FIRST INTERIM REPORT

Cost-effective Control of Acidification and Ground-Level Ozone

First Interim Report to the European Commission, DG-XI

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EXECUTIVE SUMMARY

In response to a request of DG-XI of the European Union this paper explores the likely impacts of current European policies to reduce emissions on the achievement of critical loads for acidification. While concluding that current measures will not be sufficient to fully achieve critical loads for all ecosystems in Europe, the report investigates a number of alternative strategies for further emission reductions.

The analysis makes use of the 'Regional Air Pollution Information and Simulation' (RAINS) model developed at IIASA. RAINS is an integrated assessment model, which was use for the negotiations for the Second Sulfur Protocol of the Convention on Long-range Transboundary Air Pollution. The RAINS model combines information on current and future levels of economic activity and energy consumption with inventories of available emission control options and an assessment of their costs. Based on information on national emission control strategies the model forecasts future emission levels for sulfur dioxide, nitrogen oxides, ammonia and volatile organic compounds. Relying on transfer matrices derived from the EMEP long-range transport model developed at the Norwegian Meteorological Institute, patterns of deposition of sulfur and nitrogen compounds can be calculated for any combination of future sulfur and nitrogen emissions. By comparing deposition with critical loads the extent of ecosystems' protection against acidification and eutrophication can be determined for all of Europe. Databases on critical loads have been compiled from national submissions at the Coordination Center for Effects at the National Institute for Public Health and Environment (RIVM) in the Netherlands. The optimization mode of the RAINS model also allows for the identification of cost-optimal combinations of measures in order to achieve pre-specified target deposition levels.

The preliminary analysis presented in this report suggests that the current strategies for reducing emissions in Europe will achieve significant progress in attaining the critical loads for sensitive ecosystems. Total SO_2 emissions in the EU15 are expected to decline between 1990 and 2010 by 66 percent, total NO_x by 50 percent and ammonia by 16 percent. As a result, the unprotected ecosystems (24 percent in the EU15 in the year 1990) are expected to decline to seven percent, however still leaving almost nine million hectares unprotected against acidification. The analysis demonstrates that there is room for further improvement, although at increasing costs.

Taking the situation in 1990 as a starting point, three alternative scenarios have been constructed to explore possible cost-effective solutions for further moving towards the full achievement of the critical loads. Since full achievement of critical loads means bringing down the area of unprotected ecosystems to zero, three interim targets have been defined, aiming at a reduction of the ecosystems unprotected in 1990 in each grid by 45, 50 and 55 percent, respectively.

The optimization analysis starts from existing legislation (taking into account national and international regulations, such as the various protocols of the Convention on Long-range Transboundary Air Pollution and the Directives of the European Union) and explores cost-effective action on top of the measures already in force. This means that countries at least reduce emissions down to the level expected from current legislation or policy plans.

Given this constraint, the RAINS model has been used to determine the cost-minimal allocation of the remaining emission control options to achieve the deposition levels guaranteeing the selected minimum level of ecosystems' protection. Model calculations show that the envisaged targets could be reached by balanced further reductions of SO_2, NO_x and NH_3 emissions. For the EU-15 as a whole, SO_2 emissions of the three scenarios are between 45 and 60 percent lower than the levels expected to result from current policy; NO_x is reduced further by between 7 and 22 percent, and ammonia by between 11 and 20 percent. The selection of measures depends strongly on regional aspects, particularly on the sensitivity of the ecosystems to acidification. Whereas in the southern part of Europe only modest efforts will be necessary to achieve the protection targets, emission control in other regions must be further tightened and must also address small and existing sources.

Additional abatement costs range between 5 and 13 billion ECU/year, which means an increase of the costs of current policy of between 13 to 33 percent. With these extra efforts, critical loads for acidification could be attained for 50 to 80 percent of the ecosystems expected to remain unprotected by current policy.

The second series of scenarios analyzes, i.a., the advantages of aiming at a pan-European solution, which involves also emission sources outside the direct control of the European Union. While keeping the environmental targets constant (e.g., the 50 percent gap closure), emission control measures for ships in the Baltic, the North Sea and parts of the Atlantic Ocean could reduce the overall emission control costs by two billion ECU/year, i.e., by 25 percent of the additional costs on top of current legislation. Further measures in non-EU countries could substitute the most expensive controls inside the EU15 and thereby save about 1 billion ECU/year.

It is important to mention that the cost estimates obtained from the RAINS model must be considered as upper limits for abatement costs. Earlier analysis has demonstrated that non-technical measures, modifications of the energy system (e.g., fuel substitution, energy conservation, etc.) and changes in the economic structures can reduce emission control costs substantially, in certain cases by more than 50 percent. In particular, strategies aiming at reducing emissions of greenhouse gases usually produce also significantly positive side impacts on the control costs for acidifying pollutants. A quantification of this effect remains subject to further analysis.

For the time being the preliminary analysis presented in this first interim report ignores the side impacts of emission reductions on ground-level ozone. Work is underway to quantify this effect .

There is clear evidence that strategies targeting at acidification reduce also the area of ecosystems facing excess of their critical loads for eutrophication. However, due to the focus on acidification the achieved protection levels for eutrophication are lower than for acidification. If an environmental policy aims at the full protection of ecosystems, both aspects should be considered simultaneously. Methodologies for the analysis of such a multi-effect approach combining acidification, eutrophication and tropospheric ozone will be available in the near future.

Cost-effective Control of Acidification and Ground-level Ozone

First interim Report to the European Commission, DG XI

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1. Introduction

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.

Once emitted, many air pollutants remain in the atmosphere for some time before they are finally deposited on the ground. During this time, they are transported with the air mass over long distances, often crossing national boundaries. As a consequence, at a given site the concentration of pollutants and their deposition on the ground is influenced by a large number of emission sources, often in many different countries. Thus, action to efficiently abate air pollution problems has to be coordinated internationally.

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 (SO_2), nitrogen oxides (NO_x) and volatile organic compounds (VOC). Several directives of the European Union prescribe emission standards for large combustion plants, for mobile sources, and limit the sulfur content in liquid fuels.

Most of the current agreements determine required abatement measures solely in relation to technical and economic characteristics of the sources of emissions, such as available abatement technologies, costs, historic emission levels, etc. No relation is established to the actual environmental impacts of emissions. For achieving overall cost-effectiveness of strategies, however, the justification of potential measures in relation to their environmental benefits must also be taken into account. Recently, progress has been made in quantifying the environmental sensitivities of various ecosystems. Critical loads and critical levels have been established reflecting the maximum exposure of ecosystems to one or several pollutants not leading to environmental damage in the long run. Such threshold values have been determined on a European scale, focusing on acidification and eutrophication as well as on vegetation damage from tropospheric ozone.

A recent EU document on the status of acidification prepared for the EU council shows that the current policies on emission reductions will greatly reduce the environmental threat posed by acidification and other air pollution problems. However, implied measures will not be sufficient to eliminate the problem everywhere in Europe. To meet critical loads for acidification everywhere, further measures will be necessary. Furthermore, analysis also shows that critical levels for tropospheric ozone aiming at the protection of health and vegetation are currently widely exceeded in Europe, and that current policies in Europe will not be sufficient to eliminate the problem entirely. Since most of the low-cost options for abating emissions are already adopted in the current strategies, further action aiming at the sustainability of Europe's ecosystems will have to embark on more costly measures. Cost-effectiveness will be an important argument for gaining acceptance of proposed policies.

This interim report presents a number of emission reduction scenarios aiming at improving ecosystem's protection against acidification in Europe in cost-effective ways. Although the focus is on acidification, attention is also directed towards side-impacts of emission reductions on eutrophication of terrestrial ecosystems and on ground-level ozone. The methodology adopted for the analysis is described in Section 2 of this report, and data sources are discussed in Section 3. Section 4 is divided into three parts: To set reference levels for the scenario analysis, the first part (4.1) captures the situation in the year 1990 and projects the changes expected to result from the implementation of current legislation on air pollution in the year 2010. Then, a comparison is made to the hypothetically possible achievements, if currently available emission control technologies were fully applied in the future, although constraints on the abatement schedule imposed by the actual current legislation are disregarded. The second part (4.2) starts from the situation in the year 1990 (in terms of ecosystem's protection levels) and explores alternative ways for reducing the areas that are not protected against acidification in the year 1990. The third part (Section 4.3) analyzes the robustness of the optimal solution, i.a., versus modified assumptions about the involvement of emission sources outside of the EU. The results of the analysis are summarized in Section 5.

2. Methodology

The recent progress in quantifying the sensitivities of ecosystems adds an important feature to the analysis and the development of cost-effective strategies to achieve and maintain emission levels that do not endanger the sustainability of ecosystems. Integrated assessment models are tools to combine information and databases on the economic, physical and environmental aspects relevant for strategy development. The Regional Air Pollution INformation and Simulation (RAINS)-model developed at the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria) provides a consistent framework for the analysis of emission reduction strategies, focusing at 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 environmental problems (acidification, eutrophication and tropospheric ozone), the model considers emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3) and volatile organic compounds (VOC). A detailed description of the RAINS model can be found in Alcamo *et al*., 1990. A schematic diagram of the RAINS model is displayed in Figure 1.

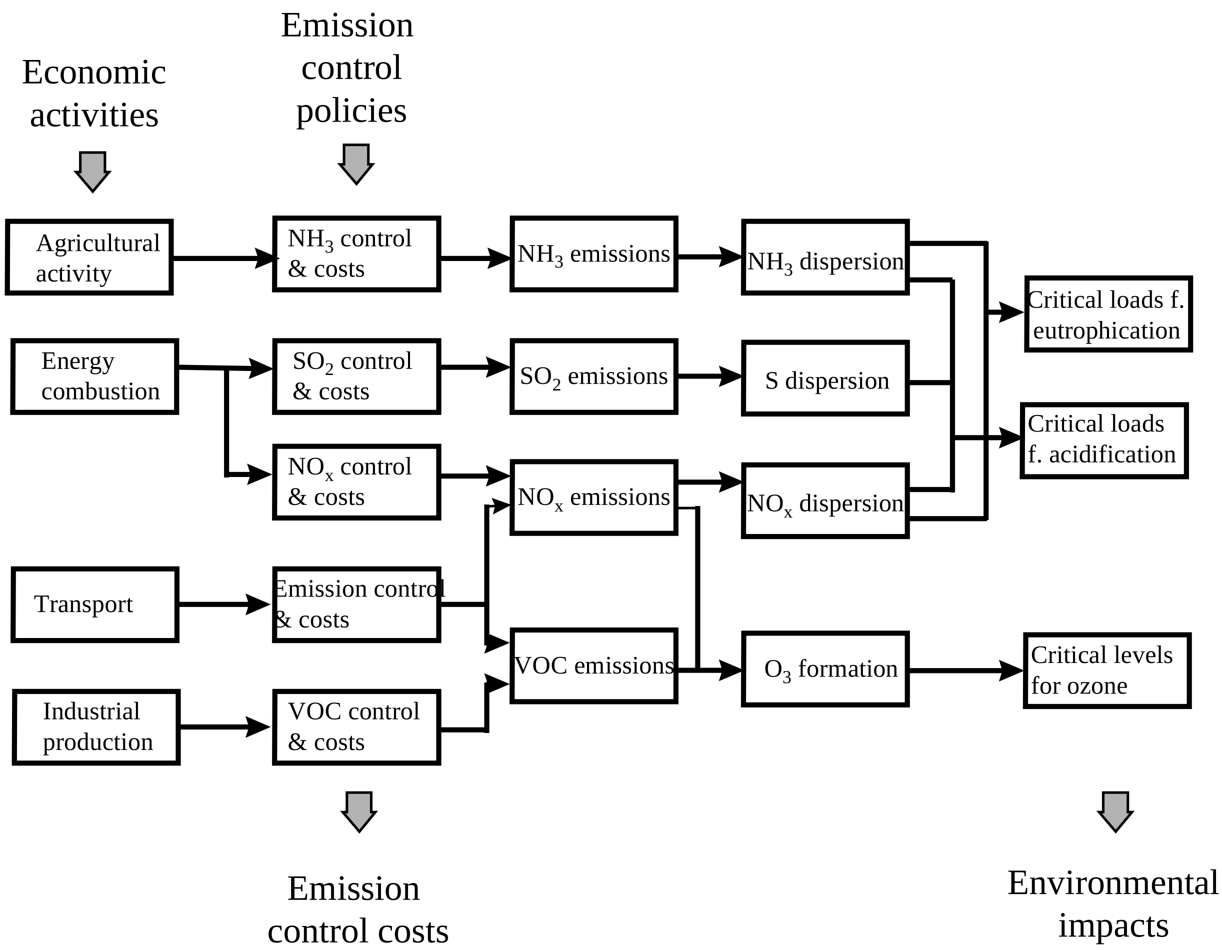

Figure 2.1: Schematic flowchart of the RAINS model framework

The European implementation of the RAINS model incorporates databases on energy consumption for 38 regions in Europe, distinguishing 21 categories of fuel use in six economic sectors. The time horizon extends from the year 1990 up to the year 2010 (Bertok *et al*., 1994). 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, 1995). 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 (Amann & Cofala, 1994). 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 (Tuovinen *et al*., 1994). 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). The RAINS model incorporates databases on critical loads and critical levels compiled at the Coordination Center for Effects (CCE) at the National Institute for Public Health and Environmental Protection (RIVM) in the Netherlands (Downing *et al*., 1993).

The RAINS model can be operated in the 'scenario analysis' mode, i.e., following the pathways of the emissions from their sources to their environmental impacts. In this case the model provides estimates of regional costs and environmental benefits of alternative emission control strategies. Alternatively, a (linear programming) 'optimization mode' is available for the acidification part to identify cost-optimal allocations of emission reductions in order to achieve specified deposition targets. This mode of the RAINS model was used extensively during the negotiation process of the Second Sulfur Protocol under the Convention on Long-range Transboundary Air Pollution for elaborating effect-based emission control strategies. A first version of a non-linear optimization module for tropospheric ozone has been recently completed and will be operational in the near future.

3. Data Sources

3.1 Energy Projections

Input 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 consumption for 22 fuel types in 6 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.).

For the purpose of this study, energy projections for the 15 EU member states have been provided by DG-XVII and have been incorporated into the RAINS data base. These projections (Table 3.2) are extracted from the 'Conventional Wisdom Scenario' of the 'Energy 2020' Study (DGXVII, 1996).

For the Non-EU member 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 Data Base (UN/ECE, 1995a). Where necessary, missing forecast data have been constructed by IIASA based on a simple energy projection model. These forecasts (Table 3.1) are also the basis for the scenario calculations conducted for the negotiations of the Second NO_x Protocol under the Convention on Long-range Transboundary Air Pollution.

The energy scenario selected for this study projects for the 15 EU countries an increase of total energy consumption of 20 percent between 1990 and 2010. The demand for coal decreases by 26 percent and for liquid fuels from stationary sources by seven percent. This decline is mainly compensated by a rapid increase in the demand for natural gas (82 percent by 2010) and for other fuels (nuclear, hydropower, renewable energy), an increase by 38 percent. The transport sector is expected to grow further, which - in spite of continuing improvement in fuel economy of new cars and trucks - results in an increase in the demand for transport fuels by 26 percent.

For the non-EU countries, the scenario projects a five percent drop in total primary energy consumption. This is due to a 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. Consumption of coal and oil by stationary sources is predicted to decrease by 23 and 33 percent, respectively. Consumption of natural gas will increase (by 12 percent). Similarly to the EU countries, the demand for transport fuels will increase (by 6 percent over the period 1990 - 2010). In spite of a fast increase in car ownership, the increase in the demand for fuels is modest because of a rapid decrease in material- and transport intensities of the former so-called planned economies. Thus, until 2010 the demand for goods transport will also 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. It is planned to analyze the feedback of stringent emission control obligations on fuel consumption patterns and the implications of alternative energy strategies (e.g., energy policies aiming at controlling CO_2 emissions) in the second interim report of this study.

Table 3.1: Projections of total primary energy consumption to the year 2010 used for this study

	1990 [PJ]	**2010** [PJ]	**Change** 1990-2010	**GDP growth** [%/year]
Austria	1236	1470	*19 %*	2.5 %
Belgium	1907	2142	*12 %*	2.2 %
Denmark	736	957	*30 %*	2.2 %
Finland	1208	1582	*31 %*	1.7 %
France	8792	11312	*29 %*	2.4 %
Germany	13880	15516	*12 %*	2.6 %
Greece	910	1184	*30 %*	3.8 %
Ireland	410	530	*29 %*	3.5 %
Italy	6560	8172	*25 %*	2.0 %
Luxembourg	122	129	*6 %*	2.3 %
Netherlands	2711	3124	*15 %*	2.1 %
Portugal	699	1163	*66 %*	3.5 %
Spain	3659	4724	*29 %*	2.7 %
Sweden	2319	2502	*8 %*	1.3 %
UK	8526	10135	*19 %*	2.0 %
EU-15	**53676**	**64642**	***20 %***	**2.3 %**
Albania	128	143	*12 %*	1.3 %
Belarus	1762	1553	*-12 %*	-0.3 %
Bosnia-H..	311	297	*-5 %*	0.3 %
Bulgaria	1296	1262	*-3 %*	1.5 %
Croatia	413	447	*8 %*	0.8 %
Czech Republic	1956	1837	*-6 %*	1.8 %
Estonia	423	366	*-13 %*	0.9 %
Hungary	1109	1350	*22 %*	1.7 %
Latvia	399	359	*-10 %*	-0.3 %
Lithuania	677	565	*-17 %*	-0.3 %
Norway	1596	1750	*10 %*	2.0 %
Poland	4201	4951	*18 %*	3.4 %
R. of Moldova	394	324	*-18 %*	-0.3 %
Romania	2425	2525	*4 %*	1.3 %
Russia	18312	16617	*-9 %*	-0.3 %
Slovakia	987	982	*0 %*	1.8 %
Slovenia	231	234	*1 %*	1. 2 %
Switzerland	1119	1198	*7 %*	1.3 %
FYR Macedonia	151	138	*-9 %*	0.8 %
Ukraine	9968	8559	*-14 %*	-0.3 %
Yugoslavia	790	725	*-8 %*	0.6 %
Non-EU	**48648**	**46183**	***-5 %***	**1.0 %**
TOTAL	**102324**	**110824**	***8 %***	**2.1 %**

Table 3.2 : Energy projection for the EU-15 (Source: DGXVII - Conventional Wisdom Scenario)

Source category/fuel	1990 [PJ]	2010 [PJ]	Change 1990-2010
Stationary combustion sources:			
Total	43651	51964	*19 %*
- Coal	11609	8580	*-26 %*
- Liquid fuels	12020	11126	*-7 %*
- Gaseous fuels	10404	18953	*82 %*
- Other	9619	13304	*38 %*
Mobile sources - total	10025	12678	*26 %*
TOTAL	**53676**	**64642**	***20 %***

Table 3.3 : Energy projection for the non-EU countries (Sources: UN/ECE, 1995a, RAINS estimates)

Source category/fuel	1990 [PJ]	2010 [PJ]	Change 1990-2010
Stationary combustion sources:			
Total	44057	41312	*-6 %*
- Coal	11540	8888	*-23 %*
- Liquid fuels	8540	5699	*-33 %*
- Gaseous fuels	18199	20440	*12 %*
- Other	5778	6285	*9 %*
Mobile sources - total	4591	4870	*6 %*
TOTAL	**48648**	**46183**	***-5 %***

3.2 Projections of Agricultural Livestock

Agricultural activities are a major source of ammonia emissions, which in turn make a contribution to the acidification problem. Next to specific measures directed at limiting the emissions from livestock farming, the development of the animal stock is an important determinant of future emissions. IIASA has compiled a forecast of European agricultural activities, based on national information (Marttila, 1995; Nemi, 1995; Pippatti, 1996; Henriksson, 1996; Riseth, 1990; Menzi, 1995), on studies performed for the Commission of the European Communities, DG-VI (EC DG-VI, 1995a-k - including countries of Central and Eastern Europe, Former Yugoslavia and Baltic Republics), and on Egmond, 1995; Stolwijk, 1996; Folmer *et .al*, 1995 for the EC-9 countries. Forecasts for Republics of Former Soviet Union were derived on the basis of an OECD study (OECD, 1995). Earlier work conducted at IIASA was used for both livestock and fertilizer forecasts (Klaassen, 1991; Klaassen, 1995).

The forecast of fertilizer consumption is based on IFA (International Fertilizer Industry Association) estimates (Ginet, 1995). This forecast extends till 1999, the values for 2005 and 2010 are based on trend extrapolation assuming the same quantitative increase (Isherwood, 1995). The forecasts of fertilizer production and use till the year 2000 in Western Europe are in good agreement with results of an overview of world nitrogen supply and demand by B.L. Bump (Bump, 1995).

Projections of livestock are presented in Table 3.4. In this table cows represent dairy cows and other cattle, pigs category includes fattening pigs and sows, and poultry comprises laying hens, broilers and other poultry.

Table 3.4: Projection of livestock up to the year 2010 (1000 animals)

	Cows			Pigs			Poultry		
	1990	**2010**		**1990**	**2010**		**1990**	**2010**	
Austria	2562	2546	*-1 %*	3773	4545	*20 %*	14000	17266	*23 %*
Belgium	3041	5103	*68 %*	6436	4740	*-26 %*	35302	27100	*-23 %*
Denmark	2241	1715	*-23 %*	9282	11650	*26 %*	16249	17120	*5 %*
Finland	1363	900	*-34 %*	1348	1200	*-11 %*	6000	4500	*-25 %*
France	21414	20860	*-3 %*	12366	17420	*41 %*	236000	279310	*18 %*
Germany	20287	15709	*-23 %*	34178	21190	*-38 %*	125489	78576	*-37 %*
Greece	624	615	*-1 %*	996	1454	*46 %*	27385	32967	*20 %*
Ireland	5899	7702	*31 %*	999	1933	*93 %*	8933	13557	*52 %*
Italy	8746	9498	*9 %*	9254	10450	*13 %*	161000	204125	*27 %*
Luxembourg	217	386	*78 %*	75	50	*-33 %*	69	50	*-28 %*
Netherlands	4926	4808	*-2 %*	13364	11164	*-16 %*	93818	79476	*-15 %*
Portugal	1341	1244	*-7 %*	2531	1484	*-41 %*	21928	26840	*22 %*
Spain	5126	5267	*3 %*	16002	21406	*34 %*	51000	56105	*10 %*
Sweden	1718	1885	*10 %*	2264	2100	*-7 %*	12269	8950	*-27 %*
UK	11872	9375	*-21 %*	7383	4845	*-34 %*	131000	111943	*-15 %*
EU-15	**91377**	**87613**	***-4 %***	**120251**	**115631**	***-4 %***	**940442**	**957885**	***2 %***
Albania	645	780	*21 %*	220	258	*17 %*	5000	8424	*68 %*
Belarus	7166	4300	*-40 %*	5204	4000	*-23 %*	49836	43300	*-13 %*
Bosnia -H	874	685	*-22 %*	614	550	*-10 %*	9000	8000	*-11 %*
Bulgaria	1577	924	*-41 %*	4352	4277	*-2 %*	36339	43609	*20 %*
Croatia	829	602	*-27 %*	1573	1300	*-17 %*	15000	8402	*-44 %*
Czech Rep.	3360	3448	*3 %*	4569	5759	*26 %*	33278	49142	*48 %*
Estonia	805	581	*-28 %*	1080	1177	*9 %*	7000	7800	*11 %*
Hungary	1598	1557	*-3 %*	7660	7907	*3 %*	58564	63500	*8 %*
Latvia	1472	710	*-52 %*	1555	1453	*-7 %*	11000	7617	*-31 %*
Lithuania	2422	2242	*-7 %*	2730	2784	*2 %*	18000	19172	*7 %*
Norway	1043	1146	*10 %*	710	782	*10 %*	5422	5300	*-2 %*
Poland	10049	13274	*32 %*	19464	23787	*22 %*	70000	97789	*40 %*
R. Moldova	1112	970	*-13 %*	2045	1487	*-27 %*	25001	19000	*-24 %*
Romania	6291	6155	*-2 %*	11671	10274	*-12 %*	119293	146782	*23 %*
Russia	42231	27293	*-35 %*	30527	30527	*0 %*	474330	326525	*-31 %*
Slovakia	1563	803	*-49 %*	2521	2711	*8 %*	16478	22021	*34 %*
Slovenia	546	427	*-22 %*	588	695	*18 %*	13521	12932	*-4 %*
Switzerland	1855	1713	*-8 %*	1787	1400	*-22 %*	6529	6500	*0 %*
FYR of Macedonia	288	285	*-1 %*	161	173	*7 %*	22000	22000	*0 %*
Ukraine	25195	20500	*-19 %*	19947	23000	*15 %*	255100	260000	*2 %*
Yugoslavia	2168	1991	*-8 %*	4329	4092	*-5 %*	28000	21000	*-25 %*
Non-EU	**113089**	**90386**	***-20 %***	**123307**	**128393**	***4 %***	**1278691**	**1198815**	***-6 %***
TOTAL	**204466**	**177999**	***-13 %***	**243558**	**244024**	***0 %***	**2219133**	**2156700**	***-3 %***

Table 3.5: Projections of nitrogen fertilizer use up to the year 2010 (in 1000 tons N/year)

Country	**N-Fertilizer use**		
	1990	**2010**	***Change***
Austria	137	102	*-26 %*
Belgium	166	112	*-33 %*
Denmark	395	273	*-31 %*
Finland	207	143	*-31 %*
France	2493	1802	*-28 %*
Germany	1786	1177	*-34 %*
Greece	428	234	*-45 %*
Ireland	370	338	*-9 %*
Italy	857	776	*-9 %*
Luxembourg	20	16	*-20 %*
Netherlands	392	232	*-41 %*
Portugal	150	121	*-19 %*
Spain	1064	887	*-17 %*
Sweden	212	233	*10 %*
UK	1516	1072	*-29 %*
EU-15	**10193**	**7518**	***-26 %***
Albania	73	60	*-18 %*
Belarus	780	676	*-13 %*
Bosnia -H	19	10	*-47 %*
Bulgaria	453	430	*-5 %*
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	76	*-32 %*
Poland	671	855	*27 %*
R. of Moldova	123	228	*85 %*
Romania	765	780	*2 %*
Russia	3418	1994	*-42 %*
Slovakia	147	150	*2 %*
Slovenia	88	102	*16 %*
Switzerland	63	39	*-38 %*
FYRMacedonia	6	3	*-50 %*
Ukraine	1885	1599	*-15 %*
Yugoslavia	146	145	*-0 %*
Non-EU	**10171**	**9337**	***-8 %***
TOTAL	**20364**	**16855**	***-17 %***

3.3 Emission Estimates

The RAINS model 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. Emission estimates are performed on a disaggregated level, which is determined by the available details of the available energy projection and the CORINAIR emission inventory. The relations between CORINAIR categories and the RAINS sectors are shown in Table 1.4. Due to the differences in the format of the energy statistics and CORINAIR, a direct and full comparison of RAINS estimates with CORINAIR data is only possible at a more aggregated level.

Table 3.7 compares for 1990 the estimates for SO_2, NO_x and NH_3 emissions incorporated into the RAINS model with the results from the CORINAIR 1990 inventory. SO_2 and NO_x emission levels calculated by RAINS are generally in good agreement with CORINAIR'90; largest differences are less than five percent. The only exception is Greece with CORINAIR estimates more than 20 percent higher than RAINS. The reason is that CORINAIR includes for Greece emissions from the total marine bunker fuel purchased in Greece, whereas the energy balances used in RAINS exclude marine bunkering from gross inland energy consumption. In reality, only a small portion of fuel purchased by sea vessels in Greece is used in the Greek coastal zone. EMEP estimates for the land-based sources in Greece (UN/ECE, 1995b) are much lower than CORINAIR results and are close to the RAINS estimates. Emission estimates for other economic sectors in Greece are in good agreement. Obviously, this issue requires further explanation with participation of national CORINAIR experts.

CORINAIR is also available for eleven non-EU countries. With some exceptions, the agreement between RAINS and CORINAIR is good also for those countries. Compared with CORINAIR'90, RAINS estimates of NO_x emission levels in the Czech Republic are more than 30 percent lower. This is due to an extremely high emission factor used in the Czech national inventory system for brown coal and lignite. National experts admit that such high emission factors have not been confirmed by the results of measurements. For Poland, the discrepancies between RAINS and CORINAIR estimates are caused by high emission factors assumed in the Polish CORINAIR inventory for some industrial processes and for open burning of agricultural wastes. In other countries the discrepancies are mainly due to uncertainties of their energy balances.

For nine non-EU countries CORINAIR has not been developed as yet. In these cases RAINS emission estimates have been compared with EMEP data (UN/ECE, 1995b). The most important differences occur for the region of the former Soviet Union and for parts of former Yugoslavia. It is known, however, that in some cases EMEP estimates do not include all emission sources (e.g., for Yugoslavia, EMEP numbers refer to stationary sources only). In spite of the above mentioned discrepancies, even for the non-EU countries differences in total emissions between CORINAIR/EMEP and RAINS are only seven percent for SO_2 and 17 percent for NO_x.

Table 3.6: Main activity groups distinguished in the CORINAIR inventory and their relation to the sectors of the RAINS model

CORINAIR'90 category	**CORINAIR'90 SNAP code**	**RAINS sector**
Extraction and distribution of fossil fuels	05	Fuel production and Conversion - Combustion Fuel production and Conversion - Losses
Public power and co-generation plants	01	Power Plants & distr. heat plants
Commercial, institutional and residential combustion plants	02	Households and other
Road transport	07	Transport - Road
Other mobile sources and machinery	08	Transport - Other (rail, inland water, coastal zone)
Combustion boilers, gas turbines and stationary engines	0301	Industry - Combustion in boilers
Industrial combustion (other than 0301)	03-0301[1]	Industry - Other combustion
Production processes[2]	04	Industry - Process emissions[3]
For the ammonia module:		
Agriculture -animal breeding (excretions)	1005	Livestock
- Dairy cows	100501	- Dairy cows
- Other cattle	100502	- Other cattle
- Fattening pigs and sows	100503,100504	- Pigs
- Laying hens	100507	- Laying hens
- Broilers and other poultry	100508,100509	- Other poultry
- Sheep	100505	- Sheep
- Fur animals	100510	- Fur animals
- Horses	100506	- Horses
Agriculture - cultures with fertilizers (except animal manure)	1001-100106	Fertilizer use
Production processes - inorganic chem. Industry	040403-040408	Fertilizer production
Production processes - nitric acid	040402	Other
Waste treatment and disposal	0901-0904	Waste treatment & disposal

[1] Excluding processes with and without contact treated separately as process emissions.

[2] Including processes with and without contact treated separately as process emissions.

[3] Emissions are not directly attributed to fuel consumption. Production processes covered: oil refineries, coke, sinter, pig iron, non-ferrous metals (zinc, lead and copper), cement, lime, sulfuric acid, nitric acid, pulp mills. Other processes are covered by item IN_OC.

