPG in Ireland. The existence of these differences is confirmed by the authors of the Auto-Oil II report (4).

Table 3.14. **Demand for liquid fuels in the road transport sector for the ShAIR and the Auto-Oil II energy scenarios (petajoules (PJ))**

		1990			2010		
Country	**Fuel**	**ShAIR**	**AOP II**	**AOP II= 100 %**	**ShAIR**	**AOP II**	**AOP II= 100 %**
Finland	Diesel	66	53	123 %	81	62	130 %
	Gasoline and LPG	85	76	112 %	98	101	97 %
France	Diesel	690	675	102 %	1 124	1 171	96 %
	Gasoline and LPG	828	802	103 %	748	673	111 %
Germany	Diesel	633	701	90 %	1 095	901	122 %
	Gasoline and LPG	1 348	1 416	95 %	1 526	1 448	105 %
Greece	Diesel	59	71	83 %	98	108	91 %
	Gasoline and LPG	108	88	123 %	181	148	122 %
Ireland	Diesel	26	20	135 %	54	34	158 %
	Gasoline and LPG	39	29	136 %	59	40	147 %
Italy	Diesel	650	536	121 %	715	509	140 %
	Gasoline and LPG	629	603	104 %	977	962	102 %
Netherlands	Diesel	145	114	127 %	205	168	122 %
	Gasoline and LPG	185	186	99 %	270	202	134 %
Spain	Diesel	321	330	97 %	644	598	108 %
	Gasoline and LPG	366	362	101 %	489	482	101 %
UK	Diesel	435	367	119 %	632	689	92 %
	Gasoline and LPG	1 088	978	111 %	1 136	914	124 %
Total EU-9	Diesel	3 026	2 866	106 %	4 648	4 241	110 %
	Gasoline and LPG	4 676	4 539	103 %	5 484	4 970	110 %

(4) The Auto-Oil II report (AOP II, 1999) states that: 'Fuel consumption data computed in the base case have been subject to limited validation against reported sales by category. Depending on the source and the level of detail available, historical figures showed differences sometimes up to 20 %. Following discussions with experts, these differences remained within an acceptable range of uncertainties. Given that the purpose of the exercise is to simulate differences against a predefined base case, further improvements would increase the overall robustness of the base case but not significantly affect the conclusions drawn from scenarios.'

For the year 2010 the ShAIR scenario projects a 10 % higher demand for transport fuels than the Auto-Oil II numbers. The differences for individual countries and fuel categories are up to 50 %, indicating that further work on harmonisation of assumptions on fuel use between energy and transport models is necessary.

3.5. Projections of agricultural activities

IIASA has compiled the development of animal stock forecasts in Europe (Table 3.15) on the basis of national information and the modelling work for the EU Member States done with the ECAM (European Community Agricultural Model) model (Folmer *et al.,* 1995). Forecasts used in this study until 2010 are identical with the forecasts used in the work on the EU national emission ceilings directive (compare Amann *et al.*, 1999a). The above study also includes forecasts of fertiliser consumption for the EU-15 based on a study by the European Fertiliser Manufacturers Association (EFMA, 1996a and b) (Table 3.16). Since projections for 2020 were not available, activity levels for that year were assumed to be identical with those for 2010.

3.6. Activity levels for stationary sources of VOC emissions

The future rates of activities that generate volatile organic compounds (VOCs), such as industrial production, fuel consumption or transport services, are derived in RAINS by modifying the present activity levels according to exogeneously provided projections for the year 2020. Unfortunately, reliable and consistent projections of future activity rates at the process level are not really available, since most long-term economic forecasts restrict themselves to a fairly aggregated level of economic activities. Therefore the temporal changes in the activity rates are derived based on the following four assumptions:

- Changes in the activity rates for processing, distribution and combustion of fossil fuels are linked to changes in fuel consumption provided by the energy scenario input to RAINS.
- Some other activity rates (dry cleaning, use of solvents in households, vehicle treatment, food and drink industry) are linked to economic growth and population development.
- The temporal development of a number of industrial activities (e.g. degreasing, paint use, solvent use in the chemical industry, printing, other industrial solvent use) is related to changes in added value generated by individual sectors. These changes are supplied with the energy scenario. In many cases experience suggests that these activities grow more slowly than GDP. To reflect this trend, sector-specific elasticities derived from statistics have been applied.
- In the absence of more information, activity rates for less important emission sectors are kept constant.

Table 3.15. **Projection of livestock numbers for the 2010–20 period (million animals)**

	Cows			Pigs			Poultry		
	1990	2010/ 2020		1990	2010/ 2020		1990	2010/ 2020	
Austria	2.6	2.2	– 15 %	3.7	3.4	– 7 %	13.1	12.0	– 9 %
Belgium	3.1	2.8	– 11 %	6.4	7.2	12 %	23.6	40.3	71 %
Denmark	2.2	1.7	– 23 %	9.3	11.7	26 %	16.2	17.4	7 %
Finland	1.4	0.9	– 33 %	1.4	1.4	– 2 %	9.5	8.1	– 14 %
France	21.4	20.9	– 3 %	12.3	17.4	42 %	236.0	279.3	18 %
Germany	19.5	15.7	– 19 %	30.8	21.2	– 31 %	113.9	78.6	– 31 %
Greece	0.7	0.6	– 20 %	1.0	1.2	21 %	27.7	33.0	19 %
Ireland	7.0	7.4	6 %	1.0	2.2	110 %	9.0	13.2	46 %
Italy	8.2	7.0	– 15 %	8.8	8.2	– 7 %	160.6	172.5	7 %
Luxembourg	0.2	0.4	78 %	0.08	0.05	– 33 %	0.07	0.05	– 28 %
Netherlands	4.9	4.8	– 2 %	13.9	11.2	– 20 %	93.8	79.5	– 15 %
Portugal	1.3	1.3	– 2 %	2.7	2.2	– 17 %	31.2	33.6	8 %
Spain	5.1	6.0	17 %	16.0	20.3	27 %	44.9	83.1	85 %
Sweden	1.7	1.8	5 %	2.3	2.4	4 %	12.6	12.6	0 %
UK	12.1	10.4	– 14 %	7.5	7.8	5 %	136.4	141.0	3 %
EU-15	**91.6**	**83.9**	**– 8 %**	**117.1**	**117.8**	**1 %**	**929**	**1 000**	**8 %**
Albania	0.6	0.8	21 %	0.2	0.3	17 %	5.0	8.4	68 %
Belarus	7.2	4.3	– 40 %	5.2	4.0	– 23 %	49.8	43.3	– 13 %
Bosnia-H.	0.9	0.7	– 22 %	0.6	0.6	– 10 %	9.0	8.0	– 11 %
Bulgaria	1.6	0.9	– 41 %	4.4	4.3	– 2 %	36.3	43.6	20 %
Croatia	0.8	0.6	– 27 %	1.6	1.3	– 17 %	15.0	8.4	– 44 %
Czech Rep.	3.4	3.4	3 %	4.6	5.8	26 %	33.3	49.1	48 %
Estonia	0.8	0.6	– 28 %	1.1	1.2	9 %	7.0	7.8	11 %
FYR Macedonia	0.3	0.3	– 1 %	0.2	0.2	7 %	22.0	22.0	0 %
Hungary	1.6	1.6	– 3 %	9.7	7.9	– 19 %	58.6	63.5	8 %
Latvia	1.5	0.7	– 52 %	1.6	1.5	– 7 %	11.0	7.6	– 31 %
Lithuania	2.4	2.2	– 7 %	2.7	2.8	2 %	18.0	19.2	7 %
Moldova	1.1	1.0	– 13 %	2.0	1.5	– 27 %	25.0	19.0	– 24 %
Norway	1.0	0.7	– 25 %	0.7	0.8	10 %	5.4	5.3	– 2 %
Poland	10.0	12.9	28 %	19.5	23.8	22 %	70.0	97.8	40 %
Romania	6.3	6.2	– 2 %	11.7	10.3	– 12 %	119.3	146.8	23 %
Russia	42.2	27.3	– 35 %	30.5	30.5	0 %	474.3	326.5	– 31 %
Slovakia	1.6	0.8	– 44 %	2.5	2.6	2 %	16.5	22.0	34 %
Slovenia	0.5	0.4	– 22 %	0.6	0.7	18 %	13.5	12.9	– 4 %
Switzerland	1.9	1.7	– 8 %	1.8	1.4	– 22 %	6.5	6.5	0 %
Ukraine	25.2	20.5	– 19 %	19.9	23.0	15 %	255.1	260.0	2 %
Yugoslavia	2.2	2.0	– 8 %	4.3	4.1	– 5 %	28.0	21.0	– 25 %
Non-EU	**113.0**	**89.6**	**– 21 %**	**125.4**	**128.3**	**2 %**	**1 279**	**1 199**	**– 6 %**
Total	**204.6**	**173.5**	**– 15 %**	**242.5**	**246.1**	**2 %**	**2 207**	**2 203**	**0 %**

Projections of nitrogen fertiliser use (thousand tonnes N/year) Table 3.16.

	Nitrogen fertiliser use		
	1990	**2010/2020**	**Change**
Austria	137	109	– 20 %
Belgium	166	137	– 17 %
Denmark	395	261	– 34 %
Finland	228	180	– 21 %
France	2 493	2 457	– 1 %
Germany	1 885	1 545	– 18 %
Greece	428	294	– 31 %
Ireland	370	357	– 4 %
Italy	879	919	5 %
Luxembourg	20	16	– 20 %
Netherlands	404	291	– 28 %
Portugal	150	144	– 4 %
Spain	1 064	1 052	– 1 %
Sweden	212	199	– 6 %
UK	1 516	1 298	– 14 %
EU-15	**10 347**	**9 259**	**– 11 %**
Albania	73	60	– 18 %
Belarus	780	676	– 13 %
Bosnia-H.	19	10	– 47 %
Bulgaria	453	530	17 %
Croatia	114	190	67 %
Czech Rep.	441	580	32 %
Estonia	110	151	37 %
FYR Macedonia	6	3	– 50 %
Hungary	359	639	78 %
Latvia	143	221	55 %
Lithuania	256	309	21 %
Moldova	123	228	85 %
Norway	111	92	– 17 %
Poland	671	855	27 %
Romania	765	780	2 %
Russia	3 418	1 994	– 42 %
Slovakia	147	150	2 %
Slovenia	88	102	16 %
Switzerland	63	30	– 52 %
Ukraine	1 885	1 599	– 15 %
Yugoslavia	146	145	– 1 %
Non-EU	**10 171**	**9 344**	**– 8 %**
Total	**20 518**	**18 603**	**– 9 %**

4. Greenhouse gases

4.1. Introduction

This chapter focuses solely on emission projections as part of climate change. State and impact indicators are due to worldwide emissions and therefore are outside the scope of this study. The main focus is on the emission of carbon dioxide (CO_2). The ShAIR emission projections are based on the Shared Analysis scenario as described in the previous chapter. The effects caused by updating the Shared Analysis energy scenario are also presented. Non-CO_2 greenhouse gas emissions are briefly overviewed.

4.2. CO_2 emissions in the European Union

In 1998 CO_2 emissions were 0.2 % above 1990 levels. After a decline in the early 1990s, CO_2 emissions increased from 1994 to 1996 and then stabilised at around the1990 levels. About 95 % of the CO_2 emissions are caused by fossil fuel combustion. Emissions or removals by carbon sinks (e.g. forests, agricultural soils) are not included in this analysis due to high uncertainties and because no agreement exists yet within the United Nations Framework Convention on Climate Change (UNFCCC) on the calculation/estimation methods. Therefore energy consumption is the main driving force. Two factors strongly influence energy consumption: economic growth and outdoor temperature. The estimates presented here are not corrected for temperature-related effects. Energy consumption increased by 8.2 % from 1990 to 1998 compared with the 0.2 % increase in CO_2 emissions. This means a noticeable decrease in the carbon intensity of energy consumption, mainly explained by the change in energy production and consumption patterns in the new Länder of Germany (economic restructuring after 1990) and the fuel switch from coal to gas in the UK power industry.

The rising share of fossil fuels will lead to an increase in the carbon intensity of the European Union (EU) energy system. Together with the modest increase in energy demand, this will lead to an increase in CO_2 and other energy-related emissions. CO_2 emissions are projected to increase by 0.44 % annually between 1990 and 2020 (0.35 % per year in 1990–2010, see Table 4.2).

Table 4.1. **Energy-related emissions of CO_2 (Mt)**

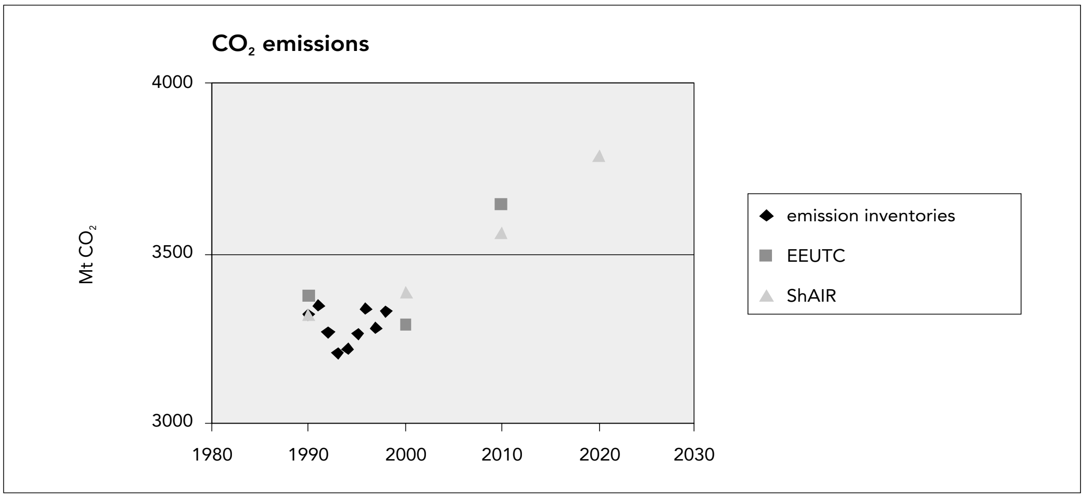
Country	ShAIR			
	1990	**1995**	**2010**	**2020**
Austria	55	57	55	60
Belgium	105	111	124	130
Denmark	53	60	55	49
Finland	51	55	74	82
France	352	346	389	423
Germany	952	848	821	868
Greece	71	78	108	119
Ireland	30	32	43	45
Italy	388	403	429	447
Netherlands	153	171	205	219
Portugal	39	48	66	84
Spain	202	236	273	279
Sweden	57	62	63	66
UK	536	556	571	614
Total EU-14	**3 114**	**3 222**	**3 274**	**3 484**

CO_2 emissions by sector in the European Union Table 4.2.

	Mt CO_2				Annual growth rate (%)		
	1990	2000	2010	2020	90-00	00-10	10-20
Total	**3068**	**3127**	**3289**	**3500**	**0.2**	**0.5**	**0.6**
Industry	424	384	378	354	- 1.0	- 0.2	- 0.6
Tertiary	193	219	220	203	1.3	0.1	- 0.8
Households	447	449	444	448	0.0	- 0.1	0.1
Transport	735	869	994	1033	1.7	1.4	0.4
Electricity-steam production	1212	1148	1201	1418	-0.5	0.5	1.7
Energy branch	57	57	52	43	0.0	- 1.0	- 1.9
Index (1990=100)	**100**	**101.9**	**107.2**	**114.1**			

In the period up to 2010, the transport and tertiary sector show emission increases. In industry, households and electricity and steam production projected emissions for 2010 are below 1990 levels. Beyond 2010, electricity and steam generation is almost solely responsible for the increase in CO_2 emissions.

Emissions of CO_2 in EU-15 according to current trends (EEA, 1999b) with the ShAIR scenario and the EEUTC report, including non-energy CO_2 emissions Figure 4.1.



4.3. Energy-related CO_2 emissions in accession countries

Trends in CO_2 emissions in the seven accession countries (Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland and Slovenia) have followed the trends in energy consumption. In 1995 the region emitted less than 555 million tonnes (Mt) of CO_2, compared with a peak of 715 Mt in 1985. In 1995, emissions from the electricity and steam sectors accounted for more than half of total emissions. The declining share of solids fuels leads to a decrease in the carbon intensity of the central and eastern accession countries' energy system by 0.4 % per year between 1995 and 2020. However, the increase in energy demand leads to an increase in CO_2 and other energy-related emissions. CO_2 emissions are projected to increase annually by 0.8 % a year in the 1995–2020 period (see Table 4.3).

CO_2 emissions by sector, baseline scenario for seven accession countries Table 4.3.

	Mt CO_2			Annual growth rate (%)		
	1995	2010	2020	95-10	10-20	95-20
Total	**555**	**604**	**674**	**0.6**	**1.1**	**0.8**
Industry	116	113	115	- 0.2	0.2	0.0
Household-tertiary	86	88	92	0.1	0.5	0.3
Transports	50	72	104	2.5	3.7	3.0
Electricity-steam production	285	324	357	0.9	1.0	0.9
Energy sector	19	8	6	- 5.3	- 3.5	-4.6
Index (1999=100)	84.9	92.5	103.2			

The transport sector has the fastest increase in emissions. However, in terms of the absolute contribution to the increase in emissions, electricity and steam generation grows the most, accounting for nearly 60 % of the overall increase in emissions between 1995 and 2020. Emissions from industry and the household and tertiary sectors are expected to exhibit a very moderate increase in terms of CO_2 emissions, although energy demand increases. This is a side effect of the shift from solid fuels towards the use of natural gas and electricity in these sectors.

Energy developments in central and eastern Europe accession countries are of great interest for the countries of the EU. This is partly because of the possibility that these countries will join the EU in the near future and partly because of the environmental and competitive implications that may follow the restructuring of the region. For example, many countries in central and eastern Europe will depend increasingly on Russian imports of natural gas. Since these countries are often served by the same pipelines that also serve many EU countries, there is an obvious scope for partnership in managing future European gas needs. Similarly, in view of the likely future integration of the region with the EU and the flexibility mechanisms taken into account under the Kyoto protocol, there is scope for cooperation in the effort to reduce emissions.

4.4. Non-CO_2 greenhouse gas emissions

Methane (CH_4) emissions decreased fairly steadily and came to 16.5 % below 1990 levels in 1998 (EEA, 1999b). The main sources of CH_4 emissions are agriculture (enteric fermentation and manure management), waste (mainly waste disposal in landfills) and fugitive emissions from the production of coal, oil and gas, and gas distribution.

The most important reasons for declining CH_4 emissions are emission control from landfills (collecting for flaring or power generation), leak reductions in gas distribution systems and reductions in coal mining. The emissions from agriculture were reduced 6 % in 1998 compared to 1990; emissions from waste decreased 24 % (EEA, 1999b).

Nitrous oxide (N_2O) emissions in 1998 were almost 10 % below 1990 levels (EEA 1999b). The main sources of N_2O emissions are agriculture (soils and fertiliser use) and industrial processes (mainly adipic and nitric acid production). Emissions from industrial processes declined by 36 % between 1990 and 1998, while the agricultural emissions only declined by 2 %. A small but rapidly increasing source of N_2O emissions, which almost doubled between 1990 and 1998, is the transport sector after the introduction of the catalytic converter (EEA, 1999b).

In 1998 the Commission published two studies (Ecofys, 1998 and AEA Technology, 1998) on future emissions and on potential new measures and costs to reduce emissions of CH_4 and N_2O. A third Commission study by Coherence (Coherence, 1998) compared the business-as-usual scenarios and constructed a new baseline. AEA Technology (AEAT) and Ecofys were using similar assumptions regarding background trends in activity indicators (e.g. fuel production and consumption, crop livestock numbers, waste production, industrial production) and management practices (e.g. manure management, reduction in fertiliser use).

Table 4.4.

Comparison of CH_4 and N_2O emission figures provided by Ecofys, AEAT and Coherence and the new ShAIR estimates

Mt CO_2-eq	1990	2010	2020	2010 as % of 1990
CH_4				
Ecofys	492	364	–	– 26 %
AEAT	490	443	–	– 10 %
Coherence	489	451	–	– 8 %
ShAIR	436	322	318	– 26 %
N_2O				
Ecofys	313	342	–	+ 9 %
AEAT	377	322	–	– 15 %
Coherence	315	339	–	+ 8 %
ShAIR	393	338	346	– 14 %

Source: Coherence, 1998

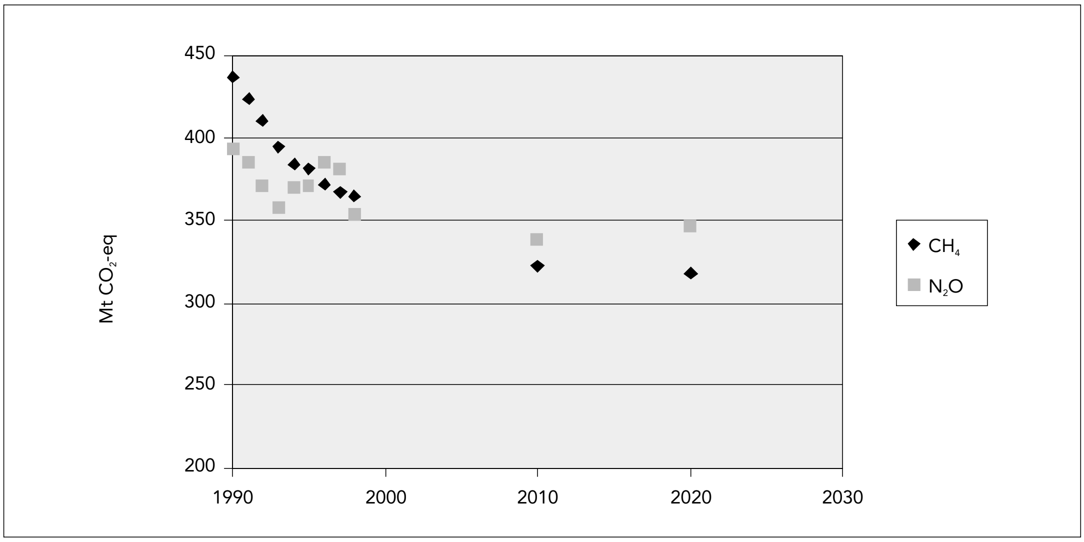
The main differences between the studies (Coherence, 1998) are:

- The inclusion of existing measures and policies on landfills (about 73 Mt of CO_2). Ecofys includes abatement measures taken or planned by the Member States (according to the Expert Group's work on EU common and coordinating measures e.g. landfill emissions), while AEAT does not. Coherence chooses explicitly not to take into account specific policies and measures which the EU and Member States may have already put in place to reduce emissions.
- The methane emissions from gas pipeline leakages. Although the AEAT and Ecofys studies both based their calculation on the pre-Kyoto energy scenario, AEAT assumes an overall better improvement of gas pipeline systems due to significantly lower leakage rates from new polyethylene gas distribution pipes, based on UK figures. Overall, methane emissions from oil and gas sectors are estimated to increase by only 10 % between 1990 and 2010 in the AEAT study, compared to 37 % in the Ecofys study.
- Coherence has scaled the 1990 emission estimates from Ecofys and AEAT to the emission levels as reported by the Member States and reported in the EU second national communications.

The business-as-usual projections of methane emissions of Coherence and AEAT are far different from Ecofys projections (a decrease of 26 % in 2010 below 1990 levels) because the latter include the effect of existing and planned policies, and measures, to reduce emissions from landfills. If these measures were taken into account in the projections reported by Coherence, methane emissions would fall by 22 % below 1990 levels in 2010.

The AEAT figures were used in the *Environment in the European Union at the turn of the century* (EEA 1999a, hereafter referred to as the EEUTC report). However, in ShAIR, current policies (up to June 2000) are included. So for the ShAIR scenario, the Dutch Institute of Public health and the Environment (RIVM) constructed a new projection based primarily on the Ecofys report, and including measures to reduce emissions from landfills. Some other smaller adaptations have also been made in order to overcome differences in base year figures and new assumptions in the driving forces.

Figure 4.2. **Emissions of CH_4 and N_2O according to current trends (EEA, 1999b) and to the ShAIR scenario**



The main differences on N_2O between the studies are (Coherence, 1998):

- The inclusion of existing measures and policies on industrial emissions. AEAT takes into account the abatement measures taken at the main adipic acid manufacturing plants, while Ecofys does not. Coherence chooses explicitly not to take into account specific policies and measures which the EU and Member States may have already put in place to reduce emissions.
- In the AEAT report, emissions from the agricultural sector were modelled using the revised IPCC methodology. For the EU these were found to be 20 % higher than those reported by Member States in their second national communications. This is believed to be due to the fact that not all Member States have, to date, adopted the revised IPCC methodology.
- Coherence has scaled the 1990 emission estimates from Ecofys and AEAT to the emission levels as reported by the Member States and in the EU second national communications.

The business-as-usual projections of N_2O emissions of Coherence and Ecofys are quite different from the AEAT projections (a decrease of 15 % below 1990 levels in 2010) because the latter includes the effect of existing measures in reducing emissions from adipic acid manufacturing plants (industrial processes). If these measures were taken into account in the business-as-usual projections of Coherence, the emissions would fall by 16 % below 1990 levels in 2010.

The Ecofys figures were used in the EEUTC report. However, in the ShAIR scenario, current policies (up to June 2000) are included. RIVM produced new projections for ShAIR, primarily based on the AEAT report, including measures for reducing emissions from adipic acid manufacturing plants. Some other smaller adaptations have been made in order to overcome differences in base year figures and new assumptions in the driving forces.

The most recent projections of the emissions of HFCs, PFCs and SF_6 are given in Table 4.5.

Emissions of HFCs, PFCs and SF_6 in 1990, 1995 and 2010 (Mt CO_2-eq.)

Table 4.5.

Country	HFC			PFC			SF_6		
	1990	1995	2010	1990	1995	2010	1990	1995	2010
Austria	0.0	0.2	1.8	0.4	0.1	0.4	0.1	0.3	0.4
Belgium	0.0	0.2	2.1	0.1	0.1	0.3	0.2	0.3	0.3
Denmark	0.0	0.1	1.0	0.1	0.1	0.4	0.1	0.2	0.2
Finland	0.0	0.1	0.6	0.0	0.1	0.2	0.1	0.1	0.1
France	2.8	4.9	11.0	2.2	2.2	4.4	2.8	3.5	3.5
Germany	5.4	6.0	18.9	3.6	3.9	6.4	4.7	7.0	7.4
Greece	0.5	0.7	1.5	0.1	0.1	0.3	0.1	0.1	0.1
Ireland	0.0	0.1	0.5	0.0	0.0	0.1	0.0	0.1	0.1
Italy		5.0	9.7	2.4	0.7	1.7	1.4	1.7	1.9
Luxembourg	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	3.9	5.2	3.2	3.5	2.9	2.7	0.4	0.6	0.6
Portugal	0.0	0.1	1.1	0.0	0.1	0.2	0.1	0.1	0.1
Spain	3.1	4.5	8.9	3.3	3.4	2.7	0.5	0.8	1.0
Sweden	0.0	0.2	1.7	0.4	0.5	1.3	0.3	0.4	0.6
UK	4.8	7.1	10.2	2.2	1.1	4.9	1.7	2.2	2.4
Total EU-15	**23.6**	**34.5**	**72.2**	**18.2**	**15.3**	**26.2**	**12.5**	**17.2**	**18.7**

Source: Harnisch and Hendriks, 2000

4.5. Updated Shared Analysis scenario

A partial update of the Shared Analysis scenario for the EU Member States has been made to take into account recent developments and trends, as well as policies that were put in place after the end of 1997. The differences between the assumptions of the updated scenario and the Shared Analysis scenario follow.

Update of energy prices

In the period since the completion of the Shared Analysis scenario (summer of 1999), there have been sharp changes in primary energy prices. The most extreme case is found in the price of crude oil, which has doubled since the beginning of 1999. Gas prices have also increased sharply over this period, since gas price contracts in Europe often include an indexation clause linking gas prices to oil prices. Table 4.6 illustrates the changes in international fuel prices as adopted in the updated scenario compared to those in the original Shared Analysis scenario.

Updated international fuel prices (1999 euro per toe)

Table 4.6.

	Update				Shared Analysis			% difference		
	1995	2000	2010	2020	2000	2010	2020	2000	2010	2020
Oil	106	160	148	176	91	112	133	76	32	32
Gas	101	131	141	171	82	104	126	59	36	36
Hard coal	67	65	66	68	65	66	68	0	0	0

In the updated scenario the price of imported oil in Europe is assumed to average EUR 160 in 2000 and that of gas just over EUR 130 during 2000. Both these prices are more than 50 % higher than those assumed in Shared Analysis scenario and this is likely to have significant impacts in the short term.

As can be seen in the above table, the prices of crude oil and natural gas in the long term are assumed to be 32 % and 36 % higher, respectively, compared to the Shared Analysis scenario. This higher level notwithstanding, it should be noted that the new price assumptions imply a considerable easing of prices in the period up to 2010 from the levels experienced in the year 2000.

An update has also been made for all end-user energy prices and excise tax assumptions to the latest information available at the beginning of 2000.

Incorporation of the ACEA (European Automobile Manufacturers Association) agreement
The transport sector is one of the most important sectors for outlooks for both energy and emissions. In recognition of the sector's role and because of its importance for oil supply security and for a number of environmental concerns, the sector has been a high-priority policy area within the EU for a number of years. It is important to recall that energy demand in the sector seems to be fairly insensitive to a number of policy instruments used in the past, including taxation on fuels used for private transport. In view of the present prices of transport fuels, which often consist of nearly 80 % tax, further use of market instruments to reduce energy consumption significantly would require high increases in taxation. ([5]) Thus, there has been an increasing emphasis on the part of EU policy-makers towards trying to influence the efficiency of the use of transport fuels through non-market instruments. This involves policy measures that relate to the manufacturers of cars, of whom there is a relatively small number, rather than trying to influence the behaviour of EU drivers. An important precedent for such a policy emphasis is the Clean Air for Europe (CAFÉ) standards adopted in the United States following the first oil crisis.

In 1998 a voluntary agreement was reached between the European Commission and the European automobile industry under the terms of which the industry is committed to reduce the average CO_2 emission figure for all new cars to 140 grams/kilometre (g/km) by 2008. ([6]) This compares with a current level of emissions of about 186 g/km. An intermediate target was set at 170 g/km for 2003. The industry had also undertaken to make available to the market cars that emit 120 g/km by 2000 and to undertake further improvements beyond 2008 (an initial target for the average of new cars was set at 120 g/km for 2012). The agreement assumes that the behaviour of non-EU producers will be compatible with the above targets and that EU policies and fuel quality will not hamper the implementation of the voluntary agreement. Of course, the agreement does still means that the EU can use additional market-based instruments and information campaigns to reduce emissions further. The above agreement was not included in the Shared Analysis scenario.

