SECOND INTERIM REPORT

Cost-effective Control of Acidification and Ground-Level Ozone

Second Interim Report to the European Commission, DG-XI

Markus Amann, Imrich Bertok, Janusz Cofala, Frantisek Gyarfas, Chris Heyes, Zbigniew Klimont, Wolfgang Schöpp

December 1996

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EXECUTIVE SUMMARY

In response to a request by DG-XI of the European Commission 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 used 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 EU-15 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 EU-15 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, a scenario has been constructed aiming at a cost-minimal move towards the full achievement of the critical loads. Since full achievement of critical loads means bringing down the area of unprotected ecosystems to zero, a 50 percent reduction of the area of ecosystems unprotected in 1990 has been established as an interim target.

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 are 52 percent lower than the levels expected to result from current policy; NO_x is reduced further by 14 percent, and ammonia by 15 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 are about seven billion ECU/year, which means an increase in the costs of current policy of 18 percent. With these extra efforts, critical loads for acidification could be attained for 50 percent of the ecosystems expected to remain unprotected by current policy.

The second series of scenarios analyzes 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% gap closure'), emission control measures for ships in the Baltic and the North Sea, as well as measures in non-EU countries, could reduce the overall emission control costs substantially.

A third set of scenarios explores the interaction with strategies addressing other environmental problems, such as the emissions of greenhouse gases, eutrophication and ground-level ozone. It is suggested that a simultaneous consideration of these problems could open a significant potential for cost savings.

Finally, the report concludes that some of the most important uncertainties in the estimates of critical loads for acidification do not significantly modify the present optimization results for the '50% gap closure' scenario.

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.

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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.

In September 1996 IIASA presented to the European Commission a First Interim Report with a number of emission reduction scenarios aiming at improving ecosystems’ protection against acidification in Europe in cost-effective ways. Discussions after the presentation of that report lead to the preliminary conclusion to take the ’50% gap closure’ scenario, which aims at halving the area of the ecosystems not protected against acidification, as a basis for further analysis. In addition, comments on the scenarios and suggestions for improvements of some of the underlying databases have been received from a number of Member States since then.

Using the updated databases, this Second Interim Report takes the ’50% gap closure’ scenario as a starting point and focuses on various aspects of the robustness of the scenario results: A first group of sensitivity runs examines the implications of limiting measures to the emission sources which are under immediate control of the Member States of the European Union, while not taking full account of the long-range (and transboundary) nature of the atmospheric transport of acidifying pollutants. The second collection of scenarios acknowledges the fact that acidification is only one among several environmental problems and explores possible interactions with strategies to control greenhouse gas emissions, eutrophication and ground-level ozone. The third part of this report analyzes the robustness against some important uncertainties in the databases used for the model calculations.

This Second Interim Report is designed as a 'self-contained' document, in which all essential information necessary for understanding of the conclusions is provided. Therefore, repetitions of some of the content of the First Interim Report, particularly referring to methodological aspects, could not be avoided, and some of the basic scenarios (i.e., the Reference scenario, the '50% gap closure' scenario and the 'Maximum Technically Feasible Reduction' scenarios) are reproduced using latest data. (A summary of the major changes introduced to the database since the First Interim Report is provided in Section 3.7). Section 2 describes the methodology adopted for the analysis, and the data sources are discussed in Section 3. Section 4 is divided into five 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 with the hypothetically possible achievements, if currently available emission control technologies were fully applied in the future. The second part (4.2) takes the situation in the year 1990 (in terms of ecosystem's protection levels) as a starting point and discusses an optimized scenario for reducing the areas that are not protected against acidification in the year 1990, by 50 percent. The third part (Section 4.3) assesses the costs of limiting action to emission sources under immediate control of the European Union. Scenarios explore the control of emissions from ships in the Baltic and the North Sea and from non-EU countries. Section 4.4 examines interactions with environmental strategies for greenhouse gas emissions, eutrophication and ground-level ozone. The robustness of the '50% gap closure' scenario against uncertainties in the critical loads databases is the subject of Section 4.5. 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 on acidification, eutrophication and tropospheric ozone. RAINS comprises modules for emission generation (with databases on current and future economic activities, energy consumption levels, fuel characteristics, etc.), for emission control options and costs, for atmospheric dispersion of pollutants and for environmental sensitivities (i.e., databases on critical loads). In order to create a consistent and comprehensive picture of the options for simultaneously addressing the three 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.

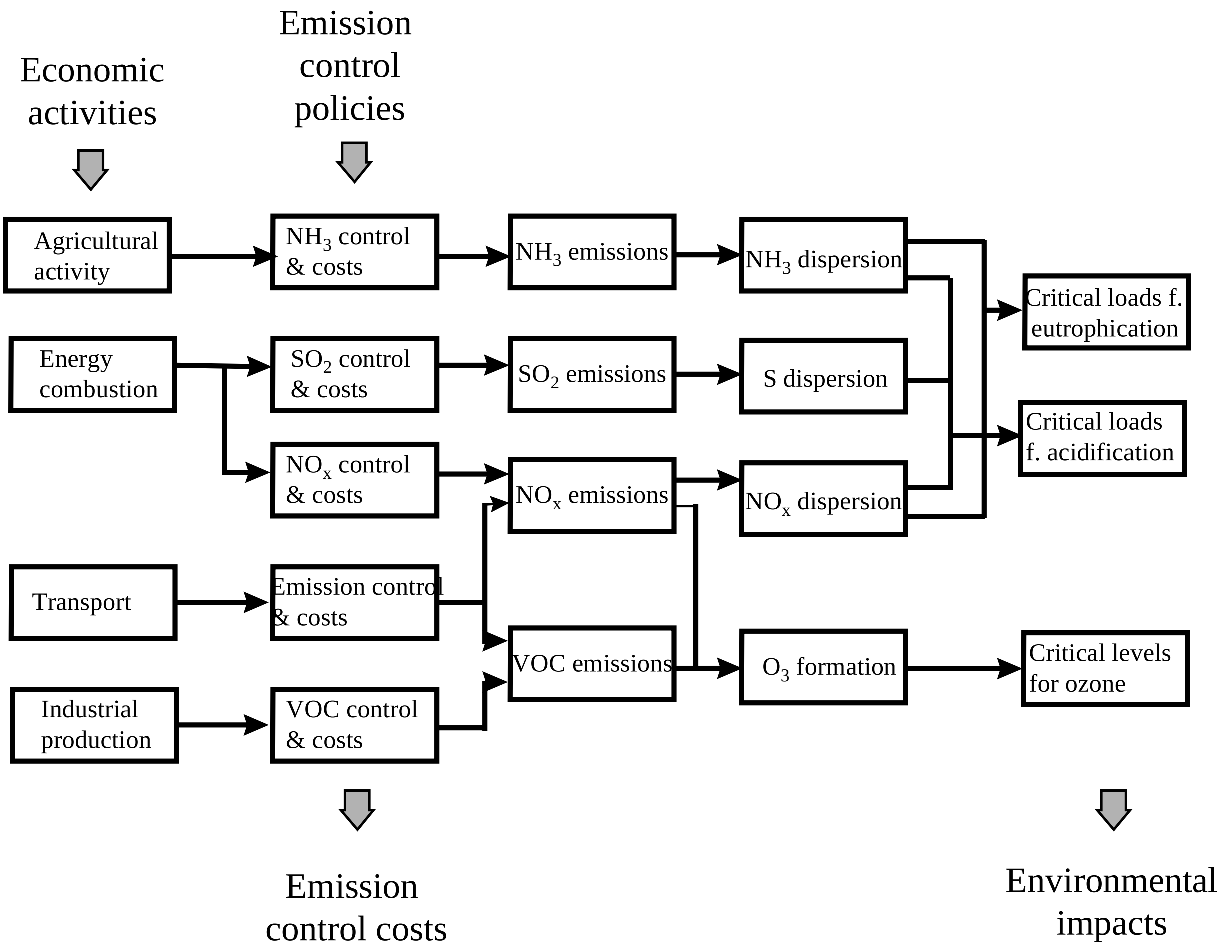

Figure 2.1: Schematic flowchart of the RAINS model framework

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, 1996) and on national information. Options and costs for controlling emissions of the various substances are represented in the model by considering the characteristic technical and economic features of the most important emission reduction options and technologies. Atmospheric dispersion processes over Europe for sulfur and nitrogen compounds are modeled based on results of the European EMEP model developed at the Norwegian Meteorological Institute (Barret and Sandnes, 1996). For tropospheric ozone, source-receptor relationships between the precursor emissions and the regional ozone concentrations are derived from the EMEP photo-oxidants model (Simpson, 1992, 1993). 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 (Posch *et al.*, 1995).

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 3.1) are extracted from the 'Conventional Wisdom Scenario' of the 'Energy 2020' Study (DG-XVII, 1996). For Denmark, however, the DG-XVII projections have been replaced by the forecast of the national energy plan recently adopted by the Danish Parliament. In the remainder of the report the resulting combination of energy scenarios (i.e., the official Danish energy scenario for Denmark and the 'Conventional Wisdom' scenario for the other 14 EU Member States) will be referred to as the 'Modified Conventional Wisdom' energy scenario.

For the non-EU countries considered in RAINS, energy projections are based on data submitted by the governments to the UN/ECE and published in the UN/ECE Energy 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 3.2) 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 19 percent between 1990 and 2010 (Table 3.3). The demand for coal decreases by 27 percent and for liquid fuels from stationary sources by nine 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) by 29 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 29 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 six 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.

Table 3.1 : Energy projection for the EU-15 (Source: DG-XVII - Conventional Wisdom Scenario, Danish Energy Plan)

Source category/fuel	**1990** [PJ]	**2010** [PJ]	**Change** 1990-2010
Stationary sources - total	44338	51741	17 %
- Coal	11620	8460	*-27 %*
- Liquid fuels	11847	10819	*-9 %*
- Gaseous fuels	10424	19009	*82 %*
- Other	10448	13453	*29 %*
Mobile sources - total	10027	12958	29 %
TOTAL	**54365**	**64699**	**19 %**

Table 3.2 : Energy projection for the non-EU countries (Sources: UN/ECE, 1995a, RAINS estimates)

Source category/fuel	**1990** [PJ]	**2010** [PJ]	**Change** 1990-2010
Stationary 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 %**

Table 3.3: 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	1478	*20 %*	2.5 %
Belgium	1907	2155	*13 %*	2.2 %
Denmark	756	765	*1 %*	2.2 %
Finland	1208	1590	*31 %*	1.7 %
France	8792	11396	*30 %*	2.4 %
Germany	14536	15465	*6%*	2.6 %
Greece	910	1194	*31 %*	3.8 %
Ireland	423	534	*26 %*	3.5 %
Italy	6560	8231	*26 %*	2.0 %
Luxembourg	122	129	*6 %*	2.3 %
Netherlands	2711	3087	*14 %*	2.1 %
Portugal	699	1172	*68 %*	3.5 %
Spain	3659	4768	*30 %*	2.7 %
Sweden	2319	2520	*9 %*	1.3 %
UK	8526	10215	*20 %*	2.0 %
EU-15	**54365**	**64699**	***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	**103013**	**110882**	***8 %***	**2.1 %**

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 set of forecasts of European agricultural activities, based on national information (Marttila, 1995; Nemi, 1995; Pippatti, 1996; Henriksson, 1996; Riseth, 1990; Menzi, 1995; Menzi *et al.*, 1996; Davidson, 1996), on studies performed for DG-VI of the Commission of the European Communities, (EC DG-VI, 1995a-k) for Eastern Europe, and on Egmond (1995), Stolwijk (1996), Folmer *et al.* (1995) for EU countries. The forecast for the EU is based on the assumptions that (i) until 2005 the Common Agricultural Policy will essentially consist of the type of the policies adopted under MacSharry, and (ii) after 2005 the EU will gradually liberalize its agricultural policy (Stolwijk, 1996). More detailed information on the ECAM (European Community Agricultural Model) model used to derive this forecast can be found in Folmer *et al.* (1995). Projections for the Republics of the Former Soviet Union were derived from an OECD study (OECD, 1995).

Projections of livestock development are presented in Table 3.4. In this table ‘cows’ include dairy cows and other cattle, ‘pigs’ include fattening pigs and sows, and poultry comprises laying hens, broilers and other poultry.

The forecast of fertilizer consumption for EU-15, Switzerland and Norway (Table 3.5) is based on a study by the European Fertilizer Manufacturers Association (EFMA, 1996a,b). A “moderate grain price” scenario was used. The basic assumptions of this projection are (i) that there will be no change in the Common Agricultural Policy (CAP) until the year 2000; thereafter a more market oriented, less regulated CAP is expected; and (ii) that by the year 2005/2006 the Central European Countries will have joined the EU. Estimates on fertilizer consumption for the rest of Europe were derived from publications of the International Fertilizer Industry Association (Ginet, 1995). Since these forecasts do not always extend up to the year 2010, missing values were constructed based on a trend extrapolation.

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	11922	9949	*-17 %*	7383	4845	*-34 %*	141011	120549	*-15 %*
EU-15	**91427**	**88187**	***-4 %***	**120251**	**115631**	***-4 %***	**950453**	**966491**	***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 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	**204516**	**178573**	***-13 %***	**243558**	**244024**	***0 %***	**2229144**	**2165306**	***-3 %***

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

	Nitrogen Fertilizer use		
	1990	**2010**	***Change***
Austria	137	109	*-20 %*
Belgium	166	137	*-17 %*
Denmark	395	261	*-34 %*
Finland	207	153	*-26 %*
France	2493	2457	*-1 %*
Germany	1786	1545	*-14 %*
Greece	428	294	*-31 %*
Ireland	370	381	*3 %*
Italy	879	911	*4 %*
Luxembourg	20	16	*-20 %*
Netherlands	392	207	*-47 %*
Portugal	150	144	*-4 %*
Spain	1064	1052	*-1 %*
Sweden	212	219	*3 %*
UK	1516	1298	*-14 %*
EU-15	**10215**	**9184**	***-10 %***
Albania	73	60	*-18 %*
Belarus	780	676	*-13 %*
Bosnia -H	19	10	*-47 %*
Bulgaria	453	530	*17 %*
Croatia	114	190	*67 %*
Czech Rep.	441	580	*32 %*
Estonia	110	151	*37 %*
Hungary	359	639	*78 %*
Latvia	143	221	*55 %*
Lithuania	256	309	*21 %*
Norway	111	92	*-17 %*
Poland	671	855	*27 %*
R. of Moldova	123	228	*85 %*
Romania	765	780	*2 %*
Russia	3418	1994	*-42 %*
Slovakia	147	150	*2 %*
Slovenia	88	102	*16 %*
Switzerland	63	40	*-37 %*
FYRMacedonia	6	3	*-50 %*
Ukraine	1885	1599	*-15 %*
Yugoslavia	146	145	*-0 %*
Non-EU	**10171**	**9354**	***-8 %***
TOTAL	**20386**	**18538**	***-9 %***

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 (EEA, 1996), national reports as well as contacts with national experts. Emission estimates are performed on a disaggregated level, which is determined by the available details of the available energy and agricultural projection and the CORINAIR emission inventory. The relations between CORINAIR categories and the RAINS sectors are shown in Table 3.6. Due to the differences in the format of the energy and agricultural 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 and Table 3.8 compare for 1990 the estimates for SO_2 and NO_x emissions incorporated into the RAINS model with the results from the CORINAIR 1990 inventory and with the EMEP database. As indicated above, RAINS generally uses information on emission factors provided by the CORINAIR'90 inventory. Consequently, SO_2 and NO_x emission levels calculated by RAINS are usually in good agreement with CORINAIR'90 with largest differences below five percent. The only exception is Greece, where CORINAIR estimates for SO_2 and NO_x are more than 20 percent higher than RAINS. The reason is that the Greek submission to CORINAIR includes 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.

Since the production of the First Interim Report, efforts have been undertaken to harmonize the treatment of emissions from coastal shipping in the RAINS model. An attempt has been made to include coastal shipping into the national emissions for the respective countries, and to apportion emissions from international shipping into separate categories for the various regional seas. However, some issues require further clarification. For instance, there is still a discrepancy between the RAINS estimate and the official Swedish EMEP submission, which includes also emissions from the ferry traffic in the Baltic Sea. RAINS numbers are consistent with CORINAIR. Also emissions from off-shore oil platforms are treated differently in different national emission inventories. Whereas the Norwegian inventory includes such emissions, they are not contained, e.g., in the UK database.

CORINAIR is also available for 11 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 waste. 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, the differences in total emissions between CORINAIR/EMEP and RAINS for the non-EU countries 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 and district heating 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 and 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 1990 emission estimates of SO_2 with results from the CORINAIR 1990 inventory and the EMEP database (in kilotons). The underlined numbers indicate the emission levels used for calculating the existing gap in critical loads achievement in 1990.

	RAINS	EMEP	CORINAIR'90
Austria	93	90	93
Belgium	317	317	317
Denmark	190	180	198
Finland	237	260	227
France	1300	1298	1298
Germany	5271	5331	5257
Greece	509	510	640
Ireland	180	178	178
Italy	1699	1678	1683
Luxembourg	14	14	14
Netherlands	197	205	200
Portugal	286	283	283
Spain	2234	2266	2206
Sweden	115	136	105
United Kingdom	3754	3752	3787
EU-15	**16396**	**16497**	**16486**
Albania	72	120	n.a.
Belarus	845	710	n.a.
Bosnia-H	482	480	n.a.
Bulgaria	1842	2020	2008
Croatia	178	180	n.a.
Czech R.	1872	1876	1863
Estonia	273	275	275
Hungary	913	1010	906
Latvia	122	115	115
Lithuania	213	222	223
Norway	54	54	54
Poland	3001	3210	3273
R. of Moldova	197	91	n.a.
Romania	1335	1311	1311
Russia	5046	4460	n.a.
Slovakia	549	543	542
Slovenia	199	195	196
Switzerland	45	43	44
FYRMacedonia	106	10	n.a.
Ukraine	3708	2782	n.a.
F.Yugoslavia (*)	581	508	n.a.
Non-EU	**21631**	**20214**	**20319**
TOTAL	**38027**	**36712**	**36805**

n.a. - not available. In such a case the underlined value was used to calculate the total.
(*) EMEP estimates refer to stationary sources only

Table 3.8: Comparison of RAINS 1990 emission estimates of NO_x with results from the CORINAIR 1990 inventory and the EMEP database (in kilotons). The underlined numbers indicate the emission levels used for calculating the existing gap in critical loads achievement in 1990.