Table 3.7: Comparison of RAINS emission estimates with results from the CORINAIR 1990 inventory (in kilotons)

	SO_2		NO_x		NH_3	
	RAINS	**CORINAIR'90**	**RAINS**	**CORINAIR'90**	**RAINS**	**CORINAIR'90/ EMEP**
Austria	94	93	242	227	94	87/99
Belgium	313	317	363	343	87	78/78
Denmark	189	197	249	263	116	126/140
Finland	232	227	276	269	42	41/41
France	1297	1298	1605	1585	646	700/700
Germany	5470	5257	2955	2981	752	739/759
Greece	*515*	640	*387*	543	77	471/78
Ireland	179	178	106	116	123	126/126
Italy	1662	1683	1975	2041	365	383/383
Luxembourg	15	14	22	23	7	7/7
Netherlands	198	200	537	537	229	195/236
Portugal	280	283	207	215	98	93/93
Spain	2198	2206	1168	1247	321	330/353
Sweden	108	105	351	345	63	73/61
UK	3735	3787	2638	2773	434	468/320
EU-15	**16486**	**16483**	**13080**	**13508**	**3455**	**3920/3475**
Albania(*)	*71*	120	24	30	31	-/30
Belarus(*)	*845*	710	402	285	214	-/257
Bosnia-H. (*)	480	480	79	54	28	-/36
Bulgaria	1841	2008	352	361	142	323/323
Croatia(*)	178	180	83	83	37	38/44
Czech Republic	1876	1863	523	773	124	90/105
Estonia	274	275	81	72	29	29/29
Hungary	917	905	214	191	113	62/176
Latvia	122	115	112	93	45	38/38
Lithuania	230	223	146	157	79	84/84
Norway	56	54	201	232	35	38/38
Poland	2999	3273	1211	1445	527	539/508
R. Moldova(*)	*197*	91	87	35	46	-/50
Romania	1300	1311	502	546	289	300/371
Russia (*)	*5049*	4459	3490	2674	1311	-/1191
Slovakia	556	542	201	226	62	60/62
Slovenia	199	196	60	57	21	27/27
Switzerland	*50*	44	162	159	63	69/62
FYR Macedonia(*)	*106*	10	39	2	16	-/18
Ukraine(*)	*3699*	2782	1890	1097	737	-/926
Yugoslavia(*) (**)	*580*	508	211	66	85	-/99
Non-EU	**21624**	**20149**	**10068**	**8640**	**4034**	**4305/4475**
TOTAL	**38110**	**36632**	**23148**	**22148**	**7489**	**8225/7950**

Explanations and comments:
(*) CORINAIR has not been developed as yet. EMEP values were used for comparison with RAINS.
(**) Emissions only from stationary sources.

For ammonia the agreement between RAINS and CORINAIR/EMEP emission estimates lies for the majority of countries within a range of 10 percent (14 countries below 5% and 13 countries between 5 and 10%). For the EU-15 with the exception of Greece, RAINS and CORINAIR estimates for ammonia emissions differ by about two percent. The Greek submission to CORINAIR contains an unreasonably high number of emissions from fertilizer use (100 times higher on a per-area basis than emissions in, e.g., Germany). Correcting this value to a reasonable range brings the total emissions down to 84 kilotons, which is close to the EMEP estimate. All other significant discrepancies to CORINAIR estimates can be explained in similar ways and have been corrected in the RAINS database. Country-specific information can be provided upon request.

For the non-EU countries the largest difference occurs for Bulgaria, where CORINAIR estimates ammonia emissions twice as high as RAINS. A detailed inspection of the CORINAIR database revealed that for Bulgaria the emission factor for dairy cows is four to six times higher than the average European factor. Since there is no plausible explanation for this, the RAINS database uses the average European emission factor. Differences for the Czech Republic and Hungary can be traced back to the omission of fertilizer use, differences in statistics on livestock, etc.

3.4 Emission Control Options and Costs

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, particularly for those measures and for those countries, where present operating experience of the equipment is poor. Consequently, the RAINS model identifies for each of its application areas (i.e., emission source categories considered in the model) a limited list of characteristic emission 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.

For each of the available emission control options, RAINS estimates the specific costs of reductions, taking into account investment-related and operating costs. Investments are annualized over the technical lifetime of the pollution control equipment, using a discount factor of four percent. Whereas the technical performance as well as investments, maintenance and material consumption are considered to be technology-specific and thereby, for a given technology, equal for all European countries, fuel characteristics, boiler sizes, capacity utilization, labor and material costs (and stable sizes and applicability rates of abatement options for ammonia) are important country-specific factors influencing the actual costs of emission reduction under given conditions. A detailed description of the methodology adopted to estimate emission control costs can be found in Amann, 1990 and Klaassen, 1991b.

The databases on emission control costs have been constructed based on actual operating experience of various emission control options documented in a number of national studies (e.g., Schärer, 1993) as well as in reports of international organizations (e.g., OECD, 1993; Takeshita, 1995; Rentz, 1987). Country-specific information has been extracted from relevant national and international statistics (UNECE, 1996). In fall 1996, the list of control options and the country-specific data used for the cost calculation will be presented to the negotiating parties of the Convention on Long-range Transboundary Air Pollution for review.

3.4.1 Control Options for Reducing SO_2 Emissions and their Costs

The national potentials and costs of emission reductions are estimated based on a detailed data base of the most common emission control techniques. For a given energy scenario, reduction options for SO_2 emissions considered in RAINS are the use of low sulfur fuel, fuel desulfurization, combustion modification (e.g., lime stone injection processes and fluidized bed combustion) and flue gas desulfurization (e.g., wet limestone scrubbing processes). Structural changes, such as fuel substitution and energy conservation can also be evaluated, although only in interaction with an appropriate energy model.

Table 3.8 presents, for the major source categories, the available control options and the data used for the analysis. The basic input data for SO_2 control technologies used in RAINS have been reviewed in the process of the negotiations for the Second Sulfur Protocol of the Convention on Long-range Transboundary Air Pollution and have been recently updated to take into account latest operating experience.

Table 3.8: Emission control options for SO_2 considered in RAINS

A. Add-on technologies

Sector/control option	Removal efficiency [%]	Costs[4] Investment [1000 ECU/MW_{th}]	Operating and maintenance [%/year][5]
Power plants - retrofits			
Limestone injection	50	30	4
Wet flue gas desulfurization (FGD)	95	69	4
Regenerative FGD	98	165	4
Power plants - new			
Limestone injection	50	22	4
Wet flue gas desulfurization (FGD)	95	49	4
Regenerative FGD	98	119	4
Industrial boilers and furnaces			
Limestone injection	50	35	4
Wet flue gas desulfurization (FGD)	95	72	4
Regenerative FGD	98	203	4

B. Low sulfur fuels

Fuel type	Price difference [ECU / GJ / %S][6]	Costs [ECU / t SO_2][7]
Hard coal and coke, 0.6 % S	0.28	397
Heavy fuel oil, 0.6 %S	0.44	905
Gas oil, 0.2% S	0.68	1444
Gas oil, 0.05 % S	2.04	4333

[4] Values are for typical hard coal fired boilers for each source category.
[5] Percent of investment cost per year
[6] percent S reduced compared to original fuel.
[7] Per ton of SO2 removed; Calculated for a typical heating value of each fuel.

C. Industrial process emissions

Control option	**Removal efficiency [%]**	**Costs [ECU / t SO_2]**
Stage 1	50	350
Stage 2	70	407
Stage 3	80	513

3.4.2 Control Options for Reducing NO_x Emissions and their Costs

Table 3.9 presents the unit costs for the major options to control NO_x emissions, as contained in the RAINS database. For stationary sources, data are based on the same literature listed above for SO_2. Data for mobile sources have been derived from various reports developed within the Auto/Oil program (European Commission, 1996, Touche-Ross&Co., 1995) and from other national and international sources (i.a., Gorißen, 1992, HSMO, 1994, McArragher *et al*., 1994, Rodt *et al.*, 1995, UN/ECE, 1994a, UN/ECE, 1994b). The assistance of consultants participating in the Auto/Oil study helped to incorporate also the suggested measures on fuel quality improvement and inspection and maintenance schemes into the RAINS model in a fully consistent way (Barrett, 1995).

It is important to mention that the European Auto/Oil program used the net present value costing methodology, whereas RAINS expresses costs in terms of total annual costs, based on annualized investments over the entire technical life time of the equipment and the fixed and variable operating costs. Although there is consistency between Auto/Oil and RAINS in the input data of the cost evaluation, the resulting output cost numbers are not directly comparable. The major characteristics of the control measures for mobile sources considered in the RAINS model are shown in part (c) of Table 3.9.

Table 3.9: Emission control options for NO_x considered in RAINS

A. Stationary boilers, furnaces and ships

Sector/control option	Removal efficiency [%]	Costs[8] Investment [ECU/MW_{th}]	Operating and maintenance [%/year][9]
Power plants:			
Retrofits of existing boilers:			
Combustion modification & primary measures (CM)[10]			
Brown coal and lignite	65	6.8	-
Hard coal	50	3.9	-
Heavy fuel oil	65	4.7	-
Gas	65	5	-
CM + selective cat. Reduction (SCR)			
Brown coal and lignite	93	24.8	6
Hard coal	90	19.6	6
Heavy fuel oil	90	21.8	6
Gas	93	23.6	6
New boilers:			
SCR			
Brown coal and lignite	80	10.0	6
Hard coal	80	8.8	6
Heavy fuel oil	80	8.7	6
Gas	80	11.8	6
Industrial boilers			
Combustion modification & primary measures (CM)			
Brown coal and lignite	50	5.6	-
Hard coal	50	5.6	-
Heavy fuel oil	50	5.0	-
Medium distillates and gas	50	5.7	-
CM + Selective Non-catalytic Reduction (SNCR)			
Brown coal and lignite	75	11.0	6
Hard coal	75	11.0	6
Heavy fuel oil	75	9.1	6
Gas	75	10.6	6
CM + Selective Catalytic Reduction (SCR)			
Brown coal and lignite	90	21.9	6
Hard coal	90	21.9	6
Heavy fuel oil	90	17.4	6
Gas	90	20.3	6

[8] Values are for typical boilers for each source category.
[9] Percent of investment cost per year
[10] Combination of various measures (e.g., low NOx burners, overfire air etc.)

Table 3.10, continued: Emission control options for NO_x considered in RAINS, stationary sources and ships

Sector/control option	Removal efficiency [%]	Costs[11]	
		Investment [ECU/MW_{th}]	Operating and maintenance [%/year][12]
Residential and commercial sector[13]			
Combustion modification, low-NO_x burners (CM)			
Heavy fuel oil	50	5.6	-
Medium distillates	30	12	-
Natural gas	50	16.3	-
Ships			
SCR	80	25	6

B. Process emissions

Control option	Removal efficiency [%]	Costs [ECU/t NO_x]
Stage 1	40	1000
Stage 2	60	3000
Stage 3	80	5000

[11] Values are for typical boilers for each source category.
[12] Percent of investment cost per year
[13] Weighted average for residential and commercial sector. Unit control costs for gas and gas oil fired boilers in commercial sector are 40 - 50 % lower

C. Mobile sources[14]

Fuel/vehicle type/control technology	Removal efficiency [%]	Costs Investments [ECU/vehicle]	Costs Operating and maintenance [%/year][15]
Gasoline passenger cars and LDV[16]			
3-way catalytic converter - 1992 standards	77	250	24
3-way catalytic converter - 1996 standards	88	300	20
Advanced converter with maintenance schemes - EU 2000 standard	94	715	8.4
Advanced converter with maintenance schemes - EU 2005 standard (**)	97	*	*
Diesel passenger cars and LDV			
Combustion modification - 1992 standards	30	150	36.0
Combustion modification - 1996 standards	49	275	19.5
Advanced combustion modification with maintenance schemes - EU 2000 standards	59	780	6.9
NO_x converter(**)	80	*	*
Heavy duty vehicles			
Euro I - 1993 standards	32	600	46
Euro II - 1996 standards	42	1800	15
Euro III - EU 2000 standards with maintenance schemes	59	4047	6.8
Euro IV (NO_x converter) (**)	85	*	*

(**) - Not yet commercially available, without cost estimates

3.4.3 Options for Reducing Ammonia Emissions

For each of the major sources of ammonia emissions (livestock farming, fertilizer use, and chemical industry), RAINS considers a number of emission control options (Klaassen, 1991b; UNECE, 1996; EEA,1996).

Ammonia emissions from livestock occur at four stages, namely in the stable, during storage of manure, its application and during the grazing period. At every stage emissions can be controlled applying various techniques. Obviously RAINS cannot distinguish all of the several hundred available control options, but considers groups of techniques with similar technical and economic characteristics. The major categories considered in RAINS are

- low nitrogen feed (dietary changes), e.g., multi-phase feeding for pigs and poultry, use of synthetic amino acids (pigs and poultry), and the replacement of grass and grass silage by maize for dairy cattle;
- biofiltration (air purification), i.e., by treatment of ventilated air, applicable mostly for pigs and poultry, using biological scrubbers to convert the ammonia into nitrate or biological beds where ammonia is absorbed by organic matter;
- stable adaptation by improved design and construction of the floor (applicable for cattle, pigs and poultry), flushing the floor, climate control (for pigs and poultry), or wet and dry manure systems for poultry;

[14] Cost estimates are given for road vehicles. Control options for off-road vehicles are the same. All options include costs and effects of fuel quality modifications proposed by the Auto Oil Program

[15] Percent of investment cost per year

[16] LDV - light duty vehicles

- covered outdoor storage of manure (low efficiency options with floating foils or polystyrene, and high efficiency options using tension caps, concrete, corrugated iron or polyester);
- low ammonia application techniques, distinguishing high efficiency (immediate incorporation, deep and shallow injection of manure) and medium to low efficiency techniques, including slit injection, trailing shoe, slurry dilution, band spreading, sprinkling (spray boom system).

Ammonia emissions from chemical industry can be reduced by introducing stripping and absorption techniques (Tangena, 1985; Technica, 1984).

The main technical and economic characteristics of the control options are presented Table 3.11 and Table 3.12. It should be mentioned that, compared to the control options for SO_2 and NO_x, the cost estimates for ammonia abatement techniques are more uncertain, mainly due to the lack of practical operating experience with many of the techniques in most European countries.

Table 3.11: Emission control options for NH_3 considered in the RAINS model and their removal efficiencies

Abatement option	**Application areas**	**Removal efficiency [%]**			
		Stables	**Storage**	**Application**	**Meadow**
Low nitrogen feed (LNF)	Dairy cows	15	15	15	20
	Pigs	20	20	20	n.a.
	Laying hens	20	20	20	n.a.
	Other poultry	10	10	10	n.a.
Biofiltration (BF)	Pigs, poultry	80		n.a,	n.a.
Stable adaptation	Dairy cows, Other cattle	50	80	n.a.	n.a.
(SA)	Pigs	50	80	n.a.	n.a.
	Laying hens	70	80	n.a.	n.a.
	Other poultry	80	80	n.a.	n.a.
Covered storage (CS - low/high)	Dairy cows, other cattle, pigs, poultry	n.a.	60/80	n.a.	n.a.
Low NH_3 application (LNA- low/high)	Dairy cows, other cattle, pigs, poultry, sheep	n.a.	n.a.	40/80	n.a.
Stripping/adsorption	Industry	50			

n.a.: not applicable

Table 3.12: Costs of emission control options for NH_3 considered in the RAINS model

Abatement option	**Application area**	**Investments** [ECU/animal-place]		**Total costs*** [ECU/animal/year]	
		Stable size **			
		small	typical	small	typical
Low nitrogen feed	Dairy cows	n.a.		45	
	Pigs	2.7		8	
	Laying hens	n.a.		0.1	
	Other poultry	n.a.		0.12	
Bio-filtration and bio-scrubbers	Pigs	200-300	170	50-70	38-40
	Laying hens	4.7		1.5-2.0	
	Other poultry	4.7		2.0-2.5	
Stable adaptation	Dairy cows, Other cattle	450-550	400	90-110	75-90
	Pigs	90-94	89	21	19
	Laying hens	0.8		0.2-0.25	
	Other poultry	1.8		0.28	
Covered storage - high efficiency	Dairy cows	200-400	160	40-60	18-40
	Other cattle	100-150	70	15-25	7-12
	Pigs	2-5	1	0.4-1	0.3
	Laying hens	0.4		0.06	
Covered storage - low efficiency	Dairy cows	100-200	80	20-30	9-20
	Other cattle	50-75	35	7-13	3-6
	Pigs	1-3	0.5	0.2-0.5	0.15
	Laying hens	0.2		0.03	
Low NH_3 application	Dairy cows	n.a.		50-70	
	Other cattle	n.a.		18-40	
	Pigs	n.a.		5-8	
	Laying hens	n.a.		0.15-0.3	
	Other poultry	n.a.		0.04-0.06	
	Sheep	n.a.		3-4	
Stripping/adsorption	Industry	625 ECU/t NH_3 removed			

n.a.: not applicable

* - Taking into account fixed and variable operating costs

** - The following stable sizes are assumed:

Pigs - small (<50 animals/stable), typical (~170)
Dairy cows - small (<20 animals/stable), typical (~35)
Other cattle - small (<30 animals/stable), typical (~40)

3.5 Atmospheric Transport

The RAINS model estimates deposition of sulfur and nitrogen compounds due to the emissions in each country, and then sums the contributions from each country with a background contribution to compute total deposition at any grid location. These calculations are based on source-receptor matrices derived from a Lagrangian model of long-range transport of air pollutants in Europe, developed by EMEP.

The EMEP model is a receptor-oriented single-layer air parcel trajectory model, in which air parcels follow two-dimensional trajectories calculated from the wind field at an altitude which represents transport within the atmospheric boundary layer. Budgets of chemical development within the air parcels are described by ordinary first-order differential equations integrated in time along the trajectories as they follow atmospheric motion. During transport, the equations take into account emissions from the underlying grid of a 150 km resolution, chemical processes in the air, and wet and dry deposition to the ground surface. Model calculations are based on six-hourly input data of the actual meteorological conditions for specific years.

In order to capture the inter-annual meteorological variability, model runs have been performed for eleven years (1985-1995, Barret et al., 1996). For each of these years, budgets of sources (aggregated to entire countries) and sinks (in a regular grid mesh with a size of 150 * 150 km) of pollutants have been calculated. These annual source-receptor budgets have been averaged over eleven years and re-scaled to provide the spatial distribution of one unit of emissions. The resulting atmospheric transfer matrices are then used as input in the RAINS model.

The use of such ‘country-to-grid’ transfer matrices implicitly assumes that the spatial relative distribution of emissions within a country will not dramatically change in the future. Although this is definitely a strong assumption, analysis undertaken at IIASA indicates that the error in computed deposition introduced by this simplification lies within the general range of model uncertainties when considering long-range transport (Alcamo, 1987).

3.6 Critical loads for Acidification and Eutrophication

A critical load for an ecosystem is defined as the deposition "below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge". Over the past years methodologies for computing critical loads have been elaborated for acidification and eutrophication and compiled by the Mapping Programme under the Working Group on Effects which operates under the UN/ECE Convention of Long-range Transboundary Air Pollution (LRTAP) (UBA, 1996). On a national level, critical loads data are compiled and submitted to the Coordination Center for Effects (CCE), located at the Dutch National Institute for Public Health and the Environment (RIVM), which collates and merges these national data into European maps and data bases, which are then approved by the Mapping Programme and the Working Group on Effects before being used in emission reduction negotiations under the LRTAP Convention.

Critical loads of sulfur have been used in the negotiations of the 1994 Second Sulfur Protocol, the first international agreement on emission reductions taking explicitly into account environmental vulnerability, in addition to technological and economic considerations (UN/ECE 1994). However, acidification is caused by the deposition of both sulfur and nitrogen, and both compounds "compete" for the counteracting (neutralizing) base cations, which are mostly provided by deposition and weathering. And, in contrast to sulfur, for nitrogen there are additional natural (sources and) sinks such as uptake by vegetation, immobilization and denitrification. Consequently, it is not possible to define a single critical load, as was the case when looking at sulfur alone, but a (simple) function, called critical load function. This function defines pairs of sulfur and nitrogen deposition for which there is no risk of damage to the ecosystem under consideration, thus replacing the single critical load value used earlier. The critical load function for each ecosystem has a trapezoidal shape and is defined by three quantities: $CL_{max}(S)$, $CL_{min}(N)$ and $CL_{max}(N)$: $CL_{max}(S)$ is essentially the critical load of acidity (as defined earlier), $CL_{min}(N)$ summarizes the net nitrogen sinks, and $CL_{max}(N)$ is the maximum deposition of nitrogen (in case of zero sulfur deposition) taking into account CLmax(S) and deposition-dependent nitrogen processes ($CL_{max}(N) >= CL_{min}(N) + CL_{max}(S)$).

In addition to acidification, nitrogen deposition also acts as a nutrient for ecosystems. Consequently, in order to avoid eutrophication, critical loads for nutrient nitrogen, $CL_{nut}(N)$, have been defined and calculated for various ecosystems. If one wants to consider the multi-effect aspect of nitrogen deposition, the critical loads of nutrient nitrogen have to be introduced as additional aspects (and eventually as constraints) in the integrated assessment of reductions of NO_x and NH_3 emission.

To be able to compare critical loads with European deposition fields, the numerous critical load values and functions (currently more than half a million; mostly for forest soils, but also lakes and semi-natural vegetation) have to be aggregated in the 150km x 150km EMEP-grid. For single values this is done by computing a percentile of the cumulative distribution function of all critical load values within an EMEP-grid cell. As an example, Figure 3.1 shows the fifth percentile of $CL_{max}(S)$ for the EMEP modeling domain.

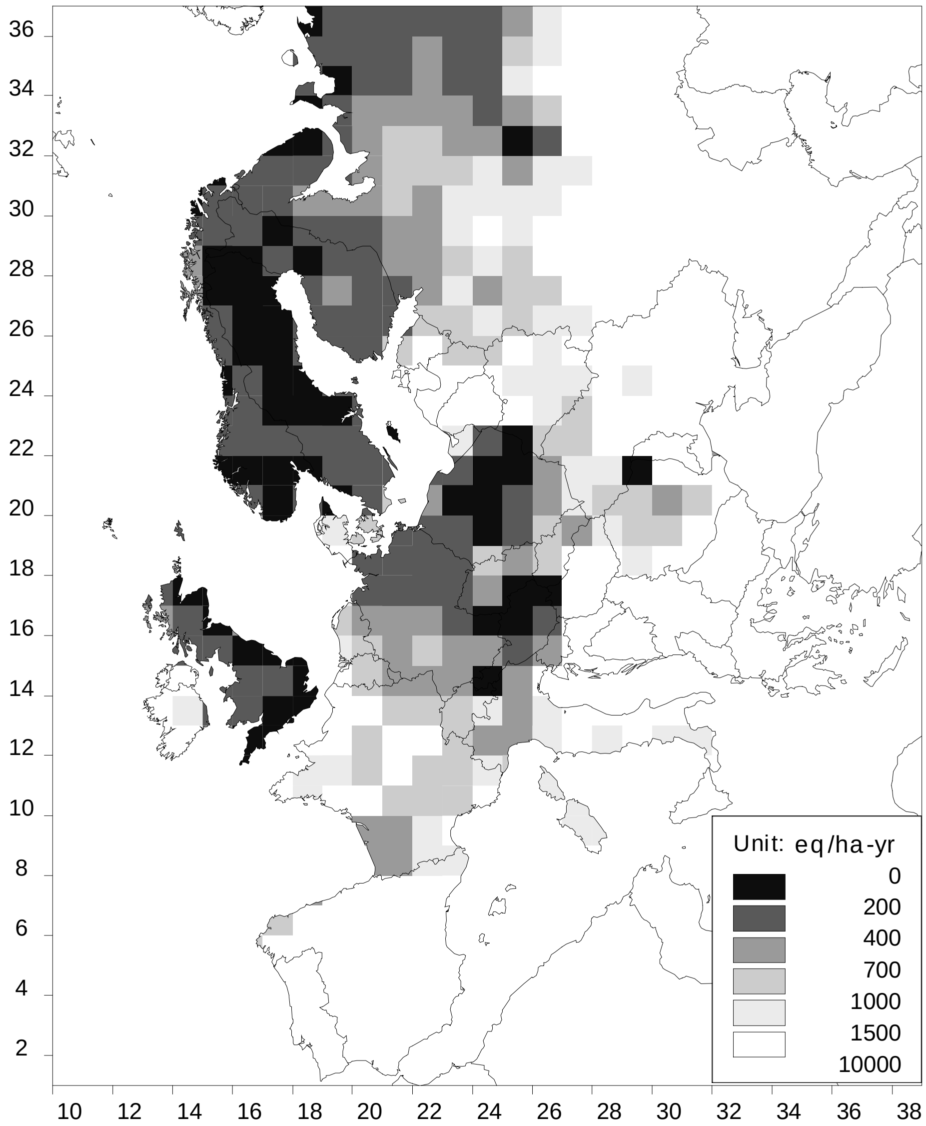

Figure 3.1: 5t[h] percentile of the critical loads for acidity ($CL_{max}(S)$)

To consider both sulfur and nitrogen deposition simultaneously, a surrogate for the multitude of critical load functions within an EMEP-grid cell has been defined: the so-called ecosystem protection isoline (for details see Posch *et al.* 1995). These isolines are a generalization of the percentile concept in the case of single critical load values. While more difficult to present in a map format, these isolines - and simplifications thereof - can be used in integrated assessment models, such as RAINS, to evaluate emission reduction strategies for both sulfur and nitrogen. Due to the different behavior of sulfur and nitrogen in the environment it is not possible to compute a unique exceedance of a critical load; however, the protection isolines derived from the critical load functions allow the computation of the percent of ecosystem's protected in each grid cell, and therefore the evaluation of the effectiveness of any given emission scenario.

Finally, it should be mentioned that the critical load database is regularly updated in order to take into account latest data and findings in the ongoing negotiations on emission reductions in Europe.

4. Results from Model Calculations

4.1 The Situation in 1990 and Changes Expected as Results from the Current Emission Reduction Policies

4.1.1 Status in 1990

As discussed later in this report, the current status in terms of emissions and ecosystems' protection will provide an important cornerstone, from which alternative strategies to reduce emissions can depart. Consequently, it is important that the model framework captures the current situation as well as possible.

Emissions for 1990 as used in the study are listed in Table 4.2.

The RAINS model enables direct comparisons of acid deposition (for sulfur and nitrogen compounds) with critical loads for acidity and eutrophication. The recent improvements in the critical loads databases make it possible to assess, for any given pattern of sulfur and nitrogen deposition, the ecosystems facing acid deposition above or below their critical loads and thereby to judge whether sustainable conditions are met by a certain strategy. Critical loads are established for the natural and semi-natural ecosystems in Europe, i.e., including forests, lakes, heath land, raised bogs, etc., but excluding agricultural areas, built-up land, and other, non-natural use of land.

Table 4.6 presents, for each grid cell, the percentage of ecosystems which experienced in the year 1990 acid deposition below their critical loads for acidity. Grids left empty in the map experienced in the year 1990 full protection of their ecosystem, i.e., had a zero percent exceedance. The figure shows that strong regional differences in the excess of critical loads occur; whereas in most parts of Greece, southern Italy, France, Spain, Portugal, Ireland and Russia acid deposition was below the critical loads, exceedance of the critical loads thresholds was a wide-spread phenomenon in many grids in Germany, Poland, the Czech Republic, northern Italy, and the UK, where more than 90 percent of the ecosystems were unprotected. A summary of the situation with country aggregates is provided in Table 4.6, giving both the share of ecosystems in each country as well as the absolute size of unprotected ecosystems (in hectares). More than 32 million hectares of ecosystems in the EU-15 received acid deposition above their critical loads, an area larger than all of Germany. Within the EU-15, least protection occurred in the Netherlands (88%) and Germany (80 percent unprotected), whereas Greek and Portuguese ecosystems enjoyed full protection. Outside the EU, the situation was worst in the Czech Republic and Poland with 95 % and 92 % of ecosystems unprotected, respectively.

Although not a major subject of this study, emissions of nitrogen oxides and ammonia contribute also to the eutrophication of terrestrial ecosystems. In a way similar to acidity, critical loads for eutrophication have been developed for the European ecosystems (Hettelingh et al., 1995). Figure 4.2 displays the percentage of ecosystems with total nitrogen deposition above the critical loads for eutrophication. For eutrophication, protection levels were even lower than for acidification, with virtually all critical loads exceeded in northern France, Germany, Poland, the Czech Republic and Belarus. In the EU-15 more than 34 percent of the ecosystems (38 million hectares) were unprotected in 1990.

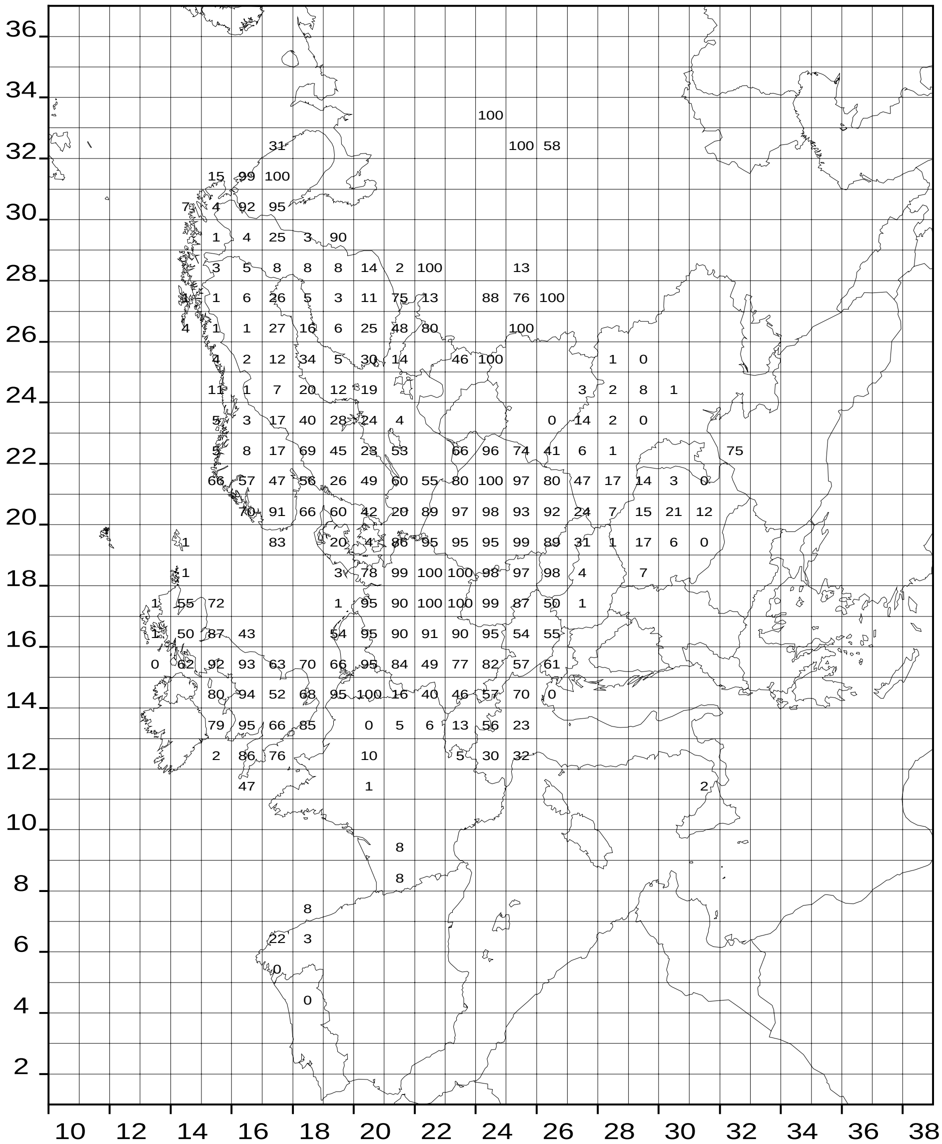

Figure 4.1: Ecosystems with acid deposition above their critical loads for acidification (i.e., ecosystems not protected from acidification) in the year 1990 (in percent of the ecosystems' area)

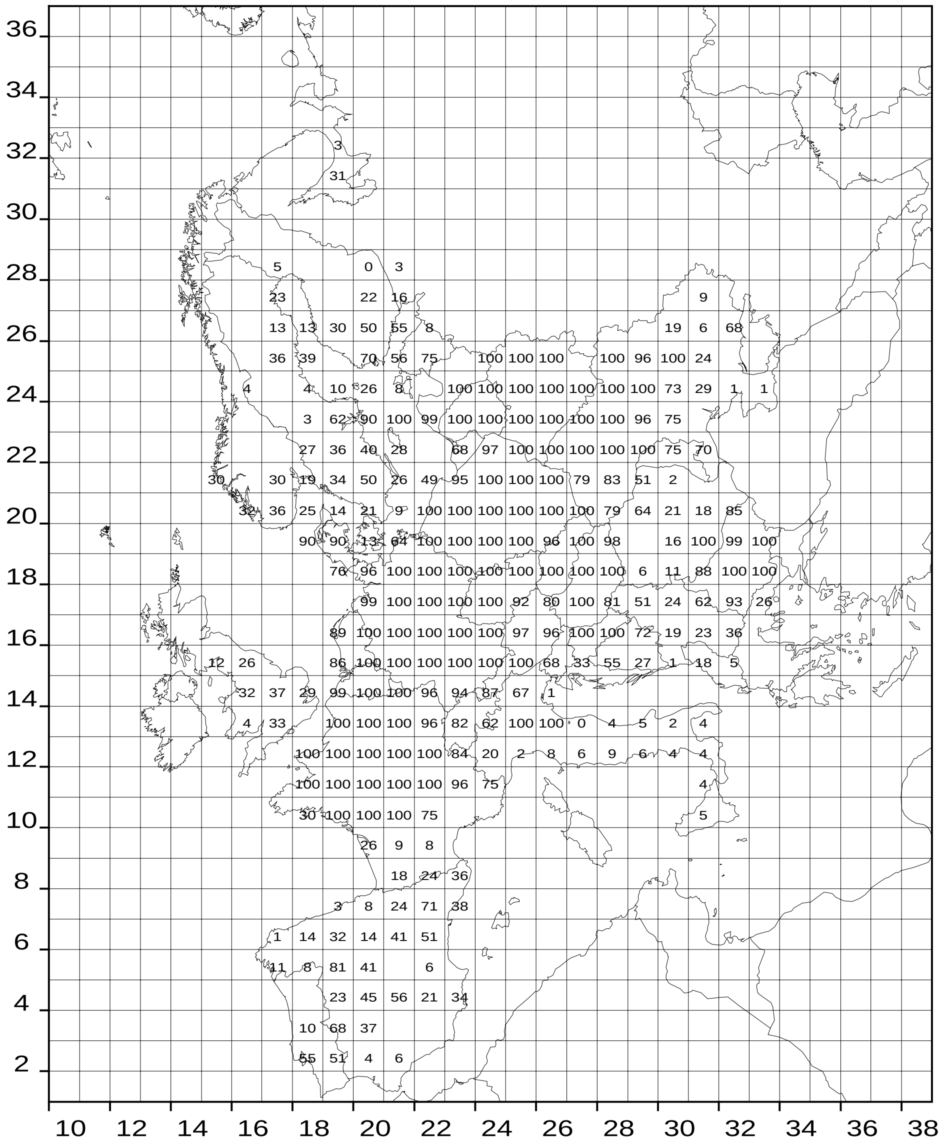

Figure 4.2: Ecosystems with nitrogen deposition above their critcial loads for eutrophication (i.e., ecosystems not protected against eutrophication) in the year 1990 (in percent of the ecosystems' area)

4.1.2 The Current Reduction Plan (CRP) Scenario for the Year 2010

The following three scenarios attempt to project likely impacts of current emission abatement policies and regulations for the year 2010. In order to capture the 'dual-track' approach adopted in Europe (regulations on emission standards for specific source categories and caps on national total emissions), two alternative scenarios are constructed mimicking the implications of these approaches. While the 'Current Reduction Plan' (CRP) scenario incorporates officially adopted or internationally announced ceilings on national emissions, the 'Current Legislation' (CLE) scenario relies on an inventory of (present and already accepted future) legally binding emission control legislation for the European countries. Finally, for the further analysis a 'Reference' (REF) scenario is constructed, selecting for each country the more stringent approach.

