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Technical Report on Acidification, Eutrophication and Tropospheric Ozone in Europe: an integrated economic and environmental assessment

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This Report has been prepared by RIVM, EFTEC, NTUA and IIASA in association with TME and TNO under contract with the Environment Directorate-General of the European Commission.

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Abstract

The economic assessment of priorities for a European environmental policy plan focuses on twelve identified Prominent European Environmental Problems such as climate change, chemical risks and biodiversity. The study, commissioned by the European Commission (DG Environment) to a European consortium led by RIVM, provides a basis for priority setting for European environmental policy planning in support of the sixth Environmental Action Programme as follow-up of the current fifth Environmental Action Plan called 'Towards Sustainability'. The analysis is based on an examination of the cost of avoided damage, environmental expenditures, risk assessment, public opinion, social incidence and sustainability. The study incorporates information on targets, scenario results, and policy options and measures including their costs and benefits.

Main findings of the study are the following. Current trends show that if all existing policies are fully implemented and enforced, the European Union will be successful in reducing pressures on the environment. However, damage to human health and ecosystems can be substantially reduced with accelerated policies. The implementation costs of these additional policies will not exceed the environmental benefits and the impact on the economy is manageable. This requires future policies to focus on least-cost solutions and follow an integrated approach. Nevertheless, these policies will not be adequate for achieving all policy objectives. Remaining major problems are the excess load of nitrogen in the ecosystem, exceedance of air quality guidelines (especially particulate matter), noise nuisance and biodiversity loss.

This report is one of a series supporting the main report: *European Environmental Priorities: an Integrated Economic and Environmental Assessment*. The areas discussed in the main report are fully documented in the various *Technical reports*. A background report is presented for each environmental issue giving an outline of the problem and its relationship to economic sectors and other issues; the benefits and the cost-benefit analysis; and the policy responses. Additional reports outline the benefits methodology, the EU enlargement issue and the macro-economic consequences of the scenarios.

Technical Report on Acidification, Eutrophication and Tropospheric Ozone

This Report has been prepared by RIVM, EFTEC, NTUA and IIASA in association with TME and TNO under contract with the Environment Directorate-General of the European Commission. This report is one of a series supporting the main report: *European Environmental Priorities: an Integrated Economic and Environmental Assessment.*
Reports in this series have been subject to limited peer review.

The report consists of three parts:

Section 1:
Environmental assessment
Prepared by Janusz Cofala, Chris Heyes, Zbigniew Klimont, and Markus Amann (IIASA)

> This section informs on work of the International Institute for Applied Systems Analysis. Views or opinions expressed herein do not necessarily represent those of IIASA, its National Member Organizations or any other organizations sponsoring the work.

Section 2:
Benefit assessment
Prepared by D.W. Pearce, A. Howarth (EFTEC)

Section 3:
Policy assessment
Prepared by D.W. Pearce, A. Howarth (EFTEC)

References
All references made in the sections on benefit and policy assessment have been brought together in the Technical Report on Benefit Assessment Methodology. The references made in the section on environmental assessment follows at the end of section 1.

The findings, conclusions, recommendations and views expressed in this report represent those of the authors and do not necessarily coincide with those of the European Commission services.

Contents

1. Environmental assessment

1.1 Introduction

Within the study originally called 'Economic Assessment of Priorities for a European Environmental Policy Plan', twelve prominent European environmental problems have been identified. Among them are Acidification, Eutrophication, and Tropospheric Ozone, which are subject of this Technical Report. For these three environmental problems the pressures that affect the quality of the environment are caused by the emissions of gaseous pollutants to the atmosphere, i.e., sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and non-methane volatile organic compounds (VOC). The major sources of SO_2 and NO_x emissions are fuel combustion in power plants, other industry, transport, and in the tertiary (residential and commercial) sectors. Ammonia emissions originate mainly from agricultural activities (livestock, fertilizer use). There are two major sources of emissions of VOC: solvent use (in industry and in the tertiary sector) and vehicles (fuel evaporation and exhaust emissions).

There is substantial concern about the environmental impacts of air pollution on the local, regional and global scale. It has been shown that observed levels of various air pollutants can threaten human health, vegetation, wild life, and cause damage to materials. In order to limit the negative effects of air pollution, measures to reduce emissions from a variety of sources have been initiated. Over the last decade several international agreements have been reached in Europe to reduce emissions in a harmonized way. Protocols under the Convention on Long-range Transboundary Air Pollution focus on reducing emissions of sulfur dioxide, nitrogen oxides, and volatile organic compounds.

The European Union has adopted a dual-track policy with regard to air pollution control. Firstly, several directives have been adopted that prescribe emission standards for all member countries. Such standards are in force, e.g., for large combustion plants and for mobile sources. There are also fuel quality standards that specify the minimum requirements regarding the quality of liquid fuels used by transport sources as well as by stationary combustion facilities. Secondly, in many European countries national standards and other types of regulations (e.g., caps on emissions of specific pollutants) are in force. This national legislation reflects the seriousness of pollution in each individual country as well as national priorities regarding environmental quality. Compared with the EU-wide legislation, national policies pose further limitations on pollution levels.

The ultimate goal of environmental policy in the EU is the achievement of sustainable conditions in all member countries. Thus, in the long-run, pollution loads should be reduced to below the 'no effect' thresholds. In spite of substantial emissions reductions resulting from the implementation of current legislation, already agreed measures do not ensure sustainable conditions. This study simulates the environmental effects of current policies in the Baseline (BL) scenario. Even the Technology Driven (TD) scenario that requires the implementation of the best available control technologies (BAT) does not ensure full sustainability within the next 10 to 15 years. Thus interim targets have been proposed. Targets included in this report are in line with the targets agreed for the development of the National Emission Ceilings Directive (COM (99) 125 final, 1999).

Emissions of pollutants relevant for acidification, eutrophication and tropospheric ozone, and, in particular, emission control costs, depend to a large extent on the development of the energy system in each country. The selection of future energy supply sources has to include targets regarding mitigation of climate change. Thus, acidification, eutrophication and ground-level ozone effects have been calculated for different energy scenarios, reflecting three different strategies for reduction of climate-relevant gases.

The acidification, eutrophication and ozone strategies play also an important role in the assessment of urban stress. Thus the effects of policies aimed at controlling of the above mentioned environmental impacts are included in the assessment of measures for urban stress.

This report compares the emissions of air pollutants and their environmental impacts for five emission scenarios relevant for the study. The scenarios have been created through a combination of assumptions about the development of emitting sectors and about the emission control policies in each of those sectors. Scenarios taken into consideration are:

- the Baseline (BL) scenario,
- the Technology Driven (TD) scenario,
- the Accelerated Policy Scenario (AP), no climate change policies, i.e., mitigation of greenhouse gases emissions (AP_NC),
- the AP scenario with Kyoto targets of reduction of greenhouse gases emissions, no trade in emission rights (AP_NT)
- the AP scenario with Kyoto targets, full trade in emission rights (AP_FT).

The assessment was done with the use of the IIASA integrated assessment model RAINS. The BL scenario assumes the implementation of all control measures that are in line with current legislation (CLE) or are in the pipeline. In particular, this scenario takes into account the enforcement of all emission and fuel quality standards currently in force. It includes Community-wide legislation as well as legislation in force in each individual country in Europe. It also takes into account 'Current Reduction Plans' (CRP), i.e., the national emission ceilings that each country has committed itself to reach by 2010. The CRP values are used in the study to define caps on national emissions if these are stricter than the emissions resulting from the implementation of emission and fuel standards. The simulations include those emission control policies decided, or in the pipeline, as of December 1997. All measures or policies agreed upon after that date are not included in the Baseline. However, the newest policies are included in the calculations done for the AP scenarios.

The TD scenario assumes the adoption of all technically feasible emission control measures in all sectors of the economy. Measures and their costs are taken from the RAINS national emission control cost curves that are available for each pollutant. The cost curves take into account the limits in implementing individual technologies resulting from, e.g., plant sizes or from the turnover of capital stock. No limits on marginal control costs of individual measures were assumed. Thus, the whole feasible reduction potential, irrespective of the costs, is included in the TD scenario.

The AP scenarios are calculated on the assumption that the environmental targets of the National Emission Ceilings Directive (COM(99)125 final, 1999) are met in each EU member country in a cost-optimal way. For non-EU countries, emissions resulting from implementing Current Legislation (i.e., the Baseline values) have been used. The cost-optimal distribution of emissions reductions in individual countries has been determined with the use of the RAINS optimization routine.

Section 2 of this report describes the methodology of integrated assessment of air pollution control strategies. A short description of the RAINS model is given, together with explanations on how the model was used in the study. Section 3 describes the environmental indicators used in the assessment, and Section 4 contains a short characterization of the emission generating activities used. Sections 5 and 6 describe the emission scenarios. The assumptions made for constructing each of the scenarios, as well as the emissions, emission control costs and environmental indicators are discussed and compared. The final section provides a summary of the work done and presents the most important conclusions and recommendations.

1.2 Method

The assessment described in this study has been made with IIASA's integrated assessment model RAINS (Amann et al., 1998). RAINS provides a consistent framework for the analysis of emission reduction strategies in the European context. RAINS focuses on acidification, eutrophication and tropospheric ozone. RAINS comprises modules for emission generation (with databases on current and future economic activities, energy consumption levels, fuel characteristics, etc.), for emission control options and costs, for atmospheric dispersion of pollutants and for environmental sensitivities (i.e., databases on critical loads). In order to create a consistent and comprehensive picture of the options for simultaneously addressing the three above mentioned environmental problems, the model considers emissions of SO_2, NO_x, NH_3, and VOC. A more detailed description of the conceptual framework of the RAINS model can be found in Alcamo et al., 1990. A schematic diagram of the RAINS model is displayed in figure 1.2.1. A description of the individual modules of RAINS, together with a simplified version of the impact module that enables on-line calculations of the environmental impacts of user-defined emission scenarios is available on the Internet (www.iiasa.ac.at/~rains).

The European implementation of the RAINS model incorporates databases on economic activities relevant for calculations of emission levels. These include forecasts of energy consumption, data on agricultural activities (development of livestock), and other types of aggregated data on future economic development (GDP, industrial production). Data is stored for 38 regions in Europe and the information is rather detailed. For instance, the energy database of RAINS distinguishes 22 categories of fuel use in six economic sectors (Bertok et al., 1993). The time horizon extends from the year 1990 up to the year 2010. Emissions of SO_2, NO_x, NH_3 and VOC for 1990 are estimated based on information collected by the CORINAIR inventory of the European Environmental Agency (EEA, 1996) and on national information. Options and costs for controlling emissions of the various substances are represented in the model by considering the characteristic technical and economic features of the most important emission reduction options and technologies. Atmospheric dispersion processes over Europe for sulfur and nitrogen compounds are modeled based on results of the European EMEP model developed at the Norwegian Meteorological Institute (Barret and Sandnes, 1996). For tropospheric ozone, source-receptor relationships between the precursor emissions and the regional ozone concentrations are derived from the EMEP photo-oxidants model (Simpson, 1992, 1993). RAINS incorporates databases on critical loads and critical levels compiled at the Coordination Center for Effects (CCE) at the National Institute for Public Health and Environmental Protection (RIVM) in the Netherlands (Posch et al., 1997).

The RAINS model can be operated in the 'scenario analysis' mode, i.e., following the pathways of the emissions from emission sources to environmental impacts. In this case the model provides estimates of regional costs and environmental benefits of pre-defined emission control strategies. The simulation mode was used for preparation of the BL and the TD scenarios. Alternatively, an 'optimization mode' is available for acidification and tropospheric ozone to identify cost-optimal allocations of emission reductions in order to achieve specified deposition or ambient level targets. The optimization capability of RAINS enables the development of multi-pollutant, multi-effect pollution control strategies. Several strategies have been analyzed within the preparation process of the proposal of the Emission Ceilings Directive for the EU-15, as well as of the revised Nitrogen Protocol to the Convention on the Long-range Transboundary Air Pollution (Amann et al., 1999a, 1999b, UN/ECE, 1999). The AP scenarios presented in this report demonstrate the cost-optimal way of achieving the targets used for preparation of the National Emission Ceilings Directive.

RAINS estimates current and future levels of SO_2, NO_x, VOC and NH_3 emissions based on information provided by the energy and economic scenario as exogenous input, and on emission factors derived from the CORINAIR emission inventory (EEA, 1996), and national sources. Emission estimates are performed on a disaggregated level that is determined by the details available on economic, energy and agricultural projections. Although there is a large variety of options to control emissions, an integrated assessment model focusing on the pan-European scale has to restrict itself to a manageable number of typical abatement options in order to estimate future emission control potentials and costs. Consequently, RAINS identifies for each emission source category a limited list of characteristic control options and extrapolates the current operating experience to future years, taking into account the most important country- and situation-specific circumstances modifying the applicability and costs of the techniques. A list of emission control technologies included in RAINS, together with a description of the methodology adopted to estimate emission control costs and the parameters of the individual control technologies (efficiencies, unit costs) can be found in Cofala and Syri (1998a,b), Klimont et al.,(1998), Klaassen (1991), and Klimont (1998). Information about the control costs in individual countries and about emission control potentials is combined in RAINS into the national emission control cost curves. Such cost curves are created in the model for each scenario of economic activity.

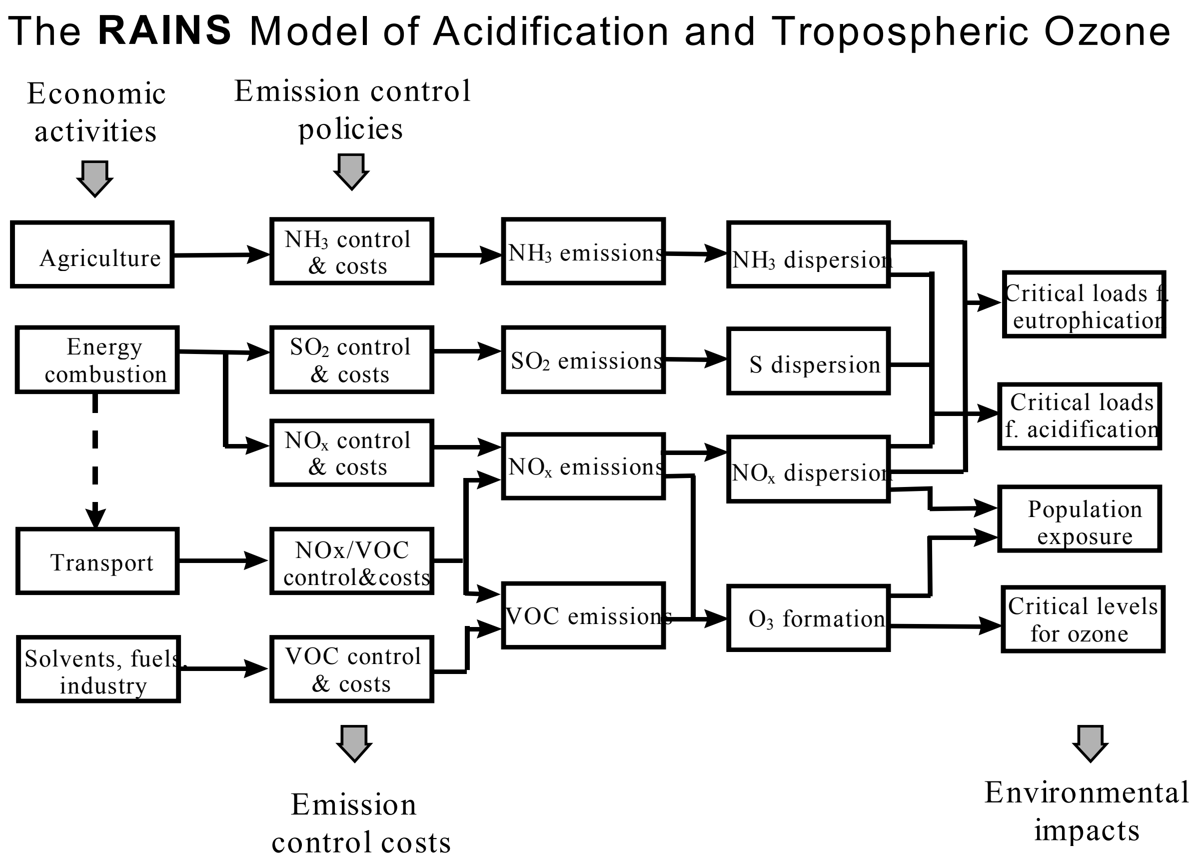

Figure 1.2.1 Schematic flowchart of the RAINS model framework.

1.3 Environmental Indicators Used in the Assessment

The impacts of scenarios developed within the study are evaluated with a series of indicators that allow quantification of progress towards achieving sustainable conditions. For acidification and eutrophication the indicator used is the area of ecosystems not protected against damage. The unprotected area is calculated for each country in absolute terms (i.e., in thousand hectares), as well as in relative terms (i.e., in percents of total ecosystems' area). The model also calculates gridded deposition for the individual pollutants and gridded exceedances of critical loads for each scenario. Gridded information is available from IIASA upon request.

For ozone, two types of indicators (measures of exceedances) have been used. The first one (AOT40) is used for the assessment of damage to vegetation (agricultural crops). The second one (AOT60) is used for human health. Both indicators are calculated using ozone concentrations that are characteristic for rural areas.

The AOT40 is the cumulative exposure index over a threshold of 40 ppb (parts per billion). It is calculated using hourly concentrations during daylight hours over a three-month period (growing season). The critical level for agricultural crops (relating to a five percent crop loss) has been set at an AOT40 of three ppm.hours, averaged over a five-year period. The AOT40 represents the sum of the differences between the hourly ozone concentrations in ppb and 40 ppb for each hour when the concentration exceeds 40 ppb, using daylight hours only. The AOT40 indicator shows excess AOT40 over the threshold of 3 ppm hours. The index is calculated on a grid resolution and considers agricultural lands, natural vegetation and forest areas. Two types of indexes are calculated for each country: the cumulative exposure index (in million hectares.excess ppm hours) and the average index (in excess ppm.hours) that reflects the weighted average excess exposure over the whole grid area.

The AOT60 index is used to quantify health-related ozone levels. It represents the cumulative excess exposure over 60 ppb, for practical reasons over a six-month period. A value of that indicator of zero is considered as an equivalent to the WHO Air Quality Guideline for Europe (WHO, 1997)[1]. In this case, two different types of indexes have also been calculated. The cumulative index reflects the total exposure of a population in each country and is expressed in person.ppm.hours. This index is the result of the average exposure per person multiplied by the total population. The RAINS model calculates these indices on a grid basis (using gridded data on AOT60 and population). Next, these grid values are aggregated to the country level. The indices presented in this report use the AOT60 concentrations per grid, representing rural ozone concentrations, and the total population per grid, in 1990. Inaccuracies may occur for grids with major urban areas where the rural ozone concentrations used for these analyses present an upper bound for the concentrations in the cities, and are lower than the concentrations occurring in the city plumes. The 'average' indicator (in ppm.hours per person) reflects the average exposure of a person in a country, calculated from gridded data. It is important to stress that these indices may not be used to derive estimates of health damage, for which more detailed information is deemed necessary. In the context of this report, these indices provide relative measures to enable a comparison of different scenarios.

Ozone exposure in each grid used for calculation of the indices is a mean of the exposures calculated using the meteorology for the period 1989–1994. In addition, for health-related ozone exposure, maps are presented that indicate the number of days on which the WHO health guideline (60 ppb) levels are exceeded.

1.4 Scenarios of Emission Generating Anthropogenic Activities

1.4.1 Energy Projections

Inputs to the RAINS model are projections of future energy consumption on a national scale up to the year 2010. The model stores this information as energy balances for selected future years, distinguishing fuel production, conversion and final consumption for 22 fuel types in six economic sectors. These energy balances are complemented by additional information relevant for emission projections, such as boiler types (e.g., dry bottom vs. wet bottom boilers, size distribution of plants, age structures, fleet composition of the vehicle stock, etc.). In order to avoid double counting, the RAINS balances do not include fuel consumption by air transport or international marine bunkers. These items are not included in the tables that compare the scenarios.

Energy projections for the 15 EU member states used in this study are based on the work of the National Technical University of Athens for DG-XVII. The Baseline and TD emission scenarios are based on the 'Business as Usual' energy paths (BAU) (Capros et al., 1997). The AP scenarios use the energy pathways developed with the use of the PRIMES model (Capros et al., 1999) as a starting point. The aggregated results by country are presented in Table 1.4.1. Energy use by source category and fuel type is presented in Table 1.4.2.

[1] The Position Paper on Ozone prepared by the Commission's Services (EC,1998) proposes a maximum eight-hour average concentration of 60 ppb (120 μg) as the long-term environmental objective for the EU ozone strategy.

Table 1.4.1 Projections of total primary energy consumption for the countries of the EU-15 in Peta Joule (PJ).
Fuel use by air transport not included.

Country	1990	2010 BL	*Change 1990=100%*	2010 AP_NC	*Change BL=100%*	2010 AP_NT	*Change BL=100%*	2010 AP_FT	*Change BL=100%*	GDP growth [%/year]
Austria	1242	1428	*15%*	1401	*-2%*	1361	*-5%*	1376	*-4%*	2.21%
Belgium	1907	2447	*28%*	2399	*-2%*	2183	*-11%*	2345	*-4%*	2.11%
Denmark	731	916	*25%*	885	*-3%*	826	*-10%*	862	*-6%*	2.19%
Finland	1233	1382	*12%*	1564	*13%*	1423	*3%*	1487	*8%*	1.71%
France	9122	11128	*22%*	11045	*-1%*	10765	*-3%*	10866	*-2%*	1.96%
Germany	14534	15178	*4%*	14309	*-6%*	13625	*-10%*	13735	*-10%*	2.28%
Greece	923	1399	*52%*	1489	*6%*	1326	*-5%*	1400	*0%*	2.84%
Ireland	409	575	*41%*	678	*18%*	623	*8%*	661	*15%*	4.59%
Italy	6676	8444	*26%*	7658	*-9%*	7118	*-16%*	7388	*-13%*	1.91%
Luxembourg	122	129	*6%*	129	*0%*	129	*0%*	129	*0%*	2.30%
The The Netherlands	2737	3563	*30%*	3520	*-1%*	2855	*-20%*	3417	*-4%*	2.46%
Portugal	699	1112	*59%*	1176	*6%*	1083	*-3%*	1144	*3%*	2.97%
Spain	3612	5215	*44%*	5239	*0%*	4984	*-4%*	5088	*-2%*	2.58%
Sweden	2430	2682	*10%*	2513	*-6%*	2417	*-10%*	2497	*-7%*	1.94%
UK	8544	9868	*16%*	9862	*0%*	9301	*-6%*	9600	*-3%*	2.31%
EU-15	**54920**	**65466**	***19%***	**63868**	***-2%***	**60020**	***-8%***	**61994**	***-5%***	**2.20%**

Table 1.4.2 Energy projections by fuel and source category for the EU-15 in Peta Joule (PJ). Fuel use by air transport not included.

Source category/fuel	1990	2010 BL	*Change 1990=100 %*	2010 AP_NC	*Change BL=100%*	2010 AP_NT	*Change BL=100%*	2010 AP_FT	*Change BL=100%*
Stationary sources:									
Total	44668	51788	*16%*	50707	*-2.1%*	47358	*-8.6%*	49007	*-5.4%*
- Coal	11561	6805	*-41%*	6747	*-0.9%*	3753	*-44.9%*	4885	*-28.2%*
- Liquid fuels	11892	12518	*5%*	11806	*-5.7%*	10096	*-19.3%*	10941	*-12.6%*
- Gaseous fuels	10603	19029	*79%*	18658	*-1.9%*	18661	*-1.9%*	19124	*0.5%*
- Other	10612	13437	*27%*	13497	*0.4%*	14848	*10.5%*	14058	*4.6%*
Mobile sources - total	10251	13678	*33%*	13160	*-3.8%*	12661	*-7.4%*	12987	*-5.1%*
of which electricity	170	228	*35%*	363	*59.0%*	338	*48.3%*	347	*52.2%*
TOTAL	**54920**	**65466**	***19%***	**63868**	***-2.4%***	**60020**	***-8.3%***	**61994**	**-5.3%**

For the 15 EU countries the BAU energy scenario projects an increase in total energy consumption of 19 percent between 1990 and 2010. The demand for coal decreases by 41 percent. This decline is compensated for by a rapid increase in the demand for natural gas (79 percent by 2010) and for other fuels (nuclear, hydropower, renewable energy) by 27 percent. The demand for liquid fuels from stationary sources also increases by five percent. The transport sector is expected to grow further, which – in spite of continuing improvement in the fuel economy of new cars and trucks – results in an increase in the demand for transport fuels of 33 percent. Energy demand in the AP_NC scenario (which is a recent update of the BAU scenario and is also called 'Baseline for Shared Analysis') is about 2.4 percent lower than the BAU. The main reason for this lower total energy use is lower demand for liquid fuels by stationary sources (-5.7 percent) as well as by mobile sources (-3.8 percent). The other two AP scenarios are even more different from the BAU. In the scenario that assumes meeting the Kyoto target for greenhouse gases without trading (AP_NT), the total primary energy demand decreases by 8.3 percent compared with the Baseline. The demand for coal decreases by 44.9 percent. Consumption of liquid fuels by stationary sources decreases by 19.3 percent. Consumption of hydrocarbon fuels by mobile sources decreases by 7.4 percent. Simultaneously, the use of electricity in the transport sector increases compared with the Baseline. Energy demand for the AP_FT energy scenario (which allows trading in CO_2 emission rights) lies between the demand for the AP_NC and the AP_NT scenarios. Detailed discussions of the energy scenarios used in this study can be found in the references cited above.

For the non-EU countries considered in RAINS, energy projections are based on data submitted by the governments to the UN/ECE and published in the UN/ECE Energy Database (UN/ECE, 1996). Recently, data for some countries (e.g., the Czech Republic, Poland, and Norway) have been revised based on inputs obtained from national experts. Where necessary, missing forecast data have been constructed by IIASA using a simple energy projection model. These forecasts (Table 1.4.3 and Table 1.4.4) were also used for the scenario calculations conducted for the negotiations on the Protocol to Abate Acidification, Eutrophication, and Ground-level Ozone under the Convention on Long-range Transboundary Air Pollution (UN/ECE, 1999).

For the non-EU countries, the energy projections imply a four percent drop in total primary energy consumption. This is due to the sharp decrease in primary energy demand that occurred in the period 1990–1995 in the countries of the former Soviet Union and in other central and east European countries with economies in transition. Processes of economic restructuring in those countries will allow further economic development while keeping the total primary energy demand until 2010 below the 1990 level. The consumption of coal and oil by stationary sources is predicted to decrease by 22 and 34 percent, respectively. Consumption of natural gas increases by 12 percent. Similar to the EU countries, the demand for transport fuels will increase by 11 percent over the period 1990–2010. In spite of a fast increase in car ownership, the increase in the demand for motor fuels is modest because of a rapid decrease in material and transport intensities in the former 'planned economy' countries. Thus, until 2010 the demand for goods transport will remain below the 1990 level.

It must be stressed that the selected energy scenario is an exogenous input to the RAINS model and does not specifically change due to constraints on emissions imposed by RAINS calculations.

Table 1.4.3 Projections of total primary energy consumption for the non-EU countries.

Country	1990 [PJ]	2010 [PJ]	*Change 1990-2010*	GDP growth [%/year]
Albania	128	143	12%	1.52%
Belarus	1762	1553	-12%	0.49%
Bosnia-H.	311	297	-5%	-0.34%
Bulgaria	1310	1276	-3%	1.00%
Croatia	413	447	8%	1.44%
Czech Republic	1949	1764	-10%	1.58%
Estonia	423	366	-13%	0.48%
Hungary	1109	1350	22%	1.73%
Latvia	399	359	-10%	-1.08%
Lithuania	677	565	-17%	-0.69%
Norway	1426	1904	34%	2.00%
Poland	4250	5253	24%	3.03%
R. of Moldova	392	324	-17%	-2.18%
Romania	2425	2525	4%	1.16%
Russia	18237	16617	-9%	-0.37%
Slovakia	987	982	0%	1.44%
Slovenia	231	234	1%	3.62%
Switzerland	1119	1184	6%	1.30%
FYR Macedonia	151	138	-9%	0.50%
Ukraine	9970	8559	-14%	-1.03%
Yugoslavia	790	725	-8%	0.61%
Non-EU	**48458**	**46567**	**-4%**	**0.55%**

Table 1.4.4 Energy projections for the non-EU countries.