	RAINS	**EMEP**	**CORINAIR'90**
Austria	242	<u>222</u>	227
Belgium	363	<u>352</u>	343
Denmark	271	<u>269</u>	273
Finland	279	<u>300</u>	269
France	1619	<u>1585</u>	1585
Germany	2985	<u>3071</u>	2980
Greece	392	<u>306</u>	543
Ireland	107	<u>115</u>	116
Italy	2009	<u>2047</u>	2041
Luxembourg	21	<u>23</u>	23
Netherlands	539	<u>575</u>	537
Portugal	208	<u>215</u>	215
Spain	1176	<u>1178</u>	1247
Sweden	345	<u>411</u>	345
United Kingdom	2664	<u>2702</u>	2773
EU-15	**13219**	**13370**	**13517**
Albania	24	<u>30</u>	n.a.
Belarus	402	<u>285</u>	n.a.
Bosnia-H	<u>80</u>	54	n.a.
Bulgaria	354	<u>376</u>	361
Croatia	83	<u>83</u>	n.a.
Czech R.	522	<u>742</u>	773
Estonia	84	<u>72</u>	72
Hungary	214	<u>238</u>	191
Latvia	114	<u>93</u>	93
Lithuania	151	<u>158</u>	158
Norway	231	<u>230</u>	232
Poland	1209	<u>1279</u>	1445
R. of Moldova	87	<u>35</u>	n.a.
Romania	513	<u>546</u>	546
Russia	3485	<u>2675</u>	n.a.
Slovakia	207	<u>227</u>	227
Slovenia	60	<u>57</u>	57
Switzerland	161	<u>165</u>	159
FYRMacedonia	<u>39</u>	2	n.a.
Ukraine	1888	<u>1097</u>	n.a.
F.Yugoslavia (*)	<u>211</u>	66	n.a.
Non-EU	**10118**	**8509**	**8872**
TOTAL	**23337**	**21880**	**22389**

n.a. - not available. In such a case the underlined value was used to calculate the total.
(*) EMEP estimate includes only stationary sources

Table 3.9: Comparison of RAINS 1990 emission estimates of ammonia (NH_3) with results from the CORINAIR 1990 inventory and the EMEP database (in kilotons NH_3). The underlined numbers indicate the emission levels used for calculating the existing gap in critical loads achievement in 1990.

	RAINS	**EMEP**	**CORINAIR'90**
Austria	92	<u>91</u>	87
Belgium	86	<u>95</u>	79
Denmark	126	<u>140</u>	126
Finland	42	<u>41</u>	41
France	692	<u>700</u>	700
Germany	741	<u>759</u>	739
Greece	78	<u>78</u>	471
Ireland	124	<u>126</u>	126
Italy	384	<u>416</u>	383
Luxembourg	7	<u>7</u>	7
Netherlands	229	<u>236</u>	196
Portugal	91	<u>93</u>	93
Spain	353	<u>353</u>	331
Sweden	62	<u>61</u>	74
UK	325	<u>320</u>	468
EU-15	**3432**	**3516**	**4011**
Albania	31	<u>30</u>	n.a.
Belarus	219	<u>257</u>	n.a.
Bosnia-H.	31	<u>36</u>	n.a.
Bulgaria	<u>141</u>	323	324
Croatia	40	<u>37</u>	n.a.
Czech Republic	115	<u>105</u>	91
Estonia	29	<u>29</u>	29
Hungary	110	<u>176</u>	62
Latvia	39	<u>38</u>	38
Lithuania	79	<u>84</u>	84
Norway	37	<u>39</u>	38
Poland	505	<u>508</u>	539
R. of Moldova	47	<u>50</u>	n.a.
Romania	290	<u>300</u>	300
Russia	1283	<u>1191</u>	n.a.
Slovakia	61	<u>62</u>	60
Slovenia	23	<u>27</u>	27
Switzerland	62	<u>62</u>	69
FYR Macedonia	<u>17</u>	18	n.a.
Ukraine	729	<u>926</u>	n.a.
Yugoslavia	90	<u>99</u>	n.a
Non-EU	**3978**	**4397**	**4305**
TOTAL	**7410**	**7913**	**8226**

n.a. - not available

Table 3.9 compares for 1990 the estimates for NH_3 emissions incorporated into the RAINS model with the results from the CORINAIR 1990 inventory and EMEP database. The agreement between RAINS and CORINAIR/EMEP emission estimates lies for the majority of countries within a range of ten percent (20 countries below five percent and nine countries between five and ten percent. For the EU countries with the exception of Greece and United Kingdom RAINS and CORINAIR/EMEP estimates differ by not more than five percent. The Greek submission to CORINAIR contains an unreasonably high number of emissions from fertilizer use (about 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. Since the First Interim Report the RAINS ammonia estimate for the UK, which was broadly in line with the UK CORINAIR submission (486 kt), has been modified in order to reflect the latest official emission inventory supplied by the UK (320 kt; Davidson 1996). Most of the resulting emission factors, however, are significantly lower than emission factors of other countries contained in the CORINAIR inventory (e.g. Menzi *et al.*,1996; Münch and Axenfeld, 1995).

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 reveals 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 partly to the omission of emissions from pigs, the use of fertilizer and partly to differences in livestock statistics.

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. 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 the 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 *et al.*, 1987). Country-specific information has been extracted from relevant national and international statistics (UN/ECE, 1996). In Fall 1996, the list of control options and the country-specific data used for the cost calculations were 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 3.10 presents, for the major source categories, the available control options and the data used for the analysis. The basic input data for the 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 recently been updated to take latest operating experience into account.

Table 3.10: 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}]	Costs[4] 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 SO_2 removed; Calculated for a typical heating value of each fuel.

Table 3.10: Emission control options for SO2 considered in RAINS, continued

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 3.11 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, 1996).

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 3.11.

Table 3.11: 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 and 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 *(low-NO_x burners are assumed by default)**:***			
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 and 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 NO_x burners, overfire air, etc.)

Table 3.11: Emission control options for NOx considered in RAINS, continued

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.

Table 3.11: Emission control options for NOx considered in RAINS, continued

C. Mobile sources[14]

Fuel/vehicle type/control technology	Removal efficiency [%]	Costs	
		Investments [ECU/vehicle]	**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 and their Costs

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; UN/ECE, 1996; EEA,1996; Menzi *et al*., 1996).

Ammonia emissions from livestock occur at four stages, i.e., in the stable, during storage of manure, its application and during the grazing period. At every stage emissions can be controlled by 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;

[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.

- 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;
- 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 the 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 in Table 3.12 and Table 3.13. 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 3.12: 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 (SA)	Dairy cows, Other cattle	50	80	n.a.	n.a.
	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 3.13: 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 11 years (1985-1995, Barret and Sandnes, 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 x 150 km) of pollutants have been calculated. These annual source-receptor budgets have been averaged over 11 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. It has been shown that the error introduced by this simplification is within the range of other model uncertainties, when considering the long-range transport of pollutants (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 for acidity, 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 emissions.

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.

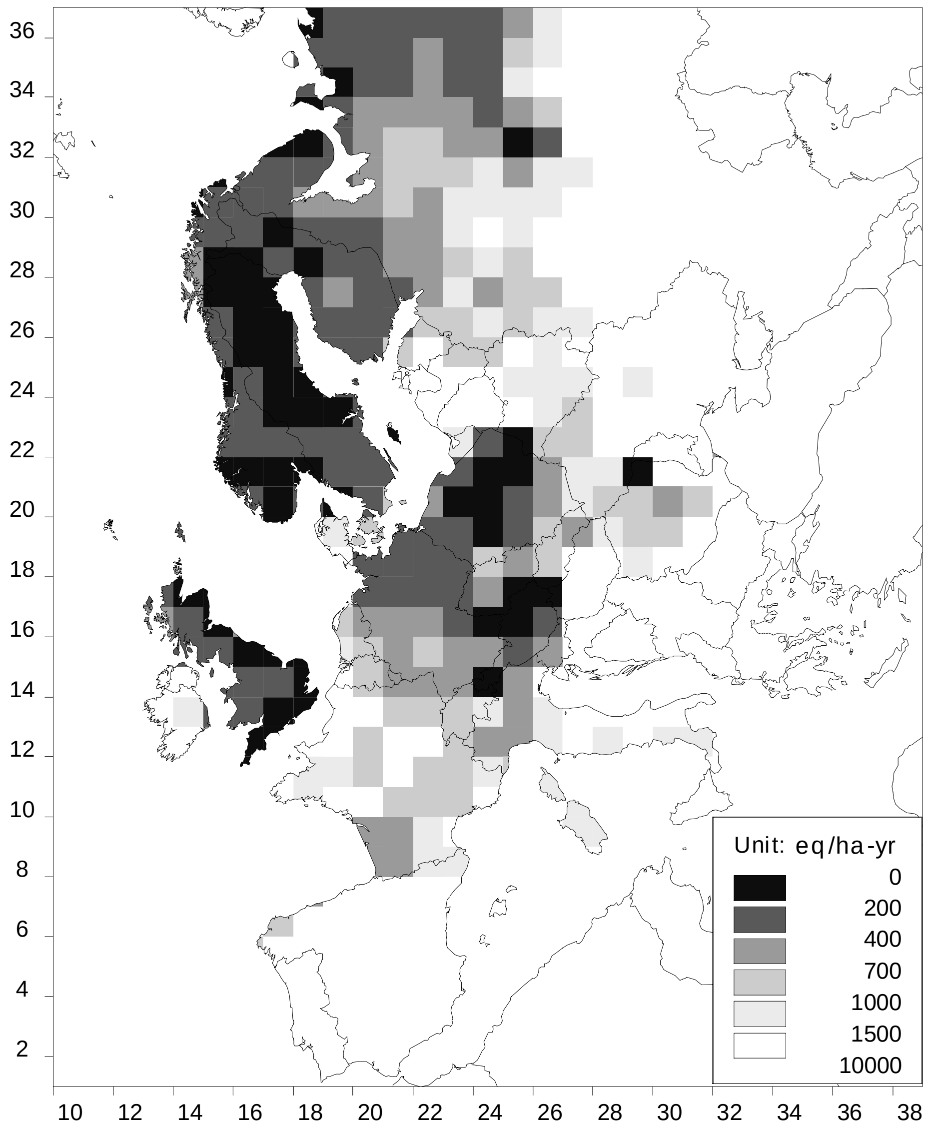

Figure 3.1: The fifth percentile of the critical loads for acidity ($CL_{max}(S)$)

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.

3.7 Changes in the Databases Introduced Since the First Interim Report

As indicated earlier, a First Interim Report of this study explored the cost-effectiveness of a range of alternative scenarios aiming at a reduction of unprotected ecosystems in Europe. Since that time a number of Member Countries of the European Union provided additional information on energy scenarios, emission projections and ecosystems' sensitivities, which were subsequently incorporated into the model databases used for the scenario calculations of this Second Interim Report.

A significant change has been introduced for Denmark, for which the energy pathway used in the First Interim Report (the 'Conventional Wisdom Scenario' developed by DG-XVII) was replaced by the energy plan recently adopted by the Danish Parliament. Material supplied by Germany, Sweden, Norway, Portugal and the UK led to minor modifications of their energy scenarios. Additional information received from the consultant responsible for the 'Conventional Wisdom scenario' as well as modifications in the translation routine of the original data format have led to an improved reflection of electricity generation in the industrial sector ('auto-producers') and thereby to slight changes in the overall energy balances.

Information provided by Sweden, Norway, the UK and Portugal helped to improve the emissions databases and to strengthen the projections of the 'Current Legislation' scenario.

In response to comments from DG-VI on the livestock forecasts for the EU countries, several attempts have been made to obtain updated projections. Unfortunately, a closer inspection of the material made available so far showed that updated information is only provided as aggregates for either the EU-12 (EUROSTAT 1996) or EU-15 (OECD, 1996), but not with the required country-specific details and time horizon.

Forecasts of fertilizer consumption were updated with material from a recent study performed by the European Fertilizer Manufacturers Association (EFMA 1996a,b).

Furthermore, the emission factors for ammonia were reviewed and brought in line with the guidelines of the latest EMEP/CORINAIR emission factor handbook (EEA 1996), taking into account new information on the volatilization rates. These modifications cause also some changes in the ammonia cost curves for many countries.

Following the review of the UK data for ammonia information on emission factors, applicability rates for abatement techniques and animal numbers provided by the Ministry for Agriculture, Fisheries and Food was incorporated into RAINS. This resulted in significantly different emission estimates (consistent with the officially reported numbers) as well as changed cost curves for the UK.

The United Kingdom supplied an alternative set of critical loads data for its territory, with significantly higher numbers than in the original data set. Although not officially submitted to and accepted by the responsible bodies of the Convention on Long-range Transboundary Air Pollution, this database was used in this report for a sensitivity run of the ’50% gap closure’ scenario (see Section 0).

4. Results from Model Calculations

4.1 The Situation in 1990 and Changes Expected as a Result of 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.

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.

Figure 4.1 presents, for each grid cell, the percentage of ecosystems which that in 1990 experienced acid deposition below their critical loads for acidity. The emission levels employed for this analysis are the underlined values of Table 3.7, Table 3.8 and Table 3.9. Grids left empty in the map experienced full protection of their ecosystems, 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, and the Czech Republic, where more than 90 percent of the ecosystems were unprotected. A summary of the situation with country aggregates is provided in Table 4.9, 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 percent) 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 percent and 93 percent of the 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.

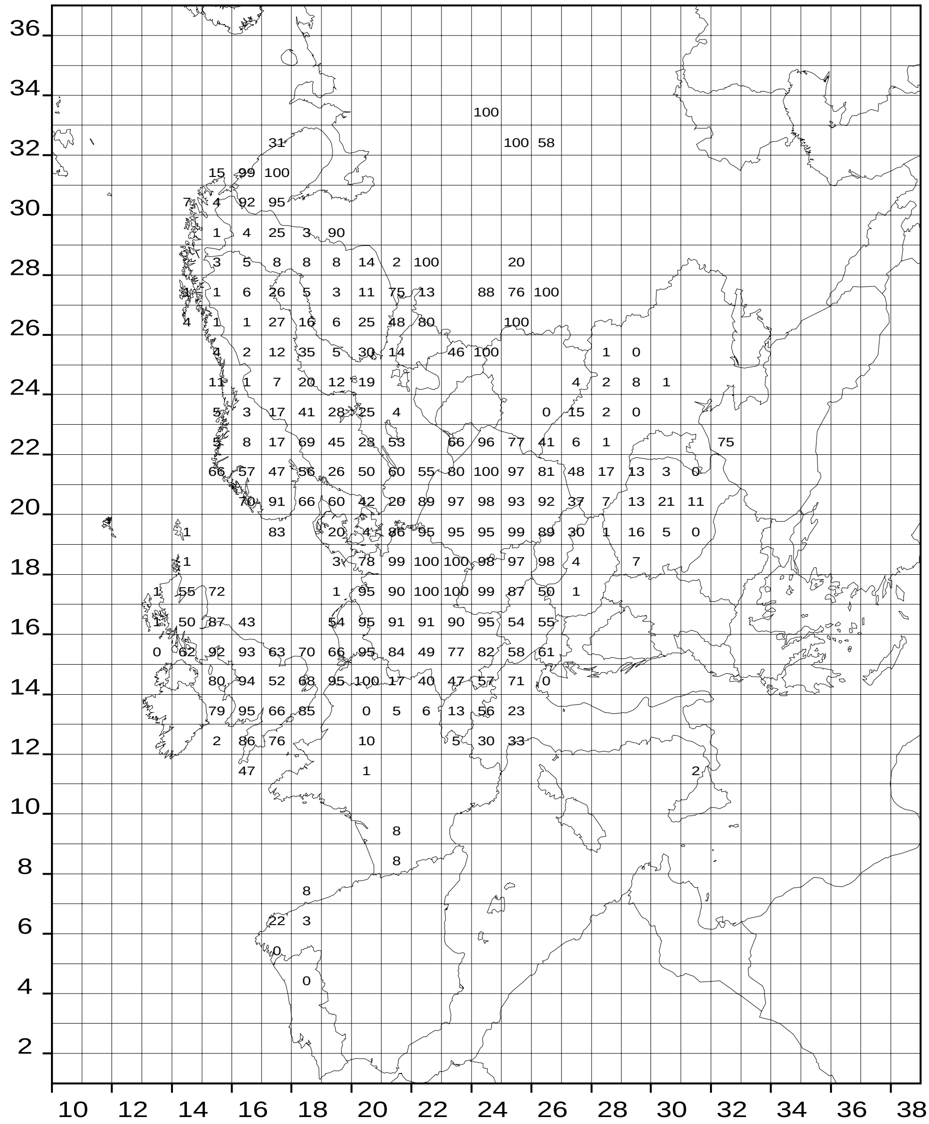

Figure 4.1: Ecosystems with acid deposition above their critical loads for acidification (i.e., ecosystems not protected from acidification) in the year 1990 (in percent of the ecosystems' area)

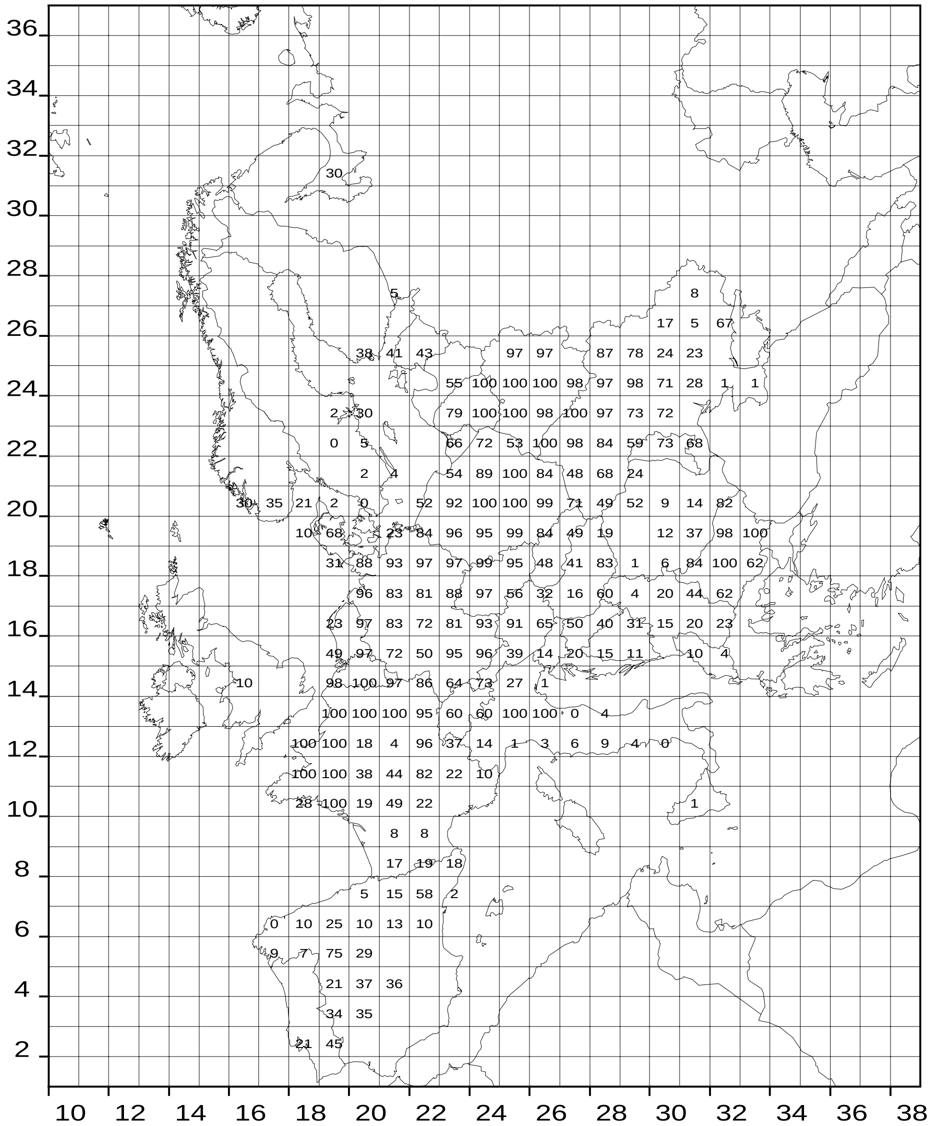

Figure 4.2: Ecosystems with nitrogen deposition above their critical loads for eutrophication (i.e., ecosystems not protected against eutrophication) in the year 1990 (in percent of the ecosystems' area)

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 further analysis, a 'Reference' (REF) scenario is constructed, selecting for each country the more stringent approach.