The 'Current Reduction Plans' (CRP) scenario is based on an inventory of officially declared national emission ceilings. Such declarations of envisaged future emission result from the various protocols of the Convention on Long-range Transboundary Air Pollution and are collected on a routine basis by the Secretariat of the Convention. The analysis in this study uses the recent data published in UN/ECE, 1995b. In cases where for the target year 2010 no projection was supplied by a country, the following rules, which are in accordance with the practice used for modeling work under the Convention, have been applied: (i) If a future projection is available, the latest number has been also used for the year 2010; (ii) if the country has signed the NO_x or VOC protocol, the resulting obligation (e.g., standstill or 30% cut in emissions relative to a base year) has been extended to the year 2010; (iii) if neither applies, the results from the RAINS estimate of the Current Legislation scenario has been used.

Emission estimates for the CRP scenario are presented in Table 4.1. Compared to the base year 1990, SO_2 emissions of the EU-15 countries would decline by 55 percent, those of the non-EU countries by 37 percent. EU-15's NO_x emissions go down by 29 percent, compared to one percent in the non-EU countries. Ammonia emissions in the EU would be lower by about 16 percent and by nine percent in the non-EU countries.

4.1.3 The Current Legislation (CLE) Scenario for the Year 2010

In contrast to the Current Reduction Plan (CRP) scenario, which projects future emission levels in Europe based on officially announced national emission caps, e.g., as laid down in the Second Sulfur Protocol, the Current Legislation (CLE) scenario explores the impacts of adopted national and international legislation for emission control, based on projections of future energy consumption.

Starting point for the analysis is 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' (OJ, 1988) and the Directive on Sulfur Content of Gas Oil (Johnson, Corcelle, 1995)) 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, 1994b) obliges its signatories to mandatory emission control according to 'Best Available Technology' (BAT) for new plants).

In addition to the emission standards for new and existing sources in each country it has been assumed that signatories to the Second Sulfur Protocol will reduce the sulfur content in gas oil for stationary sources to 0.2 percent and to 0.05 percent if used as diesel fuel for road vehicles.

For the control of NO_x emissions from mobile sources, the scenario considers the implementation of the current EU standards for all new cars, light duty trucks and heavy duty vehicles (i.e., the Directives 94/12/EC, 70/220/EEC and 88/77/EEC; see McArragher, 1994) in the Member States of the European Union. Additionally, the scenario assumes for all EU countries after the year 2000 the implementation of the measures proposed by the Auto/Oil Program. They include vehicle-related measures like improved catalytic converters, engine modifications and on-board diagnostic systems. Furthermore, the impacts of the proposed 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 study.

For non-EU members the scenario takes account of the regulations currently in force in each country. As mentioned above, the scenario does not consider the national emission caps imposed by the Second Sulfur Protocol as well as caps resulting from the 'Current Reduction Plans' of individual countries.

Table 4.1 compares the estimates for the year 1990 with the CRP and the CLE scenarios. There is clear evidence that official long-term emission targets presented to international organizations are not always coherent with what could be expected to be achieved through current legislation. In particular, the longer-term dynamics of technology-related emission limit values induced by the turnover of the capital stock often seem to be underestimated, so that frequently technology- and activity-based forecasts yield higher emission reductions. For NO_x, however, most of the differences in the estimates for the EU countries can be explained by the stricter emission standards for mobile sources resulting from the

Auto/Oil program. Whereas this new plans are considered in the CLE scenario, they are not yet taken into account in the official country submissions to the UN/ECE used for the CRP scenario.

Table 4.1: Comparison of emission estimates for 1990 with the Current Reduction Plans (CRP) and Current Legislation (CLE) scenarios in the year 2010 (in kilotons)

	SO_2			NO_x			NH_3	
	1990	**CRP**	**CLE**	**1990**	**CRP**	**CLE**	**1990**	**CRP/CLE**
Austria	90	78	43	222	155	111	91	96
Belgium	317	215	287	343	309	194	79	106
Denmark	180	90	137	269	192	147	140	103
Finland	260	116	162	300	224	158	41	23
France	1298	737	716	1590	1276	871	700	613
Germany	5331	740	928	3071	1276	1241	759	526
Greece	510	570	373	306	544	275	77	73
Ireland	178	155	205	115	105	70	126	126
Italy	1681	1042	922	2053	2060	1111	384	373
Luxembourg	14	4	9	23	19	10	7	7
Netherlands	205	56	114	575	133	222	236	85
Portugal	283	294	190	221	161	96	93	86
Spain	2266	2143	990	1188	892	833	353	329
Sweden	136	100	96	411	311	188	61	53
UK	3752	980	1908	2702	1860	1179	320	320
EU-15	**16501**	**7320**	**7080**	**13389**	**9517**	**6706**	**3467**	**2919**
Atlantic Sea	317	317	317	350	350	350	0	0
Baltic	73	73	73	81	81	81	0	0
North Sea	173	173	173	192	192	192	0	0
SEA	**563**	**563**	**563**	**623**	**623**	**623**	**0**	**0**
Albania	120	120	54	30	30	36	31	34
Belarus	710	490	495	285	260	315	214	159
Bosnia-H.	480	480	409	54	54	48	28	21
Bulgaria	2020	1127	835	376	290	293	141	141
Croatia	180	117	69	83	83	64	37	34
Czech R.	1876	632	151	742	398	226	130	130
Estonia	275	275	172	72	71	70	29	29
Hungary	1010	653	544	238	196	200	140	150
Latvia	115	115	104	93	93	113	46	38
Lithuania	222	222	118	158	157	130	79	79
Norway	54	34	31	230	161	96	39	36
Poland	3210	1397	1526	1280	1345	819	508	580
R.of Moldova	91	91	117	35	87	66	46	46
Romania	1504	1504	580	883	514	443	289	301
Russia	4459	2376	4297	2674	2653	2801	1191	918
Slovakia	543	240	115	227	197	104	62	52
Slovenia	195	37	76	53	31	36	27	27
Switzerland	43	30	46	166	113	72	62	58
FYRMacedonia	106	106	80	39	38	22	16	16
Ukraine	2782	1696	1496	1097	1890	1405	737	658
F.Yugoslavia	508	1135	263	66	147	119	85	85
Non-EU	**20503**	**12877**	**11578**	**8881**	**8808**	**7478**	**3937**	**3592**
TOTAL	**37567**	**20760**	**19221**	**22893**	**18948**	**14807**	**7404**	**6511**

4.1.4 The Reference (REF) Scenario for the Year 2010

In order to assess the likely impact of the current legislation on future emission levels by taking into account national and international legislation as well as commitments made within the framework of the Convention on Long-range Transboundary Air Pollution, the Reference (REF) scenario has been constructed by selecting, for each country individually, the more stringent outcome of the Current Reduction Plans- and the Current Legislation-scenario. Table 4.2 compares the emissions of the Reference scenario with the emission levels in the year 1990 used for this study.

For EU-15 as a whole, SO_2 emissions will be reduced by 66 percent compared to the 1990 level; NO_x will go down by 50 percent and ammonia by 16 percent. Lower relative reductions result for the non-EU countries in SO_2 declining by 54 percent, NO_x by 19 percent and ammonia by nine percent.

As discussed above, these projections are partly based on officially announced policy targets on national emission ceilings and partly on detailed forecasts of future economic activities and the application of emission control techniques in the various sectors of the economy. Table 4.3 and Table 4.4 present for the EU-15 countries simplified summaries of the emission control measures (for SO_2 and NO_x, respectively), which are implied for stationary sources in the Reference scenario (i.e., for the emission levels listed in Table 4.2). In cases where the CRP scenario (the national emission ceilings) claims lower emissions than would be expected from the application of the control options included in the CLE scenario, the excess emissions are assumed to be reduced by the most cost-effective set of the still available control measures (i.e., of the measures not already utilized in the CLE scenario).

Generally speaking, the REF scenario assumes for new plants emission standards to be at least as strict as required by the Large Combustion Plant Directive (LPCD; OJ, 1988) and by the Second Sulfur Protocol (UN/ECE, 1994c). More stringent standards are established by national legislation in Austria, Finland, Germany, the Netherlands and Sweden, and for NO_x also in Belgium, Denmark and Italy. A further reduction of emissions below the currently envisaged ceilings will have to address in the majority of countries also small sources and existing installations. Furthermore, it will also be necessary to control emissions from industrial processes other than fuel combustion[17]. For mobile sources, no substantial measures beyond the proposals of Auto/Oil emerge.

Emission control costs for the Reference Scenario in the year 2010 as estimated by the RAINS model are presented in Table 4.5. For the EU-15 countries, out of the total costs of about 40 billion ECU/year, more than three quarters are attributed to the abatement of NO_x emissions and one fifth to the control of SO_2.

As can be derived from Figure 4.3, the already agreed efforts to reduce emissions will achieve significant improvements in ecosystems' protection compared to the year 1990. Looking at acidification, over all of Europe unprotected ecosystems shrink from 91 million hectares to 20 million hectares. Also in the EU-15 countries the fraction of unprotected ecosystems declines from 24 to seven percent, however still leaving almost 9 million hectares with sulfur and nitrogen deposition above their critical loads.

The situation improves also for eutrophication, where the area under threat declines from 34 to about 17 percent. However, as displayed in Figure 4.4, eutrophication remains in many central European countries a wide-spread problem with dramatically low protection levels.

[17] In RAINS process emissions are defied as emissions that can not be directly attributed to fuel consumption. For details see Table 1.4 in Section 1.2.

Table 4.2: Emissions for the Reference Scenario in the year 2010 compared with the levels in 1990 (in kilotons)

	SO_2			NO_x			NH_3		
	1990	**REF**	***Change***	**1990**	**REF**	***Change***	**1990**	**REF**	***Change***
Austria	90	43	*-52%*	222	111	*-50%*	91	96	*5%*
Belgium	317	215	*-32%*	343	194	*-43%*	79	106	*34%*
Denmark	180	91	*-49%*	269	147	*-45%*	140	103	*-26%*
Finland	260	116	*-55%*	300	158	*-47%*	41	23	*-44%*
France	1298	716	*-45%*	1590	871	*-45%*	700	613	*-12%*
Germany	5331	740	*-86%*	3071	1241	*-60%*	759	526	*-31%*
Greece	510	373	*-27%*	306	275	*-10%*	77	73	*-5%*
Ireland	178	155	*-13%*	115	70	*-39%*	126	126	*0%*
Italy	1681	922	*-45%*	2053	1111	*-46%*	384	373	*-3%*
Luxembourg	14	4	*-71%*	23	10	*-57%*	7	7	*0%*
Netherlands	205	56	*-73%*	575	133	*-77%*	236	85	*-64%*
Portugal	283	190	*-33%*	221	202	*-9%*	93	86	*-8%*
Spain	2266	990	*-56%*	1188	833	*-30%*	353	329	*-7%*
Sweden	136	96	*-29%*	411	188	*-54%*	61	53	*-13%*
UK	3752	980	*-74%*	2702	1179	*-56%*	320	320	*0%*
EU-15	**16501**	**5687**	***-66%***	**13389**	**6723**	***-50%***	**3467**	**2919**	***-16%***
Atlantic Sea	317	317	*0%*	350	350	*0%*	0	0	*0%*
Baltic	73	73	*0%*	81	81	*0%*	0	0	*0%*
North Sea	173	173	*0%*	192	192	*0%*	0	0	*0%*
SEA	**563**	**563**	***0%***	**623**	**623**	***0%***	**0**	**0**	***0%***
Albania	120	54	*-55%*	30	30	*0%*	31	34	*10%*
Belarus	710	490	*-31%*	285	260	*-9%*	214	159	*-26%*
Bosnia-H.	480	409	*-15%*	54	48	*-11%*	28	21	*-25%*
Bulgaria	2020	835	*-59%*	376	290	*-23%*	141	141	*0%*
Croatia	180	69	*-62%*	83	64	*-23%*	37	34	*-8%*
Czech R.	1876	151	*-92%*	742	226	*-70%*	130	130	*0%*
Estonia	275	172	*-37%*	72	70	*-3%*	29	29	*0%*
Hungary	1010	544	*-46%*	238	196	*-18%*	140	150	*7%*
Latvia	115	104	*-10%*	93	93	*0%*	46	38	*-17%*
Lithuania	222	118	*-47%*	158	130	*-18%*	79	79	*0%*
Norway	54	31	*-43%*	230	96	*-58%*	39	36	*-8%*
Poland	3210	1397	*-56%*	1280	819	*-36%*	508	580	*14%*
R. of Moldova	91	91	*0%*	35	66	*89%*	46	46	*0%*
Romania	1504	580	*-61%*	883	443	*-50%*	289	301	*4%*
Russia	4459	2376	*-47%*	2674	2653	*-1%*	1191	918	*-23%*
Slovakia	543	115	*-79%*	227	104	*-54%*	62	52	*-16%*
Slovenia	195	37	*-81%*	53	31	*-42%*	27	27	*0%*
Switzerland	43	30	*-30%*	166	72	*-57%*	62	58	*-6%*
FYRMacedonia	106	80	*-25%*	39	22	*-44%*	16	16	*0%*
Ukraine	2782	1496	*-46%*	1097	1405	*28%*	737	658	*-11%*
F. Yugoslavia	508	263	*-48%*	66	119	*80%*	85	85	*0%*
Non-EU	**20503**	**9442**	***-54%***	**8881**	**7237**	***-19%***	**3937**	**3592**	***-9%***
TOTAL	**37567**	**15692**	***-58%***	**22893**	**14583**	***-36%***	**7404**	**6511**	***-12%***

Table 4.3: SO_2 emission control measures in the EU-15 in the REF scenario

Country	New plants		Existing plants	
Capacity class, MW_{th}	Coal	Oil	Coal	Oil
Austria				
10 - 50	FGD	LSHF	LSCO	LSHF
50 - 300	FGD	FGD	FGD/LSCO(1)	LSHF
> 300	FGD	FGD	FGD	FGD
Industrial processes:	Stage 2		Stage 2	
Belgium (6)				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	LSCO	LSHF
100 - 500 300 - 500	LSCO/FGD(2)	FGD	LSCO	FGD
>500 >500	FGD	FGD	LSCO	FGD
Industrial processes:	Stage 1		Stage 1	
Denmark(6):				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	LSCO	LSHF
100 - 500 300 - 500	FGD	FGD	FGD	FGD
>500 >500	FGD	FGD	FGD	FGD
Industrial processes:	Stage 3		Stage 3	
Finland(6):				
50 - 200	FGD	FGD	FGD	FGD
>200	FGD	FGD	FGD	FGD
Industrial processes:	Stage 2		Stage 2	
France:				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	-	-
100 - 500 300 - 500	LSCO/FGD(2)	FGD	-	-
>500 >500	FGD	FGD	-	-
Industrial processes:				
Germany(6):				
50 - 100	LSCO	LSHF	LSCO	LSHF
100 - 300	FGD	FGD	FGD	FGD
> 300	FGD	FGD	FGD	FGD
Industrial processes:	Stage 3		Stage 3	
Greece:				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	-	-
100 - 500 300 - 500	LSCO/FGD(2)	LSHF	-	-
>500 >500	FGD	FGD	-	-
Industrial processes:				
Ireland(6)				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	LSCO	-
100 - 500 300 - 500	LSCO/FGD(2)	FGD	LSCO	-
>500 >500	FGD	FGD	LSCO	-
Industrial processes:	Stage 1		Stage 1	

Table continued: SO_2 emission control measures in the EU-15 in the REF scenario

Country Capacity class, MW_{th}	New plants Coal	 Oil	Existing plants Coal	 Oil
Italy:				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	-	-
100 - 500 300 - 500	LSCO/FGD(2)	LSHF	-	-
>500 >500	FGD	FGD	-	-
Industrial processes:				
Luxembourg(6):				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	-	-
100 - 500 300 - 500	LSCO/FGD(2)	FGD	-	FGD
>500 >500	FGD	FGD	-	FGD
Industrial processes:	Stage 3		Stage 3	
Netherlands:				
<300(3)	FGD	FGD	LSCO/FGD	LSCO/FGD
>300	FGD	FGD	FGD	FGD
Industrial processes:	Stage 3		Stage 3	
Portugal:				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	-	-
100 - 500 300 - 500	LSCO/FGD(2)	LSHF	-	-
>500 >500	FGD	FGD	-	-
Industrial processes:				
Spain:				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	-	-
100 - 500 300 - 500	LSCO/FGD(2)	LSHF	-	-
>500 >500	FGD	FGD	-	-
Industrial processes:				
Sweden:				
<50	FGD (4)	FGD (5)	FGD (4)	FGD (5)
>50	FGD	FGD	FGD	FGD
Industrial processes:	Stage 2		Stage 2	
UK(6):				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	LSCO	-
100 - 500 300 - 500	LSCO/FGD(2)	FGD	LSCO	-
>500 >500	FGD	FGD	FGD	FGD
Industrial processes:	Stage 2		Stage 2	

(1) Lignite/hard coal
(2) Below 300 MWth/above 300 MWth
(3) Includes also sources below 50 MWth
(4) Requires at least 70 % desulfurization when low sulfur coal (0.8 % S) is used
(5) Requires at least 50 % desulfurization when low sulfur fuel oil (0.8 % S) is used
(6) Emissions determined by the national emission ceiling from the Second Sulfur Protocol

Explanations of abbreviations:

FGD - Flue gas desulfurization
LSCO - Low sulfur coal
LSHF - Low sulfur heavy fuel oil
Stage 1,2,3 - Abatement technologies for process emissions

Table 4.4: NO_x emission control measures in the EU-15 for stationary sources in the REF scenario

Country Capacity class, MW_{th}	New plants Coal	 Oil	 Gas	Existing plants Coal	 Oil	 Gas
Austria						
10 - 50	CM	CM	CM	-	-	-
50 - 300	CM/SCR(1)	SCR	SCR	CM	CM	CM
> 300	SCR	SCR	SCR	SCR	SCR	SCR
Industrial processes:		Stage 2			Stage 2	
Belgium						
>50	SCR (4)	CM	CM	CM	CM	CM
Process sources:		Stage 1			Stage 1	
Denmark:						
>50	SCR	SCR	CM/SCR(2)	CM	CM	CM
Industrial processes:		Stage 1			Stage 1	
Finland:						
50 - 150	CM	CM	CM	CM	CM	-
150 - 300	SCR	CM	SCR	CM	CM	-
>300	SCR	SCR	SCR	CM	CM	CM
Industrial processes:		Stage 1			Stage 1	
France:						
>50	CM	CM	CM	CM	CM	-
Greece:						
>50	CM	CM	CM	CM	CM	-
Germany:						
50 - 100	CM	CM	-	CM	CM	-
100 - 300	CM	CM	CM	CM	CM	CM
> 300	SCR	SCR	SCR	SCR	SCR	SCR
Industrial processes:		Stage 2			Stage 2	
Ireland:						
>50	CM	CM	CM	CM	-	-
Italy:						
50 - 300	CM	CM	CM	-	-	-
>300	SCR	CM	CM	CM	CM	CM
Luxembourg:						
>50	CM	CM	CM	CM	CM	CM
Netherlands:						
<300(3)	SCR	SCR	SCR	SCR	SCR	SCR
>300	SCR	SCR	SCR	SCR	SCR	SCR
Industrial processes:		Stage 3			Stage 3	

Table continued: NO_x emission control measures in the EU-15 for stationary sources in the REF scenario

Country	New plants			Existing plants		
Capacity class, MW_{th}	Coal	Oil	Gas	Coal	Oil	Gas
Portugal:						
>50	CM	CM	CM	CM	-	-
Spain:						
>50	CM	CM	CM	CM(5)	CM(5)	CM(5)
Sweden:						
<50	CM	CM	CM	CM	CM	CM
50 - 150	SCR	SCR	SCR	CM	CM	CM
>150	SCR	SCR	SCR	SCR	SCR	SCR
Industrial processes:		Stage 1			Stage 1	
UK:						
>50	CM	CM	CM	CM	CM	-

(1) Lignite/hard coal
(2) - Standard slightly below of what is achievable with CM
(3) - Includes also sources below 50 MWth
(4) - Since 1996
(5) - Only in the power plant sector

Abbreviations:
CM - Combustion modification, primary measures
SCR - Selective catalytic reduction
Stage 1, 2, 3 - Level of process emissions control

Table 4.5: Emission control costs for the Reference (REF) scenario in the year 2010 (in million ECU/year)

	SO_2	NO_x	NH_3	TOTAL
Austria	310	603	0	913
Belgium	231	741	0	972
Denmark	159	367	36	562
Finland	149	434	45	628
France	1303	4548	0	5851
Germany	2350	7567	0	9917
Greece	210	364	0	574
Ireland	84	168	180	432
Italy	1517	4994	0	6511
Luxembourg	9	51	12	72
Netherlands	245	1649	695	2589
Portugal	160	754	0	914
Spain	567	3181	0	3748
Sweden	284	701	37	1022
UK	818	4159	15	4992
EU-15	**8396**	**30281**	**1020**	**39697**
Atlantic Sea	0	0	0	0
Baltic	0	0	0	0
North Sea	0	0	0	0
SEA	**0**	**0**	**0**	**0**
Albania	0	0	0	7
Belarus	0	15	0	16
Bosnia-H	0	49	0	49
Bulgaria	44	0	0	51
Croatia	60	139	0	199
Czech R.	391	527	0	918
Estonia	0	0	0	0
Hungary	168	397	0	565
Latvia	0	0	0	15
Lithuania	0	0	0	0
Norway	45	420	0	465
Poland	826	980	0	1806
R. of Moldova	0	0	0	8
Romania	181	0	0	181
Russia	963	21	0	984
Slovakia	115	323	0	438
Slovenia	50	129	0	179
Switzerland	64	504	0	568
FYRMacedonia	0	29	0	29
Ukraine	452	0	0	452
F. Yugoslavia	80	154	0	234
Non-EU	**3439**	**3687**	**0**	**7164**
TOTAL	**11835**	**33968**	**1020**	**46861**

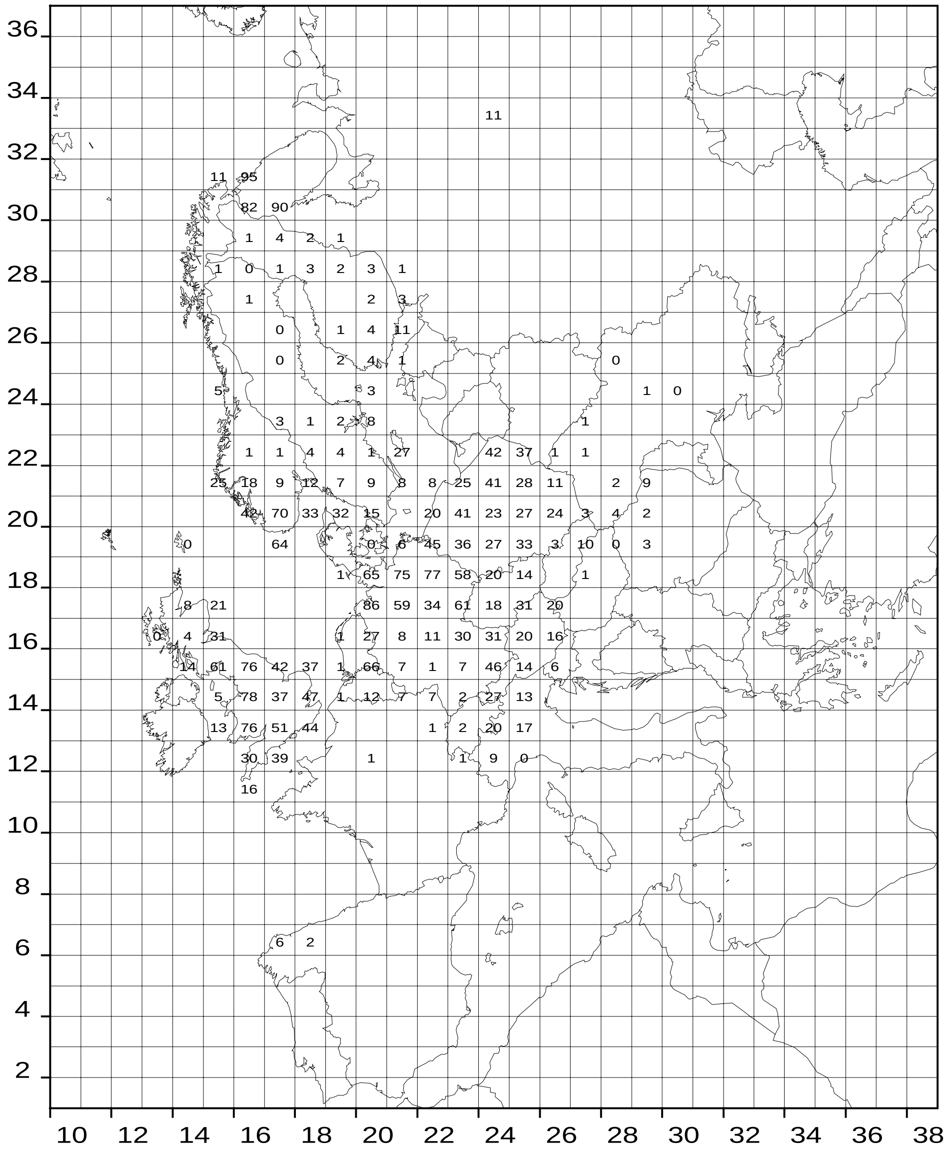

Figure 4.3: Percentage of ecosystems with sulfur and nitrogen deposition above their critical loads for acidification for the Reference scenario in the year 2010

Table 4.6: Ecosystems with acid deposition above their critical loads for acidification in the year 1990 and in the Reference (REF) scenario in the year 2010

	1990		**REF**	
	1000 ha	%	1000 ha	%
Austria	2892	*59%*	939	*19%*
Belgium	476	*77%*	115	*19%*
Denmark	174	*18%*	39	*4%*
Finland	5006	*16%*	1211	*4%*
France	617	*4%*	80	*1%*
Germany	6962	*80%*	2491	*29%*
Greece	0	*0%*	0	*0%*
Ireland	23	*5%*	4	*1%*
Italy	1153	*17%*	279	*4%*
Luxembourg	14	*16%*	7	*7%*
Netherlands	282	*88%*	118	*37%*
Portugal	1	*0%*	0	*0%*
Spain	74	*1%*	23	*0%*
Sweden	10092	*23%*	1247	*3%*
UK	4739	*60%*	2312	*29%*
EU-15	**32507**	***24%***	**8864**	***7%***
Albania	0	*0%*	0	*0%*
Belarus	358	*19%*	54	*3%*
Bosnia-H.	0	*0%*	0	*0%*
Bulgaria	0	*0%*	0	*0%*
Croatia	13	*1%*	1	*0%*
Czech Republic	2532	*95%*	641	*24%*
Estonia	389	*21%*	10	*1%*
Hungary	142	*9%*	44	*3%*
Latvia	374	*14%*	0	*0%*
Lithuania	82	*4%*	12	*1%*
FYRMacedonia	0	*0%*	0	*0%*
R. of Moldova	0	*3%*	0	*1%*
Norway	8058	*25%*	3459	*11%*
Poland	5876	*92%*	1961	*31%*
Romania	604	*10%*	66	*1%*
Russia	27308	*8%*	4579	*1%*
Slovakia	1317	*66%*	83	*4%*
Slovenia	430	*47%*	59	*7%*
Switzerland	352	*30%*	103	*9%*
Ukraine	1000	*12%*	108	*1%*
F. Yugoslavia	0	*0%*	0	*0%*
Non-EU	**48836**	***11%***	**11182**	***3%***
TOTAL	**81342**	***14%***	**20045**	***4%***

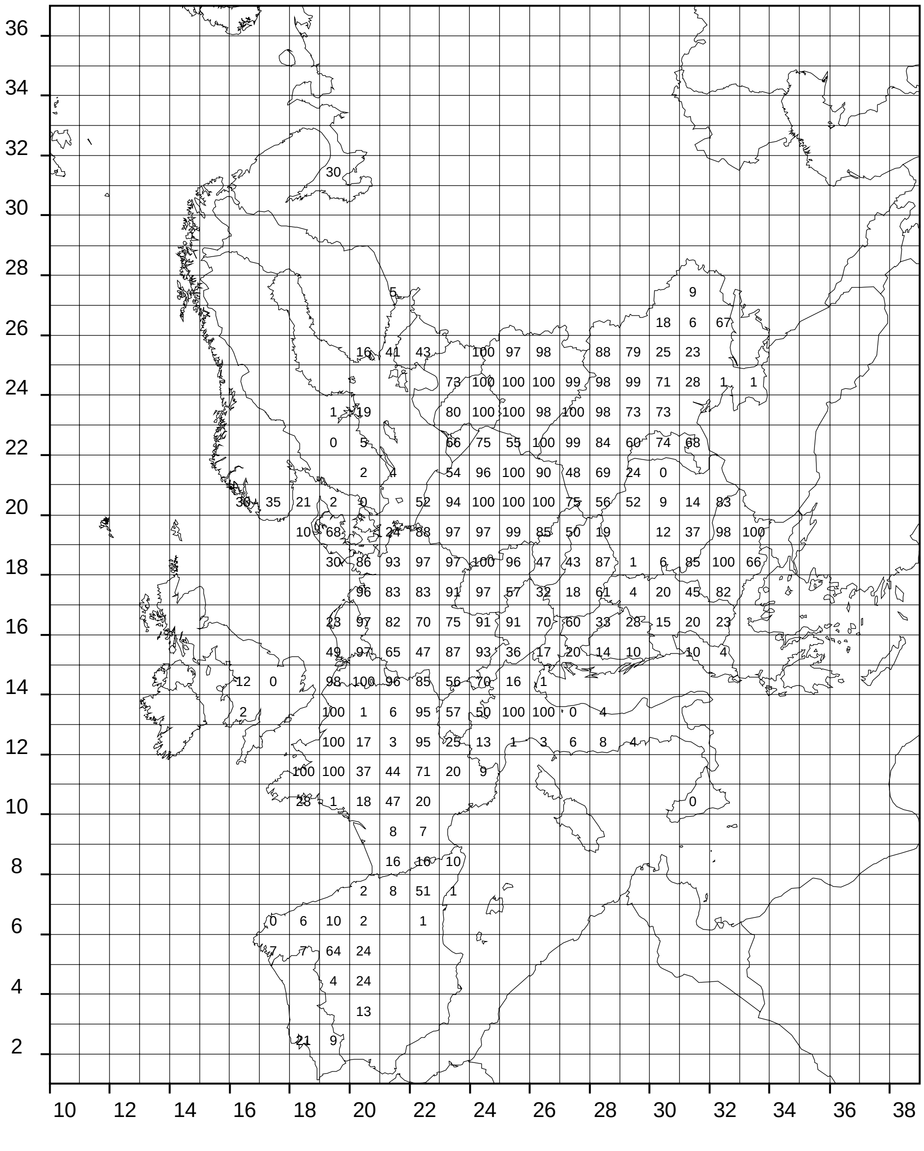

Figure 4.4: Percentage of ecosystems with nitrogen deposition above their critical loads for eutrophication for the Reference Scenario in the year 2010

Table 4.7: Ecosystems with nitrogen deposition above their critical loads for eutrophication in the year 1990 and for the Reference (REF) scenario in the year 2010

	1990		**REF**	
	1000 ha	%	1000 ha	%
Austria	4525	*93%*	3065	*63%*
Belgium	621	*100%*	595	*96%*
Denmark	593	*61%*	357	*37%*
Finland	4355	*14%*	377	*1%*
France	9996	*69%*	4831	*33%*
Germany	8596	*99%*	6857	*79%*
Greece	201	*8%*	95	*4%*
Ireland	0	*0%*	0	*0%*
Italy	1882	*28%*	1061	*16%*
Luxembourg	88	*100%*	84	*96%*
Netherlands	312	*97%*	271	*85%*
Portugal	827	*29%*	404	*14%*
Spain	2160	*25%*	810	*10%*
Sweden	3752	*18%*	88	*0%*
UK	529	*7%*	66	*1%*
EU-15	**38435**	***34%***	**18959**	***17%***
Albania	108	*10%*	68	*6%*
Belarus	1757	*92%*	1687	*89%*
Bosnia-H.	847	*58%*	300	*21%*
Bulgaria	3309	*87%*	2898	*77%*
Croatia	953	*58%*	458	*28%*
Czech Republic	2626	*99%*	2331	*88%*
Estonia	892	*47%*	511	*27%*
Hungary	1574	*97%*	674	*42%*
Latvia	1543	*57%*	749	*28%*
Lithuania	1863	*98%*	1687	*89%*
FYRMacedonia	356	*33%*	268	*25%*
R. Moldova	3	*36%*	2	*20%*
Norway	657	*12%*	276	*5%*
Poland	6338	*99%*	5782	*90%*
Romania	1817	*29%*	1119	*18%*
Russia	10921	*3%*	10631	*3%*
Slovakia	1957	*98%*	1151	*58%*
Slovenia	616	*68%*	247	*27%*
Switzerland	1704	*80%*	1120	*53%*
Ukraine	6360	*77%*	5543	*67%*
F. Yugoslavia	1021	*30%*	711	*21%*
Non-EU	**47223**	***12%***	**38213**	***10%***
TOTAL	**85658**	***17%***	**57172**	***11%***

4.1.5 Full Implementation of Current Control Technologies

A series of scenarios has been constructed to illustrate the potential of a full application of current control technology and to quantify possible progress towards the ultimate target of full achievement of critical loads as stipulated by the Council of the European Commission.