Transport activity
Analysis of recent data and trends suggests that the Shared Analysis scenario had been underestimating demand growth in the transport sector (for example, by projecting a demand of 299 Mtoe for 2000 in the EU, a figure which according to the latest Eurostat energy balances had already been attained by 1998). In view of these developments, transport activity growth has been revised upwards for both passenger and freight transport.

Table 4.7. **Changes in transport activity**

	Updated scenario				Shared Analysis			difference (%)		
	1995	2000	2010	2020	2000	2010	2020	2000	2010	2020
Travel per person (000 km/capita)	12.3	13.4	15.7	18.1	13.1	15.2	17.5	2.7	3.3	3.2
Activity per unit of gross domestic product (tkm/000 1990 euro)	280	293	289	282	273	257	241	7.0	12.5	17.1

As can be seen in Table 4.7 transport activity is assumed to be higher than Shared Analysis levels by about 2.7 % for passenger transport and 7 % for freight transport in 2000. The corresponding increases in 2010 are 3.3 % and 12.5 %, respectively. Beyond 2010 travel per capita is assumed to grow at rates similar to those reported for the Shared Analysis scenario. However, for freight transport activity, the de-linking between gross domestic product (GDP)

(5) Current levels of excise duties on gasoline within the EU vary from EUR 319/1 000 litres in Greece to EUR 670/1000 litres in the UK.
(6) Much of the information on the agreement between the EU Commission and the European automobile industry is based on information available on the Internet since 18 May 1999.

growth and activity is assumed to occur at a slower pace and to a lesser extent compared to the Shared Analysis scenario.

Nuclear capacity

The updated scenario takes into account the different current policies of EU Member States on nuclear capacity. In the Shared Analysis scenario countries without installed nuclear capacity in 1995 were assumed to desist from investing in nuclear energy over the whole outlook period while all countries using nuclear power in 1995 were given the possibility to invest in the 2000–10 period only when an existing nuclear plant was about to be decommissioned. Beyond 2010, nuclear investment was unconstrained for Belgium, Finland, France, Germany, Sweden and the United Kingdom. Bearing in mind recent policy decisions (declarations for nuclear phase-out in Belgium, Germany and Sweden and related discussions in the UK), in the updated scenario nuclear investment remains unconstrained only in France and Finland, while all other Member States are constrained in investing in new nuclear plants. However, as was the case for the Shared Analysis scenario, retrofitting (extending the lifetime by 10 years accompanied by higher operation and maintenance costs) generally remains an option when a nuclear plant is to be decommissioned.

Comparison of results

The introduction of the above assumptions in the updated scenario does not lead to significant changes in the overall future energy developments of the EU compared to those projected in the Shared Analysis. Projected gross domestic consumption is slightly lower over the time horizon of the study due to the significant increase in oil and gas prices (see Table 4.8). CO_2 emissions are projected to stabilise at 1990 levels in 2000 (–2.1 % from Shared Analysis for 2000) and remain at levels below those of the Shared Analysis in the long term.

Impacts on gross inland consumption Table 4.8.

	1990	Updated Scenario			Shared Analysis			Difference (%)		
		2000	2010	2020	2000	2010	2020	2000	2010	2020
Gross inland consumption (Mtoe)	1314	1441	1544	1605	1451	1552	1609	- 0.7	- 0.5	- 0.2
Solid fuels	301	212	192	219	207	182	218	2.3	5.6	0.5
Liquid fuels	544	565	613	631	604	653	660	- 6.5	- 6.1	- 4.4
Natural gas	222	349	408	434	337	400	430	3.6	2.0	1.0
Nuclear	181	223	226	202	223	227	199	0.0	- 0.5	1.5
Renewable energy	64	91	103	117	79	88	100	15.6	16.6	17.5
Total CO_2 (Mt)	**3068**	**3063**	**3228**	**3426**	**3127**	**3289**	**3500**	**- 2.1**	**- 1.9**	**- 2.1**
Gross inland consumption / GDP (toe/1990 mln euro)	240.4	223	188	163	225	190	164	- 0.8	- 0.6	- 0.3
Carbon intensity (t CO_2/toe)	2.2	2.1	2.1	2.1	2.2	2.1	2.2	- 1.4	- 1.3	- 1.9

However, higher oil and gas prices lead to significant differences in terms of the structure of gross inland consumption. Primary demand for liquid fuels exhibits a significant drop (ranging from –6.5 % in 2000 to –4.4 % in 2020) compared to Shared Analysis, while the energy demand for all other energy forms increases compared to Shared Analysis. Primary demand for natural gas increases significantly in 2000 (driven by changes in the fuel mix in power generation) but does not exhibit the same potential afterwards. Demand for solid fuels exhibits the highest increase in 2010, mainly through replacement of natural gas and liquid fuels in power generation. Under the economic conditions of the updated scenario, the use of renewable energy sources becomes a significantly more cost-effective solution compared to the Shared Analysis (+ 17.5 % in 2020). The main drivers for this increase are wind energy, the use of which more than doubles in 2010 compared to the Shared Analysis scenario, and biomass waste, which in absolute terms makes a substantial contribution, attributable mainly to revised data (reflecting a more complete coverage of biomass consumption).

Table 4.9. **Impact on primary consumption of renewable energy (Mtoe)**

		Updated scenario			Shared Analysis			Difference (%)		
	1990	2000	2010	2020	2000	2010	2020	2000	2010	2020
Gross inland consumption renewables	63.9	91.2	102.9	117.2	78.9	88.2	99.7	15.6	16.6	17.5
Hydro	22.3	26.7	27.0	29.3	26.8	26.5	28.7	- 0.1	1.9	1.9
Wind	0.1	3.1	10.9	18.3	1.9	5.2	10.5	61.8	109.8	74.1
Solar	0.1	0.3	0.6	1.0	0.3	0.6	0.9	12.0	4.4	11.2
Biomass	39.2	58.1	60.3	63.2	47.0	52.5	56.6	23.6	14.8	11.8
Geothermal	2.2	3.0	4.0	5.3	3.0	3.4	3.0	0.7	20.3	80.6
Share in gross inland consumption (%)	4.9	6.3	6.7	7.3	5.4	5.7	6.2	16.4	17.3	17.8
Input to electricity and steam generation (Mtoe)	42.1	67.3	80.1	96.0	57.1	66.0	77.9	17.8	21.4	23.3

Despite the higher prices assumed in the updated scenario, final energy demand is projected to be higher taken over the length of the study. As can be seen in Table 4.10, the transport sector is almost solely responsible for this result, while energy demand in other sectors is lower or remains relatively unchanged when compared to the Shared Analysis scenario.

Table 4.10. **Impact on final energy demand according to sector (Mtoe)**

		Updated Scenario			Shared Analysis			Difference (%)		
	1990	2000	2010	2020	2000	2010	2020	2000	2010	2020
Total energy (Mtoe)	852	962	1060	1119	954	1053	1108	0.9	0.8	1.0
By sector										
Industry	257	257	282	290	258	282	290	- 0.5	0.0	- 0.1
Tertiary	110	137	156	173	140	159	177	- 2.3	-2.1	- 2.0
Household	232	253	268	283	256	267	282	- 1.5	0.2	0.5
Transport	253	316	355	372	299	344	359	5.6	3.2	3.7
of which private cars	139	148	143	133	157	167	165	- 5.9	- 14.4	- 19.3
By fuel										
Solid fuels	71	37	26	19	36	27	20	3.8	-2.6	-4.4
Liquid fuels	378	430	474	486	435	477	487	-1.2	-0.6	-0.2
Natural gas	157	202	225	233	138	211	212	2.0	6.2	10.0
Steam	68	76	90	101	74	89	101	2.9	0.6	-0.3
Electricity	156	193	224	258	189	226	265	2.1	-1.1	-2.9
Renewable energy	22	24	22	20	22	22	21	9.9	2.3	-3.5
Biomass	21	23	22	19	21	21	20	9.9	2.3	-3.8
CO_2 Emission (Mt)	**1800**	**1920**	**2057**	**2085**	**1922**	**2036**	**2038**	**-0.1**	**1.0**	**2.3**
Industy	424	381	377	354	384	378	354	-0.9	-0.3	-0.1
Tertiary	193	199	209	199	219	220	203	-9.2	-5.1	-1.6
Households	447	421	438	451	449	444	448	-6.4	-1.2	0.5
Transport	735	920	1033	1081	869	994	1033	5.8	3.9	4.6

The increase, in terms of final energy, in the transport sector is due to the revised assumptions on the evolution of transport activity. The revised transport activity growth more than counterbalances the effect of the incorporation of the EU–ACEA voluntary agreement in the scenario. However, at the level of private car consumption, which is the target of the agreement, energy requirements decrease in comparison to the Shared Analysis scenario (–14.4 % in 2010 and –19.3 % in 2020), despite the higher activity growth. The fuel mix in the final energy demand of the updated scenario projects a significant shift in favour of natural gas to the detriment of liquids and, to a lesser extent, electricity, in the long term.

The power and steam generation system also undergoes significant changes in the context of the Shared Analysis scenario (see Table 4.11). High international fuel prices lead to higher electricity and steam production in the short term (+ 2.0 % in 2000 compared to Shared Analysis). However, in the medium to long term, electricity and steam production is projected to revert to Shared Analysis levels or even lower (–0.7 % in 2010, –2.2 % in 2020) due to fuel shifts and improvements in terms of equipment efficiency on the demand side. As already discussed, renewable energy forms become more cost effective in the context of the updated scenario; production from renewable sources is higher over the horizon of the study (+ 4 % in

2000, + 20 % in 2010 and + 22 % in 2020 compared to Shared Analysis). Production from nuclear plants also exhibits a small increase in 2020 (+ 1.5 %). This is a result of nuclear retrofitting which occurs between 2010 and 2020 in the UK. The increased contribution of renewable energy forms combined with the decreased demand beyond 2000 lead to a decrease in fossil fuel inputs in power generation. Furthermore, significant changes are projected in the fuel mix in power and steam generation. The role of solids and biomass waste becomes more important than it was in the Shared Analysis. This occurs to the detriment of liquids (more than –30 % over the outlook period from Shared Analysis levels) and, to a lesser extent, natural gas (especially in the long term).

Impact on the supply side Table 4.11.

		Updated Scenario			Shared Analysis			Difference (%)		
	1990	2000	2010	2020	2000	2010	2020	2000	2010	2020
Total fuel input (Mtoe)	384	391	413	466	401	436	502	-2.5	-5.3	-7.3
Fossil input electricity and steam generation	364	371	395	451	380	418	487	-2.5	-5.4	-7.4
Of which:										
Solids	198	153	147	185	150	137	183	2.0	7.7	0.9
Liquids	85	56	52	52	82	84	77	-32.6	-38.1	-31.7
Gas	62	127	158	171	122	166	192	4.3	-5.1	-10.9
Biomass/waste	18	35	38	43	26	31	36	35.0	23.4	20.5
Energy sector	20	20	18	15	21	18	15	-2.1	-2.2	-1.7
Electricity and steam output (TWh)	3159	3753	4288	4842	3681	4320	4952	2.0	-0.7	-2.2
Nuclear	720	880	892	798	880	896	787	0.0	-0.5	-1.5
Hydro and renewables	260	352	448	564	338	347	461	4.0	19.6	22.2
CO_2 emission (Mt)	**1269**	**1142**	**1171**	**1340**	**1205**	**1253**	**1461**	**-5.2**	**-6.5**	**-8.3**

Changes in the fuel mix of electricity production also lead to different decisions by producers on capacity expansion (see Table 4.12). Gains in terms of cost-effectiveness for wind turbines lead to an increase of total installed capacity of more than 35 GW in 2020 compared to the Shared Analysis (+ 75 %). Capacity expansion in gas turbine combined cycle (GTCC) plants and small gas turbines (GTs) faces a significant downward shift (– 53 and – 13 GW respectively from Shared Analysis levels in 2020). Despite the improvement of the relative price of coal (which remains at Shared Analysis levels) vis à vis oil and gas, investment in clean coal technologies is limited to just 8 GW (compared with 27 GW in Shared Analysis). This adverse result is explained by the fact that under the economic conditions of the updated scenario (higher hydrocarbon prices and stable coal prices), supercritical coal technologies (which may also utilise biomass waste as input fuel) gain in terms of competitiveness despite their relatively unfavourable technical and economic characteristics. As a result, total installed capacity of supercritical coal plants is projected to be 43.6 GW higher in 2020 when compared to the Shared Analysis. The increase in the capacity of monovalent biomass-waste plants in the updated scenario reaches 3.3 GW in 2020 (+ 55 % from Shared Analysis). Finally, under the economic assumptions of the updated scenario, fuel cell technologies become cost-effective in the long term. Installed capacity of fuel cells is projected at about 6 GW in 2020, up from 0 GW in the Shared Analysis.

Impact on installed capacity Table 4.12.

		Updated scenario			Shared Analysis			Difference (GW)		
	1995	2000	2010	2020	2000	2010	2020	2000	2010	2020
Generation capacity (GW)	569	654	745	872	613	718	872	41.7	27.3	0.0
Nuclear	132	137	135	118	136	135	117	0.2	0.2	0.4
Hydro (pumping excluded)	105	108	110	112	110	111	112	- 1.7	- 1.0	0.1
Wind, solar and geothermal	3	14	48	82	9	23	46	5.1	25.3	35.7
Thermal	329	395	452	561	357	449	597	38.2	2.8	- 36.3
Open cycle fossil fuel	278	269	187	103	268	180	107	0.7	7.3	- 4.6
Supercritical coal	0	4	28	116	0	6	72	4.2	22.0	43.6
Clean coal and lignite	0	1	2	8	0	3	27	0.1	- 1.0	- 18.5
Gas turbines combined cycle	24	92	185	252	59	209	305	33.2	- 24.2	- 53.0
Small gas turbines	22	25	43	66	25	45	79	0.1	- 2.3	- 13.1
Biomass and waste	4	4	6	9	4	5	6	0.0	1.0	3.3
Fuel Cells	0	0	0	6	0	0	0	0.0	0.0	6.1

The changes in the structure of the EU energy system, resulting from the revised assumptions, do lead to a reduction of CO_2 emissions at the EU level of almost 2 % compared to ShAIR in the year 2010 (61 Mt). And, as can be seen in Table 4.13, the impact on the Member States' CO_2 emissions is not uniform.

Table 4.13. **Impacts in CO_2 emissions according to Member States**

	Updated scenario Reduction (%)			ShAIR Reduction (%)			Difference (Mt)		
	90-00	90-10	90-20	90-00	90-10	90-20	2000	2010	2020
Austria	- 4.6	- 1.1	3.7	3.6	- 0.4	8.8	- 4.5	- 0.4	- 2.8
Belgium	18.7	30.2	40.2	12.7	18.4	24.7	6.3	12.3	16.3
Denmark	2.6	-8.2	-15.4	13.9	4.3	-6.8	- 6.0	- 6.6	- 4.5
Finland	14.2	24.6	24.2	21.4	43.3	58.9	- 3.7	- 9.6	- 17.8
France	4.8	9.6	16.6	4.3	10.6	20.2	1.7	- 3.5	- 12.5
Germany	- 12.5	- 14.9	- 10.2	- 12.3	- 13.0	- 8.0	- 2.1	- 17.5	- 20.2
Greece	19.9	49.0	72.4	26.8	54.3	70.5	- 4.9	- 3.8	1.4
Ireland	31.3	57.7	76.0	28.1	42.6	49.4	1.0	4.5	8.0
Italy	0.7	7.5	14.8	7.0	10.8	15.4	- 24.7	- 12.7	- 2.5
Netherlands	9.1	25.8	35.7	19.0	34.3	43.2	- 15.1	- 13.1	- 11.6
Poland	28.3	70.0	115.1	36.3	70.2	115.3	- 3.1	- 0.1	- 0.1
Spain	23.8	39.5	52.6	25.4	35.8	39.2	- 3.3	7.6	27.0
Sweden	7.1	16.5	16.3	13.5	26.5	32.6	- 3.3	- 5.1	- 8.3
UK	- 5.7	- 1.4	0.3	- 5.1	0.9	8.5	- 3.0	- 13.1	- 46.4
EU-14	**- 0.2**	**5.2**	**11.7**	**1.9**	**7.2**	**14.1**	**- 65**	**- 61**	**- 74**

The biggest reduction in CO_2 emissions as a result of the new assumptions is experienced in the UK (–46.4 Mt CO_2 compared with ShAIR in 2020), followed by Germany and Finland (–20.2 and –17.8 Mt CO_2 respectively, in 2020). On the other hand, CO_2 emissions in Belgium, Ireland and Spain exhibit a significant increase (+ 16.3, + 8 and + 27 Mt CO_2 in 2020). In all cases the key driver for emissions reduction or increase is power and steam generation. In the case of the UK emissions, reduction in power and steam generation is achieved through retrofitting nuclear capacity and to a lesser extent through higher penetration of renewables, while for Finland and Germany penetration of renewables is the dominant factor for reducing emissions. In Belgium the nuclear phase-out policy adopted in the updated scenario is the main cause of increased CO_2 emissions from the energy system as thermal plants replace decommissioned nuclear capacity. In the cases of Ireland and Spain, the increase in CO_2 emissions is due to the loss of market competitiveness for GTCC plants, investments which have been replaced by investment in coal technologies.

4.6. Sensitivity analysis

Two variants have been selected for an examination of the sensitivity of results of two important areas of uncertainty, namely the extent of market liberalisation in the electricity sector and the possibility of technological breakthroughs in the domain of renewable power sources.

4.6.1. The increased liberalisation variant

In the last 15 years the power generation sector has experienced widespread changes in the form of increasing deregulation and the break-up and complete or partial privatisation of state power monopolies. The extent and pace of this process has varied from country to country, and has been assisted by the emergence of cost-effective power technologies like GTCC and combined heat and power (CHP) systems which are much less marked by the massive economies of scale that characterised the hitherto dominant plant types. However, in recent years this movement towards a more liberalised multi-player market environment has been at least partially counterbalanced by a tendency towards market concentration through mergers, acquisitions and joint ventures which, in a sense, have been the industry's reaction to the increasingly uncertain and competitive environment. The updated scenario assumes a continuation of these tendencies in the future, while the increased liberalisation variant examines the case where the pace of competition accelerates through to the end of the projection.

The parameter chosen to simulate this development has been the time preference or discount rate utilised for investment decisions in the power sector. It is generally observed that in a risky environment investment decisions are taken with shoter pay-back times (higher discount rates). This is mainly due to the inability to control the market environment, rendering the consequences arising from issues like technological obsolescence and reversed economic climate particularly grave in the absence of safety nets which would have been present in a less competitive environment. Deregulation in itself potentially results in higher discount rates as the institutional character of utilities is altered to the extent that they are transformed into ordinary industrial enterprises capable of diversification into non-utility activities with potentially higher expected return. Higher discount rates would normally lead to preferences for low capital cost alternatives even when they are characterised by relatively high operating costs. For similar reasons liberalisation may favour retrofitting of existing older plants as a low fixed-cost short-term option. High capital cost options like coal-fired technologies and most of the renewable options would normally be penalised by higher discount rates even though their running costs are low or negligible. In the context of market liberalisation, alternative variant discount rates are assumed to increase from 8 % (which was the constant value for the whole projection time horizon assumed in Shared Analysis and updated scenarios) to 10 % in 2005, 12 % in 2010, 14 % in 2015 and 15 % in 2020.

The introduction of the above assumptions does not have a great influence on the broad aggregates of the EU energy system. As can be seen in Table 4.14, projected gross domestic consumption is slightly higher over the time horizon of the study while CO_2 emissions are projected higher in 2010 and lower than the updated scenario levels in 2020. However, in terms of individual fuels the differences are more marked. Driven by changes in the fuel mix in power generation, primary energy demand of natural gas exhibits a significant increase from updated scenario levels (+ 1.6 % in 2010, + 3.9 % in 2020). This occurs to the detriment of solids, especially in 2020 (–6 % from updated scenario levels), and renewable energy forms (–2.4 % in 2010, –3.7 % in 2020).

Gross inland consumption (liberalisation variant) Table 4.14.

		Liberalisation Variant		Updated Scenario		% change from Updated scenario	
	1990	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Gross inland consumption (Mtoe)	1314	1547	1607	1544	1605	0.2	0.1
Solid fuels	301	189	206	192	219	- 1.3	- 6.0
Liquid fuels	544	615	631	613	631	0.3	0.1
Natural gas	222	415	451	408	434	1.6	3.9
Nuclear	181	226	203	226	202	0.0	0.8
Renewable energy	64	100	113	103	117	- 2.4	- 3.7
Total CO_2 (Mt)	**3068**	**3239**	**3415**	**3228**	**3426**	**0.4**	**- 0.3**
Gross inland consumption / GDP(toe/1990 mln euro)	240.4	188.7	163.4	188.3	163.3	0.2	0.1
Carbon intensity (t CO_2/toe)	2.2	2.1	2.1	2.1	2.1	0.1	- 0.4

The renewable energy form that suffers the most under increased liberalisation conditions is wind energy, and this was precisely the main contributor to incremental renewable supplies in the updated scenario. Primary energy requirements for wind power drop by 18 % in 2010 and 12 % in 2020 compared to the updated scenario levels. In 2020, the use of biomass waste also faces an important downward shift (especially in absolute terms).

Table 4.15. **Primary consumption of renewable energy forms (liberalisation variant)**

		Liberalisation variant		Updated Scenario		% change from Updated scenario	
	1990	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Gross inland consumption of renewables (Mtoe)	63.9	100.4	112.9	102.9	117.2	-2.4	-3.7
Hydro	22.3	26.9	28.8	27.0	29.3	-0.7	-1.5
Wind	0.1	8.9	16.1	10.9	18.3	-18.0	-12.0
Solar	0.1	0.6	1.0	0.6	1.0	-2.2	-7.2
Biomass and waste	39.2	60.2	61.7	60.3	63.2	-0.1	-2.4
Geothermal heat	2.2	3.8	5.3	4.0	5.3	-6.0	-1.2
Shares in gross inland consumption (%)	4.9	6.5	7.0	6.7	7.3	-2.6	-3.8
Input to electricity and steam generation (Mtoe)	42.1	77.7	91.7	80.1	96.0	-3.1	-4.5

The changes projected for the demand side in the context of increased liberalisation conditions are not very significant since the exercise did not involve alteration in the investment behaviour of final consumers.

As could be expected when given the nature of the variant, the electricity and steam generation system undergoes the most significant changes in the context of the liberalisation exercise (see Table 4.16). Electricity producers tend to shift away from capital intensive options like coal-fired technologies and most of the renewable generation plants. Electricity production from renewable energy forms decreases by more than 5.5 % in both 2010 and 2020 compared to updated scenario levels. This result leads to an increase of fossil fuel inputs in power and steam generation. Under the economic conditions examined in the variant, natural gas becomes a more cost-effective solution compared to coal and, to a lesser extent, biomass waste because of the low capital costs per unit of power which characterise both large-scale GTCC and smaller-scale CHP technologies. As a result, natural gas input increases by more than 10 % in 2020 compared to the updated scenario, while solid fuel input decreases by 7 % and that of biomass waste by 3.5 %.

Table 4.16. **Supply side (liberalisation variant)**

		Liberalisation Variant		Updated Scenario		% change from Updated scenario	
	1990	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Total fuel inputs (Mtoe)	384	420	470	413	466	1.6	1.0
Fossil inputs in electricity and steam generation	364	402	455	395	451	1.7	1.0
Of which							
Solids	198	145	172	147	185	-1.6	-7.0
Liquids	85	54	53	52	52	4.3	1.6
Gas	62	164	189	158	171	4.3	10.6
Biomass and waste	18	38	42	38	43	-0.2	-3.5
Energy sector	20	18	15	18	15	0.1	-0.1
Electricity and steam output (TWh)	3159	4293	4867	4288	4842	0.1	0.5
Nuclear	720	892	804	892	798	0.0	0.7
Hydro and renewables	260	422	532	448	564	-5.7	-5.6
CO_2 emissions (Mt)	**1269**	**1184**	**1334**	**1171**	**1340**	**1.1**	**-0.5**

The above changes and the impact of increased liberalisation conditions are magnified and best illustrated by the changes in decisions of producers on capacity expansion (see Table 4.17).

Installed capacity (liberalisation variant) Table 4.17.

		Liberalisation Variant		Updated Scenario		% change from Updated scenario	
	1995	2010	2020	2010	2020	2010	2020
Generation capacity (GW)	569	734	868	745	872	-10.4	-4.3
Nuclear	132	135	119	135	118	0.0	1.0
Hydro (pumping excluded)	105	109	111	110	112	-0.6	-1.4
Wind, solar and geothermal	3	39	71	48	82	-9.3	-11.0
Thermal	329	451	568	452	561	-0.5	7.1
Open cycle fossil fuel	278	181	97	187	103	-6.2	-5.4
Supercritical coal	0	19	91	28	116	-9.7	-24.3
Clean coal and lignite	0	2	7	2	8	-0.6	-0.9
Gas turbines combined cycle	24	198	285	185	252	13.4	33.0
Small gas turbines	22	46	71	43	66	2.9	5.2
Biomass and waste	4	5	8	6	9	-0.3	-1.6
Fuel cells	0	0	7	0	6	0.0	1.1

Wind turbines remain a cost-effective solution for the energy system but not as attractive as under the updated scenario assumptions. As a result, wind-turbine installed capacity decreases by more than 10 GW in 2020 compared to the updated scenario. The technology that is most favoured in the context of the liberalisation variant is GTCC plants, installed capacity of which increases by 33 GW in 2020. The technology that suffers the most under increased liberalisation conditions is that of supercritical coal plants, installed capacity of which is projected to be more than 24 GW lower in 2020 compared to the updated scenario. This is a new clean coal technology, the prospects of which are stunted by the more short-term horizons implied by the exercise. The preference of producers for low capital-cost technologies, regardless of high operating costs, is further illustrated by the projected increase in the installed capacities of small GTs and fuel-cell technologies.

4.6.2. Failure of the EU–ACEA agreement

In the context of the increased market liberalisation scenario, an additional variant was examined, assuming the failure of the EU–ACEA agreement, and is incorporated into the updated baseline. In this case a significantly less favourable evolution of transport sector energy demand and emissions is projected in the years up to 2020.

More specifically, energy requirements for private car transport increase by some 20 Mtoe in 2010 and 5 Mtoe in 2020. However, due to modal shifts (mainly in favour of aviation) the total increase of energy demand in the transport sector reaches 27 Mtoe in 2010 and 11 Mtoe in 2020 (+ 4.3 % and + 1.8 % of EU oil demand, respectively, compared to the liberalisation variant). As expected, the impact of the failure of the EU–ACEA agreement is less pronounced in the long term as technological progress, combined with replacement of car stock, reduces the effect of the failure of the agreement. The impact of the agreement on emissions is more limited than on oil demand but very significant nevertheless. By 2010, CO_2 emissions in the EU increase by 2.6 % (+ 84 Mt CO_2) when compared to the liberalisation variant. The corresponding increase in 2020 is limited to 1 % (+ 36 Mt CO_2 from liberalisation variant). It should be noted that given the limited scope for changes in the fuel mix in the transport sector (especially regarding private car transport), a failure of the EU–ACEA agreement does not induce significant changes in other sectors of the EU energy system (on either the demand or the supply sides).

4.6.3. The renewables variant

The renewables variant assumes a faster technological development for wind turbines, assisted by particularly optimistic 'learning-by-doing' effects (improvements arising from accumulated experience in the implementation of a technology) and the development of larger turbines benefiting from large economies of scale, facilitating decreasing costs and further penetration. As a result it is assumed that the investment cost for on-shore wind turbines will reach 310 1990 euro/KW in 2020, while the corresponding cost for off-shore wind turbines reaches 370 Euro'90/KW. In addition, it is assumed that, via technological progress and more focused exploration of possible sites, the technical potential for wind energy (estimated at about 465 GW, 100 of which concerns off-shore installations (Oleson, 2000)) becomes economically exploitable in the years up to 2030. Furthermore, the scenario assumes significant technological improvements in the technical and economic performance of solar photovoltaic technologies. These translate into a reduction of investment costs by 30 and 40 % compared to Shared Analysis levels in 2010 and 2020, respectively. It must be stressed that the above assumptions constitute a very optimistic scenario for renewable energy forms, particularly for wind power which already constituted the main source of additional renewable energy contribution in the updated scenario.

In the renewable variant, the EU energy system undergoes some significant changes, especially in the long term when compared to the updated scenario. Gross domestic consumption is) to decrease by 1.5 % ([7]) in 2020 while the corresponding decrease of CO_2 emissions is close to 4 % compared to the updated scenario levels (see Table 4.18). This is the result of higher penetration of renewable energy sources in the EU energy system (+ 20.2 % in terms of primary energy requirements in 2020), which occurs to the detriment of all other energy forms. Coal was affected the most while oil — the use of which is effectively restricted to the transport sector as already described - was affected the least.

Table 4.18. **Gross inland consumption (renewables variant)**

		Renewables Variant		Updated Scenerio		% change from Updated scenerio	
	1990	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Gross inland consumption (Mtoe)	1314	1541	1581	1544	1605	-0.2	-1.5
Solid fuels	301	188	191	192	219	-2.1	-12.8
Liquid fuels	544	613	629	613	631	-0.1	-0.3
Natural gas	222	405	427	408	434	-0.8	-1.5
Nuclear	181	226	191	226	202	0.0	-5.3
Renewable energy	64	108	141	103	117	5.1	20.2
Total CO_2 (Mt CO_2)	**3068**	**3203**	**3294**	**3228**	**3426**	**-0.8**	**-3.8**
Gross inland consumption/ GDP (toe/MEU90)	240.4	188.0	160.9	188.3	163.3	-0.2	-1.5
Carbon intensity (t CO_2/toe)	2.2	2.1	2.1	2.1	2.1	-0.6	-2.4

Wind energy is almost solely responsible for this increase (see Table 4.19). Under the favourable and optimistic assumptions on the technical and economic performance of this technology, as well as the largely expanded potential implied for this variant, primary energy requirements for wind energy increase by close to 50 % in 2010 and by more than 140 % in 2020.