The 'Current Reduction Plan' (CRP) scenario is based on an inventory of officially declared national emission ceilings. Such declarations of envisaged future emissions 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 no projection was supplied by a country for the target year 2010, 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 percent 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 30 percent. NO_x emissions go down in both EU-15 and non-EU countries by 21 percent. Ammonia emissions in the EU would be lower by about 15 percent and by 17 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 and 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 Plan' of individual countries.

For constructing the CLE scenario the emission control measures listed above were combined with the future level of energy consumption as projected by the Modified Conventional Wisdom energy scenario. 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 these 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.

4.1.4 The Reference (REF) Scenario for the Year 2010

A Reference scenario has been constructed in order to assess the likely environmental impacts of the current emission control strategies. 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 selects, for each country individually, the more stringent outcome of the Current Reduction Plan and the Current Legislation scenarios. Emissions of this scenario are compared with the 1990 levels in Table 4.2.

For EU-15 as a whole, SO_2 emissions will be reduced by 66 percent compared to 1990; NO_x will go down by 48 percent and ammonia by 15 percent. Lower relative reductions result for the non-EU countries with SO_2 declining by 54 percent, NO_x by 20 percent and ammonia by 17 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 could 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 emission standards for new plants to be at least as strict as required by the Large Combustion Plant Directive (OJ, 1988) and by the Second Sulfur Protocol (UN/ECE, 1994c). More stringent standards are established by national legislation in Austria, Finland, Germany, Italy, the Netherlands and Sweden, and for NO_x also in Belgium and Denmark. A further reduction of emissions below the currently envisaged ceilings will also have to address small sources and existing installations in the majority of countries. 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.

Table 4.6 and Table 4.7 provide emissions estimates (for SO_2 and NO_x, respectively) from large combustion plants in the Member States of the European Union for 1990 and the REF scenario in the year 2010. For 1990, estimates derived from the RAINS database are compared with information from CORINAIR and with the numbers of the Large Combustion Plant Directive. Unfortunately, none of the available databases contains all the information necessary for projecting LCP emissions into the future. Since a precise analysis of LCP emissions is not within the scope of this study, some assumptions had to be made in order to create rough estimates of the volume of LCP emissions in the REF scenario. The most important assumption is that all new power stations (except biomass fired plants) will have unit capacities of larger than 50 $MW_{th,}$ and that 50 percent of the biomass-fueled power stations will be smaller than this size. It should be stressed that the estimates fo emissions from large combustion plants are preliminary and are subject to change when more detailed information is available.

[17] In RAINS process emissions are defined as emissions that can not be directly attributed to fuel consumption. For details see Table 3.6.

Table 4.1: Comparison of RAINS 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	93	78	57	242	155	116	91	93
Belgium	317	215	258	363	309	196	95	106
Denmark	190	90	71	271	192	119	140	103
Finland	237	116	160	279	224	163	41	30
France	1300	737	691	1619	1276	895	700	669
Germany	5271	740	921	2985	2130	1279	759	539
Greece	509	570	361	392	544	282	78	76
Ireland	180	155	201	107	105	73	126	126
Italy	1699	1042	847	2009	2060	1165	416	391
Luxembourg	14	4	9	21	19	10	7	6
Netherlands	197	56	115	539	120	218	236	81
Portugal	286	294	194	208	215	206	93	84
Spain	2234	2143	1035	1176	892	851	353	373
Sweden	115	100	97	345	311	207	61	53
UK	3754	980	1923	2664	1860	1224	320	270
EU-15	**16396**	**7320**	**6940**	**13219**	**10412**	**7005**	**3516**	**3000**
Atlantic Ocean	317	317	317	350	350	350	0	0
Baltic Sea	73	73	73	81	81	81	0	0
North Sea	173	173	173	192	192	192	0	0
SEA	**564**	**564**	**564**	**622**	**622**	**622**	**0**	**0**
Albania	72	120	54	24	30	36	30	34
Belarus	845	490	495	402	184	315	257	163
Bosnia-H	482	480	410	80	80	48	36	23
Bulgaria	1842	1127	835	354	290	295	141	126
Croatia	178	117	69	83	83	64	37	38
Czech R.	1872	632	152	522	398	226	105	124
Estonia	273	275	172	84	72	73	29	28
Hungary	913	653	545	214	196	201	176	136
Latvia	122	115	105	114	93	115	38	28
Lithuania	213	222	107	151	158	137	84	80
Norway	54	34	33	231	161	177	39	39
Poland	3001	1397	1513	1209	1345	821	508	545
R. of Moldova	197	91	117	87	87	66	50	48
Romania	1335	1311	590	513	546	453	300	300
Russia	5046	4297	2350	3485	2658	2797	1191	894
Slovakia	549	240	113	207	197	110	62	53
Slovenia	199	37	76	60	31	36	27	20
Switzerland	45	30	45	161	113	78	62	58
FYRMacedonia	106	106	81	39	39	22	17	16
Ukraine	3708	2310	1486	1888	1094	1402	926	648
F.Yugoslavia	581	1135	262	211	147	118	99	83
Non-EU	**21631**	**15219**	**9610**	**10118**	**8002**	**7591**	**4213**	**3484**
TOTAL	**38591**	**23103**	**17114**	**23960**	**19036**	**15219**	**7729**	**6484**

It is worth mentioning that, despite stringent standards for SO_2 and NO_x emissions in Sweden, the envisaged substitution of nuclear power by gas- and biomass-burning boilers (as described in the 'Conventional Wisdom' energy scenario) will lead to an increase of emissions from large combustion plants in this country.

Control measures of the Reference scenarios are listed in Table 4.3 to Table 4.5.

Emission control costs for the Reference scenario in the year 2010 as estimated by the RAINS model are presented in Table 4.8. 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, all European unprotected ecosystems shrink from 86 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 nine million hectares with sulfur and nitrogen deposition above their critical loads (Table 4.9).

The situation improves also for eutrophication, where the area under threat within the EU-15 declines from 34 to about 19 percent (Table 4.10). However, as displayed in Figure 4.4, eutrophication remains a wide-spread problem with dramatically low protection levels in many Central European countries.

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		
	REF	**1990**	***Change***	**REF**	**1990**	***Change***	**REF**	**1990**	***Change***
Austria	57	90	*-37%*	116	222	*-48%*	93	91	*2%*
Belgium	215	317	*-32%*	196	352	*-44%*	106	95	*12%*
Denmark	71	180	*-61%*	119	269	*-56%*	103	140	*-26%*
Finland	116	260	*-55%*	163	300	*-46%*	30	41	*-27%*
France	691	1298	*-47%*	895	1585	*-44%*	669	700	*-4%*
Germany	740	5331	*-86%*	1279	3071	*-58%*	539	759	*-29%*
Greece	361	510	*-29%*	282	306	*-8%*	76	78	*-3%*
Ireland	155	178	*-13%*	73	115	*-37%*	126	126	*0%*
Italy	847	1678	*-50%*	1160	2047	*-43%*	391	416	*-6%*
Luxembourg	4	14	*-71%*	10	23	*-57%*	6	7	*-14%*
Netherlands	56	205	*-73%*	140	575	*-76%*	81	236	*-66%*
Portugal	194	283	*-31%*	206	215	*-4%*	84	93	*-10%*
Spain	1035	2266	*-54%*	851	1178	*-28%*	373	353	*6%*
Sweden	97	136	*-29%*	207	411	*-50%*	53	61	*-13%*
UK	980	3752	*-74%*	1224	2702	*-55%*	270	320	*-16%*
EU-15	**5619**	**16497**	***-66%***	**6921**	**13370**	***-48%***	**3000**	**3516**	***-15%***
Atlantic Sea	316	316	*0%*	349	349	*0%*	0	0	*0%*
Baltic	72	72	*0%*	80	80	*0%*	0	0	*0%*
North Sea	172	172	*0%*	191	191	*0%*	0	0	*0%*
SEA	**560**	**560**	***0%***	**620**	**620**	***0%***	**0**	**0**	***0%***
Albania	54	120	*-55%*	30	30	*0%*	34	30	*13%*
Belarus	490	710	*-31%*	184	285	*-35%*	163	257	*-37%*
Bosnia-H	410	480	*-15%*	48	80	*-40%*	23	36	*-36%*
Bulgaria	835	2020	*-59%*	290	376	*-23%*	126	141	*-10%*
Croatia	69	180	*-62%*	64	83	*-23%*	38	37	*3%*
Czech R.	151	1876	*-92%*	226	742	*-70%*	124	105	*18%*
Estonia	172	275	*-37%*	72	72	*0%*	28	29	*-3%*
Hungary	544	1010	*-46%*	196	238	*-18%*	136	176	*-23%*
Latvia	105	115	*-9%*	93	93	*0%*	28	38	*-26%*
Lithuania	107	222	*-52%*	137	158	*-13%*	80	84	*-5%*
Norway	33	54	*-39%*	161	230	*-30%*	39	39	*0%*
Poland	1397	3210	*-56%*	821	1279	*-36%*	545	508	*7%*
R. Moldova	91	91	*0%*	66	35	*89%*	48	50	*-4%*
Romania	590	1311	*-55%*	453	546	*-17%*	300	300	*0%*
Russia	2350	4459	*-47%*	2658	2675	*-1%*	894	1191	*-25%*
Slovakia	113	543	*-79%*	110	227	*-52%*	53	62	*-15%*
Slovenia	37	195	*-81%*	31	57	*-46%*	20	27	*-26%*
Switzerland	30	43	*-30%*	78	165	*-53%*	58	62	*-6%*
FYRMacedonia	81	106	*-24%*	22	39	*-43%*	16	17	*-5%*
Ukraine	1486	2782	*-47%*	1094	1097	*0%*	648	926	*-30%*
F.Yugoslavia	262	581	*-55%*	118	211	*-44%*	83	99	*-16%*
Non-EU	**9407**	**20383**	***-54%***	**6952**	**8717**	***-20%***	**3484**	**4213**	***-17%***
TOTAL	**15586**	**37440**	***-58%***	**14493**	**22707**	***-36%***	**6484**	**7729**	***-16%***

Table 4.3: 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
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 4.3: SO2 emission control measures in the EU-15 in the REF scenario, continued

Country	New plants		Existing plants	
Capacity class, MW_{th}	Coal	Oil	Coal	Oil
Italy:				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	-	-
100 - 500 300 - 500	LSCO/FGD(2)	LSHF	-	-
>500 >500	FGD	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	LSHF/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	New plants			Existing plants		
Capacity class, MW_{th}	Coal	Oil	Gas	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
Industrial processes:		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	CM/SCR (1)	SCR	SCR	CM/SCR (1)	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 4.4: NOx emission control measures in the EU-15 for stationary sources in the REF scenario, continued

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: NH_3 emisssion control measures assumed for the REF scenario

Country	Dairy cows	Other cattle	Pigs	Laying hens	Other poultry	Sheep	Industry
Austria	-	-	-	-	-	-	-
Belgium	-	-	-	-	-	-	-
Denmark	-	LNA_high	LNA_high	SA+LNA	LNA_high	-	STRIP
Finland	-	-	-	-	-	-	-
France	-	-	-	-	-	-	-
Germany (N)	-	-	-	-	-	-	-
Germany (O)	-	-	-	-	-	-	-
Greece	-	-	-	-	-	-	-
Ireland	SA+LNA	CS+LNA	LNF+CS +LNA	SA+LNA	SA+LNA	-	STRIP
Italy	-	-	-	-	-	-	-
Luxembourg	SA+LNA	LNA_high	LNF+CS +LNA	SA+LNA	SA+LNA	LNA_high	-
Netherlands	LNF+SA +LNA	CS+LNA	LNF+BF+ CS+LNA	LNF+SA +LNA	LNF+SA +LNA	LNA_high	STRIP
Portugal	-	-	-	-	-	-	-
Spain	-	-	-	-	-	-	-
Sweden	CS_low	CS_low	CS_high	SA+LNA	LNA_high	LNA_high	STRIP
UK	-	-	-	-	-	-	-

Abbreviations:

LNF	Low nitrogen feed *(reduction of nitrogen intake in feed, e.g. phase feeding, synthetic amino acids, etc.)*
SA	Stable adaptation *(scraper/sprinkler systems for dairy cows and cattle; slurry aeration / flushing and grid flooring for pigs; representative value for numerous poultry housing options)*
BF	Biofiltration *(air purification)*
CS_high	High efficiency coverings for storage *(permanent rigid lids for tanks)*
CS_low	Low efficiency coverings for storage *(e.g. foil, plastic,oil, peat for any open storage system)*
LNA_high	High efficiency ammonia application *(deep and shallow slurry injection, rapid ploughing of solid wastes)*
LNA_low	Medium to low efficiency ammonia application *(slit injection, sod manuring, band-spreading / trailing hose application)*
STRIP	Stripping / absorption *(removal of ammonia from waste gases from fertilizer production)*

Table 4.6: Estimated SO_2 emissions from large combustion plants in 1990 and for the REF scenario in the year 2010 (in kilotons). For 1990, estimates of RAINS, CORINAIR and the Large Combustion Plant Directive (LCPD) are provided.

	1990			2010		Change	
Country	**RAINS**	**CORINAIR**	**LCPD**	**(1)**	**(2)**	**(1)**	**(2)**
Austria	11	14	14	13	13	-9%	-9%
Belgium	105	114	121	31	33	-73%	-73%
Denmark	119	114	119	7	7	-94%	-94%
Finland	82	73	73	12	12	-84%	-84%
France	457	462	497	128	138	-72%	-72%
Germany	3513	3493	2900	298	248	91%	-91%
Greece	299	321	276	251	216	-22%	-22%
Ireland	120	118	118	34	34	-71%	-71%
Italy	1021	999	1000	146	147	-85%	-85%
Luxembourg		0	1	-	-	-	-
Netherlands	55	56	104	6	12	-89%	-89%
Portugal	199	199	205	113	116	-43%	-43%
Spain	1581	1508	1612	435	465	-71%	-71%
Sweden	7	6	6	17	17	+181%	+181%
UK	2970	2934	2954	458	461	-84%	-84%
EU 15	**10539**	**10411**	**10000**	**1949**	**1917**	**-81%**	**-81%**

(1) Adjusted to CORINAIR estimates for 1990
(2) Adjusted to the numbers in LCP Directive

Table 4.7: Estimated NO_x emissions from large combustion plants for the REF scenario in the year 2010 (in kilotons)

	1990			2010		Change	
Country	**RAINS**	**CORINAIR**	**LCPD**	**(1)**	**(2)**	**(1)**	**(2)**
Austria	13	12	12	9	9	-24%	-24%
Belgium	63	65	71	26	29	-60%	-60%
Denmark	72	82	83	17	17	-79%	-79%
Finland	46	56	56	43	43	-23%	-23%
France	135	128	137	44	47	-66%	-66%
Germany	552	593	500	215	181	-64%	-64%
Greece	83	87	47	45	24	-48%	-48%
Ireland	38	46	46	33	33	-28%	-28%
Italy	342	432	434	266	267	-38%	-38%
Luxembourg	0	0	1	-	-	-	-
Netherlands	91	82	106	10	13	-87%	-87%
Portugal	51	54	58	63	67	+15%	+15%
Spain	213	233	249	128	137	-45%	-45%
Sweden	8	7	7	31	31	+366%	+366%
UK	754	846	850	278	279	-67%	-67%
EU 15	**2459**	**2722**	**2656**	**1207**	**1177**	**-56%**	**-56%**

(1) Adjusted to CORINAIR estimates for 1990
(2) Adjusted to the numbers in the LCP Directive

Table 4.8: Emission control costs for the Reference (REF) scenario in the year 2010 (in million ECU/year)