The first scenario - the ‘ultimate’ Maximum Technically Feasible Reduction (MTFR-ultimate) scenario - simulates the complete implementation of currently available emission control technologies to the entire stock of emission sources as predicted by the energy and agriculture scenarios for the year 2010. 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 as non-technical instruments to control emissions, are excluded. Since this scenario explores the feasibility of an ‘ultimate’ long-term target, also some emission control options, which are not yet fully commercially available, are included in the consideration (i.e., EURO-IV standards for heavy duty diesel vehicles and Stage-III catalysts for gasoline cars). Due to the early stage of development of these technologies it might be premature to provide cost estimates for this scenario.

The second scenario - the ‘realistic’ Maximum Technically Feasible Reduction (MTFR-realistic) scenario - considers historically observed turnover rates of the capital stock when determining the application potential of the currently available emission control options. As a result, the limited pace of replacement of existing capital stock and the validity of existing/adopted legislation on emission control until the year 2005 prohibits a full application of the most advanced abatement techniques in the year 2010. This applies particularly to mobile sources, where the outcomes of the Auto/Oil program determine emission control measures for new vehicles at least up to the year 2005. Consequently, in the year 2010 only a part of the vehicle fleet can therefore be equipped with eventual ‘Auto/Oil-II’ control measures.

Table 4.8 lists the resulting emissions for the two scenarios. The measures assumed in the ‘realistic’ MTFR scenario enable a reduction of SO_2 emissions in the EU-15 by 92 percent, of NO_x by 70 percent and of ammonia by 43 percent. The ultimate MTFR scenario yields 93 percent reduction of SO_2 and 85 percent of NO_x.

Table 4.9 provides cost estimates for the MTFR-realistic scenario. Out of the total annual costs of 120 billion ECU per year, the largest part (53 percent) is connected with possible measures to control NO_x emissions. 31 percent emerge for SO_2 control, and the remaining 16 percent for ammonia. Total costs of the MTFR-realistic scenario are twice the costs of the REF scenario.

Table 4.8: Emissions of the ‘realistic’ and the ‘ultimate’ Maximum Technically Feasible Reduction scenario, in kilotons

	SO_2		NO_x		NH_3	
	MTFR realistic	**MTFR ultimate**	**MTFR realistic**	**MTFR ultimate**	**MTFR realistic**	**MTFR ultimate**
Austria	36	36	85	45	55	55
Belgium	56	56	97	61	67	67
Denmark	22	22	76	38	45	45
Finland	55	55	73	40	21	21
France	220	166	615	298	388	388
Germany	311	311	904	498	311	311
Greece	41	32	139	55	51	51
Ireland	35	31	26	17	119	119
Italy	161	128	583	288	259	259
Luxembourg	2	2	6	4	7	7
Netherlands	33	33	133	81	84	84
Portugal	30	27	113	41	66	66
Spain	132	108	400	180	202	202
Sweden	58	58	108	58	39	39
UK	201	170	609	329	278	278
EU-15	**1393**	**1235**	**3967**	**2033**	**1992**	**1992**
Atlantic Sea	76	76	70	70	0	0
Baltic	18	18	16	16	0	0
North Sea	42	42	38	38	0	0
SEA	**136**	**136**	**124**	**124**	**0**	**0**
Albania	4	4	11	6	24	24
Belarus	36	36	77	45	107	107
Bosnia-H.	14	14	15	9	12	12
Bulgaria	99	94	80	46	96	96
Croatia	17	14	24	14	22	22
Czech R.	79	76	96	58	130	130
Estonia	8	8	17	9	19	19
Hungary	282	277	77	45	140	140
Latvia	16	16	36	18	26	26
Lithuania	18	18	40	20	51	51
Norway	17	17	57	28	26	26
Poland	343	326	294	202	464	464
R. of Moldova	16	16	18	11	31	31
Romania	86	75	114	67	203	203
Russia	525	485	753	439	553	553
Slovakia	60	58	53	29	29	29
Slovenia	9	8	13	7	11	11
Switzerland	13	13	51	29	44	44
FYRMacedonia	3	3	7	4	8	8
Ukraine	356	337	376	243	391	391
F. Yugoslavia	17	17	34	20	42	42
Non-EU	**2018**	**1912**	**2243**	**1349**	**2429**	**2429**
TOTAL	**3547**	**3283**	**6334**	**3506**	**4421**	**4421**

Table 4.9: Emission control costs of the ‘realistic’ Maximum Technically Feasible Reduction (MTFR-realistic) scenario for the year 2010 (in million ECU/year)

	SO_2	NO_x	NH_3	TOTAL
Austria	490	808	397	1696
Belgium	756	1170	367	2293
Denmark	601	619	800	2020
Finland	542	688	64	1294
France	2559	6329	1948	10835
Germany	5695	9928	2154	17777
Greece	820	984	137	1941
Ireland	330	287	310	926
Italy	3359	8041	1300	12700
Luxembourg	21	80	12	113
Netherlands	559	1682	704	2945
Portugal	518	1284	138	1940
Spain	1892	5135	1550	8577
Sweden	870	1036	220	2127
UK	3418	6284	485	10187
EU-15	**22430**	**44355**	**10586**	**77371**
Atlantic Sea	217	90	0	307
Baltic	50	21	0	71
North Sea	119	49	0	168
SEA	**386**	**160**	**0**	**546**
Albania	81	80	51	212
Belarus	516	684	418	1619
Bosnia-H	239	149	58	446
Bulgaria	698	684	225	1607
Croatia	173	253	86	512
Czech R.	856	838	130	1824
Estonia	197	161	66	424
Hungary	511	744	140	1396
Latvia	141	208	91	440
Lithuania	165	271	215	651
Norway	124	626	88	838
Poland	3122	2303	1536	6961
R. of Moldova	128	115	106	349
Romania	737	978	709	2424
Russia	3176	5970	2913	12059
Slovakia	257	420	160	836
Slovenia	127	174	36	337
Switzerland	196	666	130	992
FYRMacedonia	123	70	24	217
Ukraine	1789	2871	2102	6762
F. Yugoslavia	644	401	304	1349
Non-EU	**14000**	**18666**	**9588**	**42255**
TOTAL	**36816**	**63181**	**20174**	**120172**

Figure 4.5 to Figure 4.7 explore the possible extent of ecosystems' protection achievable with the maximum application of available control technology. Figure 4.5 shows the percentage of unprotected ecosystems for the MTFR-ultimate scenario. It demonstrates on the one hand that with current technology and at currently projected levels of industrial activity and energy consumption a full achievement of the critical loads for acidification does not appear entirely feasible within the next 15 years. On the other hand, only relatively few ecosystems remain unprotected. With the exception of the UK, where the critical loads data provided for this analysis appear extremely low, always more than 97 percent of the ecosystems will be protected.

Figure 4.6 evaluates ecosystems' protection with the more restrictive assumptions about the turnover of the existing capital stock (the MTFR-realistic scenario). In such a case about 1.4 million hectares of ecosystems within the EU would remain unprotected (compared to one million hectares in the MTFR-ultimate scenario and almost nine million hectares for the REF scenario). Problem areas are northern Germany, the Alpine region, parts of Scandinavia and Poland, as well as the UK.

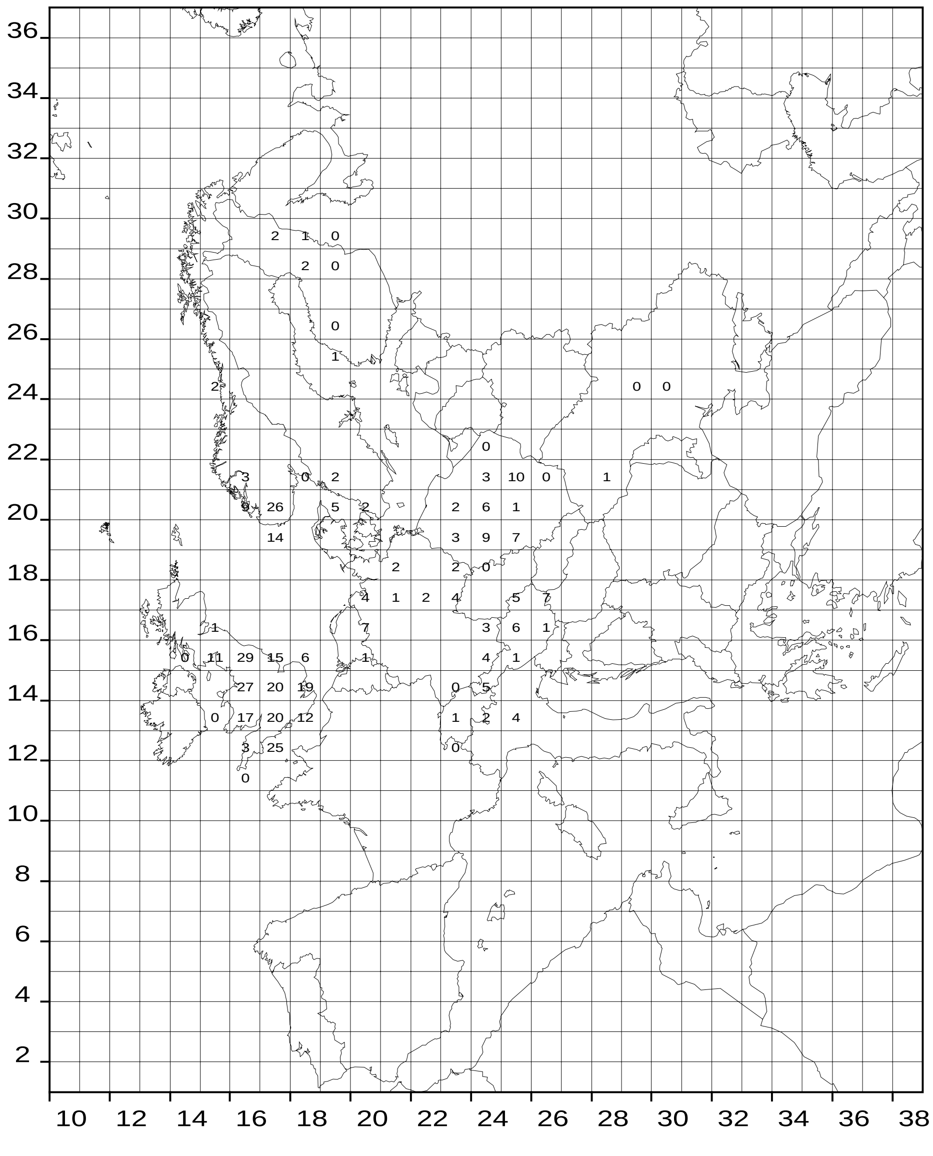

Figure 4.5: Percent of ecosystems with acid deposition above their critical loads for acidity for the MTFR-ultimate scenario

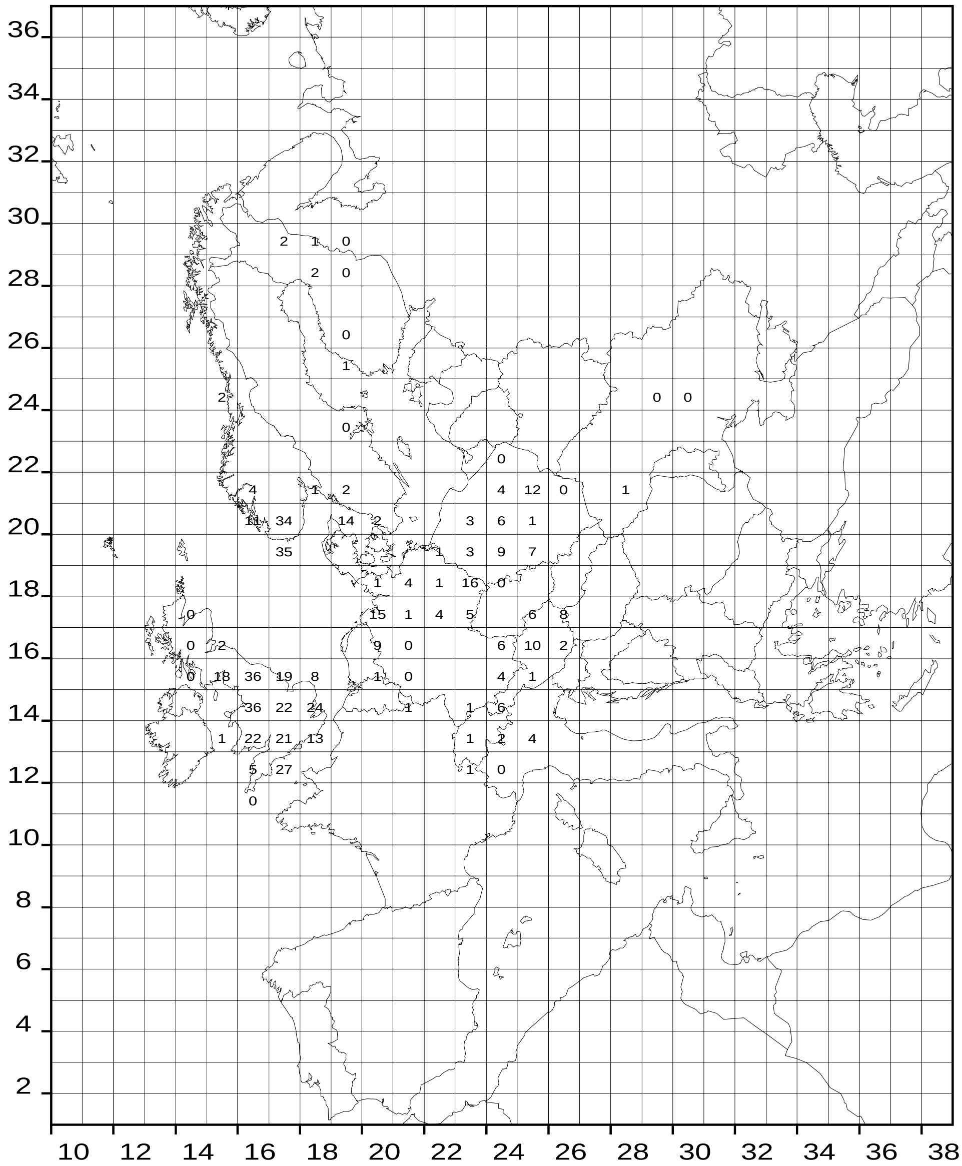

Figure 4.6: Percent of ecosystems with acid deposition above their critical loads for acidity for the MTFR-realistic scenario for the year 2010

Finally, Figure 4.7 displays the percentage of unprotected ecosystems for a so-called ‘EU-max’ scenario, which confines action to the Member States of the EU according to the realistic MTFR scenario. For the other European countries as well as for marine vessels action is limited to the REF scenario. This scenario with its assumed exclusion of measures outside of the EU demonstrates the long-range and thereby also transboundary character of the acidification problem. Even most stringent measures within the EU countries would leave about 3.3 million hectares (2.4 percent) within the EU unprotected, compared to 1.4 million hectares in the MTFR-realistic scenario. Note that the control measures and abatement costs for the EU countries are equal in both cases.

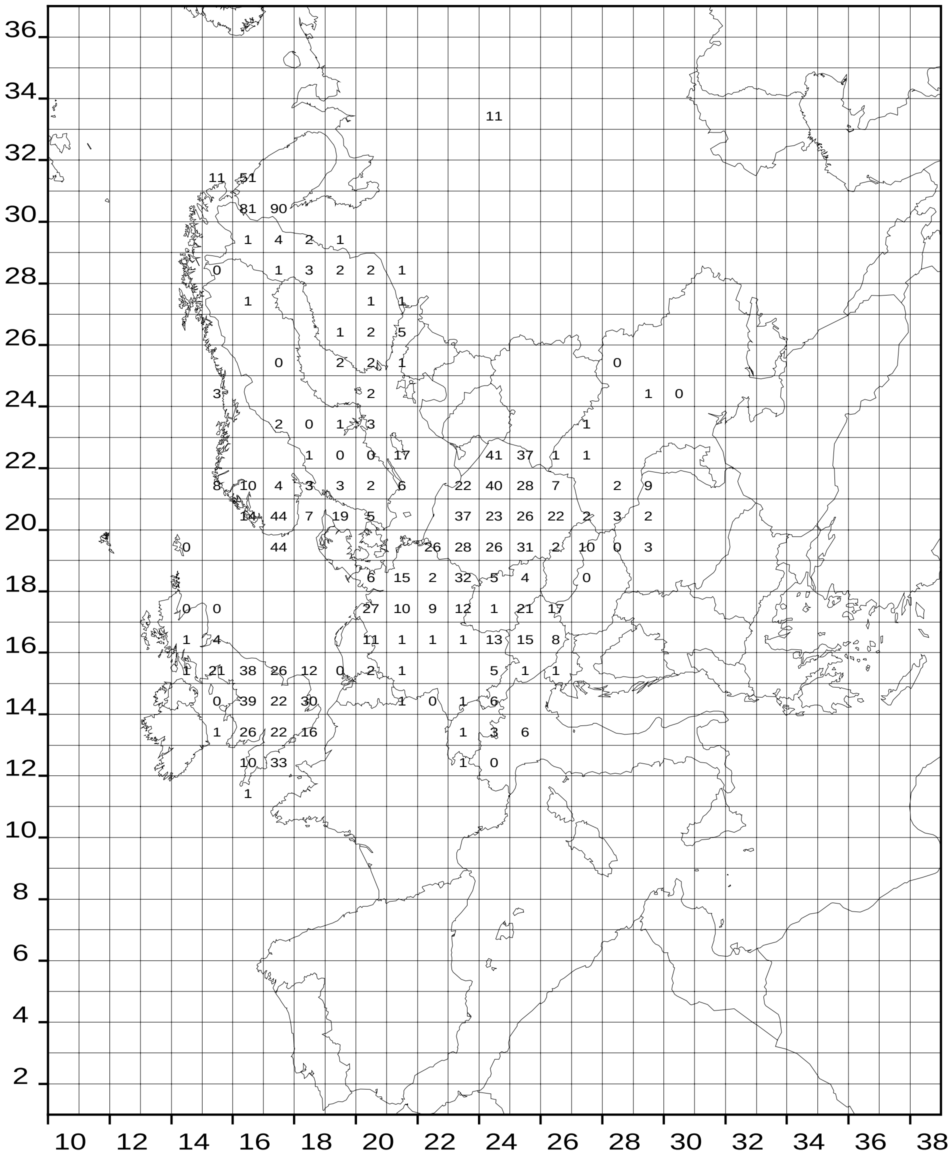

Figure 4.7: Percent of ecosystems with acid deposition above their critical loads for acidity for the EU-max scenario for the year 2010

Table 4.10: Ecosystems not protected from acidification for the EU-max (maximum technically feasible measures in the EU while REF for non-EU countries), the MTFR-realistic and the MTFR-ultimate scenarios for the year 2010

	EU-max		**MTFR-realistic**		**MTFR-ultimate**	
	1000 ha	%	1000 ha	%	1000 ha	%
Austria	451	*9.2%*	228	4.7%	162	3.3%
Belgium	3	*0.5%*	2	0.4%	1	0.1%
Denmark	12	*1.3%*	8	0.8%	3	0.3%
Finland	1014	*3.1%*	105	0.3%	98	0.3%
France	6	*0.0%*	4	0.0%	2	0.0%
Germany	435	*5.0%*	183	2.1%	82	0.9%
Greece	0	*0.0%*	0	0.0%	0	0.0%
Ireland	0	*0.1%*	0	0.0%	0	0.0%
Italy	32	*0.5%*	25	0.4%	23	0.3%
Luxembourg	1	*0.8%*	0	0.5%	0	0.0%
Netherlands	17	*5.2%*	13	4.1%	11	3.4%
Portugal	0	*0.0%*	0	0.0%	0	0.0%
Spain	0	*0.0%*	0	0.0%	0	0.0%
Sweden	453	*1.0%*	136	0.3%	84	0.2%
UK	870	*11.0%*	760	9.6%	568	7.2%
EU-15	**3292**	***2.4%***	**1464**	**1.1%**	**1033**	**0.8%**
Albania	0	*0.0%*	0	0.0%	0	0.0%
Belarus	52	*2.8%*	0	0.0%	0	0.0%
Bosnia-H	0	*0.0%*	0	0.0%	0	0.0%
Bulgaria	0	*0.0%*	0	0.0%	0	0.0%
Croatia	0	*0.0%*	0	0.0%	0	0.0%
Czech R.	198	*7.5%*	58	2.2%	36	1.3%
Estonia	5	*0.3%*	0	0.0%	0	0.0%
Hungary	36	*2.2%*	8	0.5%	7	0.4%
Latvia	0	*0.0%*	0	0.0%	0	0.0%
Lithuania	12	*0.6%*	0	0.0%	0	0.0%
FYRMacedonia	0	*0.0%*	0	0.0%	0	0.0%
R. of Moldova	0	*1.1%*	0	0.0%	0	0.0%
Norway	1912	*6.0%*	1088	3.4%	791	2.5%
Poland	1590	*25.0%*	255	4.0%	169	2.6%
Romania	64	*1.0%*	0	0.0%	0	0.0%
Russia	4045	*1.2%*	27	0.0%	27	0.0%
Slovakia	77	*3.8%*	8	0.4%	7	0.3%
Slovenia	14	*1.6%*	3	0.3%	2	0.2%
Switzerland	23	*1.9%*	19	1.6%	18	1.5%
Ukraine	98	*1.2%*	5	0.1%	5	0.1%
F. Yugoslavia.	0	*0.0%*	0	0.0%	0	0.0%
Non-EU	**8126**	***1.9%***	**1472**	**0.3%**	**1061**	**0.2%**
TOTAL	**11418**	***2.0%***	**2936**	**0.5%**	**2094**	**0.4%**

Table 4.11: Ecosystems with nitrogen deposition above their critical loads for eutrophication

	Eu-max		**MTFR-realistic**		**MTFR-ultimate**	
	1000 ha	%	1000 ha	%	1000 ha	%
Austria	872	*17.9%*	387	*7.9%*	213	*4.4%*
Belgium	561	*90.3%*	437	*70.4%*	182	*29.4%*
Denmark	12	*1.2%*	11	*1.1%*	0	*0.0%*
Finland	54	*0.2%*	0	*0.0%*	0	*0.0%*
France	1058	*7.3%*	618	*4.3%*	283	*2.0%*
Germany	3354	*38.6%*	2672	*30.7%*	956	*11.0%*
Greece	52	*2.1%*	0	*0.0%*	0	*0.0%*
Ireland	0	*0.0%*	0	*0.0%*	0	*0.0%*
Italy	302	*4.6%*	257	*3.9%*	215	*3.3%*
Luxembourg	79	*90.2%*	12	*13.6%*	6	*6.9%*
Netherlands	254	*79.4%*	252	*78.8%*	231	*72.2%*
Portugal	239	*8.4%*	238	*8.4%*	238	*8.4%*
Spain	200	*2.3%*	199	*2.3%*	190	*2.2%*
Sweden	0	*0.0%*	0	*0.0%*	0	*0.0%*
UK	0	*0.0%*	0	*0.0%*	0	*0.0%*
EU15	**7036**	***0.9%***	**5083**	***96.0%***	**2515**	***2.0%***
Albania	22	*2.1%*	0	*0.0%*	0	*0.0%*
Belarus	1565	*82.3%*	316	*16.6%*	163	*8.6%*
Bosnia-H.	138	*9.5%*	1	*0.1%*	0	*0.0%*
Bulgaria	2508	*66.3%*	48	*1.3%*	22	*0.6%*
Croatia	122	*7.4%*	9	*0.6%*	3	*0.2%*
Czech R.	1878	*70.7%*	886	*33.3%*	304	*11.4%*
Estonia	469	*24.8%*	0	*0.0%*	0	*0.0%*
Hungary	379	*23.4%*	40	*2.5%*	1	*0.1%*
Latvia	483	*17.8%*	0	*0.0%*	0	*0.0%*
Lithuania	1589	*83.8%*	129	*6.8%*	77	*4.1%*
FYRMacedonia	119	*11.2%*	0	*0.0%*	0	*0.0%*
R. Moldova	2	*19.9%*	0	*0.0%*	0	*0.0%*
Norway	0	*0.0%*	0	*0.0%*	0	*0.0%*
Poland	5270	*82.3%*	3589	*56.1%*	3260	*50.9%*
Romania	1044	*16.7%*	47	*0.8%*	20	*0.3%*
Russia	9869	*2.9%*	9763	*2.8%*	9763	*2.8%*
Slovakia	883	*44.4%*	192	*9.7%*	139	*7.0%*
Slovenia	65	*7.2%*	22	*2.4%*	16	*1.7%*
Switzerland	649	*30.6%*	281	*13.2%*	208	*9.8%*
Ukraine	5322	*64.5%*	1908	*23.1%*	1016	*12.3%*
F. Yugoslavia	563	*16.5%*	0	*0.0%*	0	*0.0%*
Non-EU	**32939**	***8.2%***	**17232**	***4.3%***	**14991**	***3.7%***
TOTAL	**39976**	***7.8%***	**22315**	***4.3%***	**17507**	***3.4%***

4.2 Strategies to Improve the Ecosystems' Protection in the EU

The analysis of the preceding section shows that current strategies to reduce emissions are expected to improve ecosystems' protection against acidification to a significant extent. Compared to the year 1990, the unprotected ecosystems' area in the EU-15 will decline from 24 percent to about seven percent (Table 4.6). Despite this significant progress, still almost nine million hectares in the EU remain (to some extent) unprotected. The maximum technically feasible reduction scenarios demonstrate that further progress towards full achievement of critical loads is possible, even with the limitations of currently available technology. Obviously, there is a price for such improvement, and the question of the cost-effective allocation of resources becomes highly relevant. Scenario analysis carried out in the process of the preparation of the Second Sulfur Protocol under the Convention on Long-range Transboundary Air Pollution showed that effect-oriented strategies aiming at environmental improvement at least cost are generally more cost-effective than traditional across-the-board abatement strategies not taking account of the regional differences in costs and environmental sensitivities.

4.2.1 Approach

To explore the cost-effectiveness of alternative approaches to reduce emissions, three scenarios are constructed, which aim at increasingly improved ecosystem protection. A common starting point for these scenarios are the ecosystems which received in the year 1990 acid deposition above their critical loads, i.e., which are not protected against acidification (see Figure 4.1 and). The rationale of the scenarios is to reduce, in each grid cell within the EU, the area of these unprotected ecosystems (expressed, e.g., in hectares) by an equal percentage. For a selected percentage reduction the critical loads database (Hettelingh *et al.*, 1995; Posch *et al.*, 1995) incorporated in RAINS allows to determine for each grid cell the target ecosystems, i.e., the most sensitive ecosystems to be protected, and subsequently the corresponding critical load (in terms of its maximum acid deposition and the sulfur/nitrogen substitution rate).

These critical loads are then used as constraints (on acid deposition) for the RAINS optimization module, which identifies the cost-minimal allocation of emission reductions satisfying the specified deposition targets (see also Figure 2.1). The optimization module uses linear programming methods to determine the optimal regional mix of measures for controlling SO_2, NO_x and NH_3 emissions, taking into account the country- and pollutant-specific costs for reducing emission (see Annex I) and the atmospheric dispersion characteristics for the species considered (i.e., the atmospheric transfer coefficients derived from the EMEP model, see Section 3.5). A general technical description of the optimization approach can be found in Amann *et al*., 1995.

The optimization used for this study represents a multi-pollutant/single effect type approach. This means that a single environmental effect (acidification) is used to establish the constraints for the optimization problem, constraints which are linked via the dispersion coefficients to the emissions of three pollutants (SO_2, NO_x and NH_3). The reduction levels (for the individual European countries) for these pollutants serve as the decision variables for the optimization task, and the objective function is the minimization of total European emission control costs, i.e., the costs summed up over all countries and all pollutants. The costs curves (see Annex I) provide the relations between emission reduction levels and control costs.