Source category/fuel	1990 [PJ]	2010 [PJ]	Change 1990-2010
Stationary combustion sources:			
Total	43927	41414	-6%
- Coal	11487	8930	-22%
- Liquid fuels	8545	5673	-34%
- Gaseous fuels	18243	20393	12%
- Other	5652	6418	14%
Mobile sources - total	4621	5153	11%
TOTAL	**48458**	**46567**	**-4%**

1.4.2 Forecast of Activity Levels used in the VOC Module for Stationary Sources

The future rates of volatile organic compounds (VOC) emitting activities, 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 2010. Unfortunately, reliable and consistent projections of future activity rates at the process level are hardly available since most long-term economic forecasts restrict themselves to a rather aggregated level of economic activities and rarely specify even the development of the main economic sectors. Therefore, the temporal changes of the activity rates are derived on the following four concepts:

1. The change of the activity rates for processing, distribution and combustion of fossil fuels is linked to changes in fuel consumption provided by the energy scenario input to RAINS. Internal consistency with the energy scenario used for calculation of SO_2 and NO_x emissions is maintained.
2. 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.
3. The temporal development of a number of industrial activities (e.g., degreasing, paint use, solvent use in chemical industry, printing, other industrial solvent use), is related to changes in value added generated by individual sectors. These changes are supplied with the energy scenario. In many cases, statistics suggest that these activities grow slower than the GDP. To reflect this trend, sector-specific elasticities derived from statistics have been applied.
4. In the absence of more information the activity rates for less important emission sectors are kept constant. This was typically done:
   - for sectors where current emissions estimates are very uncertain (e.g., agriculture, waste treatment);
   - where it is difficult to identify meaningful relations with other economic activities; and
   - for sectors where the increase in activity rates are expected to be offset by emission reductions induced by autonomous technical improvements.

The forecast of all activity rates linked to the assumptions of economic growth is based on the Baseline projections for the EU member countries prepared by Capros et al., 1997. Owing to the difficulty in presenting activity levels for the VOC module in an aggregated way (as for the energy and agricultural sectors) these data (both for the base year and the forecast) are not shown in this report. They are however documented and easily accessible at the web site http://www.iiasa.ac.at/~klimont/main-review.html. In addition, a report (Klimont et al., 1998) that describes the sectoral structure of the VOC module in more detail is also available at this web page.

1.4.3 Projections of Agricultural Livestock

Agricultural activities are a major source of ammonia (NH_3) emissions, which in turn make a contribution to the acidification and eutrophication problem. Next to specific measures directed at limiting the emissions from livestock farming, the development of animal stock is an important determinant of future emissions. IIASA has compiled a set of forecasts on European agricultural activities (Table 1.4.5), based on national information as well as on the modeling work for the EU member states done with the ECAM (European Community Agricultural Model) model (Folmer et al., 1995). Forecasts used for the Baseline and TD scenarios are identical with the forecasts used in the work on the EU National Emission Ceilings Directive (compare Amann et al., 1998). The above study also includes forecasts of fertilizer consumption for the EU-15 based on a study by the European Fertilizer Manufacturers Association (EFMA, 1996a,b) (Table 1.4.6). Since consistent alternative livestock forecasts were not available, the Baseline projection was used in all AP scenarios.

Table 1.4.5 Projection of livestock up to the year 2010 (million animals).

	Cows			Pigs			Poultry		
	1990	2010		1990	2010		1990	2010	
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%
The 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**	**1000**	**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%
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%
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%
R. Moldova	1.1	1.0	-13%	2.0	1.5	-27%	25.0	19.0	-24%
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%
FYR Macedonia	0.3	0.3	-1%	0.2	0.2	7%	22.0	22.0	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%**	**1279**	**1199**	**-6%**
Total	**204.6**	**173.5**	**-15%**	**242.5**	**246.1**	**2%**	**2207**	**2203**	-0%

Table 1.4.6 Projections of nitrogen fertiliser use (in 1000 tons N/year).

	Nitrogen fertilizer use		
	1990	2010	*Change*
Austria	137	109	*-20 %*
Belgium	166	137	*-17 %*
Denmark	395	261	*-34 %*
Finland	228	180	*-21 %*
France	2493	2457	*-1 %*
Germany	1885	1545	*-18 %*
Greece	428	294	*-31 %*
Ireland	370	357	*-4 %*
Italy	879	919	*5 %*
Luxembourg	20	16	*-20 %*
The Netherlands	404	291	*-28 %*
Portugal	150	144	*-4 %*
Spain	1064	1052	*-1 %*
Sweden	212	199	*-6 %*
UK	1516	1298	*-14 %*
EU-15	**10347**	**9259**	***-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 %*
Hungary	359	639	*78 %*
Latvia	143	221	*55 %*
Lithuania	256	309	*21 %*
Norway	111	92	*-17 %*
Poland	671	855	*27 %*
Moldova	123	228	*85 %*
Romania	765	780	*2 %*
Russia	3418	1994	*-42 %*
Slovakia	147	150	*2 %*
Slovenia	88	102	*16 %*
Switzerland	63	30	*-52 %*
FYR Macedonia	6	3	*-50 %*
Ukraine	1885	1599	*-15 %*
Yugoslavia	146	145	*-1 %*
Non-EU	**10171**	**9344**	***-8 %***
Total	**20518**	**18603**	***-9%***

1.5 Baseline (BL) and Technology Driven (TD) scenarios

1.5.1 Emission Control Measures Assumed in the Baseline Scenario

The emissions and environmental impacts of the Baseline scenario include emission control policies according to the current legislation in each country. This scenario simulates the likely impacts of current emission abatement policies and regulations for the year 2010. The simulations done for the Baseline include the emission control policies as decided or in the pipeline by December 1997. All measures or policies agreed upon after that date are not included in the Baseline[2].

In order to capture the 'dual-track' policies in Europe (regulations on emission standards for specific source categories and ceilings for national total emissions), the scenario mimics the implications of these approaches. First, the simulations of the effects of 'Current Legislation' (CLE) were performed. The emissions resulting from the implementation of present and (already accepted) future legally binding emission control legislation were calculated for each European country. Next, these emissions were compared with the officially adopted or internationally announced ceilings on national emissions, so-called 'Current Reduction Plans' (CRP), (EMEP, 1999). Finally, for further analysis the more stringent value from CLE and CRP was taken for each country.

The ceilings for the 'Current Reduction Plans' (CRP) are based on an inventory of the national caps on emissions that each country has committed itself to reach by 2010. Such declarations of envisaged future emissions result from national plans as well as from the various protocols to the Convention on Long-range Transboundary Air Pollution (UN/ECE, 1988, UN/ECE, 1994a, b). The CRPs are collected on a routine basis by the Secretariat of the Convention. The analysis in this study uses the CRP values as of June 1998.

For SO_2 and NO_x, the scenario is based on a detailed inventory of regulations on emission controls, taking into account the legislation in the individual European countries, the relevant Directives of the European Union, in particular the Large Combustion Plant Directive – LCPD (OJ, 1988), and the directives on the sulfur content of liquid fuels, i.e., gas oil (Johnson and Corcelle, 1995), heavy fuel oil (COM(97)88), 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 Sulfur Protocol (UN/ECE, 1994a) requires emission controls according to 'Best Available Technology' (BAT) for new plants.

An inventory of national and international emission standards in Europe can be found in Bouscaren & Bouchereau (1996). In addition, information on power plant emission standards has been taken from the survey of the 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.

For the control of NO_x and VOC emissions from mobile sources, the scenario considers the implementation of the current UN/ECE legislation as well as country-specific standards if stricter. For the Member States of the European Union the current EU standards for new cars, light commercial vehicles and heavy duty vehicles (HDV) have been taken into account: the Directives 70/220/EEC as amended by 96/69/EC, and 88/77/EEC as amended by 96/1/EC; see McArragher et al. (1994). Additionally, the scenario assumes for all EU countries after the year 2000 the implementation of the measures outlined in the Communication COM(96) 248 presenting the results and consequences from the Auto/Oil 1 Programme (EC, 1996). The 'Common Positions' of the Council on the envisaged legislation referred to by this Communication and the Commission's proposal on emissions from HDV (COM(97) 627) is also taken into account. This includes vehicle-related measures like improved catalytic converters, engine modifications and on-board diagnostic systems. Furthermore, the impacts of the envisaged improved inspection and maintenance practices and the changes in fuel quality are incorporated.
The pace of the implementation of the vehicle-related measures depends on the turnover of vehicle stock and has been based on modeling work performed for the Auto/Oil 1 study.

[2] However, post-1997 legislation was taken into account in the AP scenarios.

SO_2, NO_x, and VOC control measures assumed in individual countries or groups of countries are specified in Tables 1.5.1 to 1.5.6.

Table 1.5.1 Control measures for SO_2 emissions in EU countries.

Stationary and mobile sources:

- Emission standards for new plants from the Large Combustion Plant Directive - LCPD (OJ, 1988) and from the Second Sulfur Protocol (UN/ECE, 1994a).
- Limits on sulfur content of gas oil for stationary and mobile sources and for heavy fuel oil as in the appropriate directives (compare Johnson and Corcelle, 1995, COM(97)88).
- National emission standards on stationary sources if stricter than the international standards.

Table 1.5.2 Control measures for SO_2 emissions in the non-EU countries.

Stationary and mobile sources:

Signatories of the Second Sulfur Protocol (Bulgaria, Croatia, Czech Republic, Hungary, Norway, Poland, Russian Federation, Slovak Republic, Slovenia, Switzerland, Ukraine) - New plant emission standards and limits on the sulfur content of gas oil for stationary and mobile sources as in the Protocol.

Czech Republic, Croatia, Norway, Poland, Slovak Republic, Slovenia, Switzerland, Romania, Yugoslavia - national emission standards on existing and new plants.

Other countries in Central and Eastern Europe – no control.

Table 1.5.3 Control measures for NO_x emissions in EU countries.

Stationary sources:

- Emission standards for new plant and emission ceilings for existing plant from the Large Combustion Plant Directive - LCPD (OJ, 1988). These standards require implementation of primary emission measures (combustion modification) on large boilers in the power plant sector and in industry.
- National emission standards on stationary sources – if stricter than in the LCPD.

Mobile sources:

- EU standards for cars and light commercial vehicles (LCV) (Directive 70/220/EC du Conseil, du 20 mars 1970, concernant le rapprochement des législations des États membres relatives au mesures à prendre contre la pollution de l'air par les gaz provenant des moteurs à allumage commandé équipant les véhicules à moteur, OJ 76, 6.4.70, p. 1, as amended by 96/69/EC, OJ L 282, 1.11.96, p. 1)
- EU standards for heavy duty vehicles (HDV) according to Council Directive 88/77/EC of 3 December 1987 on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous pollutants from diesel engines for use in vehicles, OJ L 36, 9.2.88, p. 33, as amended by 96/1/EC, OJ L 40, 17.2.96
- EU standards for non-road machinery engines (Directive 97/68/EC of the European Parliament and the Council of 16 December 1997 on the approximation of laws of the Member States relating to measures against the emissions of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery, OJ L 59, 27.2.98, p. 1-85, as well as for mopeds and motorcycles (Directive 97/24/EC of the European Parliament and the Council of 17 June 1997 on certain components and characteristics of tow or three-wheel motor vehicles, OJ L 226, 18.8.97, p. 1)
- From 2000 - fuel quality and emission standards (for LDV, LCV, HDV) and improved inspection/maintenance, as resulting from the Auto/Oil Programme (Communication from the Commission to the European Parliament and the Council on a future strategy for the control of atmospheric emissions from road transport taking into account the results from the Auto/Oil Programme (COM(96) 248, 18.6.1996- compare EC, 1996), amended by the Common Positions of the Council related to LDV, LCV, fuels and by COM(97) 627, 3.12.97, on HDV-emissions. These standards are assumed to be implemented in the EU-15 as well as in Norway and in Switzerland.

Table 1.5.4 Control measures for NO_x emissions in the non-EU countries.

Stationary sources:

- Czech Republic, Croatia, Hungary, Norway, Poland, Slovak Republic, Slovenia, Switzerland, Romania, Yugoslavia – controls according to national emission standards on new and existing sources.
- Other countries in Central and Eastern Europe – no control[3].

Mobile sources:

- Czech Republic, Hungary, Poland, Slovak Republic, Slovenia - National mobile source standards comparable with 1992 and 1996 standards for the EU (requirement for catalytic converters for gasoline engines and combustion modifications on diesel engines).
- Other CEE countries - pre-1990 UN/ECE standards on mobile sources (no requirement for catalytic converters for gasoline engines and for combustion modifications on diesel engines).

Table 1.5.5 Measures assumed to control VOC emissions for EU countries.

Stationary sources:

- Emission ceilings and standards from the Solvent Directive (Proposal for a Council Directive on limitation of emissions of volatile organic compounds due to the use of organic solvents in certain industrial activities (COM(96) 538, 6.11.96).
- Stage I controls on gasoline storage and distribution - European Parliament and Council Directive 94/63/EC of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations, OJ L 365, 31.12.94, p. 24 (EC, 1994).
- Stage II according to existing legislation in Austria, Belgium, Denmark, Germany, Italy, Luxembourg, The Netherlands, and Sweden.

Mobile sources:

- All directives and legislation acts aimed at a reduction of emissions from mobile sources mentioned for NO_x also apply to VOC.
- Passenger cars – small canister according to the 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, OJ L 242, 30.8.91, p. 1–6 (EC, 1991).

Table 1.5.6 Measures assumed to control VOC emissions for non-EU countries.

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 acts aimed at a reduction of emissions from mobile sources mentioned for NO_x also apply to VOC.
- Introduction of small carbon canisters in Norway and Switzerland consistent with the Council Directive 91/441/EEC, EC, 1991.
- 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, EC, 1991.

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[3] Because measures depending on implementation of primary NO_x reduction measures on new power plants are state of the art technology, such controls were assumed by default in all countries.

For VOC, the scenario assumes the implementation of the Solvent Directive of the EU (COM(96)538, 1997) as proposed by the Commission. Furthermore, the obligations of the VOC Protocol of the Convention on Long-range Transboundary Air Pollution (UN/ECE, 1994b) were incorporated. For mobile sources, the measures pertaining to the regulations on carbon canisters of Directive 91/441/EEC complemented by the proposed amendment of Dir. 70/220 in the Auto/Oil 1 package are assumed to be fully implemented. Emissions from non-road mobile machinery engines are subject to Directive 97/68/EC. It was further assumed that VOC emissions from gasoline distribution will be controlled through the Stage-I measures in all the EU countries (reflecting the Directive 94/63/EC, EC, 1999), and in Norway and Switzerland. Some of the European countries also have legislation requesting stage II controls on gasoline stations (compare Table 1.5.5 and Table 1.5.6).

For ammonia, values for the 'No control' scenario (or CRP – if lower) were adopted.

1.5.2 Measures in the Technology Driven Scenario

The Technology Driven (TD) scenario assumes – for the EU countries – the implementation of all possible technical control measures in all sectors. However, this scenario includes the constraints resulting from limited possibilities of retrofitting existing emission sources, and limited applicabilities of available technologies to small plants. Consequently, the emissions from the end points of the RAINS emission abatement cost curves have been taken as the maximum feasible reductions (MFR) values. RAINS cost curves include country-specific conditions, such as the size of the plants, turnover of capital stock in industry as well as in the transport sector, farm size, natural conditions (land shape) etc. Examples of the measures included in the TD scenario for individual pollutants are described below.

Sulfur dioxide (SO_2)

1. High efficiency (wet and regenerative, if applicable) flue gases desulfurization (FGD) on existing and new large boilers in the power plant and industrial sectors;
2. Use of low sulfur fuels and simple FGD techniques for smaller combustion sources in industry, in the residential and commercial sectors;
3. High efficiency controls on process emission sources.

Nitrogen oxides (NO_x)

1. Selective catalytic reduction (SCR) at large plants in industry and in the power sector;
2. Combustion modifications (CM) for smaller sources in industry and in the residential and commercial sectors;
3. High efficiency controls on process emission sources;
4. Post-2005 standards on mobile sources for road and off-road transport;
5. CM and SCR for ships operating in coastal zones.

Ammonia (NH_3)

To achieve the maximum feasible reduction levels, the most advanced abatement measures have to be applied for all categories. Although there are differences between countries, depending on the applicability of some of the options in particular regions, the importance and relevance of them might vary. A typical set of controls would include the following options:

Substitution of urea fertilizers;

1. Low emission housing with covered storage of manure and low ammonia application techniques for slurry (dairy cattle, pigs, poultry);
2. Rapid incorporation of solid manure (cattle, pigs, poultry, sheep);
3. Low nitrogen feed and biofiltration (pigs - where applicable);
4. End-of-pipe controls in industry (fertilizer manufacturing).

Non-methane volatile organic compounds (VOC)

The VOC module of RAINS includes more emission categories than other parts of RAINS. Also the control options are somewhat less homogeneous across the sectors, i.e., only rarely can the same abatement option be applied in several emission categories. The importance of various categories, as well as the applicability of certain options, also varies significantly from country to country. A typical set of control options, applied in major emission categories, necessary to achieve TD levels is presented below (note that some sectors and options will not appear on this list as they are already part of current legislation):

1. Gasoline distribution – Stage II on gasoline stations;
2. Refineries (process) – regular inspection and maintenance, covers on oil/water separators, flaring and incineration;
3. Chemical industry – regular monitoring, flaring as well as control of the evaporative loses from storage;
4. Solvent use:
   - dry cleaning – new closed circuit machines;
   - degreasing – water based systems, low temperature plasma process, conveyored degreasers with integrated adsorption (depending on applicability);
   - use paints – full use of potential for substitution with low solvent products both in 'do it yourself' and industrial applications, additionally in industry modification of application methods and introduction of solvent management plans; and
   - application of glues and adhesives – modification of application techniques as well as substitution.

1.5.3 Emissions and Emission Control Costs

This section discusses the emissions of air pollutants and the emission control costs for the BL and the TD scenarios. The control costs include additional production costs of low sulfur 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 using an annual cost method with a four percent real interest rate. For the needs of this study the costs were converted to € 1997 prices using the deflator 27.4 percent.

Tables 1.5.7 and 1.5.8 show the emissions of pollutants contributing to acidification, eutrophication and tropospheric ozone for the EU countries. Emission levels for the non-EU countries are shown in Table 1.5.9. The 1990 emission values for all countries are given as calculated by the RAINS model. The implementation of the policies assumed in the Baseline scenario (BL) substantially decreases the emission levels. For EU-15 as a whole, SO_2 emissions will be reduced by 71 percent compared to 1990. NO_x will decrease by 45 percent and ammonia by 12 percent. VOC is expected to decline by 49 percent. Lower relative reductions are foreseen for the non-EU countries with SO_2 declining by 55 percent, NO_x by 36 percent, ammonia by 14 percent, and VOC by 20 percent.

Implementation of TD measures in the EU-15 would cut SO_2 emissions in this group of countries by 89 percent, NO_x by 65 percent, ammonia by 40 percent and VOC by 65 percent, compared with 1990. Per definition, changes to the structure and the levels of economic activities and energy consumption, e.g., as reactions to excessive emission control costs or measures resulting from non-technical instruments to control emissions, are not taken into account in the TD scenario. It should be stressed that for non-EU countries, control policies (and thus the emissions of pollutants) remain the same as in the Baseline.

Table 1.5.7 NO_x and VOC emissions in the EU-15 in 1990, and in 2010 for the Baseline (BL) and for the Technology Driven (TD) scenarios (in kilotons).

Country	NO_x			VOC		
	1990	**BL**	**TD**	**1990**	**BL**	**TD**
Austria	192	87	87	352	204	116
Belgium	351	204	124	374	206	106
Denmark	274	157	109	182	95	67
Finland	276	154	89	213	108	65
France	1867	933	631	2382	1238	767
Germany	2662	1387	909	3122	1322	986
Greece	345	338	182	336	205	129
Ireland	113	77	34	110	49	29
Italy	2037	1186	734	2055	1177	767
Luxembourg	22	10	6	19	7	5
The Netherlands	542	266	173	490	247	157
Portugal	208	197	99	212	144	90
Spain	1162	892	552	1008	669	469
Sweden	338	220	156	511	212	138
UK	2839	1186	728	2667	1276	962
EU-15	**13226**	**7296**	**4613**	**14031**	**7159**	**4851**

Table 1.5.8 SO_2 and NH_3 emissions in the EU-15 for 1990, and in 2010 for the Baseline (BL) and for the Maximum Feasible Reductions (MFR) scenarios (in kilotons).

Country	SO_2			NH_3		
	1990	**BL**	**TD**	**1990**	**BL**[4]	**TD**
Austria	93	49	36	77	67	48
Belgium	336	208	77	97	96	57
Denmark	182	90	24	77	72	40
Finland	226	116	57	40	31	23
France	1250	487	171	805	771	541
Germany	5280	740	450	757	571	353
Greece	504	371	54	80	74	59
Ireland	178	94	30	127	126	111
Italy	1679	593	209	462	432	282
Luxembourg	14	4	2	7	7	7
The Netherlands	201	84	49	233	136	105
Portugal	284	145	30	71	67	46
Spain	2189	793	172	352	353	225
Sweden	119	59	53	61	53	44
UK	3805	980	380	329	297	218
EU-15	**16339**	**4813**	**1795**	**3576**	**3153**	**2156**

[4] Emissions of ammonia in 2010 include changes in 'Current Reduction Plans' for Italy and France. Because of that change, the Baseline emissions are by 70 kilotons higher for France and by 16 kilotons higher for Italy compared with estimates done in the earlier phases of the Study.

Table 1.5.9 Emissions of atmospheric pollutants in the non-EU countries for 1990, and for the Baseline (BL) scenario for the year 2010 (in kilotons).

Country	NO_x		VOC		SO_2		NH_3	
	1990	**BL**	**1990**	**BL**	**1990**	**BL**	**1990**	**BL**
Albania	24	36	31	41	72	55	32	35
Belarus	402	180	371	301	843	480	219	163
Bosnia-H.	80	60	51	48	487	415	31	23
Bulgaria	355	290	195	190	1842	846	141	126
Croatia	82	83	103	105	180	70	40	37
Czech Republic	546	296	442	305	1873	366	107	105
Estonia	84	73	45	45	275	175	29	29
Hungary	219	196	204	145	913	546	120	137
Latvia	117	90	63	54	121	57	43	35
Lithuania	153	110	111	84	213	107	80	81
Norway	220	161	297	195	52	33	23	21
Poland	1217	879	797	807	3001	1397	505	508
Rep. of Moldova	87	34	50	41	197	117	47	48
Romania	518	458	503	504	1331	594	292	300
Russia	3486	1995	3542	2743	5012	2344	1282	894
Slovakia	219	132	151	140	548	137	60	47
Slovenia	60	31	55	25	200	37	23	21
Switzerland	163	89	278	143	43	30	72	66
FYR Macedonia	39	29	19	19	107	81	17	16
Ukraine	1888	1094	1161	851	3706	1488	729	649
Yugoslavia	211	152	142	139	585	269	90	82
Non-EU	**10170**	**6467**	**8609**	**6923**	**21599**	**9643**	**3980**	**3422**
EU-15	**13370**	**7296**	**14031**	**7159**	**16339**	**4813**	**3576**	**3153**
TOTAL	**25025**	**15393**	**22640**	**14082**	**39090**	**15609**	**7556**	**6575**

Notes:
1. Russia includes only the European part within the EMEP region.
2. TOTAL also includes emissions from sea regions.

Table 1.5.10 demonstrates the emission control costs for the scenarios. The costs of the 'Baseline' measures for the EU-15 are about € 67.3 billion/year. SO_2 control costs contribute about 16 percent to total costs. Since there are currently no emission standards for NH_3 emissions from agriculture, the BL cost includes the costs of achieving the CRP emission level by each country in a cost-optimal way. Costs of NO_x and VOC controls contribute 84 percent to total costs. They have been summed-up since measures in the transport sector reduce the emissions of both pollutants, and an allocation of the costs to NO_x and VOC emissions would be arbitrary. These costs are quite high because current legislation requires strict and expensive controls on transport sources. For the non-EU countries the total costs are about € 12.3 billion/year (compare Table 1.5.11), of which about one third are for SO_2 controls and the balance are the costs of NO_x and VOC controls.

For the EU-15 the costs of the TD measures (€ 110.5 billion/year) are 64 percent higher than the costs of the BL case. The SO_2, NO_x and VOC control costs in the TD scenario are only 43 to 44 percent higher than in the BL. This is because current legislation already requires strict controls on emissions. In the case of ammonia, the situation is different. The very low cost of the BL scenario increases by a factor of 30 if the TD measures are applied to all emission sources in agriculture.

Table 1.5.10 Emission control costs in the EU-15 for 2010 for the Baseline (BL) and for the TD scenarios (in € million/year).

Country	NO_x + VOC		SO_2		NH_3		Total cost	
	BL	**TD**	**BL**	**TD**	**BL**	**TD**	**BL**	**TD**
Austria	1270	1680	251	279	0	299	1520	2259
Belgium	1649	2441	405	678	0	632	2054	3749
Denmark	755	1051	171	284	0	883	927	2218
Finland	738	1171	251	452	0	180	989	1803
France	8363	12247	1298	1933	0	2824	9661	17005
Germany	13578	18351	2506	3667	0	2314	16084	24330
Greece	954	1852	255	599	0	283	1209	2734
Ireland	310	547	126	218	11	591	447	1356
Italy	9226	12869	2284	2502	0	870	11511	16241
Luxembourg	80	129	11	19	18	19	111	166
The Netherlands	2268	3405	287	357	301	1366	2855	5128
Portugal	1449	2195	194	334	0	476	1642	3005
Spain	6426	8682	865	1477	36	2603	7327	12762
Sweden	1293	1845	278	308	38	293	1610	2446
UK	8041	12292	1305	2049	0	981	9346	15321
EU-15	**56401**	**80754**	**10488**	**15154**	**404**	**14614**	**67293**	**110522**

Table 1.5.11 Emission control costs in the non- EU countries for 2010 for the Baseline (BL) scenario (in € million/year).

Country	NO_x+VOC	SO_2	NH_3	Total
Albania	-4	0	0	-4
Belarus	242	4	0	246
Bosnia-H.	1	0	0	1
Bulgaria	1	214	0	215
Croatia	5	66	0	71
Czech Rep.	706	543	4	1252
Estonia	0	0	0	0
Hungary	557	211	0	768
Latvia	42	19	0	61
Lithuania	42	0	0	42
Norway	676	56	0	731
Poland	3140	1089	20	4250
Moldova	57	0	0	57
Romania	-3	199	1	196
Russia	1032	899	0	1930
Slovakia	420	120	0	539
Slovenia	147	61	0	208
Switzerland	964	90	0	1055
FYR Macedonia	1	0	0	1
Ukraine	186	423	0	609
Yugoslavia	4	113	0	117
Non-EU	**8217**	**4106**	**24**	**12348**
EU-15	**56401**	**10488**	**404**	**67293**
Total	**64617**	**14594**	**428**	**79639**

Note: Negative control costs are due to solvents savings if some control technologies are implemented.

1.5.4 Impacts on Acidification and Eutrophication

The threat of acidification and eutrophication of the analyzed control strategies can be expressed by a comparison of the areas of ecosystems receiving deposition above their critical loads. The results are shown in Table 1.5.12 and in Table 1.5.13. The tables clearly demonstrate that the emission control measures assumed for the BL scenario would already significantly improve the situation for acidification. The share of unprotected ecosystems decreases in the EU-15 from about 25 percent in 1990 to 4.6 percent in 2010. For the non-EU countries the BL scenario reduces the unprotected ecosystems from about 13 percent to 2.6 percent. For some countries the improvement is even greater: in Germany the area not protected decreases from 80 percent to 18 percent; in the Netherlands from 89 percent to 62 percent.

Improvements also occur in the protection levels of eutrophication. Again, an important change already happens in the BL scenario. For the EU-15 the percentage of unprotected ecosystems decreases from 55 percent in 1990 to 41 percent in 2010. In the non-EU countries unprotected ecosystems shrink from 23 percent to 15 percent. However, for some countries the protection levels remain dramatically low. For instance, in Belgium, Germany, Luxembourg and the Netherlands more than 90 percent of ecosystems remain unprotected. In the non-EU region, low protection levels (more than 70 percent of ecosystems not protected) occur in the Czech Republic, Lithuania, Poland, the Slovak Republic and Switzerland.

The TD scenario would further reduce negative environmental impacts. For the EU countries, those ecosystems not protected against acidification would shrink to two percent, and 24 percent of the ecosystems would remain unprotected against eutrophication. The spatial distribution of the improvement is presented in Figure 1.5.1 and in Figure 1.5.2. The maps show the percentage of ecosystems additionally protected as a result of implementing the TD measures compared to the protection achieved in the BL scenario.

In spite of the fact that emission levels for the non-EU countries in the TD scenario remain the same as in the BL, important side benefits from emission reductions in the EU countries can be identified. For instance, in the Czech Republic 13 percent of ecosystems becomes additionally protected against acidification and 12 percent against eutrophication. In Switzerland the improvement is about three percent (acidification) and 22 percent (eutrophication).