	SO_2	NO_x	NH_3	TOTAL
Austria	259	625	0	884
Belgium	234	770	0	1004
Denmark	102	306	41	449
Finland	159	449	0	608
France	1344	4797	0	6141
Germany	2610	7355	0	9965
Greece	220	382	0	602
Ireland	80	176	194	450
Italy	1625	5223	0	6848
Luxembourg	10	49	7	66
Netherlands	244	1488	772	2504
Portugal	165	790	0	955
Spain	226	3337	0	3563
Sweden	291	699	16	1006
UK	844	4333	0	5177
EU-15	**8413**	**30779**	**1030**	**40222**
Atlantic Sea	0	0	0	0
Baltic	0	0	0	0
North Sea	0	0	0	0
SEA	**0**	**0**	**0**	**0**
Albania	0	7	0	7
Belarus	0	160	0	160
Bosnia-H	0	48	0	48
Bulgaria	155	4	0	159
Croatia	62	94	0	156
Czech R.	423	318	0	741
Estonia	0	0	0	0
Hungary	187	269	0	456
Latvia	0	19	0	19
Lithuania	0	0	0	0
Norway	50	411	0	461
Poland	875	682	0	1557
R. of Moldova	8	0	0	8
Romania	198	0	0	198
Russia	987	19	0	1006
Slovakia	120	185	0	305
Slovenia	57	69	0	126
Switzerland	64	504	0	568
FYRMacedonia	0	22	0	22
Ukraine	463	128	0	591
F.Yugoslavia	88	118	0	206
Non-EU	**3737**	**3057**	**0**	**6794**
TOTAL	**12150**	**33836**	**1030**	**47016**

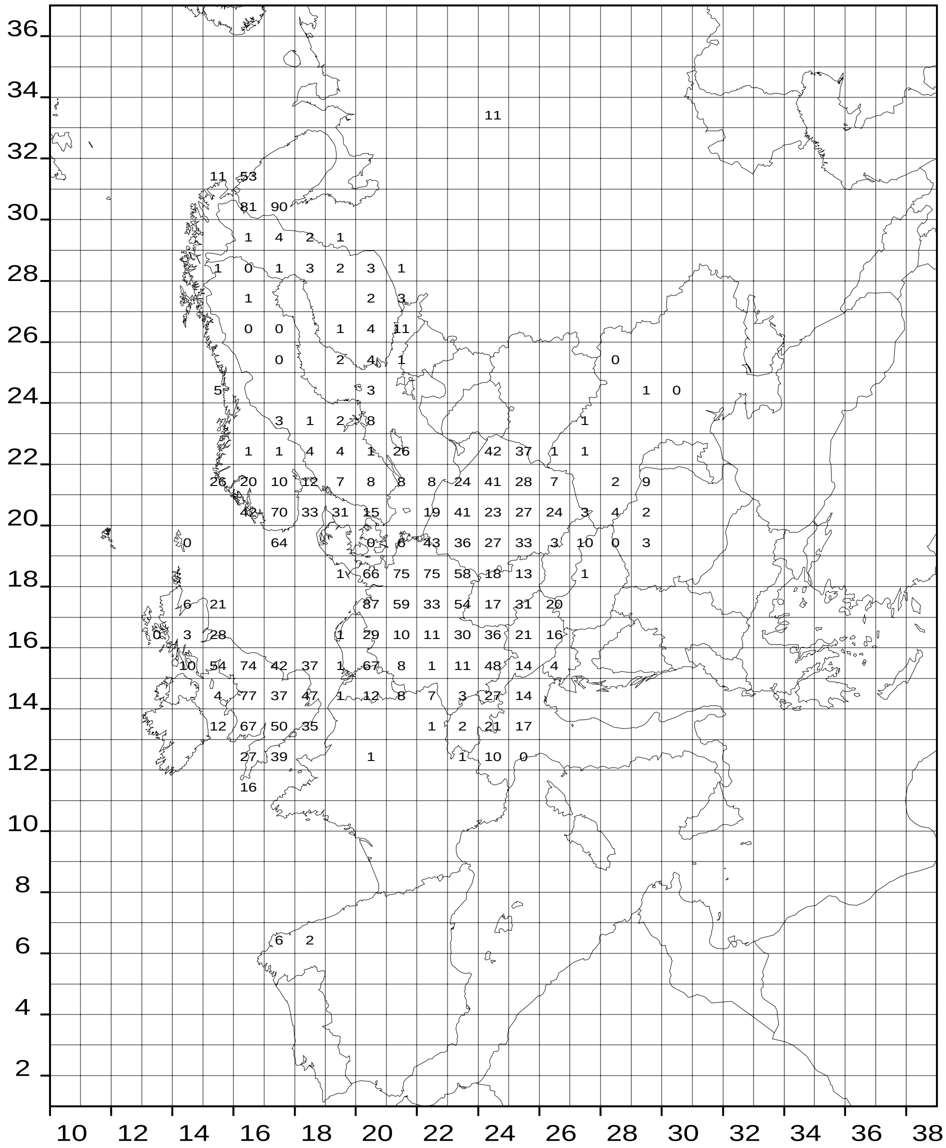

Figure 4.3: Percentage of ecosystems with sulfur and nitrogen deposition above their critical loads for acidification for the Reference scenario in the year 2010

Table 4.9: 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	2896	59%	943	19%
Belgium	477	77%	117	19%
Denmark	174	18%	38	4%
Finland	5016	16%	1211	4%
France	618	4%	82	1%
Germany	6972	80%	2541	29%
Greece	0	0%	0	0%
Ireland	23	5%	4	1%
Italy	1160	18%	285	4%
Luxembourg	15	17%	7	8%
Netherlands	282	88%	121	38%
Portugal	1	0%	0	0%
Spain	74	1%	24	0%
Sweden	10108	23%	1235	3%
United Kingdom	4741	60%	2112	27%
EU-15	**32557**	**24%**	**8719**	**7%**
Albania	0	0%	0	0%
Belarus	364	19%	53	3%
Bosnia-H	0	0%	0	0%
Bulgaria	0	0%	0	0%
Croatia	13	1%	1	0%
Czech R.	2532	95%	618	23%
Estonia	389	21%	10	1%
Hungary	142	9%	44	3%
Latvia	374	14%	0	0%
Lithuania	82	4%	12	1%
Norway	8060	25%	3539	11%
Poland	5904	93%	1930	30%
R. of Moldova	0	3%	0	1%
Romania	5779	9%	656	1%
Russia	27474	8%	4094	1%
Slovakia	1340	67%	83	4%
Slovenia	431	48%	47	5%
Switzerland	354	30%	105	9%
FYRMacedonia	0	0%	0	0%
Ukraine	1082	13%	104	1%
F.Yugoslavia	0	0%	0	0%
Non-EU	**54319**	**12%**	**11298**	**3%**
TOTAL	**86876**	**15%**	**20017**	**4%**

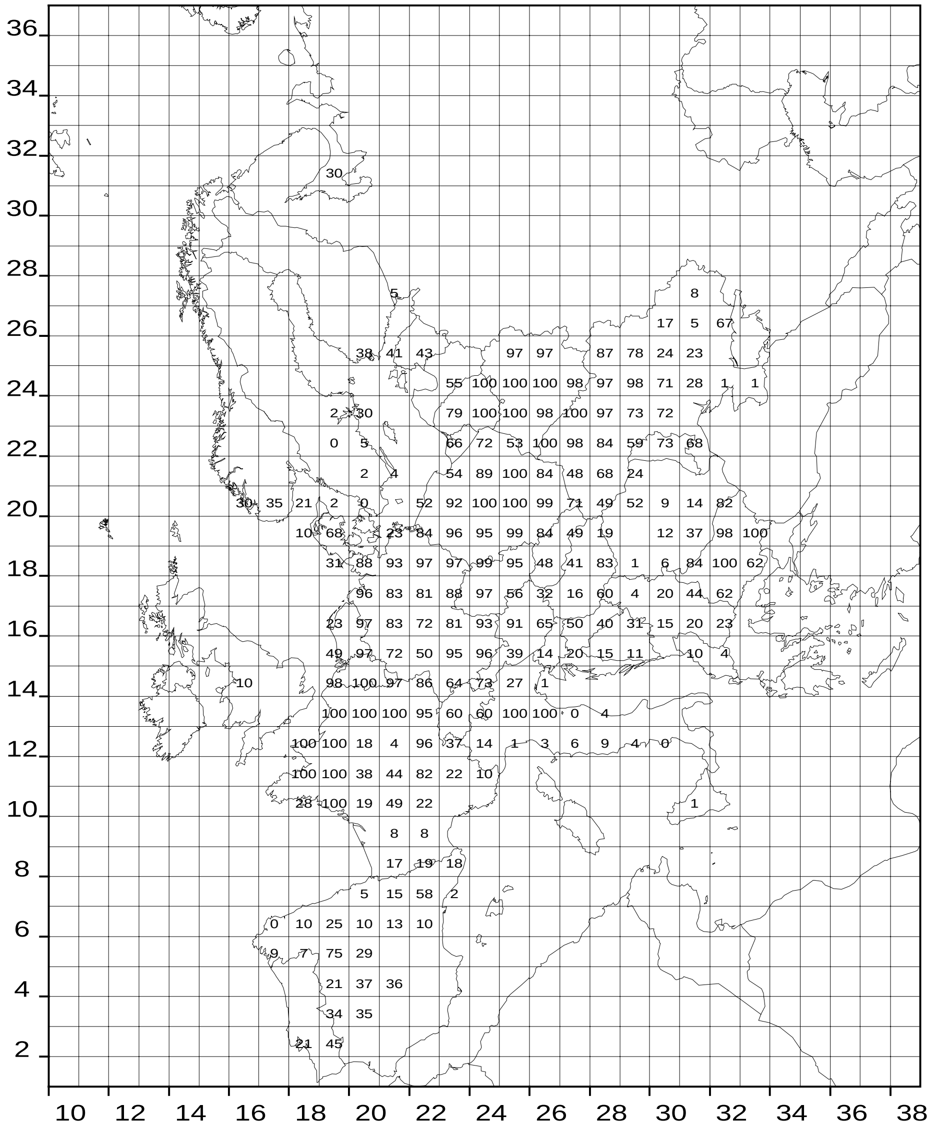

Figure 4.4: Percentage of ecosystems with nitrogen deposition above their critical loads for eutrophication for the Reference scenario in the year 2010

Table 4.10: 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	4531	93%	3019	62%
Belgium	621	100%	599	97%
Denmark	593	61%	358	37%
Finland	4464	14%	769	2%
France	10000	69%	6093	42%
Germany	8596	99%	7098	82%
Greece	204	8%	91	4%
Ireland	0	0%	0	0%
Italy	1989	30%	1193	18%
Luxembourg	88	100%	85	97%
Netherlands	312	98%	271	85%
Portugal	570	20%	277	10%
Spain	1949	23%	1180	14%
Sweden	3836	19%	100	1%
United Kingdom	530	7%	42	1%
EU-15	**38284**	**34%**	**21175**	**19%**
Albania	113	11%	69	7%
Belarus	1757	92%	1571	83%
Bosnia-H	966	67%	329	23%
Bulgaria	3393	90%	2685	71%
Croatia	976	60%	455	28%
Czech R.	2627	99%	2319	87%
Estonia	654	35%	508	27%
Hungary	1601	99%	624	39%
Latvia	1486	55%	509	19%
Lithuania	1863	98%	1656	87%
Norway	659	12%	276	5%
Poland	6345	99%	5666	89%
R. of Moldova	3	36%	2	20%
Romania	1666	3%	1097	2%
Russia	1162	0%	169	0%
Slovakia	1957	98%	1139	57%
Slovenia	624	69%	221	24%
Switzerland	1707	81%	1244	59%
FYRMacedonia	376	35%	243	23%
Ukraine	6968	84%	5429	66%
F.Yugoslavia	1770	52%	706	21%
Non-EU	**38672**	**10%**	**26917**	**7%**
TOTAL	**76956**	**18%**	**48092**	**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 Post-2005 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 constraints imposed by current legislation and historically observed turnover rates of the capital stock when determining the application potential of the presently 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 up to the year 2005 prohibits a full application of the most advanced abatement techniques for SO_2 and NO_x in the year 2010. This applies particularly to mobile sources, where the outcomes of the Auto/Oil program prescribe 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 4.11 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 91 percent, of NO_x by 69 percent and of ammonia by 45 percent compared to 1990. The ultimate MTFR scenario yields a 92 percent reduction of SO_2 and 84 percent of NO_x emissions.

Table 4.12 provides cost estimates for the MTFR-realistic scenario. Out of the total annual costs of 112 billion ECU per year, the largest part (53 percent) is connected with possible measures to control NO_x emissions; 28 percent emerge for SO_2 control, and the remaining 19 percent for ammonia. Total costs of the MTFR-realistic scenario are more than twice the costs of the REF scenario.

Table 4.11: Emissions of the 'realistic' and the 'ultimate' Maximum Technically Feasible Reduction Scenarios, in kilotons

	SO_2 MTFR		NO_x MTFR		NH_3 MTFR
	realistic	ultimate	realistic	ultimate	
Austria	38	37	89	46	54
Belgium	50	49	101	62	69
Denmark	18	17	66	35	47
Finland	56	55	77	42	20
France	222	167	644	318	409
Germany	335	333	945	538	292
Greece	42	33	152	64	53
Ireland	32	31	29	19	118
Italy	166	132	634	328	261
Luxembourg	3	2	7	4	6
Netherlands	35	34	140	84	81
Portugal	32	28	118	43	62
Spain	161	137	422	192	225
Sweden	60	59	112	60	37
United Kingdom	174	173	657	364	209
EU-15	**1424**	**1286**	**4193**	**2198**	**1944**
Atlantic Sea	76	76	70	70	0
Baltic	18	18	16	16	0
North Sea	42	42	38	38	0
SEA	**136**	**136**	**124**	**124**	**0**
Albania	5	4	12	6	26
Belarus	37	36	78	45	105
Bosnia-H	15	14	16	9	15
Bulgaria	100	94	83	49	98
Croatia	18	14	25	14	27
Czech R.	80	76	97	58	77
Estonia	9	8	19	10	18
Hungary	283	277	78	45	94
Latvia	17	16	38	19	17
Lithuania	20	19	42	22	50
Norway	19	18	88	45	27
Poland	345	327	300	208	414
R. of Moldova	17	16	19	11	31
Romania	87	76	121	74	210
Russia	528	485	751	433	521
Slovakia	61	58	60	35	39
Slovenia	10	8	14	7	14
Switzerland	14	13	59	35	46
FYRMacedonia	4	3	8	4	9
Ukraine	357	337	376	242	374
F.Yugoslavia	18	17	35	20	53
Non-EU	**2044**	**1916**	**2319**	**1391**	**2268**
TOTAL	**3604**	**3337**	**6636**	**3714**	**4212**

Table 4.12: 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	485	777	457	1719
Belgium	718	1155	413	2286
Denmark	363	474	664	1501
Finland	531	663	100	1294
France	1972	5805	2078	9855
Germany	5319	9221	1947	16487
Greece	622	783	255	1660
Ireland	310	269	442	1021
Italy	2765	7236	1376	11377
Luxembourg	20	77	16	113
Netherlands	538	1502	809	2849
Portugal	466	1015	302	1783
Spain	1246	4405	1957	7608
Sweden	847	1025	201	2073
UK	3261	6156	534	9951
EU-15	**19463**	**40563**	**11551**	**71577**
Atlantic Sea	217	90	0	307
Baltic	50	21	0	71
North Sea	119	49	0	168
SEA	**386**	**160**	**0**	**546**
Albania	63	62	63	188
Belarus	457	659	415	1531
Bosnia-H	193	131	89	413
Bulgaria	477	654	209	1340
Croatia	110	216	119	445
Czech R.	703	799	408	1910
Estonia	168	140	82	390
Hungary	360	745	351	1456
Latvia	127	188	106	421
Lithuania	130	285	231	646
Norway	138	253	112	503
Poland	2626	2294	1651	6571
R. of Moldova	97	97	122	316
Romania	549	941	664	2154
Russia	2460	5868	2838	11166
Slovakia	198	394	174	766
Slovenia	89	137	68	294
Switzerland	185	119	183	487
FYRMacedonia	85	53	48	186
Ukraine	1420	2846	2053	6319
F.Yugoslavia	569	382	369	1320
Non-EU	**11204**	**17263**	**10355**	**38822**
TOTAL	**31053**	**57986**	**21906**	**110945**

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/agricultural 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. Least protection would occur for Austria and the UK.

Figure 4.6 evaluates ecosystems' protection taking into account constraints imposed by the limited turnover of the existing capital stock and the current legislation (the MTFR-realistic scenario). In such a case about 1.1 million hectares of ecosystems within the EU-15 would remain unprotected (compared to 0.8 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.