It should be noted that, although not used for this study, the recent version of the RAINS model is also capable of dealing with multi-pollutant/multi-effect optimization tasks. In particular, it is also possible to introduce, in addition to acidification, constraints on total nitrogen deposition in order to limit eutrophication of ecosystems. The extension to ground-level ozone is under preparation.

Although this process resembles elements of the so-called 'gap-closure' approach used for the development of the abatement schedule of the Second Sulfur Protocol, there are important differences to be mentioned. For purposes of the Second Sulfur Protocol, a gap has been defined as the difference between the actual sulfur deposition in 1990 and the (hypothetical) critical load for sulfur. The 'gap closure' aimed at closing this gap (i.e., at reducing the excess deposition) for the 95 percent protection level of ecosystems by 60 percent. This means that the analysis at this time related its measure for non-protection only to the excess deposition of a single, ecologically sensitive and representative ecosystem (the '95-percentile', for which 5 percent are more sensitive and 95 percent less sensitive).

In contrast to the early single-pollutant problem, looking at total acidity is a more complex process, particularly since deposition of sulfur and nitrogen has to be weighed against each other. A definition of excess deposition is not straightforward, particularly if one looks at the variety of ecosystems in a grid, for which different sulfur/nitrogen substitution rates apply. There are ways to express excess deposition also for total acidity (always for a particular ecosystem), but these are more complex and can only be expressed in more dimensions.

Furthermore, the long-term policy target established in the Fifth Environmental Action Programme of the European Union calls for the full achievement of critical loads. Consequently, using the 95 percentile for the analysis would introduce a systematic bias since the five percent most sensitive ecosystems would be ignored.

To overcome these problems and to keep the approach of scenario analysis practical also for the acidification problem, an attempt has been made to define a gap as the area of unprotected ecosystems in the year 1990. Therefore, the excess deposition valid for a single ecosystem has been replaced by a measure providing the area of ecosystems protected at a certain deposition pattern of sulfur and nitrogen compounds.

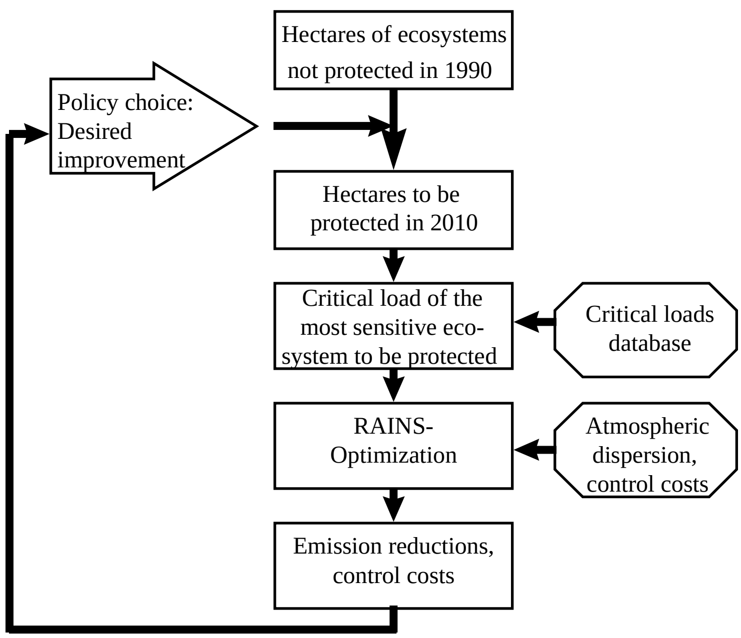

Figure 4.8: Process of scenario construction and evaluation

Summarizing, it can be stated that, instead of reducing the 'gap' of excess deposition, the scenarios in this study aim at reducing the area of unprotected ecosystems.

4.2.2 Assumptions

As mentioned above, the unprotected ecosystems of the year 1990 provide the starting point for the assessment. The objective of each scenario is to reduce the unprotected area by an equal percentage in each grid throughout the EU and thereby move closer towards the full achievement of critical loads.

Obviously, for economic, technical and physical reasons a full achievement of critical loads, i.e., a complete elimination of the unprotected areas, will not be possible by the year 2010. The EU-max scenario (Figure 4.7) provides an estimate of the maximum technically and physically possible achievements, taking into account limitations imposed by the existing capital stock, current technology and the by fact that, due to the long-range transport of pollutants, also emissions from non-EU countries and from international shipping contribute to acid deposition in the EU. Ignoring grids at the EU border which are shared with non-EU countries, an analysis shows that the maximum achievable decline of the unprotected area is as low as 56-57 percent in some grids of the UK (grid 18/14 and 17/12) and 66-68 percent in Scandinavia (grids 19/25 and 21/22)[18].

To explore the implications on emission control measures and costs, three alternative scenarios have been calculated, setting targets for reducing the unprotected areas in each grid by at least 45, 50 and 55 percent, respectively (Scenarios 1-3 below).

Furthermore, it has been recognized that the common approach to move towards the full achievement of critical loads in a harmonized way should not prevent countries from adopting a faster pace in reducing emissions. Consequently, it has been postulated that a reversal of current legislation should be excluded from consideration, especially as the concern about acidification, which is the driving force for this analysis, might not be the only reason for reducing emissions. In practice this aspect materializes by adopting the Reference (REF) scenario as a minimum reduction requirement for the optimization.

For technical reasons (uncertainty in the critical loads estimates for the most sensitive ecosystems) a cut-off level was introduced at the 98 percentile of the critical loads database; i.e., no critical load data (total acidity or sulfur/nitrogen substitution rate) for the two percent of the most sensitive ecosystems have been used as targets for the optimization. This was done in order to prevent the optimization from being driven by imperfections of the marginal critical loads estimates. However, the adoption of the REF scenario as a maximum bound for emissions as mentioned above leads also to the effect that no grid will experience a decrease in ecosystems' protection levels compared to the Reference scenario. This means that grids having full protection (100 percent) in the Reference scenario will never obtain lower protection levels, although the optimization uses formally only the data for the 98 percentile as a target.

[18] Obviously, this result is strongly influenced also by the estimates of critical loads. Possible changes in the critical loads database might cause significant modifications.

4.2.3 Scenario 1: Reducing the unprotected areas by at least 45 percent

A first scenario explores for the year 2010 the cost-minimal allocation of emission reductions which attain in the year 2010 in each grid cell within the EU a decline of the area of unprotected ecosystems by at least 45 percent (i.e, closing the gap of unprotected ecosystems by 35 percent). As in the following scenarios it is assumed that the economic development and energy consumption in the Member States of the EU follows the 'Conventional Wisdom' scenario, in the non-EU countries the 'Official Energy Pathway' (see Section 3.1).

According to the scope of the study, environmental targets are set for all grids belonging to Member States of the European Union. Exceptions have been made for three grids at the Finnish/Russian border, where acid deposition is strongly dominated by sulfur emissions from Russian sources at the Kola Peninsula (grids 18/29, 16/30 and 17/30). Since at these sites a significant environmental improvement can only be reached by addressing the sources outside of the EU, they were excluded from this scenario runs.

Although acidification is a transboundary problem not confined to the borders of the EU, it has been assumed for the first group of scenarios that an envisaged acidification strategy of the EU will primarily consider control measures in the Member States of the EU. Consequently, it has been assumed that the non-EU countries will not reduce their emissions further than in the REF scenario and also that no measures will be taken to reduce emissions from ships on the sea.

On the other hand, as discussed in the preceding section, for the EU Member States the REF scenario has been adopted as minimum requirement for the optimization, restricting the set of possible control measures available for optimization to additional measures not already taken in the Reference scenario.

Table 4.12 presents the resulting emissions of SO_2, NO_x and NH_3. In the optimized case, SO_2 emissions in the EU-15 would be reduced by 45 percent below the Reference scenario, NOx by seven percent and ammonia by 11 percent. Compared to the Reference scenario, emission control costs would be 16 percent higher (Table 4.13). Out of the total extra costs of 5.1 billion ECU/year, 48 percent are allocated to SO_2 control, 12 percent to further measures on NO_x and the remaining 40 percent on ammonia. Sulfur control would be required in all EU countries with the exception of Austria, Sweden and Finland, where most of the targeted improvement is already reached by the Reference scenario, and Greece and Portugal, where ecosystems are less sensitive to acidification. Belgium, France, Germany and the UK are scheduled for further controlling their NO_x and NH_3 emissions beyond the Reference scenario. Ammonia abatement is also required for Italy, and some more control on NOx in Ireland.

Figure 4.9 displays for all of Europe the percentage of ecosystems with acid deposition above their critical loads in Scenario 1 . The grid cells left empty indicate where already in 1990 full protection occurred, i.e., which had zero percent unprotected in 1990. A '0%' in the map means that there were some unprotected ecosystems in 1990, but through the measures of the scenario full protection has been achieved. Numbers larger than zero provide the percentage of ecosystems with acid deposition above their critical loads in Scenario 1.

The graph shows that with the exception of Ireland, Portugal and Greece, all other EU countries still would have excess deposition for at least some of their ecosystems. In some grids of the UK and Germany, up to 50 percent and more of the ecosystems remain unprotected. Major problem areas outside the EU are Norway, Poland and the Czech Republic. Table 4.14 provides the country totals of unprotected ecosystems. Compared to 1990, unprotected ecosystems decline in the EU-15 from 32.5 to 5.3 million hectares, i.e. from 24 percent to 5 percent. This is a further decrease of more than 3.5 million hectares compared to the Reference scenario. However, despite this improvement, Austria, Germany, the Netherlands and the UK still have 13-14 percent of their ecosystems not sufficiently protected.

Table 4.12: Emissions of Scenario 1 (the 45% gap closure scenario), compared to the emissions of the Reference (REF) scenario

	SO_2			NO_x			NH_3		
	Scen 1 (45 %)	**REF**	***Change***	**Scen 1 (45 %)**	**REF**	***Change***	**Scen 1 (45 %)**	**REF**	***Change***
Austria	43	43	*0%*	111	111	*0%*	96	96	*0%*
Belgium	77	215	*-64%*	148	194	*-24%*	96	106	*-9%*
Denmark	42	91	*-54%*	147	147	*0%*	103	103	*0%*
Finland	116	116	*0%*	158	158	*0%*	23	23	*0%*
France	236	716	*-67%*	862	871	*-1%*	588	613	*-4%*
Germany	447	740	*-40%*	1206	1241	*-3%*	332	526	*-37%*
Greece	373	373	*0%*	275	275	*0%*	73	73	*0%*
Ireland	42	155	*-73%*	50	70	*-29%*	126	126	*0%*
Italy	328	922	*-64%*	1111	1111	*0%*	314	373	*-16%*
Luxembourg	4	4	*0%*	10	10	*0%*	7	7	*0%*
Netherlands	37	56	*-34%*	133	133	*0%*	85	85	*0%*
Portugal	190	190	*0%*	202	202	*0%*	86	86	*0%*
Spain	846	990	*-15%*	833	833	*0%*	329	329	*0%*
Sweden	96	96	*0%*	188	188	*0%*	53	53	*0%*
UK	252	980	*-74%*	831	1179	*-30%*	289	320	*-10%*
EU-15	**3129**	**5687**	***-45%***	**6265**	**6723**	***-7%***	**2600**	**2919**	***-11%***
Atlantic Sea	317	317	*0%*	350	350	*0%*	0	0	*0%*
Baltic	73	73	*0%*	81	81	*0%*	0	0	*0%*
North Sea	173	173	*0%*	192	192	*0%*	0	0	*0%*
SEA	**563**	**563**	***0%***	**623**	**623**	***0%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	260	260	*0%*	159	159	*0%*
Bosnia-H.	409	409	*0%*	48	48	*0%*	21	21	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	141	141	*0%*
Croatia	69	69	*0%*	64	64	*0%*	34	34	*0%*
Czech R.	151	151	*0%*	226	226	*0%*	130	130	*0%*
Estonia	172	172	*0%*	70	70	*0%*	29	29	*0%*
Hungary	544	544	*0%*	196	196	*0%*	150	150	*0%*
Latvia	104	104	*0%*	93	93	*0%*	38	38	*0%*
Lithuania	118	118	*0%*	130	130	*0%*	79	79	*0%*
Norway	31	31	*0%*	96	96	*0%*	36	36	*0%*
Poland	1397	1397	*0%*	819	819	*0%*	580	580	*0%*
R. of Moldova	91	91	*0%*	66	66	*0%*	46	46	*0%*
Romania	580	580	*0%*	443	443	*0%*	301	301	*0%*
Russia	2376	2376	*0%*	2653	2653	*0%*	918	918	*0%*
Slovakia	115	115	*0%*	104	104	*0%*	52	52	*0%*
Slovenia	37	37	*0%*	31	31	*0%*	27	27	*0%*
Switzerland	30	30	*0%*	72	72	*0%*	58	58	*0%*
FYRMacedonia	80	80	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1496	1496	*0%*	1405	1405	*0%*	658	658	*0%*
F. Yugoslavia	263	263	*0%*	119	119	*0%*	85	85	*0%*
Non-EU	**9442**	**9442**	***0%***	**7237**	**7237**	***0%***	**3592**	**3592**	***0%***
TOTAL	**13134**	**15692**	***-16%***	**14125**	**14583**	***-3%***	**6192**	**6511**	***-5%***

Table 4.13: Abatement costs of Scenario 1 (the 45% gap closure scenario), compared to the costs of the Reference (REF) scenario (in million ECU/year)

	SO_2			**NO_x**			**NH_3**			**Total costs**		
	Scen 1 45 %	**REF**	**add.**	**Scen 1 45 %**	**REF**	**add.**	**Scen 1 45 %**	**REF**	**add.**	**Scen 1 45 %**	**REF**	**add.**
Austria	310	310	0	603	603	0	0	0	0	913	913	0
Belgium	391	231	160	795	741	54	37	0	37	1223	972	251
Denmark	237	159	78	367	367	0	36	36	0	640	562	78
Finland	149	149	0	434	434	0	45	45	0	628	628	0
France	1603	1303	300	4554	4548	6	17	0	17	6174	5851	323
Germany	3029	2350	679	7637	7567	70	1566	0	1566	12232	9917	2315
Greece	210	210	0	364	364	0	0	0	0	574	574	0
Ireland	147	84	63	176	168	8	180	180	0	503	432	71
Italy	1780	1517	263	4994	4994	0	219	0	219	6993	6511	482
Luxembourg	9	9	0	51	51	0	12	12	0	72	72	0
Netherlands	322	245	77	1649	1649	0	695	695	0	2666	2589	77
Portugal	160	160	0	754	754	0	0	0	0	914	914	0
Spain	611	567	44	3181	3181	0	0	0	0	3792	3748	44
Sweden	284	284	0	701	701	0	37	37	0	1022	1022	0
UK	1629	818	811	4630	4159	471	196	15	181	6455	4992	1463
EU15	**10871**	**8396**	**2475**	**30890**	**30281**	**609**	**3040**	**1020**	**2020**	**44801**	**39697**	**5104**
Atlantic Sea	0	0	0	0	0	0	0	0	0	0	0	0
Baltic	0	0	0	0	0	0	0	0	0	0	0	0
North Sea	0	0	0	0	0	0	0	0	0	0	0	0
SEA	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table continued on next page

Table continued.: Abatement costs of Scenario 1 (the 45% gap closure scenario), compared to the costs of the Reference (REF) scenario (in million ECU/year)

	SO_2			NO_x			NH_3			Total costs		
	Scen 1 45 %	**REF**	**add.**	**Scen 1 45 %**	**REF**	**add.**	**Scen 1 45 %**	**REF**	**add.**	**Scen 1 45 %**	**REF**	**add.**
Albania	0	0	0	0	0	0	0	0	0	0	0	0
Belarus	0	0	0	15	15	0	0	0	0	15	15	0
Bosnia-H	0	0	0	49	49	0	0	0	0	49	49	0
Bulgaria	44	44	0	0	0	0	0	0	0	44	44	0
Croatia	60	60	0	139	139	0	0	0	0	199	199	0
Czech R.	391	391	0	527	527	0	0	0	0	918	918	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	168	168	0	397	397	0	0	0	0	565	565	0
Latvia	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	45	45	0	420	420	0	0	0	0	465	465	0
Poland	826	826	0	980	980	0	0	0	0	1806	1806	0
R. of Moldova	0	0	0	0	0	0	0	0	0	0	0	0
Romania	181	181	0	0	0	0	0	0	0	181	181	0
Russia	963	963	0	21	21	0	0	0	0	984	984	0
Slovakia	115	115	0	323	323	0	0	0	0	438	438	0
Slovenia	50	50	0	129	129	0	0	0	0	179	179	0
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	29	29	0	0	0	0	29	29	0
Ukraine	452	452	0	0	0	0	0	0	0	452	452	0
F.Yugoslavia	80	80	0	154	154	0	0	0	0	234	234	0
SUM	**3439**	**3439**	**0**	**3687**	**3687**	**0**	**0**	**0**	**0**	**7126**	**7126**	**0**
TOTAL	**14310**	**11835**	**2475**	**34577**	**33968**	**609**	**3040**	**1020**	**2020**	**51927**	**46823**	**5104**

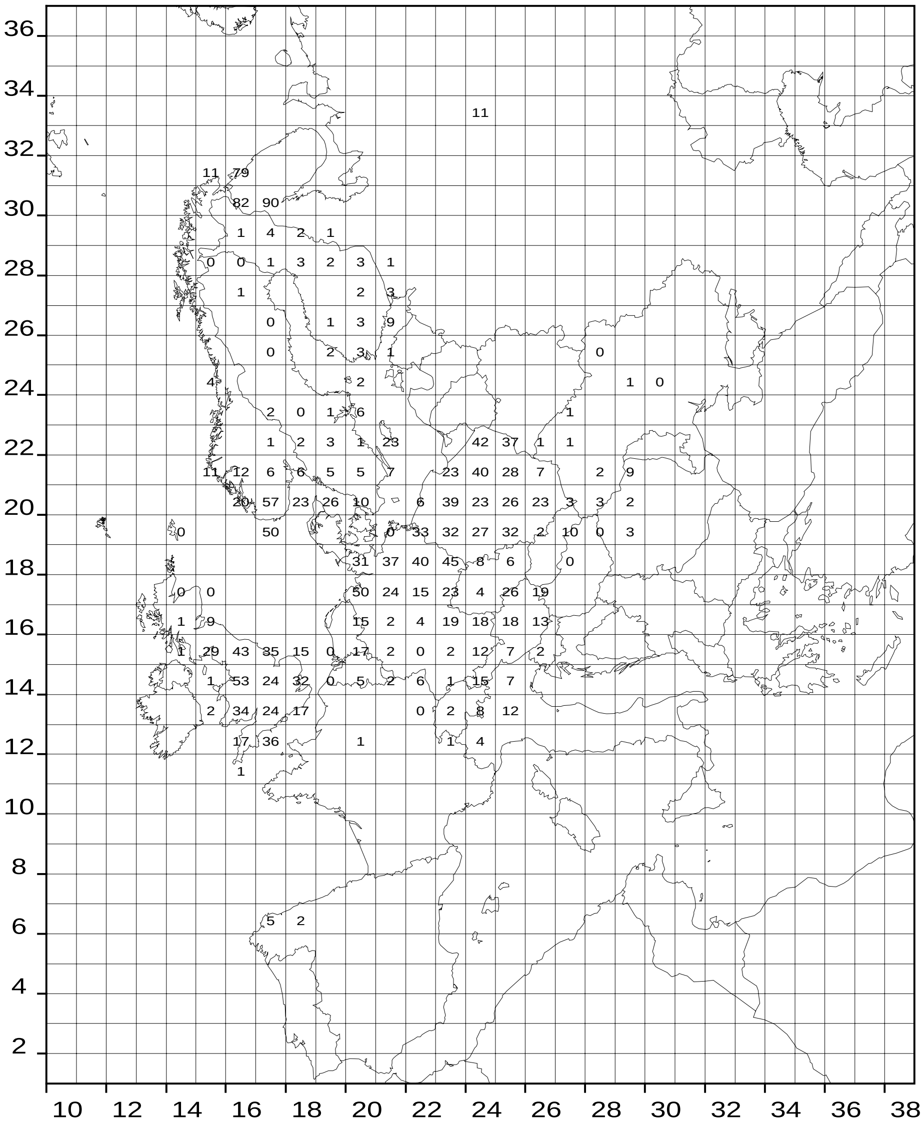

Figure 4.9: Percentage of ecosystems with deposition above their critical loads for acidity for Scenario 1 (the 45% gap closure scenario)

Table 4.14: Ecosystems not protected against acidification and eutrophication in Scenario 1 (the 45% gap closure scenario)

	Acidification		**Eutrophication**	
	1000 ha	%	1000 ha	%
Austria	680	*14%*	2542	*52%*
Belgium	36	*6%*	582	*94%*
Denmark	24	*2%*	315	*32%*
Finland	1165	*4%*	197	*1%*
France	48	*0%*	3914	*27%*
Germany	1215	*14%*	4810	*55%*
Greece	0	*0%*	90	*4%*
Ireland	1	*0%*	0	*0%*
Italy	145	*2%*	672	*10%*
Luxembourg	2	*2%*	83	*95%*
Netherlands	41	*13%*	262	*82%*
Portugal	0	*0%*	403	*14%*
Spain	18	*0%*	792	*9%*
Sweden	853	*2%*	58	*0%*
UK	1123	*14%*	40	*1%*
EU-15	**5351**	*4%*	**14761**	*11%*
Albania	0	*0%*	67	*6%*
Belarus	53	*3%*	1684	*89%*
Bosnia-H.	0	*0%*	249	*17%*
Bulgaria	0	*0%*	2680	*71%*
Croatia	0	*0%*	272	*17%*
Czech Republic	314	*12%*	2124	*80%*
Estonia	9	*0%*	508	*27%*
Hungary	41	*3%*	522	*32%*
Latvia	0	*0%*	737	*27%*
Lithuania	12	*1%*	1669	*88%*
FYRMacedonia	0	*0%*	235	*22%*
R. of Moldova	0	*1%*	2	*20%*
Norway	2488	*8%*	17	*0%*
Poland	1737	*27%*	5667	*89%*
Romania	65	*1%*	1080	*17%*
Russia	4389	*1%*	10614	*3%*
Slovakia	80	*4%*	1083	*54%*
Slovenia	29	*3%*	170	*19%*
Switzerland	50	*4%*	941	*79%*
Ukraine	101	*1%*	5455	*66%*
F. Yugoslavia	0	*0%*	646	*19%*
Non-EU	**9367**	*2%*	**36423**	*9%*
TOTAL	**14719**	*0%*	**51184**	*0%*

4.2.4 Scenario 2: Reducing the unprotected areas by at least 50 percent

A second scenario has been constructed, aiming at a reduction of the area of unprotected ecosystems by at least 50 percent in each grid cell (instead of 45 percent). All other assumptions (Conventional Wisdom energy scenario for the year 2010, exclusion of three grids at the Finnish/Russian border, adoption of the REF scenario as the minimum control level for the EU-15 countries, no action beyond the REF scenario for the non-EU countries, no abatement of ship emissions) are the same as in Scenario 1.

In order to halve the size of the unprotected ecosystems the optimization calculates a further reduction of SO_2 emissions by 53 percent below the Reference scenario, and for NO_x and ammonia 15 percent cuts each. As a result, the area of unprotected ecosystems in the EU-15 decreases from 5.3 million to 4.65 million hectares, with extra abatement costs (Table 4.19) on top of the REF scenario increasing from 13 percent to 22 percent. 38 percent of the costs would be spent for SO_2 control, 26 percent for NO_x and 36 percent for NH_3 (Table 4.14). In contrast to Scenario 1, reducing the unprotected ecosystems by 50 percent requires also further measures for SO_2 emissions in Finland and Sweden, since the Reference scenario is not sufficient to fully achieve these targets in Scandinavia. In an increased number of countries ammonia abatement measures are applied (Belgium, Denmark, Finland, Germany, Italy, Sweden and the UK).

Table 4.16 and Table 4.17 summarize for the countries of the EU-15 the selected control measures for SO_2 and NO_x emissions, respectively. The tables show that the achievement of the 50 percent gap closure target on ecosystems' protection requires in the majority of countries the use of strict control measures, not only for large new installations, but also for existing and small sources. Only in some Mediterranean countries (Greece, Portugal, and also - to a lesser extent - in Spain) less stringent measures are required.

Table 4.15: Emissions of Scenario 2 (the 50% gap closure scenario), compared to the emissions of the Reference (REF) scenario

	SO_2			NO_x			NH_3		
	Scen 2 50 %	**REF**	***Change***	**Scen 2 50 %**	**REF**	***Change***	**Scen 2 50 %**	**REF**	***Change***
Austria	43	43	*0%*	111	111	*0%*	96	96	*0%*
Belgium	60	215	*-72%*	125	194	*-36%*	74	106	*-30%*
Denmark	34	91	*-63%*	87	147	*-41%*	80	103	*-22%*
Finland	85	116	*-27%*	158	158	*0%*	23	23	*0%*
France	236	716	*-67%*	738	871	*-15%*	542	613	*-12%*
Germany	423	740	*-43%*	1040	1241	*-16%*	332	526	*-37%*
Greece	373	373	*0%*	275	275	*0%*	73	73	*0%*
Ireland	42	155	*-73%*	32	70	*-54%*	126	126	*0%*
Italy	254	922	*-72%*	1111	1111	*0%*	297	373	*-20%*
Luxembourg	4	4	*0%*	10	10	*0%*	7	7	*0%*
Netherlands	37	56	*-34%*	133	133	*0%*	85	85	*0%*
Portugal	190	190	*0%*	202	202	*0%*	86	86	*0%*
Spain	551	990	*-44%*	805	833	*-3%*	329	329	*0%*
Sweden	66	96	*-31%*	184	188	*-2%*	46	53	*-13%*
UK	252	980	*-74%*	676	1179	*-43%*	278	320	*-13%*
EU-15	**2650**	**5687**	***-53%***	**5687**	**6723**	***-15%***	**2474**	**2919**	***-15%***
Atlantic Sea	317	317	*0%*	350	350	*0%*	0	0	*0%*
Baltic	73	73	*0%*	81	81	*0%*	0	0	*0%*
North Sea	173	173	*0%*	192	192	*0%*	0	0	*0%*
SEA	**563**	**563**	***0%***	**623**	**623**	***0%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	260	260	*0%*	159	159	*0%*
Bosnia-H.	409	409	*0%*	48	48	*0%*	21	21	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	141	141	*0%*
Croatia	69	69	*0%*	64	64	*0%*	34	34	*0%*
Czech R.	151	151	*0%*	226	226	*0%*	130	130	*0%*
Estonia	172	172	*0%*	70	70	*0%*	29	29	*0%*
Hungary	544	544	*0%*	196	196	*0%*	150	150	*0%*
Latvia	104	104	*0%*	93	93	*0%*	38	38	*0%*
Lithuania	118	118	*0%*	130	130	*0%*	79	79	*0%*
Norway	31	31	*0%*	96	96	*0%*	36	36	*0%*
Poland	1397	1397	*0%*	819	819	*0%*	580	580	*0%*
R. of Moldova	91	91	*0%*	66	66	*0%*	46	46	*0%*
Romania	580	580	*0%*	443	443	*0%*	301	301	*0%*
Russia	2376	2376	*0%*	2653	2653	*0%*	918	918	*0%*
Slovakia	115	115	*0%*	104	104	*0%*	52	52	*0%*
Slovenia	37	37	*0%*	31	31	*0%*	27	27	*0%*
Switzerland	30	30	*0%*	72	72	*0%*	58	58	*0%*
FYRMacedonia	80	80	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1496	1496	*0%*	1405	1405	*0%*	658	658	*0%*
F. Yugoslavia	263	263	*0%*	119	119	*0%*	85	85	*0%*
Non-EU	**9442**	**9442**	***0%***	**7237**	**7237**	***0%***	**3592**	**3592**	***0%***
TOTAL	**12655**	**15692**	***-19%***	**13547**	**14583**	***-7%***	**6066**	**6511**	***-7%***

Table 4.16: SO_2 emission control measures applied in the '50 percent gap closure' scenario (Scenario 2)

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxemb.	Netherl.	Portugal	Spain	Sweden	Un. King.
New power plants:															
Coal	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD
Heavy fuel oil	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD	FGD
Existing power plants:															
Coal	FGD	FGD	FGD	FGD	FGD	FGD	-	FGD	FGD	FGD	FGD	-	LSCO	FGD	FGD
Heavy fuel oil	FGD	FGD	FGD	FGD	FGD	FGD	-	FGD	FGD	FGD	FGD	-	FGD	FGD	FGD
Industry															
Coal	FGD	FGD	FGD	FGD	FGD	FGD	-	FGD	LSCO	FGD	FGD	-	LSCO	FGD	FGD
Heavy fuel oil	FGD	FGD	FGD	FGD	FGD	FGD	-	FGD	FGD	FGD	FGD	-	FGD	FGD	FGD
Domestic															
Coal	LSCO	LSCO	LSCO	LSCO	LSCO	LSCO	-	LSCO	LSCO	LSCO	LSCO	-	LSCO	LSCO	LSCO
Heavy fuel oil	LSHF	LSHF	LSHF	LSHF	LSHF	LSHF	-	LSHF	LSHF	LSHF	LSHF	-	-	LSHF	LSHF
Industrial process emissions	Stage 3	Stage 3	Stage 3	Stage 3	Stage 3	Stage 3	-	Stage 3	Stage 2	Stage 3	Stage 3	-	Stage 2	Stage 3	Stage 3
Gas oil for stat. sources	0.05%S	0.05%S	0.05%S	0.1%S	0.2%S	0.05%S	0.2%S	0.2%S	0.2%S	0.2%S	0.05%S	0.2%S	0.2%S	0.05%S	0.05/0.2%S

Explanations of abbreviations:

FGD - Flue gas desulfurization
LSCO - Low sulfur coal
LSHF - Low sulfur heavy fuel oil
Stage 1,2,3 - Abatement technologies for process emissions

Table 4.17: NO_x emission control measures applied in the '50 percent gap closure' scenario for stationary sources and off-road transport

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxemb.	Netherl.	Portugal	Spain	Sweden	Un. King.
New power plants:															
Coal	SCR	SCR	SCR	SCR	SCR	SCR	CM	SCR	CM	CM	SCR	CM	CM	SCR	SCR
Heavy fuel oil	SCR	SCR	SCR	CM	SCR	SCR	CM	SCR	CM	CM	SCR	CM	CM	CM	CM
Gas	CM/SCR	SCR	SCR	CM	CM	SCR	CM	SCR	CM	CM	SCR	CM	CM	CM	SCR
Existing power plants:															
Coal	SCR	SCR	SCR	CM	SCR	SCR	CM	SCR	CM	CM	SCR	-	CM	SCR	SCR
Heavy fuel oil	CM	CM	CM	CM	CM	SCR	CM	CM	CM	CM	SCR	-	CM	CM	SCR
Gas	CM	CM	CM	CM	CM	CM	CM	CM	CM	CM	SCR	-	-	CM	SCR
Industry															
Coal	CM/SNCR	SCR/SNCR	SNCR	CM	CM/SNCR	SCR	CM	SCR/SNCR	CM	CM	SCR	CM(2)	CM	SCR/SNCR	SCR
Heavy fuel oil	CM/SNCR	SCR/SNCR	SNCR	CM	CM/SNCR	SCR	CM	SCR/SNCR	CM	CM	SCR	CM(2)	CM	CM	SCR
Gas	CM	CM/SNCR	CM	CM	CM	SCR/SNCR	CM	CM	CM	CM	SCR	CM(2)	CM(2)	CM	SCR/SNCR
Domestic															
Heavy fuel oil	CM	CM	CM	CM	CM	CM	-	CM	-	-	CM	-	-	CM	CM
Natural gas(1)	- / -	CM/ -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	CM	- / -	- / -	- / -	CM/ -
Gas oil(1)	- / -	CM/ -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	CM	- / -	- / -	- / -	CM/ -
Transport - other															
Other h. duty diesel engines	EUR3	EUR2	EUR3	EUR2	EUR3	EUR3	-	EUR3	-	-	EUR3	-	-	EUR3	EUR3
Industrial process emissions	Stage 1	Stage 1	Stage 1	-	Stage 1	Stage 1	-	Stage 1	-	Stage 1	Stage 3	-	-	Stage 1	Stage 2