Table 1.5.12 Ecosystems with acid deposition above their critical loads for acidification in 1990 and for the BL and TD scenarios in 2010.

Country	1000 hectares			Percent of ecosystems		
	1990	Baseline	TD	1990	Baseline	TD
Austria	2376	200	66	47.6	4.0	1.3
Belgium	410	162	20	58.4	23.1	2.8
Denmark	54	10	4	13.8	2.5	1.0
Finland	4693	1167	985	17.2	4.3	3.6
France	8191	224	37	25.8	0.7	0.1
Germany	8158	1893	479	79.5	18.4	4.7
Greece	0	0	0	0.0	0.0	0.0
Ireland	97	14	7	10.7	1.5	0.8
Italy	2065	117	47	19.6	1.1	0.5
Luxembourg	58	6	0	66.7	6.6	0.5
The Netherlands	285	200	56	89.3	62.4	17.5
Portugal	1	1	0	0.0	0.0	0.0
Spain	78	18	0	0.9	0.2	0.0
Sweden	6341	1693	1059	16.4	4.4	2.7
UK	4117	1204	226	43.0	12.6	2.4
EU-15	**36924**	**6907**	**2987**	**24.7**	**4.6**	**2.0**
Albania	0	0	0	0.0	0.0	0.0
Belarus	2709	1031	953	53.9	20.5	19.0
Bosnia-H.	132	131	0	9.1	9.1	0.0
Bulgaria	0	0	0	0.0	0.0	0.0
Croatia	7	0	0	2.7	0.0	0.0
Czech Republic	2394	543	193	90.1	20.4	7.3
Estonia	312	10	6	16.5	0.5	0.3
Hungary	144	65	48	50.7	22.9	16.7
Latvia	127	0	0	4.7	0.0	0.0
Lithuania	817	78	76	43.1	4.1	4.0
Norway	5313	2621	1842	24.0	11.9	8.3
Poland	12634	1409	915	72.8	8.1	5.3
Rep. of Moldova	84	29	29	7.1	2.4	2.4
Romania	230	51	51	3.7	0.8	0.8
Russia	27072	4063	3943	7.8	1.2	1.1
Slovakia	1033	296	248	51.5	14.8	12.3
Slovenia	363	19	4	40.1	2.1	0.5
Switzerland	508	65	32	41.1	5.2	2.6
FYR Macedonia	0	0	0	0.0	0.0	0.0
Ukraine	2397	634	510	29.1	7.7	6.2
Yugoslavia	2	2	1	0.1	0.1	0.0
Non-EU	**56280**	**11047**	**8851**	**13.1**	**2.6**	**2.1**
TOTAL	**93204**	**17954**	**11837**	**16.1**	**3.1**	**2.0**

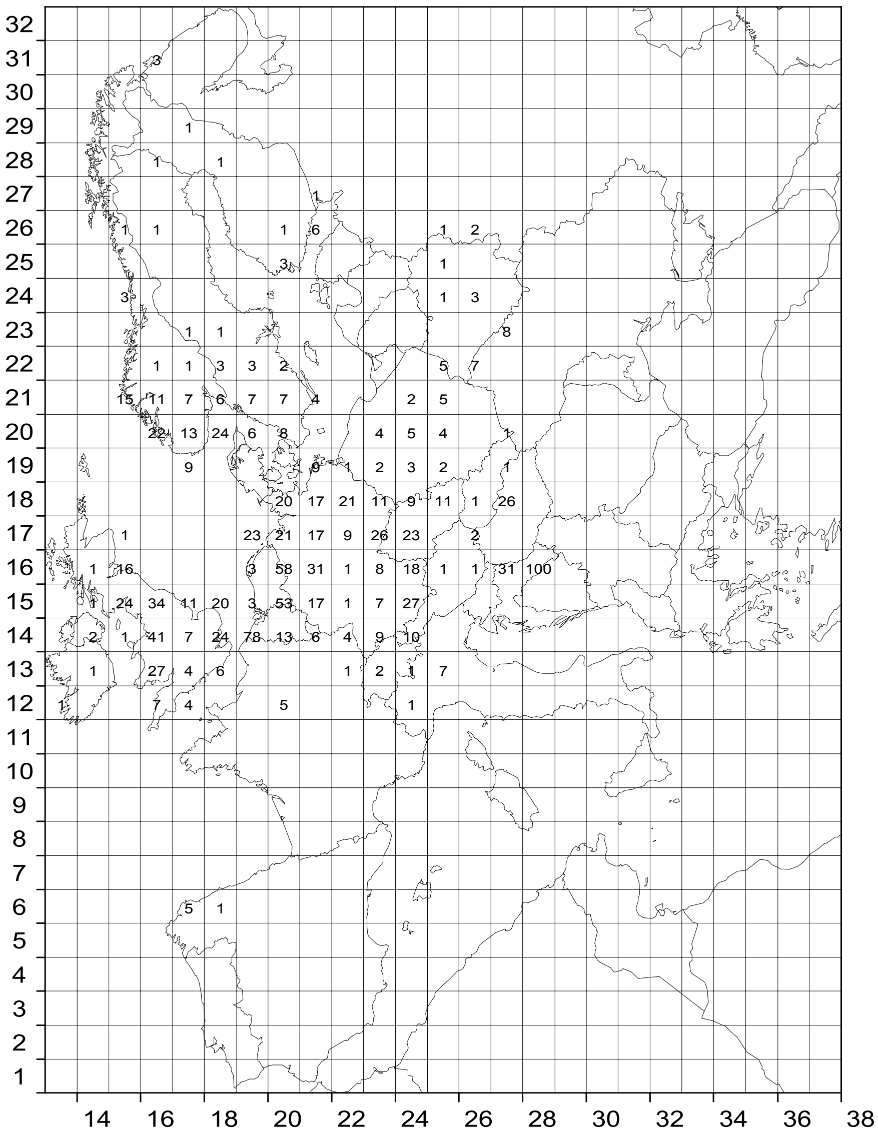

Figure 1.5.1 Ecosystems additionally protected against acidification in 2010 in the TD scenario compared with the BL scenario (in percent of the ecosystems' area).

Table 1.5.13 Ecosystems with nitrogen deposition above their critical loads for eutrophication in 1990 and for the BL and TD scenario in 2010.

Country	1000 hectares			Percent of ecosystems		
	1990	Baseline	TD	1990	Baseline	TD
Austria	5392	3519	1664	90.3	58.9	27.9
Belgium	700	681	458	99.6	97.0	65.2
Denmark	197	124	7	62.7	39.5	2.1
Finland	7386	2186	1210	44.8	13.2	7.3
France	29320	26233	16987	92.3	82.6	53.5
Germany	10157	9317	5826	99.0	90.8	56.8
Greece	295	225	68	12.0	9.2	2.8
Ireland	91	59	26	10.0	6.4	2.8
Italy	5921	3821	1891	49.4	31.9	15.8
Luxembourg	88	81	53	100.0	92.3	60.1
The Netherlands	312	292	269	97.8	91.2	84.2
Portugal	913	830	61	32.3	29.3	2.2
Spain	2390	1334	23	28.0	15.7	0.3
Sweden	2588	965	469	13.8	5.1	2.5
UK	1030	127	0	11.2	1.4	0.0
EU-15	**66778**	**49793**	**29011**	**55.3**	**41.3**	**24.0**
Albania	240	200	144	22.6	18.8	13.5
Belarus	2049	1219	1124	40.8	24.2	22.3
Bosnia-H.	1104	726	555	76.2	50.1	38.3
Bulgaria	3964	3261	2804	80.1	65.9	56.7
Croatia	70	18	11	25.9	6.8	4.0
Czech Republic	2608	2314	1986	98.2	87.1	74.8
Estonia	1296	686	585	68.5	36.3	30.9
Hungary	166	150	143	58.2	52.6	50.3
Latvia	2260	1544	1396	83.2	56.9	51.4
Lithuania	1462	1352	910	77.1	71.3	48.0
Norway	2053	292	12	14.7	2.1	0.1
Poland	16875	16164	15262	97.3	93.2	88.0
Rep. of Moldova	1	0	0	0.1	0.0	0.0
Romania	3450	2428	2302	55.4	39.0	36.9
Russia	47704	20659	19842	13.8	6.0	5.8
Slovakia	1874	1501	1290	93.5	74.9	64.3
Slovenia	489	155	86	54.0	17.1	9.5
Switzerland	2105	1832	1327	92.4	80.4	58.2
FYR Macedonia	242	145	116	22.7	13.6	10.9
Ukraine	6181	4889	4709	75.0	59.3	57.2
Yugoslavia	2306	1994	1844	67.6	58.5	54.0
Non-EU	98498	61527	56448	23.2	14.5	13.3
TOTAL	**165276**	**111320**	**85459**	**30.3**	**20.5**	**15.7**

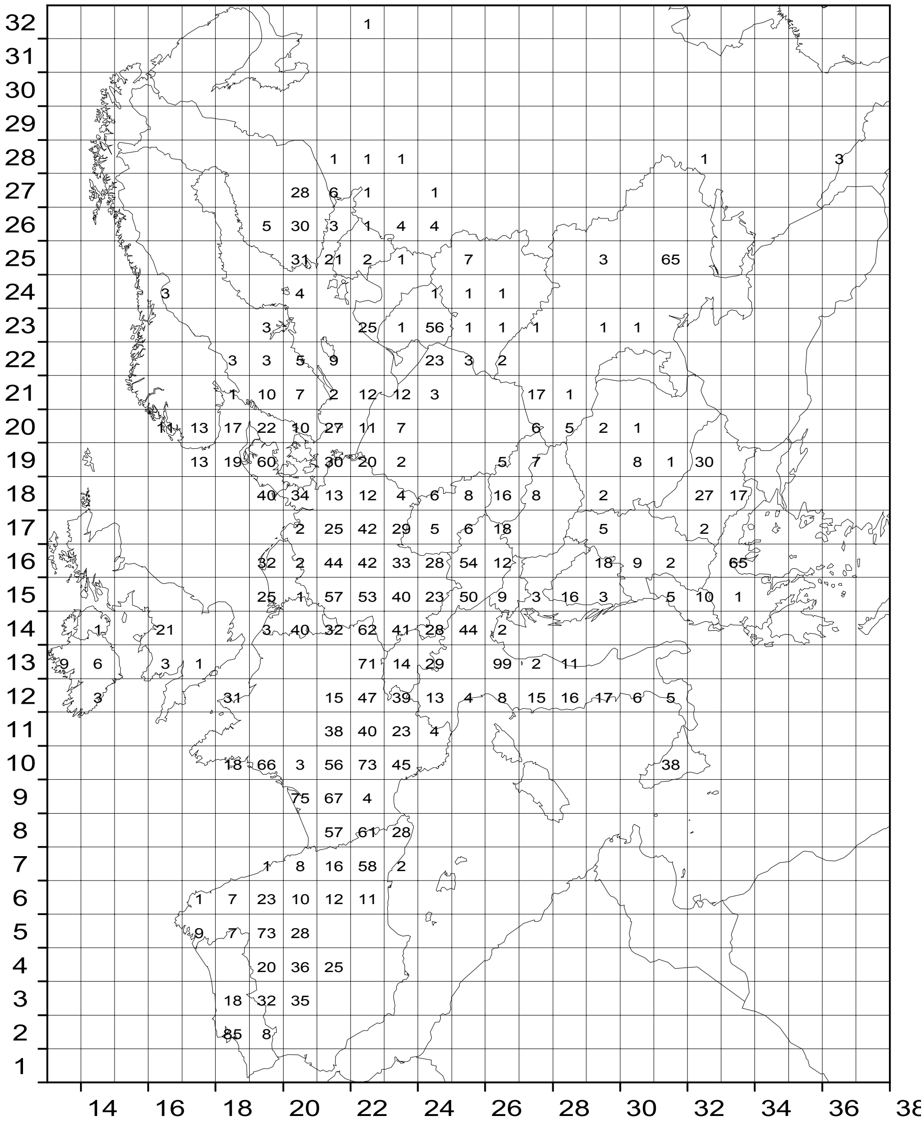

Figure 1.5.2 Ecosystems additionally protected against eutrophication in 2010 in the TD scenario compared with the BL scenario (in percent of the ecosystems' area).

1.5.5 Impacts on Tropospheric Ozone

The indicators outlined in Section 3 (AOT40, AOT60) are used to quantify the impacts of the analyzed control strategies on ozone levels. Table 1.5.14 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 Baseline scenario will substantially reduce population exposure to elevated ozone levels. The average exposure of a person in the EU-15 decreases from 3.5 ppm.hours in 1990 to 1.4 ppm.hours in 2010, i.e., by about 60 percent. Higher relative reductions (70 percent on average) occur in non-EU countries. However, absolute exposure levels in many of the non-EU countries are less than one third of the EU average. Only in Croatia, the Czech Republic, Hungary, Poland, Slovak Republic, Slovenia, and Switzerland are the exposure levels comparable with typical exposures in the EU. For the latter group of countries the reduction in average exposure is similar to the reduction in the EU (57 to 68 percent, respectively).

The TD scenario causes further improvement in mitigation of elevated ozone levels. The average health-related exposure index in EU-15 decreases to 0.7 ppm.hours, i.e., to less than 20 percent of the exposure in 1990. Similarly as for acidification, reduction in emissions in the EU countries also brings benefits in the neighboring non-EU countries. For instance, exposure in the Czech Republic decreases by about 0.4 ppm.hours.

Figure 1.5.3 illustrates the change in spatial distribution of the AOT60 resulting from the TD policies compared with the Baseline. The highest improvements, up to 1.5 ppm.hours, occur in the eastern part of France, in Belgium, the Netherlands and in Luxembourg. A decrease in exposure of more than one ppm.hour occurs in the northwestern part of Germany and in Italy.

Similarly as for health effects, two vegetation-related exposure indices were calculated and they are presented in Table 1.5.15. The cumulative exposure index is calculated as the excess AOT40 (i.e., the AOT40 in excess of the critical level of three ppm.hours) multiplied by the area of ecosystems that are exposed to the excess concentration. The average vegetation exposure index reflects the average excess AOT40 (over all grids in a country). The BL scenario causes a 37 percent decrease of the exposure index for the whole European Union – from 6.6 to 4.1 excess.ppm.hours. The improvement in non-EU countries is 44 percent – from 2.8 to 1.6 excess.ppm.hours. The TD scenario brings further benefits. For the EU-15 the index decreases to 2.7 excess.ppm.hours in TD, i.e., to 41 percent of the exposure in 1990.

The spatial distribution of the decrease in the exposure levels in 2010 achieved through the implementation of the TD scenario is shown in Figure 1.5.4. Values in each grid represent the difference in AOT40 over three ppm.hours between the BL scenario and the TD scenario. In large areas in France, Germany, Italy, Portugal and Spain the exposure in the TD scenario decreases by more than two ppm.hours compared with the Baseline.

Table 1.5.14 Population exposure indices (AOT60) for 1990, the Baseline and the TD scenario.

Country	Cumulative (million person.ppm.hours)			Average (ppm.hours)		
	1990	Baseline	TD	1990	Baseline	TD
Austria	16	4	2	2.0	0.5	0.2
Belgium	71	37	21	6.5	3.4	2.0
Denmark	10	4	1	2.0	0.7	0.3
Finland	0	0	0	0.1	0.0	0.0
France	310	100	45	5.5	1.8	0.8
Germany	405	159	88	5.1	2.0	1.1
Greece	8	3	1	0.8	0.3	0.1
Ireland	3	1	0	0.9	0.3	0.1
Italy	191	69	25	3.3	1.2	0.4
Luxembourg	3	1	1	8.5	3.3	1.7
The Netherlands	74	41	25	4.9	2.8	1.7
Portugal	16	8	3	1.7	0.8	0.3
Spain	39	9	1	1.0	0.2	0.0
Sweden	5	1	0	0.6	0.1	0.0
UK	126	79	43	2.2	1.4	0.7
EU-15	**1276**	**515**	**256**	**3.5**	**1.4**	**0.7**
Albania	2	0	0	0.6	0.1	0.0
Belarus	4	1	0	0.4	0.1	0.0
Bosnia-H.	3	1	0	0.7	0.1	0.0
Bulgaria	4	1	0	0.4	0.1	0.1
Croatia	9	3	2	1.9	0.7	0.4
Czech Republic	34	12	8	3.3	1.1	0.7
Estonia	0	0	0	0.2	0.0	0.0
Hungary	27	12	9	2.6	1.1	0.9
Latvia	1	0	0	0.4	0.1	0.0
Lithuania	2	0	0	0.6	0.1	0.0
Norway	1	0	0	0.2	0.0	0.0
Poland	91	37	26	2.4	1.0	0.7
Rep. of Moldova	3	0	0	0.7	0.1	0.1
Romania	17	5	4	0.8	0.2	0.2
Russia	21	2	2	0.2	0.0	0.0
Slovakia	15	6	5	2.8	1.1	0.9
Slovenia	4	1	0	2.2	0.7	0.2
Switzerland	14	2	0	2.1	0.3	0.0
FYR Macedonia	0	0	0	0.1	0.0	0.0
Ukraine	46	7	6	0.9	0.1	0.1
Yugoslavia	8	3	2	0.7	0.2	0.2
Non-EU	**308**	**95**	**66**	**0.9**	**0.3**	**0.2**
TOTAL	**1584**	**610**	**322**	**2.3**	**0.9**	**0.5**

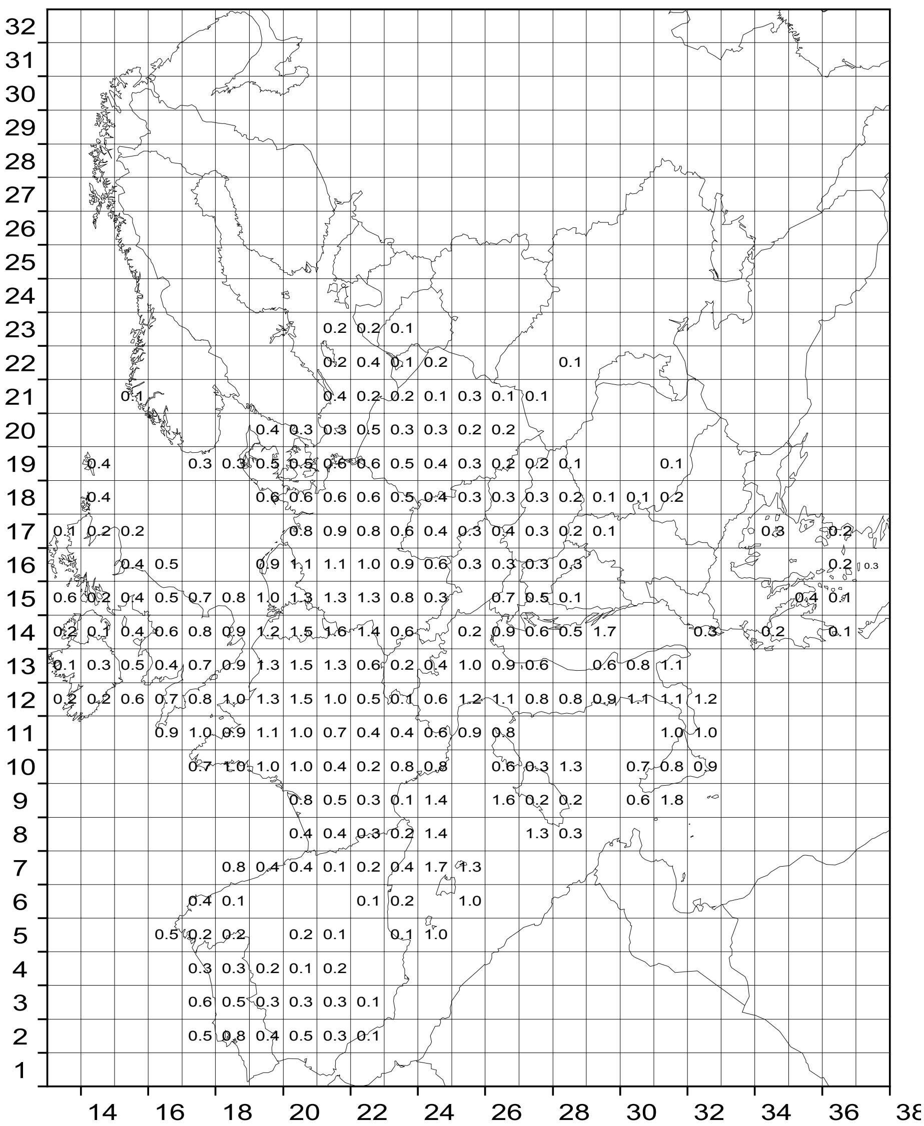

Figure 1.5.3 Decrease in AOT60 in 2010 in the TD scenario compared with the BL scenario (in ppm.hours).

Table 1.5.15 Vegetation exposure indices (AOT40) for 1990, and the BL and the TD scenarios in 2010.

Country	Cumulative (million ha.excess.ppm.hours)			Average (excess.ppm.hours)		
	1990	Baseline	TD	1990	Baseline	TD
Austria	47	26	19	9.0	5.1	3.7
Belgium	18	15	12	11.4	9.5	7.5
Denmark	16	7	4	5.3	2.4	1.2
Finland	0	0	0	0.0	0.0	0.0
France	416	250	164	12.9	7.7	5.1
Germany	234	133	90	11.1	6.3	4.3
Greece	24	17	11	4.5	3.2	2.1
Ireland	3	1	0	1.2	0.5	0.2
Italy	185	127	90	11.7	8.0	5.7
Luxembourg	2	2	1	16.6	10.1	6.9
The Netherlands	11	9	7	8.5	6.6	5.2
Portugal	38	28	17	6.6	4.9	2.9
Spain	209	139	74	6.8	4.5	2.4
Sweden	16	4	1	0.5	0.1	0.0
UK	20	16	11	2.5	2.0	1.4
EU-15	**1240**	**774**	**502**	**6.6**	**4.1**	**2.7**
Albania	9	6	4	5.1	3.5	2.6
Belarus	19	4	2	2.1	0.4	0.3
Bosnia-H.	24	16	13	6.4	4.3	3.4
Bulgaria	36	28	26	4.8	3.8	3.5
Croatia	35	25	20	9.7	6.9	5.6
Czech Republic	57	33	25	10.2	5.9	4.5
Estonia	0	0	0	0.1	0.0	0.0
Hungary	63	40	35	9.7	6.2	5.4
Latvia	4	0	0	1.0	0.1	0.0
Lithuania	8	1	0	1.8	0.4	0.1
Norway	0	0	0	0.0	0.0	0.0
Poland	151	85	65	6.6	3.7	2.9
Rep. of Moldova	8	4	4	4.9	2.6	2.4
Romania	84	61	55	5.4	3.9	3.5
Russia	177	65	61	0.9	0.3	0.3
Slovakia	34	21	18	9.6	6.0	5.1
Slovenia	14	9	7	10.7	7.2	5.6
Switzerland	15	9	6	8.7	5.1	3.5
FYR Macedonia	5	4	3	3.3	2.5	2.0
Ukraine	178	99	92	4.5	2.5	2.3
Yugoslavia	33	25	22	4.8	3.7	3.2
Non-EU	**955**	**538**	**461**	**2.8**	**1.6**	**1.3**
TOTAL	**2195**	**1312**	**962**	**4.1**	**2.5**	**1.8**

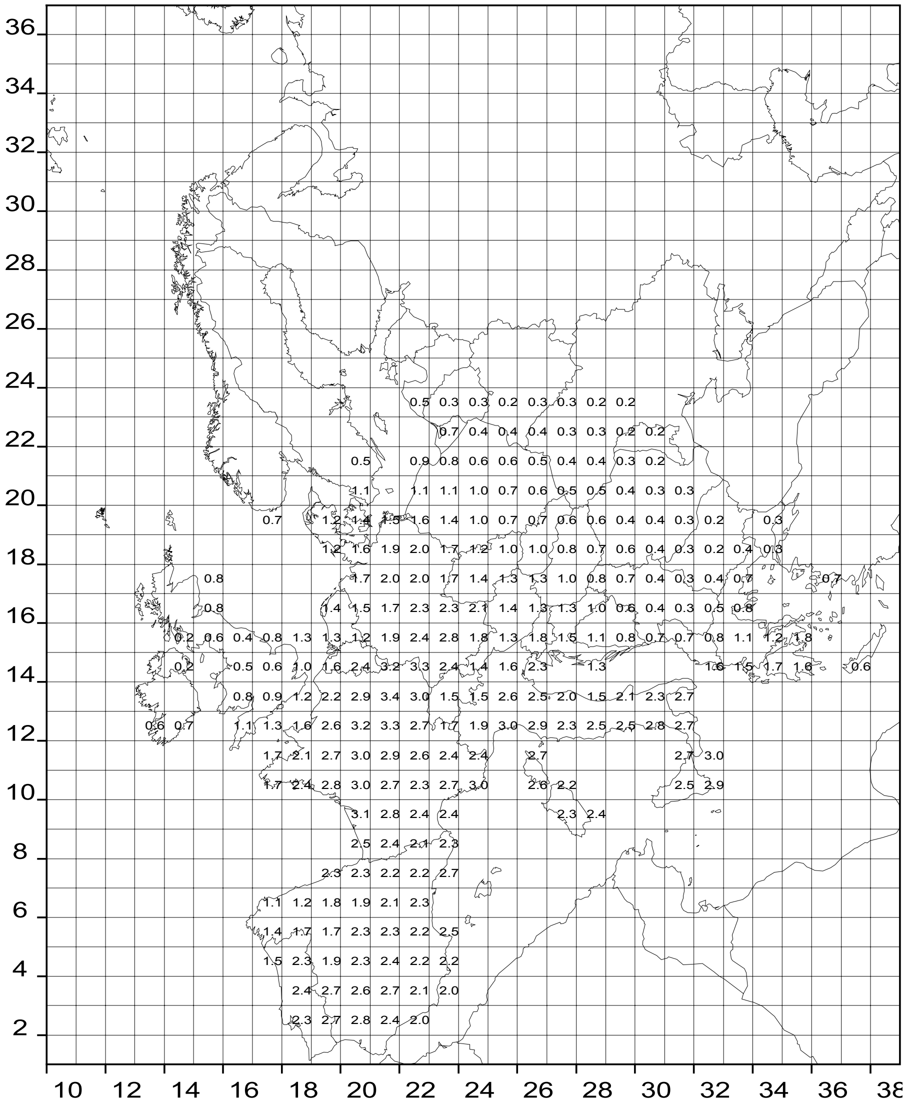

Figure 1.5.4 Decrease in excess of AOT40 over the critical level of 3 ppm.hours in 2010 in the TD scenario compared with the BL scenario (in ppm.hours).

1.6 Accelerated Policy (AP) Scenarios

1.6.1 Environmental Targets for the AP Scenarios

As demonstrated in the section describing the Baseline scenario, currently adopted emission controls are expected to significantly reduce harmful excess exposure to ground-level ozone and acidification by the year 2010. However, there will still be significant areas in Europe where health and vegetation protection will not be achieved. Furthermore, model analysis of the TD scenario shows that the presently available technical emission control measures will not be sufficient to meet the no-damage levels everywhere in Europe within the next one or two decades without interfering with the 'business as usual' expectations on economic development and energy consumption.

Therefore, the acidification and ozone strategies of the EU (COM(97)88,1987, COM(99)125 final, 1999) formulated environmental interim targets, which should guide the next step towards the full achievement of the environmental long-term objectives. This report adopts those interim targets and explores, for the AP activity levels resulting from the energy forecasts, the cost-optimal allocation of emission reductions to simultaneously achieve the acidification and ozone targets. No targets have been set for eutrophication. Thus all changes of eutrophication indicators are caused by emission reductions necessary to achieve acidification targets.For the individual environmental problems, the environmental constraints to be achieved by the optimized emission reductions can be summarized as follows.

1.6.1.1 Acidification

- **The general target of the EU acidification strategy is to reduce by the year 2010 the area of ecosystems not protected against acidification by at least 50 percent compared to 1990. For the energy and agricultural scenarios used for the development of that strategy, the target area results in about 4.3 million hectares of unprotected ecosystems in the EU-15.**

  In the optimization routine, a scenario based on a 95 percent gap closure of the accumulated excess acidity[5], which achieves a 50 percent area gap closure target, was implemented. In order to increase the cost-effectiveness of the scenario so that single ecosystems might not demand excessively expensive measures, some spatial flexibility in achieving the overall target was introduced. A balancing mechanism now allows limited violation of the targets in single grid cells, as long as they are compensated for by additional improvements (in terms of accumulated excess acidity) in other grid cells in the same country.

1.6.1.2 Health-relevant ozone exposure

- **The principal interim target towards the environmental long-term objective is a relative reduction of the AOT60 (the surrogate indicator for health-related excess ozone exposure) by two thirds between 1990 and 2010.**

  In order to minimize the influence of existing model uncertainties and to increase the robustness of the optimized solution, this 67 percent 'gap closure' is defined in relation to a model confidence interval. Furthermore, within certain limits, violations of these targets are allowed for individual grid cells or meteorological years, if the excess is compensated for by additional improvements in other years or other grid cells in the same country (on a population-weighted basis).