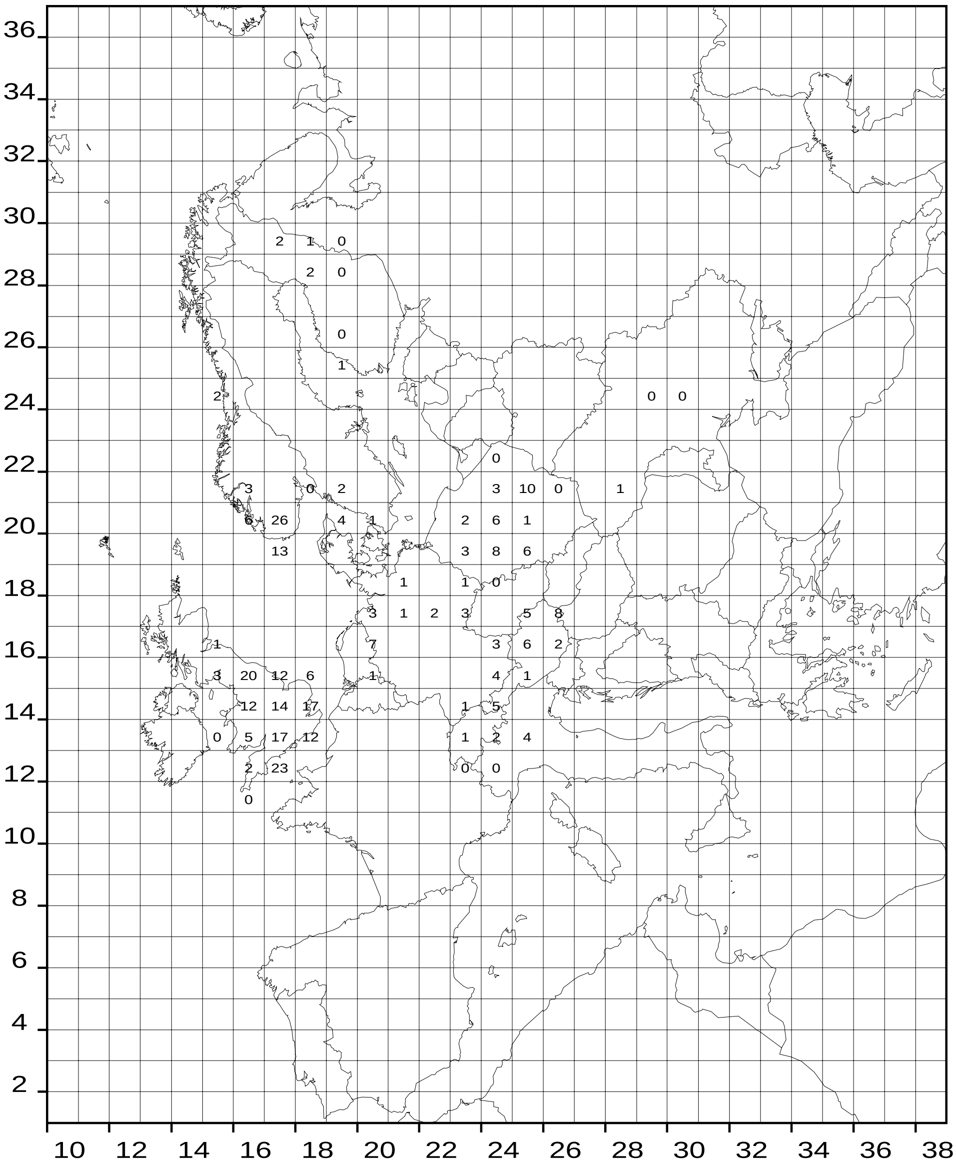

Figure 4.5: Percent of ecosystems with acid deposition above their critical loads for acidity for the MTFR-ultimate scenario

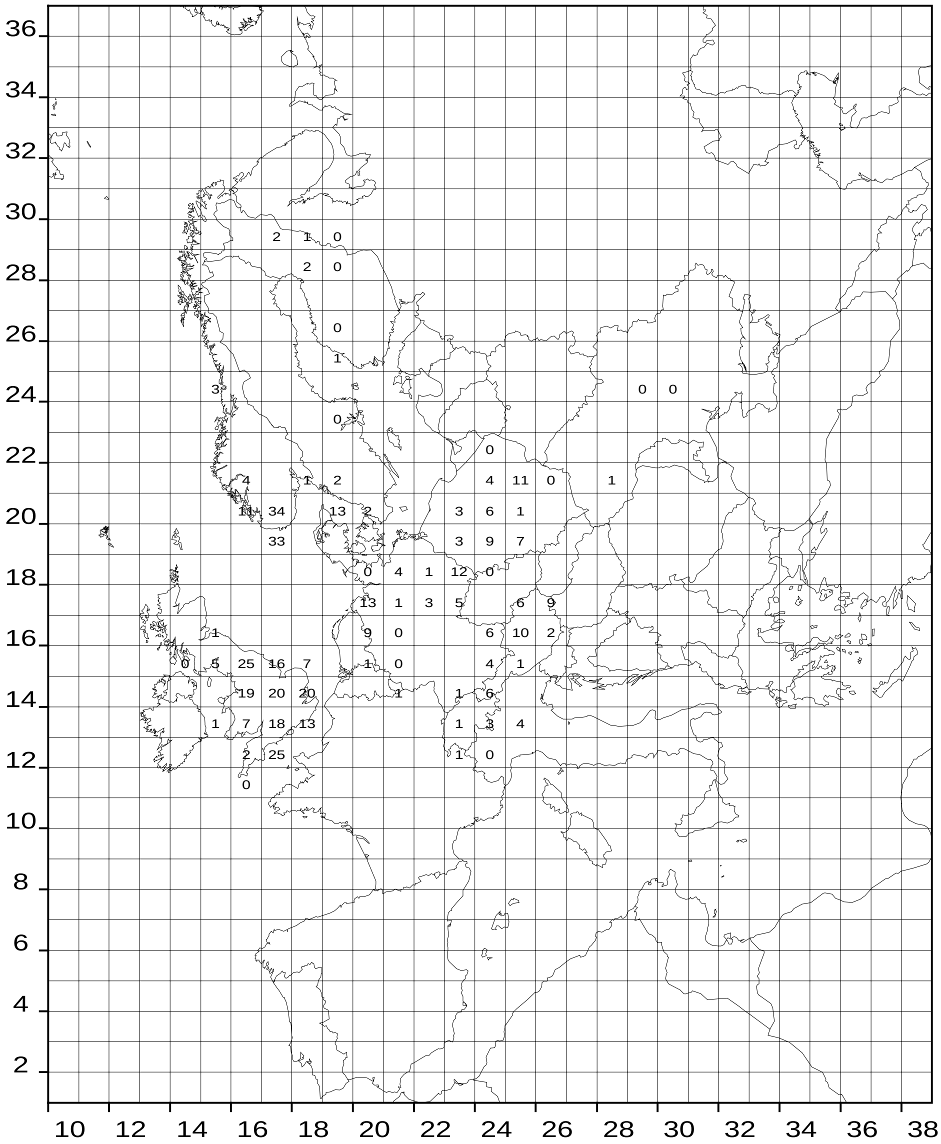

Figure 4.6: Percent of ecosystems with acid deposition above their critical loads for acidity for the MTFR-realistic scenario for the year 2010

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 European Union 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 the most stringent measures within the EU countries would leave about 2.9 million hectares (2.4 percent) within the EU unprotected, compared to 1.1 million hectares in the MTFR-realistic scenario. Note that the control measures and abatement costs for the EU-15 countries are equal in both cases. Summaries of ecosystems’ protection are provided in Table 4.13 and Table 4.14.

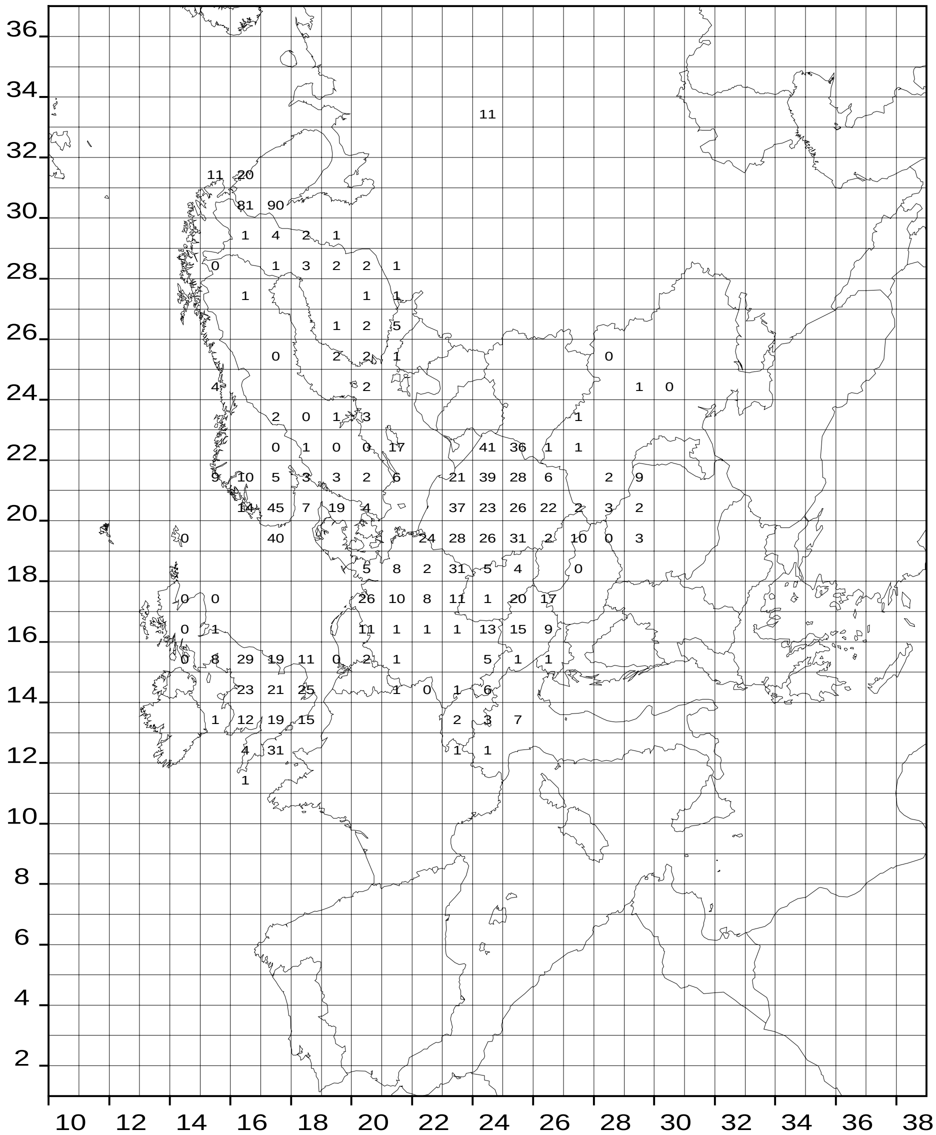

Figure 4.7: Percent of ecosystems with acid deposition above their critical loads for acidity for the EU-max scenario for the year 2010

Table 4.13: 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	461	10%	234	5%	168	4%
Belgium	3	1%	2	0%	1	0%
Denmark	12	1%	7	1%	2	0%
Finland	1009	3%	105	0%	99	0%
France	7	0%	4	0%	2	0%
Germany	401	5%	164	2%	79	1%
Greece	0	0%	0	0%	0	0%
Ireland	0	0%	0	0%	0	0%
Italy	35	1%	26	0%	23	0%
Luxembourg	1	1%	1	1%	0	0%
Netherlands	16	5%	13	4%	11	3%
Portugal	0	0%	0	0%	0	0%
Spain	0	0%	0	0%	0	0%
Sweden	456	1%	131	0%	80	0%
United Kingdom	522	7%	406	5%	310	4%
EU-15	**2922**	**2%**	**1094**	**1%**	**775**	**1%**
Albania	0	0%	0	0%	0	0%
Belarus	52	3%	0	0%	0	0%
Bosnia-H	0	0%	0	0%	0	0%
Bulgaria	0	0%	0	0%	0	0%
Croatia	0	0%	0	0%	0	0%
Czech R.	191	7%	58	2%	37	1%
Estonia	5	0%	0	0%	0	0%
Hungary	37	2%	8	1%	7	0%
Latvia	0	0%	0	0%	0	0%
Lithuania	12	1%	0	0%	0	0%
Norway	1959	6%	1084	3%	759	2%
Poland	1569	25%	226	4%	165	3%
R. of Moldova	0	1%	0	0%	0	0%
Romania	64	0%	0	0%	0	0%
Russia	3683	1%	27	0%	27	0%
Slovakia	76	4%	9	0%	7	0%
Slovenia	16	2%	3	0%	2	0%
Switzerland	23	2%	20	2%	18	2%
FYRMacedonia	0	0%	0	0%	0	0%
Ukraine	97	1%	5	0%	5	0%
F.Yugoslavia	0	0%	0	0%	0	0%
Non-EU	**7785**	**2%**	**1439**	**0%**	**1027**	**0%**
TOTAL	**10708**	**2%**	**2533**	**0%**	**1802**	**0%**

Table 4.14: Ecosystems with nitrogen deposition above their critical loads for eutrophication

	EU-max		MTFR-realistic		MTFR-ultimate	
	1000 ha	**%**	**1000 ha**	**%**	**1000 ha**	**%**
Austria	899	19%	470	10%	218	5%
Belgium	561	90%	439	71%	424	68%
Denmark	12	1%	7	1%	0	0%
Finland	53	0%	0	0%	0	0%
France	1199	8%	913	6%	502	4%
Germany	3313	38%	2264	26%	874	10%
Greece	65	3%	0	0%	0	0%
Ireland	0	0%	0	0%	0	0%
Italy	323	5%	288	4%	222	3%
Luxembourg	79	90%	13	14%	6	7%
Netherlands	253	79%	251	79%	228	72%
Portugal	0	0%	0	0%	0	0%
Spain	12	0%	11	0%	8	0%
Sweden	0	0%	0	0%	0	0%
UK	0	0%	0	0%	0	0%
EU-15	**6770**	**6%**	**4657**	**4%**	**2483**	**2%**
Albania	61	6%	9	1%	0	0%
Belarus	1560	82%	265	14%	84	4%
Bosnia-H	205	14%	3	0%	1	0%
Bulgaria	2517	67%	129	3%	35	1%
Croatia	142	9%	15	1%	6	0%
Czech R.	1833	69%	839	32%	274	10%
Estonia	467	25%	0	0%	0	0%
Hungary	384	24%	48	3%	3	0%
Latvia	241	9%	0	0%	0	0%
Lithuania	1538	81%	112	6%	22	1%
Norway	0	0%	0	0%	0	0%
Poland	5031	79%	3377	53%	2900	45%
R. of Moldova	2	20%	0	0%	0	0%
Romania	1041	2%	78	0%	24	0%
Russia	107	0%	0	0%	0	0%
Slovakia	881	44%	184	9%	124	6%
Slovenia	72	8%	33	4%	18	2%
Switzerland	686	32%	386	18%	237	11%
FYRMacedonia	158	15%	2	0%	0	0%
Ukraine	5279	64%	1631	20%	607	7%
F.Yugoslavia	621	18%	19	1%	0	0%
Non-EU	**22825**	**6%**	**7132**	**2%**	**4336**	**1%**
TOTAL	**29595**	**6%**	**11789**	**2%**	**6819**	**1%**

4.2 Reducing the Area of Unprotected Ecosystems by at least 50 Percent

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 4.9). Despite this significant progress, almost nine million hectares in the EU will still remain 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 that do not take account of the regional differences in costs and environmental sensitivities.

To explore the cost-effectiveness of alternative approaches to reduce emissions, the First Interim Report analyzed three scenarios that aimed at increasingly improved ecosystem protection. The ecosystems that received acid deposition above their critical loads in 1990, i.e., those not protected against acidification (see Figure 4.1) served as a common starting point. The rationale of the scenarios was 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 the target ecosystems for each grid cell, 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 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 and Klaassen, 1995.

The optimization used for the First Interim Report of 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 with 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 problem, 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 provide the relationships between emission reduction levels and control costs.

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, i.e., the gap refers to excess deposition. 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 done for the Second Sulfur Protocol related its measure for non-protection only to the excess deposition of a single, ecologically sensitive and representative ecosystem (the '95-percentile', for which five 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, setting the target at the 95 percentile 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 (multi-pollutant) acidification problem, an attempt has been made to define the gap as the area of unprotected ecosystems in the year 1990. Thereby, the excess deposition valid for a single ecosystem has been replaced by a measure of the area of ecosystems unprotected at a certain deposition pattern of sulfur and nitrogen compounds.

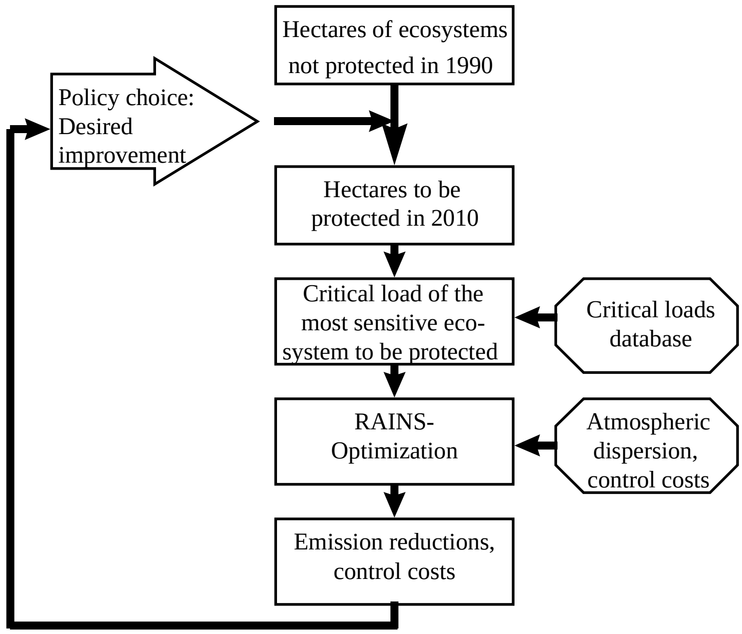

Figure 4.8: Process of scenario construction and evaluation

4.2.1 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 cell 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 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.

To explore the relation between ecosystems' protection, emission control measures and costs, the First Interim Report explored a range of three alternative scenarios aiming at a 45, 50 and 55 percent gap closure, respectively. This means that optimizations have been performed for three different sets of target deposition, reducing in each grid cell the area of unprotected ecosystems by at least 45, 50 and 55 percent, respectively.

In order to exclude possible uncertainties in the critical loads estimates for the most sensitive ecosystems and to base the optimization runs on robust data, a cut-off level was introduced at the 98 percentile of the critical loads database. This means that 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. The implications of using the 95 percentile are analyzed in Section 0 of this report.

It has also 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 materialized by adopting the Reference scenario as a minimum reduction requirement for the optimization, assuming a development of energy consumption according to the 'Modified Conventional Wisdom' scenario.

4.2.2 Scenario B1: Reducing The Areas not Protected from Acidification by at least 50 Percent

The discussions of the results of the First Interim Report led to a provisional acceptance of the '50% gap closure' scenario (Scenario 2 in the First Interim Report) as a reference for further analysis. This scenario identified for the year 2010 the cost-minimal allocation of emission reductions to attain in each grid cell within the EU a decrease of the area of unprotected ecosystems by at least 50 percent (i.e, closing the gap of unprotected ecosystems by 50 percent). It was assumed that the economic development and energy consumption in the Member States of the EU follows the 'Modified Conventional Wisdom' scenario, and in the non-EU countries the 'Official Energy Pathway' (see Section 3.1).

According to the scope of the study, environmental targets have been 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 significant environmental improvement can only be reached at these sites 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 in this scenario that an envisaged acidification strategy of the EU will primarily consider control measures within the Member States. Consequently, it has been postulated 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, the REF scenario has been adopted for the EU Member States as the minimum requirement for optimization, restricting the set of possible control measures available to the optimization to those additional measures not already taken in the Reference scenario.

Using the updated database of the RAINS model (see Section 3.7) the optimization analysis has been repeated and its results are presented as Scenario B1 in this report.
Table 4.15 lists 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 52 percent below the Reference scenario, NO_x by 14 percent and ammonia by 15 percent.

Sulfur control would be required in all EU countries with the exception of Austria, Finland and Luxembourg, 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, Denmark, 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 Sweden, and some more control on NO_x in Ireland.