(1) Large boilers in commercial sector/ small boilers in residential sector
(2) Only for new boilers according to LPCD

Explanations of abbreviations:
CM - Combustion modifications
SCR - Selective catalytic reduction
SNCR - Selective non-catalytic reduction
Stage 1, 2, 3 - Abatement technologies for process emissions
EUR3 - Post 2000 standards for heavy duty diesel vehicles
LPCD - Large Combustion Plants Directive

Table 4.18: Comparison of emission control costs of Scenario 2 (the 50% gap closure scenario) with the Reference scenario, in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	Scen 2 50%	**REF**	**add.**	**Scen 2 50%**	**REF**	**add.**	**Scen 2 50%**	**REF**	**add.**	**Scen 2 50%**	**REF**	**add.**
Austria	310	310	0	603	603	0	0	0	0	913	913	0
Belgium	580	231	349	867	741	126	193	0	193	1640	972	668
Denmark	289	159	130	479	367	112	137	36	101	905	562	343
Finland	181	149	32	434	434	0	45	45	0	660	628	32
France	1603	1303	300	4704	4548	156	141	0	141	6448	5851	597
Germany	3161	2350	811	8162	7567	595	1653	0	1653	12976	9917	3059
Greece	210	210	0	364	364	0	0	0	0	574	574	0
Ireland	147	84	63	213	168	45	180	180	0	540	432	108
Italy	1886	1517	369	4994	4994	0	368	0	368	7248	6511	737
Luxembourg	9	9	0	51	51	0	12	12	0	72	72	0
Netherlands	322	245	77	1649	1649	0	717	695	22	2688	2589	99
Portugal	160	160	0	754	754	0	0	0	0	914	914	0
Spain	722	567	155	3181	3181	0	0	0	0	3903	3748	155
Sweden	425	284	141	707	701	6	93	37	56	1225	1022	203
UK	1629	818	811	5279	4159	1120	510	15	495	7418	4992	2426
EU-15	**11634**	**8396**	**3238**	**32441**	**30281**	**2160**	**4049**	**1020**	**3029**	**48124**	**39697**	**8427**
Atlantic Sea	0	0	0	0	0	0	0	0	0	0	0	0
Baltic	0	0	0	0	0	0	0	0	0	0	0	0
North Sea	0	0	0	0	0	0	0	0	0	0	0	0
SEA	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table continued on next page

Table continued: Comparison of emission control costs of Scenario 2 (the 50% gap closure scenario) with the Reference scenario, in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	Scen 2 50%	**REF**	**add.**	**Scen 2 50%**	**REF**	**add.**	**Scen 2 50%**	**REF**	**add.**	**Scen 2 50%**	**REF**	**add.**
Albania	0	0	0	0	0	0	0	0	0	0	0	0
Belarus	0	0	0	15	15	0	0	0	0	15	15	0
Bosnia-H	0	0	0	49	49	0	0	0	0	49	49	0
Bulgaria	44	44	0	0	0	0	0	0	0	44	44	0
Croatia	60	60	0	139	139	0	0	0	0	199	199	0
Czech R.	391	391	0	527	527	0	0	0	0	918	918	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	168	168	0	397	397	0	0	0	0	565	565	0
Latvia	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	45	45	0	420	420	0	0	0	0	465	465	0
Poland	826	826	0	980	980	0	0	0	0	1806	1806	0
R. of Moldova	0	0	0	0	0	0	0	0	0	0	0	0
Romania	181	181	0	0	0	0	0	0	0	181	181	0
Russia	963	963	0	21	21	0	0	0	0	984	984	0
Slovakia	115	115	0	323	323	0	0	0	0	438	438	0
Slovenia	50	50	0	129	129	0	0	0	0	179	179	0
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	29	29	0	0	0	0	29	29	0
Ukraine	452	452	0	0	0	0	0	0	0	452	452	0
F.Yugoslavia	80	80	0	154	154	0	0	0	0	234	234	0
Non-EU	**3439**	**3439**	**0**	**3687**	**3687**	**0**	**0**	**0**	**0**	**7126**	**7126**	**0**
TOTAL	**15073**	**11835**	**3238**	**36128**	**33968**	**2160**	**4049**	**1020**	**3029**	**55250**	**46823**	**8427**

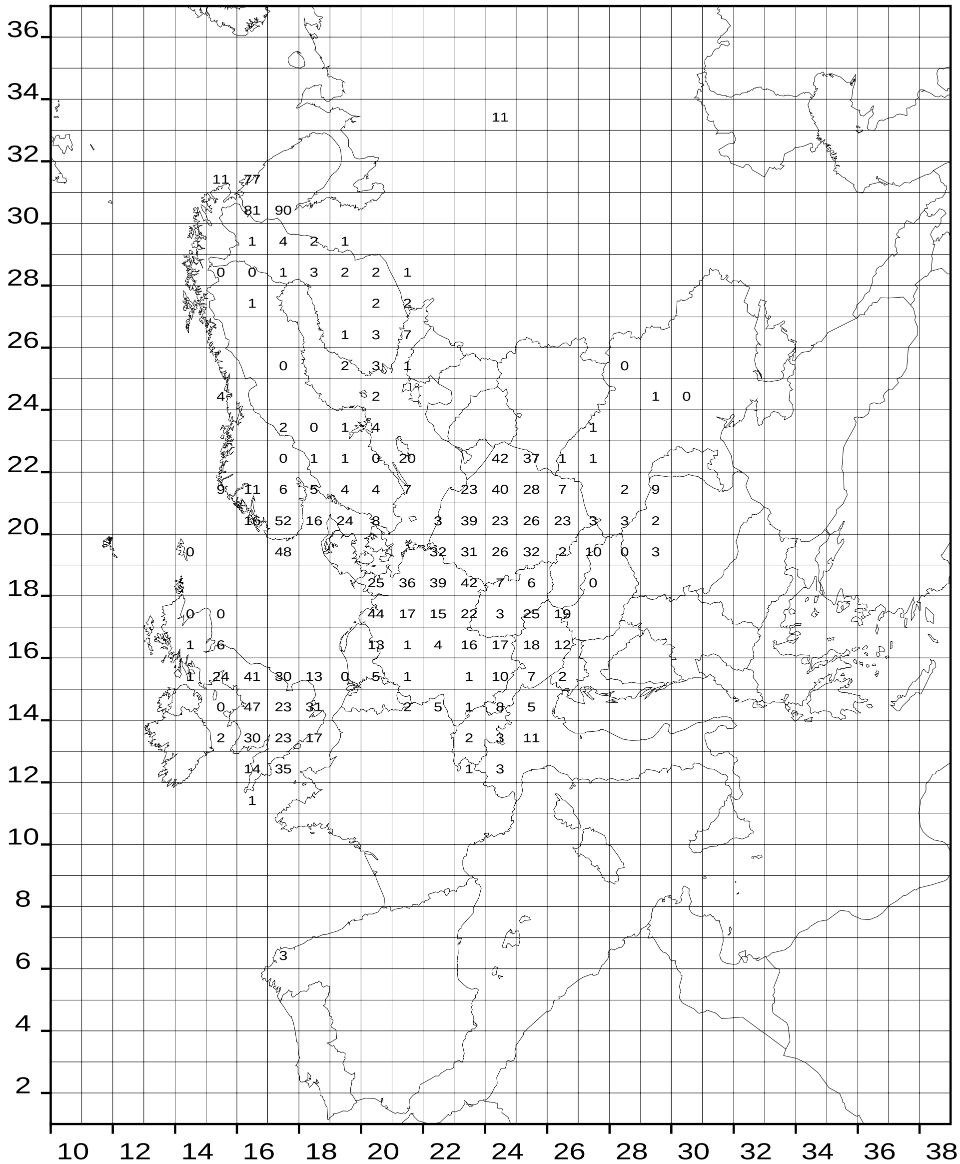

Figure 4.10: Percentage of ecosystems with acid deposition above their critical loads in the 50% gap closure scenario (Scenario 2)

Table 4.19: Ecosystems not protected against acidification and eutrophication in Scenario 2 (the 50% gap closure scenario)

	Acidification		Eutrophication	
	1000 ha	%	1000 ha	%
Austria	632	13%	2349	48%
Belgium	8	1%	576	93%
Denmark	21	2%	196	20%
Finland	1098	3%	114	0%
France	32	0%	2551	18%
Germany	1074	12%	4431	51%
Greece	0	0%	89	4%
Ireland	1	0%	0	0%
Italy	96	1%	646	10%
Luxembourg	2	2%	82	93%
Netherlands	23	7%	257	80%
Portugal	0	0%	400	14%
Spain	7	0%	711	8%
Sweden	659	2%	12	0%
UK	992	13%	0	0%
EU-15	**4645**	3%	**12415**	11%
Albania	0	0%	66	6%
Belarus	53	3%	1681	88%
Bosnia-H.	0	0%	231	16%
Bulgaria	0	0%	2670	71%
Croatia	0	0%	216	13%
Czech Republic	291	11%	2064	78%
Estonia	7	0%	504	27%
Hungary	40	2%	477	29%
Latvia	0	0%	707	26%
Lithuania	12	1%	1624	86%
FYRMacedonia	0	0%	233	22%
R. of Moldova	0	1%	2	20%
Norway	2250	7%	0	0%
Poland	1697	27%	5575	87%
Romania	65	1%	1073	17%
Russia	4346	1%	10607	3%
Slovakia	79	4%	1045	52%
Slovenia	27	3%	152	17%
Switzerland	28	2%	891	42%
Ukraine	100	1%	5424	66%
F. Yugoslavia	0	0%	638	19%
Non-EU	**8994**	2%	**35880**	9%
TOTAL	**13638**	2%	**48295**	9%

4.2.5 Scenario 3: Reducing the unprotected areas by at least 55 percent

As a third alternative, Scenario 3 explores the requirements for improving ecosystems' protection in each grid cell in the EU by at least 55 percent. Again, other assumptions (Conventional Wisdom energy scenario for the year 2010, exclusion of three grids at the Finnish/Russian border, adoption of the REF scenario as the minimum control level for the EU-15 countries, no action beyond the REF scenario for the non-EU countries) are the same as in Scenarios 1 and 2. Initial optimization runs, however, show that the achievement of this target deposition set is not possible, given the limitations to the removal of sulfur assumed in this scenario. Particularly, the exclusion of emission control at marine vessels makes it impossible to bring acid deposition below the targets in a number of grids around the Baltic Sea. Consequently, the constraint on not reducing ships' emissions in the Baltic has been lifted for the further analysis.

With these assumptions, the area of ecosystems in the EU with deposition above their critical loads for acidity drops from 32.5 million hectares in the Reference scenario to 4.1 million hectares. Despite this improvement, the shares of unprotected ecosystems range from zero (full protection against acidification), e.g., in Greece, to 12 percent in Austria (Table 4.22).

Extra abatement costs amount to 13 billion ECU/year, which is about 65 percent higher than in Scenario 2. 40 percent of the costs are linked to the further abatement of SO_2 emissions, 28 percent to NO_x and the remaining 32 percent to NH_3. Ships in the Baltic Sea reduce both SO_2 and NO_x at the maximum possible extent. Generally speaking, the tightened demand for emission control affects all three pollutants.

Despite the stricter environmental target, some countries (Finland, Germany and Sweden) face less reduction requirements than for instance in the 50 percent gap closure targets. The reason for this is that the most expensive measures in these countries are substituted by reductions of ships' emissions in the Baltic Sea.

Table 4.20: Emissions of the 55% gap closure scenario (Scenario 3) compared to the emissions of the Reference (REF) scenario

	SO_2			NO_x			NH_3		
	Scen 3 55 %	**REF**	***Change***	**Scen 3 55 %**	**REF**	***Change***	**Scen 3 55 %**	**REF**	***Change***
Austria	43	43	*0%*	111	111	*0%*	94	96	*-2%*
Belgium	60	215	*-72%*	97	194	*-50%*	71	106	*-33%*
Denmark	34	91	*-63%*	87	147	*-41%*	69	103	*-33%*
Finland	116	116	*0%*	158	158	*0%*	23	23	*0%*
France	236	716	*-67%*	696	871	*-20%*	421	613	*-31%*
Germany	391	740	*-47%*	1035	1241	*-17%*	335	526	*-36%*
Greece	373	373	*0%*	275	275	*0%*	73	73	*0%*
Ireland	42	155	*-73%*	28	70	*-60%*	126	126	*0%*
Italy	206	922	*-78%*	845	1111	*-24%*	290	373	*-22%*
Luxembourg	4	4	*0%*	10	10	*0%*	7	7	*0%*
Netherlands	37	56	*-34%*	133	133	*0%*	85	85	*0%*
Portugal	190	190	*0%*	197	202	*-2%*	86	86	*0%*
Spain	262	990	*-74%*	754	833	*-9%*	329	329	*0%*
Sweden	66	96	*-31%*	184	188	*-2%*	48	53	*-9%*
UK	202	980	*-79%*	609	1179	*-48%*	278	320	*-13%*
EU-15	**2262**	**5687**	***-60%***	**5219**	**6723**	***-22%***	**2335**	**2919**	***-20%***
Atlantic Sea	317	317	*0%*	350	350	*0%*	0	0	*0%*
Baltic	18	73	*-75%*	16	81	*0%*	0	0	*0%*
North Sea	173	173	*0%*	192	192	*0%*	0	0	*0%*
SEA	**508**	**563**	***-10%***	**558**	**623**	***0%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	260	260	*0%*	159	159	*0%*
Bosnia-H.	409	409	*0%*	48	48	*0%*	21	21	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	141	141	*0%*
Croatia	69	69	*0%*	64	64	*0%*	34	34	*0%*
Czech R.	151	151	*0%*	226	226	*0%*	130	130	*0%*
Estonia	172	172	*0%*	70	70	*0%*	29	29	*0%*
Hungary	544	544	*0%*	196	196	*0%*	150	150	*0%*
Latvia	104	104	*0%*	93	93	*0%*	38	38	*0%*
Lithuania	118	118	*0%*	130	130	*0%*	79	79	*0%*
Norway	31	31	*0%*	96	96	*0%*	36	36	*0%*
Poland	1397	1397	*0%*	819	819	*0%*	580	580	*0%*
R. of Moldova	91	91	*0%*	66	66	*0%*	46	46	*0%*
Romania	580	580	*0%*	443	443	*0%*	301	301	*0%*
Russia	2376	2376	*0%*	2653	2653	*0%*	918	918	*0%*
Slovakia	115	115	*0%*	104	104	*0%*	52	52	*0%*
Slovenia	37	37	*0%*	31	31	*0%*	27	27	*0%*
Switzerland	30	30	*0%*	72	72	*0%*	58	58	*0%*
FYRMacedonia	80	80	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1496	1496	*0%*	1405	1405	*0%*	658	658	*0%*
F. Yugoslavia	263	263	*0%*	119	119	*0%*	85	85	*0%*
Non-EU	**9442**	**9442**	***0%***	**7237**	**7237**	***0%***	**3592**	**3592**	***0%***
TOTAL	**12212**	**15692**	***-22%***	**13014**	**14583**	***-11%***	**5927**	**6511**	***-9%***

Table 4.21 : Emission control costs for Scenario 3 (the 55% gap closure scenario), in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	Scen 3	**REF**	**add.**	**Scen 3**	**REF**	**add.**	**Scen 3**	**REF**	**add.**	**Scen 3**	**REF**	**add.**
Austria	310	310	0	603	603	0	0	0	0	913	913	0
Belgium	580	231	349	1110	741	369	235	0	235	1925	972	953
Denmark	289	159	130	479	367	112	223	36	187	991	562	429
Finland	149	149	0	434	434	0	45	45	0	628	628	0
France	1603	1303	300	4830	4548	282	1034	0	1034	7467	5851	1616
Germany	3347	2350	997	8212	7567	645	1733	0	1733	13292	9917	3375
Greece	210	210	0	364	364	0	0	0	0	574	574	0
Ireland	147	84	63	236	168	68	180	180	0	563	432	131
Italy	1956	1517	439	5248	4994	254	496	0	496	7700	6511	1189
Luxembourg	9	9	0	51	51	0	12	12	0	72	72	0
Netherlands	322	245	77	1649	1649	0	717	695	22	2688	2589	99
Portugal	160	160	0	754	754	0	0	0	0	914	914	0
Spain	938	567	371	3210	3181	29	0	0	0	4148	3748	400
Sweden	425	284	141	707	701	6	76	37	39	1208	1022	186
UK	3178	818	2360	5985	4159	1826	510	15	495	9673	4992	4681
EU-15	**13623**	**8396**	**5227**	**33872**	**30281**	**3591**	**5261**	**1020**	**4241**	**52756**	**39697**	**13059**
Atlantic Sea	0	0	0	0	0	0	0	0	0	0	0	0
Baltic	50	0	50	21	0	21	0	0	0	71	0	71
North Sea	0	0	0	0	0	0	0	0	0	0	0	0
SEA	**50**	**0**	**50**	**21**	**0**	**21**	**0**	**0**	**0**	**71**	**0**	**71**

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Table continued: Emission control costs for Scenario 3 (the 55% gap closure scenario), in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	Scen 3	**REF**	**add.**	**Scen 3**	**REF**	**add.**	**Scen 3**	**REF**	**add.**	**Scen 3**	**REF**	**add.**
Albania	0	0	0	0	0	0	0	0	0	0	0	0
Belarus	0	0	0	15	15	0	0	0	0	15	15	0
Bosnia-H	0	0	0	49	49	0	0	0	0	49	49	0
Bulgaria	44	44	0	0	0	0	0	0	0	44	44	0
Croatia	60	60	0	139	139	0	0	0	0	199	199	0
Czech R.	391	391	0	527	527	0	0	0	0	918	918	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	168	168	0	397	397	0	0	0	0	565	565	0
Latvia	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	45	45	0	420	420	0	0	0	0	465	465	0
Poland	826	826	0	980	980	0	0	0	0	1806	1806	0
R. of Moldova	0	0	0	0	0	0	0	0	0	0	0	0
Romania	181	181	0	0	0	0	0	0	0	181	181	0
Russia	963	963	0	21	21	0	0	0	0	984	984	0
Slovakia	115	115	0	323	323	0	0	0	0	438	438	0
Slovenia	50	50	0	129	129	0	0	0	0	179	179	0
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	29	29	0	0	0	0	29	29	0
Ukraine	452	452	0	0	0	0	0	0	0	452	452	0
F. Yugoslavia	80	80	0	154	154	0	0	0	0	234	234	0
Non-EU	**3439**	**3439**	**0**	**3687**	**3687**	**0**	**0**	**0**	**0**	**7126**	**7126**	**0**
TOTAL	**17112**	**11835**	**5277**	**37580**	**33968**	**3612**	**5261**	**1020**	**4241**	**59953**	**46823**	**13130**

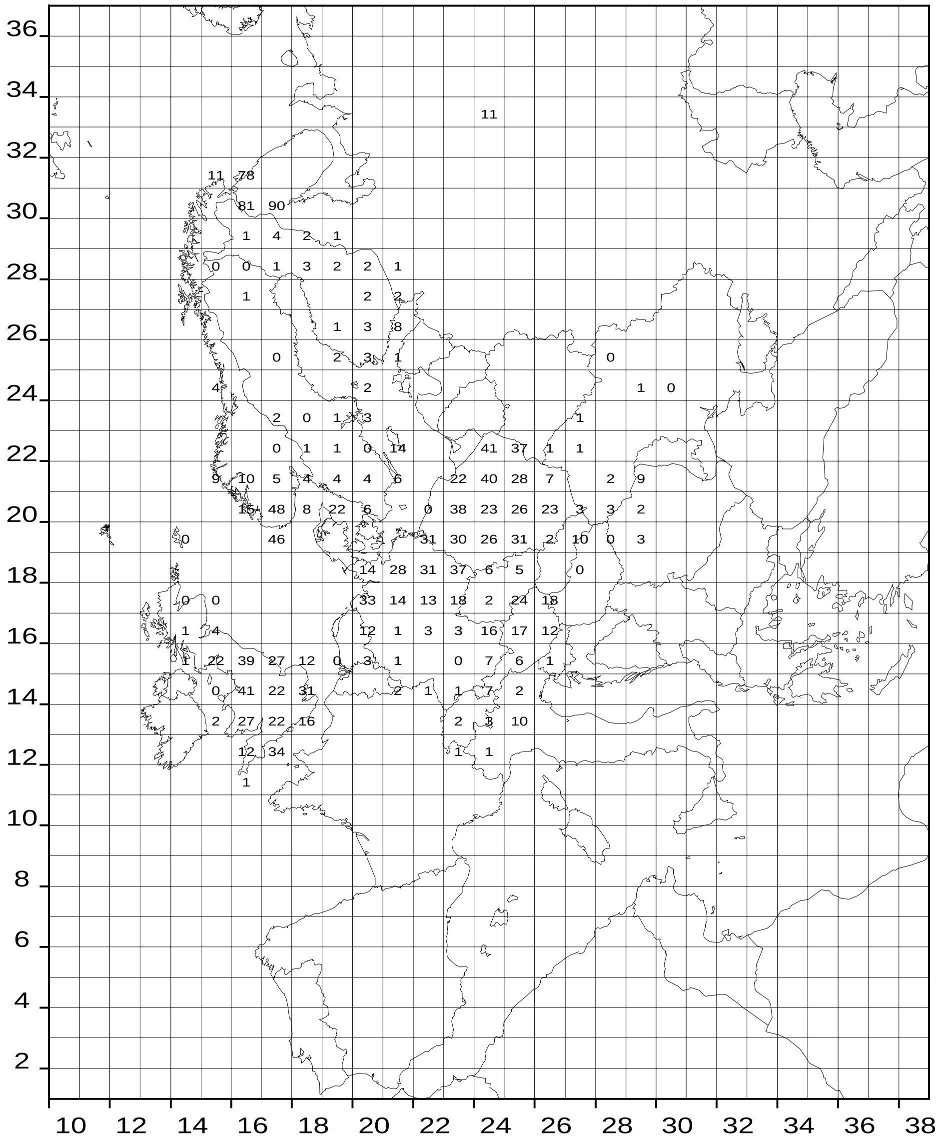

Figure 4.11: Percentage of ecosystems with acid deposition above their critical loads in Scenario 3 (the 55% gap closure scenario)

Table 4.22: Ecosystems not protected from acidification and eutrophication in Scenario 3 (the 55% gap closure scenario)

	Acidification		**Eutrophication**	
	1000 ha	%	1000 ha	%
Austria	596	12%	2209	45%
Belgium	6	1%	570	92%
Denmark	16	2%	109	11%
Finland	1127	3%	81	0%
France	11	0%	1493	10%
Germany	796	9%	4129	48%
Greece	0	0%	88	4%
Ireland	1	0%	0	0%
Italy	61	1%	588	9%
Luxembourg	1	2%	80	91%
Netherlands	20	6%	255	80%
Portugal	0	0%	360	13%
Spain	0	0%	660	8%
Sweden	564	1%	11	0%
UK	903	11%	0	0%
EU-15	**4103**	3%	**10634**	10%
Albania	0	0%	65	6%
Belarus	53	3%	1568	83%
Bosnia-H.	0	0%	210	14%
Bulgaria	0	0%	2661	70%
Croatia	0	0%	161	10%
Czech Republic	256	10%	2018	76%
Estonia	8	0%	502	27%
Hungary	39	2%	461	28%
Latvia	0	0%	506	19%
Lithuania	12	1%	1602	84%
FYRMacedonia	0	0%	230	22%
R. of Moldova	0	1%	2	20%
Norway	2083	6%	0	0%
Poland	1651	26%	5476	86%
Romania	65	1%	1066	17%
Russia	4366	1%	9891	3%
Slovakia	78	4%	1008	51%
Slovenia	23	3%	133	15%
Switzerland	25	2%	781	37%
Ukraine	99	1%	5401	65%
F. Yugoslavia	0	0%	620	18%
Non-EU	**8759**	2%	**34360**	9%
TOTAL	**12861**	2%	**44994**	9%

4.3 Sensitivity Analysis for the 50% Gap Closure Scenario

The following paragraphs take Scenario 2 (the 50 % gap closure scenario) as the central optimization outcome and explore the robustness of the calculation results. Obviously, model calculations are associated with a variety of uncertainties, which are related to a number of factors, such as modeling methodology, imperfections and gaps in input data, etc.. It has been shown earlier that general uncertainties about the future pace of economic development and, particularly for the acidification problem, about the structure of the future energy supply system dominate the overall uncertainties of model outcomes (Rentz et al., 1994). Most prominently, assumptions incorporated in the selected energy pathway about eventual future action to control greenhouse gas emissions adopted in the energy pathway are most relevant for the potential and the costs of reducing acidifying emissions. Further sources of uncertainties are atmospheric source-receptor relationships and critical loads estimates (Shaw & Amann, 1990).

A detailed analysis of the robustness of optimization results against alterations of the energy projections (e.g., due to plans to control emissions of greenhouse gases) is planned for the second report of this study. This first report, however, concentrates on the robustness of solutions against important changes of exogenous assumptions on target setting (critical loads estimates) and on an eventual involvement of emission sources outside the direct control of the European Union. Section 4.3.1 identifies the grid cells for which the specified deposition targets have immediate impact on the optimization result. For these ‘binding’ grids, changes in critical loads estimates or in the selected deposition targets would result directly in modified emission reduction requirements for one or more countries. Section 4.3.2 explores the implications on emission reduction requirements for land-based sources, if emissions from marine vessels were also subject to control (Scenario 4). Section 4.3.3 makes an attempt to quantify the continental scale of the air pollution problem by exploring modifications of the abatement schedule, if European countries outside of the EU also participated in an effort to reduce the unprotected area within the EU by 50 percent (Scenario 5). Finally, Scenario 6 hypothesizes the 50 percent gap closure target to be extended over all of Europe in order to check whether the reduction requirements established in Scenario 2 would reverse (Section 4.3.4).

4.3.1 Binding Receptor Targets

To judge the robustness of an optimized solution it is instructive to inspect the deposition pattern after the optimization. Due to the nature of the atmospheric source-receptor relationships (basically the long-range characteristic of the dispersion of the pollutants) it is usually not possible to exactly meet all the spatially differentiated deposition targets. In reality, i.a., caused by the spatial structure of the location of sources, some grids will always receive higher (or lower) deposition than others, irrespective of their environmental sensitivity or target deposition. As a consequence, there are always grids where it is more difficult to attain deposition thresholds, or expressed differently, there are always (other) grids where actual deposition will be below the target, whereas the ‘difficult’ grids just meet their targets.

Translated into the optimization problem, this means that not all constraints on deposition are ‘binding’ in the optimal case, and deposition targets for a number of grids are usually overachieved. Consequently, changing such a ‘non-binding’ target within certain limits will not modify the result of the optimization, since this is determined by the constraints for the ‘binding’ receptor grids. For the practical optimization problem discussed in this report this means that, from an ex-post perspective, precise critical loads estimates and/or target choices are only relevant for the binding grids, since only a change of these numbers will influence the result of the optimization.

The linear programming (LP) technique used in the RAINS model allows to identify the ‘binding’ grid cells, i.e., for which after the optimization the resulting deposition is exactly at the target, on a routine basis. Furthermore, the LP solver also provides for each binding grid information on marginal costs, i.e., the amount by which the overall objective function (in this case the total European abatement costs) would change if the value of the constraint is modified by one unit. Marginal costs are another useful piece of information when evaluating optimization results.

Table 4.23: List of 'binding' receptors for the optimized scenarios and the associated marginal costs (in million ECU per year per equivalent of acid deposition per hectare)

Grid cell coordinates	Country		Scenario 1	Scenario 2	Scenario 3
16/14	UK	Manchester/ Liverpool	8.2	24.8	126.0
20/17	Germany/ Netherlands	Hannover/ Groningen	26.1	65.2	70.6
21/22	Sweden	Gotland	--	15.3	11.6
22/18	Germany	Berlin	3.3	0.2	--
25/13	Italy	Milano	2.7	3.1	5.7
18/6	Spain		0.05	--	--

Table 4.23 shows that for all three scenarios the binding grids are well-distributed over the EU countries, indicating that the optimized solution is not driven by a single ecosystem, but determined by a balanced spread of targets over Europe. Since each of the scenarios aim at different ecosystems, there is no need that the same grids always occur as binding. Important is the cumulative distribution of critical loads in each grid cell.

Taking Scenario 2 as an example and judging from the marginal costs, the targets specified for the northern German/Dutch border is most costly to attain, followed by the Manchester/Liverpool area and Gotland in the Baltic Sea. Obviously, the target for the German/Dutch border determines measures in a number of countries in the EU and is immediately responsible for targets in Germany, Denmark, Belgium and France. Via its source-receptor relations, the receptor in the UK is directly linked to emissions from the UK and from Ireland, whereas the Gotland grid determines the marginal extent of abatement in Sweden and Finland. Finally, ecosystems in northern Italy limit emissions in Italy and the long-range contribution from Spain. The targets on acid deposition selected for the current set of scenarios does not have a limiting influence on emissions in Austria, Portugal and Greece.

Although removing or relaxing one of these deposition targets will decrease total European abatement costs, it does not immediately relieve the associated countries from any action, since in such a case other receptors will become binding, leading to a balanced distribution of emission reductions. Experiments showed that an elimination, e.g. of the most expensive grid 20/17, will move much of the burden to grid 22/18. Furthermore it can be stated that eventual reduction requirements in countries not having binding receptors in their own territories (e.g., Spain in Scenario 2) are determined by their transboundary long-range contribution to deposition at one of the binding receptors rather than by local effects close to a source.

4.3.2 Scenario 4: Reducing the unprotected area by at least 50 percent - including emission reductions from ships

For Scenarios 1 to 3 it has been assumed that measures to control emissions are limited to Member States of the EU. Due to the transboundary nature of air pollution, however, also emissions from sources outside of the EU influence deposition within the EU.

Whereas the EU legislation has access to emissions in its Member States, emissions from shipping in international seas are not immediately accessible. Obviously there is a contribution from these marine sources to deposition on land. Scenario 4 explores the cost-effectiveness of reducing emissions in certain sea regions for achieving the deposition targets of Scenario 2 (the 50 percent reduction of the unprotected area).

The current version of the EMEP model allows to distinguish three different source regions in international water: the North Sea, parts of the Atlantic Ocean and the Baltic Sea. Reliable data for the Mediterranean Sea are not yet introduced in the EMEP model and the current numbers in use are likely to be underestimated. However, the RAINS model is currently able to perform a preliminary study of the cost-effectiveness of controlling emissions from the three regions and to compare them with controlling emissions from land-based sources.

By comparing the result of an optimized scenario allowing ships to reduce emissions with the outcomes of Scenario 2, Table 4.24 shows an inhomogeneous pattern for the regional seas. Both SO_2 and NO_x emissions would be reduced in the North Sea, whereas in the Baltic only sulfur and in the Atlantic only NO_x emissions would be subject to control. As to be expected, this increased reduction would relieve the most expensive measures for land-based sources: EU-15 SO_2 emissions could be 18 percent higher than in Scenario 2, NO_x eight percent and ammonia four percent. Most interesting is a look to Table 4.25: While costs for reducing ships' emissions are estimated at about 300 million ECU/year, land-based sources would experience a decline in their costs of about 2400 million ECU/year. Most savings would occur in Germany, Belgium, Denmark, France, Sweden and the UK.

It should be mentioned that, although this result has to be considered as preliminary (particularly the valuation of SO_2 versus NO_x), the magnitude of cost savings (2 billion ECU per year, i.e., about 25 percent of the additional costs of Scenario 2 compared to the Reference scenario could justify a more in-depth analysis of this aspect.