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[5] Acid deposition in excess of critical loads, accumulated for all ecosystems in a grid cell. The purpose of using the accumulated excess is to avoid focussing on a specific ecosystem (percentile of the cumulative critical load distribution) and thus increase the robustness of the modeling results.

- **Further, highest excess ozone in the EU-15 is addressed by introducing an absolute ceiling on the AOT60 of 2.9 ppm.hours.**

  In order to minimize the influence of rare and perhaps untypical meteorological conditions and to tailor the strategy for maximum effectiveness for the most frequent meteorological ozone regimes, this ceiling must be maintained under the meteorological conditions of four out of the five years for which model analyses are available. This means that for each grid cell the meteorological conditions of the year in which improvements are most difficult to achieve is neglected.

1.6.1.3 Vegetation-relevant ozone exposure

- **The general objective is to reduce the excess AOT40 (the indicator for vegetation-related excess ozone) by one third between 1990 and 2010.**

  The definition of the AOT40 relates to the average meteorological conditions over a five- year period. Violations of the gap closure targets are allowed for individual grid cells if the excess is compensated for by additional improvements in other grid cells in the same country (on an ecosystems area-weighted basis).

- **Further, the highest excess AOT40 in the EU-15 is limited to an absolute ceiling of 10.0 ppm.hours.**

  Since the definition of the AOT40 already refers to the average meteorological conditions and considers extreme meteorological conditions only on a weighted basis, no exceptions are applied to this target.

The summary of the above-described targets is shown in Table 1.6.1. It should be stressed that no specific targets have been set for eutrophication. However, NO_x and NH_3 emissions reductions for acidification and ground-level ozone have an influence on the eutrophication situation. Thus, eutrophication impacts result from ozone and acidification targets. Details on the target setting rules can be found in (Amann et al., 1998).

Table 1.6.1 Summary of the environmental targets for the AP scenarios.

Effect/target	Value
Acidification	
Gap closure on accumulated excess acidity	95 %
Maximum excess deposition for the 2-percent of the most sensitive ecosystems	(850 eq/ha)
Health-related ozone	
Gap closure on AOT60	67 %
Maximum AOT60, to be achieved in 4 out of 5 years	2.9 ppm.h
Vegetation-related ozone	
Gap closure on AOT40	33 %
Maximum excess AOT40, mean over five years	10 ppm.h

1.6.2 Emissions and Emission Control Costs

This section discusses the emission ceilings for individual countries that enables the achievement of the targets specified in the previous section. The ceilings were determined by the RAINS optimization routine. As explained in Section 5.1, the Baseline scenario includes only legislation decided upon until the end of 1997. During 1998, new environmental legislation (emission standards) have been either proposed or adopted, but are not taken into account in the Baseline. However, they have been included in the AP runs. These are:

- the Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel and amending Council Directive 93/12/EEC (OJ, 1998);
- the 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 from motor vehicles and amending Council Directive 70/220/EEC (OJ, 1998);
- post-2005 standards for heavy-duty vehicles reflecting the Common Position reached in December 1998 between the European Parliament and the Council on amending the 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). These standards will be implemented in two stages (2005/2006 and 2008/2009).
- standards from the proposal for a revision of the Large Combustion Plant Directive (COM(98)415 final);
- the limit the sulfur content of gas oil for stationary sources to 0.1 percent (Directive on sulfur in liquid fuels).

This legislation decided upon in 1998 would have decreased the Baseline emissions of SO_2 in the EU member states by 170 kilotons (three percent), emissions of NO_x by 510 kilotons (seven percent) and emissions of VOC form mobile sources by 180 kilotons (11 percent). The emission control costs increase by 13 percent compared to the case where only 1997 legislation is included.

Emissions of the pollutants contributing to acidification, eutrophication and tropospheric ozone for the EU countries for the AP scenarios are shown in Tables 1.6.2 to 1.6.4. The AP emissions are lower than for the Baseline. This is caused by the:

- introduction of strict environmental targets in the optimization routine;
- lower activity levels (energy consumption) in those scenarios; and
- inclusion of 1998 emission and fuel standards for all countries.

In the AP_NT scenario, where the most profound changes in energy supplies are induced by the requirement to reduce emissions of greenhouse gases, the emissions of SO_2 are 42 percent lower than in the Baseline. Emissions of NO_x and VOC are 25 percent and 20 percent lower, respectively. Emissions of NH_3 decrease by six percent compared with the Baseline.

Emission control costs have also been calculated for each of the scenarios. Compared with the costs of the Baseline measures for the EU-15 (about € 67.3 billion/year), costs in the 'No climate change policy' (AP_NC) scenario are € 13.6 billion/year, or 20 percent higher. The cost of controlling NO_x and VOC emissions contributes 79 percent to total costs, and controls of SO_2 and NH_3 eight percent and three percent, respectively. In the case where the targets for reducing the emissions of greenhouse gases needs to be achieved for each country without trading emission rights, i.e., exclusively through structural changes in the energy system (AP_NT case), the control costs decrease by 7.5 percent to € 74.8 billion/year. For the 'Full trade' (AP_FT) scenario the costs savings are about four percent compared with the AP_NC scenario. These examples clearly demonstrate a synergistic effect between climate change, acidification and ozone policies. The achievement of acidification and ozone targets becomes cheaper if climate change policies are simultaneously implemented.

Significant spatial differences in (i) the severity of the ozone and acidification problems, (ii) the extent to which emission controls are already implemented, and (iii) the structures of energy consumption and energy intensities, are the main factors explaining the fact that additional measures for individual pollutants are not uniformly allocated across all Member States. For instance, in Belgium the SO_2 control costs in the 'No Climate Policy' (AP_NC) scenario are 41 percent higher than in the 'No Trade' (AP_NT) scenario, while the emissions in the latter scenario are 19 percent lower than in the AP_NC case.

Table 1.6.2 Emissions and emission control costs of pollutants contributing to acidification, eutrophication and elevated ozone levels in the EU-15 for 2010, AP_NC scenario.

Country	Emissions, kilotons				Costs, € million/a			
	NO_x	VOC	NH_3	SO_2	NO_x/VOC	NH_3	SO_2	Total
Austria	88	138	67	43	1236	0	290	1526
Belgium	116	101	60	73	2311	396	589	3296
Denmark	147	86	71	90	761	0	199	959
Finland	149	128	31	116	803	0	321	1124
France	681	858	718	307	9442	52	2144	11638
Germany	1005	961	445	410	15556	678	4733	20966
Greece	260	172	74	508	1054	0	321	1375
Ireland	58	49	123	30	442	38	218	698
Italy	850	1013	430	374	10914	0	1873	12787
Luxembourg	6	6	7	3	125	19	17	161
The Netherlands	243	156	105	50	2711	1094	476	4282
Portugal	176	104	67	161	1508	0	241	1749
Spain	748	620	353	745	6383	36	1235	7653
Sweden	155	172	48	67	1491	144	583	2218
UK	1180	1014	264	464	8828	29	1582	10439
EU-15	**5861**	**5578**	**2863**	**3441**	**63565**	**2486**	**14824**	**80875**

Table 1.6.3 Emissions and emission control costs of pollutants contributing to acidification, eutrophication and elevated ozone levels in the EU-15 for 2010, AP_NT scenario.

Country	Emissions, kilotons				Costs, € million/a			
	NO_x	VOC	NH_3	SO_2	NO_x/VOC	NH_3	SO_2	Total
Austria	89	174	67	36	1108	0	241	1349
Belgium	99	97	69	59	2161	187	418	2766
Denmark	137	85	71	58	724	0	175	898
Finland	128	130	31	116	759	0	176	935
France	648	802	771	245	9433	0	1795	11228
Germany	995	968	473	399	15078	397	4053	19528
Greece	251	182	74	378	996	0	299	1296
Ireland	51	47	126	25	417	11	143	571
Italy	831	1079	432	162	10462	0	1297	11759
Luxembourg	6	6	7	4	126	19	17	162
The Netherlands	192	150	107	39	2394	981	333	3707
Portugal	127	119	67	91	1455	0	206	1661
Spain	695	618	353	750	6225	36	1074	7334
Sweden	179	213	48	57	1331	144	466	1942
UK	1083	1064	274	383	8313	15	1330	9658
EU-15	**5510**	**5732**	**2969**	**2801**	**60980**	**1790**	**12020**	**74790**

Table 1.6.4 Emissions and emission control costs of pollutants contributing to acidification, eutrophication and elevated ozone levels in the EU-15 for 2010, AP_FT scenario.

Country	Emissions, kilotons				Costs, € million/a			
	NO_x	VOC	NH_3	SO_2	NO_x/VOC	NH_3	SO_2	Total
Austria	89	148	67	39	1170	0	257	1427
Belgium	111	100	69	68	2288	187	547	3022
Denmark	143	86	71	90	750	0	168	919
Finland	138	130	31	116	785	0	220	1005
France	658	873	725	270	9271	42	1886	11198
Germany	974	966	466	369	15312	464	4291	20067
Greece	260	187	74	382	1023	0	316	1339
Ireland	58	48	125	27	432	24	192	648
Italy	815	1081	432	255	10732	0	1612	12344
Luxembourg	7	6	7	4	107	19	17	143
The Netherlands	230	156	105	43	2656	1057	412	4125
Portugal	145	109	67	149	1501	0	227	1728
Spain	715	617	353	746	6324	36	1145	7505
Sweden	160	214	48	63	1405	144	553	2102
UK	1136	1020	274	424	8696	15	1371	10082
EU-15	**5639**	**5739**	**2912**	**3045**	**62451**	**1989**	**13213**	**77653**

1.6.3 Impacts on Acidification and Eutrophication

As described in Section 5.4, the implementation of environmental legislation as in the Baseline scenario causes a substantial improvement in the protection of natural ecosystems in Europe compared with the protection level at the beginning of the 1990s. The AP scenarios bring further improvement. In the ‘No trade’ (AP_NT) scenario, the share of ecosystems unprotected against acidification decreases from 4.6 percent in the Baseline to 2.8 percent. In Germany, the share of unprotected ecosystems decreases to 7.2 percent, and in the Netherlands to 23.6 percent. Implementation of the AP_NT scenario causes an additional protection of 39 percent of the Dutch ecosystems compared with the Baseline (Table 1.6.5). Since the solution for the AP group of scenarios is driven by the same environmental targets, the differences in protection levels for individual countries within the AP group of scenarios are small.

Improvements also occur in the protection levels of eutrophication (Table 1.6.6). Again, important changes occur already in the BL scenario. For the EU-15 the percentage of unprotected ecosystems decreases from 55 percent in 1990 to 41 percent in 2010. The AP scenarios reduce the area not protected against eutrophication in the whole EU to less than 36 percent. The highest improvement – compared with the Baseline (9–14 percent) occurs in Austria, Belgium, Denmark, Germany and Luxembourg. As for acidification, the differences in protection levels for individual countries among the AP scenarios are small.

The spatial distribution of the improvement in protection levels is presented in Figure 1.6.1and in Figure 1.6.2. The maps show the percentage of ecosystems additionally protected in the AP_NT case compared with the protection achieved in the Baseline (BL).

Table 1.6.5 Ecosystems with acid deposition above their critical loads for acidification for the AP scenarios in 2010.

Country	1000 hectares				Percent of ecosystems			
	Baseline	AP_NC	AP_NT	AP_FT	Baseline	AP_NC	AP_NT	AP_FT
Austria	200	98	95	95	4.0	2.0	1.9	1.9
Belgium	162	53	52	53	23.1	7.5	7.4	7.5
Denmark	10	6	5	6	2.5	1.5	1.3	1.5
Finland	1167	1150	1137	1143	4.3	4.2	4.2	4.2
France	224	89	90	89	0.7	0.3	0.3	0.3
Germany	1893	756	738	724	18.4	7.4	7.2	7.1
Greece	0	0	0	0	0.0	0.0	0.0	0.0
Ireland	14	9	9	9	1.5	1.0	0.9	1.0
Italy	117	55	53	53	1.1	0.5	0.5	0.5
Luxembourg	6	1	1	1	6.6	0.9	0.9	0.9
The Netherlands	200	76	75	75	62.4	23.7	23.6	23.5
Portugal	1	1	1	1	0.0	0.0	0.0	0.0
Spain	18	17	17	17	0.2	0.2	0.2	0.2
Sweden	1693	1432	1339	1403	4.4	3.7	3.5	3.6
UK	1204	626	556	608	12.6	6.5	5.8	6.3
EU-15	**6907**	**4368**	**4167**	**4276**	**4.6**	**2.9**	**2.8**	**2.9**

Table 1.6.6 Ecosystems with nitrogen deposition above their critical loads for eutrophication for the AP scenarios in 2010.

Country	1000 hectares				Percent of ecosystems			
	Baseline	AP_NC	AP_NT	AP_FT	Baseline	AP_NC	AP_NT	AP_FT
Austria	3519	2786	2814	2799	58.9	46.7	47.1	46.9
Belgium	681	592	612	608	97.0	84.3	87.2	86.6
Denmark	124	93	91	92	39.5	29.5	29.0	29.3
Finland	2186	2171	2035	2075	13.2	13.2	12.3	12.6
France	26233	22521	23532	22525	82.6	70.9	74.1	70.9
Germany	9317	7668	7896	7843	90.8	74.7	77.0	76.5
Greece	225	208	202	207	9.2	8.5	8.2	8.4
Ireland	59	53	55	55	6.4	5.8	6.1	6.0
Italy	3821	3443	3444	3434	31.9	28.7	28.7	28.7
Luxembourg	81	67	69	68	92.3	75.9	78.7	77.1
The Netherlands	292	279	279	279	91.2	87.1	87.0	87.1
Portugal	830	765	632	743	29.3	27.1	22.3	26.3
Spain	1334	964	847	880	15.7	11.3	9.9	10.3
Sweden	965	753	746	746	5.1	4.0	4.0	4.0
UK	127	63	64	66	1.4	0.7	0.7	0.7
EU-15	**49793**	**42425**	**43318**	**42419**	**41.3**	**35.2**	**35.9**	**35.2**

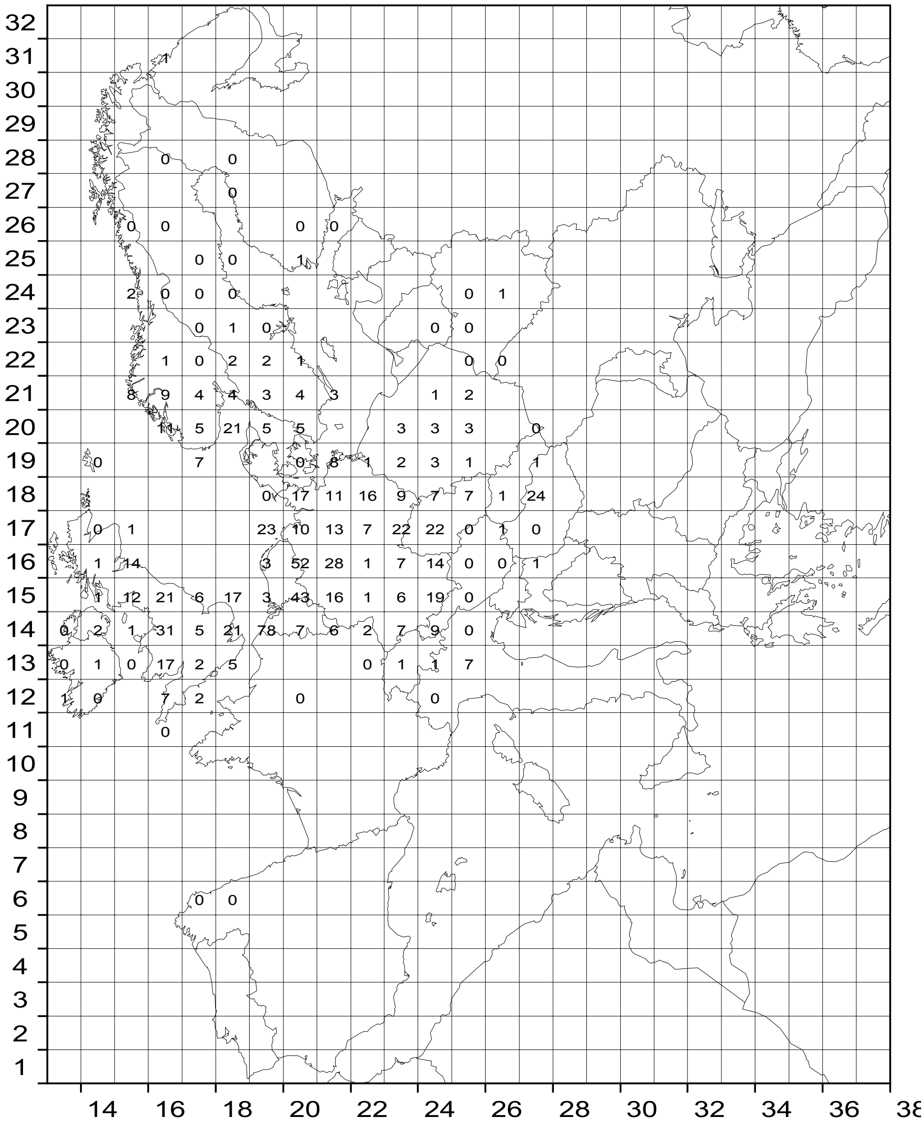

Figure 1.6.1 Ecosystems additionally protected against acidification in 2010 in the AP_NT scenario compared with the BL scenario (in percent of the ecosystems' area).

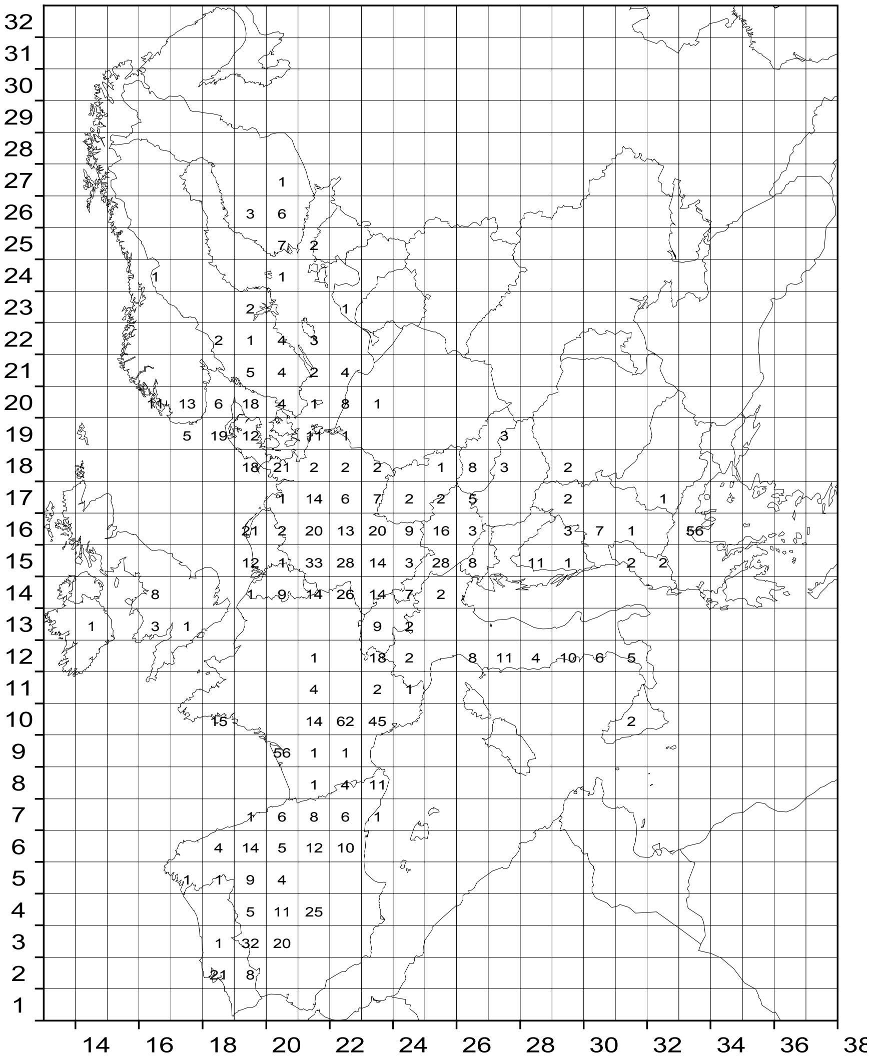

Figure 1.6.2 Ecosystems additionally protected against eutrophication in 2010 in the AP_NT scenario compared with the BL scenario (in percent of the ecosystems' area).

1.6.4 Impacts on Tropospheric Ozone

Table 1.6.7 presents the AOT60 indicators for the AP scenarios in 2010 and compares them with the Baseline. Already the implementation of the Baseline scenario substantially reduces the population exposure to elevated ozone levels. The average exposure of a person in the EU-15 decreases from 3.5 ppm.hours in 1990 to 1.4 ppm.hours in 2010, i.e., by 60 percent. The AP scenarios cause further decline in exposure. The average health-related exposure index in the EU-15 decreases to 0.8 ppm.hours, i.e., to 23 percent of the exposure in 1990. Compared with the Baseline, the average EU-15 exposure is reduced by 42 percent. For France, this reduction reaches 50 percent. Since the same environmental targets drive the AP scenarios, the differences in impacts for those scenarios are small.

Figure 1.6.3 illustrates the likely change in spatial distribution of AOT60 as a result of implementing the AP_NT scenario compared with the Baseline. The highest improvements, up to 1.3 ppm.hours, occur in the eastern part of France, Belgium, the Netherlands and in Luxembourg. A decrease in exposure of more than 0.6 ppm.hour occurs in the northwestern part of Germany and in single grids in Italy.

Vegetation-related indices for the AP scenarios are presented in Table 1.6.8. The BL scenario causes a 38 percent decrease of the exposure index for the whole European Union - from 6.6 to 4.1 excess.ppm.hours. The AP scenarios further reduce the impacts. For instance, for the AP_NT case the EU-wide index decreases to 3.0 excess.ppm.hours, i.e., to 45 percent of the exposure in 1990. Spatial distribution of the decrease in the exposure levels in 2010 associated with the implementation of the AP_NT scenario is shown in Figure 1.6.4. Values in each grid represent the difference in AOT40 over three ppm.hours between the BL scenario and the AP_NT case. In France, Germany and Belgium the exposure decreases by more than two ppm.hours compared with the Baseline. The improvement in Italy, the Netherlands, Portugal and Spain is higher than one ppm.hour.

There are other statistics against which improvement in ozone exposure could be evaluated. One indicates the remaining days on which the WHO health guideline (60 ppb) level is exceeded. Figure 1.6.5 to Figure 1.6.7 illustrate the spatial distribution of that indicator in 1990, and in 2010 for the Baseline and for the AP_NT scenario. Numbers in the graphs present the maximum of the three-years moving averages over the five years. Figure 1.6.5 displays the number of days on which the WHO health guideline value (60 ppb, eight-hour moving average) was exceeded with the 1990 emissions. Most frequent excess is calculated for Italy (about 60 days), while northern France experienced about 50 days and Germany 30–45 days. Spain, Portugal, Greece, Ireland and the UK are mainly between 10 and 20, while Scandinavian grids show typically below 10 days excess. The decrease in emissions due to controls implemented in the Baseline case (NO_x 45 percent and VOC 49 percent compared to 1990) is expected to have profound impacts on ozone exposure. The maximum number of violations is expected to decline to 35 days in France, about 30 in Italy and approximately 25 in Germany (Figure 1.6.6). As is to be expected from the stringency of the environmental targets, ozone exposure resulting from the AP emissions is clearly lower than the Baseline. The number of days with ozone above the WHO guideline value declines, e.g., in northern France from about 35 for the Baseline, to about 25 in the AP_NT scenario. In Italy, exceedances decline from 30 to about 20 days, and in Germany and the Netherlands from 2025 days down to 13–19 days (Figure 1.6.7). The maximum exceedance, if averaged over three years, declines for AP_NT from about 55–60 days[6] in 1990 (at the German/French border and in Italy) to about 27 in the Benelux region.

[6] For land-based grid cells only.

Table 1.6.7 Population exposure indices (AOT60) for the NTPS scenarios in 2010.

Country	Cumulative (million person.ppm.hours)				Average (ppm.hours)			
	Baseline	AP_NC	AP_NT	AP_FT	Baseline	AP_NC	AP_NT	AP_FT
Austria	4	2	2	2	0.5	0.3	0.3	0.3
Belgium	37	23	22	22	3.4	2.1	2.0	2.1
Denmark	4	1	2	2	0.7	0.3	0.3	0.3
Finland	0	0	0	0	0	0.0	0.0	0.0
France	100	52	50	51	1.8	0.9	0.9	0.9
Germany	159	98	96	96	2	1.2	1.2	1.2
Greece	3	2	3	3	0.3	0.2	0.3	0.3
Ireland	1	0	0	0	0.3	0.1	0.1	0.1
Italy	69	39	40	40	1.2	0.7	0.7	0.7
Luxembourg	1	1	1	1	3.3	2.0	1.9	2.0
The Netherlands	41	27	26	27	2.8	1.8	1.8	1.8
Portugal	8	6	5	6	0.8	0.6	0.6	0.6
Spain	9	3	3	3	0.2	0.1	0.1	0.1
Sweden	1	0	0	0	0.1	0.0	0.0	0.0
UK	79	47	48	47	1.4	0.8	0.8	0.8
EU-15	**515**	**301**	**297**	**300**	**1.4**	**0.8**	**0.8**	**0.8**

Table 1.6.8 Vegetation exposure indices (AOT40) for the AP scenarios in 2010.

Country	Cumulative (million ha.excess.ppm.hours)				Average (excess.ppm.hours)			
	Baseline	AP_NC	AP_NT	AP_FT	Baseline	AP_NC	AP_NT	AP_FT
Austria	26	21	21	21	5.1	4.1	4.1	4.1
Belgium	15	12	12	12	9.5	7.4	7.4	7.4
Denmark	7	4	4	4	2.4	1.3	1.3	1.3
Finland	0	0	0	0	0	0.0	0.0	0.0
France	250	180	173	177	7.7	5.6	5.4	5.5
Germany	133	94	94	94	6.3	4.5	4.4	4.4
Greece	17	14	14	14	3.2	2.5	2.5	2.5
Ireland	1	0	0	0	0.5	0.1	0.1	0.1
Italy	127	100	101	101	8	6.4	6.4	6.4
Luxembourg	2	1	1	1	10.1	7.2	7.0	7.1
The Netherlands	9	6	7	7	6.6	4.9	5.1	5.0
Portugal	28	24	22	23	4.9	4.1	3.8	3.9
Spain	139	107	98	101	4.5	3.5	3.2	3.3
Sweden	4	1	1	1	0.1	0.0	0.0	0.0
UK	16	10	11	10	2	1.2	1.3	1.2
EU-15	**774**	**574**	**558**	**564**	**4.1**	**3.1**	**3.0**	**3.0**

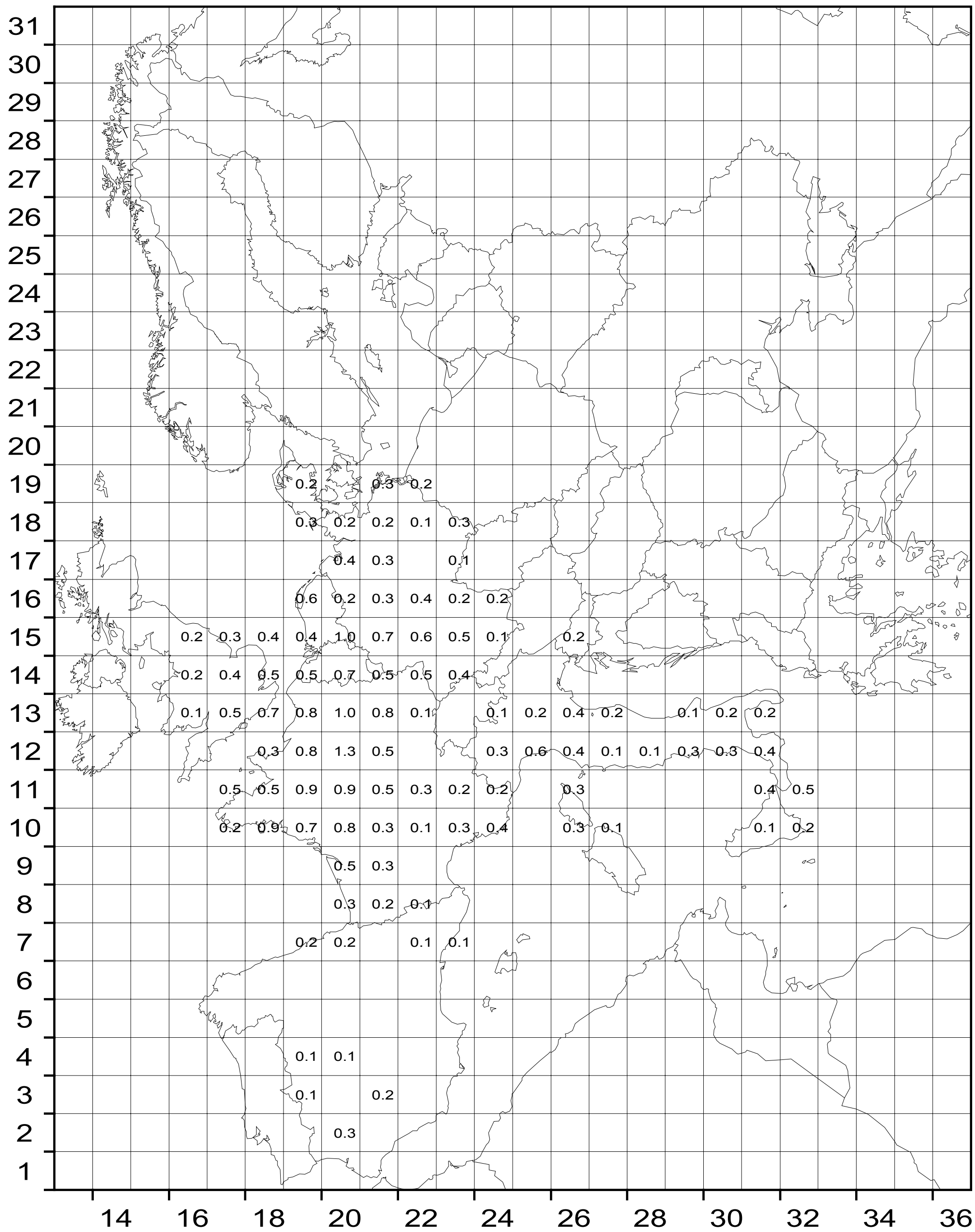

Figure 1.6.3 Decrease in AOT60 in 2010 in the AP_NT scenario compared with the BL scenario (in ppm.hours).