The modifications of the databases introduced after the First Interim Report led to minor differences compared to the earlier optimization results. Most differences are related to changes in the estimates of the CLE and thereby the REF scenario. Lower energy consumption of the new Danish energy scenario and the significantly lower NH_3 estimates for the UK facilitate the achievement of lower emission levels in ecologically sensitive zones and thereby relieve measures at more distant sources (e.g., in Finland).

Table 4.16, Table 4.17 and Table 4.18 summarizethe implied control measures for SO_2, NO_x and NH_3 emissions, respectively, for the countries of the EU-15. The tables show that the achievement of the 50 percent gap closure target 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) are less stringent measures required.

Table 4.19 and Table 4.20 contain provisional estimates of emissions from large combustion plants for Scenario B1 and compares them with various estimates for the year 1990. All assumptions and caveats listed for the estimates of the REF scenario (Table 4.16 and Table 4.17) apply also to these tables. For the EU-15 as a whole, SO_2 emissions from large combustion plants would be reduced by 90 percent compared to the level of the year 1990, and for NO_x by about 65 percent. In most countries these reductions exceed the measures envisaged for the REF scenario. Despite the strong overall reduction, substantial differences occur between the individual Member Countries of the European Union: Due to differences in energy development, changes in SO_2 emissions (compared to 1990) range from reductions of 96/97 percent in the France and the UK to increases of 60 percent in Sweden. For NO_x, the range spans from a 93 percent decrease in the UK to a 366 percent growth in Sweden.

Table 4.21 presents abatement costs of Scenario B1. Compared to the Reference scenario, emission control costs would be 18 percent higher. Out of the total extra costs of seven billion ECU/year, 42 percent are allocated to SO_2 control, 25 percent to further measures on NO_x and the remaining 33 percent to ammonia.

Figure 4.9 displays for all of Europe the percentage of ecosystems with acid deposition above their critical loads in Scenario B1. 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 B1.

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, 30-40 percent of the ecosystems remain unprotected. Major problem areas outside the EU are Norway, Poland and the Czech Republic. Table 4.22 provides the country totals of unprotected ecosystems. Compared to 1990, unprotected ecosystems decline in the EU-15 from 32.5 to 4.5 million hectares, i.e. from 24 percent to three percent. This is a further decrease of almost four million hectares compared to the Reference scenario. However, despite this improvement, Austria, Germany and the UK still have ten percent and more of their ecosystems not sufficiently protected.

Table 4.15: Emissions of the '50% gap closure' scenario (B1) compared to the emissions of the Reference (REF) scenario (in kilotons)

	SO_2			NO_x			NH_3		
	B1	**REF**	***Change***	**B1**	**REF**	***Change***	**B1**	**REF**	***Change***
Austria	57	57	*0%*	116	116	*0%*	93	93	*0%*
Belgium	52	215	*-76%*	129	196	*-34%*	74	106	*-30%*
Denmark	31	71	*-56%*	88	119	*-26%*	82	103	*-20%*
Finland	116	116	*0%*	163	163	*0%*	30	30	*0%*
France	235	691	*-66%*	766	895	*-14%*	630	669	*-6%*
Germany	414	740	*-44%*	1079	1279	*-16%*	318	539	*-41%*
Greece	361	361	*0%*	282	282	*0%*	76	76	*0%*
Ireland	41	155	*-74%*	42	73	*-42%*	126	126	*0%*
Italy	204	847	*-76%*	1160	1160	*0%*	305	391	*-22%*
Luxembourg	4	4	*0%*	10	10	*0%*	6	6	*0%*
Netherlands	38	56	*-32%*	140	140	*0%*	81	81	*0%*
Portugal	194	194	*0%*	206	206	*0%*	84	84	*0%*
Spain	618	1035	*-40%*	826	851	*-3%*	373	373	*0%*
Sweden	66	97	*-32%*	207	207	*0%*	49	53	*-8%*
UK	279	980	*-72%*	753	1224	*-38%*	224	270	*-17%*
EU-15	**2710**	**5619**	***-52%***	**5967**	**6921**	***-14%***	**2551**	**3000**	***-15%***
Atlantic Sea	316	316	*0%*	349	349	*0%*	0	0	*0%*
Baltic	72	72	*0%*	80	80	*0%*	0	0	*0%*
North Sea	172	172	*0%*	191	191	*0%*	0	0	*0%*
SEA	**560**	**560**	***0%***	**620**	**620**	***0%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	184	184	*0%*	163	163	*0%*
Bosnia-H	410	410	*0%*	48	48	*0%*	23	23	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	126	126	*0%*
Croatia	69	69	*0%*	64	64	*0%*	38	38	*0%*
Czech R.	151	151	*0%*	226	226	*0%*	124	124	*0%*
Estonia	172	172	*0%*	72	72	*0%*	28	28	*0%*
Hungary	544	544	*0%*	196	196	*0%*	136	136	*0%*
Latvia	105	105	*0%*	93	93	*0%*	28	28	*0%*
Lithuania	107	107	*0%*	137	137	*0%*	80	80	*0%*
Norway	33	33	*0%*	161	161	*0%*	39	39	*0%*
Poland	1397	1397	*0%*	821	821	*0%*	545	545	*0%*
R. of Moldova	91	91	*0%*	66	66	*0%*	48	48	*0%*
Romania	590	590	*0%*	453	453	*0%*	300	300	*0%*
Russia	2350	2350	*0%*	2658	2658	*0%*	894	894	*0%*
Slovakia	113	113	*0%*	110	110	*0%*	53	53	*0%*
Slovenia	37	37	*0%*	31	31	*0%*	20	20	*0%*
Switzerland	30	30	*0%*	78	78	*0%*	58	58	*0%*
FYRMacedonia	81	81	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1486	1486	*0%*	1094	1094	*0%*	648	648	*0%*
F.Yugoslavia	262	262	*0%*	118	118	*0%*	83	83	*0%*
Non-EU	**9407**	**9407**	***0%***	**6952**	**6952**	***0%***	**3484**	**3484**	***0%***
TOTAL	**12677**	**15586**	***-19%***	**13539**	**14493**	***-7%***	**6035**	**6484**	***-7%***

Table 4.16: SO_2 emission control measures applied in the '50% gap closure' scenario (Scenario B1)

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxemb.	Netherl.	Portugal	Spain	Sweden	UK
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

Explanation 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% gap closure' (B1) scenario for stationary sources and off-road transport

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxemb.	Netherl.	Portugal	Spain	Sweden	UK.
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 heavy 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 LCPD

Explanation 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
LCPD - Large Combustion Plants Directive

Table 4.18: Measures for the '50% gap closure' scenario for ammonia

Country	Dairy cows	Other cattle	Pigs	Laying hens	Other poultry	Sheep	Industry
Austria	-	-	CS-low	LNA-high	LNA-high	-	STRIP
Belgium	SA+LNA	CS+LNA	LNF+CS+LNA	SA+LNA	SA+LNA	-	STRIP
Denmark	LNA-high	CS+LNA	LNA-high	SA+LNA	SA+LNA	-	STRIP
Finland	-	-	-	-	-	-	-
France	-	-	LNA-high	SA+LNA	LNA-high	-	STRIP
Germany (New L.)	LNA-high	LNA-high	LNF+CS+LNA	SA+LNA	SA+LNA	LNA-high	STRIP
Germany (Old L.)	SA+LNA	CS+LNA	LNF+BF+CS+ LNA	SA+LNA	SA+LNA	LNA-high	STRIP
Greece	-	-	-	-	-	-	-
Ireland	SA+LNA	CS+LNA	LNF+CS+LNA	SA+LNA	SA+LNA	-	STRIP
Italy	SA+LNA	LNA-high	LNF+CS	SA+LNA	SA+LNA	LNA-high	STRIP
Luxembourg	SA+LNA	LNA-high	LNF+CS+LNA	SA+LNA	SA+LNA	LNA-high	-
Netherlands	LNF+SA+ LNA	CS+LNA	LNF+BF+CS+ LNA	LNF+SA+ LNA	LNF+SA+ LNA	LNA-high	STRIP
Portugal	-	-	-	-	-	-	-
Spain	-	-	-	-	CS-high	-	-
Sweden	CS-low	CS-high	LNA-high	SA+LNA	SA+LNA	LNA-high	STRIP
UK	SA+LNA	LNA-high	LNF+CS	SA+LNA	SA+LNA	-	STRIP

Abbreviations:

LNF	Low nitrogen feed *(reduction of nitrogen intake in feed, e.g. phase feeding, synthetic amino acids, etc.)*
SA	Stable adaptation *(scraper/sprinkler systems for dairy cows and cattle; slurry aeration / flushing and grid flooring for pigs; representative value for numerous poultry housing options)*
BF	Biofiltration *(air purification)*
CS_high	High efficiency coverings for storage *(permanent rigid lids for tanks)*
CS_low	Low efficiency coverings for storage *(e.g. foil, plastic,oil, peat for any open storage system)*
LNA_high	High efficiency ammonia application *(deep and shallow slurry injection, rapid ploughing of solid wastes)*
LNA_low	Medium to low efficiency ammonia application *(slit injection, sod manuring, band-spreading / trailing hose application)*
STRIP	Stripping / absorption *(removal of ammonia from waste gases from fertilizer production)*

Combinations of these technologies are possible and indicated by merged codes

Table 4.19: Provisional emission estimates for SO_2 for large combustion plants for the '50% gap closure' scenario (Scenario B1), in kilotons

Country	1990 RAINS	1990 CORINAIR	1990 LCPD	2010 (1)	2010 (2)	Change (1)	Change (2)
Austria	11	14	14	8	8	-41%	-41%
Belgium	105	114	121	7	7	-94%	-94%
Denmark	119	114	119	5	6	-95%	-95%
Finland	82	73	73	12	12	-84%	-84%
France	457	462	497	19	20	-96%	-96%
Germany	3513	3493	2900	189	157	-95%	-95%
Greece	299	321	276	247	212	-23%	-23%
Ireland	120	118	118	11	11	-90%	-90%
Italy	1021	999	1000	76	76	-92%	-92%
Luxembourg	0	0	1	-	-	-	-
Netherlands	55	56	104	5	9	-91%	-91%
Portugal	199	199	205	113	116	-43%	-43%
Spain	1581	1508	1612	229	245	-85%	-85%
Sweden	7	6	6	10	10	+60%	+60%
UK	2970	2934	2954	75	75	-97%	-97%
EU 15	**10539**	**10411**	**10000**	**1006**	**965**	**-90%**	**-90%**

(1) Adjusted to CORINAIR estimates for 1990
(2) Adjusted to numbers in LCPD

Table 4.20: Provisional estimates for NO_x emission from large combustion plants for the '50% gap closure' scenario (Scenario B1), in kilotons

Country	1990 RAINS	1990 CORINAIR	1990 LCPD	2010 (1)	2010 (2)	Change (1)	Change (2)
Austria	13	12	12	9	9	-24%	-24%
Belgium	63	65	71	9	10	-86%	-86%
Denmark	72	82	83	6	6	-93%	-93%
Finland	46	56	56	43	43	-23%	-23%
France	135	128	137	33	35	-75%	-75%
Germany	552	593	500	198	167	-67%	-67%
Greece	83	87	47	45	24	-48%	-48%
Ireland	38	46	46	12	12	-75%	-75%
Italy	342	432	434	266	267	-38%	-38%
Luxembourg	0	0	1	-	-	-	-
Netherlands	91	82	106	10	13	-87%	-87%
Portugal	51	54	58	63	67	+15%	+15%
Spain	213	233	249	128	137	-45%	-45%
Sweden	8	7	7	31	31	+366%	+366%
UK	754	846	850	60	60	-93%	-93%
EU 15	**2459**	**2722**	**2656**	**913**	**881**	**-66%**	**67%**

(1) Adjusted to CORINAIR estimates for 1990
(2) Adjusted to numbers in LCPD

Table 4.21: Abatement costs of Scenario B1 (the '50% gap closure' scenario), compared to the costs of the Reference (REF) scenario, in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B1	**REF**	***add.***	**B1**	**REF**	***add.***	**B1**	**REF**	***add.***	**B1**	**REF**	***add.***
Austria	259	259	*0*	625	625	*0*	0	0	*0*	884	884	*0*
Belgium	598	234	*364*	888	770	*118*	193	0	*193*	1679	1004	*675*
Denmark	161	102	*59*	348	306	*42*	121	41	*80*	630	449	*181*
Finland	159	159	*0*	449	449	*0*	0	0	*0*	608	608	*0*
France	1638	1344	*294*	4950	4797	*153*	36	0	*36*	6624	6141	*483*
Germany	3234	2610	*624*	7941	7355	*586*	1435	0	*1435*	12610	9965	*2645*
Greece	220	220	*0*	382	382	*0*	0	0	*0*	602	602	*0*
Ireland	155	80	*75*	202	176	*26*	194	194	*0*	551	450	*101*
Italy	2058	1625	*433*	5223	5223	*0*	400	0	*400*	7681	6848	*833*
Luxembourg	10	10	*0*	49	49	*0*	7	7	*0*	66	66	*0*
Netherlands	320	244	*76*	1488	1488	*0*	772	772	*0*	2580	2504	*76*
Portugal	165	165	*0*	790	790	*0*	0	0	*0*	955	955	*0*
Spain	385	226	*159*	3342	3337	*5*	0	0	*0*	3727	3563	*164*
Sweden	436	291	*145*	699	699	*0*	34	16	*18*	1169	1006	*163*
United Kingdom	1555	844	*711*	5198	4333	*865*	143	0	*143*	6896	5177	*1719*
EU-15	**11353**	**8413**	**2940**	**32574**	**30779**	***1795***	**3335**	**1030**	***2305***	**47262**	**40222**	***7040***
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 4.21: Abatement costs of Scenario B1 (the '50% gap closure' scenario), compared to the costs of the Reference (REF) scenario, in million ECU/year, continued

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B1	**REF**	***add.***	**B1**	**REF**	***add.***	**B1**	**REF**	***add.***	**B1**	**REF**	***add.***
Albania	0	0	0	7	7	0	0	0	0	7	7	0
Belarus	0	0	0	160	160	0	0	0	0	160	160	0
Bosnia-H	0	0	0	48	48	0	0	0	0	48	48	0
Bulgaria	155	155	0	4	4	0	0	0	0	159	159	0
Croatia	62	62	0	94	94	0	0	0	0	156	156	0
Czech R.	423	423	0	318	318	0	0	0	0	741	741	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	187	187	0	269	269	0	0	0	0	456	456	0
Latvia	0	0	0	19	19	0	0	0	0	19	19	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	50	50	0	411	411	0	0	0	0	461	461	0
Poland	875	875	0	682	682	0	0	0	0	1557	1557	0
R. of Moldova	8	8	0	0	0	0	0	0	0	8	8	0
Romania	198	198	0	0	0	0	0	0	0	198	198	0
Russia	987	987	0	19	19	0	0	0	0	1006	1006	0
Slovakia	120	120	0	185	185	0	0	0	0	305	305	0
Slovenia	57	57	0	69	69	0	0	0	0	126	126	0
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	22	22	0	0	0	0	22	22	0
Ukraine	463	463	0	128	128	0	0	0	0	591	591	0
F.Yugoslavia	88	88	0	118	118	0	0	0	0	206	206	0
Non-EU	**3737**	**3737**	**0**	**3057**	**3057**	**0**	**0**	**0**	**0**	**6794**	**6794**	**0**
TOTAL	**15090**	**12150**	**2940**	**35631**	**33836**	**1795**	**3335**	**1030**	**2305**	**54056**	**47016**	**7040**

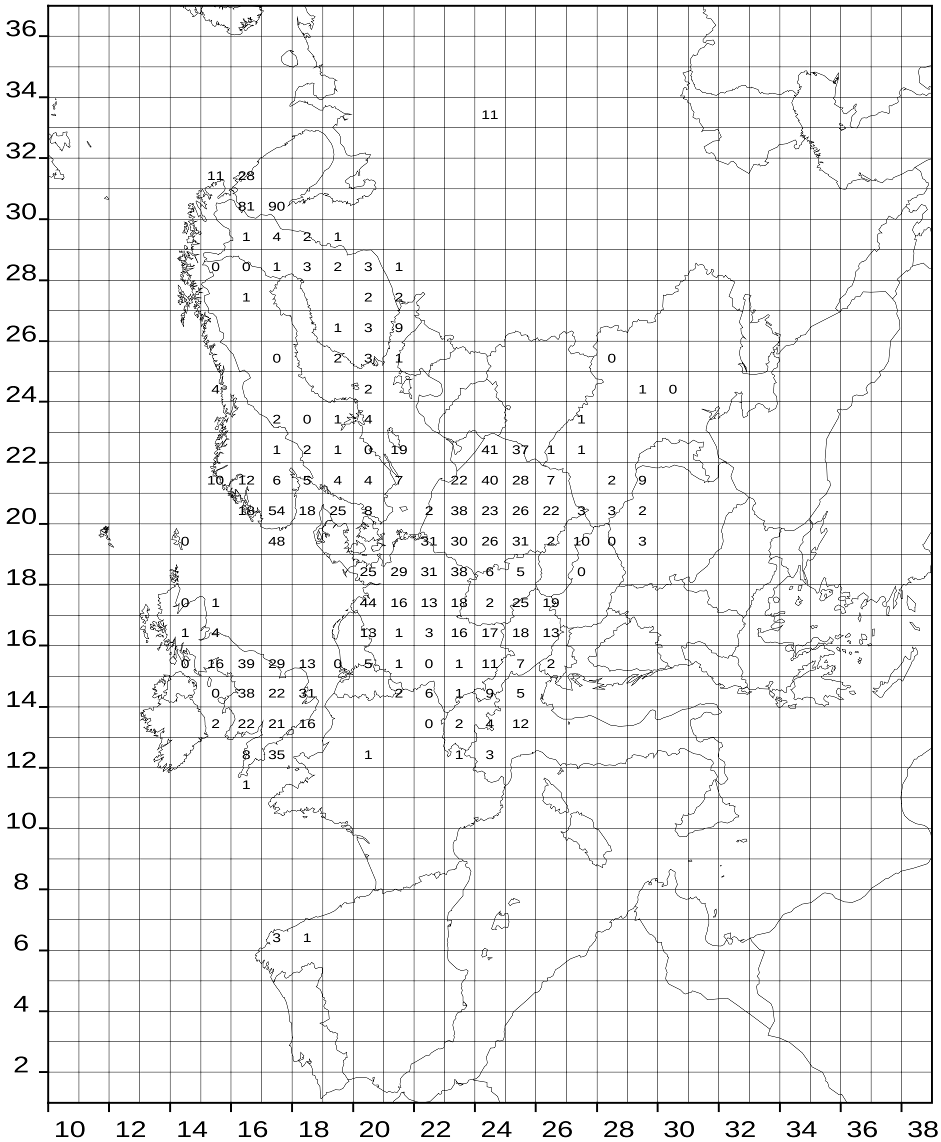

Figure 4.9: Percentage of ecosystems with deposition above their critical loads for acidity for Scenario B1 (the '50% gap closure' scenario)