Table 4.19. **Primary consumption of renewable energy forms (renewables variant)**

		Renewables Variant		Updated Senario		% change from Updated senario	
	1990	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Gross inland consumption of renewables (Mtoe)	63.9	108.1	140.8	102.9	117.2	5.1	20.2
Hydro	22.3	26.9	28.5	27.0	29.3	-0.4	-2.5
Wind	0.1	16.3	44.2	10.9	18.3	49.8	141.1
Solar	0.1	0.6	1.1	0.6	1.0	0.0	3.8
Biomass and waste	30.2	60.2	62.2	60.3	63.2	-0.2	-1.6
Geothermal heat	2.2	4.0	4.8	4.0	5.3	0.0	-9.3
Shares in gross inland consumption (%)	4.9	7.0	8.9	6.7	7.3	5.2	22.0
Input to electricity and steam generation (Mtoe)	42.1	85.3	119.7	80.1	96.0	6.5	24.6

(7) This decrease occurs despite an increase in electricity generated and is due to statistical convention which attributes a 100 % efficiency to many renewable technologies and notably wind power which is clearly the 'winner' among renewables in this scenario.

On the other hand, the results indicate that for solar energy, the technological progress assumed is not sufficient to make solar photovoltaic technologies a cost-effective solution for larger scale applications within the energy system. Consequently, photovoltaics increase their penetration only in 'niche' markets, where they already have a presence under updated Scenario assumptions.

The most noticeable impact of the renewable variant on the demand side is an increase in electricity consumption of the order of 1.4 % in 2020 (see Table 4.20). This increase comes as a result of reduced electricity prices due to lower generation costs, themselves a result of a greater number of generating options, including lower cost wind sources.

Final energy demand by sector (renewables variant) Table 4.20.

		Renewables variant		Updated scenario		% change from Updated scenario	
	1990	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Total energy (Mtoe)	852	1061	1121	1060	1119	0.1	0.2
By sector							
Industry	257	282	291	282	290	0.0	0.2
Tertiary	110	157	175	156	173	0.5	0.7
Households	232	268	283	268	283	0.0	0.1
Transport	253	255	372	355	372	0.0	0.0
By fuels							
Solid	71	26	19	26	19	-0.1	-0.4
Liquid	378	473	485	474	486	0.0	-0.2
Natural gas	157	224	232	225	233	-0.1	-0.7
Steam	68	90	102	90	101	0.3	1.0
Electricity	156	225	261	224	258	0.5	1.4
Renewable energy	22	22	20	22	20	0.0	0.0
Biomass	21	22	19	22	19	0.0	0.0
CO_2 Emissions (Mt)	**1800**	**2056**	**2078**	**2057**	**2085**	**-0.1**	**- 0.3**
Industry	424	376	352	377	354	-0.2	-0.4
Tertiary	193	208	195	209	199	-0.4	-2.3
Households	447	438	450	438	451	0.0	-0.1
Transport	735	1033	1080	1033	1081	0.0	0.0

Power and steam generation undergoes significant changes in the renewables variant (see Table 4.21). The contribution of renewable energy forms in electricity production increases substantially, especially in the long term, to reach 17.5 % of total electricity produced in 2020 (compared to 11 % in the updated scenario). Fossil fuel input in power plants decreases by 7.5 % in 2020 compared to the updated scenario. Solid fuels face the highest pressure (–15.1 % in 2020). The nuclear energy contribution to electricity production decreases by more than 5 % in 2020 due to lower levels of plant utilisation and because of nuclear retrofitting becomes less cost-effective. The above changes in power and steam generation lead to a decrease of CO_2 emissions in the sector of more than 9 % by comparison to the updated scenario in 2020.

Table 4.21. **Supply side (renewables variant)**

		Renewables variant		Updated Scenario		% change from Updated scenario	
	1990	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Total fuel inputs (Mtoe)	384	406	431	413	466	-1.8	-7.5
Fossil fuel inputs in electricity and steam generation	364	388	416	395	451	-1.9	-7.7
Of which							
Solids	198	144	157	147	185	-2.6	-15.1
Liquids	85	51	51	52	52	-1.0	-2.2
Gas	62	155	166	158	171	-1.8	-2.8
Biomass and waste	18	38	42	38	43	-0.3	-2.4
Energy sector	20	18	14	18	15	-0.1	-0.2
Electricity and steam output (TWh)	3159	4303	4882	4288	4842	0.3	0.8
Nuclear	720	892	756	892	798	0.0	-5.3
Hydro and renewables	260	509	855	448	564	13.8	51.8
CO_2 emission (Mt)	**1269**	**1147**	**1216**	**1171**	**1340**	**-2.0**	**-9.3**

In the renewables variant the capacity of wind turbines is higher than in the updated scenario by almost 110 GW in 2020, accounting for 19.5 % of total installed capacity (9 % in the updated scenario). Given the intermittent character of wind energy capacity, additions need to be in excess of the capacity replaced; this translates into an expansion of total installed capacity of the order of 100 GW in 2020. This is naturally accompanied by a decline in the overall load factor of electricity generation from 45 % (in the updated scenario) to 41 %.

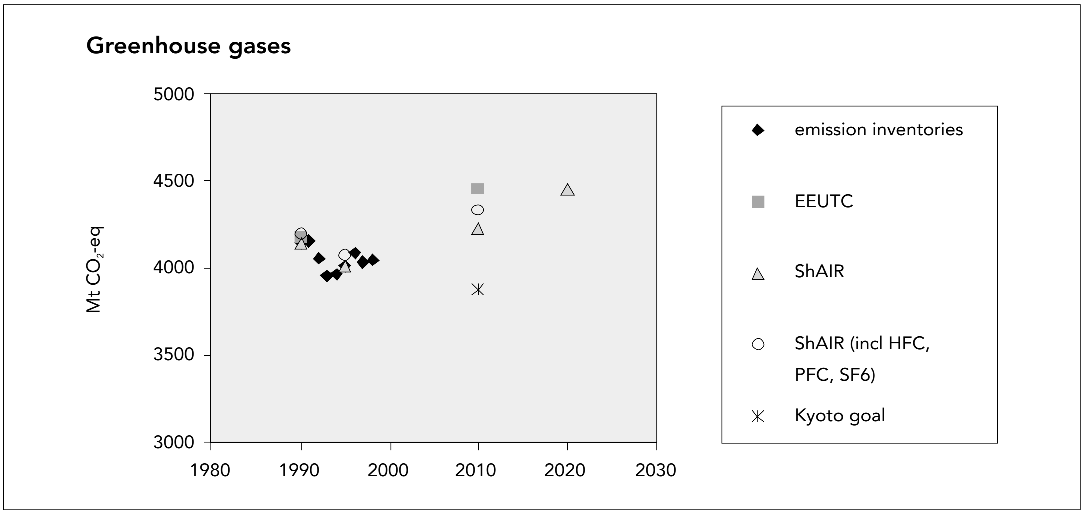
Table 4.22. **Installed capacity (renewables variant)**

		Renewables Variant		Updated Scenario		% changes from Updated scenario	
	1995	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Generation capacity	569	768	970	745	872	22.9	98.4
Nuclear	132	135	116	135	118	0.0	-2.0
Hydro (pumping exluded)	105	110	111	110	112	-0.2	-0.6
Wind, solar and geothermal	3	70	192	48	82	21.6	109.9
Wind turbines	2	68	188	47	79	21.6	109.6
Thermal	329	453	552	452	561	1.5	-8.9
Open cycle-fossel fuel	278	188	106	187	103	0.7	3.4
Supercritical caol	0	27	99	28	116	-1.6	-16.9
Clean coal and lignite	0	2	12	2	8	0.0	3.8
Gas turbines combined cycle	24	184	249	185	252	-1.2	- 3.0
Small gas turbines	22	47	75	43	66	3.6	9.3
Biomass and waste	4	6	7	6	9	0.1	-2.3
Fuel cells	0	0	3	0	6	0.0	-3.3

Of the thermal technologies, the technology most favoured in the context of the renewables variant is the small GT, which due to its flexibility is best suited to cover for the intermittent character of wind power. The installed capacity is then 9.3 GW higher than the updated scenario by 2020. On the other hand, the technology that loses in terms of competitiveness is supercritical coal, installed capacity of which is projected to be 17 GW lower in 2020 compared to the updated scenario.

4.7. Conclusions

Total emission of greenhouse gases (CO_2, CH_4 and N_2O) according to the current trends and to ShAIR scenario, giving the total emission including HFC, PFC and SF_6 Figure 4.3.



In the ShAIR scenario the emissions of the six greenhouse gases for the EU as a whole in 2010 are about 12 % above the Kyoto goal. This is mainly due to a rise of the CO_2 emissions in the period 1990–2010 by about 7 %. The emissions of CH_4 and N_2O decline in the same period by 26 % and 14 %, respectively. The emissions of hydrofluorocarbons (HFC), perfluorcarbons (PFC) and sulphur hexafluoride (SF_6) increase about 75 % between 1995 and 2010.

The projected greenhouse gas emissions are lower than the baseline of the EEUTC report. The CO_2 emission trend is about 1 % lower because of the use of a different and more recent energy scenario. The discrepancies on CH_4 and N_2O are large because current policies and measures are included in the ShAIR scenario, while the EEUTC projection assumed no improvement in emission factors at all. The effect of changes in the trends of the underlying driving forces is almost negligible compared to the assumptions on policies and measures.

An update of the energy scenario on energy prices and taxes, transport volume and inclusions of the EU–ACEA agreement (a voluntary agreement between EU and car manufacturers) results in about 2 % fewer CO_2 emissions in the year 2010 than in the ShAIR scenario. If the EU–ACEA agreement fails, the CO_2 emission might, however, be 2 % higher.

Based on the updated energy scenario two variants have been studied: a further liberalisation of the electricity markets and more optimistic assumptions on renewables. A further liberalisation of the electricity market than assumed in the updated scenario results in important changes in the fuel mix: in 2010 the use of coal (–2 %) and renewables (–6 %) decreases, while the use of gas (+ 4 %) and oil (+ 4 %) increases. The changing fuel mix compensates for the increase in total energy use, so CO_2 emissions are not affected by liberalisation. After the year 2010 the changes in the fuel mix become even larger, but even then the CO_2 emission levels remain the same.

If the assumptions on the technical and economic performance of renewables are made more favourable, the share of wind energy in 2010 will be more than 50 % higher than in the updated scenario. The effect on the emissions of CO_2 is –1 % in 2010. In 2020 the effect of the changed assumptions on renewables results in a decrease of CO_2 emissions compared to the updated scenario by about 5 %.

5. Transboundary air pollution

5.1. Introduction

Transboundary air pollution comprises acidification, eutrophication, summer smog (ground-level ozone) and winter smog (particulate matter (PM)). Based on the Shared Analysis scenario (see Chapter 3) projections were made on transboundary air pollution for the ShAIR scenario. The results of ShAIR are compared with those for *Environment in the European Union at the turn of the century* (EEA 1999a, hereafter referred to as the EEUTC report). In addition, two variants were looked at. The first shows the effects of adoption of European Union (EU) air pollution legislation by the accession countries. The second identifies the impacts of the development of the road transport sector according to the assumptions adopted within the Auto-Oil II Programme.

The projections on the emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), and non-methane volatile organic compounds (VOCs) and on acidification, eutrophication and ground-level ozone were performed by the International Institute for Applied System Analysis (IIASA) with the RAINS model. The PM emissions were provided by TNO (the Netherlands Organisation for Applied Scientific Research). The analysis of transport emissions includes additional calculations with the ForeMove model (which is part of Tremove used in the Auto-Oil Programme) by Aristotle University Thessaloniki (AUTh).

The ShAIR scenario includes emission control measures according to the present legislation in each country, thereby simulating the likely impacts of today's emission abatement regulations for the period after 2010. In order to capture the 'dual-track' nature of European policy (emission standards for specific source categories and ceilings on national total emissions), the scenario first analyses both approaches and then, in a second step, selects the more stringent result. The impacts of current legislation (i.e. that already in place or decided on by the end of 1999) were explored for each country for 2010 and 2020 and then compared with internationally announced target ceilings on national emissions for the year 2010. Such emission ceilings were taken from the Gothenburg protocol to the Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-Level Ozone (UNECE, 1999a).

5.2. Policies and legislation

For SO_2 and NO_x, the scenario takes the legislation in the individual European countries into account, and also the relevant directives of the EU as well as the obligatory clauses regarding emission standards from the protocols under the Convention on Long-Range Transboundary Air Pollution. For instance, the second sulphur protocol (UNECE, 1994a) requires emission control according to 'best available technology' for new plants. It also requires the reduction of the sulphur content in gas oil for stationary sources to 0.2 %, and 0.05 % if used as a diesel fuel for road vehicles. An inventory of national and international emission standards in Europe can be found in Bouscaren and Bouchereau (1996). In addition, information on power plant emission standards has been taken from the survey by IEA Coal Research (McConville, 1997). For countries of central and eastern Europe the environmental standards database developed by the Central European University (CEU, 1996) has also been used. All this information has been updated on the basis of recently published sources (e.g. UNECE, 1999b).

For the control of NO_x and VOC emissions from mobile sources, the scenario considers the implementation of the current United Nations Economic Commission for Europe (UNECE) legislation and country-specific standards if stricter. For the Member States of the EU the current EU standards for new cars, light commercial vehicles and heavy-duty vehicles (HDVs) have been taken into account. The pace of the implementation of these measures depends on the turnover of vehicle stock; it has been based on modelling work performed for the Auto-Oil I study.

For heavy-duty vehicles, the post-2005 standards were introduced, reflecting the common position reached in December 1998 between the European Parliament and the European Council on amending Directive 88/77/EEC (on the approximation of laws of the Member States relating to the measures to be taken against the emissions of gaseous and particulate pollutants from diesel engines for use in vehicles). The implementation of these standards is assumed to take place in two stages (2005/06 and 2008/09).

Measures assumed as current legislation (CLE) for SO_2 emissions (mobile and stationary sources) and for NO_x and VOC emissions from stationary sources in EU countries Table 5.1.

SO_2

- Emission limit values for new plants from the second sulphur protocol (UNECE, 1994a)
- Emission limit values for new plants from the large combustion plant directive (LCPD) (88/609/EEC), taking into account the proposal for a revision of the LCPD adopted by the Commission on 8 July 1998 (COM(98) 415 final)
- Limits on the sulphur content of gas oil for stationary and mobile sources and for heavy fuel oil (Directives 98/70/EC and 1999/32/EC)
- National emission standards for stationary sources if stricter than the international standards

NO_x

- Emission limit values for new plants from the large combustion plant directive (88/609/EEC), taking into account the proposal for a revision of the LCPD adopted by the Commission on 8 July 1998 (COM(98) 415 final)
- National emission standards for stationary sources if stricter than the international standards

VOCs

- Council Directive 1999/13/EC of 11 March 1999 on the limitation of emissions of volatile organic compounds (VOCs) due to the use of organic solvents in certain activities and installations
- European Parliament and Council Directive 94/63/EC of 20 December 1994 on the control of VOC emissions resulting from the storage of petrol and its distribution from terminals to service (Stage I controls)
- Stage II according to existing legislation in Austria, Belgium, Denmark, France, Germany, Italy, Luxembourg, Netherlands and Sweden

Besides the directives of the EU, the obligations for VOCs of the VOC protocol of the Convention on Long-Range Transboundary Air Pollution (UNECE, 1994b) were incorporated. For ammonia, values for the ‘no control’ scenario or the protocol value — if lower — were/was adopted.

Table 5.2. Measures assumed as current legislation (CLE) for emissions from mobile sources in the countries of the European Union

Cars and light duty vehicles

- Standards for cars and light commercial vehicles according to Directive 70/220/EC
- Council Directive 91/441/EEC of 26 June 1991 amending Directive 70/220/CEE on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles (small canisters for passenger cars)
- Commission Directive 96/44/EC of 1 July 1996 adapting to technical progress Council Directive 70/220/EEC on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles
- 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
- Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC
- Directive 91/441/EEC of 26 June 1991 amending Directive 70/220/CEE on small carbon canisters

Heavy-duty vehicles

- Standards for heavy-duty vehicles (HDV) according to Council Directive 88/77/EC, as amended by 96/1/EC
- Commission Directive 97/20/EC of 18 April 1997 adapting to technical progress Council Directive 72/306/EEC on the approximation of the laws of the Member States relating to the measures to be taken against the emission of pollutants from diesel engines for use in vehicles
- Post-2005 standards for HDVs reflecting the common position reached in December 1998 between the European Parliament and the Council on amending Directive 88/77/EEC. The stricter standards will be implemented in two stages (2005/06 and 2008/09)

Off-road machinery

- Directive 97/68/EC of the European Parliament and of the Council of 16 December 1997 on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery

Mopeds and motorcycles

- Directive 97/24/EC of the European Parliament and the Council of 17 June 1997 for mopeds and motorcycles

Table 5.3. Measures assumed as current legislation (CLE) for SO2 emissions in the non-EU countries

- Signatories of the second sulphur protocol (Bulgaria, Croatia, Czech Republic, Hungary, Norway, Poland, Russian Federation, Slovakia, Slovenia, Switzerland, Ukraine):
  Emission limit values for new plants and limits on the sulphur content of gas oil for stationary and mobile sources as in the protocol
- Czech Republic, Croatia, Norway, Poland, Slovakia, Slovenia, Switzerland, Romania, former Yugoslavia:
  National emission standards for existing and new plants
- Other countries in central and eastern Europe:
  No control

Table 5.4. Measures assumed as current legislation (CLE) for the control of NOx emissions in the non-EU countries

Stationary sources:

- Czech Republic, Croatia, Hungary, Norway, Poland, Slovakia, Slovenia, Switzerland, Romania, Yugoslavia:
  Controls according to national emission standards for new and existing sources
- Other countries in central and eastern Europe:
  No control[a]

Mobile sources:

- Czech Republic, Hungary, Poland, Slovakia, Slovenia:
  National standards comparable with the 1992 and 1996 standards of the EU (catalytic converters for gasoline engines and combustion modifications on diesel engines)
- Other central and eastern European countries:
  Pre-1990 UNECE standards (no requirement for catalytic converters for gasoline engines and for combustion modifications on diesel engines)
- Norway and Switzerland: EU emission standards

a. Because primary NO_x reduction measures represent the state of the art technology for new plants, such controls were assumed by default in all countries.

Measures assumed to control VOC emissions for non-EU countries Table 5.5.

Stationary sources:

- National legislation for solvent use and gasoline storage and distribution (Stage I and Stage II) in Norway and Switzerland

Mobile sources:

- All directives and legislation aimed at a reduction of emissions from mobile sources mentioned for NO_x also apply to non-methane volatile organic compounds (see Table 5.2 and Table 5.4)
- Introduction of small carbon canisters in Norway and Switzerland consistent with Council Directive 91/441/EEC
- For Czech Republic, Hungary, Poland, Slovakia and Slovenia it is assumed that in the year 2010 part of the fleet will be equipped with small carbon canisters following the EU Council Directive 91/441/EEC

5.3. Emissions

5.3.1. Current legislation and the Gothenburg protocol

In many cases the current legislation (CLE) emissions (i.e. those derived from the projected economic development and the present set of emission and fuel standards) are lower than the obligations of the Gothenburg protocol (Tables 5.6 to 5.9). There are, however, other cases where present legislation would not achieve the Gothenburg target, given the projected economic development, and where additional measures will be necessary. The ShAIR scenario includes the minimum of the current legislation and the Gothenburg emission levels. For calculating the cost of additional measures it has been assumed that the emission ceilings will be achieved by the most cost-efficient control options that are still available in a country (according to the RAINS emission-reduction cost curves).

Countries with stringent legislation expect a general decline of emissions between 2010 and 2020, mainly due to progressive replacement of existing plants with new equipment with stricter emission standards. For instance, in the EU-15 the CLE emissions of NO_x decrease from 6.7 million tonnes in 2010 to 5.3 million tonnes in 2020. Similarly, the emissions of SO_2 decrease from 4.9 to 3.4 million tonnes.

For the non-EU countries, the development of emissions is strongly dependent on the stringency of emission standards on the one side and the volume of economic activity on the other. Continuing the shift from high-sulphur coal to cleaner fuels and further penetration of flue gas desulphurisation will lead to further cuts in SO_2 emissions after 2010, while NO_x emissions may increase due to fast growth in private transport and the absence of emission regulations for mobile sources in central and eastern European countries.

5.3.2. Emissions and emission control costs of the ShAIR scenario

Since the lower value from the CLE and the protocol ceiling is always taken as the ShAIR, the reductions achieved in the ShAIR scenario are the highest. For 2010 the differences between the ShAIR scenario and the Gothenburg protocol are rather small, except for SO_2, where high reductions are already achieved in 2010 through structural changes in energy systems in the countries of central and eastern Europe. Until 2020 the differences between the protocol ceilings and the ShAIR scenario increase due to the advanced penetration of control technologies implied by current legislation and the continuation of structural changes in the energy systems. Again, the latter factor is of particular importance for sulphur emissions, leading in 2020 to 14 % lower emissions in the ShAIR scenario compared to the protocol ceilings.

Emission control measures in the ShAIR scenario will substantially cut NO_x emissions in Europe from 25 million tonnes in 1990 to 15.3 million tonnes in 2010 (–39 %) and to 14 million tonnes in 2020 (–44 % compared with the1990 level). The EU-15 emissions decrease by 50 % up to 2010 and by an additional 10 % up to 2020. For the accession countries, emissions would decrease by 35 % up to 2010 and stabilise thereafter. NO_x emissions in other countries would decrease by 28 % up to 2010 and then remain practically unchanged due to the obligations of the Gothenburg protocol.

VOC emissions will show a similar development. In the EU-15, VOCs will be 55 % lower than in 1990; for the accession countries a 14 % decline is expected, and a 24 % cut for the other countries. From 2010 to 2020, EU-15 emissions decrease by another 3 %, whereas the emissions in the accession countries and in the other non-EU countries would increase by 1 % and 4 %, respectively.

Figure 5.1. **Emissions of NO_x according to the current trends (EEA, 2000b) and the ShAIR scenario**

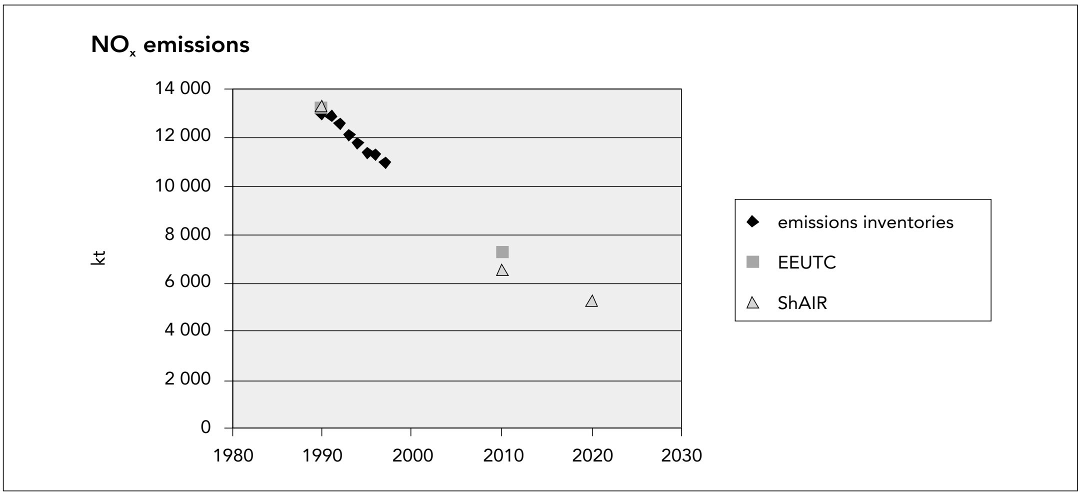


Table 5.6. **Comparison of current legislation NO_x emissions in Europe with emission ceilings from the Gothenburg protocol (in kt)**

Country	1990	Protocol ceiling	CLE		ShAIR	
			2010	2020	2010	2020
Austria	192	107	98	81	98	81
Belgium	351	181	169	141	169	141
Denmark	274	127	**141**	105	127	105
Finland	276	170	149	117	149	117
France	1 867	860	860	700	860	700
Germany	2 662	1 081	**1 092**	845	1 081	845
Greece	345	344	342	293	342	293
Ireland	113	65	**79**	62	65	58
Italy	2 037	1 000	**1 013**	812	1 000	812
Luxembourg	22	11	10	10	10	10
Netherlands	542	266	247	218	247	218
Portugal	303	260	259	191	259	191
Spain	1 162	847	847	623	847	623
Sweden	338	148	**189**	**154**	148	148
UK	2 839	1 181	**1 198**	964	1 181	964
Total EU-15	**13 322**	**6 648**	**6 693**	**5 315**	**6 582**	**5 305**
Bulgaria	355	266	**297**	**336**	266	266
Czech Rep.	546	286	**312**	**336**	286	286
Estonia	84	n.a.	52	64	52	64
Hungary	219	198	159	184	159	184
Latvia	117	84	**85**	**110**	84	84
Lithuania	153	110	98	**132**	98	110
Poland	1 217	879	728	719	728	719
Romania	518	437	**458**	**469**	437	437
Slovakia	219	130	**132**	**139**	130	130
Slovenia	60	45	**57**	**62**	45	45
Total accession ([b])	**3 489**	**2 499**	**2 377**	**2 550**	**2 285**	**2 324**
Albania	24	n.a.	36	42	36	42
Belarus	402	255	**316**	**346**	255	255
Bosnia-H.	80	n.a.	60	67	60	67
Croatia	82	87	**91**	**100**	87	87
FYR Macedonia	39	n.a.	29	30	29	30
Moldova	87	90	66	64	66	64
Norway	220	156	**178**	**164**	156	156
Russia ([a])	3 486	2 653	**2 798**	**2 927**	2 653	2 653
Switzerland	163	79	79	70	79	70
Ukraine	1 888	1 222	**1 433**	**1 659**	1 222	1 222
Yugoslavia	211	n.a.	152	163	152	163
Total other ([b])	**6 681**	**4 843**	**5 238**	**5 632**	**4 794**	**4 808**
Total ([c])	**25 134**	**15 633**	**15 950**	**15 139**	**15 304**	**14 080**

([a]) For Russia the protocol specifies only the emission ceilings for the so-called pollutant emissions management area (PEMA). Values given in the table are for the European part of Russia within the EMEP area as in the calculations for the preparation of the protocol.

([b]) For calculating totals in the 'protocol ceiling' columns, the missing values (n.a.) were replaced with higher values of CLE emissions for 2010 or 2020.

([c]) Total also includes emissions from shipping within the EMEP area.

Table 5.7. **Comparison of current legislation VOC emissions in Europe with emission ceilings from the Gothenburg protocol (in kt)**

Country	1990	Protocol ceiling	CLE		ShAIR	
			2010	2020	2010	2020
Austria	352	159	**196**	**183**	196	183
Belgium	376	144	**190**	**176**	190	176
Denmark	182	85	78	67	78	67
Finland	213	130	**131**	120	131	120
France	2 382	1 100	1 048	947	1 048	947
Germany	3 122	995	**1 229**	**1 097**	1 229	1 097
Greece	336	261	216	177	216	177
Ireland	110	55	49	47	49	47
Italy	2 055	1 159	1 116	991	1 116	991
Luxembourg	19	9	7	7	7	7
Netherlands	490	191	**246**	**233**	246	233
Portugal	294	202	201	183	201	183
Spain	1 008	669	645	543	645	543
Sweden	511	241	197	180	197	180
UK	2 672	1 200	**1 634**	**1 553**	1 634	1 553
Total EU-15	**14 120**	**6 599**	**7 185**	**6 503**	**7 185**	**6 503**
Bulgaria	195	185	**190**	**201**	190	201
Czech Rep.	442	220	**365**	**362**	365	362
Estonia	45	n.a.	46	55	46	55
Hungary	204	137	**138**	**153**	138	153
Latvia	63	136	49	59	49	59
Lithuania	111	92	**93**	**96**	93	96
Poland	800	800	**806**	**859**	806	859
Romania	504	523	504	**530**	504	530
Slovakia	151	140	140	127	140	127
Slovenia	55	40	**59**	**66**	59	66
Total accession ([b])	**2 570**	**2 329**	**2 391**	**2 509**	**2 391**	**2 509**
Albania	31	n.a.	41	45	41	45
Belarus	371	309	309	**324**	309	324
Bosnia-H.	51	n.a.	48	55	48	55
Croatia	103	90	**111**	**127**	111	127
FYR Macedonia	19	n.a.	19	21	19	21
Moldova	50	100	42	42	42	42
Norway	297	195	**301**	**290**	301	290
Russia ([a])	3 542	3 528	2 787	3 005	2 787	3 005
Switzerland	278	144	144	134	144	134
Ukraine	1 161	797	**851**	**921**	851	921
Yugoslavia	142	n.a.	139	149	139	149
Total other ([b])	**6 043**	**5 434**	**4 792**	**5 114**	**4 792**	**5 114**
Total	**22 734**	**14 036**	**14 368**	**14 362**	**14 368**	**14 127**

([a]) For Russia the protocol specifies only the emission ceilings for the so-called Pollutant Emissions Management Area (PEMA). Values given in the table are for the European part of Russia within the EMEP area, as in the calculations for the preparation of the protocol.

([b]) For calculating totals in the 'protocol ceiling' columns, the missing values (n.a.) were replaced with higher values of CLE emissions for 2010 or 2020.

Table 5.8.