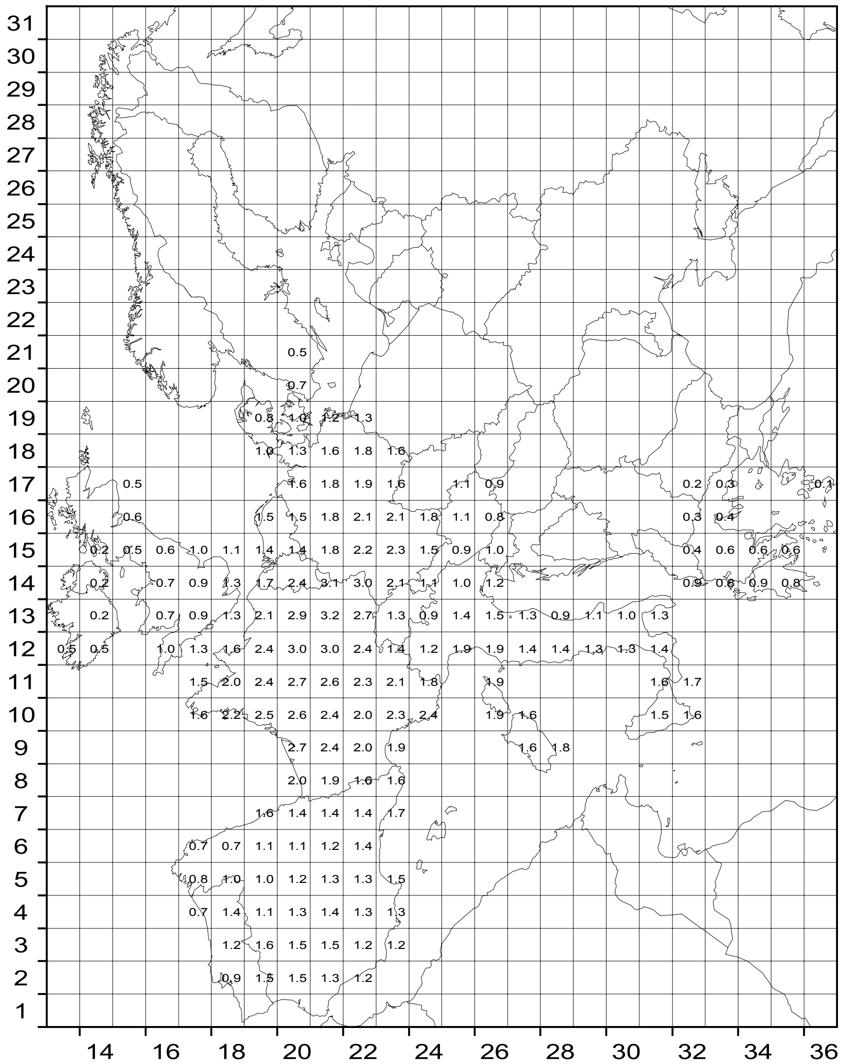

Figure 1.6.4 Decrease in excess of AOT40 over the critical level of 3 ppm.hours in 2010 in the AP_NT scenario compared with the BL scenario (in ppm.hours).

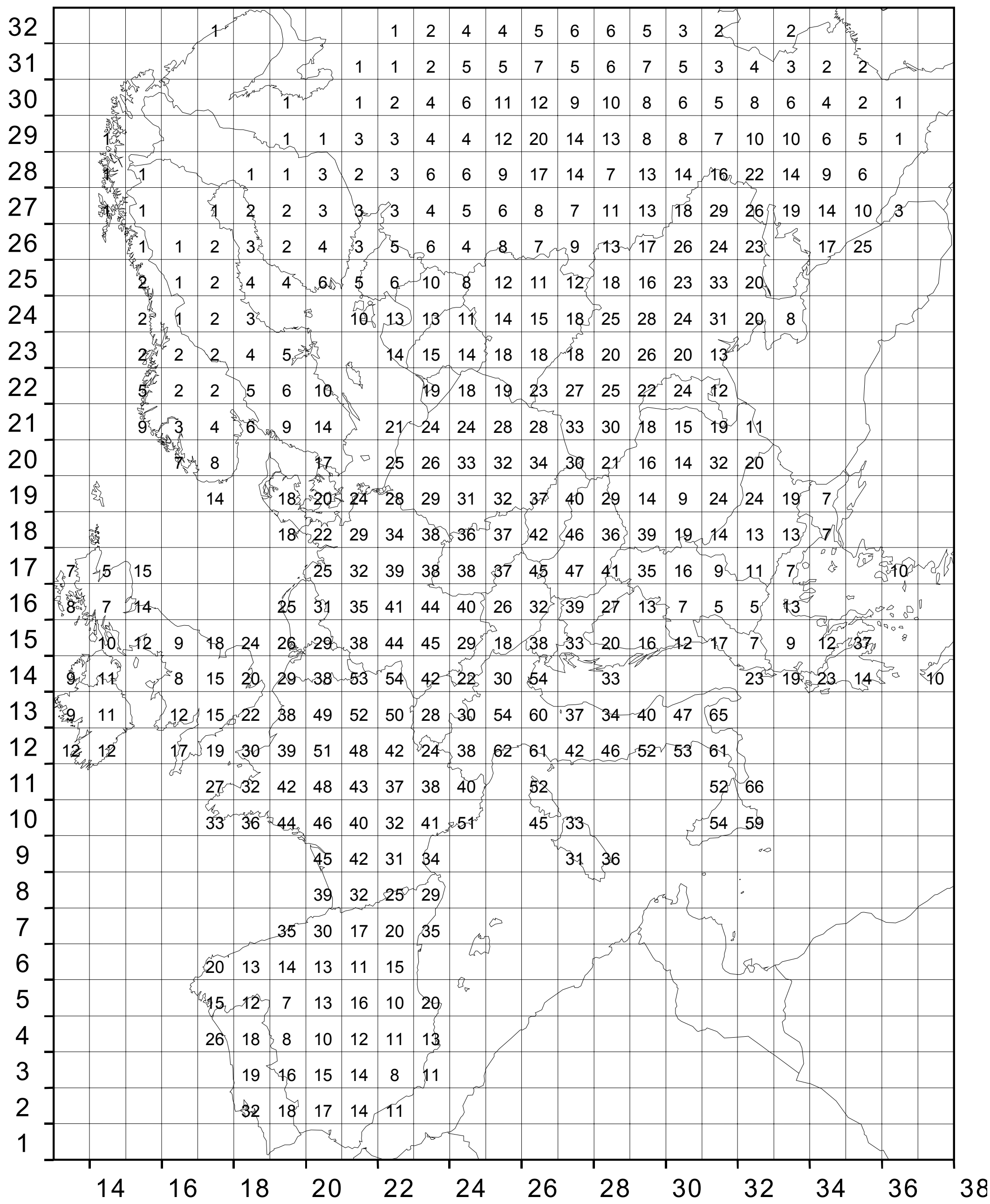

Figure 1.6.5 Number of days with ozone above 60 ppb, emissions of 1990, maximum of the three-years moving average over the five meteorological years.

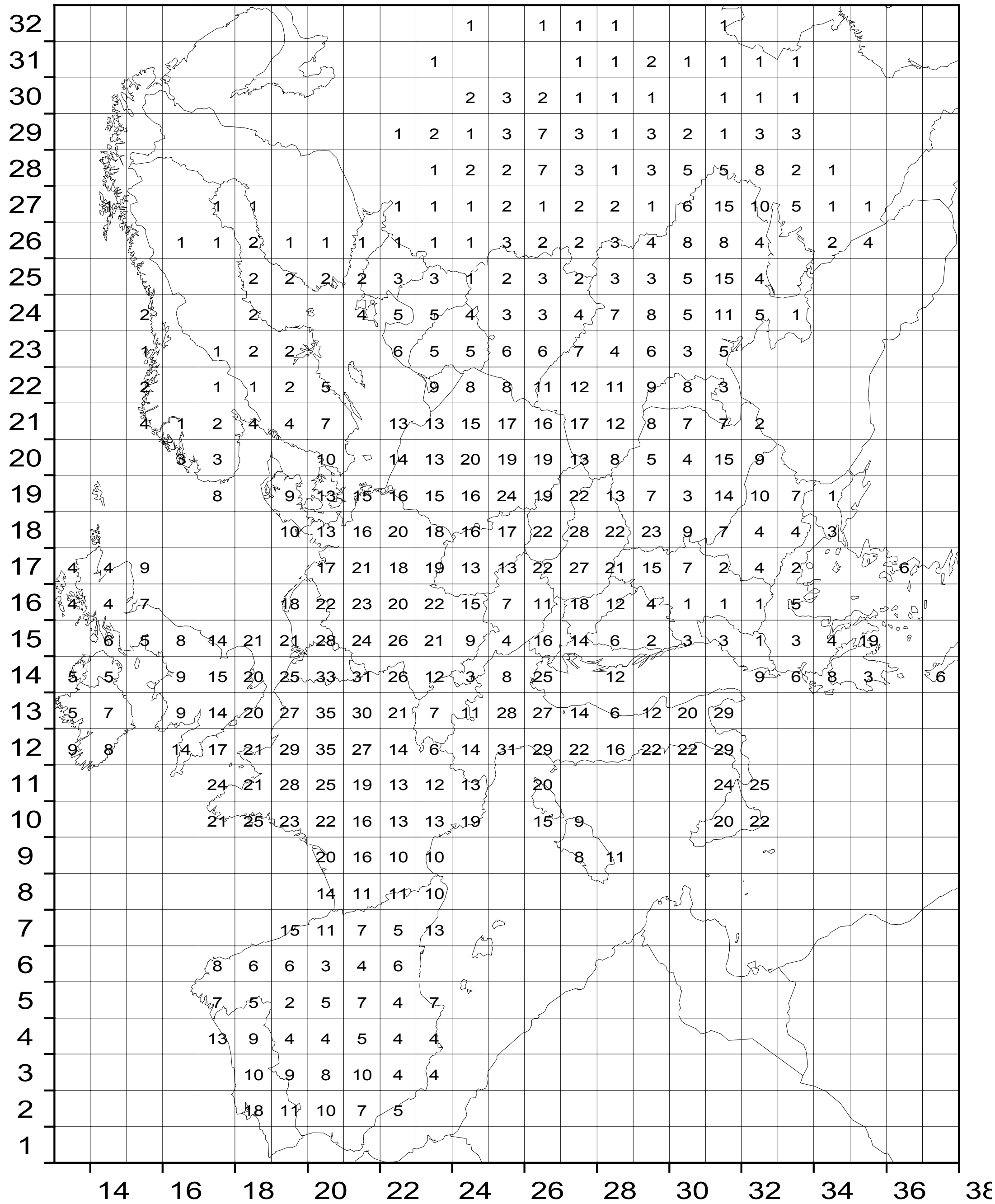

Figure 1.6.6. Number of days with ozone above 60 ppb, emissions of the Baseline case, maximum of the three-years moving average over the five meteorological years.

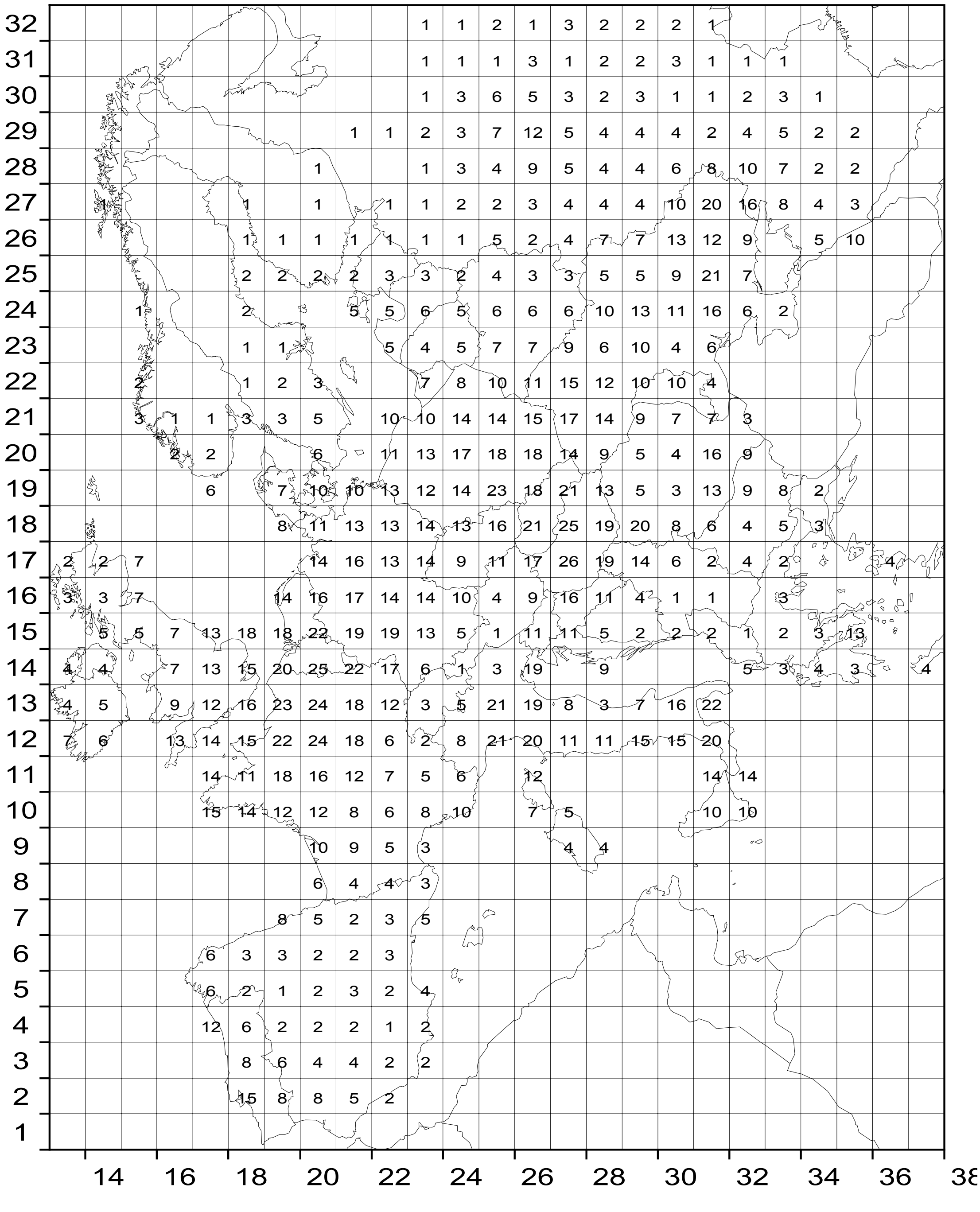

Figure 1.6.7 Number of days with excess of the WHO guideline value of 60 ppb resulting from the emissions of the NTPS_NT scenario, three-years moving average over five years.

1.7 Robustness of Results and Key Policy Actions

Without doubt there exists considerable uncertainty in almost all parts of the model framework, e.g., in emission inventories, the estimates of activity rates and emission control potentials, the atmospheric dispersion calculations and the estimate of environmental sensitivities. A systematic assessment of the role of individual model and data uncertainties is a complex matter and would require substantial time and resources which is currently not available. Standard techniques for estimating the propagation of individual uncertainties through the chain of calculation steps (as is the case for the optimization routine in RAINS) typically requires several (10,00–100,000) model runs. A single, non-linear optimization for one of the AP scenarios presented in this report might consume about 72 hours of CPU time on a fast workstation, illustrating the technical difficulties of performing standard methods of uncertainty analysis.

Nevertheless, work done at IIASA on uncertainties in the modeling approach, as well as sensitivity analyses (Heyes et al., 1999), allows the conclusion that the optimized emission reduction levels appear as robust towards (limited) increases in projected activity rates (first of all energy consumption), reduced emission control potentials and increased costs for emission controls. Lower activity rates, however, do generally result in lower emission levels to relax the most expensive emission controls. Cost savings for scenarios with lower activity rates are substantial: 20 to 40 percent of the costs for the original scenario with the same environmental targets but with higher activity rates.

These general conclusions from a wider work on uncertainty of RAINS are confirmed by the results obtained in this study. As demonstrated in Section 1.6, the emission ceilings for the family of AP scenarios are similar. This is because the solution is driven by the same set of environmental targets for all scenarios. However, for the AP_NT scenario with a lower level of energy consumption (induced by compliance with Kyoto targets in each of the EU member countries) the emission control costs are 20 percent lower than in the AP_NC scenario where no restructuring of the energy system is assumed.

The results also demonstrate that uniform implementation of the best available control technologies in all countries, as in the TD scenario, is costly and brings limited environmental benefits. Thus, European control strategies should be driven by environmental sensitivities in individual regions and be tailored to the needs of each country. The AP policies, with country-specific targets, achieve 92 to 97 percent of the potential improvement of TD measures for acidification and ozone and more than 60 percent for acidification. Depending on the type of policy regarding mitigation of greenhouse gas emissions the costs are 27 to 32 percent lower than the TD costs.

As mentioned above, the Baseline control policies are already quite strict. They include Community-wide emission and fuel standards. However, further measures need to be taken in each country to achieve the environmental targets for acidification and tropospheric ozone of the AP scenarios. These measures need to be implemented on top of Baseline measures. There are no measures that are cost-efficient in all EU member countries. Additional technical measures that are cost-efficient for at least one third of the EU member countries are:

- Limiting sulfur contents for fuels used in national sea traffic[7] as well as implementation of NO_x control measures in that sector;
- Stricter controls on emissions from industrial processes other than energy combustion;
- Further reduction of NO_x emissions from off-road vehicles through enforcement of standards similar to those for road vehicles;
- Implementation of techniques to further control SO_2 and NO_x emissions from stationary combustion sources going beyond current legislation in countries with high sensitivities of ecosystems to air pollution as well with a high density of emissions of ozone precursors;
- Further controls of VOC emissions from liquid fuels processing and distribution;

[7] Ships operating in coastal zones and among ports in the same country.

- Promotion of low solvent paints in professional, industrial, and 'do it yourself' applications; and
- Better controls of VOC emissions from two-stroke engines.

For acidification and ground-level ozone, the cost-effectiveness of other measures, including those for controlling ammonia emissions, depends on the particular situation in a given country. The degree to which the measures need to be implemented in individual member countries to reach the environmental targets is not uniform. While the decision on the overall environmental policy objectives and the ambition level remains a task for coordinated Community action, the choice and the implementation of further measures to achieve the common policy objectives must take into account national circumstances. Subsidiarity-based measures and market mechanisms will play a more important role in designing national policies regarding further control of emissions of pollutants contributing to acidification and tropospheric ozone.

The environmental policy of the European Union needs to take into account the likely effects of European enlargement. Because of limited resources and time constraints, it was not possible to perform detailed simulations of the impacts of European enlargement within this Priorities Study. Thus, only a qualitative assessment, based on the results of other studies, has been done. The most important findings are summarized below.

It can be expected that the EU enlargement will cause profound changes in the economies of accession countries. In those countries that are advanced in the implementation of economic reforms (the ‘first wave’ of accession), energy consumption has dramatically decreased and the demand structures have changed towards cleaner fuels. Energy intensities have also decreased. Earlier studies (e.g., Cofala et al., 1999) demonstrate that economic restructuring and convergence of energy intensities to the values typical for the EU member countries is likely to decrease total energy use in Central and Eastern Europe by 20 to 30 percent compared with 1990. However, accession will result in additional economic growth in transport and agriculture, leading to future environmental problems.

Lower energy consumption and the implementation of stricter air emission standards in some of the accession countries have already caused a decrease in emissions of air pollutants. In 1996, the emissions of SO_2 in the accession countries were 35 percent lower and those of NO_x 28 percent lower than in 1990 (EMEP, 1999). These emissions will further decrease as a result of harmonization of air emission legislation with the EU standards. Studies performed by IIASA (Amann et al., 1999a,b; Cofala et al., 1999) indicate that the adoption of EU standards combined with continued economic restructuring is likely to further decrease the emissions of SO_2 and NO_x by 70 percent and 60 percent respectively compared to 1990 levels. Lower emissions in the accession countries will bring benefits in the neighboring countries. In Germany and Austria, up to two percent of ecosystems can be additionally protected against acidification due to measures undertaken in the accession countries.

Applying the environmental targets of the EU acidification and ozone strategies in the accession countries will also bring positive environmental effects in the present fifteen EU member countries. Because of lower emissions in the accession countries, the targets for the EU-15 can be achieved at lower cost. These cost savings are up to three percent of the total cost of controlling pollutants contributing to acidification and ground-level ozone. Cost savings in the EU-15 are about 40 percent of the extra expenditures needed in the accession countries necessary to achieve the EU standards and targets.

These examples clearly indicate that European enlargement will have a positive effect on the environmental situation also within the EU-15. An approximation of emission control policies in Central and Eastern Europe with those of the European Union will make the achievement of environmental goals within the EU-15 easier and cheaper. Thus, unification of environmental legislation in Central and Eastern Europe with that of the European Union deserves special attention and support. It is also critical that environmental considerations are integrated into economic planning in the accession countries.

Summary and Conclusions

This report compares the emissions of air pollutants and their impacts on acidification, eutrophication and tropospheric ozone for five emission scenarios. The scenarios combine assumptions about the development of emitting sectors with specific assumptions about emission control policies. Scenarios analyzed are:

- the Baseline (BL) scenario,
- the Technology Driven (TD) scenario,
- the Accelerated Policy Scenario (AP), no mitigation of greenhouse gases emissions (AP_NC),
- the AP scenario with Kyoto targets of reduction of greenhouse gases emissions, no trade in rights (AP_NT), and
- the AP scenario with Kyoto targets, full trade in emission rights (AP_FT).

The assessment was done with IIASA's integrated assessment model RAINS. Pollutants included are sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and non-methane volatile organic compounds (VOC). The baseline scenario simulates the effects of implementing current policies or, strictly speaking, the policies as decided by the end of 1997, for the 'Business as Usual' scenario of economic development and energy consumption. The TD policy explores the implementation of all technical measures that are regarded as the best available control technologies in the EU member countries. The AP family of scenarios explores cost-efficient ways of achieving environmental targets for acidification and tropospheric ozone identical with those underlying the National Emission Ceilings Directive. Each of the AP scenarios demonstrates the effects of different policies with regard to climate change.

The analysis described in this Report allows drawing the following conclusions:

1. Current policies are an important step towards achieving environmental sustainability for acidification, eutrophication and tropospheric ozone. Compared with the base year (1990), the implementation of the Baseline (BL) scenario is likely to reduce the share of ecosystems area not protected against acidification from 25 percent to only five percent in the EU-15 by 2010. Similarly, the area of ecosystems not protected from eutrophication decreases from 55 percent to 41 percent. The health-related index of ozone exposure is reduced by 60 percent and the vegetation-related index by 38 percent.

2. The TD scenario brings limited additional improvements. The unprotected ecosystems decrease to two percent for acidification and to 24 percent for eutrophication. The indicators of ozone exposure improve further. The health-related ozone index declines by more than 80 percent compared with the situation in 1990. The vegetation-related ozone index decreases to 40 percent of the 1990 value. However, the TD policy is costly. The emission control costs for the EU-15 increase from about € 67.3 billion per year in the BL scenario to € 110.5 billion per year in the TD scenario. Across-the-board implementation of the best available control technologies is expensive. Thus, European policies should be driven by environmental sensitivities in individual countries and should be tailored to the needs of individual countries.

3. The AP policies, with country-specific targets, achieve 92 to 97 percent of the potential improvement of TD measures for acidification and ozone and more than 60 percent for acidification. Depending on the type of policy regarding mitigation of greenhouse gas emissions the costs are 27 to 32 percent lower than the TD costs.

4. Because of stricter environmental targets, the emission control costs in the AP scenarios are higher than in the Baseline (BL). The cost of the AP_NC (No Climate Change Policy) scenario is € 80.9 billion per year, 20 percent higher than the Baseline costs. The lowest costs within the AP family of scenarios are for the 'No Trade' scenario, in which energy consumption is reduced and its structure is drastically changed to meet the Kyoto CO_2 targets without allowing trading of emission rights. Costs of the AP_NT scenario are € 6.1 billion per year, i.e., by 7.5 percent, lower than in the 'No Climate Change Policy' scenario. Trading greenhouse gas emission rights as assumed in the AP_FT scenario makes it possible to achieve the Kyoto targets with less drastic changes in energy consumption patterns. However, the cost of controlling pollutants contributing to

acidification and ground-level ozone are higher by € 2.8 billion per year. This illustrates the synergistic effects between the climate change, and ozone and acidification policies.

5. Measures to be implemented in individual countries are country-specific. For the ozone and acidification scenarios considered in this study there were no common measures (on top of the Baseline) found to be cost-efficient in all EU member countries. While setting the overall environmental policy objectives and ambition levels will remain a matter for Community action, the choice and implementation of specific measures will crucially depend on national circumstances. Subsidiarity and market mechanisms will play an important role in designing national policies regarding further control of precursor emissions of ground-level ozone and acidification.

6. The effects of EU enlargement on the environmental situation in the current EU member countries are likely to be positive. An approximation of the emission control policies in Central and Eastern Europe with those of the European Union will make the achievement of environmental goals within the EU-15 easier and cheaper. Thus, unification of environmental legislation in Central and Eastern Europe with that of the European Union deserves special attention and support. It is also critical that environmental considerations are integrated into economic planning in the accession countries.

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List of abbreviations

AP	Accelerated Policy Scenarios
AP	FT – Kyoto targets, full trade in emission rights
AP	NC – No climate change policy
AP	NT – Kyoto targets, no trade in emission rights
BL	baseline scenario
BAT	best available technologies
BAU	business as usual scenario
CLE	current legislation
CM	combustion modifications
CPU	central processor unit
CRP	current reduction plans
HDV	heavy duty vehicles
FGD	flue gases desulfurization
IIASA	International Institute for Applied Systems Analysis
MFR	maximum feasible reductions
NH_3	ammonia
NO_x	nitrogen oxides
PJ	Peta Joule
RAINS	IIASA integrated assessment model
SCR	selective catalytic reduction
SO_2	sulfur dioxide
TD	technology driven scenario
VOC	non-methane volatile organic compounds

2. Benefit assessment

2.1 Benefit assessment regarding acidification and eutrophication

2.1.1 Public opinion

Acidification is considered the most serious environmental problem facing Europe today according to the ISSP study of eight European counties. This is supported by public opinion surveys in Denmark and Ireland, which find acidification to be the 2nd most serious environmental issue, while the Eurobarometer in 1995 and 1992 gives a ranking of 4th to the acidification problem. Opinion varies across Europe. In particular, in the UK it is ranked with the least important environmental issues, at 7th place. Taking all surveys into account, acidification is ranked in 4th place.