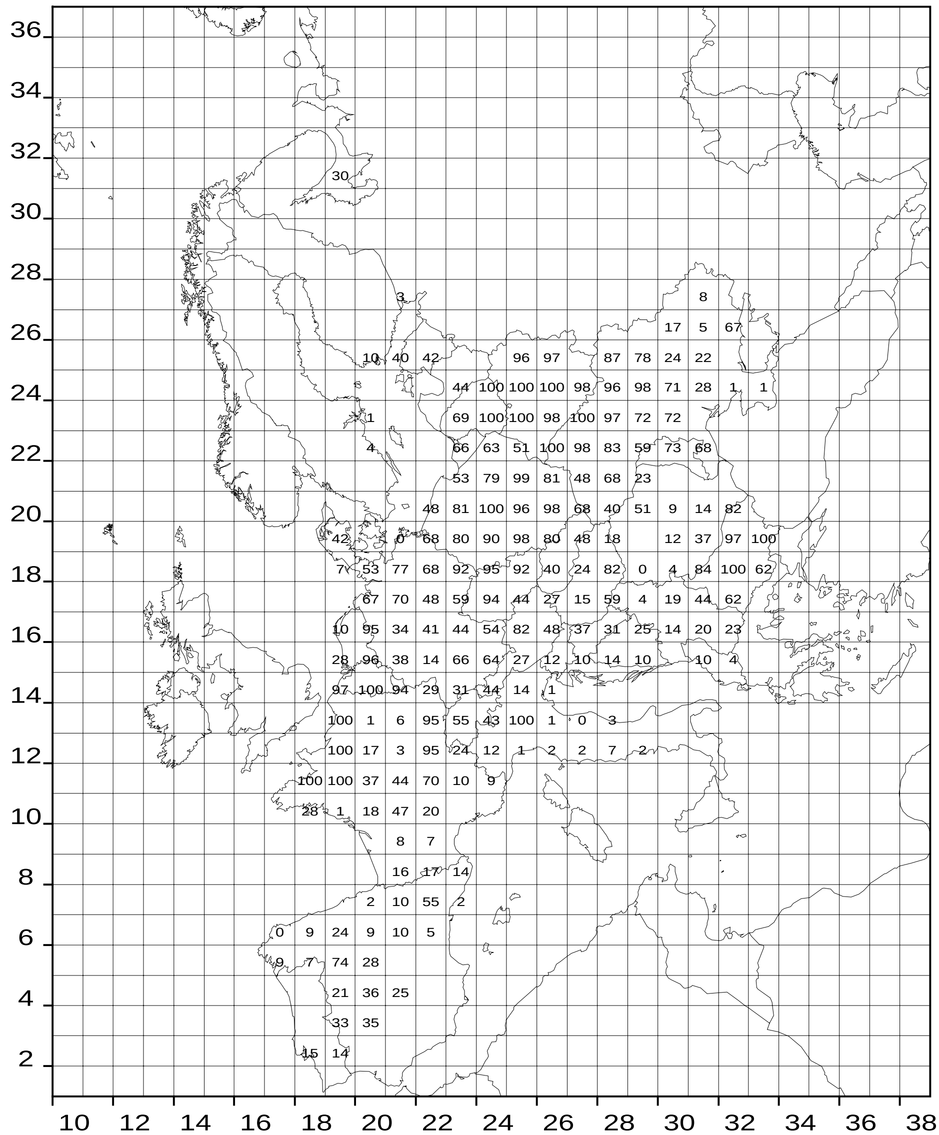

Figure 4.10: Percentage of ecosystems with nitrogen deposition above their critical loads for eutrophication for Scenario B1 (the ‘50% gap closure’ scenario)

Table 4.22: Ecosystems not protected against acidification and eutrophication in Scenario B1 ('50% gap closure')

	Acidification		Eutrophication	
	1000 ha	*%*	**1000 ha**	*%*
Austria	642	*13%*	2376	*49%*
Belgium	9	*1%*	578	*93%*
Denmark	21	*2%*	205	*21%*
Finland	1144	*4%*	260	*1%*
France	40	*0%*	4511	*31%*
Germany	978	*11%*	4436	*51%*
Greece	0	*0%*	91	*4%*
Ireland	1	*0%*	0	*0%*
Italy	103	*2%*	669	*10%*
Luxembourg	2	*2%*	82	*94%*
Netherlands	23	*7%*	257	*80%*
Portugal	0	*0%*	164	*6%*
Spain	10	*0%*	996	*12%*
Sweden	699	*2%*	17	*0%*
United Kingdom	809	*10%*	0	*0%*
EU-15	**4481**	***3%***	**14642**	***13%***
Albania	0	*0%*	68	*6%*
Belarus	52	*3%*	1564	*82%*
Bosnia-H	0	*0%*	276	*19%*
Bulgaria	0	*0%*	2675	*71%*
Croatia	0	*0%*	305	*19%*
Czech R.	267	*10%*	2022	*76%*
Estonia	8	*0%*	502	*27%*
Hungary	40	*3%*	515	*32%*
Latvia	0	*0%*	434	*16%*
Lithuania	12	*1%*	1589	*84%*
Norway	2373	*7%*	0	*0%*
Poland	1655	*26%*	5273	*82%*
R. of Moldova	0	*1%*	2	*20%*
Romania	647	*1%*	10563	*17%*
Russia	3787	*1%*	144	*0%*
Slovakia	79	*4%*	1032	*52%*
Slovenia	28	*3%*	167	*18%*
Switzerland	32	*3%*	948	*45%*
FYRMacedonia	0	*0%*	241	*23%*
Ukraine	99	*1%*	5311	*64%*
F. Yugoslavia	0	*0%*	678	*20%*
Non-EU	**9079**	***2%***	**34310**	***6%***
TOTAL	**13560**	***2%***	**48952**	***10%***

4.3 Exploring the Robustness of the 50% Gap Closure Scenario against Alternative Approaches

Scenario B1 aims at a reduction of the area of unprotected ecosystems within the Member States of the European Union by 50 percent with emission reduction measures which are under direct control of the Community legislation. It has been demonstrated before, however, that acidification is a long-range and transboundary phenomenon, and that emissions from outside the European Union make a certain contribution to the acidification within the EU. (In the same way emissions from the EU contribute to acid deposition in other countries.) This section takes account of this fact and explores alternative and possible cheaper approaches for achieving the same environmental improvements as stipulated for Scenario B1.

4.3.1 Scenario B2: Achieving the 50% Gap Closure Target for the EU by Considering a Lower Sulfur Content in Heavy Fuel Oil used for Marine Shipping

One important finding of the First Interim Report was that by reducing emissions outside the area of the European Union some of the most expensive measures for land-based sources within the European Union could be relaxed and thereby significantly lower overall emission control costs achieved. One particular example concerned the reduction of SO_2 and NO_x emissions from marine shipping activities (Scenario 4 in the First Interim Report) and indicated a possible decrease of the total emission control costs of the '50% gap closure' scenario of about 25 percent.

As a follow-up a scenario was constructed exploring the potential impacts of the measures recently proposed in the framework of the MARPOL Convention. In practice, Scenario B2 analyzes the potential gains of limiting the sulfur content in heavy fuel oil used for vessels in the Baltic and the North Sea to a maximum of 1.5 percent. No measures were considered for SO_2 emissions on the Atlantic and for NO_x emissions on all three regional seas in the modeling domain.

All other assumptions (Modified Conventional Wisdom energy scenario for the year 2010, 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) and environmental targets (50 percent gap closure for the grid cells within the EU, exclusion of three grids at the Finnish/Russian border) are the same as in Scenario B1.

Table 4.23 presents the optimized abatement schedule. Although not forced to use of low-sulfur heavy fuel oil in ships, the optimization selects the available potentials in the North Sea and the Baltic to its full extent. The resulting emission reductions relieve in turn a number of the most expensive measures for land-based sources: SO_2 emissions of Belgium could be 33 % higher than in Scenario B1, in Sweden even by 47 percent, and in the UK by eight percent. Furthermore, lower SO_2 emissions on the sea could also substitute measures for NO_x in Germany and Ireland and for NH_3 in Belgium, Sweden and Germany. For the UK, lower sulfur emissions from ships in the North Sea could abolish the need for almost all measures for reducing ammonia emissions.

Most interesting are the results shown in Table 4.24: While the costs for limiting the sulfur content of marine bunkers in the North Sea and the Baltic to 1.5 percent are estimated at about 87 million ECU/year, land-based sources would experience a decline in their costs of about 1150 million ECU/year. Most savings would occur in Germany, Belgium, Sweden and the UK.

For comparison, measures for reducing SO_2 and NO_x emissions from ships in the Baltic, the North Sea and the Atlantic were estimated in the First Interim Report at about 300 million ECU/year, yielding a decrease in control costs for land-based sources of about 2.4 million ECU/year. The higher cost saving ratio of Scenario B2 (13.2 ECU saved per ECU spent, compared to a ratio of 7.9 in the scenario of the

First Interim Report) indicates that limiting the sulfur content of heavy fuel oil to 1.5 percent and focusing on the North Sea and the Baltic are the more cost-effective options for reducing acidifying emissions from ships.

Table 4.23: Emissions of Scenario B2 ('50% gap closure', low sulfur fuel oil for ships in the Baltic and North Sea) compared with Scenario B1 (in kilotons)

	SO_2			NO_x			NH_3		
	B2	**B1**	***Change***	**B2**	**B1**	***Change***	**B2**	**B1**	***Change***
Austria	57	57	*0%*	116	116	*0%*	93	93	*0%*
Belgium	69	52	*33%*	129	129	*0%*	83	74	*12%*
Denmark	31	31	*0%*	88	88	*0%*	82	82	*0%*
Finland	116	116	*0%*	163	163	*0%*	30	30	*0%*
France	235	235	*0%*	766	766	*0%*	630	630	*0%*
Germany	414	414	*0%*	1184	1079	*10%*	337	318	*6%*
Greece	361	361	*0%*	282	282	*0%*	76	76	*0%*
Ireland	41	41	*0%*	52	42	*24%*	126	126	*0%*
Italy	204	204	*0%*	1160	1160	*0%*	305	305	*0%*
Luxembourg	4	4	*0%*	10	10	*0%*	6	6	*0%*
Netherlands	38	38	*0%*	140	140	*0%*	81	81	*0%*
Portugal	194	194	*0%*	206	206	*0%*	84	84	*0%*
Spain	617	618	*0%*	851	826	*3%*	373	373	*0%*
Sweden	97	66	*47%*	207	207	*0%*	53	49	*8%*
UK	300	279	*8%*	753	753	*0%*	236	224	*5%*
EU-15	**2778**	**2710**	***3%***	**6107**	**5967**	***2%***	**2595**	**2551**	***2%***
Atlantic Sea	316	316	*0%*	349	349	*0%*	0	0	*0%*
Baltic	47	72	*-35%*	80	80	*0%*	0	0	*0%*
North Sea	104	172	*-40%*	191	191	*0%*	0	0	*0%*
SEA	**467**	**560**	***-17%***	**620**	**620**	***0%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	184	184	*0%*	163	163	*0%*
Bosnia-H	410	410	*0%*	48	48	*0%*	23	23	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	126	126	*0%*
Croatia	69	69	*0%*	64	64	*0%*	38	38	*0%*
Czech R.	151	151	*0%*	226	226	*0%*	124	124	*0%*
Estonia	172	172	*0%*	72	72	*0%*	28	28	*0%*
Hungary	544	544	*0%*	196	196	*0%*	136	136	*0%*
Latvia	105	105	*0%*	93	93	*0%*	28	28	*0%*
Lithuania	107	107	*0%*	137	137	*0%*	80	80	*0%*
Norway	33	33	*0%*	161	161	*0%*	39	39	*0%*
Poland	1397	1397	*0%*	821	821	*0%*	545	545	*0%*
R. of Moldova	91	91	*0%*	66	66	*0%*	48	48	*0%*
Romania	590	590	*0%*	453	453	*0%*	300	300	*0%*
Russia	2350	2350	*0%*	2658	2658	*0%*	894	894	*0%*
Slovakia	113	113	*0%*	110	110	*0%*	53	53	*0%*
Slovenia	37	37	*0%*	31	31	*0%*	20	20	*0%*
Switzerland	30	30	*0%*	78	78	*0%*	58	58	*0%*
FYRMacedonia	81	81	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1486	1486	*0%*	1094	1094	*0%*	648	648	*0%*
F.Yugoslavia	262	262	*0%*	118	118	*0%*	83	83	*0%*
Non-EU	**9407**	**9407**	***0%***	**6952**	**6952**	***0%***	**3484**	**3484**	***0%***
TOTAL	**12652**	**12677**	***0%***	**13679**	**13539**	***1%***	**6079**	**6035**	***1%***

Table 4.24: Emission control costs for Scenario B2 ('50% gap closure', 1.5 percent sulfur oil for ships in the Baltic and North Sea), in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B2	**B1**	***add.***	**B2**	**B1**	***add.***	**B2**	**B1**	***add.***	**B2**	**B1**	***add.***
Austria	259	259	*0*	625	625	*0*	0	0	*0*	884	884	*0*
Belgium	398	598	*-200*	888	888	*0*	73	193	*-120*	1359	1679	*-320*
Denmark	161	161	*0*	348	348	*0*	121	121	*0*	630	630	*0*
Finland	159	159	*0*	449	449	*0*	0	0	*0*	608	608	*0*
France	1638	1638	*0*	4950	4950	*0*	36	36	*0*	6624	6624	*0*
Germany	3234	3234	*0*	7575	7941	*-366*	1350	1435	*-85*	12159	12610	*-451*
Greece	220	220	*0*	382	382	*0*	0	0	*0*	602	602	*0*
Ireland	155	155	*0*	184	202	*-18*	194	194	*0*	533	551	*-18*
Italy	2058	2058	*0*	5223	5223	*0*	406	400	*6*	7687	7681	*6*
Luxembourg	10	10	*0*	49	49	*0*	7	7	*0*	66	66	*0*
Netherlands	320	320	*0*	1488	1488	*0*	772	772	*0*	2580	2580	*0*
Portugal	165	165	*0*	790	790	*0*	0	0	*0*	955	955	*0*
Spain	386	385	*1*	3337	3342	*-5*	0	0	*0*	3723	3727	*-4*
Sweden	291	436	*-145*	699	699	*0*	16	34	*-18*	1006	1169	*-163*
UK	1420	1555	*-135*	5198	5198	*0*	73	143	*-70*	6691	6896	*-205*
EU-15	**10874**	**11353**	**-479**	**32185**	**32574**	**-389**	**3048**	**3335**	**-287**	**46107**	**47262**	***-1155***
Atlantic Sea	0	0	*0*	0	0	*0*	0	0	*0*	0	0	*0*
Baltic	24	0	*24*	0	0	*0*	0	0	*0*	24	0	*24*
North Sea	63	0	*63*	0	0	*0*	0	0	*0*	63	0	*63*
SEA	**87**	**0**	**87**	**0**	**0**	**0**	**0**	**0**	**0**	**87**	**0**	***87***

Table continued on next page

Table 4.24: Emission control costs for Scenario B2 ('50% gap closure', 1.5 percent sulfur oil for ships in the Baltic and North Sea), continued

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B2	**B1**	***add.***	**B2**	**B1**	***add.***	**B2**	**B1**	***add.***	**B2**	**B1**	***add.***
Albania	0	0	0	7	7	0	0	0	0	7	7	0
Belarus	0	0	0	160	160	0	0	0	0	160	160	0
Bosnia-H	0	0	0	48	48	0	0	0	0	48	48	0
Bulgaria	155	155	0	4	4	0	0	0	0	159	159	0
Croatia	62	62	0	94	94	0	0	0	0	156	156	0
Czech R.	423	423	0	318	318	0	0	0	0	741	741	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	187	187	0	269	269	0	0	0	0	456	456	0
Latvia	0	0	0	19	19	0	0	0	0	19	19	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	50	50	0	411	411	0	0	0	0	461	461	0
Poland	875	875	0	682	682	0	0	0	0	1557	1557	0
R. of Moldova	8	8	0	0	0	0	0	0	0	8	8	0
Romania	198	198	0	0	0	0	0	0	0	198	198	0
Russia	987	987	0	19	19	0	0	0	0	1006	1006	0
Slovakia	120	120	0	185	185	0	0	0	0	305	305	0
Slovenia	57	57	0	69	69	0	0	0	0	126	126	0
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	22	22	0	0	0	0	22	22	0
Ukraine	463	463	0	128	128	0	0	0	0	591	591	0
F.Yugoslavia	88	88	0	118	118	0	0	0	0	206	206	0
Non-EU	**3737**	**3737**	**0**	**3057**	**3057**	**0**	**0**	**0**	**0**	**6794**	**6794**	**0**
TOTAL	**14698**	**15090**	**-392**	**35242**	**35631**	**-389**	**3048**	**3335**	**-287**	**52988**	**54056**	**-1068**