Comparison of current legislation SO_2 emissions in Europe with emission ceilings from the Gothenburg protocol (in kt)

Country		Protocol ceiling	CLE		ShAIR	
			2010	2020	2010	2020
Austria	93	39	39	**40**	39	39
Belgium	336	106	**171**	**152**	106	106
Denmark	182	55	**146**	**64**	55	55
Finland	226	116	**137**	**128**	116	116
France	1 250	400	**574**	**454**	400	400
Germany	5 280	550	518	486	518	486
Greece	504	546	508	439	508	439
Ireland	178	42	**119**	**76**	42	42
Italy	1 679	500	381	255	381	255
Luxembourg	14	4	**8**	**7**	4	4
Netherlands	201	50	**76**	**81**	50	50
Portugal	343	170	**195**	**181**	170	170
Spain	2 189	774	**999**	405	774	405
Sweden	117	67	65	61	65	61
UK	3 812	625	**962**	587	625	587
Total EU-15	**16 403**	**4 044**	**4 897**	**3 417**	**3 853**	**3 216**
Bulgaria	1 842	856	846	465	846	465
Czech Rep.	1 873	283	**336**	**295**	283	283
Estonia	275	n.a.	111	58	111	58
Hungary	913	550	227	84	227	84
Latvia	121	107	73	129	73	107
Lithuania	213	145	73	72	73	72
Poland	3 001	1 397	**1 453**	739	1 397	739
Romania	1 331	918	594	358	594	358
Slovakia	548	110	**137**	96	110	96
Slovenia	200	27	**114**	18	27	18
Total accession ([b])	**10 315**	**4 504**	**3 964**	**2 312**	**3 742**	**2 279**
Albania	72	n.a.	55	48	55	48
Belarus	843	480	**494**	440	480	440
Bosnia-H.	487	n.a.	415	387	415	387
Croatia	180	70	70	64	70	64
FYR Macedonia	107	n.a.	81	70	81	70
Moldova	197	135	117	102	117	102
Norway	52	22	**32**	**32**	22	22
Russia ([a])	5 012	3 902	2 344	1 864	2 344	1 864
Switzerland	43	26	26	25	26	25
Ukraine	3 706	1 457	**1 506**	1 041	1 457	1 041
Yugoslavia	585	n.a.	269	158	269	158
Total other ([b])	**11 284**	**6 912**	**5 408**	**4 221**	**5 335**	**4 221**
Total ([c])	**39 167**	**16 624**	**15 434**	**11 125**	**6 678**	**6 678**

([a]) For Russia the protocol specifies only the emission ceilings for the so-called pollutant emissions management area (PEMA). Values given in the table are for the European part of Russia within the EMEP area as in the calculations for the preparation of the protocol.

([b]) For calculating totals in the 'protocol ceiling' columns, the missing values (n.a.) were replaced with higher values of CLE emissions for 2010 or 2020.

([c]) Total also includes emissions from shipping within the EMEP area.

Table 5.9. **Comparison of current legislation NH_3 emissions in Europe with emission ceilings from the Gothenburg protocol (in kt)**

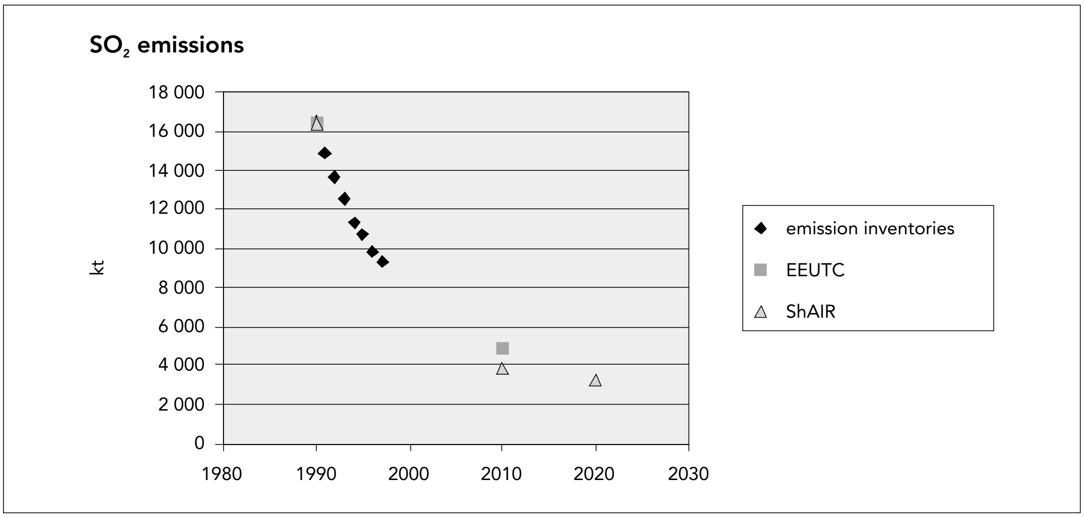
Country	1990	Protocol ceiling	CLE		ShAIR	
			2010	2020	2010	2020
Austria	77	66	**67**	**67**	66	66
Belgium	97	74	**96**	**96**	74	74
Denmark	122	69	**72**	**72**	69	69
Finland	40	31	31	31	31	31
France	810	780	780	780	780	780
Germany	757	550	**571**	**571**	550	550
Greece	80	73	**74**	**74**	73	73
Ireland	127	116	**130**	**130**	116	116
Italy	462	419	**432**	**432**	419	419
Luxembourg	7	7	**9**	**9**	7	7
Netherlands	233	128	**141**	**141**	128	128
Portugal	77	108	73	73	73	73
Spain	352	353	**383**	**383**	353	353
Sweden	61	57	**61**	**61**	57	57
UK	329	297	297	297	297	297
Total EU-15	**3 631**	**3 129**	**3 216**	**3 216**	**3 093**	**3 093**
Bulgaria	141	108	**126**	**126**	108	108
Czech Rep.	107	101	**108**	**108**	101	101
Estonia	29	n.a.	29	29	29	29
Hungary	120	90	**137**	**137**	90	90
Latvia	43	44	35	35	35	35
Lithuania	80	84	81	81	81	81
Poland	505	468	**541**	**541**	468	468
Romania	292	210	**304**	**304**	210	210
Slovakia	60	39	**47**	**47**	39	39
Slovenia	23	21	21	21	21	21
Total accession ([b])	**1 398**	**1 193**	**1 427**	**1 427**	**1 181**	**1 181**
Albania	32	n.a.	35	35	35	35
Belarus	219	158	**163**	**163**	158	158
Bosnia-H.	31	n.a.	23	23	23	23
Croatia	40	30	**37**	**37**	30	30
FYR Macedonia	17	n.a.	16	16	16	16
Moldova	47	42	**48**	**48**	42	42
Norway	23	23	21	21	21	21
Russia ([a])	1 282	1 179	894	894	894	894
Switzerland	72	63	**66**	**66**	63	63
Ukraine	729	592	**649**	**649**	592	592
Yugoslavia	90	n.a.	82	82	82	82
Total other ([b])	**2 582**	**2 243**	**2 034**	**2 034**	**1 956**	**1 956**
Total	**7 611**	**6 380**	**6 678**	**6 564**	**6 231**	**6 231**

([a]) For Russia the protocol specifies only the emission ceilings for the so-called pollutant emissions management area (PEMA). Values given in the table are for the European part of Russia within the EMEP area as in the calculations for the preparation of the protocol.

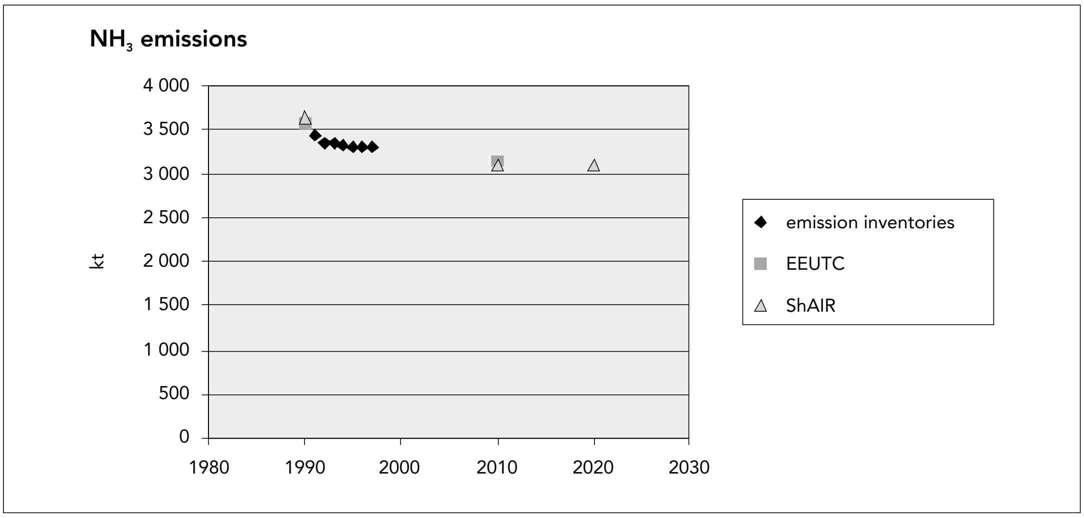
([b]) For calculating totals in the 'protocol ceiling' columns, the missing values (n.a.) were replaced with higher values of CLE emissions for 2010 or 2020.

European emissions of sulphur dioxide decrease by 64 % till 2010 and by 72 % till 2020. Since the reductions are mainly driven by the requirements of the protocols to the Convention on Long-Range Transboundary Air Pollution, reductions occur in all countries. However, the highest reductions (77 % in 2010 and 81 % in 2020) are expected for the EU-15 countries. The decline in ammonia emissions (15 % in the EU-15 and the accession countries, 24 % for the other countries) is mainly due to the expected decrease in livestock population. (The latter decrease is mainly due to a more than 30 % decrease in the emissions from Russia.)

Emissions of SO_2 according to current trends (EEA, 2000b) and to the ShAIR scenario Figure 5.2.



Emissions of NH_3 according to current trends (EEA, 2000b) and to the ShAIR scenario Figure 5.3.



The estimate of emission control costs includes additional production costs of better quality fuels as well as costs of pollution control equipment necessary to reach the assumed emission standards or ceilings. The costs were calculated by the RAINS model in constant 1990 prices, annualising the investments over the full technical lifetime of the equipment with a 4 % real interest rate.

The costs of the ShAIR measures for the whole of Europe in 2010 are about EUR 67 billion per year (in 1990 prices); see Table 5.10. They increase to about EUR 84 billion per year in 2020. More than 80 % of these costs are for controlling NO_x and VOC emissions. They have been summed, since measures in the transport sector reduce the emissions of both pollutants and allocation of the costs to NOx and VOC emissions would be arbitrary. These costs are quite high because current legislation requires strict and expensive controls on transport sources, especially in the European Union.

About 85 % (EUR 58 billion per year in 2010 and EUR 71 billion per year in 2020) of total European costs are spent in the EU-15. For the accession countries control costs increase from EUR 5.5 billion per year in 2010 to EUR 8.5 billion per year in 2020. Because not all accession countries have introduced emission standards on mobile sources, the share of costs of controlling the emissions of NOx and VOCs is lower (only 68 % compared with 84 % for the EU). Since there are currently no emission standards for NH_3 emissions from agriculture, the ShAIR cost includes the costs of having each country reach the protocol emission level in a cost-optimal manner. Thus ammonia control costs appear only for a limited number of countries and contribute relatively little to the total.

Table 5.10. **Emission control costs in Europe in 2010 and in 2020 for the ShAIR scenario (in million 1990 euro per year)**

Country	NOx + VOCs		SO_2		NH_3		Total	
	2010	2020	2010	2020	2010	2020	2010	2020
Total EU-15	46 863	59 509	10 852	11 203	597	597	58 312	71 309
Total accession	3 066	5 770	1 526	1 805	928	928	5 520	8 503
Total other	1 497	2 513	1 332	1 685	36	36	2 865	4 235
Total	51 426	67 792	13 710	14 693	1 561	1 561	66 697	84 047

5.3.3. PM_{10}

The general approach to estimating air emissions of PM_{10} (respirable particulate matter with aerodynamic diameter between 2.5 and 10 micrometres) per country and per emission source category is to multiply a specific emission characteristic for a certain activity (emission factor) by an activity level.

For the reference year 1990 the emission factors and activity rates for PM_{10} have been estimated by TNO (Berdowski *et al.*, 1997). Most of the emission data is based on factors from the literature; little use has been made of data submitted by countries. An emission source characterisation similar to that of TNO-MEP (1997) is applied in the data processing.

The TNO emission database distinguishes the following source categories relevant for PM_{10}:

- stationary combustion (split according to combustion and fuel type);
- industrial processes (split according to process type);
- transport (road and non-road);
- waste treatment and disposal (mainly waste incineration);
- agriculture (mainly pig/poultry breeding);
- non-specified emissions (of minor importance).

Activity rates

The activity rates of stationary combustion and transport are based on the energy consumption for 2010 and 2020 as described in Chapter 4. Volumes of the industrial production processes and activities for EU countries are based on production volume indices available for several important processes from the National Technical University of Athens (NTUA) MIDAS model (Capros and Georgakopoulos, 1997). For other countries indices related to the energy projections are applied. In some cases, however, indices are only present in an aggregated form (e.g. the iron and steel sector as a whole). In general, all sub-processes to which the index refers are, in that case, projected according to the aggregated index, unless additional information suggests differently (e.g. open-hearth furnaces in the iron and steel industry are expected to be phased out before 2010). For these activities no additional developments have been taken into account from 2010 to 2020. Finally, for some specific processes no projection of activity is available (e.g. storage and handling of specific products). Either a growth index of a corresponding category, the country's total energy consumption or a constant activity rate at the 1990 level has been applied in such cases.

For waste treatment and disposal, projected data for waste incineration have been taken from EFTEC, 1997. For agriculture-related activities the livestock projections have been used as described in Chapter 3, where no changes take place between 2010 and 2020.

Emission factors
In the ShAIR scenario all emission reduction measures and policies that have been implemented since 1990 have been taken into account, plus all measures that were (at the end of 1997) expected to become effective before 2010. Emission reduction measures that are scheduled to be implemented during 2010 to 2020 have not been considered in this study.

The determination of emission factors corresponding to measures and policies can be rather difficult because the degree of enforcement and implementation of current legal obligations is not easily traceable.

Combustion of fossil fuels
Measures implemented to reduce emissions of SO_2 are also relevant for the emissions of particulate matter (and therefore for PM_{10}) from combustion processes. Because the measures and policies included for PM_{10} date from 1997, the measures on SO_2 resulting from recent policies like the Gothenburg protocol have not been implemented. On the other hand, the abatement technology for SO_2 needed to reach the limits of the second sulphur protocol has been included. These measures to reduce the emission of particulate matter have been evaluated in Berdowski *et al.* (1998). The emission factor for PM_{10} for the transformation of crude oil and the combustion of heavy fuel oil was changed on the basis of Berdowski *et al.* (1997). A future decrease in sulphur content of these fuels will cause the emission factor to be reduced to 60 % of the 1990 level (EPA, 1997).

Power generation
The implementation of the protocol in power-generating facilities is difficult to estimate and varies with the capacity of the power plants. For the countries which signed the second sulphur protocol, it was assumed that 85 % of the solid fuel for large power plants would be consumed in power plants with emission factors for particulate matter corresponding to an emission concentration of 50 mg/m^3 maximum (Berdowski *et al.*, 1998). The remaining 15 % of the solid fuel for large power plants will be consumed in plants with emission factors that remain at the 1990 level.

In some central and eastern European countries which did not sign the protocol, existing large power plants will be partly replaced in the period up to 2010. Based on the prognoses for replacement (IIASA, 1997) the ratio of old to new power plants was calculated for 2000 and 2010 for the different countries. This ratio, combined with the 85 %–15 % distribution for new power plants, was used to calculate the emission factors for PM_{10} in these countries. For those countries for which no data on replacement were available, the emission factors for PM_{10} are assumed to remain at the 1990 level. The emissions of PM_{10} from oil-fired power plants will decrease by 60 % as a result of a lower sulphur content in the oil, as mentioned above.

Industrial combustion
For industrial combustion in western and eastern European countries it was estimated that, on average, 60 % of the capacity could be treated as large combustion plants and 40 % as small combustion sources (IEA, 1997). The emission factor for large industrial combustion is based on the best available technology emission factors multiplied by 2.5 (to be in line with power plants). No improvement in emission factors compared to 1990 is assumed for the small combustion sources. In industrial combustion the emissions of PM_{10} from oil-fired combustion sources will also decrease by 60 % as result of a lower sulphur content in the oil.

Non-combustion sources in industry
The effect of current legislation on the non-combustion emissions in industry is poorly documented and therefore only poorly quantifiable. Only national legislation seems to apply in this case. For the western European countries the ShAIR emission factors for industrial activities were kept at 1990 levels. Interpretation of rough data from several eastern European countries leads to the conclusion that some relevant industrial activities had ceased. Activity rates for those industries have been removed from the scenario calculation.

Mobile sources
In the base PM_{10} inventory, emissions are split into exhaust and non-exhaust emission. For all vehicle categories, non-exhaust emission factors (for road abrasion and tyre and brake wear) remain unchanged compared to 1990. The methodology used to estimate the exhaust emission factors for the transport sector comprise the implementation of several emission limit values in the EU context. For the implementation schedule, the following starting points have been used. New vehicles sold within the EU, except heavy-duty trucks, have to conform to the EURO-3 standard. For heavy-duty vehicles EURO-1 will apply. The emission factors are determined by the gradual phase-in of these standards. A vehicle life expectancy of 10 years is assumed. A rough division between countries is made for the implementation schedule (see below):

Group 1: EU-15/Norway/Switzerland
Group 2: Czech Republic, Hungary, Poland and Slovakia
Group 3: Other countries

Group 1 follows the agreed implementation schedule within the EU framework. Group 2 follows group 1 with an expected delay of 5 years and group 3 follows group 1 within 10 years.

Projected emissions in 2010 and 2020 for PM10 according to the ShAIR scenario for Europe per country Table 5.11.

PM_{10} in kt	1990	2010	2020
Albania	15	8	6
Austria	68	32	33
Belarus	280	140	120
Belgium	140	89	88
Bosnia-Herzegovina	78	49	46
Bulgaria	250	110	110
Czech Republic	300	110	110
Croatia	82	25	25
Cyprus	0	0	0
Denmark	100	51	49
Estonia	44	32	32
Finland	95	43	42
FYR Macedonia	37	22	20
France	710	450	440
Germany	1 900	790	810
Greece	110	81	80
Hungary	210	85	81
Ireland	55	32	29
Italy	560	430	420
Latvia	75	46	47
Lithuania	100	110	110
Luxembourg	7	5	5
Moldova	120	60	57
Netherlands	67	74	74
Norway	46	18	17
Poland	1 100	460	410
Portugal	54	44	45
Romania	370	210	210
Russian Federation	4 100	1 200	1 100
Serbia and Montenegro	180	80	86
Slovakia	170	63	58
Slovenia	34	12	12
Spain	370	220	210
Sweden	79	44	42
Switzerland	39	24	22
Ukraine	1 400	420	360
United Kingdom	500	230	230
Total Europe	**14 000**	**5 900**	**5 700**

Table 5.12. **Projected emissions in 2010 and 2020 for PM10 according to the ShAIR scenario for Europe per sector (kt)**

SNAP1	Description	1990	2010	2020
1	Public power, co-generation and district heating	2 000	730	740
2	Commercial, institutional and residential combustion	1 600	910	800
3	Industrial combustion	2 400	710	630
4	Production processes	3 700	1 400	1 500
7	Road transport	2 000	1 000	1 100
8	Other mobile sources and machinery	910	120	64
9	Waste treatment and disposal	100	320	320
10	Agriculture	1 100	580	580
	Total	14 000	5 900	5 700

5.4. Impacts

5.4.1. Acidification and eutrophication

The ecosystem areas receiving acid deposition above their critical loads are used as an indicator for a quantitative comparison of the achievements of emission control scenarios. Tables 5.13 and 5.14 clearly demonstrate that the emission control measures that will be implemented in Europe within the next 20 years will significantly improve the situation for acidification. The share of unprotected ecosystems will decrease from 16 % in 1990 to less than 2 % in 2020. In the EU-15, the share will diminish from about 25 % in 1990 to 3.4 % in 2010 and to 2.9 % in 2020. However, despite such impressive improvements, there will be still countries in Europe (e.g. Belgium and the Netherlands), where a substantial ecosystem area will not attain sustainable conditions.

Improvements are also expected for eutrophication. In the EU-15 ecosystem areas with excess deposition of nutrient nitrogen will shrink from 56 % in 1990 to 36 %. For the accession countries the area of unprotected ecosystems will decrease from 84 % to 62 %. For some countries the protection level remains dramatically low even in 2020. For instance, in Belgium, France, Germany, Luxembourg, the Netherlands, Czech Republic, Poland and Switzerland 75 % of ecosystems and more will see nitrogen deposition exceeding the sustainable level. The main source for the excess deposition is ammonia emissions, for which only limited control strategies have been developed up to now. In future the reduction of ammonia emissions will require profound changes in agricultural practices and production levels in endangered areas.

Table 5.13. **Ecosystems with acid deposition above their critical loads for acidification in the ShAIR scenario for 1990, 2010 and 2020**

Country	Thousand hectares			% of ecosystems		
	1990	2010	2020	1990	2010	2020
Total EU-15	37 028	5 101	4 394	24.8	3.4	2.9
Total accession	18 077	1 256	479	44.2	3.1	1.2
Total other	38 269	7 602	6 410	9.8	1.9	1.6
Total	93 374	13 958	11 282	16.1	2.4	1.9

Table 5.14. **Ecosystems with nitrogen deposition above their critical loads for eutrophication within the EU framework in 1990, 2010 and 2020**

Country	Thousand hectares			% of ecosystems		
	1990	2010	2020	1990	2010	2020
Total EU-15	67 241	46 806	43 600	55.7	38.8	36.1
Total accession	34 477	26 193	25 320	84.3	64.1	61.9
Total other	64 312	33 219	32 522	16.8	8.7	8.5
Total	166 033	106 221	101 442	30.5	19.5	18.6

5.4.2. Tropospheric ozone

The indicators AOT40 and AOT60 are used to quantify the impacts of the control strategies on ozone levels. Table 5.15 presents two different types of population exposure (AOT60). The cumulative index reflects the total exposure of a population in each country and is expressed in person.ppm.hours. The 'average' indicator reflects the average exposure of a person in a country, calculated from gridded data.

Implementation of the ShAIR scenario will substantially reduce population exposure to elevated ozone levels. The average exposure of a person in Europe will decrease from 2.3 ppm.hours in 1990 to 0.6 ppm.hours in 2020. For the EU this indicator decreases from 3.5 ppm.hours in 1990 to 0.9 ppm.hours in 2020, i.e. by 75 %. The improvement for the accession countries is of the same order of magnitude, although in absolute terms the ozone levels in the accession countries are lower than in high ozone areas in western Europe (the Benelux countries, France and Germany).

Similar to health effects, two vegetation-related exposure indices were calculated (Table 5.16). The cumulative exposure index is calculated as the excess AOT40 (i.e. the AOT40 in excess of the critical level of 3 ppm.hours) multiplied by the area of ecosystems that is exposed to the excess concentration. The average vegetation exposure index reflects the average excess AOT40 (over all grids in a country). The ShAIR scenario causes a 49 % decrease in the exposure for the whole of Europe — from 4.1 excess.ppm.hours in 1990 to 2.0 excess.ppm.hours in 2020. In the EU the average decrease is 53 %. However, even after such a reduction the absolute exposure in some countries remains high. The index for the accession countries decreases up to 2020 to about 50 % of the 1990 level.

Population exposure indices (AOT60) for 1990, 2010 and 2020 in the ShAIR scenario Table 5.15.

Country	Cumulative (million person.ppm.hours)			Average (ppm.hours)		
	1990	2010	2020	1990	2010	2020
Total EU-15	1 265	386	318	3.5	1.1	0.9
Total accession	196	56	52	1.8	0.5	0.5
Total other	108	17	16	0.5	0.1	0.1
Total	1 571	461	389	2.3	0.7	0.6

Vegetation exposure indices for 1990, 2010 and 2020 for the ShAIR scenario Table 5.16.

Country	Cumulative (1 000 km^2.excess.ppm.hours)			Average (excess.ppm.hours)		
	1990	2010	2020	1990	2010	2020
Total EU-15	12 270	6 708	5 715	6.6	3.6	3.1
Total accession	4 505	2 399	2 270	6.1	3.2	3.1
Total other	4 931	2 748	2 697	1.8	1.0	1.0
Total	21 705	11 852	10 681	4.1	2.2	2.0

5.5. Comparison with previous studies

5.5.1 EEUTC scenario

The ShAIR and the EEUTC scenarios differ in the assumed levels of future economic activities (represented by different energy demand, see Chapter 3) as well as in the degree to which emission control measures are implemented.

The EEUTC scenario reflected environmental legislation (i.e. emission and fuel standards and emission ceilings from international treaties) decided or close to being decided at the end of 1997. A range of additional legal acts were introduced *inter alia* in 1998 and 1999:

- legislation on road transport sources (EURO 4 on light-duty and heavy-duty vehicles);
- further tightening of quality standards for diesel fuel and light fuel oil;
- emission ceilings from the Gothenburg protocol to the Convention on Long-Range Transboundary Air Pollution.

In contrast to the EEUTC scenario, all these amendments are included in the ShAIR scenario.

Tables 5.17 and 5.18 compare the differences in the emissions of atmospheric pollutants. In general, the ShAIR scenario has lower emissions than the EEUTC. This is due to lower energy demand and stricter environmental legislation in the ShAIR case. For the EU-15, the (controlled) emissions of NO_x in 2010 are 10 % lower in the ShAIR scenario than in the EEUTC. The difference for VOCs, SO_2 and NH_3 is 11, 20 and 2 %, respectively. Lower emissions of ammonia are due to stricter emission ceilings adopted in the Gothenburg protocol. Since the 2010 emissions in the EEUTC case were already substantially reduced compared with the base year (1990) emissions, relative reductions are much lower if compared with 1990 emission levels. For instance, the difference in SO_2 emissions between the EEUTC and the ShAIR is only 6 % of 1990 emission level. It is worth noting the change in emissions for Portugal, which was caused by recent revisions of Corinair numbers for 1990. Higher base-year emissions have also caused the increase in the protocol ceilings for Portugal.

Accession countries also have lower emissions in the baseline scenario. The difference is 11 % for NO_x, 4 % for VOCs, 12 % for SO_2 and 15 % for NH_3. These lower emissions are due to lower energy demand and to the emission ceilings of the Gothenburg protocol, which are stricter than the 'current reduction plans' at the time the EEUTC scenario was developed.

Assumptions on energy and agricultural development and current legislation for the other, non-EU, countries remained, in principle, unchanged compared with EEUTC ([8]). Thus the differences in the emission levels are mainly due to the Gothenburg protocol. Some eastern European countries, and in particular the countries of the former Soviet Union, accepted higher emission ceilings in the Gothenburg protocol than what was assumed for the 'current reduction plans' in 1997.

Tables 5.19 and 5.20 compare the environmental indicators of the EEUTC and the ShAIR scenarios. In general, all indicators improve because of lower emission levels. If compared to the EEUTC scenario, the ShAIR case will, for the EU-15, provide protection in 2010 to an additional 1.8 million hectares of ecosystems (i.e. to an additional 26 % of ecosystems that remained unprotected in the EEUTC scenario). An additional 3 million hectares (or 6 % of the ecosystems area not protected in the EEUTC) enjoy full protection against eutrophication. Health-related and vegetation-related ozone indicators also improve by 25 % and 13 % if compared to the EEUTC values. There is also a substantial improvement in the indicators for accession countries.

The less stringent commitments accepted by the countries of the former Soviet Union in the Gothenburg protocol, however, will lead to a deterioration of environmental indicators compared to what was estimated for the EEUTC case.

(8) The exceptions are Norway and Switzerland, where the ShAIR scenario assumes the same controls on vehicles and improvements in liquid fuels quality as in the EU countries.

Differences in NO_x and VOC emission estimates for 2010 between the EEUTC and the ShAIR scenarios (kt) — Table 5.17.

Country	NO_x			VOCs		
	EEUTC	ShAIR	Difference	EEUTC	ShAIR	Difference
Austria	87	98	13 %	204	159	– 22 %
Belgium	204	169	– 17 %	206	144	– 30 %
Denmark	157	127	– 19 %	95	78	– 17 %
Finland	154	149	– 3 %	108	130	20 %
France	933	860	– 8 %	1 238	1 048	– 15 %
Germany	1 387	1 081	– 22 %	1 322	995	– 25 %
Greece	338	342	1 %	205	216	6 %
Ireland	77	65	– 15 %	49	49	– 1 %
Italy	1 186	1 000	– 16 %	1 177	1 116	– 5 %
Luxembourg	10	10	– 7 %	7	7	– 4 %
Netherlands	266	247	– 7 %	247	191	– 23 %
Portugal	197	259	31 %	144	201	39 %
Spain	892	847	– 5 %	669	645	– 4 %
Sweden	220	148	– 33 %	212	197	– 7 %
UK	1 186	1 181	0 %	1 276	1 200	– 6 %
Total EU-15	**7 296**	**6 582**	**– 10 %**	**7 159**	**6 377**	**– 11 %**
Bulgaria	290	266	– 8 %	190	185	– 2 %
Czech Rep.	296	286	– 3 %	305	220	– 28 %
Estonia	73	52	– 29 %	45	46	1 %
Hungary	196	159	– 19 %	145	137	– 6 %
Latvia	90	84	– 7 %	54	49	– 9 %
Lithuania	110	98	– 10 %	84	92	10 %
Poland	879	728	– 17 %	807	800	– 1 %
Romania	458	437	– 5 %	504	504	0 %
Slovakia	132	130	– 1 %	140	140	0 %
Slovenia	31	45	45 %	25	40	62 %
Total accession	**2 555**	**2 285**	**– 11 %**	**2 299**	**2 214**	**– 4 %**
Albania	36	36	0 %	41	41	0 %
Belarus	180	255	42 %	301	309	3 %
Bosnia-H.	60	60	0 %	48	48	0 %
Croatia	83	87	5 %	105	90	– 14 %
FYR Macedonia	29	29	0 %	19	19	0 %
Moldova	34	66	93 %	41	42	4 %
Norway	161	156	– 3 %	195	195	0 %
Russia	1 995	2 653	33 %	2 743	2 787	2 %
Switzerland	89	79	– 11 %	143	144	1 %
Ukraine	1 094	1 222	12 %	851	797	– 6 %
Yugoslavia	152	152	0 %	139	139	0 %
Total other	**3 913**	**4 794**	**23 %**	**4 625**	**4 611**	**0 %**
Total	**15 392**	**15 291**	**– 1 %**	**14 082**	**13 202**	**– 6 %**

Table 5.18. **Differences in SO_2 and NH_3 emission estimates for 2010 between the EEUTC and the ShAIR scenarios (kt)**

Country	SO_2			NH_3		
	EEUTC	ShAIR	Difference	EEUTC	ShAIR	Difference
Austria	49	39	– 20 %	67	66	– 1 %
Belgium	208	106	– 49 %	96	74	– 23 %
Denmark	90	55	– 39 %	72	69	– 4 %
Finland	116	116	0 %	31	31	0 %
France	489	400	– 18 %	771	780	1 %
Germany	740	518	– 30 %	571	550	– 4 %
Greece	371	508	37 %	74	73	– 1 %
Ireland	94	42	– 55 %	126	116	– 8 %
Italy	593	381	– 36 %	432	419	– 3 %
Luxembourg	4	4	0 %	7	7	4 %
Netherlands	84	50	– 41 %	136	128	– 6 %
Portugal	145	170	17 %	67	73	9 %
Spain	793	774	– 2 %	353	353	0 %
Sweden	59	65	10 %	53	57	8 %
UK	980	625	– 36 %	297	297	0 %
Total EU-15	**4 815**	**3 853**	**– 20 %**	**3 153**	**3 093**	**– 2 %**
Bulgaria	846	846	0 %	126	108	– 14 %
Czech Rep.	366	283	– 23 %	105	101	– 4 %
Estonia	175	111	– 36 %	29	29	0 %
Hungary	546	227	– 58 %	137	90	– 34 %
Latvia	57	73	29 %	35	35	0 %
Lithuania	107	73	– 32 %	81	81	0 %
Poland	1 397	1 397	0 %	508	468	– 8 %
Romania	594	594	0 %	300	210	– 30 %
Slovakia	137	110	– 20 %	47	39	– 17 %
Slovenia	37	27	– 27 %	21	21	0 %
Total accession	**4 262**	**3 742**	**– 12 %**	**1 388**	**1 181**	**– 15 %**
Albania	55	55	0 %	35	35	0 %
Belarus	480	480	0 %	163	158	– 3 %
Bosnia-H.	415	415	0 %	23	23	0 %
Croatia	70	70	0 %	37	30	– 19 %
FYR Macedonia	81	81	0 %	16	16	0 %
Moldova	117	117	0 %	48	42	– 12 %
Norway	33	22	– 33 %	21	21	0 %
Russia	2 344	2 344	0 %	894	894	0 %
Switzerland	30	26	– 15 %	66	63	– 5 %
Ukraine	1 488	1 457	– 2 %	649	592	– 9 %
Yugoslavia	269	269	0 %	82	82	0 %
Total other	**5 382**	**5 335**	**– 1 %**	**2 034**	**1 956**	**– 4 %**
Total	**15 611**	**14 082**	**– 10 %**	**6 575**	**6 231**	**– 5 %**

Differences in environmental indicators for 2010 between the EEUTC and the ShAIR scenarios — acidification and eutrophication

Table 5.19.