Table 4.24: Emissions of Scenario 4 (50% reduction of the unprotected area, measures also for marine vessels)

	SO_2			NO_x			NH_3		
	Scen 4	**Scen 2**	***diff.***	**Scen 4**	**Scen 2**	***diff.***	**Scen 4**	**Scen 2**	***diff.***
Austria	43	43	*0%*	111	111	*0%*	96	96	*0%*
Belgium	77	60	*28%*	148	125	*18%*	106	74	*43%*
Denmark	90	34	*165%*	147	87	*69%*	103	80	*29%*
Finland	116	85	*36%*	158	158	*0%*	23	23	*0%*
France	236	236	*0%*	862	738	*17%*	588	542	*8%*
Germany	449	423	*6%*	1206	1040	*16%*	347	332	*5%*
Greece	373	373	*0%*	275	275	*0%*	73	73	*0%*
Ireland	42	42	*0%*	32	32	*0%*	126	126	*0%*
Italy	254	254	*0%*	1111	1111	*0%*	297	297	*0%*
Luxembourg	4	4	*0%*	10	10	*0%*	7	7	*0%*
Netherlands	45	37	*22%*	133	133	*0%*	85	85	*0%*
Portugal	190	190	*0%*	202	202	*0%*	86	86	*0%*
Spain	852	551	*55%*	833	805	*3%*	329	329	*0%*
Sweden	96	66	*45%*	188	184	*2%*	53	46	*15%*
UK	252	252	*0%*	706	676	*4%*	279	278	*0%*
EU-15	**3119**	**2650**	***18%***	**6122**	**5687**	***8%***	**2598**	**2474**	***5%***
Atlantic Sea	317	317	*0%*	70	350	*-80%*	0	0	*0%*
Baltic	22	73	*-70%*	81	81	*0%*	0	0	*0%*
North Sea	42	173	*-76%*	38	192	*-80%*	0	0	*0%*
SEA	**381**	**563**	***-32%***	**189**	**623**	***-70%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	260	260	*0%*	159	159	*0%*
Bosnia-H.	409	409	*0%*	48	48	*0%*	21	21	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	141	141	*0%*
Croatia	69	69	*0%*	64	64	*0%*	34	34	*0%*
Czech R.	151	151	*0%*	226	226	*0%*	130	130	*0%*
Estonia	172	172	*0%*	70	70	*0%*	29	29	*0%*
Hungary	544	544	*0%*	196	196	*0%*	150	150	*0%*
Latvia	104	104	*0%*	93	93	*0%*	38	38	*0%*
Lithuania	118	118	*0%*	130	130	*0%*	79	79	*0%*
Norway	31	31	*0%*	96	96	*0%*	36	36	*0%*
Poland	1397	1397	*0%*	819	819	*0%*	580	580	*0%*
R. of Moldova	91	91	*0%*	66	66	*0%*	46	46	*0%*
Romania	580	580	*0%*	443	443	*0%*	301	301	*0%*
Russia	2376	2376	*0%*	2653	2653	*0%*	918	918	*0%*
Slovakia	115	115	*0%*	104	104	*0%*	52	52	*0%*
Slovenia	37	37	*0%*	31	31	*0%*	27	27	*0%*
Switzerland	30	30	*0%*	72	72	*0%*	58	58	*0%*
FYRMacedonia	80	80	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1496	1496	*0%*	1405	1405	*0%*	658	658	*0%*
F. Yugoslavia	263	263	*0%*	119	119	*0%*	85	85	*0%*
Non-EU	**9442**	**9442**	***0%***	**7237**	**7237**	***0%***	**3592**	**3592**	***0%***
TOTAL	**12942**	**12655**	***2%***	**13548**	**13547**	***0%***	**6190**	**6066**	***2%***

Table 4.25: Comparison of emission control costs for Scenario 4 (measures for ships allowed) with Scenario 2 (50% gap closure scenario), costs in million ECU/year

	SO_2			**NO_x**			**NH_3**			**TOTAL COSTS**		
	Scen 4	**Scen 2**	**diff.**	**Scen 4**	**Scen 2**	**diff.**	**Scen 4**	**Scen 2**	**diff.**	**Scen 4**	**Scen 2**	**diff.**
Austria	310	310	0	603	603	0	0	0	0	913	913	0
Belgium	391	580	-189	795	867	-72	4	193	-189	1190	1640	-450
Denmark	159	289	-130	367	479	-112	36	137	-101	562	905	-343
Finland	149	181	-32	434	434	0	45	45	0	628	660	-32
France	1603	1603	0	4554	4704	-150	17	141	-124	6174	6448	-274
Germany	3017	3161	-144	7637	8162	-525	1653	1653	0	12307	12976	-669
Greece	210	210	0	364	364	0	0	0	0	574	574	0
Ireland	147	147	0	213	213	0	180	180	0	540	540	0
Italy	1886	1886	0	4994	4994	0	368	368	0	7248	7248	0
Luxembourg	9	9	0	51	51	0	12	12	0	72	72	0
Netherlands	262	322	-60	1649	1649	0	717	717	0	2628	2688	-60
Portugal	160	160	0	754	754	0	0	0	0	914	914	0
Spain	609	722	-113	3181	3181	0	0	0	0	3790	3903	-113
Sweden	284	425	-141	701	707	-6	37	93	-56	1022	1225	-203
UK	1629	1629	0	5025	5279	-254	510	510	0	7164	7418	-254
EU-15	**10825**	**11634**	**-809**	**31322**	**32441**	**-1119**	**3579**	**4049**	**-470**	**45726**	**48124**	**-2398**
Atlantic Sea	0	0	0	90	0	90	0	0	0	90	0	90
Baltic	47	0	47	0	0	0	0	0	0	47	0	47
North Sea	119	0	119	49	0	49	0	0	0	168	0	168
SEA	**166**	**0**	**166**	**139**	**0**	**139**	**0**	**0**	**0**	**305**	**0**	**305**

Table continues on next page

Table continued: Comparison of emission control costs for Scenario 4 (measures for ships allowed) with Scenario 2 (50% gap closure scenario) , costs in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	Scen 4	**Scen 2**	**diff.**	**Scen 4**	**Scen 2**	**diff.**	**Scen 4**	**Scen 2**	**diff.**	**Scen 4**	**Scen 2**	**diff.**
Albania	0	0	0	0	0	0	0	0	0	0	0	0
Belarus	0	0	0	15	15	0	0	0	0	15	15	0
Bosnia-H	0	0	0	49	49	0	0	0	0	49	49	0
Bulgaria	44	44	0	0	0	0	0	0	0	44	44	0
Croatia	60	60	0	139	139	0	0	0	0	199	199	0
Czech R.	391	391	0	527	527	0	0	0	0	918	918	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	168	168	0	397	397	0	0	0	0	565	565	0
Latvia	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	46	45	1	420	420	0	0	0	0	466	465	1
Poland	827	826	1	980	980	0	0	0	0	1807	1806	1
R. of Moldova	0	0	0	0	0	0	0	0	0	0	0	0
Romania	181	181	0	0	0	0	0	0	0	181	181	0
Russia	963	963	0	21	21	0	0	0	0	984	984	0
Slovakia	115	115	0	323	323	0	0	0	0	438	438	0
Slovenia	51	50	1	129	129	0	0	0	0	180	179	1
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	29	29	0	0	0	0	29	29	0
Ukraine	452	452	0	0	0	0	0	0	0	452	452	0
F. Yugoslavia	80	80	0	154	154	0	0	0	0	234	234	0
SUM	**3442**	**3439**	**3**	**3687**	**3687**	**0**	**0**	**0**	**0**	**7129**	**7126**	**3**
TOTAL	**14433**	**15073**	**-640**	**35148**	**36128**	**-980**	**3579**	**4049**	**-470**	**53160**	**55250**	**-2090**

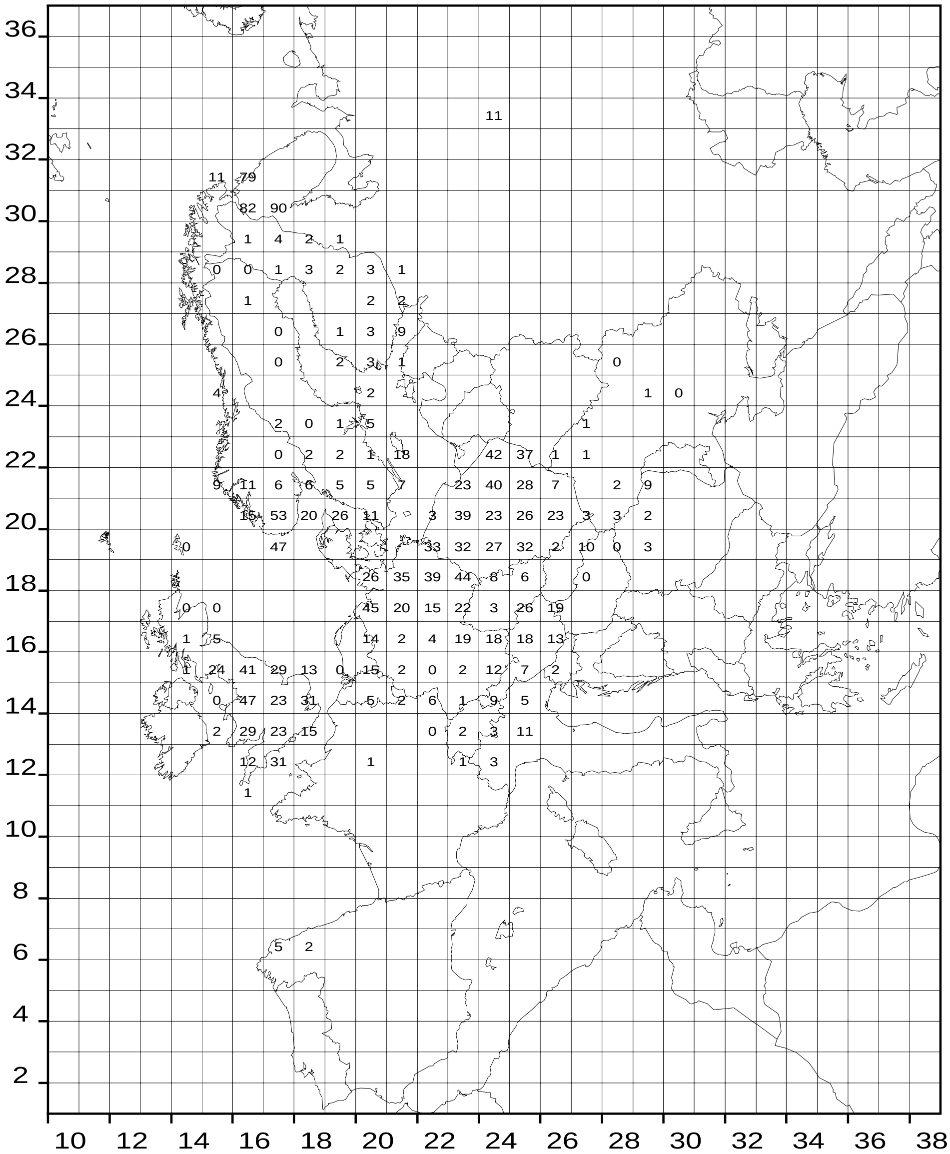

Figure 4.12: Percentage of ecosystems with acid deposition above their critical loads for acidity (Scenario 4)

Table 4.26: Unprotected ecosystems for Scenario 4 (50% reduction of the unprotected area, ships allowed to reduce emissions)

	Acidification		Eutrophication	
	1000 ha	%	1000 ha	%
Austria	649	13%	2515	52%
Belgium	33	5%	581	94%
Denmark	23	2%	307	32%
Finland	1148	4%	162	1%
France	47	0%	3205	22%
Germany	1152	13%	4721	54%
Greece	0	0%	90	4%
Ireland	1	0%	0	0%
Italy	98	1%	654	10%
Luxembourg	2	2%	83	95%
Netherlands	37	11%	259	81%
Portugal	0	0%	326	12%
Spain	18	0%	748	9%
Sweden	824	2%	47	0%
UK	972	12%	0	0%
EU-15	**5004**	4%	**13699**	12%
Albania	0	0%	67	6%
Belarus	53	3%	1683	89%
Bosnia-H.	0	0%	247	17%
Bulgaria	0	0%	2680	71%
Croatia	0	0%	242	15%
Czech R.	308	12%	2112	80%
Estonia	8	0%	508	27%
Hungary	40	2%	500	31%
Latvia	0	0%	734	27%
Lithuania	12	1%	1663	88%
FYRMacedonia	0	0%	235	22%
R. of Moldova	0	1%	2	20%
Norway	2302	7%	17	0%
Poland	1721	27%	5648	88%
Romania	65	1%	1079	17%
Russia	4387	1%	10612	3%
Slovakia	80	4%	1074	54%
Slovenia	27	3%	164	18%
Switzerland	28	2%	919	43%
Ukraine	100	1%	5448	66%
F. Yugoslavia	0	0%	644	19%
Non-EU	**9132**	2%	**36277**	9%
TOTAL	**14136**	3%	**49976**	10%

4.3.3 Scenario 5: Reducing the unprotected areas by at least 50 percent - Including measures in non-EU countries, but not for ships

Compared to Scenario 4, another group of emitters with impacts on ecosystems in the EU are the countries outside of the EU. Scenario 5 presented in this Section explores, again for the 50 percent gap closure target, the allocation of measures if also emissions from non-EU countries are open to reduction. It should be mentioned that this scenario explores this option from an EU perspective, i.e., by setting deposition targets only within the EU and ignoring potential environmental benefits for countries outside the EU. The alternative case, in which environmental targets are also specified for the non-EU countries, is subject of Scenario 6.

In order to ensure the comparability with Scenario 2, all other assumptions have been maintained (Conventional Wisdom-energy scenario for the EU-15, Official Energy Pathway for non-EU countries, REF scenario as the minimum requirements for emission reductions, exclusion of three grids in Finland, no measures for ships).

Table 4.27 presents the optimized emission abatement schedule and compares it with Scenario 2. According to the definition of the scenario, also non-EU countries reduce their emissions, underlining the fact that, even after implementation of the Second Sulfur Protocol, it would be cost-effective to stimulate further measures outside the EU in order to improve environmental protection within the EU. Most strikingly, however, is the aspect that only SO_2 emissions would be a candidate for a cooperative strategy, and that the potential sources are limited to the Czech Republic, Hungary and Poland. Measures in these three countries could relax the most expensive abatement options in a number of EU countries (Belgium, Denmark, Finland, Italy, Spain and Sweden). For the EU-15, the remaining SO_2 emissions could be 13 percent higher than in Scenario 2.

While spending 300 million ECU/year outside of the EU, abatement costs within the EU could be lowered by about 1300 million ECU/year, leaving a net benefit of about one billion ECU/year or 13 percent of the additional costs of Scenario 2. About half of the savings results from lower control of SO_2 emissions, and about one third from ammonia.

The measures placed outside of the EU create also local benefits close to the sources. More than 400.000 hectares of European ecosystems in non-EU countries will be protected in addition to the outcome of Scenario 2.

Table 4.27: Emissions in Scenario 5 compared to Scenario 2 (the 50% gap closure scenario)

	SO_2			NO_x			NH_3		
	Scen 5	**Scen 2**	***diff.***	**Scen 5**	**Scen 2**	***diff.***	**Scen 5**	**Scen 2**	***diff.***
Austria	43	43	*0%*	111	111	*0%*	96	96	*0%*
Belgium	77	60	*28%*	125	125	*0%*	103	74	*39%*
Denmark	42	34	*24%*	110	87	*26%*	103	80	*29%*
Finland	116	85	*36%*	158	158	*0%*	23	23	*0%*
France	236	236	*0%*	738	738	*0%*	588	542	*8%*
Germany	447	423	*6%*	1098	1040	*6%*	347	332	*5%*
Greece	373	373	*0%*	275	275	*0%*	73	73	*0%*
Ireland	42	42	*0%*	32	32	*0%*	126	126	*0%*
Italy	269	254	*6%*	1111	1111	*0%*	297	297	*0%*
Luxembourg	4	4	*0%*	10	10	*0%*	7	7	*0%*
Netherlands	37	37	*0%*	133	133	*0%*	85	85	*0%*
Portugal	190	190	*0%*	202	202	*0%*	86	86	*0%*
Spain	762	551	*38%*	805	805	*0%*	329	329	*0%*
Sweden	96	66	*45%*	188	184	*2%*	53	46	*15%*
UK	252	252	*0%*	675	676	*0%*	278	278	*0%*
EU-15	**2986**	**2650**	***13%***	**5771**	**5687**	***1%***	**2594**	**2474**	***5%***
Atlantic Sea	317	317	*0%*	350	350	*0%*	0	0	*0%*
Baltic	73	73	*0%*	81	81	*0%*	0	0	*0%*
North Sea	173	173	*0%*	192	192	*0%*	0	0	*0%*
SEA	**563**	**563**	***0%***	**623**	**623**	***0%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	260	260	*0%*	159	159	*0%*
Bosnia-H.	409	409	*0%*	47	48	*-2%*	21	21	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	141	141	*0%*
Croatia	69	69	*0%*	64	64	*0%*	34	34	*0%*
Czech R.	111	151	*-26%*	226	226	*0%*	130	130	*0%*
Estonia	172	172	*0%*	69	70	*-1%*	29	29	*0%*
Hungary	361	544	*-34%*	196	196	*0%*	150	150	*0%*
Latvia	104	104	*0%*	93	93	*0%*	38	38	*0%*
Lithuania	118	118	*0%*	130	130	*0%*	79	79	*0%*
Norway	31	31	*0%*	96	96	*0%*	36	36	*0%*
Poland	829	1397	*-41%*	819	819	*0%*	580	580	*0%*
R. of Moldova	91	91	*0%*	66	66	*0%*	46	46	*0%*
Romania	580	580	*0%*	443	443	*0%*	301	301	*0%*
Russia	2376	2376	*0%*	2653	2653	*0%*	918	918	*0%*
Slovakia	115	115	*0%*	104	104	*0%*	52	52	*0%*
Slovenia	37	37	*0%*	31	31	*0%*	27	27	*0%*
Switzerland	30	30	*0%*	72	72	*0%*	58	58	*0%*
FYRMacedonia	80	80	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1496	1496	*0%*	1405	1405	*0%*	658	658	*0%*
F. Yugoslavia	263	263	*0%*	119	119	*0%*	85	85	*0%*
Non-EU	**8651**	**9442**	***-8%***	**7235**	**7237**	***0%***	**3592**	**3592**	***0%***
TOTAL	**12200**	**12655**	***-4%***	**13629**	**13547**	***1%***	**6186**	**6066**	***2%***

Table 4.28: Comparison of emission control costs between Scenario 5 and Scenario 2 (in million ECU/year)

	SO_2			NO_x			NH_3			TOTAL COSTS		
	Scen 5	**Scen 2**	**diff.**	**Scen 5**	**Scen 2**	**diff.**	**Scen 5**	**Scen 2**	**diff.**	**Scen 5**	**Scen 2**	**diff.**
Austria	310	310	0	603	603	0	0	0	0	913	913	0
Belgium	391	580	-189	867	867	0	4	193	-189	1262	1640	-378
Denmark	237	289	-52	419	479	-60	36	137	-101	692	905	-213
Finland	149	181	-32	434	434	0	45	45	0	628	660	-32
France	1603	1603	0	4704	4704	0	17	141	-124	6324	6448	-124
Germany	3029	3161	-132	8002	8162	-160	1653	1653	0	12684	12976	-292
Greece	210	210	0	364	364	0	0	0	0	574	574	0
Ireland	147	147	0	213	213	0	180	180	0	540	540	0
Italy	1865	1886	-21	4994	4994	0	368	368	0	7227	7248	-21
Luxembourg	9	9	0	51	51	0	12	12	0	72	72	0
Netherlands	322	322	0	1649	1649	0	717	717	0	2688	2688	0
Portugal	160	160	0	754	754	0	0	0	0	914	914	0
Spain	636	722	-86	3181	3181	0	0	0	0	3817	3903	-86
Sweden	284	425	-141	701	707	-6	37	93	-56	1022	1225	-203
UK	1629	1629	0	5279	5279	0	510	510	0	7418	7418	0
EU-15	**10981**	**11634**	**-653**	**32215**	**32441**	**-226**	**3579**	**4049**	**-470**	**46775**	**48124**	**-1349**
Atlantic Sea	0	0	0	0	0	0	0	0	0	0	0	0
Baltic	0	0	0	0	0	0	0	0	0	0	0	0
North Sea	0	0	0	0	0	0	0	0	0	0	0	0
SEA	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

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Table continued: Comparison of emission control costs between Scenario 5 and Scenario 2 (in million ECU/year)

	SO_2			NO_x			NH_3			TOTAL COSTS		
	Scen 5	**Scen 2**	**diff.**	**Scen 5**	**Scen 2**	**diff.**	**Scen 5**	**Scen 2**	**diff.**	**Scen 5**	**Scen 2**	**diff.**
Albania	0	0	0	0	0	0	0	0	0	0	0	0
Belarus	0	0	0	15	15	0	0	0	0	15	15	0
Bosnia-H	0	0	0	49	49	0	0	0	0	49	49	0
Bulgaria	44	44	0	0	0	0	0	0	0	44	44	0
Croatia	60	60	0	139	139	0	0	0	0	199	199	0
Czech R.	434	391	43	527	527	0	0	0	0	961	918	43
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	214	168	46	397	397	0	0	0	0	611	565	46
Latvia	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	45	45	0	420	420	0	0	0	0	465	465	0
Poland	1043	826	217	980	980	0	0	0	0	2023	1806	217
R. of Moldova	0	0	0	0	0	0	0	0	0	0	0	0
Romania	181	181	0	0	0	0	0	0	0	181	181	0
Russia	963	963	0	21	21	0	0	0	0	984	984	0
Slovakia	115	115	0	323	323	0	0	0	0	438	438	0
Slovenia	50	50	0	129	129	0	0	0	0	179	179	0
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	29	29	0	0	0	0	29	29	0
Ukraine	452	452	0	0	0	0	0	0	0	452	452	0
F. Yugoslavia	80	80	0	154	154	0	0	0	0	234	234	0
Non-EU	**3745**	**3439**	**306**	**3687**	**3687**	**0**	**0**	**0**	**0**	**7432**	**7126**	**306**
TOTAL	**14726**	**15073**	**-347**	**35902**	**36128**	**-226**	**3579**	**4049**	**-470**	**54207**	**55250**	**-1043**

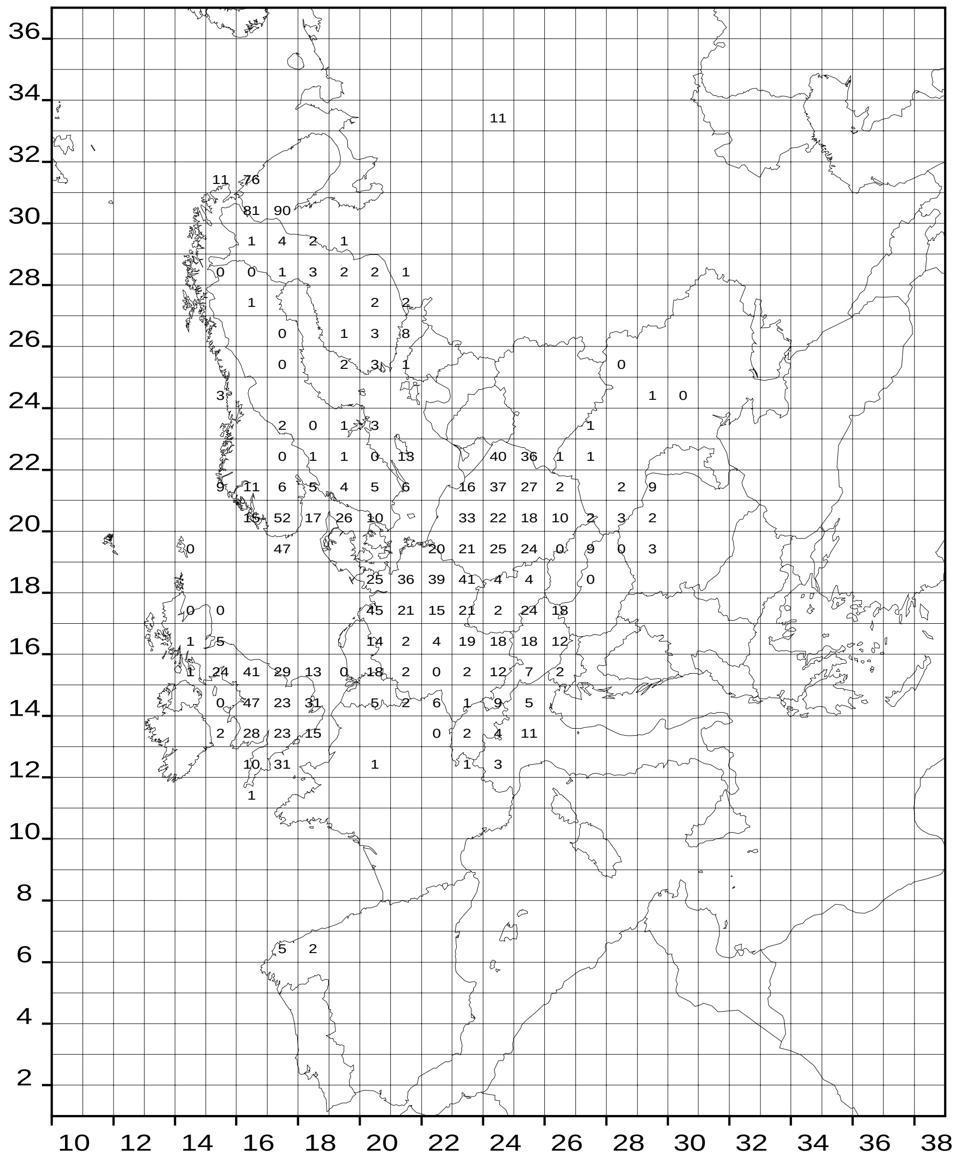

Figure 4.13: Percentage of ecosystems with acid deposition above their critical loads for acidity (Scenario 5)

Table 4.29: Unprotected ecosystems for Scenario 5

	Acidification		Eutrophication	
	1000 ha	%	1000 ha	%
Austria	597	12%	2365	49%
Belgium	9	1%	576	93%
Denmark	22	2%	306	31%
Finland-	1127	3%	153	0%
France	32	0%	2606	18%
Germany	1055	12%	4584	53%
Greece	0	0%	89	4%
Ireland	1	0%	0	0%
Italy	95	1%	647	10%
Luxembourg	2	2%	82	93%
Netherlands	24	8%	257	80%
Portugal	0	0%	400	14%
Spain	16	0%	711	8%
Sweden	705	2%	37	0%
UK	993	13%	0	0%
EU-15	**4680**	3%	**12815**	11%
Albania	0	0%	67	6%
Belarus	50	3%	1681	88%
Bosnia-H.	0	0%	232	16%
Bulgaria	0	0%	2676	71%
Croatia	0	0%	217	13%
Czech R.	235	9%	2076	78%
Estonia	8	0%	507	27%
Hungary	36	2%	478	30%
Latvia	0	0%	726	27%
Lithuania	12	1%	1633	86%
FYRMacedonia	0	0%	234	22%
R. of Moldova	0	1%	2	20%
Norway	2280	7%	17	0%
Poland	1329	21%	5523	86%
Romania	62	1%	1074	17%
Russia	4350	1%	10610	3%
Slovakia	64	3%	1041	52%
Slovenia	24	3%	153	17%
Switzerland	28	2%	892	42%
Ukraine	77	1%	5422	66%
F. Yugoslavia	0	0%	639	19%
Non-EU	**8555**	2%	**35900**	9%
TOTAL	**13234**	2%	**48714**	9%

4.3.4 Scenario 6: Reducing the unprotected areas in all of Europe by at least 50 percent - including measures in non-EU countries and for ships

As a last example Scenario 6 explores the implications if the target to reduce unprotected ecosystems by 50 percent was applied throughout Europe. Since this scenario features a comprehensive solution to the pan-European acidification problem, emissions from non-EU countries as well as from international shipping are also open to control. Furthermore, the three grids at the Finnish/Russian border have been included in the optimization. Obviously, this initial analysis can only offer a first outlook into the range of possible solutions and must, for the time being, exclude various options for refinement and sophistication of strategy development.

The most prominent feature of such a scenario is the fact that including environmental targets also for ecosystems outside the EU has a major impact on the binding grid cells. Low critical loads at the most southern part of Norway (grid 17/19) determine the extent of emission reductions in the northern part of Europe, with marginal costs of 165.8 million ECU/acid equivalent/ha/year (this is 2.5 times higher than the most expensive grid 20/17 in Scenario 2). Consequently, this deposition target supersedes also the constraints active in the EU-only Scenarios 1 to 3 in the UK, Sweden and partly in Germany. In addition, also grids in Romania/Ukraine and Finland/Russia become relevant.

The strict target for Norway would force all EU countries with the exception of Austria, Greece, Luxembourg and the Netherlands to take additional measures. Although in a few cases the re-arranged abatement schedule would impose less requirements for some pollutants, no major reversals of strategies following from Scenario 2 would occur.