2.1.2 Expert opinion

Acidification is not mentioned in the GEP et al.(1997) study of expert opinions. It is likely though that the issue of air pollution may have been contained within other categories, such as 'industrial waste', 'transport', 'climate change'. Thus, it isn't possible to assign a level of importance to the issue of European acidification problems from the experts.

2.1.3 Benefit estimation

The 'No Trade' and 'Full Trade' AP emission reduction targets are achieved through the direct control of the acidifying pollutants and the measures targeted at the climate change problem. The TD target is met only by the direct control of SO_x, NO_x and NH_3. Table 2.1.1 presents the primary benefits due to the direct control of SO_x, NO_x and NH_3, the secondary benefits to low level ozone and PM_{10} reduction. The benefits from climate change related measures that reduce the acidifying pollutants are reported separately (in italics). These values are already accounted for in the secondary benefit estimates for climate change. They are reported here for clarity only. The benefit estimates presented in Table 2.1.1 assume premature mortality is valued with VOSL.

Table 2.1.1 Summary of benefit estimates for AP and TD scenarios

Scenario	mid	low - high
Measures due to direct control of SO_x, NO_x and NH_3		
NT: primary benefit	21.7	5.6 - 83.1
FT: primary benefit	25.2	6.5 - 96.6
NT: primary + secondary benefits to O_3 and PM_{10}	28.8	-
FT: primary + secondary benefits to O_3 and PM_{10}	33.0	-
TD: primary	58.9	15.2 -226
TD: primary + secondary benefit to O_3	71.5	
Climate change related measures that reduce SO_x, NO_x and increase NH_3		
NT	13.1	3.4 - 50.3
FT	7.3	1.9 - 28.1

Low - high estimates are based on the 68% confidence interval of the mid values. 95% confidence intervals are not reported as the range is so great that it is questionable if a meaningful interpretation can be made from the results.

The main area of uncertainty is due to the valuation of premature mortality. Thus, two estimates are reported, the lower values in each range use VOLY, whilst the upper values use VOSL. Benefit estimates may be biased downwards due to i) omission of impacts: i.e. ecosystems, cultural assets (a form of material damage) and visibility impacts and ii) use of UNECE average unit damage values, which will be lower than EU unit damage values since UNECE includes EU and the poorer economies in transition. The impacts of eutrophication are omitted because the NH_3 impacts are restricted to health and agriculture, i.e. ecosystem impacts are omitted.

Unit damage values for SO_2 and NO_x and NH_3

The unit damage values for SO_2, NO_x and NH_3 required for the purposes of this study, are drawn from a study of pan-European benefits from reductions in emissions (AEA Technology, 1999). The study used is judged to be the best available. These values are based on UNECE average values. The unit damage values include / exclude the following impacts:

Impact included		Pollutant
Health	acute mortality and morbidity	NO_3 and SO_4 aerosols, SO_2
Materials		SO_2
Crops	fertilisation effect	SO_2 and N
Impact omitted		**Pollutant**
Health	chronic mortality and morbidity	NO_3 and SO_4 aerosols, SO_2
	direct effects of VOCs	VOCs
	direct effects of NOx	NOx
Materials	effects on cultural assets,	SO_2
	steel in re-inforced concrete	SO_2
Agriculture	indirect effects on livestock	SO_2
Crops	interactions between pollutants, with pests, pathogens, climate[8], etc.	All
Forests		All
Other ecosystems		All
Visibility		All
Note: The effects of NH_3 are covered under other pollutants (i.e. aerosols, N deposition, acidic deposition). Impacts included are: health (mortality and morbidity), fertilisation impact on agriculture. The effects of ozone are covered in tropospheric ozone.		

The AEA Technology study begins by estimating current emissions (called the reference scenario) and then estimates a range of possible reductions in emissions. For each emission reduction scenario, the total avoided damages or net benefits are estimated. Unit damage values required for the purposes of this study are established using total UNECE avoided damages due to the 'medium ambition' (G5/2) emissions reduction scenario, divided by UNECE emissions reductions. Generally, the results show declining unit benefits of emissions reductions, in all cases though, an average per tonne damage value is used. The unit damage values are applied as the damage cost of each unit of emission in the AP and TD scenarios. The unit damage values are converted to € 1997 prices[9] and then adjusted for rising relative environmental prices due to income change at a rate of 0.5% per annum

The main areas of uncertainty associated with the unit damage values are:

(a) the approach to mortality valuation. Thus two estimates are given, the lower uses VOLY, whilst the upper makes use of VOSL;
(b) use of UNECE average unit damage values. UNECE values will be lower than EU unit damage values since UNECE includes EU and poorer economies in transition; and

[8] For example, the negative impact of SO_2 on global warming is omitted.
[9] To convert € 1990 to € 1997, the deflator 27.4% is used.

(c) omission of impacts such; i) other ecosystems; ii) cultural assets (a form of materials damage); iii) visibility impacts; iv) the impacts of ammonia emissions relate only to health and agriculture, i.e. the impacts to ecosystems (i.e. eutrophication effects) are omitted. Lastly, the dampening effect of SO_2 on global warming is omitted.
(d) use of average monetary unit damage values per tonne of pollutant rather than the marginal values. direction of bias due to this effect is unknown.

The omission of impacts with potentially large benefits from the control of acidifying pollutants (i.e. ecosystems) and the use of UNECE unit damage values suggests that the overall direction of error in the benefit estimates is biased towards underestimation. On the other hand, benefits to health dominate the results. In response to the fact that one of the main areas of uncertainty is due to the treatment of premature mortality valuation, benefit estimates are calculated using both the 'value of life-year' (VOLY) and the 'value of statistical life' (VOSL) approach. However, the VOLY estimates are themselves subject to unknown error due to the fact that they are not founded in sound economic theory. The relevant unit pollutant damage values for this study are marginal values, unfortunately these values are not known. The second best values are average unit pollutant damage values. But, we do not know whether the average values are greater or less than the relevant marginal values. Thus the direction of bias in the benefit estimates due to this type of uncertainty is unknown.

The reliability of the average damage values for the different pollutants is measured by using the 68% confidence limits around the mean values[10]. Low, mid and high benefit estimates are presented in Table 2.1.1, they suggest that the benefit estimates for acidification can be estimated to within a factor of roughly 4. Thus the results should be interpreted with caution and considered as an assessment of the order of magnitude only.

Table 2.1.2 provides the mid unit damage values for NO_x, SO_2 and NH_3. Based on the fact that the main area of uncertainty is due to the treatment of mortality valuation, mid unit damage values are presented based on VOSL and VOLY. Table 2.1.2 also reports upper and lower unit damage values based on the 68% confidence interval[11] of the mid values.

Table 2.1.2 Unit damage values for SO_x, NO_x and NH_3: € per tonne pollutant (1997 prices)

	SO_x	NO_x	NH_3
VOSL			
Lower	1027	3192	2155
Mid	3,950	12,280	8,300
Upper	15222	47316	31938
VOLY			
Lower	669	2064	1385
Mid	2,575	7,950	5,330
Upper	9912	30597	20527

[11] Benefit estimation is based on the impact pathway approach which is typically multiplicative. The distribution of estimates from multiplicative analysis are assumed to be lognormal. With a lognormal distribution the confidence range of a particular value can be predicted from the geometric mean (μg) and the geometric standard deviation (σg). 68% confidence limits are defined by the range: μg / σg to μg . σg

Application to the Scenarios

Table 2.1.3 applies the mid unit damage values to the different scenarios in the year 2010. Lower and upper values are reported in the sensitivity analysis at the end of this section.

Table 2.1.3 Acidification benefits for AP and TD scenarios: € billion

	TD	NT		FT	
		Acidification related measures	*Climate change related measures*	Acidification related measures	*Climate change related measures*
VOSL					
SO_x	13.2	3.7	*5.1*	4.6	*3.1*
NO_x	36.6	16.3	*8.0*	18.4	*4.2*
NH_3	9.1	1.7	*-0.01*	2.2	*-0.01*
Total	**58.9**	**21.7**	***13.1***	**25.2**	***7.3***
VOLY					
SO_x	8.6	2.4	*3.3*	3.0	*2.0*
NO_x	23.7	10.6	*5.2*	11.9	*2.7*
NH_3	5.6	1.1	*-0.01*	1.4	*-0.01*
Total	**38.1**	**14.0**	***8.5***	**16.3**	***4.7***

Note: lower and upper value estimates are given in the sensitivity analysis.

The benefit estimates for the TD scenario are the primary benefits due to the direct control of the acidifying pollutants only. As expected the benefits (SO_x, NO_x and NH_3) are greatest for the TD scenario, balanced at about € 38 – 59 billion. The estimates given for the 'No Trade' and 'Full Trade' variants of the AP scenario are given in two parts, i) benefits due to direct control of acidifying pollutants and ii) benefits due to climate change related measures that reduce acidifying pollutants. As expected the secondary benefits due to climate change policies are greater for the 'No Trade' scenario this is because greater levels of carbon control takes place in the EU15. Correspondingly, the primary benefits for the 'No Trade' scenario are less than the 'Full Trade' as there is less direct control of the acidifying pollutants in this scenario.

The scenarios generate secondary benefits to low level ozone and urban stress, (i.e. the reduction of primary PM_{10} and secondary aerosols). Table 2.1.4 presents the secondary benefits of acidification related measures that control SO_x, NO_x and NH_3.

Table 2.1.4 Secondary benefits of acidification

Scenario	Secondary benefits to low level ozone	Secondary benefits to urban stress	
		Primary PM_{10} reduction	Secondary aerosols reduction
VOSL			
NT	5.6	1.6	5.3
FT	6.3	1.6	5.3
TD	12.6	n.k	n.k
VOLY			
NT	0.7	0.9	3.1
FT	0.8	0.9	3.1
TD	1.7	n.k	n.k

Note; n.k = not known. Due to the nature of the unit damage values used, the secondary benefits to urban stress due to reductions in SO_x and NO_x and hence reductions in secondary aerosols are already included in the primary benefit estimates given in Table 2.1.3. Thus the secondary benefits reported in Table 2.1.4 are to be interpreted as an indication of their size only.

Sensitivity analysis

Some of the assumptions made in this analysis may have a significant effect on the results. This section examines what happens to the benefit estimates if the key assumptions are changed. The results are presented in Table 2.1.5.

Table 2.1.5 Key assumptions and the estimated results of changing these assumptions

Current Assumption	Current value € 10^9	Revised assumption	Revised value € 10^9	
Primary benefit in 2010 only:mid unit damage: VOSL TD NT FT	58.9 21.7 25.2	Primary benefit in 2010 only: Mid unit damage: VOLY TD NT FT	38.1 14.0 16.3	
Primary benefit in 2010 only mid unit damage: VOSL TD NT FT	58.9 21.7 25.2	Primary benefit in 2010 only Low,high unit damage:VOSL TD NT FT	Lower 15.2 5.6 6.5	Upper 226 83.1 96.6
Primary benefit in 2010 only mid unit damage:VOLY TD NT FT	38.1 14.0 16.3	Primary benefit in 2010 only Low,high unit damage:VOLY TD NT FT	Lower 9.8 3.6 4.2	Upper 146 53.8 62.5
Primary benefit: mid unit damage (VOLY -VOSL) TD NT FT	38.1 - 58.9 14.0 - 21.7 16.3 - 25.2	Climate change related benefit, i.e. total benefit NT FT	8.5 - 13.1 4.7 - 7.3	
Total benefit: mid unit damage (VOLY-VOSL) value modified by 0.5% p.a TD NT FT NC	38-59 23-35 21-33 18-28	Total benefit: mid unit damage (VOLY-VOSL) value held at 1997 values TD NT FT NC	34 - 53 20 - 31 16 - 25 19 -29	
Total benefit in 2010 only: mid unit damage; health, materials and crop impacts TD NT FT NC	38-59 23-35 21-33 18-28	Total benefit in 2010 only: mid unit damage: Materials and crop impacts only TD NT FT NC	-0.28 -0.13 -0.12 -0.11	
Total benefit in 2010 only: mid unit damage: health, mat,crop impacts TD NT FT NC	38-59 23-35 21-33 18-28	Total benefit in 2010 only: mid unit damage; health impacts only TD NT FT NC	38.28 - 59.28 23.13 - 35.13 21.12 - 33.12 18.11 - 28.11	

The benefit estimates could under estimate the true benefit due to reduced EU15 emissions of SO_2, NO_x and NH_3 because impacts are omitted from the analysis, such as, ecosystems and eutrophication, visibility etc. There is also a downward bias because UNECE unit damage values are used and these values are typically lower than EU unit damage values because they include the poorer economies in transition. However, the unit damage values based on AEA Technology (1999) study, may over-estimate the true benefit due to reduced EU15 emissions of SO_2, NO_x and NH_3, because AEA Technology (1999) assumes an unadjusted VOSL, i.e. no adjustment is made for the fact that pollution-related mortality largely affects the elderly (Maddison 1997).

Exposure response functions

The unit damage values used for the above benefit estimates for the acidification scenarios contain within them damage to human health, materials and agriculture. The quantification of human health impacts, damage to materials and the effects of air pollution on agricultural symptoms are estimated using the exposure response relationships given below.

Human health: In Table 2.1.6, the coefficient 'b' is interpreted as the increase in annual incidence of each symptom. For example, i) for morbidity: the coefficient is the number of cases / year.person.$\mu g/m^3$, ii) for acute mortality the coefficient b is the % change in mortality / rate. $\mu g/m^3$ and iii) for chronic mortality, b is the years of life lost for chronic effects on mortality.

Table 2.1.6 Exposure response coefficients for health impacts

Receptor	Impact category	Reference	Pollutant	b
ASTHMATICS				
Adults	Bronchodilator usage	Dusseldorp et al., 1995	PM10	0.163
	Cough	Dusseldorp et al., 1995	PM10	0.168
	Lower respiratory symptoms (wheeze)	Dusseldorp et al., 1995	PM10	0.061
Children	Bronchodilator usage	Roemer et al., 1993	PM10	0.078
	Cough	Pope, Dockery, 1992	PM10	0.133
	Lower respiratory symptoms (wheeze)	Roemer et al., 1993	PM10	0.103
All	Asthma attack	Whittemore, Korn, 1980	O_3	4.29×10^{-3}
ELDERLY 65 YEARS +				
	Congestive heart failure	Schwartz, Morris, 1995	PM10	1.85×10^{-5}
CHILDREN				
	Chronic bronchitis	Dockery et al., 1989	PM10	1.61×10^{-3}
	Chronic cough	Dockery et al., 1989	PM10	2.07×10^{-3}
ADULTS				
	Restricted activity days	Ostro, 1987	PM10	0.025
	Minor restricted activity days	Ostro, Rothschild, 1989	O_3	9.76×10^{-3}
	Chronic bronchitis	Abbey et al., 1995	PM10	4.9×10^{-5}
ENTIRE POPULATION				
	Respiratory hospital admission	Dab et al., 1996 Ponce de Leon, 1996	PM10 SO_2 O_3	2.07×10^{-6} 2.04×10^{-6} 7.09×10^{-6}
	Cerebrovascular hospital admissions	Wordley et al., 1997	PM10	5.04×10^{-6}
	Symptom days	Krupnick et al., 1990	O_3	0.033
DEATH RATES				
	Acute mortality	WHO, 1997	PM10	0.074%
	Acute mortality	Anderson et al., 1996 Touloumi et al., 1996 Sunyer et al., 1996	SO_2 O_3	0.072% 0.059%
	Chronic mortality	Pope et al., 1995	PM10	0.00036

Source: ExternE, European Commission, 1995b, 1998) and (Hurley and Donnan, 1997) as presented in AEA Technology (1999) Table AII.1.

The valuation of the different health end points is achieved by using the following values:

Table 2.1.7 Values used for the assessment of mortality and morbidity impacts.(€ 1990).

	€
Premature mortality	
VOSL VOLY	2,200,000 110,000
Chronic mortality	
VOSL VOLY	67,000 1,100,000
Acute morbidity	
Restricted activity day	63
Symptom day / minor activity day	6.3
Wheeze	6.3
Emergency room visits	186
Respiratory hospital admissions	6.560
Cardiovascular hospital admissions	6,560
Acute asthma attack	31
Chronic morbidity	
Chronic illness	1,000,000
Chronic bronchitis in adults	88,000

Source: Markandya in AEA Technology (1999)

Materials: AEA Technology (1999) report that the dose response functions used are derived mainly from the UN ECE Programme (Kucera, 1993a, 1993b, 1994), unless otherwise referenced. Table 2.1.9 lists the functions.

The following key applies to all the relationships given:

ER	Erosion rate (um / year)
P	Precipitation rate (m/year)
SO_2	Sulphur dioxide concentration ($\mu g/m^3$)
O_3	Ozone concentration ($\mu g/m^3$)
H^+	Acidity (meq/m^2/year
R_H	Average relative humidity, %
f_l	$1-\exp(-0.121.R_H/(100-R_H))$
TOW	Fraction of time relative humidity exceeds 80% and temperature >0°C
ML	Mass loss(g/m^2) after 4 years

In all the relationships, the original H^+ concentration term (in mg/l) is replaced by an acidity term, using the conversion: $P.H^+$ (mg/l) = $0.001.H^+$ (acidity in meq/m^2/year). To convert mass loss for stone and zinc into an erosion rate in terms of material thickness, respective densities of 2.0 and 7.14 tonnes / m^3 are assumed. The relationships are given in Table 2.1.8.

Table 2.1.8 Exposure response functions for materials damage

Unsheltered limestone (4 years)	ML = 8.6 + 1.49.TOW.SO_2 + 0.097.H^+
Unsheltered sandstone (4 years) (also mortar)	ML = 7.3 + 1.56.TOW.SO_4 + 0.12.H^+
Brickwork	No effect
Concrete	Assumed no effect, though air pollution may affect steel reinforcement
Carbonate paint, (Haynie, 1986)	ΔER/tc = 0.01(P)8.7(10^{-pH} - $10^{-5.2}$)+0.006.SO_2.f_1
Silicate paint, (Haynie, 1986)	ΔER/tc =0.01(P)1.35(10^{-pH} - $10^{-5.2}$)+0.00097.SO_2.f_1
Steel	Assumed either pained or galvanised, not assessed independently
Unsheltered zinc (4 years)	ML = 14.5 + 0.043.TOW.SO_2.O_3+ 0.08.H^+
Sheltered zinc (4 years)	ML = 5.5 + 0.013.TOW.SO_2.O_3
Aluminium	Assumed too corrosion resistant to be affected significantly

Agriculture: crops and pasture grass: The unit damage values used in this study include the four major impacts to agricultural systems, i) acidifying soils / liming, ii) N deposition as fertiliser, iii) direct effects of SO_2 and O_3 on crop yield and iv) indirect SO_2 and O_3effects on livestock. Quantification of the first two impacts follows a simple methodology, the former measures the additional costs of liming at € 16.8 per tonne of lime, and the latter measures the cost savings of reduced nitrogen fertiliser at € 430 per tonne nitrogen (Nix 1990). For further details refer to AEA Technology (1999).

The damage to crops from exposure to ozone is measured using EMEP's accumulated ozone above a threshold of 40ppb (AOT40) metric (ppm.hours). The ozone exposure response functions differ according to the sensitivity of crops to ozone, (for a breakdown of the sensitivity of different crops to ozone refer to AEA Technology (1999). The functions are given in Table 2.1.9.

Table 2.1.9 Exposure response functions for impacts to crops.

Crop type	Exposure response function % loss per ppm.hour AOT40
Tolerant crops	0
Slightly sensitive crops	1.0
Sensitive crops	1.75
Very sensitive crops	3.57
Meat and milk production	0.5

Source: AEA Technology (1999) Table AII.9.

The following functions are used to quantify the % yield change from SO_2 effects on different crops[12]. These functions take into account the fertilisation effect of sulphur at low concentrations.

From 0 to 13.6 ppb SO_2: $\Delta = 0.74(SO_2) - 0.55(SO_2)^2$
Above 13.6 ppb SO_2: $\Delta = -0.69(SO_2) +9.35$

Whilst for pasture the following exposure response functions are assumed:

From 0 to 15.3 ppb: $\Delta = 0.20(SO_2) - 0.013(SO_2)^2$
Above 15.3 ppb: $\Delta = -0.18(SO_2) +2.75$

Agriculture: livestock: the impacts of acidifying pollutants to meat and milk production are assumed to be 50% as sensitive to pasture grass. AEA Technology (1999).

[12] Such as: maize, oats, leaf crops, soybeans, sunflower, barley, wheat, rice, millet, potato, linseed, tomato, hops, tobacco, rye, sugar beet, beans, carrots, hemp, raspberries, cucumber, sorghum, strawberries, flax, sesame seeds.

2.2 Benefit assessment regarding tropospheric ozone

2.2.1 Public opinion

Low level ozone is rarely specifically cited as an environmental problem in public opinion surveys. However, if it is assumed that 'air pollution' in the 'immediate environment' could represent low level ozone, then we see that the Eurobarometer 1995 and 1992 would rank tropospheric ozone in ninth position (out of eleven) together with urban stress.

2.2.2 Expert opinion

Tropospheric ozone is not cited in the lexicometric analysis presented in the GEP et al.(1997) expert opinion survey.

2.2.3 Benefit estimation

The 'No Trade' and 'Full Trade' emission reduction targets for tropospheric ozone (or low level ozone), are achieved through the direct control of VOCs (i.e. primary benefits) as well as climate change and acidification related measures that reduce NO_x, the precursor pollutants for tropospheric ozone (i.e. secondary benefits from climate and acidification measures). The benefit estimate results are summarised in Table 2.2.1.

Table 2.2.1 *Summary of TD and AP benefit estimates: € billion*

	Total benefit*	Primary benefit	*Secondary benefit*	
		from direct VOC control	*climate change*	*acidification*
TD	2.8 - 21.7	1.2 - 9.1	-	*1.7 - 12.6*
NT-AP	1.8 - 14.0	0.7 - 5.6	*0.4 - 2.8*	*0.7 - 5.6*
FT-AP	1.8 - 13.4	0.7 - 5.7	*0.2 - 1.5*	*0.8 - 6.3*
NC-AP	1.7 - 13.0	-	-	-

Low / high benefit estimates assume premature mortality is valued with VOLY / VOSL respectively.
TD= technology driven scenario, AP = accelerated policy scenario, NC = 'No Carbon' variant, NT = 'No Trade' variant, FT = 'Full Trade' variant of the AP scenario.
Note, AP/TD emissions reduction targets are met by a combination of direct VOC control plus the acidification and climate change related measures that reduce NO_x, the overall benefit estimates are presented in column 2 (total benefit). Primary benefit estimates related to the control of VOCs only. These values are used in the cost benefit analysis of VOC control. Whilst the figures in italics, i.e. Secondary benefits, are assigned to the overall benefit estimates for climate change and acidification.

The primary benefit estimates for the 'No Trade' and 'Full Trade' variants of the AP scenario are due to the direct control of the precursor pollutant VOCs only. These results are used in the cost benefit analysis for the control of low level ozone, whilst the secondary benefits are assigned to climate change and acidification. The total secondary benefits from climate change and acidification to tropospheric ozone are: NT € 8.4 billion (from € 2.8 + 5.6 billion) and FT: € 7.8 billion (from € 2.5 + 6.3 billion).The overall benefit estimates for the Technology Driven scenario are € billion 2.8 - 21.7, where premature mortality is valued with VOLY / VOSL respectively.

The benefit estimates may be an underestimate because ozone damage relates to crops and human health only. I.e. damage to materials, forests, biodiversity and non-crop vegetation are excluded. There is also a high degree of uncertainty due to the statistical relationship between low level ozone exposure and premature mortality.

Methodology

Low level ozone is a secondary pollutant. It is generated from reactions of the primary pollutants NO_x and VOCs catalysed by sunlight (SO_x and NH_3 are also implicated). Consequently concentrations of low level ozone are generally higher during the day and in the summer. Estimating damages from low level ozone is complex because it forms over time and may be worse in rural areas downwind of significant sources of emission.

Tropospheric ozone is implicated in the following forms of damage:

- Crop yield impairment
- Human health: morbidity and premature mortality
- Forest, biodiversity and non-crop vegetation damage
- Materials damage

Rabl and Eyre (1997) suggest that while the effect of ozone to materials is potentially significant, it is likely to be small. Thus, low level ozone damage to materials is excluded. Low level ozone is known to reduce tree growth. However, there is currently very little information about the damage to forests due to the complexity of their growth and management systems. Similarly, while it is likely that ozone causes damage to ecosystems, there are very few studies estimating these effects. Thus ozone damage to forests and biodiversity are also excluded from this study.

The analysis here estimates the benefits of avoided damage to crops and human health due to the control of low level ozone, i.e. moving from the Baseline scenario to the TD and AP scenarios. The method is based on a modified extension of the Rabl and Eyre (1997) analysis and it assigns unit damage costs to NO_x and VOCs.

The robustness of these values are cross checked according to i) yield loss estimates based on dose-response functions for crop damage, ii) AEA Technology (1998) estimates and iii) IIASA et al.,(1998).

Valuing Crop Damage

The procedure followed is based on a modified Rabl-Eyre (1997) approach. Rabl and Eyre (1997) estimate Europe wide crop and health damages which, they then allocate to NO_2 and VOCs. The essential equations for crops are:

$$D / year / ppb \times 0.37 ppb / MtNO_2 = D / tNO_2 \qquad [1]$$

$$D / year / ppb \times 0.31 ppb / MtVOC = D / tVOC \qquad [2]$$

Where D is damage in million €. The ppb-$MtNO_2$ and ppb-MtVOC relationships come from Simpson (1993) using the EMEP model where a hypothesised 10.5 Mt reduction in NO_2 produces a 3.92 ppb/year reduction in O_3, i.e. 0.37 ppb/$MtNO_2$, and a 50% reduction in VOCs produces a 5.61 ppb reduction. This is for the wider Europe.

Rabl and Eyre's estimate of damage (D) is taken from yield loss equations in ExternE (1995) and thus predates the more recent estimates in Jones et al.,(1997). Thus, they include positive damages for barley, sugar beet, and maize, all of which are classified as 'tolerant' crops by Jones et al., and hence with zero damages. The effect of removing these three crops from the Rabl-Eyre analysis is to lower the ppb damages from 516 M€/ppb to 414 M€/ppb, and we make this adjustment here. Hence equations [1] and [2] produce crop damages of: 153 € / tNO_2 and 128 € / tVOC. These values are adjusted to 1997 prices using the deflator 27.4%. *2* Table.2.2 reports the unit crop damage values for NO_x and VOCs

Table 2.2.2 Crop unit damage values: € / tNOx, € / tVOC (1997 prices)

	NO_x	VOC
Crop unit damage value	195	163

These sums are applied to changes in VOCs and NO_x emissions in the EU15 under the various scenarios. The results are summarised in Table 2.2.3.

Table 2.2.3 Crop damages from ozone, EU15: € billion

	NO_x	VOC	Total damage to crops
1990	2.58	2.29	4.87
Baseline	1.42	1.17	2.59
TD	0.90	0.79	1.69
NC-AP	1.14	0.91	2.05
NT-AP	1.07	0.94	2.01
FT-AP	1.10	0.93	2.03

Table 2.2.4 shows that moving from the Baseline to the TD scenario produces gross crop benefits of some € 890 million in the year 2010. The crop benefits associated with the other scenarios are of the same order of magnitude.

Table 2.2.4 Benefit due to reduced crop damage: € billion

TD	0.89
NC-AP	0.54
NT-AP	0.58
FT-AP	0.55

Valuing health damage

Again the procedure used here is based on a modified Rabl-Eyre (1997) approach. Rabl and Eyre (1997) obtain parallel damage costs for health. Here the equations are:

POP x D / yr / person / ppb x 0.37ppb / $MtNO_2$ / yr [3]

and POP x D / yr / person / ppb x 0.31ppb / MtVOC / yr [4]

The complication in this instance is that the damage cost D, is an amalgam of mortality and morbidity costs, and the mortality costs have been expressed in 'value of life years lost' (VOLYs). A VOLY is an attempt to allow for the fact that air pollution tends to 'harvest' those at risk, i.e. tends to affect those who are already elderly. This is confirmed in recent work by Maddison (1997). The implication is that the life at risk is foreshortened by a few months rather than by a number of years as in the case of, say, stratospheric ozone or road accidents, and that it should therefore be valued less. But this is a controversial conclusion to reach from a correct assumption, for what is being valued is the risk rather than the time over which the risk reduction occurs. It may well be that values should be higher for longer expected risk-exposure times, but the only evidence on this suggests that the elderly value risks at perhaps 0.7 of those of people of median age (see Urban Stress).