Country	Unprotected ecosystems, thousand hectares					
	Acidification			Eutrophication		
	EEUTC	ShAIR	Difference	EEUTC	ShAIR	Difference
Total EU-15	6 909	5 101	– 26 %	49 794	46 806	– 6 %
Total accession	2 471	1 256	– 49 %	29 555	26 193	– 11 %
Total other	8 576	7 602	– 11 %	31 974	33 219	4 %
Total	**17 954**	**13 958**	**– 22 %**	**111 320**	**106 221**	**– 5 %**

Differences in environmental indicators for 2010 between the EEUTC and the ShAIR scenarios — tropospheric ozone

Table 5.20.

Country	Cumulative ozone exposure indices					
	AOT60 (million person.ppm.hours)			AOT40 (thousand km².excess ppm.hours)		
	EEUTC	ShAIR	Difference	EEUTC	ShAIR	Difference
Total EU-15	516	386	– 25 %	7 740	6 708	– 13 %
Total accession	74	56	– 24 %	2 780	2 399	– 14 %
Total other	19	17	– 11 %	2 570	2 748	7 %
Total	**610**	**461**	**– 24 %**	**13 120**	**11 852**	**– 10**

Table 5.21 summarises the relative improvement in environmental indicators for the EEUTC scenario and compares it with the values for the new ShAIR scenario for 2010 and 2020. The most important improvements are caused by the emission control measures already included in the EEUTC scenario. In 2010 the additional reductions of the ShAIR scenario are due to lower energy consumption and the more stringent environmental legislation. After 2010, increased penetration of emission control technologies and changes in energy consumption towards less polluting fuels will lead to additional improvements.

Comparison of relative improvement of environmental indicators between the EEUTC and the current (ShAIR) scenario (% reduction of 1990 indicator)

Table 5.21.

Impact	EEUTC	ShAIR	
Type	2010	2010	2020
EU-15			
Acidification	– 81 %	– 86 %	– 88 %
Eutrophication	– 26 %	– 30 %	– 35 %
AOT60	– 59 %	– 69 %	– 75 %
AOT40	– 37 %	– 45 %	– 53 %
Accession countries			
Acidification	– 86 %	– 93 %	– 97 %
Eutrophication	– 14 %	– 24 %	– 27 %
AOT60	– 62 %	– 71 %	– 73 %
AOT40	– 38 %	– 47 %	– 50 %

5.5.2 Auto-Oil II

Tables 5.22 and 5.23 compare the transport emissions of NO_x and VOCs from ShAIR with Auto-Oil II (AOP II) results. For 1990, the emissions for the EU-9 according to ShAIR are 7 % higher for NO_x and 14 % higher for VOCs than the Auto-Oil II values. The differences for individual countries for NO_x range from –8 % to + 27 %. For VOCs differences for individual countries range between –3 and + 54 %.

One of the reasons for these differences is the different fuel consumption levels used by the two scenarios (see Chapter 3). If RAINS uses fuel consumption data from the Auto-Oil database (see scenario variant AO2R), differences for the year 1990 are reduced to 3 % for NO_x and 8 % for VOCs for the EU-9 as a whole and for the majority of countries to less than 10 to 15 %. Larger discrepancies still exist for VOC emissions in Germany and in the Netherlands. In case of Germany this is probably caused by the uncertainty on the share of two-stroke engines in the former German Democratic Republic. In turn, the VOC emissions from light-duty vehicles in the Netherlands may be too high in RAINS because RAINS uses aggregated information on the consumption of gasoline and liquefied petroleum gas (LPG), possibly overestimating the evaporative emissions as well as combustion emissions for LPG vehicles.

NO_x emissions for 2010 in the ShAIR scenario are 19 % higher than those estimated by Auto-Oil II, and VOC emissions are 44 % higher. However, more than half of these differences for NO_x and two thirds for VOCs are explained by different assumptions on fuel use in the scenarios (compare the results of the AO2R columns). If the same fuel consumption is used, differences in the estimates of NO_x and VOC emissions in 2010 for individual countries and vehicle categories remain below 25 % for most countries. The exception is NO_x from heavy-duty vehicles in Greece, where the Auto-Oil study calculated 45 % fewer emissions than RAINS, even using the same fuel consumption.

The differences between the results in the ShAIR and the Auto-Oil II scenarios are due to differences in models and the use of different activity data for the emission estimates. The Auto-Oil Programme used a more detailed methodology (Tremove: Nitziachristos and Samaras, 1997) for estimating emissions from the transport sector than the RAINS model (compare Cofala and Syri, 1998a and b) which encompasses all emission sources. Important differences can be explained by motorcycle emissions, which were not included in the Auto-Oil II scenario; VOC emissions of Auto-Oil II also stand for exhaust emissions alone, i.e. evaporation losses are not taken into account.

Table 5.22.

Comparison of transport emissions of NO_x as in the Auto-Oil II Programme with the ShAIR scenario values for 2010 (kt)

Country	Vehicle category	NO_x					
		1990			2010		
		RAINS		AOP II	RAINS		AOP II
		ShAIR	AO2R		ShAIR	AO2R	
Finland	Light-duty	78.7	69.7	75.4	9.9	9.0	16.8
	Heavy-duty	45.1	36.2	32.3	17.4	14.2	13.8
	Total	123.8	105.9	107.7	27.3	23.2	30.6
	AOP II=100 %	115 %	98 %	100 %	89 %	76 %	100 %
France	Light-duty	733.4	711.6	763.4	115.9	120.6	159.1
	Heavy-duty	281.6	268.7	304.7	183.2	165.4	136.8
	Total	1 015.1	980.2	1 068.2	299.1	286.0	295.9
	AOP II=100 %	95 %	92 %	100 %	101 %	97 %	100 %
Germany	Light-duty	829.2	895.8	909.4	172.4	138.7	167.6
	Heavy-duty	407.9	475.1	372.6	238.0	242.2	165.3
	Total	1 237.1	1 370.9	1 282.0	410.3	380.9	332.8
	AOP II=100 %	97 %	107 %	100 %	123 %	114 %	100 %
Greece	Light-duty	65.9	56.8	55.3	23.0	17.6	17.3
	Heavy-duty	52.5	57.9	52.0	45.2	54.0	29.3
	Total	118.4	114.6	107.3	68.2	71.7	46.5
	AOP II=100 %	110 %	107 %	100 %	147 %	154 %	100 %
Ireland	Light-duty	34.6	25.4	32.4	6.7	4.5	7.3
	Heavy-duty	11.8	9.2	7.7	9.4	5.6	5.9
	Total	46.4	34.6	40.1	16.1	10.2	13.2
	AOP II=100 %	116 %	86 %	100 %	122 %	77 %	100 %
Italy	Light-duty	527.4	535.0	570.7	115.4	114.1	135.1
	Heavy-duty	449.1	264.9	228.8	204.4	119.4	92.2
	Total	976.5	799.9	799.5	319.8	233.5	227.3
	AOP II=100 %	122 %	100 %	100 %	141 %	103 %	100 %
Netherlands	Light-duty	151.4	149.6	156.7	21.8	18.9	30.0
	Heavy-duty	118.1	82.9	55.3	49.6	34.8	25.4
	Total	269.5	232.4	211.9	71.4	53.7	55.3
	AOP II=100 %	127 %	110 %	100 %	129 %	97 %	100 %
Spain	Light-duty	318.9	295.8	320.6	99.0	72.9	74.3
	Heavy-duty	188.2	300.6	230.3	150.3	210.4	145.1
	Total	507.1	596.4	550.9	249.3	283.3	219.4
	AOP II=100 %	92 %	108 %	100 %	114 %	129 %	100 %
UK	Light-duty	813.8	729.7	809.9	72.8	79.0	1 30.3
	Heavy-duty	505.6	429.8	267.1	207.7	173.9	112.1
	Total	1 319.4	1 159.5	1 077.0	280.5	253.0	242.4
	AOP II=100 %	123 %	108 %	100 %	116 %	104 %	100 %
Total EU-9	Light-duty	3 553.4	3 469.3	3 693.8	637.0	575.4	737.7
	Heavy-duty	2 060.0	1 925.1	1 550.7	1 105.1	1 020.0	725.8
	Total	5 613.4	5 394.4	5 244.5	1 742.1	1 595.3	1 463.5
	AOP II=100 %	107 %	103 %	100 %	119 %	109 %	100 %

Explanations:

AOP II Emissions as reported for the base case of the Auto-Oil II Programme cost-effectiveness study (AOP II, 1999).

AO2R Emissions calculated by RAINS model from energy consumption, as reported by the Auto-Oil II Programme.

Table 5.23. **Comparison of transport emissions of VOCs as in the Auto-Oil II Programme with the ShAIR scenario values for 2010 (kt)**

Country	Vehicle category	VOCs					
		1990			2010		
		RAINS		AOP II	RAINS		AOP II
		ShAIR	AO2R		ShAIR	AO2R	
Finland	Light-duty	76.1	67.4	79.1	9.7	10.0	11.2
	Heavy-duty	8.3	6.8	2.5	2.5	2.1	2.1
	Total	84.4	74.2	81.6	12.2	12.1	13.2
	AOP II=100 %	103 %	91 %	100 %	92 %	91 %	100 %
France	Light-duty	1 101.6	1 091.5	1 026.2	158.0	148.1	125.8
	Heavy-duty	27.2	24.5	19.1	13.6	12.2	13.6
	Total	1 128.8	1 116.0	1 045.3	171.6	160.4	139.4
	AOP II=100 %	108 %	107 %	100 %	123 %	115 %	100 %
Germany	Light-duty	1 356.8	1 394.5	1 036.4	157.3	128.5	113.8
	Heavy-duty	57.8	66.8	37.8	26.5	26.9	24.1
	Total	1 414.6	1 461.3	1 074.2	183.8	155.4	137.8
	AOP II=100 %	132 %	136 %	100 %	133 %	113 %	100 %
Greece	Light-duty	128.1	94.8	103.7	51.2	32.6	26.3
	Heavy-duty	10.0	11.0	6.5	7.8	9.3	5.9
	Total	138.0	105.8	110.2	59.0	41.9	32.2
	AOP II=100 %	125 %	96 %	100 %	183 %	130 %	100 %
Ireland	Light-duty	60.5	44.6	39.8	11.8	7.9	4.2
	Heavy-duty	2.3	1.8	0.8	1.4	0.8	0.9
	Total	62.7	46.4	40.7	13.2	8.8	5.1
	AOP II=100 %	154 %	114 %	100 %	257 %	171 %	100 %
Italy	Light-duty	861.9	758.1	714.6	260.1	200.5	153.3
	Heavy-duty	80.4	44.7	28.4	28.6	16.7	16.3
	Total	942.3	802.7	743.0	288.6	217.2	169.6
	AOP II=100 %	127 %	108 %	100 %	170 %	128 %	100 %
Netherlands	Light-duty	172.2	168.1	136.9	30.5	20.6	20.1
	Heavy-duty	16.8	12.9	6.7	5.2	4.4	4.1
	Total	189.0	181.0	143.5	35.7	25.0	24.2
	AOP II=100 %	132 %	126 %	100 %	148 %	103 %	100 %
Spain	Light-duty	430.0	410.0	439.0	130.7	100.7	74.0
	Heavy-duty	43.6	52.3	32.3	21.3	30.4	34.1
	Total	473.5	462.3	471.4	152.0	131.1	108.0
	AOP II=100 %	100 %	98 %	100 %	141 %	121 %	100 %
UK	Light-duty	1 052.4	927.5	1 115.5	111.2	76.1	82.6
	Heavy-duty	65.4	55.5	31.1	20.9	17.5	18.2
	Total	1 117.8	983.0	1 146.6	132.1	93.6	100.8
	AOP II=100 %	97 %	86 %	100 %	131 %	93 %	100 %
Total EU-9	Light-duty	5 239.7	4 956.5	4 691.2	920.5	725.1	611.3
	Heavy-duty	311.6	276.2	165.2	127.7	120.2	119.1
	Total	5 551.3	5 232.7	4 856.4	1 048.2	845.3	730.4
	AOP II=100 %	114 %	108 %	100 %	144 %	116 %	100 %

In addition, emissions have been calculated on the basis of figures on vehicle fleets and data on use in the EU as produced in the MEET (methodology for calculating transport emissions and energy consumption) project (EC, 1999c). This was done with the ForeMove model that is fully incorporated in the Tremove model. A description of the differences in methodologies of the models is shown in the textbox. This MEET run is performed for all EU-15 countries.

A comparison between ShAIR, Auto-Oil II and MEET shows that all three scenarios have different results (see Table 5.24). For some countries though, the differences between the three approaches are quite important. Thus NO_x emissions in Finland are expected to drop by 78 % and 70 % by 2010 compared to 1990, respectively, according to the results of the ShAIR scenario and the Auto-Oil Programme. ForeMove calculates a corresponding decrease of 42 %. Major differences in medium-term predictions are also observed in Greece, Italy and Portugal. The picture provided by the long-term trends of NO_x and VOC emissions is more homogeneous in the majority of the countries examined. However, the differences between model results in Finland, Greece and Italy remain significant.

Trends of NO_x and VOC emissions as calculated for the ShAIR scenario (this report), as reported for nine countries in the Auto-Oil Programme (AOP II), and as calculated in an additional scenario run with the ForeMove model.

Table 5.24.1

	1990 / 2010 in %					
	NO_x			VOCs		
	ShAIR	AOP II	LAT	ShAIR	AOP II	LAT
Austria	– 66.3		– 62.9	– 75.4		– 71.6
Belgium	– 68.8		– 71.0	– 83.0		– 78.8
Denmark	– 73.6		– 73.9	– 82.4		– 81.0
Finland	**– 77.9**	**– 69.5**	**– 42.1**	**– 86.6**	**– 72.8**	**– 41.2**
France	**– 70.5**	**– 69.9**	**– 72.4**	**– 83.2**	**– 82.0**	**– 77.9**
Germany	**– 66.8**	**– 72.0**	**– 64.6**	**– 82.4**	**– 79.2**	**– 70.3**
Greece	**– 42.4**	**– 56.5**	**– 24.7**	**– 45.5**	**– 70.3**	**– 36.2**
Ireland	**– 65.4**	**– 64.3**	**– 69.4**	**– 81.8**	**– 72.1**	**– 79.4**
Italy	**– 67.1**	**– 71.4**	**– 59.0**	**– 59.6**	**– 76.5**	**– 70.6**
Luxembourg	– 83.4		– 75.6	– 89.9		– 78.8
Netherlands	**– 73.5**	**– 73.4**	**– 71.5**	**– 83.2**	**– 76.5**	**– 76.1**
Portugal	– 25.9		– 42.8	– 53.1		– 60.2
Spain	**– 50.9**	**– 60.7**	**– 51.0**	**– 65.7**	**– 69.6**	**– 61.9**
Sweden	– 75.8		– 67.2	– 86.6		– 74.4
United Kingdom	**– 78.7**	**– 76.2**	**– 80.5**	**– 90.4**	**– 84.9**	**– 84.0**
EU 9	**– 68.9**	**– 70.9**	**– 66.1**	**– 78.4**	**– 79.3**	**– 72.8**
	1990/2020					
Austria	– 81.5		– 71.7	– 83.5		– 77.3
Belgium	– 82.1		– 81.6	– 88.7		– 84.0
Denmark	– 87.9		– 86.2	– 93.3		– 88.4
Finland	**– 88.8**	**– 82.7**	**– 73.7**	**– 94.3**	**– 84.2**	**– 70.3**
France	**– 84.9**	**– 77.8**	**– 83.3**	**– 90.8**	**– 86.1**	**– 85.7**
Germany	**– 83.4**	**– 83.3**	**– 79.3**	**– 90.5**	**– 87.0**	**– 79.2**
Greece	**– 81.2**	**– 69.5**	**– 58.4**	**– 71.4**	**– 77.0**	**– 65.7**
Ireland	**– 82.2**	**– 78.6**	**– 80.4**	**– 91.7**	**– 81.6**	**– 85.2**
Italy	**– 79.5**	**– 82.4**	**– 77.8**	**– 64.6**	**– 84.6**	**– 83.2**
Luxembourg	– 89.0		– 84.9	– 93.5		– 82.0
Netherlands	**– 83.7**	**– 79.4**	**– 83.4**	**– 88.6**	**– 81.4**	**– 82.4**
Portugal	– 70.9		– 69.8	– 79.2		– 75.7
Spain	**– 79.3**	**– 73.4**	**– 71.0**	**– 84.7**	**– 76.4**	**– 77.8**
Sweden	– 87.7		– 84.3	– 92.8		– 87.5
United Kingdom	**– 88.7**	**– 84.2**	**– 88.2**	**– 94.7**	**– 89.2**	**– 88.3**
EU 9	**– 84.0**	**– 80.8**	**– 80.5**	**– 86.0**	**– 85.4**	**– 82.7**

There are a number of differences between both Tremove and ForeMove estimates on fuel consumption and the corresponding values provided by RAINS. For some countries the estimates of Tremove and ForeMove are higher than the figures used in the ShAIR scenario, while in other countries it is the other way around. The differences vary between 7 and 9 % for the nine EU countries in the Auto-Oil II Programme for the year 1990, while they are around 12 % for 2010.

With regard to NO_x emissions, RAINS estimates are, in general, relatively higher than those of Tremove and ForeMove. The calculated deviations remain well below 20 % for the whole period examined. In the case of VOC emissions, RAINS estimates are constantly higher than those of the other models (in 1990 the difference between RAINS and Tremove is of the order of 26 %). The results of the Auto-Oil II study are in fairly good agreement with ForeMove calculations. The observed deviations between RAINS and Tremove/ForeMove should be attributed to the two-stroke vehicle emissions accounted for in RAINS calculations. Taking into account two-stroke vehicle emissions in Tremove/ForeMove would certainly increase the corresponding emission levels.

The differences in total national emissions are smaller than the differences for transport. The average EU-9 difference is only 2 % for both NO_x and VOCs (see Table 5.25). It is worth noting that the absolute values of differences for national totals are smaller than the differences for road transport only. This is because in both scenarios emission ceilings from the Gothenburg protocol were applied to national emissions. Since the protocol ceilings remain unchanged, smaller emissions from road transport in the AOP II scenario mean for some countries that fewer emissions from stationary sources need to be reduced. This is the case, for instance, for VOC emissions in Germany, the Netherlands and the UK.

Table 5.25. **Difference between the emission estimates of the ShAIR and AOP II scenario for 2010, presented as ShAIR minus AOP II**

Country	Road transport emissions				Total national emissions			
	Kilotonnes		% of 1990 emissions		Kilotonnes		% of 1990 emissions	
	NOx	VOCs	NOx	VOCs	NOx	VOCs	NOx	VOCs
Finland	– 3	– 1	– 3 %	– 1 %	– 3	0	– 1 %	0 %
France	3	32	0 %	3 %	3	32	0 %	3 %
Germany	77	46	6 %	3 %	67	0	3 %	0 %
Greece	22	27	18 %	19 %	22	27	6 %	8 %
Ireland	3	8	6 %	13 %	0	8	0 %	7 %
Italy	93	119	9 %	13 %	80	119	4 %	6 %
Netherlands	16	12	6 %	6 %	16	0	3 %	0 %
Spain	30	44	6 %	9 %	30	44	3 %	4 %
UK	38	31	3 %	3 %	21	0	1 %	0 %
Total EU-9	**279**	**318**	**5 %**	**6 %**	**236**	**230**	**2 %**	**2 %**

The models

RAINS distinguishes three categories of vehicles: light-duty and heavy-duty (with both two-stroke and four-stroke engines). Calculations of emissions of nitrogen oxides (NO_x) and non-methane volatile organic compounds (VOCs) in RAINS are based on fuel consumption by each vehicle category. RAINS distinguishes three types of fuels: light fractions of liquid fuels (gasoline and liquefied petroleum gas), medium distillates (diesel fuel) and natural gas. For each vehicle type, present and future fuel consumption is extracted from the energy scenario for a given country. The energy data used by RAINS for historical years are consistent with international energy statistics (e.g. IEA, 1997). For the EU-15 countries, energy projections were generated by the energy model PRIMES (compare EC, 1999b) and include sufficient details about the transport sector. For other countries usually only more aggregated information is available. Thus the RAINS team in consultation with national experts was split into individual categories.

RAINS uses a country-specific 'uncontrolled' emission factor for each vehicle/fuel category, reflecting national characteristics in fleet composition and driving modes. These emission factors are derived from national estimates and from the Corinair inventory. Actual emissions are then determined on the basis of the country-specific implementation schedule of emission standards, taking into account the specific turnover rate of national vehicle fleets. Information on these schedules is extracted from the costing studies of the Auto-Oil I Programme (Touche Ross & Co., 1995).

The emissions with the Tremove model are calculated bottom-up with the aid of a transport model (products for which activity data are related to passenger and tonne kilometres for various transport modes and vehicle classes) and the ForeMove scheme. The latter includes the vehicle dynamics module used to estimate the fleet population for each country and COPERT III (in a version close to its final form) for the calculation of detailed, technology-based emission factors and total emissions on the basis of the estimated activity data. Estimations with COPERT (which stands for computer program to calculate emissions from road transport) are performed for a detailed vehicle category split, additionally taking into account activity data on different driving models (i.e. urban, rural, highway, number of cold starts, etc.). The vehicle dynamics module calculates the total vehicle number per year in each country based on a Gompertz function. In the next step, the technology distribution of the fleet is calculated on the basis of a Weibull function, taking into account rates of new vehicle registrations and vehicle removal from circulation. Historical data on vehicle stock, population, vehicle use and official population projections are used for the calculation of the future activity trends, whereas age distribution and lifetime functions of vehicle types form the basis for the predictions of the internal vehicles turnover.

Fuel consumption estimates are a product of both Tremove and ForeMove.

Conceptual differences between the RAINS, Tremove and ForeMove models Table ??

Activity	RAINS	Tremove	ForeMove
Energy/fuel consumption	Input	Product	Product
Transport (person km or tonne km)	-	Input Calculated	-
Vehicle fleet data	-	Input	Input Calculated
Emission factors	Input	Calculated	Calculated
Future technology penetration	Input	Calculated	Calculated

5.6. Sensitivity analysis

5.6.1. The introduction of EU emission standards in the accession countries

This section explores the potential consequences of harmonisation of national environmental legislation in the accession countries with the EU regulations. Potential accession countries are grouped into 'first-wave' (Czech Republic, Estonia, Hungary, Poland, and Slovenia[9]) and 'second-wave' (Bulgaria, Latvia, Lithuania and Slovakia) countries, for which different compliance deadlines are assumed (2003 for the first-wave and 2006 for the second-wave countries).

The most important pieces of legislation that need to be adopted by the accession countries and that have an effect on SO_2, NO_x and VOC emissions are:

- the large combustion plant directive with the proposed amendments
- the liquid fuels quality directives
- emission standards on vehicles (road, off-road)
- legislation aimed at limiting VOC emissions (small carbon canisters, solvent directive).

(9) Cyprus is not included in the RAINS model domain.

In addition, it has been assumed that, just as in the ShAIR scenario, the emission ceilings from the Gothenburg protocol to the Convention on Long-Range Transboundary Air Pollution need to be achieved by all countries.

Tables 5.26 to 5.28 compare the emissions of SO_2, NO_x, and VOCs for the accession (ACC) scenario with those for ShAIR. Approximation with the EU environmental legislation brings substantial benefits in terms of reduction of emission levels, especially in the longer term. In 2020, NO_x emissions will be 28 % below the ShAIR level, VOCs 11 % and SO_2 12 %. Since some standards need to be implemented, so the effects up to 2010 are smaller only for new sources. Nevertheless, even in 2010 NO_x emissions are 8 %, VOCs 2 % and SO_2 7 % below the ShAIR levels.

Tables 5.29 to 5.30 highlight the environmental improvements in the harmonisation scenario using the indicators discussed above. In 2020, implementation of EU legislation in the accession countries would yield protection against acidification of an additional 52 000 hectares (ha) of ecosystems in these countries and about 1.2 million ha against eutrophication. The AOT60 indicator improves by 29 % and AOT40 indicator by 20 %, compared with the ShAIR scenario. These emission reductions will also bring positive effects to other countries. For instance, 115 000-ha ecosystems, i.e. 3 % of ecosystems, are still not protected against acidification in 2020 under the ShAIR but are protected in the accession scenario. The ozone indicators in the EU-15 will improve by about 2 % of the remaining excess in ShAIR.

Table 5.26. **Change in NO_x emissions in ShAIR and accession (ACC) variant (kt)**

Country	1990	2010			2020		
		ShAIR	ACC	Change	ShAIR	ACC	Change
Bulgaria	355	266	255	– 4%	266	179	– 33%
Czech Rep.	546	286	286	0 %	286	261	– 9 %
Estonia	84	52	38	– 26 %	64	26	– 59 %
Hungary	219	159	134	– 16 %	184	111	– 40 %
Latvia	117	84	73	– 13 %	84	56	– 33 %
Lithuania	153	98	84	– 14 %	110	68	– 38 %
Poland	1 217	728	672	– 8 %	719	562	– 22 %
Romania	518	437	406	– 7 %	437	301	– 31 %
Slovakia	219	130	118	– 9 %	130	89	– 31 %
Slovenia	60	45	45	0 %	45	27	– 41 %
Total	**3 489**	**2 285**	**2 113**	**– 8 %**	**2 324**	**1 679**	**– 28 %**

Table 5.27. **Change in VOC emissions in ShAIR and accession (ACC) variant (kt)**

Country	1990	2010			2020		
		ShAIR	ACC	Change	ShAIR	ACC	Change
Bulgaria	195	185	185	0 %	185	140	– 24 %
Czech Rep.	442	220	220	0 %	220	220	0 %
Estonia	45	46	38	– 18 %	55	33	– 40 %
Hungary	204	137	137	0 %	137	117	– 15 %
Latvia	63	49	43	– 12 %	59	31	– 48 %
Lithuania	111	92	92	0 %	92	92	0 %
Poland	800	800	800	0 %	800	750	– 6 %
Romania	504	504	484	– 4 %	523	466	– 11 %
Slovakia	151	140	140	0 %	127	117	– 8 %
Slovenia	55	40	40	0 %	40	30	– 25 %
Total	**2 570**	**2 214**	**2 179**	**– 2 %**	**2 239**	**1 996**	**– 11 %**

Table 5.28. Change in SO_2 emissions in ShAIR and accession (ACC) variant (kt)

Country	1990	2010			2020		
		ShAIR	ACC	Change	ShAIR	ACC	Change
Bulgaria	1 842	846	766	– 9 %	465	390	– 16 %
Czech Rep.	1 873	283	283	0 %	283	283	0 %
Estonia	275	111	92	– 17 %	58	38	– 35 %
Hungary	913	227	223	– 2 %	84	79	– 6 %
Latvia	121	73	43	– 42 %	107	63	– 41 %
Lithuania	213	73	47	– 36 %	72	40	– 44 %
Poland	3 001	1 397	1 397	0 %	739	714	– 3 %
Romania	1 331	594	502	– 15 %	358	281	– 22 %
Slovakia	548	110	110	0 %	96	92	– 3 %
Slovenia	200	27	27	0 %	18	16	– 12 %
Total	**10 315**	**3 742**	**3 490**	**– 7 %**	**2 279**	**1 996**	**– 12 %**

Table 5.29. Improvement of acidification and eutrophication indicators in the accession (ACC) variant compared with the ShAIR; values in the table show ecosystems that are not protected (thousand ha)

Country	1990	2010			2020		
		ShAIR	ACC	Change	ShAIR	ACC	Change
Acidification							
Total EU-15	37 028	5 101	5 049	– 1 %	4 394	4 279	– 3 %
Total accession	18 077	1 256	1 218	– 3 %	479	427	– 11 %
Total other	38 269	7 602	7 451	– 2 %	6 410	6 320	– 1 %
Total	**93 374**	**13 958**	**13 720**	**– 2 %**	**11 282**	**11 025**	**– 2 %**
Eutrophication							
Total EU-15	67 241	46 806	46 647	0 %	43 600	43 060	– 1 %
Total accession	34 477	26 193	25 619	– 2 %	25 320	24 116	– 5 %
Total other	64 312	33 219	32 807	– 1 %	32 522	31 571	– 3 %
Total	**166 033**	**106 221**	**105 071**	**– 1 %**	**101 442**	**98 744**	**– 3 %**

Table 5.30. Improvement of health-related ozone indicators (AOT60) in the accession (ACC) scenario compared with ShAIR (million person.ppm.hours)

Country	1990	2010			2020		
		ShAIR	ACC	Change	ShAIR	ACC	Change
Total EU-15	1 265	386	386	0 %	318	312	– 2 %
Total accession	196	56	50	– 11 %	52	37	– 29 %
Total other	108	17	17	0 %	16	13	– 19 %
Total	**1 571**	**461**	**455**	**– 1 %**	**389**	**364**	**– 6 %**

Table 5.31. **Improvement of vegetation-related ozone indicators in the accession scenario (ACC) compared with the ShAIR; values in the table show AOT40 in thousand km2.excess.ppmhours**

Country	1990	2010			2020		
		ShAIR	ACC	Change	ShAIR	ACC	Change
Total EU-15	12 270	6 708	6 689	0 %	5 715	5 612	– 2 %
Total accession	4 505	2 399	2 288	– 5 %	2 270	1 813	– 20 %
Total other	4 931	2 748	2 695	– 2 %	2 697	2 480	– 8 %
Total	**21 705**	**11 852**	**11 669**	**– 2 %**	**10 681**	**9 905**	**– 7 %**

5.6.2. The impacts of the Auto-Oil II road transport scenario

A further test explores the sensitivity of environmental impacts if, instead of the ShAIR base case emission, the base case of the Second European Auto-Oil Programme (AOP II, 1999) were assumed. Tables 5.32 and 5.33 show the differences in the environmental indicators of the two scenarios to be fairly small. For the EU-15 the acidification indicator (area of unprotected ecosystems) of the Auto-Oil II emission estimate is 0.9 % lower than if the ShAIR emissions are assumed, suggesting additional protection of 0.03 % of the ecosystems area. For eutrophication Auto-Oil estimates this would imply additional protection to 1.4 % of the ecosystems. The 2010 indicators for ozone are lower by 4 % (AOT60) and 3 % (AOT40), or by about 1.5 % if related to the base year (1990). Differences also occur in non-EU countries; while in percentage terms the numbers sometimes appear as quite significant, the absolute change is small because of the already low values of indicators in the ShAIR scenario.