Table 4.30: Emissions of Scenario 6 compared with the 50% gap closure scenario (Scenario 2), in kilotons

	SO_2			**NO_x**			**NH_3**		
	Scen 6	**Scen 2**	***diff.***	**Scen 6**	**Scen 2**	***diff.***	**Scen6**	**Scen 2**	***diff.***
Austria	43	43	*0%*	111	111	*0%*	96	96	*0%*
Belgium	60	60	*0%*	114	125	*-9%*	74	74	*0%*
Denmark	28	34	*-18%*	79	87	*-9%*	50	80	*-38%*
Finland	116	85	*36%*	158	158	*0%*	23	23	*0%*
France	236	236	*0%*	696	738	*-6%*	542	542	*0%*
Germany	391	423	*-8%*	1087	1040	*5%*	402	332	*21%*
Greece	373	373	*0%*	275	275	*0%*	73	73	*0%*
Ireland	42	42	*0%*	28	32	*-13%*	126	126	*0%*
Italy	206	254	*-19%*	1111	1111	*0%*	313	297	*5%*
Luxembourg	4	4	*0%*	10	10	*0%*	7	7	*0%*
Netherlands	37	37	*0%*	133	133	*0%*	85	85	*0%*
Portugal	190	190	*0%*	190	202	*-6%*	86	86	*0%*
Spain	262	551	*-52%*	768	805	*-5%*	329	329	*0%*
Sweden	66	66	*0%*	159	184	*-14%*	53	46	*15%*
UK	210	252	*-17%*	609	676	*-10%*	286	278	*3%*
EU-15	**2264**	**2650**	***-15%***	**5528**	**5687**	***-3%***	**2545**	**2474**	***3%***
Atlantic Sea	76	317	*-76%*	70	350	*-80%*	0	0	*0%*
Baltic	18	73	*-75%*	16	81	*-80%*	0	0	*0%*
North Sea	42	173	*-76%*	38	192	*-80%*	0	0	*0%*
SEA	**136**	**563**	***-76%***	**124**	**623**	***-80%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	82	490	*-83%*	260	260	*0%*	159	159	*0%*
Bosnia-H.	36	409	*-91%*	48	48	*0%*	21	21	*0%*
Bulgaria	153	835	*-82%*	290	290	*0%*	141	141	*0%*
Croatia	36	69	*-48%*	64	64	*0%*	34	34	*0%*
Czech R.	151	151	*0%*	226	226	*0%*	130	130	*0%*
Estonia	16	172	*-91%*	70	70	*0%*	29	29	*0%*
Hungary	302	544	*-44%*	196	196	*0%*	150	150	*0%*
Latvia	37	104	*-64%*	93	93	*0%*	38	38	*0%*
Lithuania	25	118	*-79%*	118	130	*-9%*	79	79	*0%*
Norway	17	31	*-45%*	63	96	*-34%*	26	36	*-28%*
Poland	418	1397	*-70%*	819	819	*0%*	542	580	*-7%*
R. of Moldova	21	91	*-77%*	52	66	*-21%*	34	46	*-26%*
Romania	96	580	*-83%*	361	443	*-19%*	221	301	*-27%*
Russia	2045	2376	*-14%*	2653	2653	*0%*	918	918	*0%*
Slovakia	64	115	*-44%*	104	104	*0%*	52	52	*0%*
Slovenia	13	37	*-65%*	31	31	*0%*	27	27	*0%*
Switzerland	30	30	*0%*	72	72	*0%*	58	58	*0%*
FYRMacedonia	80	80	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	388	1496	*-74%*	1205	1405	*-14%*	576	658	*-12%*
F. Yugoslavia	34	263	*-87%*	119	119	*0%*	85	85	*0%*
Non-EU	**4098**	**9442**	***-57%***	**6896**	**7237**	***-5%***	**3370**	**3592**	***-6%***
TOTAL	**6498**	**12655**	***-49%***	**12548**	**13547**	***-7%***	**5915**	**6066**	***-2%***

Table 4.31: Comparison of costs between Scenario 6 and Scenario 2 (in million ECU/year)

	SO_2			NO_x			NH_3			TOTAL COSTS		
	Scen 6	**Scen 2**	**diff.**	**Scen 6**	**Scen 2**	**diff.**	**Scen 6**	**Scen 2**	**diff.**	**Scen 6**	**Scen 2**	**diff.**
Austria	310	310	0	603	603	0	0	0	0	913	913	0
Belgium	580	580	0	931	867	64	193	193	0	1704	1640	64
Denmark	350	289	61	518	479	39	603	137	466	1471	905	566
Finland	149	181	-32	434	434	0	45	45	0	628	660	-32
France	1603	1603	0	4830	4704	126	141	141	0	6574	6448	126
Germany	3347	3161	186	7956	8162	-206	663	1653	-990	11966	12976	-1010
Greece	210	210	0	364	364	0	0	0	0	574	574	0
Ireland	147	147	0	236	213	23	180	180	0	563	540	23
Italy	1956	1886	70	4994	4994	0	229	368	-139	7179	7248	-69
Luxembourg	9	9	0	51	51	0	12	12	0	72	72	0
Netherlands	322	322	0	1649	1649	0	717	717	0	2688	2688	0
Portugal	160	160	0	754	754	0	0	0	0	914	914	0
Spain	938	722	216	3201	3181	20	0	0	0	4139	3903	236
Sweden	425	425	0	758	707	51	37	93	-56	1220	1225	-5
UK	2572	1629	943	5985	5279	706	246	510	-264	8803	7418	1385
EU-15	**13078**	**11634**	**1444**	**33264**	**32441**	**823**	**3066**	**4049**	**-983**	**49408**	**48124**	**1284**
Atlantic Sea	217	0	217	90	0	90	0	0	0	307	0	307
Baltic	50	0	50	21	0	21	0	0	0	71	0	71
North Sea	119	0	119	49	0	49	0	0	0	168	0	168
SEA	**386**	**0**	**386**	**160**	**0**	**160**	**0**	**0**	**0**	**546**	**0**	**546**

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Table continued: Comparison of costs between Scenario 6 and Scenario 2 (in million ECU/year)

	SO_2			NO_x			NH_3			TOTAL COSTS		
	Scen 6	**Scen 2**	**diff.**	**Scen 6**	**Scen 2**	**diff.**	**Scen 6**	**Scen 2**	**diff.**	**Scen 6**	**Scen 2**	**diff.**
Albania	0	0	0	0	0	0	0	0	0	0	0	0
Belarus	161	0	161	15	15	0	0	0	0	176	15	161
Bosnia-H	83	0	83	49	49	0	0	0	0	132	49	83
Bulgaria	211	44	167	0	0	0	0	0	0	211	44	167
Croatia	78	60	18	139	139	0	0	0	0	217	199	18
Czech R.	391	391	0	527	527	0	0	0	0	918	918	0
Estonia	74	0	74	0	0	0	0	0	0	74	0	74
Hungary	266	168	98	397	397	0	0	0	0	663	565	98
Latvia	29	0	29	0	0	0	0	0	0	29	0	29
Lithuania	58	0	58	0	0	0	0	0	0	58	0	58
Norway	110	45	65	538	420	118	112	0	112	760	465	295
Poland	1437	826	611	980	980	0	39	0	39	2456	1806	650
R. of Moldova	48	0	48	0	0	0	61	0	61	109	0	109
Romania	431	181	250	27	0	27	318	0	318	776	181	595
Russia	1086	963	123	21	21	0	0	0	0	1107	984	123
Slovakia	147	115	32	323	323	0	0	0	0	470	438	32
Slovenia	62	50	12	129	129	0	0	0	0	191	179	12
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	29	29	0	0	0	0	29	29	0
Ukraine	974	452	522	37	0	37	143	0	143	1154	452	702
F. Yugoslavia	259	80	179	154	154	0	0	0	0	413	234	179
SUM	**5969**	**3439**	**2530**	**3869**	**3687**	**182**	**673**	**0**	**673**	**10511**	**7126**	**3385**
TOTAL	**19433**	**15073**	**4360**	**37293**	**36128**	**1165**	**3739**	**4049**	**-310**	**60465**	**55250**	**5215**

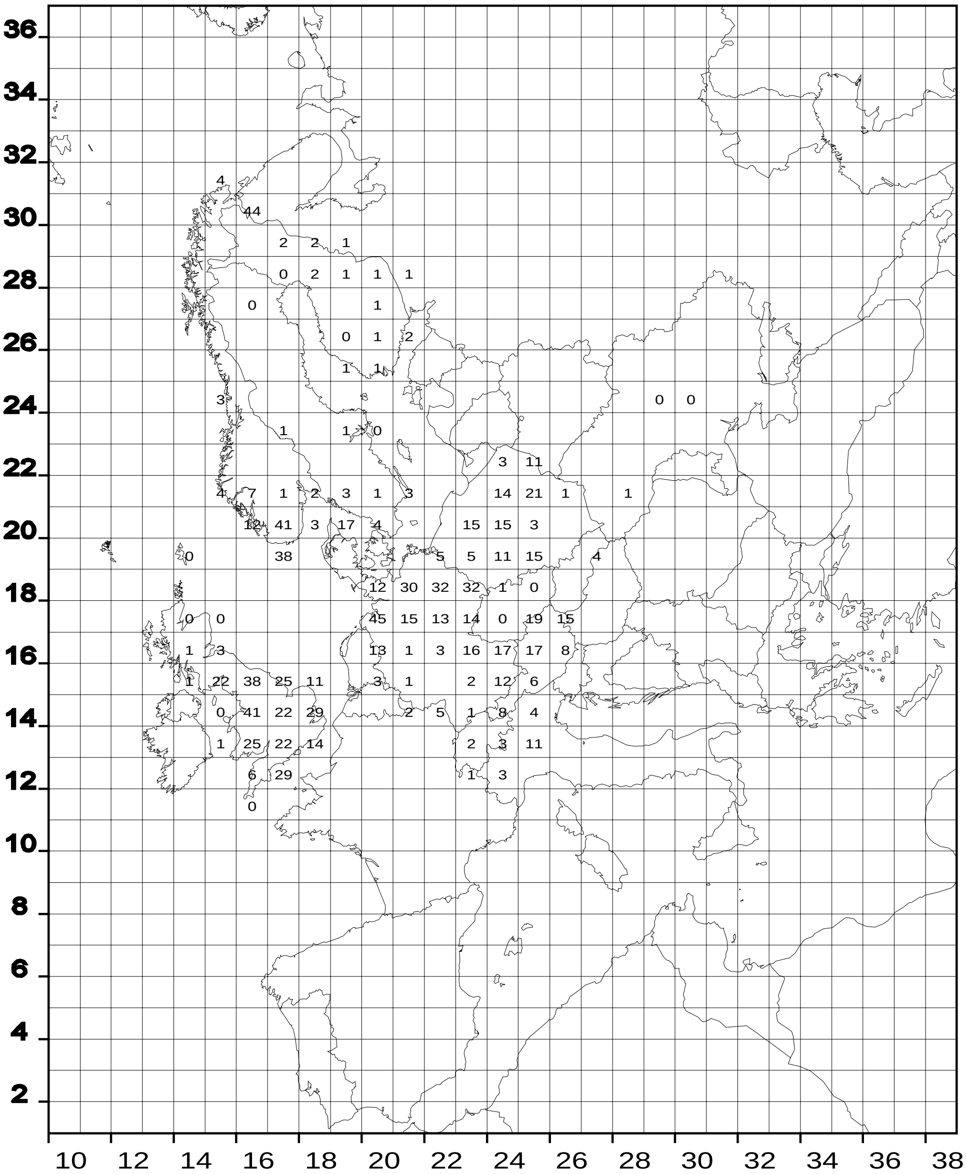

Figure 4.14: Percentage of ecosystems with acid deposition above their critical loads for acidity in Scenario 6

Table 4.32: Unprotected ecosystems in Scenario 6

	Acidification		Eutrophication	
	1000 ha	%	1000 ha	%
Austria	516	11%	2351	48%
Belgium	7	1%	576	93%
Denmark	12	1%	12	1%
Finland	496	2%	75	0%
France	31	0%	2467	17%
Germany	927	11%	4894	56%
Greece	0	0%	86	4%
Ireland	0	0%	0	0%
Italy	91	1%	656	10%
Luxembourg	2	2%	82	93%
Netherlands	21	7%	256	80%
Portugal	0	0%	316	11%
Spain	0	0%	644	8%
Sweden	263	1%	11	0%
UK	862	11%	0	0%
EU-15	**3228**	2%	**12424**	11%
Albania	0	0%	66	6%
Belarus	13	1%	1559	82%
Bosnia-H.	0	0%	218	15%
Bulgaria	0	0%	2466	65%
Croatia	0	0%	194	12%
Czech Republic	178	7%	2062	78%
Estonia	1	0%	502	27%
Hungary	24	1%	422	26%
Latvia	0	0%	484	18%
Lithuania	1	0%	1587	84%
FYRMacedonia	0	0%	220	21%
R. of Moldova	0	0%	2	19%
Norway	1493	5%	0	0%
Poland	591	9%	5218	82%
Romania	0	0%	706	11%
Russia	658	0%	9881	3%
Slovakia	34	2%	918	46%
Slovenia	11	1%	150	17%
Switzerland	27	2%	894	42%
Ukraine	6	0%	5169	63%
F. Yugoslavia	0	0%	616	18%
Non-EU	**3037**	1%	**33333**	8%
TOTAL	**6265**	1%	**45758**	9%

5. Summary

5.1 Cross-scenario comparisons

To simplify a comparative evaluation of model results the following section presents tables with emissions, abatement costs and ecosystems' protection.

Table 5.1: Cross-scenario comparison of SO_2 emissions (kt of SO_2)

	1990	REF	Scen 1 45%	Scen 2 50%	Scen 3 55%	MTFR realistic	MTFR ultimate
Austria	90	43	43	43	43	36	36
Belgium	317	215	77	60	60	56	56
Denmark	180	91	42	34	34	22	22
Finland	260	116	116	85	116	55	55
France	1298	716	236	236	236	220	166
Germany	5331	740	447	423	391	311	311
Greece	510	373	373	373	373	41	32
Ireland	178	155	42	42	42	35	31
Italy	1681	922	328	254	206	161	128
Luxembourg	14	4	4	4	4	2	2
Netherlands	205	56	37	37	37	33	33
Portugal	283	190	190	190	190	30	27
Spain	2266	990	846	551	262	132	108
Sweden	136	96	96	66	66	58	58
UK	3752	980	252	252	202	201	170
EU15	**16501**	**5687**	**3129**	**2650**	**2262**	**1393**	**1235**
Atlantic Sea	317	317	317	317	317	76	76
Baltic	73	73	73	73	18	18	18
North Sea	173	173	173	173	173	42	42
SEA	**563**	**563**	**563**	**563**	**508**	**136**	**136**
Albania	120	54	54	54	54	4	4
Belarus	710	490	490	490	490	36	36
Bosnia-H.	480	409	409	409	409	14	14
Bulgaria	2020	835	835	835	835	99	94
Croatia	180	69	69	69	69	17	14
Czech R.	1876	151	151	151	151	79	76
Estonia	275	172	172	172	172	8	8
Hungary	1010	544	544	544	544	282	277
Latvia	115	104	104	104	104	16	16
Lithuania	222	118	118	118	118	18	18
Norway	54	31	31	31	31	17	17
Poland	3210	1397	1397	1397	1397	343	326
R. of Moldova	91	91	91	91	91	16	16
Romania	1504	580	580	580	580	86	75
Russia	4459	2376	2376	2376	2376	525	485
Slovakia	543	115	115	115	115	60	58
Slovenia	195	37	37	37	37	9	8
Switzerland	43	30	30	30	30	13	13
FYRMacedonia	106	80	80	80	80	3	3
Ukraine	2782	1496	1496	1496	1496	356	337
F. Yugoslavia	508	263	263	263	263	17	17
Non-EU	**20503**	**9442**	**9442**	**9442**	**9442**	**2018**	**1912**
TOTAL	**37567**	**15692**	**13134**	**12655**	**12212**	**3547**	**3283**

Table 5.2: Cross-scenario comparison of NO_x emissions (in kt NO_2)

	1990	REF	Scen 1 45%	Scen 2 50%	Scen 3 55%	MTFR realistic	MTFR ultimate
Austria	222	111	111	111	111	85	45
Belgium	343	194	148	125	97	97	61
Denmark	269	147	147	87	87	76	38
Finland	300	158	158	158	158	73	40
France	1590	871	862	738	696	615	298
Germany	3071	1241	1206	1040	1035	904	498
Greece	306	275	275	275	275	139	55
Ireland	115	70	50	32	28	26	17
Italy	2053	1111	1111	1111	845	583	288
Luxembourg	23	10	10	10	10	6	4
Netherlands	575	133	133	133	133	133	81
Portugal	221	202	202	202	197	113	41
Spain	1188	833	833	805	754	400	180
Sweden	411	188	188	184	184	108	58
UK	2702	1179	831	676	609	609	329
EU15	**13389**	**6723**	**6265**	**5687**	**5219**	**3967**	**2033**
Atlantic Sea	350	350	350	350	350	70	70
Baltic	81	81	81	81	16	16	16
North Sea	192	192	192	192	192	38	38
SEA	**623**	**623**	**623**	**623**	**558**	**124**	**124**
Albania	30	30	30	30	30	11	6
Belarus	285	260	260	260	260	77	45
Bosnia-H.	54	48	48	48	48	15	9
Bulgaria	376	290	290	290	290	80	46
Croatia	83	64	64	64	64	24	14
Czech R.	742	226	226	226	226	96	58
Estonia	72	70	70	70	70	17	9
Hungary	238	196	196	196	196	77	45
Latvia	93	93	93	93	93	36	18
Lithuania	158	130	130	130	130	40	20
Norway	230	96	96	96	96	57	28
Poland	1280	819	819	819	819	294	202
R. of Moldova	35	66	66	66	66	18	11
Romania	883	443	443	443	443	114	67
Russia	2674	2653	2653	2653	2653	753	439
Slovakia	227	104	104	104	104	53	29
Slovenia	53	31	31	31	31	13	7
Switzerland	166	72	72	72	72	51	29
FYRMacedonia	39	22	22	22	22	7	4
Ukraine	1097	1405	1405	1405	1405	376	243
F. Yugoslavia	66	119	119	119	119	34	20
Non-EU	**8881**	**7237**	**7237**	**7237**	**7237**	**2243**	**1349**
TOTAL	**22893**	**14583**	**14125**	**13547**	**13014**	**6334**	**3506**

Table 5.3: Cross-scenario comparison of NH_3 emissions

	1990	REF	Scen 1 45%	Scen 2 50%	Scen 3 55%	MFTR
Austria	91	96	96	96	94	55
Belgium	79	106	96	74	71	67
Denmark	140	103	103	80	69	45
Finland	41	23	23	23	23	21
France	700	613	588	542	421	388
Germany	759	526	332	332	335	311
Greece	77	73	73	73	73	51
Ireland	126	126	126	126	126	119
Italy	384	373	314	297	290	259
Luxembourg	7	7	7	7	7	7
Netherlands	236	85	85	85	85	84
Portugal	93	86	86	86	86	66
Spain	353	329	329	329	329	202
Sweden	61	53	53	46	48	39
UK	320	320	289	278	278	278
EU15	**3467**	**2919**	**2600**	**2474**	**2335**	**1992**
Atlantic Sea	0	0	0	0	0	0
Baltic	0	0	0	0	0	0
North Sea	0	0	0	0	0	0
SEA	**0**	**0**	**0**	**0**	**0**	**0**
Albania	31	34	34	34	34	24
Belarus	214	159	159	159	159	107
Bosnia-H.	28	21	21	21	21	12
Bulgaria	141	141	141	141	141	96
Croatia	37	34	34	34	34	22
Czech R.	130	130	130	130	130	130
Estonia	29	29	29	29	29	19
Hungary	140	150	150	150	150	140
Latvia	46	38	38	38	38	26
Lithuania	79	79	79	79	79	51
Norway	39	36	36	36	36	26
Poland	508	580	580	580	580	464
R. of Moldova	46	46	46	46	46	31
Romania	289	301	301	301	301	203
Russia	1191	918	918	918	918	553
Slovakia	62	52	52	52	52	29
Slovenia	27	27	27	27	27	11
Switzerland	62	58	58	58	58	44
FYRMacedonia	16	16	16	16	16	8
Ukraine	737	658	658	658	658	391
F. Yugoslavia	85	85	85	85	85	42
Non-EU	**3937**	**3592**	**3592**	**3592**	**3592**	**2429**
TOTAL	**7404**	**6511**	**6192**	**6066**	**5927**	**4421**

Table 5.4:Cross-scenario comparison of emission control costs (in million ECU/year)

	SO_2					NO_x					NH_3					TOTAL COSTS				
	REF	**Scen 1 45%**	**Scen 2 50%**	**Scen 3 55%**	**MTFR - real.**	**REF**	**Scen 1 45%**	**Scen 2 50%**	**Scen 3 55%**	**MTFR - real.**	**REF**	**Scen 1 45%**	**Scen 2 50%**	**Scen 3 55%**	**MTFR - real.**	**REF**	**Scen1 45%**	**Scen2 50%**	**Scen3 55%**	**MTFR - real.**
Austria	310	310	310	310	490	603	603	603	603	808	0	0	0	0	397	913	913	913	913	1695
Belgium	231	391	580	580	756	741	795	867	1110	1170	0	37	193	235	367	972	1223	1640	1925	2293
Denmark	159	237	289	289	601	367	367	479	479	619	36	36	137	223	800	562	640	905	991	2020
Finland	149	149	181	149	542	434	434	434	434	688	45	45	45	45	64	628	628	660	628	1294
France	1303	1603	1603	1603	2559	4548	4554	4704	4830	6329	0	17	141	1034	1948	5851	6174	6448	7467	10836
Germany	2350	3029	3161	3347	5695	7567	7637	8162	8212	9928	0	1566	1653	1733	2154	9917	12232	12976	13292	17777
Greece	210	210	210	210	820	364	364	364	364	984	0	0	0	0	137	574	574	574	574	1941
Ireland	84	147	147	147	330	168	176	213	236	287	180	180	180	180	310	432	503	540	563	927
Italy	1517	1780	1886	1956	3359	4994	4994	4994	5248	8041	0	219	368	496	1300	6511	6993	7248	7700	12700
Luxembourg	9	9	9	9	21	51	51	51	51	80	12	12	12	12	12	72	72	72	72	113
Netherlands	245	322	322	322	559	1649	1649	1649	1649	1682	695	695	717	717	704	2589	2666	2688	2688	2945
Portugal	160	160	160	160	518	754	754	754	754	1284	0	0	0	0	138	914	914	914	914	1940
Spain	567	611	722	938	1892	3181	3181	3181	3210	5135	0	0	0	0	1550	3748	3792	3903	4148	8577
Sweden	284	284	425	425	870	701	701	707	707	1036	37	37	93	76	220	1022	1022	1225	1208	2126
UK	818	1629	1629	3178	3418	4159	4630	5279	5985	6284	15	196	510	510	485	4992	6455	7418	9673	10187
EU15	**8396**	**10871**	**11634**	**13623**	**22430**	**30281**	**30890**	**32441**	**33872**	**44355**	**1020**	**3040**	**4049**	**5261**	**10586**	**39697**	**44801**	**48124**	**52756**	**77371**
Atlantic Sea	0	0	0	0	217	0	0	0	0	90	0	0	0	0	0	0	0	0	0	307
Baltic	0	0	0	50	50	0	0	0	21	21	0	0	0	0	0	0	0	0	71	71
North Sea	0	0	0	0	119	0	0	0	0	49	0	0	0	0	0	0	0	0	0	168
SEA	**0**	**0**	**0**	**50**	**386**	**0**	**0**	**0**	**21**	**160**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**71**	**546**

Table continued on next page

Table continued: Cross-scenario comparison of emission control costs (in million ECU/year)

	SO_2					NO_x					NH_3					TOTAL				
	REF	**Scen 1 45%**	**Scen 2 50%**	**Scen 3 55%**	**MTFR - real.**	**REF**	**Scen 1 45%**	**Scen 2 50%**	**Scen 3 55%**	**MTFR - real.**	**REF**	**Scen 1 45%**	**Scen 2 50%**	**Scen 3 55%**	**MTFR - real.**	**REF**	**Scen1 45%**	**Scen2 50%**	**Scen3 55%**	**MTFR - real.**
Albania	0	0	0	0	81	0	0	0	0	80	0	0	0	0	51	0	0	0	0	212
Belarus	0	0	0	0	516	15	15	15	15	684	0	0	0	0	418	15	15	15	15	1618
Bosnia-H	0	0	0	0	239	49	49	49	49	149	0	0	0	0	58	49	49	49	49	446
Bulgaria	44	44	44	44	698	0	0	0	0	684	0	0	0	0	225	44	44	44	44	1607
Croatia	60	60	60	60	173	139	139	139	139	253	0	0	0	0	86	199	199	199	199	512
Czech R.	391	391	391	391	856	527	527	527	527	838	0	0	0	0	130	918	918	918	918	1824
Estonia	0	0	0	0	197	0	0	0	0	161	0	0	0	0	66	0	0	0	0	424
Hungary	168	168	168	168	511	397	397	397	397	744	0	0	0	0	140	565	565	565	565	1395
Latvia	0	0	0	0	141	0	0	0	0	208	0	0	0	0	91	0	0	0	0	440
Lithuania	0	0	0	0	165	0	0	0	0	271	0	0	0	0	215	0	0	0	0	651
Norway	45	45	45	45	124	420	420	420	420	626	0	0	0	0	88	465	465	465	465	838
Poland	826	826	826	826	3122	980	980	980	980	2303	0	0	0	0	1536	1806	1806	1806	1806	6961
R. Moldova	0	0	0	0	128	0	0	0	0	115	0	0	0	0	106	0	0	0	0	349
Romania	181	181	181	181	737	0	0	0	0	978	0	0	0	0	709	181	181	181	181	2424
Russia	963	963	963	963	3176	21	21	21	21	5970	0	0	0	0	2913	984	984	984	984	12059
Slovakia	115	115	115	115	257	323	323	323	323	420	0	0	0	0	160	438	438	438	438	837
Slovenia	50	50	50	50	127	129	129	129	129	174	0	0	0	0	36	179	179	179	179	337
Switzerland	64	64	64	64	196	504	504	504	504	666	0	0	0	0	130	568	568	568	568	992
FYRMacedonia	0	0	0	0	123	29	29	29	29	70	0	0	0	0	24	29	29	29	29	217
Ukraine	452	452	452	452	1789	0	0	0	0	2871	0	0	0	0	2102	452	452	452	452	6762
F. Yugoslavia	80	80	80	80	644	154	154	154	154	401	0	0	0	0	304	234	234	234	234	1349
Non-EU	**3439**	**3439**	**3439**	**3439**	**14000**	**3687**	**3687**	**3687**	**3687**	**18666**	**0**	**0**	**0**	**0**	**9588**	**7126**	**7126**	**7126**	**7126**	**42254**
TOTAL	**11835**	**14310**	**15073**	**17112**	**36816**	**33968**	**34577**	**36128**	**37580**	**63181**	**1020**	**3040**	**4049**	**5261**	**20174**	**46823**	**51927**	**55250**	**59953**	**120171**

Table 5.5: Cross-scenario comparison of ecosystems not protected against acidification

	1990	REF	Scen 1 45 %	Scen 2 50%	Scen 3 55%	EU-max	MTFR-realistic	MTFR-ultimate
Austria	59%	19%	14%	13%	12%	9.2%	4.7%	3.3%
Belgium	77%	19%	6%	1%	1%	0.5%	0.4%	0.1%
Denmark	18%	4%	2%	2%	2%	1.3%	0.8%	0.3%
Finland	16%	4%	4%	3%	3%	3.1%	0.3%	0.3%
France	4%	1%	0%	0%	0%	0.0%	0.0%	0.0%
Germany	80%	29%	14%	12%	9%	5.0%	2.1%	0.9%
Greece	0%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Ireland	5%	1%	0%	0%	0%	0.1%	0.0%	0.0%
Italy	17%	4%	2%	1%	1%	0.5%	0.4%	0.3%
Luxembourg	16%	7%	2%	2%	2%	0.8%	0.5%	0.0%
Netherlands	88%	37%	13%	7%	6%	5.2%	4.1%	3.4%
Portugal	0%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Spain	1%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Sweden	23%	3%	4%	2%	1%	1.0%	0.3%	0.2%
UK	60%	29%	14%	13%	11%	11.0%	9.6%	7.2%
EU-15	**24%**	**7%**	**5%**	**3%**	**3%**	**2.4%**	**1.1%**	**0.8%**
Albania	0%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Belarus	19%	3%	3%	3%	3%	2.8%	0.0%	0.0%
Bosnia-H.	0%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Bulgaria	0%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Croatia	1%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Czech Republic	95%	24%	12%	11%	10%	7.5%	2.2%	1.3%
Estonia	21%	1%	0%	0%	0%	0.3%	0.0%	0.0%
Hungary	9%	3%	3%	2%	2%	2.2%	0.5%	0.4%
Latvia	14%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Lithuania	4%	1%	1%	1%	1%	0.6%	0.0%	0.0%
FYRMacedonia	0%	0%	0%	0%	0%	0.0%	0.0%	0.0%
R. of Moldova	3%	1%	1%	1%	1%	1.1%	0.0%	0.0%
Norway	25%	11%	8%	7%	6%	6.0%	3.4%	2.5%
Poland	92%	31%	27%	27%	26%	25.0%	4.0%	2.6%
Romania	10%	1%	1%	1%	1%	1.0%	0.0%	0.0%
Russia	8%	1%	1%	1%	1%	1.2%	0.0%	0.0%
Slovakia	66%	4%	4%	4%	4%	3.8%	0.4%	0.3%
Slovenia	47%	7%	3%	3%	3%	1.6%	0.3%	0.2%
Switzerland	30%	9%	4%	2%	2%	1.9%	1.6%	1.5%
Ukraine	12%	1%	1%	1%	1%	1.2%	0.1%	0.1%
F. Yugoslavia	0%	0%	0%	0%	0%	0.0%	0.0%	0.0%
Non-EU	**11%**	**3%**	**2%**	**2%**	**2%**	**1.9%**	**0.3%**	**0.2%**
TOTAL	**14%**	**4%**	**3%**	**2%**	**2%**	**2.0%**	**0.5%**	**0.4%**

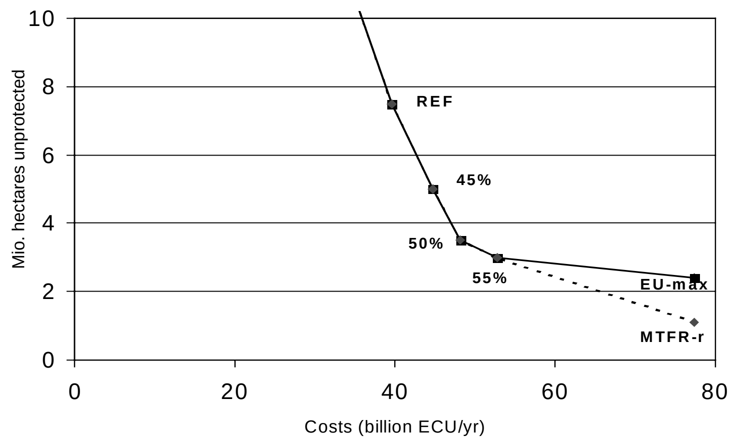

Figure 5.1 : Cost-effectiveness of the gap closure scenarios

Figure 5.1 displays for the main scenario the hectares of unprotected ecosystems versus the involved abatement costs. The figure shows cost-effectiveness to be similar from the 1990 levels over the REF and the 45 % gap closure scenario down to the 50 % gap closures scenario. After this, the cost-effectiveness decreases with the step from the 50 % to the 55 % gap closure scenario and even further down to the maximum reduction scenario (with and without involvement of the non-EU countries).

5.2 Discussion and Conclusions

The preliminary analysis presented in this paper suggests that the current strategies for reducing emissions in Europe will achieve significant progress in attaining the critical loads for sensitive ecosystems. The unprotected ecosystems (24 percent in the EU15 in the year 1990) are expected to decline to seven percent as a result of current policy, however, still leaving almost nine million hectares unprotected. The analysis demonstrates that there is room for further improvement, although at increasing costs.

Taking the situation in 1990 as a starting point, three alternative scenarios have been constructed to explore possible cost-effective solutions for further moving towards the full achievement of the critical loads. Since full achievement of critical loads means bringing down the area of unprotected ecosystems to zero, three interim targets have been defined, aiming at a reduction of the unprotected ecosystems in each grid by 45, 50 and 55 percent, respectively. The RAINS model has been used to determine the cost-minimal allocation of reduction measures.

Model calculations show that the envisaged targets could be reached by balanced further reductions of SO_2, NO_x and NH_3 emissions. For the EU-15 as a whole, SO_2 emissions of the three scenarios range between 45 and 60 percent below the levels envisaged as results from current policy; NO_x is reduced between 7 and 22 percent, and ammonia between 11 and 20 percent. The selection of measures depends strongly on regional aspects, particularly on the sensitivity of the ecosystems to acidification. Whereas in the southern part of Europe only modest efforts will be necessary to achieve the protection targets, emission control in other regions must be further tightened and must also address small and existing sources.

Additional abatement costs range between 5 and 13 billion ECU/year, which is 13 to 33 percent higher than the costs of current policy. On the other hand, sustainability can be reached for additional five to seven million hectares out of the nine million hectares remaining unprotected by current policy.

The second series of scenarios analyzes, i.a., the advantages of aiming at a pan-European solution, which involves also emission sources outside the direct control of the European Union. While keeping the environmental targets the same(e.g., the 50% gap closure), emission control measures at ships in the Baltic, the North Sea and parts of the Atlantic Ocean could reduce the overall emission control costs by two billion ECU/year, i.e., 25 percent of the additional costs on top of current legislation. Further measures in non-EU countries could substitute the most expensive controls inside the EU15 and thereby save about 1 billion ECU/year.

It is important to mention that the cost estimates obtained from the RAINS model must be considered as upper limits for abatement costs. Earlier analysis has demonstrated that non-technical measures, modifications of the energy system (e.g., fuel substitution, energy conservation) and structural changes of the economic activities can reduce emission control costs substantially, possibly by more than 50 percent. In particular, strategies aiming at reducing emissions of greenhouse gases usually produce also significantly positive side impacts on the control costs for acidifying pollutants. A quantification of this effect remains subject to further analysis. However, although such factors have significant impact on the absolute level of emission control costs, analysis conducted for the Second Sulfur Protocol proved that they cause only relatively small changes to overall emission reduction requirements (expressed in physical terms, e.g., tons of SO_2), if the environmental targets (i.e., target deposition) are maintained.

Furthermore, the preliminary analysis presented in this first interim report ignores the side impacts of emission reductions on ground-level ozone. Work is underway to quantify this aspect.

Although, following its terms of reference, this analysis focused on acidification, the side effects on the ecosystems' protection against eutrophication has been analyzed. There is clear evidence that the scenarios aiming at acidification reduce also the area of ecosystems facing excess of their critical loads for eutrophication. However, due to the focus on acidification the achieved protection levels for eutrophication are lower than for acidification. If an environmental policy aims at the full protection of ecosystems, both aspects should be considered simultaneously.

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