Rabl and Eyre assume an average 9 month reduction in expected life and a VOLY of 110,000 €. We prefer to use the VOSL approach which makes the relevant valuation of acute mortality: € 3.31 million x 0.7 (for the age effect) = € 2.3 million. The effect of this on the Rabl-Eyre estimates is shown below:

Effect	Rabl-Eyre Value € / year / person / ppb	Adjusted for VOSL € / year / person / ppb
acute mortality	0.965	27.109
respiratory hospital admissions	0.093	0.093
restricted activity days	1.209	1.209
symptom days	0.416	0.416
Total € / yr / person / ppb	**2.680**	**28.827**

The effect of using VOSL rather than VOLY is therefore fairly dramatic, increasing damages by a factor of about 11. The acute mortality effect is taken from the APHEA studies for Europe.

Equations [3] and [4] now become:

$365.3 \times 10^6 \times 28.8$ € / yr / person / ppb x 0.37ppb / $MtNO_2$ / yr [3] and

$365.3 \times 10^6 \times 28.8$ € / yr / person / ppb x 0.31ppb / MtVOC / yr [4]

Using these equations, Table 2.2.5 gives the health damages for EU-15 population 1990 due to the precursor pollutants of ozone. Lower and upper ranges are presented. The lower bound uses VOLY in the valuation of health effects and the upper bound uses VOSL. We recommend the upper bound figures for the purposes of this study.

Table 2.2.5 Health unit damage values: € / tNO_x, € / tVOCs (1997 prices)

	NO_x	VOC
Unit damage values based on VOLY	362	303
Unit damage values based on VOSL	3893	3261

Allowing for the rise in population in EU:15 to 386.7 people and rising relative prices for health risks we multiply the unit values given for 1990 by 1.05 for population change and 0.5% per annum for the relative price effect in order to estimate the unit damage values relevant for 2010. The unit damage values are then applied to the emissions of NO_x and VOCs in 1990 and 2010. The resulting health damages using unit health damage values based on VOSL are reported in Table 2.2.6. Results based on VOLY are given in the sensitivity analysis. The sensitivity analysis, also includes the benefit estimates, where unit damage values are not adjusted for population growth or rising relative price linked to income.

Table 2.2.6 Health damages from low level ozone in EU15: € billion

	NO_x	VOC	Total damage to health
1990	51.5	45.8	97.3
2010			
Baseline	32.9	27.1	60.0
TD	20.8	18.4	39.2
NC-AP	26.5	21.1	47.6
NT-AP	24.9	21.7	46.6
FT-AP	25.5	21.7	47.2

The benefits of moving to the different scenarios are shown in Table 2.2.7. The benefits are greatest for the TD scenario at some € billion 20 in 2010.

Table 2.2.7 Benefit due to reduced health damage: € billion

TD	20.8
NC-AP	12.4
NT-AP	13.4
FT-AP	12.9

Summary damage caused by low level ozone

The analysis presented above (based on the modified Rabl-Eyre (1997) approach) suggests that health effects dominate the benefits of moving to 2010 scenarios. Total benefits are given in Table 2.2.8. Table 2.2.8 also presents the component parts of the benefit estimate, i) the secondary benefits from climate change and acidification related measures that reduce NO_x. These estimates are assigned to climate change and acidification benefit estimtes, and ii) the primary benefit due to VOC reduction. Note that the low / high estimates assume premature mortality is valued with VOLY / VOSL respectively.

Table 2.2.8 Total benefit due to reduced low level ozone: € billion

	Total benefit	Secondary benefit due to NO_x reduction*	Primary benefit due to VOC
TD	2.8 - 21.7	1.7 - 12.6	1.2 - 9.1
NC -AP	1.7 - 13.0	-	-
NT-AP	1.8 - 14.0	1.1 - 8.4	0.7 - 5.6
FT-AP	1.8 - 13.4	1.0 - 7.8	0.7 - 5.7

*Secondary benefits from both climate change and acidification related measures that reduce NO_x.

The main reservations about these figures are:

(a) the use of a VOSL rather than a VOLY number. The latter would reduce health damages in any period by a factor of about 11 (see sensitivity analysis at the end of this chapter)

(b) the use of those studies in the APHEA programme which found a statistical relationship between ozone and mortality. It is worth noting that of the four APHEA studies that tested this relationship, two - for Paris and Lyon - found no relationship, while those for Barcelona and London did. The approach here has been to use the Barcelona study, but, clearly, the selection can be disputed. The effects of excluding acute mortality from the study are reported in the sensitivity analysis at the end of this chapter.

Cross check 1: Valuing crop damage based on dose-response functions

Low level ozone is the dominant photochemical oxidant[13]. Low level ozone concentrations are measured in accumulated ozone above a threshold of X ppb (AOTX), where X is usually 40 (AOT40) for crops and 60 (AOT60) for health.

The equation is $AOT(40) = \int \max (O_3 - 40, 0).dt$

Where t is time in daylight hours only. The units of AOT(40) are ppm.hours or ppb.hours. The thresholds tend to be 3000 ppb.h (3 ppm.h) for crops May-July daylight hours, and 10,000 ppb.h (10 ppm.h) for forests April-September daylight hours. So, (AOT40) is measured by the number of hours in those periods when O_3 concentrations exceed the thresholds, multiplied by the ppb-exceedance

[13] others include peroxyacetyl nitrate - PAN - and nitric acid

Low level ozone is considered to cause yield reduction for 'ozone sensitive' crops. Jones et al.,(1997) list these crops as follows.

Tolerant Crops	Slightly Sensitive Crops	Sensitive Crops		Very Sensitive Crops
maize barley raspberries strawberries leaf crops cabbages olives sugar beet	pasture grass sorghum oats rye millet rice	wheat potato tomato sunflower soybeans beans grapes most tree fruits	melons carrots cucumbers onions hops flax hemp oil seeds	Tobacco

Jones et al.,(1997) review the effects of air pollution on crops and reports the dose response functions reproduced below.

Tolerant crops:	0.00%	loss in yields per ppm hour AOT40
Slightly sensitive crops: Sensitive	1.00%	loss in yields per ppm hour AOT40
crops:	1.75%	loss in yields per ppm hour AOT40
Very sensitive crops:	3.57%	loss in yields per ppm hour AOT40

The problems with these dose-response functions include:

- the omission of farmer adaption, and
- plant adaptation is not fully accounted for. Ozone concentrations are highest on hot dry days and there is evidence to suggest that plants protect themselves on such days to conserve moisture. This protection also has the effect of protecting against damage from ozone.

The first problem is potentially serious since most studies of ozone damage have found that farmers respond by substituting inputs (e.g. fertilisers) and outputs (crop types) - see the review in Adams and Crocker (1991). Unfortunately, there appear to be no models of ozone damage in Europe akin to those for the USA where these substitutions have been modelled. The degree of error in proceeding with a more simplistic approach is therefore not known, but ozone damages to crops are almost certainly *overstated* due to the inability to model reactive behaviour.

An illustrative approach - UK wheat output loss

To get a rough check of the monetary value of crop yield losses due to ozone, we consider the case for UK and check the results against methodologies 2 and 3.

AOT(40) is exceeded by 2.50 ppm.hours in 1990 in the UK (RIVM data).

UK output of wheat in 1990 was some 14,000,000 tonnes, worth £1423 million. Using the dose response relationship above, the damage due to ozone would be:

$$2.50 \times 0.0175 \times 14 \times 10^6 \text{ tonnes} = 612{,}500 \text{ tonnes}$$

Multiplying by the average realised price of £109.5 tonne gives £67 million, or some € 57.5 million at 1997 prices

Brown et al.(1995) estimate wheat losses in the UK for 1989 due to ozone and using the AOT(40) threshold as 900,000 tonnes worth £120 million. They use 1km grid squares and hence a far more 'decomposed' ozone measure. However, they also note that their baseline figure for wheat output is exaggerated (20 million tonnes as against the 14 million), so they acknowledge their loss figure is 30% overstated.

Making that adjustment would produce a loss figure for their analysis of 692,000 tonnes, which is very close to the broad estimate provided here. Brown et al.,s implied price per tonne is also £133.3 per tonne which appears to exceed the average realised price of £109.5. Making this further adjustment would produce a loss of 692,000 tonnes x £109.35 = £75.6 million or some € 65 million (1997 prices) compared to their estimate of £120 million.

The estimates for the value of wheat yield loss due to ozone in the UK are therefore in agreement (i.e. 57.5 - 65 million €) once the required adjustments have been made

EU 15- Crop Damage

The damage to crops at EU15 level is again estimated using the yield loss equations of Jones et al.(1997). Data on crop production and prices are taken from UN FAO (1999). Crop losses in 1990 are valued in local market prices for each affected country. The results are summarised in Table 2.2.9.

Table 2.2.9 Value of crop yield losses to EU15 due to low level ozone

Class	DRF	Ppm.h 1990	Total output 1990 mt	Output loss 1990 mt	Value of yield loss € 10^9
Slightly sensitive	0.01	6.6	16.7	1.1	0.1
Sensitive	0.0175	6.6	259.0	29.9	4.2
Very sensitive	0.0357	6.6	0.4	0.1	0.1
TOTAL			276	31.1	4.5

The conclusion we can draw from *cross-check-1* is that:

- UK study suggested UK wheat crop losses in 1990 are, € 57.5 - 65 million;
- EU:15 crop damages in 1990 are estimated to be € 4.5 billion in 1990 prices or € 5.7 billion (1997 price);
- Modified Rabl-Eyre (1997) estimates of crop damage in 1990 give a monetary loss of some € 4.8 billion.

We conclude that there is a broad consistency across the results for damage to crops due to low level ozone.

Cross check 2: Crop benefits: based on AEA Technology (1998)

AEA Technology (1998) estimates gains to the European Union of some € 3.69 billion for moving from a 'reference' to a ‘maximum feasible reduction’ scenario for control of nitrogen and nitrogen-related compounds. In fact the scenarios are very similar in terms of emissions changes to those analysed above. The AEA study therefore appears to produce very much higher crop benefits for the TD scenario than suggested here (i.e. € 3690 million versus € 960 million). Assuming ozone benefits can be ascribed to NO_x and VOCs in roughly equal proportions (see above), the per tonne benefits would be 420 € / t VOC and 671 € / t NO_x[14]. These results are a factor of 2.5 higher for VOCs and 3.4 higher for NO_x.

Cross-check 3: based on IIASA et al.,(1998)

IIASA et al.,(1998) give a more detailed analysis of the economic costs and benefits of air quality targets for ozone. This analysis now permits us to differentiate the benefits arising from the avoidance of direct nitrogen effects and those arising from ozone effects. In what follows, we have taken account of the benefits from reduced materials damage, any N-fertilisation effects, acute mortality valued at the VOSL, morbidity effects and damage to crops and forests. Of these, damage to forests is probably the least certain. We have excluded any visibility effects and any effects on chronic mortality.

[14] This is found by taking the 3.65 x 10^9 € and dividing equally gives 1.83 x 10^9 € for a 4.34mt reduction in VOC and a 2.72mt reduction in NO_x, thus leading to 420 and 671 € / t VOC and NO_x respectively.

The emissions scenarios analysed in IIASA et al.,(1998) are referred to as 12/2 and 14/2. Where, 12/2 corresponds to 65% gap closure on AOT 60 and 35% gap closure on AOT 40, and the 14/2 scenario corresponds to zero gap closure. In each case there are absolute targets of 2.6 ppm.h for AOT 60 and 10 ppm.h for AOT 40. In this analysis, we adopt the 12/2 scenario on the basis that the UNECE have adopted this scenario and the 14/2 scenario is a zero gap closure scenario. Thus the emissions in the Reference and 12/2 scenarios analysed in IIASA et al.,(1998) are given below:

10^6 tonnes	Reference	Scenario 12/2	12/2 - Reference
NO_x	7.027	5.838	-1.189
VOCs	7.117	5.682	-1.435

Effects attributed to nitrogen include materials damage, N-fertilisation, morbidity and mortality. Effects attributed to ozone include morbidity, mortality and crops.

Comparing the 12/2 scenario with the Reference scenario shows that a 1.189 x 10^6 tonne nitrogen reduction results in € billion 7.324 damage reduction plus a share of the ozone benefits. Here we assign half the ozone benefits to NO_x and half to VOCs. Thus:

For NO_x:

Emission reduction	Damage due to NO_x effects	Damage due to ozone attributed to NO_x	Total damage due to NO_x	Unit damage per tonne NO_x € / tNO_x
1.189 x 10^6	υ 7.324 x 10^9	+ 0.5(7.093) x 10^9	= 10.871 x 10^9	υ 9143

Similarly for VOCs:

Emission reduction		Damage due to ozone attributed to VOCs	Total damage due to VOCs	Unit damage per tonne VOC € / tVOC
1.435 x 10^6		υ 0.5(7.093) x 10^9	= 3.5465 x 10^9	υ 2471

The IIASA (1998) study uses a VOSL of 2.2 x 10^6 € and values are given in 1990 prices. The IIASA (1998) value per tonne NO_x is roughly 3 times greater than the adjusted Rabl-Eyre (1997) values used in this report, (i.e. € 9143 /tNOx versus € 3893 / t NO_x). This difference can be explained mainly because the adjusted Rabl-Eyre figure relates to health damage only. Whilst, for a tonne of VOCs, the IIASA (1998) value is slightly less i.e. € 2471 / tVOC versus € 3261 / tVOC for ozone effects only.

Adjusted Rabl-Eyre (1997) Health only		IIASA et al.,(1998) All damage	
€ / t NOx	€ / t VOC	€ / t NO_x	€ / t VOC
3893	3261	9143	2471

The analysis suggests that the estimates of € damage / tonne of NO_x and VOCs are robust.

Sensitivity analysis

Some of the assumptions made in this analysis could have a significant effect on the results. This section examines what happens to the benefit estimates if the assumptions are changed.

Table 2.2.10 Key assumptions and estimated results of changing these assumptions.

Current Assumption	Current estimate € 10^9	Revised assumption	Revised estimate € 10^9
Health and crop estimates in 2010: VOSL TD NC-AP NT-AP FT-AP	 21.7 13.0 14.0 13.4	Health and crop estimates in 2010: VOLY TD NC-AP NT-AP FT-AP	 2.8 1.7 1.8 1.8
Health and crop estimates in 2010: Adjusted unit damage values for population growth and rising relative price linked to income: VOSL - VOLY TD NC-AP NT-AP FT-AP	 21.7 - 2.8 13.0 - 1.7 14.0 - 1.8 13.4 - 1.8	Health and crop estimates in 2010: Unadjusted unit damage values. VOSL - VOLY TD NC-AP NT-AP FT-AP	 2.6 - 18.9 1.5 - 11.3 1.6 - 12.2 1.6 - 11.6
Health estimates only in 2010 *VOSL* TD NC-AP NT-AP FT-AP	 20.8 12.4 13.4 12.9	Health estimates only in 2010 *VOLY* TD NC-AP NT-AP FT-AP	 1.9 1.2 1.3 1.2
Health estimates only in 2010 *Including acute mortality (VOSL)* TD NC-AP NT-AP FT-AP	 20.8 12.4 13.4 12.9	health estimates only in 2010 *Excluding acute mortality* TD NC-AP NT-AP FT-AP	 1.25 - 0.8 0.8
Crop estimates only in 2010 *Based on modified Rabl-Eyre (1997)* TD NC-AP NT-AP FT-AP	 0.9 0.5 0.6 0.6	Crop estimates only in 2010 *Based on AEA Technology (1998)* TD NC-AP NT-AP FT-AP	 2.8 1.6 1.8 1.7
Crop damage in 1990 *Based on modified Rabl-Eyre (1997)*	 4.9	Crop damage in 1990 *Based on dose-response functions*	 5.7

3. Policy assessment

3.1 Policy package regarding acidification and eutrophication

3.1.1 Key issues

Eutrophication: the focus on air emissions should not be allowed to divert attention from the huge problem of eutrophication in regional waters, i.e. Baltic Sea. A cost benefit analysis of a 50% nutrient load reduction in the Baltic Sea shows (see Technical report on benefit assessment section), it shows benefits exceed costs, with a ratio of 2.2:1. This suggests therefore, that the seemingly ambitious programme is justified in cost benefit terms.

3.1.1.1 Recommended policy initiatives

Nitrogen Tax

Direct NOx emission charges can only be levied on stationary sources where measurement equipment is in place. A suitable proxy for NO_x emissions is difficult to accept because NO_x emissions depend on the method by which the fuel is burned as well as the type of fuel. For example, a feasible range of NOx emissions from coal is 60 - 230 mg NOx/MJ and for natural gas, 20 - 110 mg NOx/MJ. However, the installation of measuring equipment is expensive. Thus an NOx charge can only be levied on large or medium sized plants where the cost of measuring emissions is fairly proportional to the saving the plant can make by cutting emissions and thus reducing the environmental charge payable.

In 1992, Sweden levied an NO_x tax on all plants with a capacity $_{above}$ 10MW, producing more than 50GWh but this was later extended to all plants producing more than 25GWh. Despite the greater coverage of NO_x sources, EEA (1998) estimate, emissions from stationary sources in Sweden represented just over 14% of national NOx emissions, in 1994. Emissions from plants liable to the tax constitute only one third of total NO_x emissions from stationary sources (TFEAAS 1999). Thus, we would expect the Swedish charge to have a very limited impact on total national NOx emissions.

The charge was set at € 4.86 / kg NO_x (SEK 40 / kg NO_x). The Swedish Environmental Protection Agency (1997) reports, plants liable to the charge emitted 24,000 and 12,500 tonnes NO_x in 1990 and in 1995 respectively, i.e. a reduction of 11,500 tonnes over 5 years. This is equivalent to a 48% reduction of emissions from charged plants. The major impact of the NO_x charge can be explained, in part, by the relatively cheap abatement measures available to the industry. The Swedish EPA estimate (1997) the average cost of nitrogen removal taken as a consequence of the tax to be less than € 1.1 / kg NO_x (SEK 10). This is significantly lower than the NO_x tax levied.

Some of the combustion modification measures used to reduce NO_x emissions in Sweden are already in place in Europe and these are included in the Baseline scenario. This means a similar tax levied in Europe will not generate such a dramatic reduction in NOx emissions.

Thus, disregarding absolute values of abatement costs and tax, we assume a European NO_x tax, set according to the ratio of 4:1 tax to costs (as experienced in Sweden), generates a similar environmental effect to that seen in Sweden. The European NOx tax will encourage use of other technologies that remain available for further limiting emissions, such as, selective non-catalytic reduction technologies (SNCR) requiring the injection of ammonia / urea and further combustion modifications.

We estimate the reduction in NO_x emissions by the following procedure: 35% of total stationary source NO_x emissions originate from power plants i.e. 1130 k tonnes NOx, IIASA (1999). IIASA reports that, 95% of NO_x emissions in the power plant sector come from plants bigger than 50 MW thermal (i.e. 20 MW electric). Assuming the tax is levied on all plants with a capacity of 20MW and the impact of the tax causes emissions to fall by 48%. We estimate a reduction of 515,300 tonnes NO_x (i.e. (0.95 x 1130) x 0.48 = 515,300) will take place across Europe as a result of the NO_x tax.

Sulphur Tax

The greatest part of sulphur dioxide emissions in Europe emanate from power generation, in particular from coal fired power plants. In countries with a low share of coal in power generation such as (Sweden, The Netherlands, Luxembourg, Finland and Austria) industrial processes and mobile sources are the main emitters. To reduce sulphur dioxide emissions a sulphur tax can be levied on the sulphur content of fossil fuels used for energy production.

The experience in Sweden demonstrates that a sulphur tax can be highly effective at reducing already low sulphur contents in fossil fuels even further. In 1991, Sweden introduced a sulphur tax on coal, peat and oil consumption. It corresponds to SEK 30 per kilogram of sulphur emitted, about € 3.5 / Kg S. Although, Ekins and Speck (1998), report nominal tax rates of the combined energy taxes in Sweden (i.e. CO_2, NO_x and sulphur taxes) are greater by a factor of 3 to the effective tax rate for the manufacturing industry. Thus assuming the relationship between nominal and effective tax rates are the same for all three energy taxes, it follows that the effective sulphur tax for industry corresponds to € 1.2 / Kg S.

The tax was set, based upon the marginal cost of reducing sulphur emissions. The cost of reducing sulphur emissions is dependent, among other things, on the world market prices of very low sulphur oils in relation to other oils. Thus, the tax rate was set so as to allow room for increasing relative prices of very low sulphur oils. The marginal emission abatement cost was assumed to be SEK 10-15 / Kg S abated, about € 1.2-1.8 / Kg S.

At the time of introduction, the actual average content of sulphur in heavy fuel oil was around 0.65%, i.e. lower than the Swedish maximum value of 0.8% (L¬vgren, 1994). The sulphur content of light oil was 0.2% and coal was also quite low (SEPA 1992). Between 1991 and 1994, the sulphur content of heavy fuel oil fell to 0.4% and light oil to 0.1% (fuels with a sulphur content of 0.1% or less are exempt from the tax). While, total Swedish SO_2 emissions from combustion in stationary sources fell from 54,000 tonnes in 1990 to 40,000 tonnes in 1991, a reduction of about 25% (Statistics Sweden, 1993).

Several factors contributed to the dramatic reduction in SO_2 emissions in Sweden, these include the sulphur tax, tightening of emission standards, carbon dioxide tax, other energy taxes and changes in the level of industrial activity. It is impossible to identify the precise impact of the sulphur tax on emissions reduction. However, the Swedish experience can help inform the expected effects of a Europe wide sulphur tax.

Based on the Swedish experience, we assume a European sulphur tax set according to the ratio of 3:1 tax to abatement costs, generates a similar reduction in sulphur content to that experienced in Sweden. To estimate the reduction in SO_2 emissions, the following procedure is used. Where, 35% of total stationary source SO_2 emissions originate from stationary combustion sources, i.e. in 2010, 1680 k tonnes SO_2, IIASA (1999). The impact of the tax is assumed to cause further reduction in the sulphur content of fuels, i.e. for heavy fuel oil, from an average of 0.6% to 0.4%. Assuming SO_2 emissions fall by 25% an estimated reduction of 420,000 tonnes of SO_2 will take place across Europe as a result of the SO_2 tax.

Tradable permits for sulphur

Tradable permits in sulphur have long been established in the USA. Policy simulations show that substantial cost savings can be obtained through trading. However, the European context may be such that emissions trading will be of limited feasibility. First, trading would only 'fine tune' the measures undertaken through the Second Sulphur Protocol, i.e. unlike the USA, trades would not be the main instrument of control, but rather a means of accommodating residual inefficiencies in the Second Sulphur Protocol. Thus, trades are likely to be comparatively few. This is borne out by available simulations (Klaasen (1997), and Sorrell (1998). Second, whereas the US trades are based on a 'one-to-one' exchange rate (i.e. one tonne of S increase can be traded for one tonne of S decrease), one-to-one trades in Europe may infringe the ecosystem integrity of third parties. The Second Sulphur Protocol essentially restricts trades so as to avoid significant impacts of this kind, further restricting the potential for trade. Accordingly, while sulphur trading has many attractions it is not likely to be a dominant policy instrument in the European context.

Mineral accounting and an ammonia tax

The major source of NH_3 emissions in Europe is agriculture, and within that source, most emissions are relating to animal manure, the rest to the use of fertilisers. NH_3 emissions are implicated in acidification and, because of the potassium, nitrogen and phosphorus in the manure, also in eutrophication. The 'divorce' between mineral inputs and outputs at the farm level in modern agriculture means that mineral surpluses are generated and these find their way to the environment as opposed to being 'embodied' in food output. Policy therefore needs to aim for a better balance between mineral inputs and outputs.

Unfortunately, the issue of how best to control NH_3 is extremely complicated. Mineral losses are determined by the number of animals, the type of animal, the nature of the farming operation (intensive, extensive), storage facilities, uses of the manure (e.g. plough-back), the nature of the crops grown on land treated with manure, the nature of the soil, climate variables, and so on. No single policy measure is therefore likely to achieve the desired change in concentrations.

Since the NH_3 problems are particularly acute in the Netherlands it is not surprising that a wide range of policy measures are in place there (Hotte et al., 1995; RIVM, 1995). These have the potential for general applicability across the EU, but there are major doubts about the environmental and economic efficiency of the measures. The essential features are:

construction of 'manure accounts' whereby farmers keep records of livestock, from which estimates can be made of manure generated, the amount used on the farmer's own land, and hence the amount that is surplus and which requires disposal. Surplus manure can be made available to farmers who are below the stated standards for manure application; guidelines and requirements relating to the management of manure in terms of storage, spreading on land, and mixing with soil; a levy on 'excess' manure expressed in terms of weight per hectare. The proceeds from the Dutch levy are recycled back into the sector to finance research, processing and transport. Some of the levy may be refunded if farmers can demonstrate they are using low-mineral animal feed;
eco-labelling for livestock housing units.

Hotte et al.(1995) indicate that the Dutch policy has not so far achieved its environmental objectives. They identify several shortcomings – an over-emphasis on phosphates and a neglect of nitrogen minerals, over lenient manuring standards, a perverse effect of manure 'rights' which results in farmers holding on to livestock for fear of losing those rights, possible contradictions in the effect of reduced manuring on increased fertiliser use, and the levy being too low. Overall, they doubt if the package of targeted measures is cost-effective. They suggest that more detailed but operable *mineral* accounts be constructed (as opposed to *manure* accounts and that a more effective levy be charged on nitrogen and phosphorus surpluses. Quoting work by CLM, they suggest that levies per kilogramme of mineral lost (i.e. surplus) of 1-2.5 guilders per kg for nitrogen and 1-5 guilders per kg of phosphorus would reduce Dutch emissions by 50% and 20-40% respectively. Revenues would be neutral and used to subsidise low mineral practices.

Overall, then, while NH_3 control is obviously complex, there is a need for a policy instrument, which is targeted at the damage done. The concept of a mineral surplus, i.e. the excess of any output of minerals over any input to an economic system, provides a suitable proxy for damage. There is therefore a need for an accounting system, which at least approximately measures mineral surpluses. Any levy should then be proportional to the surpluses and should account for all the main minerals involved.

The benefits of achieving the AP scenarios range from € billion 1 - 3, (see Benefit Assessment Section). In order to reach the target a tax set at a level above the marginal cost of abatement is necessary. If the ammonia to livestock functions are known, then it would be possible to tax livestock.

3.1.2 Multiple benefits

The policies recommended above will also benefit urban stress via the reduction of nitrates and sulphates and low level ozone through the reduction of NOx. The issue of climate change will also benefit if the demand for energy derived from fossil fuels is reduced in general.

A number of policy options recommended for other environmental issues will reduce the issue of acidification and eutrophication as well. These are listed below.

- EU carbon / energy tax
- aviation tax
- methane tax on fossil fuel emissions
- methane tax on livestock
- transport policies

COHERENCE et al.1997) estimate that the carbon tax that will lead to a 10% reduction in CO_2 emissions across the EU will also result in 7% reduction in SO_2 emissions, 3% reduction in NO_x emissions and a 4% increase in NH_3 emissions. Given that the SO_2, NO_x and NH_3 emissions were 16.3, 13.2 and 3.5 million tonnes, respectively, in 1990. The percentage changes due to a carbon tax correspond to 1.1, 0.4 million tonnes reduction in SO_2, NO_x, respectively and a 0.1million tonne increase in NH_3 emissions.

COHERENCE et al.(1997) also estimate the savings from the emissions control costs for SO_2, NOx and NH_3 as a result of the same scenario for a carbon tax to be € 2.2 billion per year, € 1.4 billion per year and € 556 million per year, respectively.

If the full carbon – energy tax is not feasible, then the recommended policy becomes minimum rates of excise duties.

In 1997 EC issued a directive on minimum rate of excise duties for all energy products - COM(97)30. It relates to end-users in transport, industry, commercial and domestic sectors but excludes power generation. The minimum rates were to be introduced by 2004. Since the proposal relates to minimum taxes only, and most energy is already taxed quite heavily in the EU and since it excludes electricity, the effects of this measure are likely to be small. COHERENCE et al.(1997) suggests that it would reduce CO_2 emissions by 1.5% off baseline emissions in 2007. Reductions in other pollutants are 2.5% for particulate matter, 1.25% for SO_2 and 0.5 - 1% for NOx and VOCs. Assuming that EU emissions of SOx in 1990 was 16.3 million tonnes and NO_x emissions in the same year was 13.3million tonnes, these percentage reductions corresponds to 0.2 mt SO_2 and 0.1 mt of NO_x (average of 0.5-1%).

The suggested aviation tax, methane tax on fossil fuels, methane tax on livestock and the transport policy package will all affect the emission levels of SO_x, NO_x and NH_3. However, we do not have enough information to estimate what this spill-over effect would be.

3.1.2.1 B/C ratios for recommended policy initiatives

Benefit-cost ratio of a nitrogen tax

Based on the Swedish experience, we estimate that a tax of approximately € 5 / kg NO_2 (or 5,000 € / tonne NO_2) would produce a reduction in emissions of about 0.5 million tonnes NO_2 in 2010. Assuming that the ratio of tax to costs is 4:1 (as above), the total abatement cost of a NO_x tax would be:

$TAC_{NOx\ tax}$ = ¼ x (tax rate per tonne NO_2) x (expected total tonnage reduction of NO_2)
= ¼ x (€ 5,000 / t) x (0.5 million tonnes)
= € billion 0.625

Where TAC is total abatement cost. Note that this is the total abatement cost for the year 2010.