Although for some countries the relative differences between the abated emissions for 2010 calculated by RAINS for the ShAIR scenario and the emissions from the Auto-Oil II study are significant, it can be concluded that these differences are small if compared with total national emissions from the base year (1990). Thus the improvement in environmental indicators calculated on the European scale for the two scenarios does not dramatically differ. This means that the assessment done by RAINS on environmental impacts of future scenarios is quite robust.

Nevertheless, in future it would be useful to improve the consistency between the models of road transport emissions and RAINS. Within the current study only aggregated results and indicators from RAINS and Tremove could be compared. In the future a more detailed comparison and harmonisation of both models should be carried out to better coordinate assumptions and technological parameters in the models. In particular, the Tremove database should be improved to better reproduce fuel consumption for historical years. In turn, results of the Tremove runs could be aggregated into the categories used by RAINS, so that more accurate emission factors could be used by the RAINS model. Large uncertainties are also associated with the estimates of emissions from off-road transport. Here, methods similar to those currently applied for road transport would help to narrow the information gap. More such in-depth analysis and linking of the models should be the subject of a separate project.

Table 5.32. **Comparison of acidification and eutrophication indices between ShAIR and Auto-Oil II (AOP II) scenarios for 2010**

Country	Ecosystems not protected, 1 000 hectares					
	Acidification			Eutrophication		
	ShAIR	AOP II	% change	ShAIR	AOP II	% change
Total EU-15	5 101	5 056	– 0.9 %	46 806	46 147	– 1.4 %
Total accession	1 256	1 240	– 1.3 %	26 193	25 747	– 1.7 %
Total other	7 602	7 583	– 0.2 %	33 219	32 965	– 0.8 %
Total	**13 958**	**13 874**	**– 0.6 %**	**106 221**	**104 858**	**– 1.3 %**

Comparison of ozone exposure indices between ShAIR and Auto-Oil II (AOP II) scenarios for 2010 — Table 5.33.

Country	Cumulative ozone exposure indices					
	AOT60 (million person.ppm.hours)			AOT40 (thousand km^2.excess ppm.hours)		
	ShAIR	AOP II	% change	ShAIR	AOP II	% change
Total EU-15	386	370	– 4.1 %	6 708	6 510	– 3.0 %
Total accession	56	54	– 3.6 %	2 399	2 359	– 1.7 %
Total other	17	17	0.0 %	2 748	2 718	– 1.1 %
Total	**459**	**441**	**– 3.9 %**	**11 852**	**11 585**	**– 2.3%**

5.7. Conclusions

In the ShAIR scenario, emissions will significantly decline in the future. Up to 2020 emissions of sulphur dioxide in Europe are likely to be reduced by 73 % compared with 1990, emissions of nitrogen oxides by 44 %, emissions of non-methane volatile organic compounds by 38 % and emissions of PM_{10} by about 60 %. Ammonia emissions are expected to decrease by 18 %. For the EU-15, expected cuts are 80 % for SO_2, 60 % for NO_x, 54 %, for VOCs and 15 % for NH_3. Since environmental legislation assumed in the scenario needs to be enforced until 2010, a large proportion of this reduction occurs already in 2010. Further reductions up to 2020 are caused by better penetration of control technologies due to the turnover of capital stock, as well as to structural changes in energy systems (e.g. switching to cleaner fuels).

Current policies form an important step towards achieving environmental sustainability for acidification, eutrophication and tropospheric ozone. Reduction in environmental pressures (emissions) causes a substantial reduction in ecosystem impacts. The area of ecosystems in Europe that is not protected against acidification will decrease from 16 % in 1990 to less than 2 % in 2020. The corresponding reduction for the EU-15 countries is from 25 % of ecosystems not protected in 1990 to only 2.9 % in 2020. Lower deposition of nutrient nitrogen means that the area of European ecosystems threatened by eutrophication decreases from 31 % to 19 % (in the EU-15 from 56 % to 36 %). A health-related ozone indicator (AOT60) improves by 75 % compared with 1990. Finally, the vegetation-related excess ozone indicator (AOT40) improves by about 50 %.

The study demonstrates that despite different assumptions about the development of energy and transport systems, the expected improvements in environmental impacts are associated with much smaller uncertainties, especially in the short term (up to 2010).

An anticipated extension of EU environmental legislation to the accession countries will play a decisive role for future emission levels. This is of particular importance for emissions from road transport because of the large expected increase of private transport and the relatively liberal current emission standards for mobile sources in many of the accession countries. The emission reductions in the accession countries also have a positive impact on the present EU Member States.

Whereas the indicators for acidification and ozone are expected to substantially improve, eutrophication will remain a problem even after 2020. This is due to the limited controls on ammonia emissions. According to the calculations, in 2020 more than 50 % of nitrogen deposition in Europe will originate from ammonia emissions. Thus in the future work should concentrate on trying to control ammonia emissions, either by technical or structural means.

Further progress towards environmental sustainability in Europe can be achieved through:

- Continued restructuring of economic and energy systems, leading to lower energy intensities and increased use of cleaner fuels. Important synergistic effects can be expected from implementing climate change control policies. The necessity of reaching emission ceilings for climate-relevant gases will induce changes in the structure of energy supplies towards renewable energy forms, thus limiting too the emissions of gases contributing to regional air pollution.

- Approximation of emission control legislation in the countries of central and eastern Europe (where present emission standards are either missing or liberal) to those of the European Union. This will bring environmental benefits, not only within the countries that implement stricter standards, but also to help achieve the environmental targets of the EU-15.

- Implementation of additional emission control measures in ‘hot spots’, even in countries with strict standards.

- Further reduction of ammonia emissions in Europe to reduce the threat of eutrophication, e.g. by changes in the distribution and the number of livestock and by rethinking agricultural practices.

6. Urban air quality

6.1. Introduction

Within the Auto-Oil II Programme (AOP II), the European topic centres on air emissions (ETC-AE) and air quality (ETC-AQ) have developed an infrastructure for modelling urban air quality. This approach, called generalised exposure assessment (GEA), is based on relatively simple atmospheric dispersion models, which enable model applications to a large set of urban agglomerations (typically 200–300 cities) (de Leeuw *et al.,* 2001a and b). The goal of GEA is to estimate the fraction of the urban population living in European cities whose air quality is not in compliance with air quality guidelines for the future and to estimate additional emission reductions needed to reach compliance. In the GEA approach, simple robust tools are used to calculate, in a consistent way, air quality in a relatively large number of cities. The consistency allows for a generalisation of the results on the continental scale.

The set of modelled cities has been extended to include cities in European Environment Agency (EEA) member countries and in accession countries.

6.2. Methodology

6.2.1. Indicators for urban air quality

Several endpoints for evaluating the results can be defined in a sensitivity analysis of urban air quality:

- Compliance with air quality guidelines. The air quality guidelines used in this study are all related to the protection of human health; they are based on adopted or proposed daughter directives (EC, 1999d and e).
- Population exposure. Population exposure can be expressed in several ways, giving emphasis to different features of exceedances. The simplest way is to calculate the number of inhabitants exposed to concentrations above guidelines. For evaluating the extent of exceedance of environmental guidelines, the *population exposure above a threshold (PET)* is defined as:

  $$PET = \sum_{n=1}^{N_{city}} \sum_{i=1}^{E_n} \left(C_{i,n} - T\right) pop_n$$

  where $C_{i,n}$ is the concentration in excess of the threshold value T in city n during exceedance i; N_{city} is the number of cities where an exceedance is calculated; E_n is the number of exceedances; and pop_n is the population of city n. PET is expressed in persons x micrograms per cubic metre (µg/m^3). PET values are largely determined by concentrations in the upper tail of the frequency distribution.
- Impact on human health. A quantitative estimate of the impact on human health can be based on the calculation of the attributable proportion (Krzyzanowski, 1997). This indicates the fraction of the health outcome that can be attributed to the exposure in a given population (provided that there is a causal association between the exposure and the health outcome). Relative risk estimates for daily mortality associated with sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) exposure are taken from the updated WHO *Air quality guidelines for Europe* (WHO, 1997). For both components a no-health-effect threshold value of 10 µg/m^3 is assumed. In contrast to the PET value, almost the full concentration frequency distribution contributes to the excess rate.

6.2.2. Air pollution models

In the AOP II GEA study, three air pollution models have been used for the calculation of air quality parameters from urban emissions. These are:

- The cQ model (Olsthoorn *et al.,* 1999) for 'inert' species, where sufficient monitoring data were available, i.e. nitrogen oxides (NO_x)/NO_2, SO_2 and respirable particulate matter with aerodynamic diameter between 2.5 and 10 micrometres (PM_{10}).
- The UAQAM model (van Pul *et al.,* 1996) for 'inert' species in all cities, i.e. NO_x/NO_2, SO_2 and PM_{10}, lead (Pb), carbon monoxide (CO) and benzene.
- The OFIS model (Sahm and Moussiopoulos, 1999), which was applied to calculate ozone concentrations for a limited number of cities.

In the present study an updated and improved version of the OFIS model (Moussiopoulos and Sahm, 1998) is applied to assess urban ozone levels in numerous large European cities. Compared to the model version used for the needs of *Environment in the European Union at the turn of the century* (EEA 1999a, hereafter referred to as the EEUTC report) this updated version takes into account local circulation systems (such as sea breeze in coastal areas) and emissions from neighbouring cities, based on data derived from the Corinair 90 database of the EEA/ETC-AE (EEA, 1996a). Moreover, background boundary layer concentrations are computed with a 20-layer box model embedded in OFIS, instead of the 3-layer box model that was used in the previous model version.

The UAQAM model has been extended with a procedure to estimate a health indicator (see below). In comparison to the AOP II applications, the meteorological database used has been improved and extended. In the current application, the cQ model has not been included.

All models calculate the contribution to the urban background concentrations resulting from the local, urban emissions. The regional background contributions from emissions outside the urban area considered were derived from the EMEP (cooperative programme for monitoring and evaluation of long-range transmission of air pollutants in Europe) acidifying (Tsyro, 1998) and photochemical model (Simpson, 1992 and 1993) or from the TREND model (van Jaarsveld, 1995). In UAQAM simulations daily concentrations obtained from the routine applications of the EMEP lagrangian model are used for the years, 1991–95. Concentrations for the reference years 2010 and 2020 are estimated using a reduction factor calculated at a national level from the published SO_x and NO_x source-receptor matrices. The OFIS simulations were performed for about 180 individual days with meteorological conditions as in period 1 (April–30 September 1990). For this period, meteorological data and EMEP model results (regional background concentrations) are available at a spatial resolution of 150 kilometres (km) and a temporal resolution of six hours. The EMEP results refer to the emission situation in 1990 and the one projected for 2010 using the AOP II emission scenario.

Although in regional and urban modelling the emission information is prepared consistently (see above), the urban air quality is not linked directly with the air quality part of the RAINS model.

6.2.3. Selection of cities

The selection of cities used in the Auto-Oil II Programme yielded 192 conurbations in the 15 Member States of the European Union. For the ShAIR scenario this set has been extended with cities in EEA member states and in accession countries with more than 100 000 inhabitants (UN, 1997), since violation of air quality guidelines is primarily expected in larger conurbations with a high emission density. In each country at least one city is selected. The final list contains 309 conurbations in 30 countries, with a total population of 146 million inhabitants. An overview of selected cities is presented in Table 6.1.

The built-up area of the selected cities has been estimated by a procedure developed by the European topic centre on land cover (ETC-LC, 1997), using detailed land-use and land-cover information.

Table 6.1.

Number of cities, total urban population and percentage of national population per country; data on national population obtained from UN Statistical Division

	No of cities	Urban pop. (million)	% of total		No of cities	Urban pop. (million)	% of total
Austria	6	2.332	29	Bulgaria	10	2.942	35
Belgium	6	2.763	27	Cyprus	2	0.335	45
Denmark	5	2.043	39	Czech Republic	8	2.510	24
Germany	51	21.272	26	Estonia	2	0.555	38
Finland	3	1.268	25	Hungary	9	3.162	31
France	34	21.368	36	Iceland	1	0.153	57
Greece	2	3.822	36	Latvia	3	1.071	43
Ireland	1	0.916	25	Liechtenstein	1	0.005	16
Italy	22	11.020	19	Lithuania	5	1.487	40
Luxembourg	1	0.076	18	Malta	1	0.014	4
Netherlands	11	5.034	32	Norway	4	1.219	28
Portugal	3	2.936	30	Poland	42	11.606	30
Spain	15	11.030	28	Romania	25	7.125	32
Sweden	9	2.111	24	Slovakia	2	0.691	13
United Kingdom	23	24.624	42	Slovenia	2	0.411	21
				Total	309	145.901	30

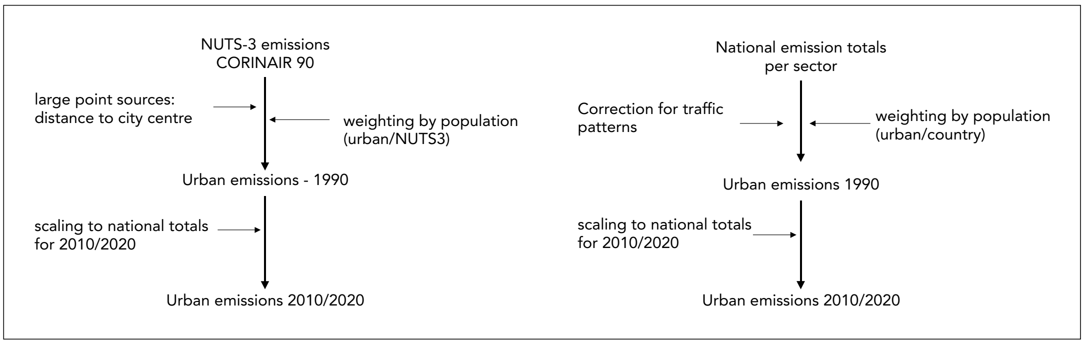
Source: UN, 1999.

6.3. Urban emissions

Urban emissions were estimated by downscaling emission totals at the highest level of geographical details (EEA, 1996b). While this simple procedure is clearly approximate, it offers the advantage of providing comparable emissions for all cities. As the geographical details differ for European Union (EU) Member States and non-EU countries, two approaches have been used.

Figure 6.2.

Schematic data flow in estimating urban emissions; left: EU Member States, right: non-EU countries



For the EU Member States detailed information on emissions is available from Corinair-90 at a NUTS3 administrative level and at a SNAP1 sector level for SO_2, NO_x, CO and volatile organic compounds (VOCs) (EEA,1996a). This includes detailed information on large point sources. The top-down approach is different for large point sources than for low-level area sources. Large point sources with known coordinates were allocated to a city if their distance to the city centre was less than the radius of the city. For area sources, the top-down approach involved scaling of NUTS3 emission estimates to a local level through the use of indicators dealing with proportion of a particular activity occurring in the specified local area. In the current application, the population was used as a proxy for the statistical indicator for all sectors. Total urban emissions are obtained by summing the area and point-source emissions.

In non-EU countries emissions are available only at a national level. Information on individual point sources is not available. Downscaling is therefore based on national totals instead of NUTS3 totals.

Emissions from agriculture and natural areas were assumed to occur in rural areas only so were excluded from the urban emissions.

A schematic overview of the procedures is given in Figure 6.2. The Corinair information and traffic correction factors were delivered by the European topic centre on air emissions (ETC-AE). For traffic-induced pollutants, the approach guarantees a consistent set of emission inputs, both to the regional dispersion model and the urban models. Substantial improvements in estimating urban emissions can be made by preparing a more recent inventory at a NUTS3 or corresponding geographical level of detail. The use of population numbers as proxy variable might not be correct for all sectors and needs reconsideration.

In addition to urban SO_2, NO_2 and VOC emissions, the OFIS model used to model urban ozone levels requires urban CO emissions. Estimates were made using Auto-Oil II data for EU Member States; for non-EU countries a combination of information submitted to the EMEP steering body (September 2000) and educated guesses were used. This crude, inconsistent approach is acceptable as long as one is interested in urban ozone levels. Urban ozone is not expected to be very sensitive to variations in urban CO emissions. However, the assumption underlying the set of urban CO emissions prepared here differs too much from the ShAIR scenario assumptions to allow for modelling of urban CO concentrations. The results of the Auto-Oil II Programme (de Leeuw *et al.*, 2001a and b) indicate that exposure of the urban population to CO will, at least in EU-15 cities, become a minor problem in the foreseeable future.

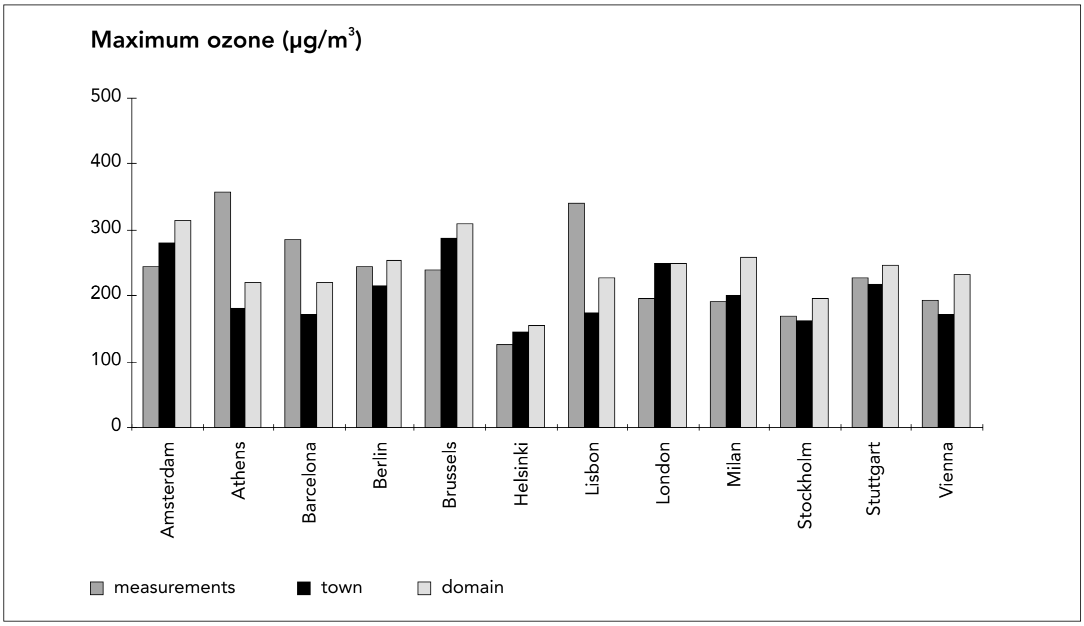
6.4. Urban air quality

6.4.1. Urban ozone

Figures 6.3 and 6.4 show the measured and computed maximum hourly and six-month averaged ozone concentrations in the year 1990 for all cities for which measurements were available (data taken from EEA, 1998, and Airbase). Since the observational data sources do not clarify the characteristics of the measurement location, both figures contain OFIS results valid for the urban area (middle bar) and the whole domain (right bar). With the exception of Athens and Lisbon, re the maximum ozone values, and Milan, re the six-month averaged ozone concentrations, the agreement between the model results and observations is satisfactory.

For the years 2010 and 2020 the OFIS model was applied for the meteorological conditions of 1990 and regional background concentrations based on EMEP model results valid for the year 2010 (corresponding results for 2020 were not available).

Figure 6.3. **Measured and computed maximum hourly ozone concentrations in 1990**



Measured and computed six-month averaged ozone concentrations in 1990 — Figure 6.4.

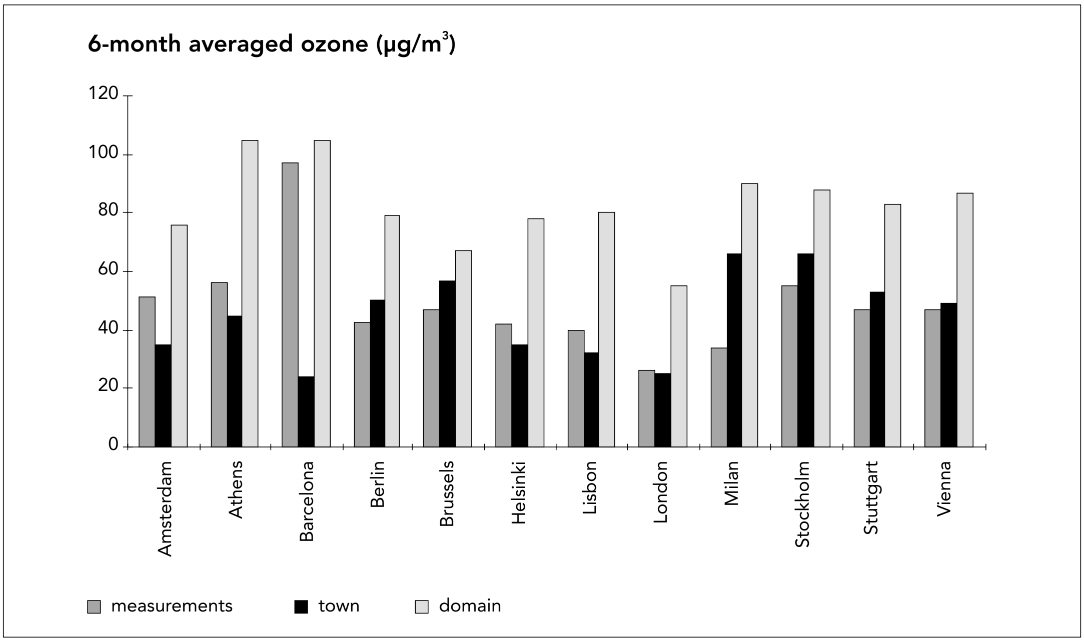


Figure 6.5 shows the calculated maximum ozone concentrations for the years 1990, 2010 and 2020. With the exception of Rome, the situation appears to be improved in 2010 for all cities examined. The maximum ozone levels are reduced by more than 15% in the collection of cities, while reductions of the order of 25 % are computed for Berlin, Brussels, Dublin, Lyon, Marseilles and Paris. Maximum ozone levels are reduced even in Amsterdam, Madrid and Vienna, i.e. in cities for which an ozone increase was indicated by the results included in the EEUTC report.

Computed maximum ozone concentrations for 1990, 2010 and 2020 (the latter based on regional background concentrations valid for 2010) — Figure 6.5.

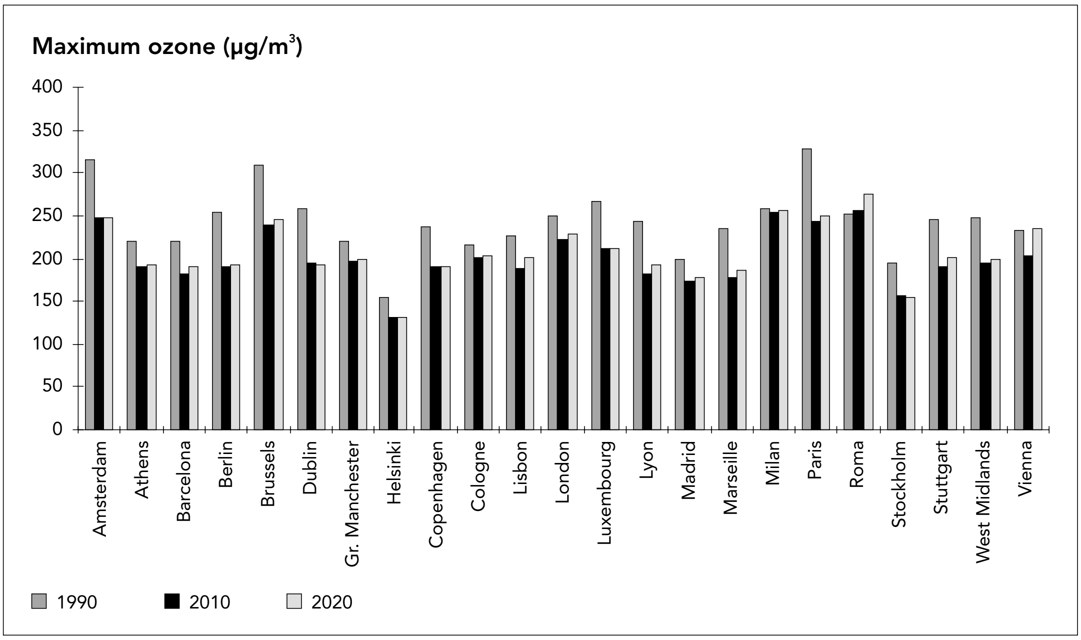


Figure 6.6. **Computed six-month averaged AOT60 values for 1990, 2010 and 2020 (the latter based on regional background concentrations valid for 2010)**

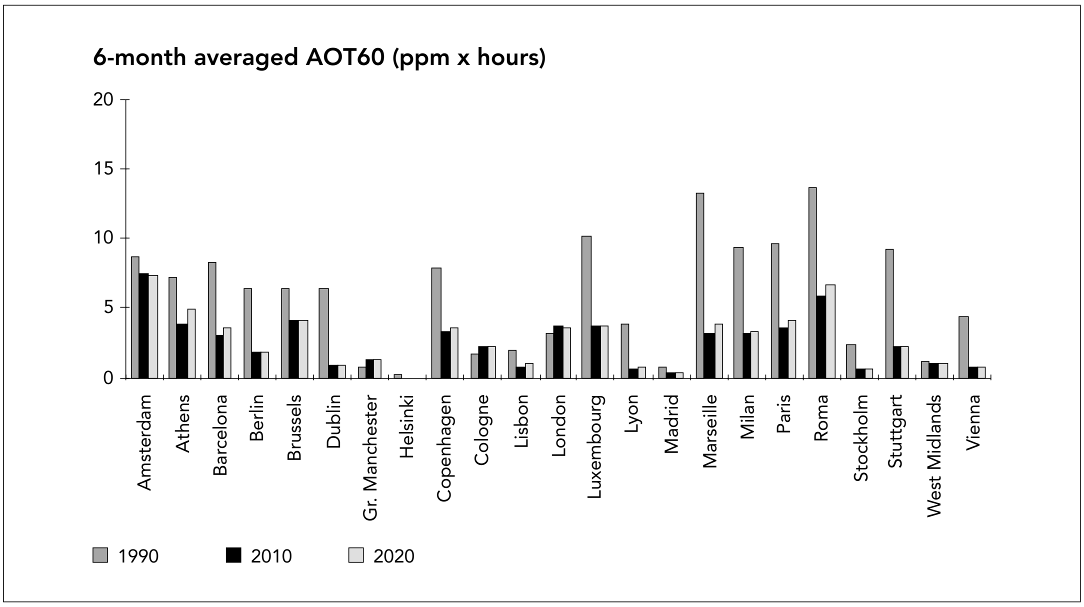


Figure 6.6 shows the domain averaged AOT60 values calculated with OFIS for meteorological conditions as for the period of 1 April–30 September 1990 and the 1990, 2010 and 2020 emission scenarios (in the latter case assuming regional background concentrations as in 2010). With regard to AOT60, the impact of emission reductions in 2010 appears to be significant. Reductions ranging from 20 % (for Amsterdam) to 85 % (for Dublin) are expected for the collection of cities. AOT60 values are found to increase only in Greater Manchester, Cologne and London, i.e. in cities with rather low 1990 values.

The projections for 2020 lead to only minor changes of the urban ozone concentrations compared with the situation in 2010. This result implies that a noticeable urban ozone decrease in the period 2010–20 can only be associated with favourable changes in the regional scale emission pattern.

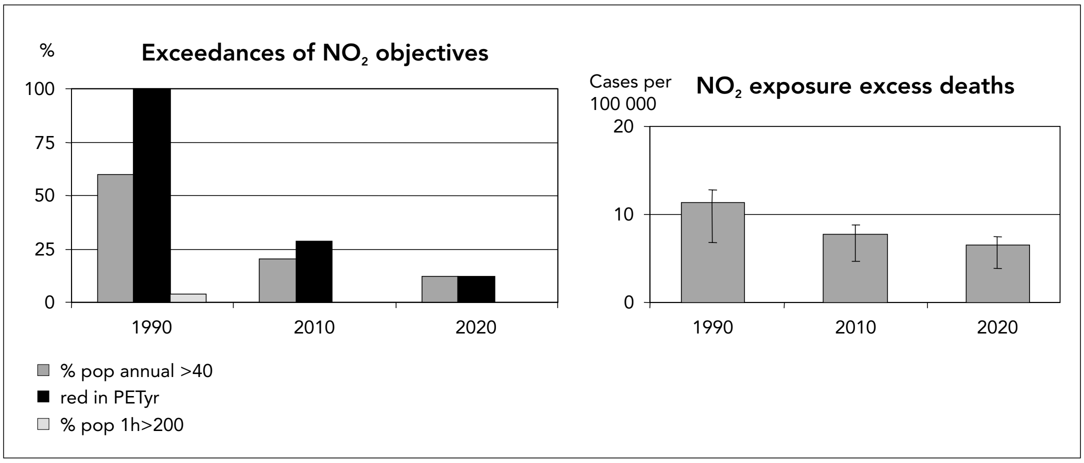
6.4.2. SO_2 and NO_2

The NO_2 concentrations have been strongly reduced for 2010 and 2020 (see Figure 6.7). For the period 1990–2020, the reduction in urban NO_2 concentrations (annual mean) is, averaged over all the cities, about 12 µg/m^3. The number of cities with an annual background concentration in excess of 40 µg/m^3 decreases from 124 (covering about 60 % of the population) in 1990 to 30 (12 % of the population) in 2020. The short-term guideline (less than 18 times exceedance of a one-hour concentration of 200 µg/m^3) was exceeded in two Spanish cities in 1990. Violation of this guideline is not expected in 2010 and 2020. The number of excess deaths attributed to NO_2 exposure shows a decrease from 11.3 to 6.5 cases per 100 000 over the 1990–2020 period.

The SO_2 calculations show large reductions in ambient concentrations in urban areas (Figure 6.8). In 1990, SO_2 exposure was a severe problem in eastern Europe: in 92 out of the 108 modelled cities the daily objective was exceeded. In 2020 both the number of cities and the exposed fraction of the population is strongly reduced, but the major problems with SO_2 exposure are still found in eastern Europe. In a limited number of cities a deterioration of air quality is modelled between 2010 and 2020. Although total emissions at national level are decreasing, there is an absolute increase in emissions from traffic and domestic heating (see, for example, Bulgaria). These low-level sources have a larger contribution to urban concentrations than the high-level industrial sources. With respect to exceedances of the guideline for hourly concentrations, similar conclusions can be drawn. In general terms, one can state that compliance with the guideline for daily values forms the binding factor in required emission reductions.

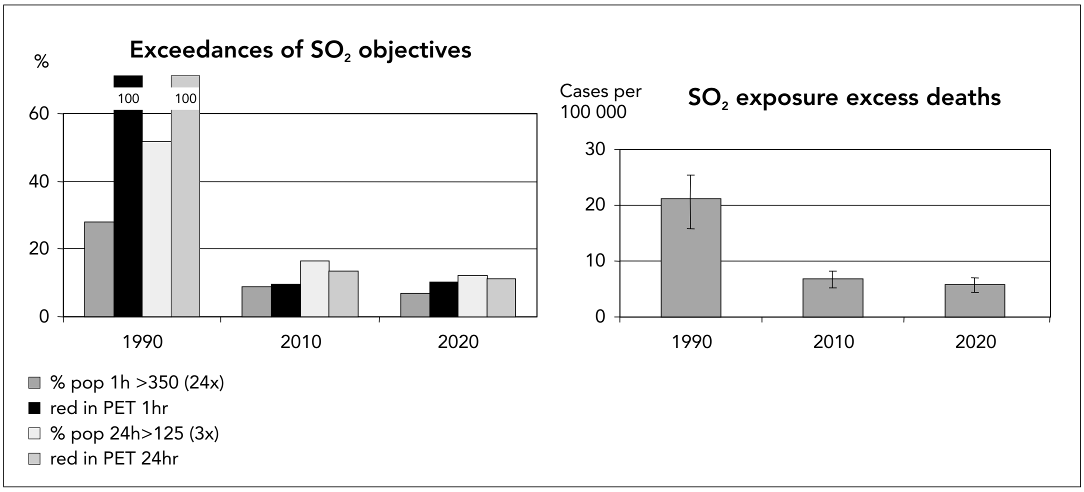
Left: Percentage of urban population living in cities where the annual mean NO_2 concentration is above 40 mg/m^3 or where the one-hour guideline is violated, with the scaled reduction in PET values for annual mean. Right: estimated number of excess deaths per 100 000 inhabitants attributed to NO_2 exposure

Figure 6.7.



Left: Percentage of urban population living in cities where the hourly or daily SO_2 guideline is violated, with the scaled reduction in PET values (1990 is set to 100 %) for hourly and daily concentrations. Right: estimated number of excess deaths per 100 000 inhabitants attributed to SO_2 exposure

Figure 6.8.



6.5. Comparison with previous studies

In Figures 6.9 and 6.10 the maximum and six-month averaged ozone concentrations obtained in ShAIR are compared with corresponding values calculated in the framework of the EEUTC study. According to these figures, slightly higher values are computed for most of the cities in our study (differences are 20 %), the difference being significant only in the case of Amsterdam (higher than 40 %). For only a few of the cities, notably Milan, Paris and Stuttgart, did our study results lead to lower urban ozone concentrations compared to the simulations performed for the needs of the EEUTC report.

The main reason for the above differences is the use of a different source for city emissions. To what extent the use of the new OFIS version may have had an influence on these differences is not yet entirely clear, but there can be no doubt that the role of the model version in this context is less important. In any case, the updated version of OFIS and the new city emission data are found to lead to much smaller deviations between measured and computed urban ozone values.

Figure 6.9. **EEUTC results for maximum ozone concentrations compared with corresponding values computed with the improved version of the OFIS model and the new emission estimates for 1990**

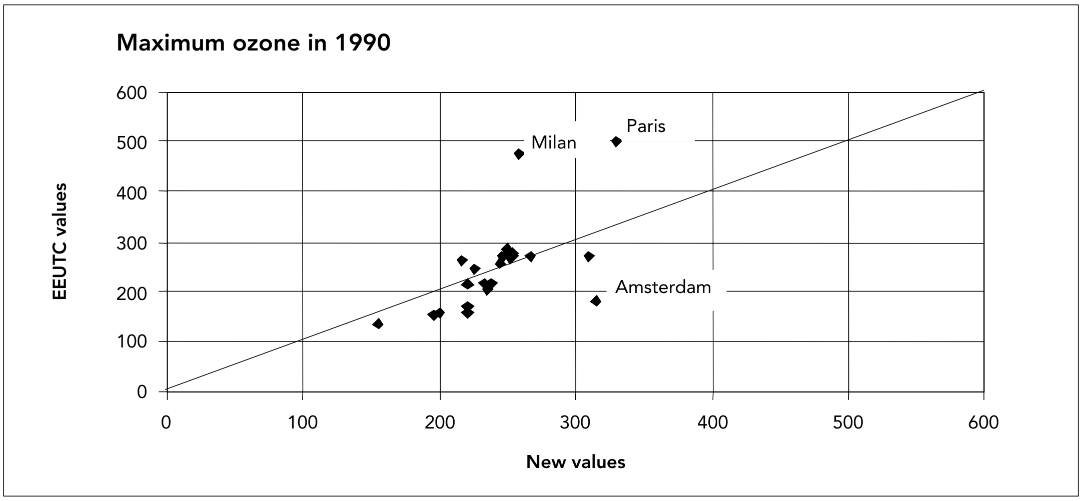
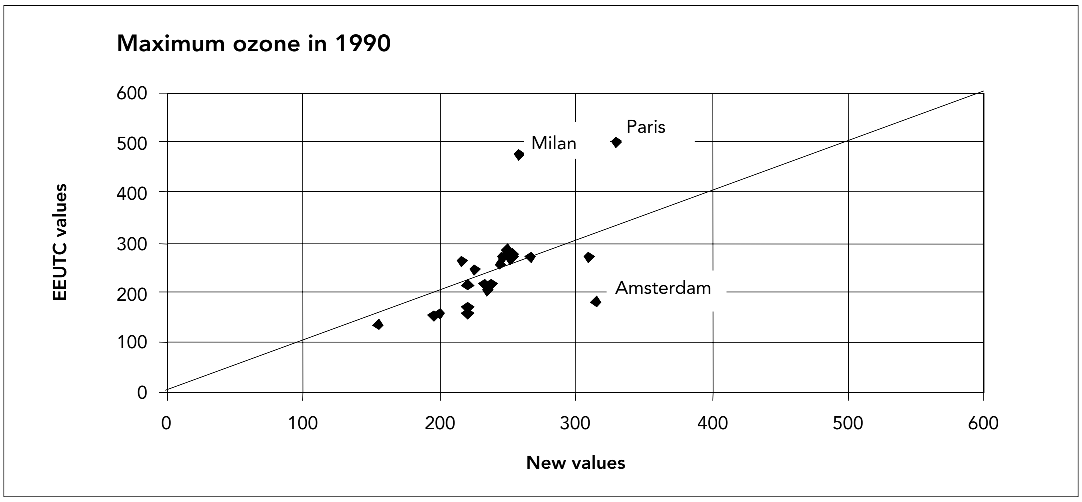
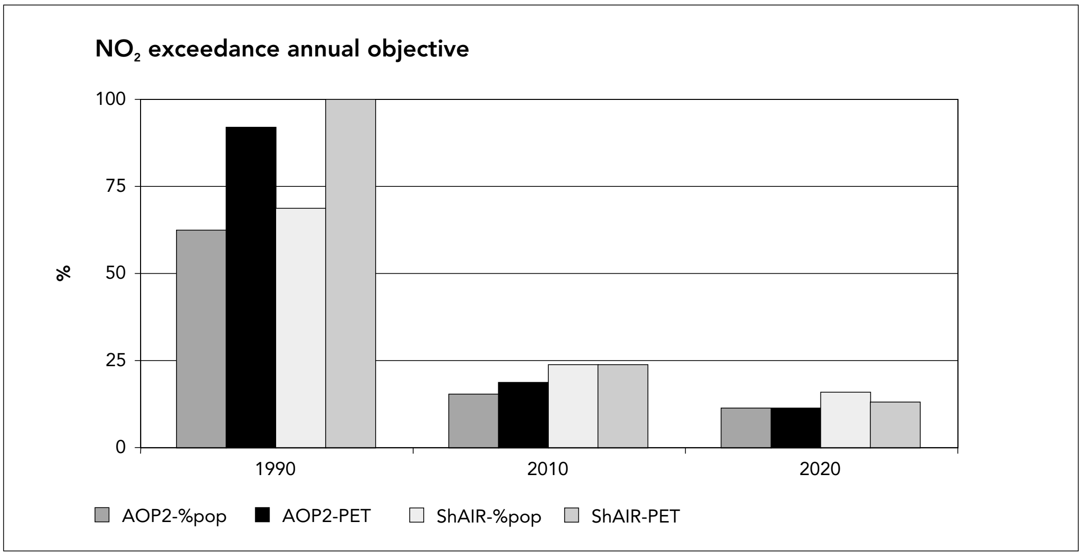


Figure 6.10. **EEUTC results for six-month averaged ozone concentrations compared to corresponding values computed with the improved version of the OFIS model and the new emission estimates for 1990**



For most of the cities examined the above projections for urban ozone values in 2010 are higher compared to the results included in the EEUTC report. Generally, the differences are of the order of 20 %. Being consistent with the trend identified in the discussion of the results for 1990, this finding underlines the importance of using adequate input data for reliable urban air quality assessments.

Figure 6.11. **Comparison between modelled NO_2 concentrations for AOP II and ShAIR baselines for the cities within the EU-15. The PET (person.mg/m³) values have been scaled to the 1990 ShAIR values (= 100 %)**



NO_x emissions estimated for the ShAIR scenario are higher than previous estimates made within the Auto-Oil II Programme (see Chapter 5). The modelled concentrations mimic the differences in emissions in both the scenarios. Following the ShAIR scenario a slightly larger fraction of the population is exposed to annual mean concentrations above 40 µg/m³ and a slightly higher PET value is found. In both scenarios, it is estimated that in 2010 and 2020 all cities will be in compliance with the air quality guideline for hourly concentrations. A summary of the comparison of NO_2 results is presented in Figure 6.11. Note that this comparison is limited to cities in the EU-15 only. Taking account of all cities, including those which are in compliance, results in a difference of about 3–5 % for annual mean NO_2 concentrations in both baselines.

6.6. Sensitivity analysis

6.6.1. Spatial variation within urban areas

One of the simplifications in the UAQAM model is that only a city-wide averaged concentration is calculated. Even if we exclude street-level concentrations from the evaluation, variations in ambient concentration levels of about 20–40 % are expected over the urban area (Lebret *et al.,* 2000; Fisher and Newlands, 2000). When the difference between threshold value and averaged urban background concentration is small, the assumption of one constant concentration may either over- or under-estimate the non-compliance area. To evaluate the sensitivity to the variation within the urban area, calculations were made assuming that the urban contributions would follow a gaussian distribution over the city. At the city edge a minimum concentration was assumed of 0.75 times the average urban contribution to concentration, with in the centre a maximum factor of 1.3. If a uniform population density is further assumed, the fraction of the urban population exposed to concentration above the threshold can be evaluated.

Application of this method on the one-hour guideline for NO_2 shows that a substantial larger number of cities (19 versus 2) is not in compliance with the reference year, 1990; the proportion of the exposed population is, however, very similar: 3.6 % versus 3.8 % in the reference calculation. Assuming a spatial variation, the outlook for 2010 and 2020 results in small violations of this guideline (0.4 and 0.0 % of the population, respectively).

For the NO_2 guideline on an annual base, a similar pattern is shown: the number of cities which are (partly) not in compliance with the guideline increases but the exposed population decreases (see Table 6.2). Similar results are obtained when analysing exceedances of the guideline for daily SO_2 concentrations. The consequences for emission reductions required to meet the target are not yet clear.

Table 6.2. **Number of cities that are (partly) not in compliance with the air quality guidelines and percentage of total modelled population living in the non-compliance cities. Results for reference situation and assuming a spatial concentration distribution over the city. Top: guideline for NO_2 annual mean; bottom: guideline for SO_2 daily mean**

NO_2	Number of cities		Percentage of population exposed	
Year	Reference	Variable	Reference	Variable
1990	124	200	59.7	43.5
2010	42	93	20.6	15.1
2020	30	79	12.4	8.2
SO_2				
Year	Reference	Variable	Reference	Variable
1990	135	173	51.7	36.0
2010	51	77	16.4	10.8
2020	42	55	12.3	8.3

6.6.2. Meteorological variation

It is evident that air pollution concentrations depend on the meteorological dispersion conditions. In particular, it is the upper tail of the concentration frequency distribution that shows relatively large sensitivity. In AOP II the inter-annual variability was estimated at about 6 % for SO_2 concentration annual mean values and about 10 % for the 98-percentile values.

For the ShAIR scenario NO_2 calculations were made for 2010 emissions using actual meteorological conditions for the years 1991–95. The results show that conclusions on exceedance of the one-hour air quality guideline do not depend at all on the meteorological situation: estimated urban concentrations are so far below the threshold value that even under worst dispersion conditions exceedance is modelled only incidentally. As 18 exceedances per year are permitted for the one-hour guideline, there is no violation of the guideline modelled.

In selecting exceedance of the annual guideline as the evaluation criterion, it is shown that the number of non-compliance cities varies between 42 and 48 (corresponding range in population is 20.7 to 22.2 %). The model runs suggests that overall, 1991 is the year with the worst and 1995 the year with the best dispersion conditions. However, a more in-depth analysis shows that this conclusion is not valid at a city level.

A second example of the large variation introduced by different meteorological conditions can be illustrated with a calculation of SO_2. As can be seen from the results presented above, compliance with the daily mean concentration guideline will lead to the most stringent requirements on emission reduction. For the reference year 2010 we have made a first-order estimate for each city of the emission reduction which must be in compliance with the air quality guideline. In estimating the emission reduction, only the local urban contribution has been considered; the impact of emission reduction on neighbouring cities has not been considered. Therefore the reductions presented here are only indicative. Required emission reductions are calculated using meteorological data for the years 1991–95. In Figure 6.12 the cities are ranked according to the averaged required reduction; the minimum and maximum required reduction in this five-year period is shown as well. Three groups of cities can be identified. In the first group of about 240 cities, the guideline is met, even under the worst dispersion condition. In the third group (about 20 cities), the guideline is largely exceeded and a sharp reduction is required, irrespective of the meteorological conditions. In the second group (about 50 cities), the concentration levels are just above or below the guideline. Accidental meteorological conditions lead to relatively large variations in the required reductions.

In optimisation studies the required emission reduction may vary highly, depending on the selected meteorological year. It is therefore recommended that multiannual dispersion calculations are used in this type of study.

Figure 6.12. **Estimated reduction in urban SO_2 emission required to meet the air quality guideline for the daily mean calculated using emission conditions for 2010 and meteorological conditions for the five-year period 1991–95. Cities are ranked according to the required averaged reduction, the range in required reduction calculated for the individual meteorological years is plotted as well**

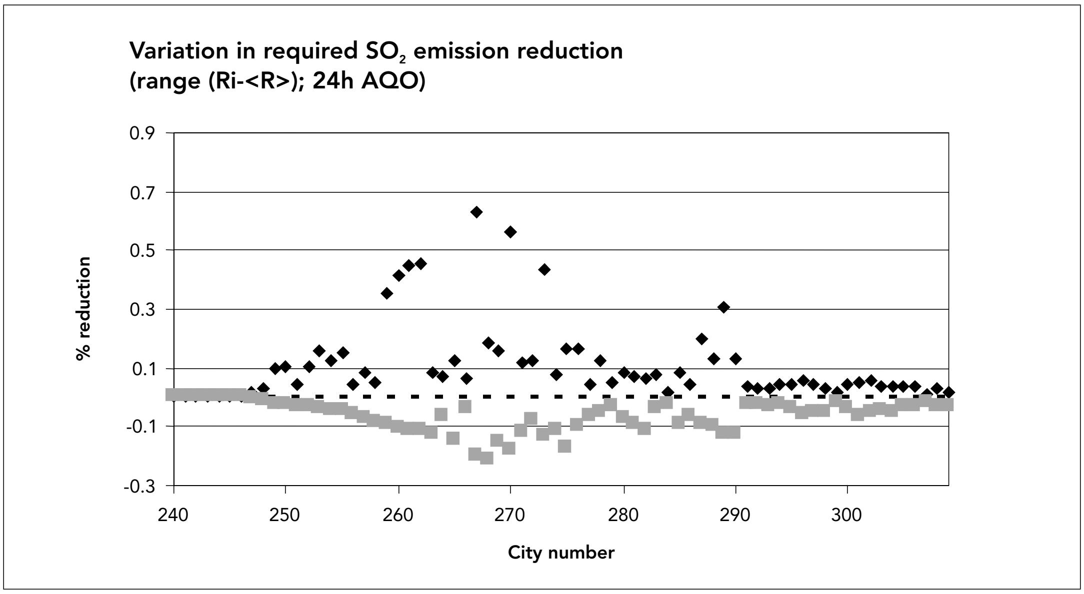


Table 6.3. **Influence of meteorological input data uncertainties on the uncertainty of various 'target output' values (TOV), characterising the ozone levels in Stuttgart and Athens (Max: maximum exceedance days, Ave: average exceedance days, 8hmax: maximum 8-hour ozone concentration, Cex: averaged concentration on days showing exceedance)**

Symbol	O	↗	↑	**⬆**	↘	↓	**⬇**
Difference	±5%	+5% to +20%	+20% to +50%	> +50%	-5% to -20%	-20% to -50%	< -50%

TOV	Area considered	Stuttgart	Speed -10%	Speed +10%	Dir -45°	Dir +45°	Athens	Speed -10%	Speed +10%	Dir -45°	Dir +45°
Max	domain	71 days	↗	O	O	O	110 days	↗	O	O	↗
	urban	52 days	O	O	O	↘	43 days	↗	↘	O	↘
Ave	domain	60 days	↗	O	O	O	65 days	↗	↘	O	O
	urban	42 days	O	O	↘	↘	17 days	↗	↘	↑	↓
8hmax	domain	274 $\mu g/m^3$	O	O	O	O	438 $\mu g/m^3$	O	O	↘	O
	urban	222 $\mu g/m^3$	O	O	O	O	236 $\mu g/m^3$	↗	↘	↑	O
Cex	domain	154 $\mu g/m^3$	O	O	O	O	140 $\mu g/m^3$	O	O	O	O
	urban	149 $\mu g/m^3$	O	O	O	O	152 $\mu g/m^3$	O	↘	↗	O

The effect of uncertainties in meteorological data on ozone production has been studied by comparing predicted differences in the 'target output' values for the cities of Athens and Stuttgart (Moussiopoulos *et al.*, 2000). Emission and meteorological data for 1990 have been used in the reference calculation. In the sensitivity calculation wind velocity was changed by ± 10 % and wind direction by ± 45°. The sensitivity of the 'target output' values is shown in Table 6.3, separated for the whole domain and the urban area, respectively. While a 10 % variation in the wind speed does not appear to have a noticeable effect on the 'target output' values in Stuttgart, differences emerge in the case of Athens. Although most of the air pollution episodes in the Greater Athens area are associated with the development of a sea breeze, the situation is probably even worse in the case of stagnant conditions (i.e. a critical balance between synoptic and mesoscale circulations). Consequently, an increase in wind speed leads to lower 'target output' values, whereas a decrease in wind speed leads to a higher ozone burden. In general, the variation of the wind direction has only a marginal effect on the 'target output' values in Stuttgart. Differences occur mostly due to the fact that different urban areas upwind of the city were taken into account, depending on the changes in the prevailing wind direction. The picture is different in Athens, since different days with sea breeze now occur due to changes in the wind direction and have their strongest impact in the ozone exceedance days averaged over the urban area.

The effect of uncertainties in initial and boundary concentrations on ozone production has been studied by comparing predicted differences in the 'target output' values. Initial and boundary concentrations were varied with ± 10 % for ozone and NO_2 and with ± 50 % for VOCs. The sensitivities of the 'target output' values are shown in Table 6.4 separated into the whole domain and the urban area, respectively. In general, the variation of the boundary concentrations has only a marginal effect on the maximum 8-hour mean ozone concentration and the averaged concentration on exceedance days. However, decreasing the ozone boundary concentration by 10 % lowered the exceedance days by 10 % in Stuttgart and 20–40 % in Athens, whereas an increase of 10 % led to considerably higher days of exceedance (more than 50 % in the case of Athens). The response to the change in NO_x boundary concentrations is marginal in the case of Stuttgart and remains low (of the order of 10 %) in the case of Athens. Simulations using the VOC boundary concentrations varying by ± 50 % show a similar pattern to the variations in boundary ozone.

Table 6.4. **Similar to table 6.3, but shows boundary concentration input data**

Symbol	O	↗	↑	**↑**	↘	↓	**↓**
Difference	±5%	+5% to +20%	+20% to +50%	> +50%	-5% to -20%	-20% to -50%	< -50%

TOV	Area considered	Stuttgart	O_3 -10%	O_3 +10%	NO_x -10%	NO_x +10%	VOC -50%	VOC +50%	Athens	O_3 -10%	O_3 +10%	NO_x -10%	NO_x +10%	VOC -50%	VOC +50%
Max	domain	71 days	↘	↗	O	O	↘	↗	110 days	↓	↑	O	O	↘	↗
	urban	52 days	↘	↑	O	O	↓	↑	43 days	↓	**↑**	↘	↗	↓	↗
Ave	domain	60 days	↘	↗	O	O	↘	↗	65 days	↓	**↑**	↘	↗	↓	↗
	Urban	42 days	↘	↗	O	O	↓	↑	17 days	↘	↑	O	O	↘	↗
8hmax	Domain	274 µg/m³	O	O	O	O	↘	↗	438 µg/m³	O	O	O	O	O	O
	Urban	222 µg/m³	O	O	O	O	↘	↗	236 µg/m³	O	O	O	O	↘	↗
Cex	Domain	154 µg/m³	O	O	O	O	O	O	140 µg/m³	O	O	O	O	O	O
	Urban	149 µg/m³	O	O	O	O	O	O	152 µg/m³	O	O	O	O	O	O

6.7. Conclusions

The GEA-model tools for the assessment of urban air quality applied in the Auto-Oil II Programme are further extended for application to cities in central and eastern Europe. The model system is extended with procedures to estimate the number of excess deaths attributed to exposure to SO_2 and NO_2.

Under the assumption of the ShAIR emission scenario, urban air quality shows great improvement but violations of (proposed) air quality guidelines are still expected in 2020. Major problems with SO_2 exposure are found in eastern Europe; in a limited number of cities a deterioration in air quality is modelled for 2010–2020. The estimated number of excess deaths attributed to SO_2 exposure shows a sharp decrease between 1990 and 2010; from 2010 to 2020 a further decrease to about six excess deaths per 100 000 inhabitants is estimated. Compared with the calculations based on the emission scenarios developed for EEUTC and AOP II, the current results are generally higher.

Sensitivity calculations show that the modelled concentrations are sensitive to meteorological conditions. For example, using meteorological data for the period 1991–95, we found the inter-annual variability in SO_2 concentration to be about 6 % for annual mean and 10 % for the 98-percentile. However, in considering the compliance to air quality guidelines, sensitivity depends strongly on the ratio between threshold value and current concentrations. For example, conclusions on exceedance of the one-hour air quality guideline for NO_2 do not depend at all on the meteorological situation: estimated urban concentrations are so far below the threshold value that even under the worst dispersion conditions the guideline is realised. However, when making a first estimate of the required reduction in urban emissions needed to meet the 24-hour air quality guideline for SO_2, the reduction may vary up to 50–60 %, depending on the meteorological year selected.

7. Assessment of current approach and suggestions for improvement

7.1. Introduction

Besides producing a new scenario and assessing some sensitivities a main goal of this study was to gain more experience in assessing future trends on air and climate change. This chapter focuses on the findings regarding the process and organisation and presents a number of recommendations for further improvement of these assessments.

The recommendations and findings are structured under the following headings:

- integration issues: problems with linkages of the various components (models) in the integrated assessment, creating gaps and twists in smooth data flow;
- consistency issues: problems with differences in assumptions of the various components creating inconsistencies in the results;
- institutional issues: gaps in the data flow as a result of missing components due to the lack of institutional capacity for integrated assessment.

Before discussing the findings of this study, which mainly focus on the weak points, one general positive remark has to be made. The construction of the ShAIR scenario as described in the previous chapters has proven that the partners participating in this study have the capacity to contribute to integrated assessment studies in air pollution and climate change. In a relatively short time frame and within limited budgets, projections on transboundary and urban air quality, and greenhouse gas emissions, were made for Europe for the next 20 years based on a common scenario of economic and energy developments.

7.2. Integration issues

Urban emissions
Urban emissions are derived from the national emissions per sector. In recent years this has been done by different institutes and with different people. Originally, the idea was to have the European topic centre on air emissions/Netherlands Organisation for Applied Scientific Research (ETC-AE/TNO)) do this work. But as the urban air quality models include the accepted methods, it seemed easier to make a direct link with the emissions produced by the International Institute for Applied System Analysis (IIASA) RAINS model to prevent an extra data twist through TNO.

Three main issues remain on urban emissions. In the first place, a spatial distribution for urban emissions instead of the assumed homogeneous distribution might improve the results considerably. The physical rather than the administrative city should be used. Information on population size and built-up area should preferably be based on high-resolution land-cover and/or population density maps. Secondly, the procedure for downscaling can be improved at various points:

- development of an emission inventory at a NUTS3 or corresponding geographical level of detail;
- re-evaluating proxy variables for relating NUTS3 emissions with urban emissions;
- including small countries (e.g. Cyprus, Liechtenstein) in the RAINS model.

Thirdly, a distinction between urban and non-urban traffic projections would be very welcome. The latter will be dealt with in a joint project carried out by the National Technical University of Athens (NTUA) and the University of Leuven for the Directorate-General for Transport and Energy.

Link between urban and transboundary air quality

RAINS did not deliver the regional background air quality data for the urban models. The urban models require six-hourly or one-hourly data; RAINS provides only yearly averages. In the urban models the background concentrations were derived from the same European-scale dispersion model (EMEP — cooperative programme for monitoring and evaluation of long-range transmission of air pollutants in Europe) as is used by RAINS. This assures some consistency of background information, although no scenario runs of the EMEP models were available on the basis of the ShAIR scenario. As long as the differences in emission levels between the scenario and the available EMEP runs are small there is no problem. Otherwise some additional EMEP runs are needed. Further harmonisation is recommended. The TREND model was used to calculate regional background concentrations for the *Environment in the European Union at the turn of the century* (EEA 1999a, hereafter referred to as the EEUTC report). This model is able to present a better spatial resolution. However, the time resolution is worse than in the UAQAM and OFIS models. UAQAM and OFIS in the current version are, on the other hand, not able to deal with high spatial resolution and should possibly be improved on this aspect.

In the future the accuracy of the assessment of regional impacts, as well as of background concentrations, will improve when finer spatial resolution (50 x 50 kilometres (km) instead of 150 x 150 km) is applied for transfer/blame matrices produced by the European-scale EMEP model. This is of particular importance for urban pollutants but also for ozone and for pollutants like ammonia that are deposited relatively close to the emission source.

Carbon monoxide (CO) emissions, needed for modelling of urban ozone levels, have not been provided. Various assumptions had to be made. According to the *Environmental signals* report (EEA 1999c), CO is good for about 20 % of the ozone precursor emissions. Introduction of CO in RAINS is therefore recommended.

Link between PRIMES and RAINS

It is necessary to develop a better interface between PRIMES and RAINS. Currently, data from PRIMES are delivered in a spreadsheet format. For each country, data are stored in three spreadsheets, each with several worksheets. The structure of these spreadsheets also differs for the current European Union (EU) Member States and from those for the accession countries. Appropriate data need to be converted to four databases used by RAINS. A routine that saves the results of PRIMES directly to the databases in the RAINS format would speed up and smooth out this part of the data transfer.

Link between global background concentrations and regional air quality

The RAINS model does not include changes in the global atmosphere. This is also not the case in the EMEP models. Given the developments in the field of greenhouse gases, it might be expected that this will influence the global background concentrations on ozone especially.

7.3. Consistency issues

Policies and measures

Depending on the goal of the scenario, a choice has to be made beforehand on what policies and measures have to be included. This requires knowledge on the state of the implementation of European legislation in the Member States, but also on additional policies and measures of the individual countries. Both aspects are poorly developed at the moment.

An assessment of current policies needs to include current legislation. The results can be used to show compliance with the current reduction plans or, to put it differently, to show the extra effort needed, as a kind of distance to target analysis. The ShAIR scenario shows improvement on this subject in comparison with the EEUTC baseline (e.g. greenhouse gases: no measures; acidification: current reduction plans). Although this seems an open door, the ShAIR scenario does not deal with this in a consistent way. The transboundary air pollution part includes current reduction plans. In the PM_{10} (respirable particulate matter with aerodynamic diameter between 2.5 and 10 micrometres) projections current policy is defined as policies up to mid-1997, while on other emissions, policies and measures up to the year 2000 are included. A way also has to be found to ensure consistent implementation of measures in the different models so as to show secondary benefits and costs.