The benefits of emissions reduction are derived from AEA Technology (1999). The impacts considered are restricted to morbidity, mortality, crops and materials. For a reduction in emissions of 2.43 million tonnes of NO_2 they estimate total benefits to be € billion 18.6 - 28.8 (1997 prices), or unit values between € 7,950 - 12,280 per tonne NO_2 abated. Multiplying these unit values by the expected reduction in emissions due to the NO_x tax gives total benefits as follows:

$TB_{NOx\ tax}$ = benefit per tonne abated x tonnes abated
= (€ 7,950 - 12,280 / tonne NO_2) x (0.5 million tonnes)
= € billion 3.98 - 6.14

Combining the estimates for benefits and costs produces benefit-cost ratios of between 6.4 and 9.8 for the NO_x tax.

Benefit-cost ratio of a sulphur tax

Based on the Swedish experience, a marginal abatement cost of approximately € 1.2 - 1.8 / kg S (or 600-900 € / tonne SO_2) for a tax rate of between € 1,800-2,700 / tonne SO_2. This would be expected to produce a reduction in emissions of about 0.4 million tonnes SO_2 in 2010. The total abatement cost of a SO_x tax would be:

$TAC_{SOx\ tax}$ = abatement cost per tonne SO_2 reduced x tonnes SO_2 reduced
= (€ 600 - 900 / t) x (0.4 million tonnes)
= € million 240 - 360

Where TAC is total abatement cost. Note that this is the total abatement cost for the year 2010.

The benefits of emissions reduction are derived from AEA Technology (1999). For a reduction in emissions of 3.95 million tonnes of SO_2 they estimate total benefits to be € billion 10.2 - 15.6 (1997 prices), or unit values between € 2,575 - 3,950 per tonne SO_2 abated. Multiplying these unit values by the expected reduction in emissions due to the SO_x tax gives total benefits as follows:

$TB_{SOx\ tax}$ = benefit per tonne SO_2 abated x tonnes of SO_2 abated
= (€ 2,575 - 3,950 / tonne SO_2) x (0.4 million tonnes)
= € billion 1.03 - 1.58

Combining the estimates for benefits and costs produces benefit-cost ratios of between 7.2 and 16.5 for the SO_x tax.

Control of NH_3 to address issue of eutrophication

Eutrophication involves nutrient build-up in water bodies, resulting in oxygen depletion and hence interference with life forms in the water ecosystem. The sources of eutrophication tend to be nitrogen and phosphorus.

Ammonia: costs and benefits

The analysis above includes the impacts to the environment via ammonia. The unit damage values are taken from AEA Technology (1999). However, the only benefits estimated relate to health and agricultural effects. The notable omission is *ecosystem* damage where, currently, the number of economic valuation studies are few and unreliable. The benefits from NH_3 control are therefore understated, perhaps seriously so.

We illustrate the cost-benefit picture by selecting the 'G5/2' scenario for control, representing a scenario of 'medium ambition' relative to the reference scenario[15].

	Reference scenario 2010 emissions 10^6 tonnes	'Medium ambition' scenario G5/2 2010 10^6 tonnes	Change in emissions G5/2 over Ref 10^6 tonnes
EU 15	3.16	2.67	-0.49
Non-EU	3.46	3.08	-0.38
Total ECE	6.62	5.75	-0.87

The costs of reducing NH_3 emissions to the levels in the G5/2 scenario in 2010, are estimated at: € billion:

EU: € billion 3.4
Non-EU: € billion 1.4
Total: € billion 4.8

For the benefits estimate the health benefits dominate the estimate of total benefits. Depending on the approach – country specific or UNECE wide (the latter takes an average valuation across UNECE) – the benefits in 2010 are:

€ billion 7.2 - 8.6 (benefits to health valued with VOSL)
€ billion 4.6 - 5.6 (benefits to health value with VOLY)

Benefit cost ratios for 2010 are thus:

VOSL: 1.5 to 1.8
VOLY: 0.9 to 1.2

As noted above, this is very probably a serious understatement of benefits. Additionally, the costs of control are based on end of pipe technology which almost certainly over-estimates costs. True benefit cost ratios are therefore likely to be even higher still. This further suggests that very strict targets for NH_3 would be justified. Based on this analysis, we suggest the control of ammonia is a highly cost-effective strategy.

3.1.3 Policy initiatives summary section

Table 3.1.1 gives the required targets for NO_x, SO_x and NH_3 emission reduction for the direct control measures and the ‘secondary’ targets for climate change policies in the ‘No Trade’ and ‘Full Trade’ variants of the AP scenario for acidification. Table 3.1.1 lists the potential policy initiatives that could be put in place in order to achieve emissions reduction.

[15] All costs and benefits are converted to € 1997 using the deflator 1.274.

Where possible, estimates of their effectiveness are given as well as the monetary benefit estimates associated with these emissions reductions. Where known, costs of policies are given also.

The information shows that the N-tax alone will not meet the direct control targets for NO_x. There is a short fall of 0.9 mt NO_x for the 'No Carbon' variant, and a shortfall of 0.7 - 0.8 mt NO_x for the 'No Trade' and 'Full Trade' variants respectively. It is possible that through the implementation of the transport policy package, the targets for NO_x could be met, unfortunately, it has not been possible to determine the effectiveness of these policies. Based on COHERENCE et al.(1997) the carbon / energy tax secures a 0.4 mt reduction in NO_x. This meets the target for the 'Full Trade' variant, but there is a shortfall of 0.2 mt NO_x for the 'No Trade' variant. If both the carbon tax and the N-tax are put in place the targets for all the scenarios are not met by a short fall of: 'No Carbon': 0.5mt NO_x, 'No Trade': 0.9 mt NO_x and 'Full Trade': 0.7 mt NO_x.

Likewise the targets are not met for sulphur emissions. The sulphur tax is expected to reduce emissions by 0.4 mt SO_2. This means there is a shortfall of 1.0, 0.4, 0.6, mt SO_2 for the 'No Carbon', 'No Trade' and 'Full Trade' variants respectively. The impact of a carbon tax on sulphur emissions is an expected reduction of 1.0 mt SO_2. This overrides the target for the 'Full Trade' scenario and if combined with the sulphur tax, the targets for the 'No Carbon' variant are met, but there is a shortfall of the 'No Trade' targets by 0.2 mtSO_2. These shortfalls can be reduced through the introduction of the aviation tax and the transport policy package, but it is not possible to determine by how much.

The targets for ammonia are a reduction of 0.3 mt NH_3 for the ‘No Carbon’ variant and roughly 0.2 mt NH_3 for the remaining scenarios. The introduction of a carbon / energy tax would increase the emissions of ammonia, estimated to be roughly 0.1mt NH_3. Unfortunately, the effects of policies to reduce ammonia emissions, such as an ammonia tax on the number of livestock (and hence the level of emissions) are not known.

Turning to the EU Acidification Strategy, the 1997 draft strategy to combat acidification involves the following targets; NO_x: 1.4 mt, SO_2: 1.2 mt, NH_3: 0.3 mt. Thus, for nitrogen, if the N-tax and the carbon / energy tax are introduced, there is a shortfall of; 0.5 mt NO_x. This shortfall is increased to 0.8 mt NO_x, if the carbon tax is not introduced. Whilst for sulphur, the acidification strategy target is met if the S-tax and the C-tax are implemented, but a shortfall of 0.6mt if the carbon tax is not introduced.

Thus, we see that if the carbon / energy tax is not introduced there will be a massive policy target shortfall for both NO_x and SO_2.

Table 3.1.1 exposure response functions for impacts to crops.

<table>
<tr><th colspan="2">Main objective
Mt emission reduction</th><th>Policy measure</th><th>Effect</th><th>Benefits
€ billion</th><th>Direct costs
€ billion</th></tr>
<tr><td rowspan="9">'No Carbon'
NO_x: 1.4
SO_x: 1.4
NH_3: 0.3

'No Trade'
Direct control:
NO_x: 1.2
SO_x: 0.8
NH_3: 0.2

'Full Trade'
Direct control:
NO_x: 1.3
SO_x: 1.0
NH_3: 0.2</td><td rowspan="9">

'No Trade'
Climate targets
NO_x: 0.6
SO_x; 1.2
NH_3: 0.0

'Full Trade'
Climate targets
NO_x; 0.3
SO_x: 0.7
NH_3: 0.0</td><td>Nitrogen tax 1)</td><td>0.5mt NO_x</td><td>3.98 – 6.14</td><td>0.625</td></tr>
<tr><td>Sulphur tax 1)</td><td>0.4 mt SO_2</td><td>1.03 – 1.58</td><td>0.24 – 0.36</td></tr>
<tr><td>Mineral accounting 2)
with charges on N and P</td><td>50% farmyard N
30% farmyard P</td><td>n.k</td><td>n.k</td></tr>
<tr><td>Carbon - energy tax 3)
at $75 per tonne of C
(€ 63 per tonne) (spillover)</td><td>1 mt SO_2
0.4 mt NO_x</td><td>2.8 - 4.2
3.4 - 5.2</td><td>-</td></tr>
<tr><td>Excise duty (min. energy tax)
(spillover)</td><td>0.2 mt SO_2
0.1 mt NO_x</td><td>0.6 - 0.8
0.8 - 1.3</td><td>-</td></tr>
<tr><td>CH_4 tax on fossil fuel emissions at € 353 per tonne</td><td>n.k</td><td>-</td><td>-</td></tr>
<tr><td>CH_4 tax on livestock
(spillover – NH_3)</td><td>n.k.</td><td>-</td><td>-</td></tr>
<tr><td>Transport policy package</td><td>n.k.</td><td>-</td><td>-</td></tr>
<tr><td>Total effect</td><td>1 mt NO_x
1.6 mt SO_2
? mt NH_3</td><td></td><td></td></tr>
</table>

Note that 2.2a and 2.2b are mutually exclusive.
1) Costs based on the Swedish experience; Benefits based on AEA (1999)
2) Based on the Dutch experience with 1-2.5 guilders per kg for nitrogen and 1-5 guilders per kg of phosphorus
3) COHERENCE et al.,(1997) estimate that NH_3 emissions would increase by 4% or 0.1 mt

3.2 Policy assessment regarding acidification and eutrophication

Three policy initiatives are recommended: (i) NO_x emissions tax for stationary sources, (ii) SO_x emissions tax for stationary sources, and (iii) a tax on NH_3.

3.2.1 Causal criterion

Table 3.2.1 presents the driving forces and the underlying causes behind the problem of acidification and eutrophication.

Table 3.2.1 Driving forces and underlying causes of acidification

	Driving force	Underlying cause		
		MF	IntF	ImpF
D1	Power generation: main source SO_x	X		
D2	Transport growth: main source NO_x	X		
D3	Use of inorganic fertilisers and intensive animal husbandry: main source NH_3		X	X

X = main underlying cause, MF = market failure, IntF = intervention failure, ImpF = implementation failure. Note that for driving forces D1 the main cause is due to the growth in real income, whilst for D2, the main causes are growth in real income and population growth.

The nitrogen and sulphur taxes are both policy initiatives that address the underlying causes of acidification. An NH_3 levy, based on a system of thorough accounting which measure mineral surpluses, set proportional to mineral surpluses would also address the underlying cause.

3.2.2 Efficiency criterion

Benefit-cost ratio for TD and AP scenarios

The B/C ratios reported in Table 3.2.2 for acidification are based on i) primary benefit estimates of reduced SO_x, NO_x and NH_3, and ii) primary benefits and secondary benefits to tropospheric ozone and urban stress. The costs relate to costs of control for SO_x, NO_x and NH_3.

Table 3.2.2 B/C ratios for AP and TD scenarios

Scenario	Welfare costs			Direct costs		
	low	mid	high	low	mid	high
VOSL						
NT: primary benefit	2.2	8.3	31.9	1.3	5.0	19.2
NT: primary +secondary benefit	-	9.8	-		5.9	
FT: primary benefit	1.8	6.8	26.1	1.1	4.1	15.6
FT: primary + secondary benefit	-	8.0	-		4.8	
TD: primary	0.7	2.8	10.9	0.4	1.7	6.5
TD: primary +secondary benefit		3.4			2.1	
VOLY						
NT: primary benefit	1.4	5.4	20.7	0.8	3.2	12.4
NT: primary +secondary benefit		5.9			3.5	
FT: primary benefit	1.1	4.4	16.9	0.4	2.6	10.1
FT: primary + secondary benefit		4.7			2.8	
TD: primary	0.5	1.8	7.0	0.3	1.1	4.2
TD: primary +secondary benefit		1.9			1.1	

As expected the B/C ratios based on welfare costs are greater than B/C ratios based on direct costs in all cases. It is important to note that B/C ratios based on direct costs are a 'worst case scenario' this is because 'end of pipe' technology costs tend to provide an upper limit to costs. They are typically more expensive than behavioural changes which would avoid full adoption of 'end of pipe' abatement technology.

The B/C ratios based on welfare costs suggest that even omitting all benefits to ecosystems, cultural assets, visibility and the benefits due to reduced levels of low level ozone, investments in the reduction of SO_x, NO_x (VOCs) and NH_3 emissions have substantial benefit-cost ratios in the mid and upper range for all scenarios. B/C ratios are also near and above unity even in the lower band of estimates for all scenarios. Surprisingly the B/C ratios are greatest for the TD scenario, this is explained by the assumption that welfare costs are roughly two thirds less for the TD scenario, whilst only one third less in the AP scenario.

B/C ratios based on direct costs also show that even with the omission of some important benefits, investments in the reduction of acidifying pollutants have large B/C ratios in the mid and high band estimates for the AP scenarios. The greatest B/C ratios are for the 'No Trade' variant followed by 'Full Trade' variant and finally the TD scenario.

Benefit assessment of TD and AP scenarios

The benefit estimates for reduced acidifying pollutants in the different scenarios are reported in Table 3.1.4. Mid values are reported with a range based on the 68% confidence interval. Two values are reported for each band, mid, low and high. They differ in their treatment of the valuation of premature mortality, i.e. the former value uses VOLY, whilst the latter makes use of VOSL.

Table 3.2.3 Acidification benefits for AP and TD scenarios: € billion

Scenario	Primary benefit due to acidification related measures	Secondary benefit estimate to low level ozone and urban stress	*Benefit from climate change related measures*
VOSL			
NT	21.7	7.1	*23.1*
FT	25.2	7.8	*7.3*
TD	58.9	12.6*	-
VOLY			
NT	14.0	1.6	*8.5*
FT	16.3	1.7	*4.7*
TD	38.1	1.7*	

* Secondary benefits of acidification in the TD scenario are to tropospheric ozone only. Due to data limitations it is not possible to estimate the secondary benefits to urban stress. Secondary benefits to urban stress due to the reduction of secondary aerosols are not reported separately in Table 3.2.3 because they are already accounted for in the primary benefit estimates. Secondary benefits from climate change related measures are reported for consistency's sake only, i.e. they are not used in the cost benefit analysis of acidification control.

Costs of TD and AP scenario

Table 3.2.4. provides the direct costs and welfare costs for the control of the acidifying pollutants.

Table 3.2.4. Welfare costs and direct costs for the control of acidification: € billion

	Welfare costs	Direct costs
NT	2.6	4.3
FT	3.7	6.2
TD	20.8	34.6

Benefit cost ratio for recommended policies

The benefit cost ratios is large for both policies:

(a) *NO_x tax*: AEA Technology (1999) estimate the benefits of reduced NO_x emissions in wider Europe. Monetised benefits of emissions reduction cover only impacts to morbidity, mortality, crops and materials. For details see Technical report on Benefit assessment methodology). The monetary benefits of a predicted reduction in emissions of 0.5 million tonnes of NO_x due to the tax are estimated to be between 3.98 and 6.14 billion €, in 2010.

The cost of an EU-wide tax measure is estimated, based on the Swedish experience, to be 0.625 billion € in 2010. Combining these estimates gives a benefit-cost ratio of between 6.4 and 9.8. Note this is for the year 2010 only.

(b) *SO_x tax:* Benefits estimates are again derived from AEA Technology (1999). For a reduction of 0.4 million tonnes of SO_2 in 2010, monetised benefits are estimated to be € billion 1.0 to 1.6. Again, costs of emissions reduction due to a tax measure are based on the Swedish experience, and are approximately € billion 0.24 - 0.36 in 2010. Combining these estimates gives a benefit cost ratio of between 7.2 and 16.5.

Eutrophication: cost benefit analysis of a 50% nutrient load reduction in the Baltic Sea shows that benefits exceed costs, i.e. 2.2:1. Therefore, such an ambitious programme is justified in cost benefit terms. (see Technical report on Coastal Zones, Benefit Assessment section). Policy option not given

NH_3 control: based on AEA Technology (1999) the costs of reducing NH_3 emission by 0.87 million tonnes are estimated at € billion 3.77. The benefits are estimated to be, € billion 5.67 - 6.8. Thus the benefit cost ratio for 2010 is thus 1.5 - 1.8. The benefit estimates are underestimates as they omit impacts to ecosystems. And the costs of control are based on end-of-pipe technology which almost certainly over-estimates costs. Therefore, true

benefit cost ratios are likely to be even higher still. This further suggests that very strict targets for NH_3 would be justified.

Public opinion

Considerable industrial and household opposition to the imposition of taxes that may lead to increased energy prices.

3.2.3 Administrative complexity

NO_x tax: the administrative complexity of NO_x taxes is low, as most countries already have suitable institutions in place TFEAAS (1999).

Sulphur taxes: are comparatively easy to introduce in administrative terms. Sulphur emissions are closely correlated with the sulphur content of the relevant fossil fuels so that a tax on the fuel according to its sulphur content will approximate an emissions tax. An emissions tax is not however an accurate proxy for a damage related tax, since damage additionally depends on the dispersion pattern of the emissions, on the sensitivity of receiving ecosystems and on population density in the receiving area. Theoretically, taxes could be varied according to damage by using EMEP matrices to trace the emissions - impact relationships. In practice, sulphur taxes that vary regionally, even within one Member State, are likely to be difficult to enforce. Thus, an emissions tax represents a second - best approximation of an externality tax.

Ammonia tax: administrative complexity is high. In order to establish mineral surpluses for each farm, a system of mineral accounting is required to demonstrate mineral inputs / outputs at the farm level. However, mineral levels are dependent on a great number of diverse factors, such as: the number of animals, the type of animals, the nature of the farming operation (intensive, extensive), storage facilities, uses of manure (e.g. plough back), the nature of the crops grown on land treated with manure, the nature of the soil, climate variables etc.

3.2.4 Equity criterion

Emissions taxes that lead to higher energy prices are likely to be regressive. The regressive effects can be reduced by side payments from the tax revenues to those harmed by the tax. In Sweden, the nitrogen charge is refunded to the plants that pay the tax in order to avoid a distortion of competition between large (i.e. liable) and small (i.e.non liable) firms. The distributive impacts of the sulphur tax will vary greatly, depending on the degree of dependence a nation has on coal fired power plants, again payments could be made to those harmed by the tax.

3.2.5 Jurisdictional criterion

Acidification and eutrophication are transboundary environmental concerns. However, credibility of centralisation is low relative to UN ECE.

Macroeconomic effect

Details provided in *Technical Report on Socio-Economic Trends, Macro-Economic Impacts and Cost Interface* .

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3.3 Policy package regarding tropospheric ozone

3.3.1 Key issue

Relevant policies either already in place or they are recommended for other environmental issues. These are mainly taxes that reduce energy demand derived from fossil fuels, such as the carbon / energy tax, minimum excise duty, methane tax on fossil fuels, (see *Technical report on Climate Change*) and the NOx tax (see *Section 3.2*). Low level ozone emissions will also be reduced through the policy initiatives recommended for the transport sector (for further details see acidification, climate change and the transport policy package), this suggest major new initiatives are not needed.

3.3.2 Recommended policy initiatives

Other policy actions that could reduce low level ozone further would include:

VOC Tax

A new VOC tax is due to be implemented in Switzerland from 1 January 2000 aimed at reducing photochemical smog. The tax will be set at SF2/kg (or € 1260 per tonne VOCs). The government expects this tax to cut 27,000 tonnes of VOCs off total emissions of 172,000 tonnes. This corresponds to a 16% decrease. If we assume that the same tax rate is implemented in the EU with the same percentage effect, this would correspond to 16% of 14 million tonnes of VOCs (1990 emissions), i.e. 2.2 mt VOCs. This assumption is a rather weak one and the total reduction assumed here is in fact greater than the target reduction.

Ecolabelling of solvents

In the UK, B&Q (a DIY store) has introduced a new labelling system to classify all paint products sold in its stores by their solvent content (ENDS, 1996). Since January 1997, the paint products listed by the store carry one of five phrases, ranging from 'solvent free' to 'very high solvent' indicating the level of solvent content. B&Q also set solvent limits for the company's own brand products to be reached by the end of 1997. In UK, water-based paints have been steadily increasing their market share and now account for almost all wall and ceiling paints. However, they still account for less than 10% of the gloss paints market (compared to more than 90% and 40-50% in Germany), because solvent-based paints still cost much less than water-based ones. B&Q's targets are tighter than both the limits suggested in the EC proposed solvent Directive and those in the EC eco-label criteria. Moreover, the EC eco-label applies solely to interior decorative paints, rather than to all paints products, and its eco-label criteria (VOC limit of 30 g/l for matt paints and 200 g/l for gloss paints) are weaker.

There does not seem to be any evidence to the effect of ecolabelling on solvent use and hence VOC emissions.

3.4 Policy assessment regarding tropospheric ozone

Major new initiatives for the control of tropospheric ozone are not needed because the relevant policies are either already in place or they are recommended for other environmental issues, such as; acidification, climate change and the transport policy package. However, further control of ozone, could be achieved through the introduction of a VOC tax.

3.4.1 Causal criterion

Table 3.4.1 presents the driving forces behind the tropospheric ozone problem. The underlying causes of are also identified.

Table 3.4.1 Driving forces and underlying causes of climate change

		Underlying causes		
		MF	IntF	ImpF
D1	Industrial growth (solvent using sectors, power stations)	X		
D2	Transport growth	X		

X = main underlying cause, MF = market failure, IntF = intervention failure, ImpF = implementation failure. Note that for driving forces D1 and D2, the main causes are also growth in real income and population.

The underlying causes of tropospheric ozone will be dealt with directly by the recommended emissions taxes.

Emissions taxes should be set according to the damage done, i.e. approximating the ideal 'externality' tax. However, there is of course, substantial uncertainty about the marginal damages from VOCs and NOx, and environmental damage additionally depends on the climatic conditions, the dispersion pattern of the emissions, on the sensitivity of the receiving ecosystems and on the population density in the receiving area. In theory, emission taxes should be varied according to the damage done, however, in practice, taxes that vary regionally are very difficult to enforce. Thus the emission tax is a second best policy option to the ideal 'externality' tax, to deal with the underlying causes of tropospheric ozone.

3.4.2 Efficiency criterion

Benefit-cost ratio for TD and AP scenario

The cost benefit analysis for the TD and AP scenarios give the following B/C ratios for the control of NO_x and VOCs. Note low / high B/C ratios relate to the approach to premature mortality valuation, i.e. low makes use of VOLY and high B/C ratios assume VOSL.

Table 3.4.2 B/C ratios for the control of VOC

	Welfare costs
NT: AP	0.4 - 3.0
FT: AP	0.3 - 2.3
TD	0.2 - 1.7

Note: B/C ratios based on direct costs of VOC control are not estimated due to missing direct cost data.
Also, B/C ratios for the NC variant of the AP scenario are not estimated as cost data are absent.

B/C ratios for tropospheric ozone based on the primary control for VOCs compared to the welfare costs of control for VOCs only are greater than unity for all scenarios. The Full Trade variant lowers the benefit cost ratio for tropospheric ozone due to the increase in costs associated with greater levels of VOC control. The B/C ratio for the TD scenario is estimated to be 1.7.

A key issue relating to the B/C ratios for the control of the tropospheric ozone precursor pollutant, VOCs, is the approach to premature mortality valuation. Assuming VOLY means all scenarios fail the cost benefit test, i.e. B/C ratios are below unity. For example, B/C ratios based on primary benefits of VOC control compared to welfare costs of VOC control, for the No Trade, Full Trade and Technology Driven scenario become, 0.4, 0.3 and 0.2 respectively.

If we compare total benefits to tropospheric ozone i.e. primary benefits of VOC control plus secondary benefits to tropospheric ozone from the acidification strategy, to the combined welfare costs of NO_x and VOCs. The B/C ratios for the No Trade, Full Trade and Technology Driven scenarios are 2.9, 2.4 and 1.5 respectively. These B/C ratios may be an underestimation due to the omission of the primary benefits of NO_x control. VOLY also has a significant effect on the B/C ratios based on total benefits to tropospheric ozone. For example, B/C ratios for the No Trade, Full Trade and Technology Driven scenarios are, 1.3, 1.0 and 0.2 respectively.

Benefit assessment of TD and AP scenarios

The benefits of TD and AP scenarios over the Baseline are presented in Table 3.4.3.

Table 3.4.3 Total benefit due to reduced low level ozone: € billion

	Total benefit	Secondary benefit due to NO_x reduction*	Primary benefit due to VOC
TD	2.8 - 21.7	1.7 - 12.6	1.2 - 9.1
NC -AP	1.7 - 13.0	-	-
NT-AP	1.8 - 14.0	1.1 - 8.4	0.7 - 5.6
FT-AP	1.8 - 13.4	1.0 - 7.8	0.7 - 5.7

Low / high estimates assume premature mortality is valued with VOLY / VOSL respectively.
*Secondary benefits from both climate change and acidification related measures that reduce NO_x.

The second column gives the total benefits for low level ozone control. The third column reports the benefits of reduced low level ozone control through the control of NO_x from both climate change and acidification related measures; and finally the last column gives the benefits due to the direct control VOC emissions.

The primary benefit estimates for the control of VOC emissions can be used directly to estimate the B/C ratio for VOC control reported in Table 3.4.2.

Costs of TD and AP scenarios

Table 3.4.4 provides the welfare and direct costs for the control of NO_x and VOCs. Welfare costs are established on the assumption that welfare loss is about one third less than the technical costs for the TD and AP scenarios.

Table 3.4.4 Welfare costs and direct costs for tropospheric ozone control: € billion

	Welfare costs		Direct costs	
	NO_x + VOC	VOC	*NO_x + VOC*	VOC
NT-AP	*2.7*	1.9	*4.6*	-
FT-AP	*3.6*	2.5	*6.1*	-
TD	*14.6*	5.3	*24.4*	-

Note, for purposes of cost benefit analysis, we compare benefits of direct VOC control with costs of VOC reduction only.

Cost-effectiveness

The VOC emissions tax is an economically efficient measure because, like all emission taxes, it can ensure the emissions reduction target is achieved at the lowest cost. The condition of economic efficiency is met when the price to be paid to reduce the last unit of abatement is the same everywhere. Emission taxes have an advantage over other regulatory instruments, because they allow the market for pollution abatement to decide how the reduction effort is distributed among polluters, which in turn, should lead to the standardisation of the marginal abatement costs.

Public opinion

Although public opinion regarding the issue of low level ozone control measures is not known with certainty, Eurobarometer (1995) shows that most Europeans are prepared to change their consumption behaviour as a step to slow down or perhaps even stop the deterioration in the environment as a whole. This could be an indication that the public would accept a VOC tax.

3.4.3 Administrative complexity:

In principle, a VOC tax is administratively feasible. First, reliable monitoring systems need to be in place and institutions may need to be set up, in order for the VOC tax to function successfully. Then, the VOC tax must be set according to the damage done, in order to approximate a 'true' externality tax.

3.4.4 Equity criterion

A VOC tax will affect those industrial enterprises that are major emitters of VOCs, such as metallurgy, cement, chemicals, bricks, paints, glass, oil refineries, etc. The transport sector will also be affected (i.e. paint spraying). Thus, we see that a wide diversity of products are associated with VOC emissions and a high number of diffuse sources are involved. This makes it very difficult to determine the equity effects of the VOC tax.

The spatial distribution of the environmental benefits brought about by the VOC tax depends on many factors, such as: season, climatic conditions, dispersion, sensitivity of the receiving ecosystem, population density etc. At the time of writing, there were no known studies examining this issue.

3.4.5 Jurisdictional criterion

Tropospheric ozone is a regional and transboundary environmental concern. The issue is treated in the same manner as acidification, which suggests credibility of centralisation is low relative to UN ECE.

Macroeconomic effects

Macroeconomic effects are discussed in *Technical Report on Socio-Economic Trends, Macro-Economic Impacts and Cost Interface.*