Base year estimates
There is a need to agree on which data sets are used for the base year as there appear to be differences in the figures in the different data sets. The sensitivity runs that compared ShAIR with the Auto-Oil II scenario clearly showed the need for this.

Definitions
Different definitions of economic sectors are used at the various institutes; a clear set of conversion factors from one system to the other should be defined.

7.4. Institutional issues

Geographical coverage
The models used for transboundary and urban air quality are able to demonstrate the situation in all European countries. However, the economic and energy scenario was only available in detail for the EU-15 (or even EU-14 since Luxembourg is missing in the PRIMES model). The greenhouse gas emission projections also only include the EU Member States. An extension of the economic and energy scenario and the related models to all accession countries or even all European countries is a main issue.

Transport
In the comparison of the results of energy use and resulting emissions by PRIMES/RAINS, used for the ShAIR scenario and by ForeMove/Tremove models, used in Auto-Oil II, important differences have been identified in the estimates of energy consumption and emission levels for a number of countries and vehicle categories. These differences originate not only from different scenario assumptions but also from the different structures of the models and the different focus of the two approaches. To make the results of different approaches more consistent, a fine-tuning of all models is necessary. In particular, transport sources in PRIMES may be additionally disaggregated to better reflect the sources that are relevant for estimating emissions. Emission factors and assumptions on the turnover of vehicle stock in RAINS should also be made consistent with (verified and checked) estimates from ForeMove. In turn, the ForeMove model should be calibrated, so that it properly reflects consumption of transport fuels as reported by national and international energy statistics. Separate emission factors for two-stroke engines should also be used in the ForeMove routine.

Agriculture
For some aspects trends in the agricultural sector are available for the period up to 2005. IIASA extrapolated these trends up to 2010 as far as the number of cattle and the use of fertilisers are concerned. However, extending the agricultural trends up to 2020 in a meaningful way was not possible. Therefore the assumption was made that no changes would take place between 2010 and 2020. In its current greenhouse gas study, AEA Technology (AEAT) uses the same basic information up to 2005 as IIASA for input into its own agricultural model to extrapolate nitrous oxide (N_2O) projections up to 2020. This has not yet been reported. At the moment there is no way of showing the effects of changes in the Common Agricultural Policy (CAP) and the accession process on the emission trends of the sector. These processes might be expected to strongly influence the number of cattle and the use of fertilisers in the future; therefore they are very relevant factors influencing the emission projections. A model to get a better insight into these consequences is greatly needed.

Greenhouse gas emissions apart from energy related CO_2
Non-CO_2 (carbon dioxide) greenhouse gas projections were based on studies by the European Commission made by AEAT and Ecofys. These studies include measures and costs on these gases. Although information is available and improved studies are underway, there is no ‘formal’ model. Apart from the other greenhouse gases, there is also a need to include the non-energy CO_2 emissions (about 5 %) caused by industrial processes. Clarification is needed on how to deal with land-use changes (also depending on the policy process).

Particulate matter
Particulate matter (PM) is a relatively new concern in air pollution policies. There are several gaps in the knowledge on particulate matter. These include uncertainties in emission estimations, the measurement of PM concentrations in the air and in the understanding of the effects. The differences in PM monitoring methods in the European countries are large. The different methods give different results and are therefore not completely comparable. The daughter directive of the European Union has given reason to start a comparison study on measurement methods. Such efforts are meant to result in a common opinion about the best methods and correction factors to be used. Due to the uncertainties it is not clear to what extent particulate matter is an urban or a regional air quality problem. It is also not certain how far the particulate matter concentrations can be explained with current emission estimates.

In recent years TNO has produced a first emission database on particulate matter and on possible measures to reduce emissions. This information has been used to produce the ShAIR emission projection on PM_{10}. Currently, as part of a joint United Nations Economic Commission for Europe (UNECE), EC and European Environment Agency (EEA) programme called CEPMEIP (coordinated European programme on particulate matter emission inventories, projections and guidance), TNO and the Norwegian Institute for Air Research (NILU) are improving the emission database. In 2001 this will lead to an update of the 1995 figures. This will be the starting point for countries reporting their own PM emissions for the year 2000.

Recently IIASA has started work on including strategies to control fine particles in Europe in the RAINS model. A prototype version of the PM module of RAINS has been prepared (Johanson *et al.,* 2000). However, there are still important information gaps regarding emission factors and other parameters in the module. Data on country-specific factors determining emission levels still need to be collected and verified. Data on emissions of fine particles from the transport sector also require further verification and validation. Therefore meaningful results for the whole of Europe are not available yet. More comprehensive results regarding emissions and dispersion of primary and secondary fine particles in Europe are expected in 2001-2001.

Besides PM_{10}, $PM_{2.5}$ should be included in the model network since it is included in EU legislation (Council Directive 1999/30/EC).

7.5. Methods and tools: options for the EEA

Scenario studies can be used in a number of ways. Options of interest for the EEA are studies:

- providing an integrated baseline scenario which includes current policies, shows distances to targets and can be used as a starting point for policy analysis;
- interacting with the policy process to arrive at a number of (integrated) policy variants;
- for developing new scenarios and policy variants with participation of stakeholders.

Projections under a baseline scenario might be presented in the EEA state of the environment report. In between the state of the environment reports, partial updates could be made in order to show the effects of the latest policies. The greenhouse gas and air pollution projections should be based on EU-wide accepted economic and energy scenarios.

The need for the EEA to present more than one baseline scenario is limited. The EEA always has to be clear about there not being only one future, and a scenario is just one possible projection. Presenting more scenarios makes this uncertainty about the future clear. However, the differences between economic and energy scenarios have to be large enough to result in significant differences in terms of emissions. Another solution might be to show some sensitivity runs, for instance, on the effect of higher energy prices or higher economic growth on the emissions of CO_2.

Improvement of the models themselves is costly and time consuming, and not within reach of the EEA itself. The EEA might, however, support some developments by showing its interest and support. The efforts of the EEA can be directed at the network, meaning the interaction between the models used in the different policy processes on climate change, long-range air pollution and urban air quality.

A baseline projection can be made along the lines of the ShAIR scenario. This study used a model network, which needs improvements on a number of points (see previous sections). The models and tools used were linked through data exchanges. The data exchange can be organised loosely (by exchanging spreadsheets and tables), gently (by standardised interfaces) or formally (by connecting models as if they are modules of a large overall model). At first hand, it would seem very attractive to choose the formal way. However every single model is complicated, having databases on several hundreds of non-homogeneous processes and categories. Experience shows that attempts to formally link variables used by two or more complex models designed for a different type of assessment have not been successful. Therefore, it is more practical to use separate models that build a hierarchical structure and exchange only the most important information.

If the choice is for a baseline, the use of RAINS within the model network might be revised. RAINS clearly has a role in calculating emissions as it contains a good database on measures and policies. For the projections of concentrations and depositions, however, EMEP or comparable models might be used. This ensures the coupling between long-range and urban air quality and because of the connection between RAINS and EMEP models, RAINS can still be used to make the policy evaluation against the baseline.

Involvement of stakeholders can be in the form of incidental consultation. Real stakeholder participation, for two-way interaction, requires a much smoother model network than is now the case.

8. Environmental assessment outside the field of air pollution

8.1. Introduction

Most of this report has focused on scenario construction for the assessment of air and climate change policies. This chapter gives recommendations to the European Environment Agency (EEA) on how to build capacity on assessment studies outside the air medium. Due to years of experience in this field the assessment tools and methods in the field of air and climate change are relatively advanced.

The less advanced state of projections and tools in other fields became apparent during the production of *Environment in the European Union at the turn of the century* (EEA 1999a, hereafter referred to as the EEUTC report). The EEA depended very much on compiling information from various sources 'off the shelf', without guarantee of consistency.

First, a short review of the Priorities Study for EEA-relevant experiences will be given, since this study was one of the important inputs for the EEUTC report. Next, recommendations will be formulated with a view to the expected policy questions in the coming years.

8.2. Experiences with the Priorities Study

Based on the experience in the Priorities Study a number of strengths and weaknesses were recognised (see Table 8.1). Many issues outside air, such as water stress, coastal zones, soil degradation and biodiversity, are less well defined. Indicators are missing, data are lacking and policy objectives are not clear. All this hampers the development of assessments. Specific findings are given below.

Judgement of information gaps and uncertainties for the Priorities Study by the Priorities Study project team Table 8.1.

Environmental issue	Pressure	Impact
Stratospheric ozone depletion	++	++
Climate change; carbon dioxide	++	+
Climate change; other greenhouse gases	+	+
Nuclear accidents	++	++
Oil spills and chemical accidents	0	0
Acidification and eutrophication	++	++
Tropospheric ozone	++	+
Chemicals and particulate matter	+	+
Water quantity and quality	+	+
Coastal zones	0	0
Waste: municipal solid waste	++	++
Waste: other	0	0
Soil degradation	0	0
Biodiversity	+	0
Human health, air quality	+	+
Noise	+	0

Legend: relative range of uncertainty or information gaps
++ most certain; well defined
+ intermediate
0 uncertain; many gaps

Transport and agricultural trends: The Priorities Study used a well-defined set of economic trends for the development of agriculture and transport. These were derived from the RAINS model as applied to the Convention on Long-Range Transboundary Air Pollution. These trends consist of national inputs supplied by the Member States and are not necessarily consistent with each other or with socio-economic trends. It is believed that sufficient expertise to identify consistent trends is present at the European Union (EU) level. Linkages between research expertise and integrated assessment communities should be enhanced.

Expansion of the EU: For the Priorities Study additional information was collected on the accession process. However, the domain of most environmental models used for the Priorities Study does not include accession countries. Also, the consequences of the accession process (market, production and consumption, as well as institutional changes) are poorly understood. There is a clear need for strengthening this area in future assessment processes.

Biodiversity: Biodiversity loss is caused by such factors as land-use change, including temporal change to any existing land use (e.g. summer to winter crops) and fragmentation of ecosystems; pollution and eutrophication of watercourses; and climate change. In Europe, land-use changes were a dominant factor in biodiversity loss during the 20th century. There is a need to trace through future scenarios of land-use change to assess their impact on biodiversity, allowing for the likely implementation of the EU Natura 2000 programme and changes in accession countries. A land-use change model needs to account for natural and migratory human population change; economic development, especially housing, roads and tourism; and changes in farming practice due to a reform of the Common Agricultural Policy (CAP).

The links between the CAP and biodiversity require special emphasis. For an assessment in terms of biodiversity, information on the extent of natural areas needs to be combined with information in quality terms (past and present: occurrence and distribution of indicator species; future: projections of pressure factors). For example, future assessments can give rise to questions as to whether much actual biodiversity gain can be expected of CAP reform before 2050 or 2100. The main challenge for the EEA in this respect lies in supporting innovative, broad-brush methods allowing scenario evaluation. A need for assessing feasible policy measures to counteract negative impacts on biodiversity can be raised.

Coastal zones: There is a major need for a 'land-use change' study (see recommendations under Biodiversity). Special attention needs to be paid to leisure and tourism developments; changes in sewerage discharge drop due to existing or planned policies; and transport developments (ports etc.).

Water stress: The water stress problem requires local conditions to be taken into account. The proposed water framework directive does this by referring to local ecological targets and abatement action plans. For retrospective analysis, the introduction of a monitoring system — Eurowaternet — should alleviate the data problem in the near future. For prospective analysis there is still an urgent need for a European water policy assessment model to play a role similar to the RAINS model for acidification.

Health effects: A common feature of many environmental issues is the impact of policy change on human health, for example, in the cases of stratospheric ozone, climate change, chemical risks, accidents, air pollution and bathing water quality (coastal zones). In turn, health impacts may be broken down into morbidity, premature mortality and illnesses and effects on one's general well-being. An approach is needed to bring all the different health effects together in one indicator.

Because the Priorities Study is one of few projects using a model network based on integrated assessment (see Chapters 2 and 7) the performance of this study will be considered on some general organisational criteria. Table 8.2 schematises the experiences specifically with a view to the increased complexity that needs to be addressed when other environmental themes are fully integrated into assessments.

Expert judgement of the degree to which the methods of the Priorities Study supported general assessment requirements Table 8.2.

	Judgement	Remark
Transparency (once ready)	thorough but complicated	
Transparency (during study)	no special provision	*other than the development of fact sheets*
Flexibility	not flexible	
Cost-effectiveness	expensive	*as is natural for a complex innovative study*
Coverage in environmental field	satisfactory	*good for air- and climate-related issues;* *satisfactory for sub-regional issues (water, waste);* *poor for land-use related issues (biodiversity, soil, coastal zones)*
Coverage of territory	good for EU problematic outside EU	
Spatial differentiation	good	
Analysis integrated?	varied	
Consistency with surrounding world	varied	*good for macro-economic assumptions and climate change;* *scenarios for rest of Europe not integrated, but in add-on analysis*
Indicators for presentation	good	*although not mechanised*
Reproducibility	fair	*version problems can be expected in the future*
Acceptance of methods by peers	generally good	*no generally accepted scenario evaluation method for biodiversity*
Participation of stakeholders	poor	*by design, only DG Environment involved*
Suitable for policy optimisation	very good	*design target*

Note: Some of the characteristics follow from the terms of reference of the study.

8.3. Next steps towards an EEA integrated environmental assessment

In what sequence can the thematic scope of EEA integrated assessment best be expanded with the ultimate purpose of covering all priority problems as distinguished by the EEA? This section provides an answer to this question along two lines. First, a start is made on an issue-by-issue basis, assuming modular expansion; and, second, by identifying a limited number of circumstances providing either opportunities or obstacles to be factored in when planning such an expansion.

The following criteria can be applied to prioritising topics for EEA integrated environmental assessment when it comes to going beyond air and climate change issues and to strengthening key weak points:

- for what issues are assessments practically possible?
- for what issues are policy issues that require IEA studies to be expected?
- what is necessary in order to get information on spill-over of costs and benefits?

In the light of these criteria, the status of the various non-air topics is as follows.

- *Water quality*
  The European Commission and Parliament recently agreed on the new framework directive on water. By 2015 this directive will be in full force, including with respect to preparing new policies. Efforts will first concentrate on improving European-wide monitoring. Only later, probably not before the 2003/04 report, are ex ante assessment of policies related to this directive thought to require important analyses.

Therefore, integrated reporting in this field may not yet be required from the EEA. However, the road towards a widely accepted assessment method and model (with the stature of RAINS, in the water domain, so to speak) is long and work should be started on time.

Organising an accepted water pollution and eutrophication assessment approach and model might be a task for the European topic centre (ETC) on water. From a technical point of view, but maybe not in terms of wide acceptance, the Carmen model, used in the Priorities Study, is available and can easily be adapted to include the fate of chemicals in the aquatic environment. It is important to develop a suitable infrastructure for integrated catchment modelling. The EEA should support this kind of development. From a perspective of integrated assessment, it would also seem a priority to ensure that the regionalisation of data on catchments is compatible with the data provision for the remainder of the EEA assessments.

- *Water quantity*
  The modelling of water quantity is based on trend analysis and is especially important for the south of Europe and the UK. The ETC on inland water has carried out a trend analysis. This analysis can be improved with the support of the national focal points. Information and knowledge of the models on climate change can also be used for improving the trend analysis. In particular, Water Gap (originally an off-shoot of the IMAGE model, and therefore still compatible with it) simulates changes in availability as well as in demand per drainage basin on the basis of driving forces as found in current global scenarios.

- *Biodiversity*
  Assessments on biodiversity are seriously hampered by the controversy on the definition and approach of biodiversity. This must be resolved first. Another step, which does not necessarily have to wait for biodiversity assessment issues to be resolved, might be the modelling of land use (as this is related to the habitat directive) in relation to spatial aspects. It seems logical to link such an activity with modelling of at least the agricultural sector.

- *Accidents*
  In view of the fast growth of air transport (passengers as well as freight), external safety around airports is a topic where requests for scenario-based assessments can be expected. Obviously, it is a topic that is prone to dispute.

- *Waste*
  Assessment of the waste stream from households has been part of the work of the current ETC on waste. Other waste streams are difficult to model as there is a lack of information. On the policy level there is a framework directive on waste. This issue might raise policy interest up to 2003/04, as differences in national legislation lead to unintended ‘recycling’ streams between member countries.

- *Soil degradation*
  On the global level the focus is on the risks of soil degradation. The topic is strongly linked to land use and land management and is a very location-specific problem. Policy processes to link with soil degradation are potentially the development of ‘good agricultural practices’ (with associated eco-labelling and trade regulations) and the structural funds of the EU. Risk of water-induced soil degradation (the largest degradation category) is successfully being modelled worldwide, but not the effects of land management, good or bad.

- *Agriculture*
  Beside these environmental themes, the driving forces should be considered, as these represent the starting point for most scenario studies. Energy and transport have been discussed in the previous chapters. Another key sector, not only for air, is agriculture, as it affects water quality and quantity, the use of chemicals and soil degradation. For one thing, this requires plausible and broadly accepted scenarios that are consistent with assumptions elsewhere. The scenarios should address consequences of *inter alia* reform of the CAP, regional funds and enlargement.

In view of this, the thematic spearheads for the EEA on integrated assessment outside the air and climate change topics can be:

- to develop a European model on agriculture, serving land-use change (part of biodiversity) and soil degradation;
- to develop a European model on water quality;
- to continue and improve the ETC activities in the field of waste and water quantity, in particular, improving the link to scenarios;
- to stimulate closure on a biodiversity assessment methodology.

In conclusion two key factors on integrated environmental assessment must be stressed:

- It is essential for the EEA to have information on the status of policies and measures.
- Prospective analysis needs to be connected with retrospective analysis, including model-based estimation of the impact of past policies, as currently under experiment for the agency as part of the *Environmental signals* report (EEA 1999c).

9. References

AEA Technology, 1998. *Options to reduce methane emissions (final report)*. Bates, J (ed.) A report produced for DG Environment.

Amann, M., Bertok, I., Cofala, J., Gyarfas, F., Heyes, C., Klimont, Z., Makowski, M., Schöpp, W. and Syri, S., 1999a. *Economic evaluation of air quality targets for tropospheric ozone. Part A: Cost-effectiveness analysis.* European Communities, Brussels, Belgium.

AOP II (Auto-Oil II Programme), 1999. *The Auto-Oil II cost-effectiveness study. Final report.* European Commission, Standard and Poor's DRI and K.U. Leuven, Brussels, 1999.

Berdowski *et al.*, 1997. 'Particulate matter emissions (PM_{10} — $PM_{2.5}$ — $PM_{0.1}$) in Europe in 1990 and 1993', TNO-MEP Report No R96/472, Apeldoorn, the Netherlands.

Berdowski *et al.*, 1998. 'Incremental cost and remaining emission in 2010 of heavy metals (HM) resulting from the implementation of the draft HM protocol under the UNECE Convention for Long Range Transboundary Air Pollution', TNO-MEP Report No R98/020, the Netherlands.

Bouscaren, R. and Bouchereau, J. M., 1996. 'Review of strategies and policies developed in the European Union and east and central Europe to prevent acidification and tropospheric ozone formation', Report CITEPA/IIASA 348. Centre Interprofessionnel Technique d'Etudes de la Pollution Atmospherique, Paris, France.

Capros, P. *et al.*, 1997. 'Business as Usual Energy Scenario for EU-15', National Technical University of Athens, Greece.

Capros, P. and Georgakopoulos, T., 1997. 'European macroeconomic projections for baseline scenario, 2nd version', National Technical University of Athens, Greece.

CEU (Central European University), 1996. Environmental Standards Database. Budapest, Hungary.

Cofala, J. and Syri, S., 1998a. 'Sulphur emissions, abatement technologies, and related costs for Europe in the RAINS model', IIASA, Laxenburg, Austria (available at http://www.iiasa.ac.at/~rains/).

Cofala, J. and Syri, S., 1998b. 'Nitrogen oxides emissions, abatement technologies and related costs for Europe in the RAINS model', IIASA, Laxenburg, Austria (available at http://www.iiasa.ac.at/~rains/).

Coherence, 1998. 'Comparison of CH_4 reduction studies', paper by Dominique Gusbin, Coherence, Louvain la Neuve, Belgium, published as Annex 5 to AEA Technology, 1998.

de Leeuw, F. A. A. M., Moussiopoulos, N., Sahm, P. and Bartonova, A., 2001a. 'Air quality in larger conurbations in the European Union', European topic centre on air quality, European topic centre on air emissions.

de Leeuw, F. A. A. M., Moussiopoulos, N., Sahm, P. and Bartonova, A., 2001b. 'Air quality in larger conurbations in the European Union', submitted to *Environmental Modelling & Software.*

EC (European Commission), 1999a. *Energy in Europe: Economic foundations for energy policy*, Special issue, December 1999, Commission of European Communities, DG Energy, Brussels, Belgium.

EC (European Commission), 1999b. *Energy in Europe: European Union energy outlook to 2020*, Special issue, December 1999, Commission of European Communities, DG Energy, Brussels, Belgium.

EC (European Commission), 1999c. *Methodology for calculating transport emissions and energy consumption (MEET)*, Transport Research, Fourth Framework Programme, DG VII (Transport), Luxembourg.

EC (European Commission), 1999d. 'Council Directive 1999/30/EC of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air', OJ No L163, 29.6.1999, p. 41, European Commission, Brussels.

EC (European Commission), 1999e. 'Proposal for a directive of the European Parliament and of the Council relating to ozone in ambient air', COM/1999/125/FINAL, European Commission, Brussels.

Ecofys, 1998. *Emission reduction potential and costs for methane and nitrous oxide in the EU-15*, Hendriks, C. A., de Jager, D. and Blok, K. (eds), by order of the DG Environment, European Commission, M714, Ecofys, Utrecht, the Netherlands.

EEA (European Environment Agency), 1996a. 'Corinair 1990 summary report 1', Topic Report 7-1996 Air Emissions, European Environment Agency, Copenhagen.

EEA (European Environment Agency), 1996b. 'Review study on European urban emission inventories', Topic Report 30-1996 Air Emissions, European Environment Agency, Copenhagen.

EEA (European Environment Agency), 1998. *Europe's environment: The second assessment*, European Environment Agency, EU Publications, Copenhagen.

EEA (European Environment Agency), 1999a. *Environment in the European Union at the turn of the century*, Environmental Assessment Report No 2, Copenhagen, Denmark.

EEA (European Environment Agency), 1999b. *Assessment of EC and Member States greenhouse gas emission trends 1990–1998*, Copenhagen, Denmark.

EEA (European Environment Agency), 1999c. *Environmental signals 2000*, Copenhagen, Denmark.

EEA (European Environment Agency), 2000a. *Cloudy crystal balls. An assessment of recent European and global scenarios studies and models,* Environmental issues No 17, prepared by International Centre for Integrative Studies (ICIS) for EEA, Copenhagen.

EEA (European Environment Agency), 2000b. Database on Air Emissions, European topic centre on air emissions, Copenhagen, Denmark (http://warehouse.eea.eu.int).

EEA (European Environment Agency), 2001a. 'Participatory integrated assessment methods', Technical Report 64, EEA, August.

EEA (European Environment Agency), 2001b. 'Scenarios as tools for international environmental assessments', *Environmental Issues* (forthcoming).

EEUTC report, see EEA, 1999a.

EFMA (European Fertilizer Manufacturers Association), 1996a. *Forecast for the development of mineral fertilizer consumption in western Europe until the year 2005/06,* EFMA Agro-Economic Task Force.

EFMA (European Fertilizer Manufacturers Association), 1996b. *Agriculture and fertilizer consumption in EFMA countries (moderate grain price scenario)*, Zurich, Switzerland.

EFTEC, 1997. *Scenarios for development of municipal solid waste incineration for EU countries*, EFTEC.

EPA, 1997. *Compilation of air pollutant emission factors*, AP-42, updated fifth edition, USA.

ETC-LC (European topic centre on land cover), 1997. Workshop on land cover applications — needs and use. 12–13 May 1997, Copenhagen.

Fisher, B. E. A. and Newlands, A. G., 2000. 'The designation of fuzzy air quality management areas', Paper presented at the millennium NATO/CCMS international technical meeting on air pollution modelling and its application, 15–19 May 2000, Boulder, Colorado, USA.

Folmer, C., Keyzer, M. A, Merbis, M. D., Stolwijk, H. J. J. and Veenendaal, P. J. J., 1995. 'The Common Agricultural Policy beyond the MacSharry Reform', *North-Holland Contributions to Economic Analysis*, p. 230, Elsevier Science, Amsterdam, the Netherlands.

Harnisch, J. and Hendriks, C., 2000. *Economic evaluation of emission reductions of HFCs, PFCs and SF_6 in Europe*, Ecofys Energy and Environment, Cologne, Germany.

IEA (International Energy Agency), 1997. *Energy statistics and balances of the OECD Countries 1994–1995*, OECD, Paris, France.

IIASA (International Institute for Applied System Analysis), 1997. Regional air pollution information and simulation (RAINS) model, version 7.2.

Johanson, M., Luekeville, A., Bertok, I., Amann, M., Cofala, J., Gyarfas, F., Heyes, C., Klimont, Z., Schöpp, W. and Gonzales del Campo, T., 2000. 'An initial framework to assess the control of fine particulate matter in Europe', Report to the 25th Task Force on Integrated Assessment Modeling, Stockholm, April 2000, IIASA, Laxenburg, Austria.

Krzyzanowski, M., 1997. 'Methods for assessing the extent of exposure and effects of air pollution', *Occupational and Environmental Medicine* Vol. 54, pp. 145–151.

Lebret, E., Briggs, D., van Reeuwijk, H., Fischer, P., Smallbone, K., Harssema, H., Kriz, B., Gorynski, P. and Elliotyt, P., 2000. 'Small area variations in NO_2 concentrations in four European areas', *Atmospheric Environment* Vol. 34, pp. 177–185.

McConville, A., 1997. *Emission standards handbook 1996: Air pollutant standards for coal-fired plants*, IEA Coal Research, London, UK.

Moussiopoulos, N. and Sahm, P., 1998. 'The OFIS model: An efficient tool for assessing ozone exposure and evaluating air pollution abatement strategies', Proceedings of the fifth International Conference on Harmonization within Atmospheric Dispersion Modelling for Regulatory Purposes, 18–21 May 1998, Rhodos, Greece.

Moussiopoulos, N., Sahm, P., Münchow, S., Tonneen, D., de Leeuw, F. and Tarrason, L., 2000. 'Uncertainty analysis of modelling studies included in air quality assessment', *International Journal of Environment & Pollution.*

Nitziachristos, L. and Samaras, Z., 1997. *COPERT II: Computer program to calculate emissions from road transport — users manual*, Technical report No 5, European Environment Agency, ETC-AEM.

Oleson, G. B., 2000. 'Wind power for western Europe, an INFORSE proposal for 2000-2020', International Network for Sustainable Energy — Europe (INFORSE-Europe), September.

Olsthoorn, X., Amann, M., Bartonova, A., Clench-Aas, J., Cofala, J., Dorland, K., Guerreiro, C., Hendriksen, J. F., Jansen, H. and Larssen, S., 1999. 'Cost benefit analysis of European air quality targets for sulphur dioxide, nitrogen dioxide and fine and suspended particulate matter in cities', Environmental and Resource Economics Vol. 14, pp. 333–351.

RIVM (Dutch National Institute of Public Health and the Environment), EFTEC, NTUA, IIASA, 2001. 'European environmental priorities: An integrated economic and environmental assessment', RIVM report nr. 481505010, Bilthoven, the Netherlands.

Sahm, P. and Moussiopoulos, N., 1999. 'The OFIS model: A new approach in urban scale photochemical modelling', *EUROTRAC Newsletter* 21/99, pp. 22–28, EUROTRAC-ISS, Garmisch-Partenkirchen.

Senco (Sustainable Environment Consultants Ltd), 1999. 'The AOPII Emissions Base Case', Bristol, United Kingdom.

Simpson, D., 1992. Long period modelling of photochemical oxidants in Europe: A) hydrocarbon reactivity and ozone formation in Europe. B) On the linearity of country-to-country ozone calculations in Europe, EMEP MSC-W Note 1/92, Norwegian Meteorological Institute, Oslo, Norway.

Simpson, D., 1993. 'Photochemical model calculations over Europe for two extended summer periods: 1985 and 1989. Model calculations and comparison with observations', *Atmos. Environ.* Vol. 27A, No 6, pp. 921–943.

Tsyro, S., 1998. 'Description of the Lagrangian Acid Deposition Model. In: Transboundary Acidifying Air Pollution in Europe. Part 2: Numerical Addendum' MSC-W Status Report 1998.

UN, 1997. *United Nations Statistical Division Demographic Yearbook 1995*, United Nations publication, Sales No E/F.97.XIII.1.

UN, 1999. United Nations Statistical Division, URL: www.unece.org/stats/trend

UNECE, 1994a. *Protocol to the 1979 Convention on Long-Range Transboundary Air Pollution on Further Reduction of Sulphur Emissions*, Document ECE/EB.AIR/40, United Nations, Economic Commission for Europe, New York, USA and Geneva, Switzerland.

UNECE, 1994b. *Protocol to the 1979 Convention on Long-range Transboundary Air Pollution on the Control of Volatile Organic Compounds or their Transboundary Fluxes done at Geneva on 18 November 1991*, GE.94-30788, United Nations Economic Commission for Europe, Geneva, Switzerland.

UNECE, 1996. *Energy Balances for Europe and North America 1992, 1993–2010*, United Nations Economic Commission for Europe, Geneva, Switzerland.

UNECE, 1999a. *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/).

UNECE, 1999b. *Strategies and policies for air pollution abatement*, ECE/EB.AIR/65, United Nations Economic Commission for Europe, Geneva, Switzerland.

van Jaarsveld, J. A., 1995. 'Modelling the long-term atmospheric behaviour of pollutants on various spatial scales', Thesis, University of Utrecht, the Netherlands.

van Pul, W. A. J., van Zantvoort, E. D. G., de Leeuw, F. A. A. M. and Sluyter R. J. C. F., 1996. 'Urban air quality assessment model UAQAM', Report 722401010, RIVM, Bilthoven, the Netherlands.

TNO-MEP, 1997. *The European emission inventory of heavy metals and persistent organic pollutants for 1990*, TNO Institute of Environmental Sciences, Energy Research and Process Innovation (MEP).

WHO (World Health Organization), 1997. *Air quality guidelines for Europe*, WHO Regional Office for Europe, Bilthoven, the Netherlands.