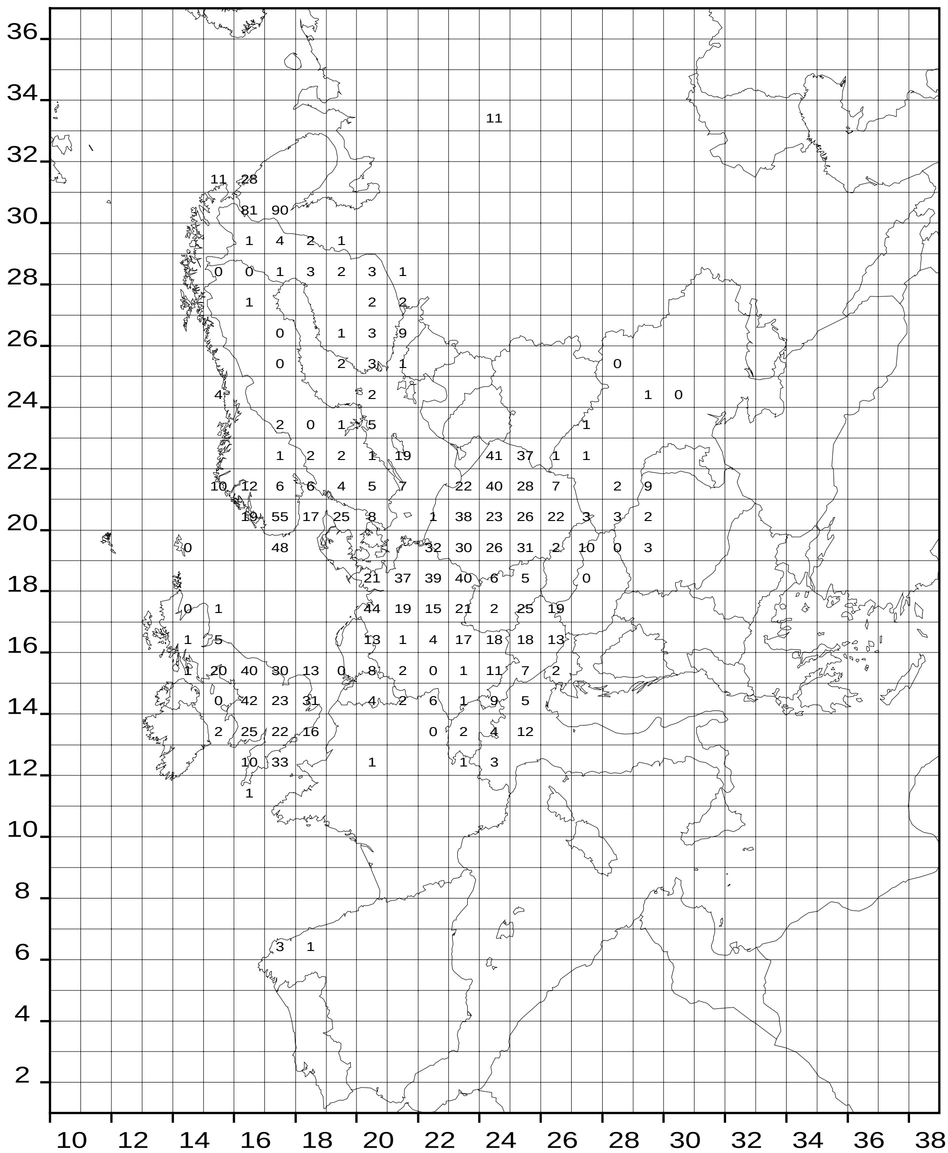

Figure 4.11: Percentage of ecosystems with deposition above their critical loads for acidity for Scenario B2 (‘50% gap closure’, low sulfur fuel oil for ships)

A summary table of the resulting ecosystems’ protection is presented in Table 4.29

4.3.2 Scenario B3: Achieving the 50% Gap Closure Target within the EU also with Emission Reductions in Non-EU Countries

Another group of emitters which impact the ecosystems of the EU are the countries outside of the EU. Scenario B3 explores, again for the 50 percent gap closure target, the allocation of measures if emissions from non-EU countries were also open for 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 the subject of Scenario B4.

In order to ensure comparability with Scenario B1, all other assumptions have been maintained (The Modified 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 4.25 presents the optimized emission abatement schedule and compares it with Scenario B1. According to the definition of the scenario, non-EU countries also 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 primarily SO_2 emissions would be a candidate for a cooperative strategy, and that the potential sources are limited to the Czech Republic, Hungary, Poland and Slovenia. Measures in these four countries could relax the most expensive abatement options for SO_2 (in Belgium, Sweden and the UK), for NO_x in Germany and Ireland, and for ammonia in Belgium, Germany, Sweden and the UK. By spending about 420 million ECU/year outside of the EU, abatement costs within the EU could be lowered by about 980 million ECU/year, leaving a net benefit of about 560 million ECU/year compared to Scenario B1 (Table 4.26).

The measures placed outside of the EU create also local benefits close to the sources. More than 700,000 hectares of European ecosystems in non-EU countries will be protected in addition to the outcome of Scenario B1 (Table 4.29).

Table 4.25: Emissions of Scenario B3 ('50% gap closure' in the EU, measures also in non-EU countries), in kilotons

	SO_2			NO_x			NH_3		
	B3	**B1**	***Change***	**B3**	**B1**	***Change***	**B3**	**B1**	***Change***
Austria	57	57	*0%*	116	116	*0%*	93	93	*0%*
Belgium	69	52	*33%*	129	129	*0%*	83	74	*12%*
Denmark	31	31	*0%*	88	88	*0%*	82	82	*0%*
Finland	116	116	*0%*	163	163	*0%*	30	30	*0%*
France	235	235	*0%*	766	766	*0%*	630	630	*0%*
Germany	414	414	*0%*	1137	1079	*5%*	334	318	*5%*
Greece	361	361	*0%*	282	282	*0%*	76	76	*0%*
Ireland	41	41	*0%*	52	42	*24%*	126	126	*0%*
Italy	204	204	*0%*	1160	1160	*0%*	308	305	*1%*
Luxembourg	4	4	*0%*	10	10	*0%*	6	6	*0%*
Netherlands	38	38	*0%*	140	140	*0%*	81	81	*0%*
Portugal	194	194	*0%*	206	206	*0%*	84	84	*0%*
Spain	617	618	*0%*	851	826	*3%*	373	373	*0%*
Sweden	97	66	*47%*	207	207	*0%*	53	49	*8%*
United Kingdom	300	279	*8%*	753	753	*0%*	236	224	*5%*
EU-15	**2778**	**2710**	***3%***	**6060**	**5967**	***2%***	**2595**	**2551**	***2%***
Atlantic Sea	316	316	*0%*	349	349	*0%*	0	0	*0%*
Baltic	72	72	*0%*	80	80	*0%*	0	0	*0%*
North Sea	172	172	*0%*	191	191	*0%*	0	0	*0%*
SEA	**560**	**560**	***0%***	**620**	**620**	***0%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	184	184	*0%*	163	163	*0%*
Bosnia-H	410	410	*0%*	48	48	*0%*	23	23	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	126	126	*0%*
Croatia	69	69	*0%*	64	64	*0%*	38	38	*0%*
Czech R.	106	151	*-30%*	226	226	*0%*	117	124	*-6%*
Estonia	172	172	*0%*	72	72	*0%*	28	28	*0%*
Hungary	375	544	*-31%*	196	196	*0%*	136	136	*0%*
Latvia	105	105	*0%*	93	93	*0%*	28	28	*0%*
Lithuania	107	107	*0%*	137	137	*0%*	80	80	*0%*
Norway	33	33	*0%*	161	161	*0%*	39	39	*0%*
Poland	728	1397	*-48%*	821	821	*0%*	521	545	*-4%*
R. of Moldova	91	91	*0%*	66	66	*0%*	48	48	*0%*
Romania	590	590	*0%*	453	453	*0%*	300	300	*0%*
Russia	2350	2350	*0%*	2658	2658	*0%*	894	894	*0%*
Slovakia	113	113	*0%*	110	110	*0%*	53	53	*0%*
Slovenia	13	37	*-65%*	31	31	*0%*	20	20	*0%*
Switzerland	30	30	*0%*	78	78	*0%*	58	58	*0%*
FYRMacedonia	81	81	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1486	1486	*0%*	1094	1094	*0%*	648	648	*0%*
F.Yugoslavia	262	262	*0%*	118	118	*0%*	83	83	*0%*
Non-EU	**8500**	**9407**	***-10%***	**6952**	**6952**	***0%***	**3453**	**3484**	***-1%***
TOTAL	**11838**	**12677**	***-7%***	**13632**	**13539**	***1%***	**6048**	**6035**	***0%***

Table 4.26: Emission control costs for Scenario B3 ('50% gap closure', measures also in non-EU countries), in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B3	**B1**	***add.***	**B3**	**B1**	***add.***	**B3**	**B1**	***add.***	**B3**	**B1**	***add.***
Austria	259	259	0	625	625	0	0	0	0	884	884	0
Belgium	398	598	-200	888	888	0	73	193	-120	1359	1679	-320
Denmark	161	161	0	348	348	0	121	121	0	630	630	0
Finland	159	159	0	449	449	0	0	0	0	608	608	0
France	1638	1638	0	4950	4950	0	36	36	0	6624	6624	0
Germany	3234	3234	0	7780	7941	-161	1362	1435	-73	12376	12610	-234
Greece	220	220	0	382	382	0	0	0	0	602	602	0
Ireland	155	155	0	184	202	-18	194	194	0	533	551	-18
Italy	2058	2058	0	5223	5223	0	363	400	-37	7644	7681	-37
Luxembourg	10	10	0	49	49	0	7	7	0	66	66	0
Netherlands	320	320	0	1488	1488	0	772	772	0	2580	2580	0
Portugal	165	165	0	790	790	0	0	0	0	955	955	0
Spain	386	385	1	3337	3342	-5	0	0	0	3723	3727	-4
Sweden	291	436	-145	699	699	0	16	34	-18	1006	1169	-163
United Kingdom	1420	1555	-135	5198	5198	0	73	143	-70	6691	6896	-205
EU-15	10874	11353	-479	32390	32574	-184	3017	3335	-318	46281	47262	-981
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 4.26: Emission control costs for Scenario B3 ('50% gap closure', measures also in non-EU countries), in million ECU/year, continued

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B3	**B1**	***add.***	**B3**	**B1**	***add.***	**B3**	**B1**	***add.***	**B3**	**B1**	***add.***
Albania	0	0	0	7	7	0	0	0	0	7	7	0
Belarus	0	0	0	160	160	0	0	0	0	160	160	0
Bosnia-H	0	0	0	48	48	0	0	0	0	48	48	0
Bulgaria	155	155	0	4	4	0	0	0	0	159	159	0
Croatia	62	62	0	94	94	0	0	0	0	156	156	0
Czech R.	480	423	57	318	318	0	5	0	5	803	741	62
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	231	187	44	269	269	0	0	0	0	500	456	44
Latvia	0	0	0	19	19	0	0	0	0	19	19	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	50	50	0	411	411	0	0	0	0	461	461	0
Poland	1166	875	291	682	682	0	15	0	15	1863	1557	306
R. of Moldova	8	8	0	0	0	0	0	0	0	8	8	0
Romania	198	198	0	0	0	0	0	0	0	198	198	0
Russia	987	987	0	19	19	0	0	0	0	1006	1006	0
Slovakia	120	120	0	185	185	0	0	0	0	305	305	0
Slovenia	67	57	10	69	69	0	0	0	0	136	126	10
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	22	22	0	0	0	0	22	22	0
Ukraine	463	463	0	128	128	0	0	0	0	591	591	0
F.Yugoslavia	88	88	0	118	118	0	0	0	0	206	206	0
Non-EU	**4139**	**3737**	**402**	**3057**	**3057**	**0**	**20**	**0**	**20**	**7216**	**6794**	**422**
TOTAL	**15013**	**15090**	**-77**	**35447**	**35631**	**-184**	**3037**	**3335**	**-298**	**53497**	**54056**	**-559**

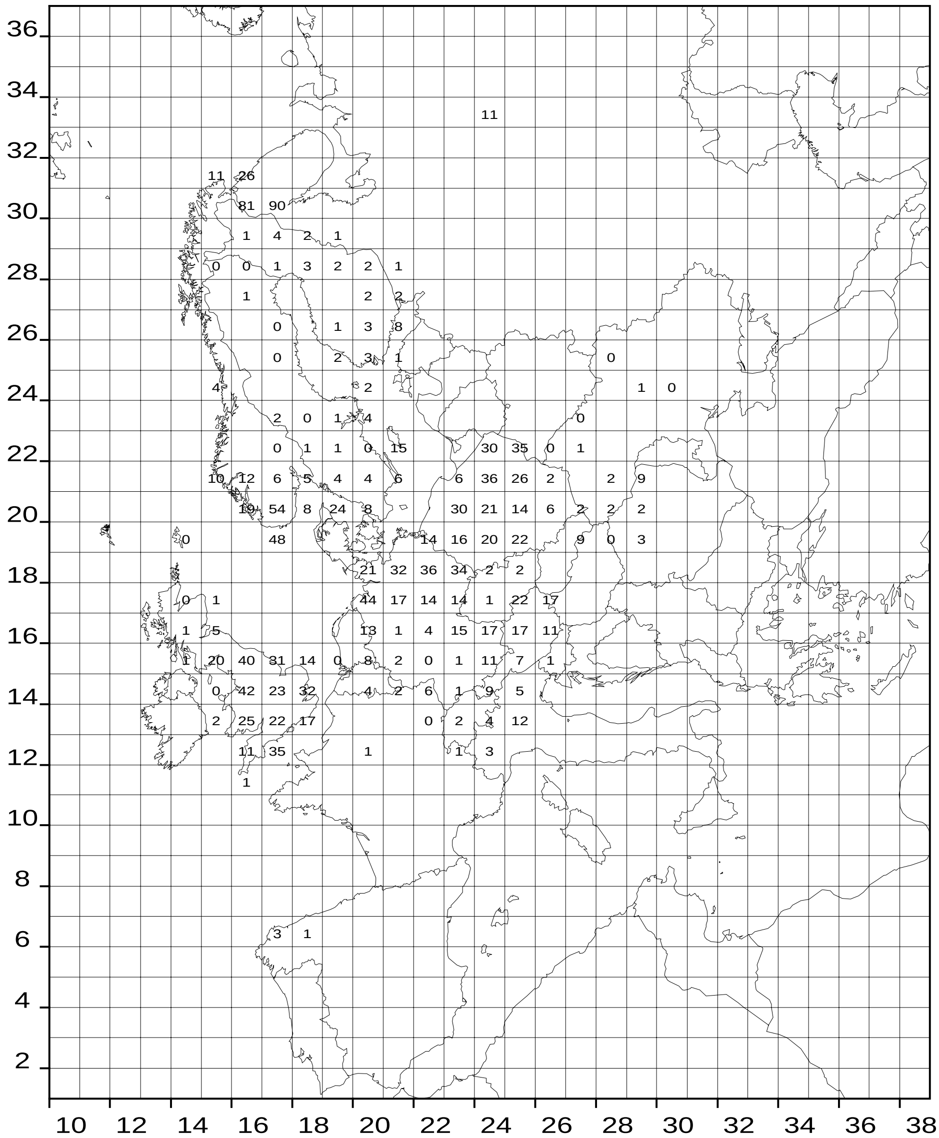

Figure 4.12: Percentage of ecosystems with deposition above their critical loads for acidity for Scenario B3 ('50% gap closure', measures also in non-EU countries)

A summary table of the resulting ecosystems' protection is presented in Table 4.29

4.3.3 Scenario B4: Achieving the 50% Gap Closure Target for all of Europe

As a last example of an alternative approach for halving the area of the ecosystems unprotected against acidification, Scenario B4 explores the implications if this target 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 for 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 look 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 the inclusion of environmental targets for ecosystems outside the EU imposes significant requirements for emission reductions in the non-EU countries. It is interesting to note that in these countries the target on acidification will mainly force further measures for reducing SO_2 emissions (-57 percent compared to the REF scenario), but comparably little further efforts for NO_x (-2 %) and NH_3 (-6 %) are needed. The scenario demonstrates clearly the impact emissions from the EU have on ecosystems outside the European Union: In order to achieve this 50 percent gap closure target throughout Europe, the EU-15 would have to reduce its SO_2 emissions seven percent below the level of the B1 scenario, i.e., beyond what would be necessary to achieve the target only within its own territory. This means that for most countries of the European Union Scenario B1 could be considered also as an interim step towards an eventual Europe-wide 50 percent gap closure goal (the only exceptions are Germany, Belgium and Italy, which would experience a slight relaxation of their obligations). It is also interesting to note that in this scenario emissions from ships are reduced to the maximum possible extent.

The strict control of acidifying emissions throughout Europe leaves only 2.9 million hectares unprotected within the EU-15, compared to 4.5 million in Scenario B1 (Table 4.29).

Table 4.27: Emissions for Scenario B4 ('50% gap closure' for all of Europe), in kilotons

	SO_2			NO_x			NH_3		
	B4	**B1**	***Change***	**B4**	**B1**	***Change***	**B4**	**B1**	***Change***
Austria	57	57	*0%*	116	116	*0%*	93	93	*0%*
Belgium	69	52	*33%*	129	129	*0%*	83	74	*12%*
Denmark	20	31	*-35%*	75	88	*-15%*	53	82	*-35%*
Finland	116	116	*0%*	163	163	*0%*	30	30	*0%*
France	235	235	*0%*	766	766	*0%*	580	630	*-8%*
Germany	414	414	*0%*	1200	1079	*11%*	361	318	*14%*
Greece	361	361	*0%*	282	282	*0%*	76	76	*0%*
Ireland	41	41	*0%*	30	42	*-29%*	126	126	*0%*
Italy	204	204	*0%*	1160	1160	*0%*	315	305	*3%*
Luxembourg	4	4	*0%*	10	10	*0%*	6	6	*0%*
Netherlands	38	38	*0%*	140	140	*0%*	81	81	*0%*
Portugal	194	194	*0%*	206	206	*0%*	84	84	*0%*
Spain	521	618	*-16%*	788	826	*-5%*	373	373	*0%*
Sweden	66	66	*0%*	185	207	*-11%*	51	49	*4%*
United Kingdom	181	279	*-35%*	693	753	*-8%*	215	224	*-4%*
EU-15	**2521**	**2710**	***-7%***	**5943**	**5967**	***0%***	**2527**	**2551**	***-1%***
Atlantic Sea	76	316	*-76%*	70	349	*-80%*	0	0	*0%*
Baltic	18	72	*-75%*	16	80	*-80%*	0	0	*0%*
North Sea	42	172	*-76%*	38	191	*-80%*	0	0	*0%*
SEA	**136**	**560**	***-76%***	**124**	**620**	***-80%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	78	490	*-84%*	184	184	*0%*	156	163	*-4%*
Bosnia-H	39	410	*-90%*	48	48	*0%*	23	23	*0%*
Bulgaria	132	835	*-84%*	290	290	*0%*	126	126	*0%*
Croatia	34	69	*-51%*	64	64	*0%*	38	38	*0%*
Czech R.	106	151	*-30%*	226	226	*0%*	115	124	*-7%*
Estonia	17	172	*-90%*	72	72	*0%*	28	28	*0%*
Hungary	288	544	*-47%*	196	196	*0%*	131	136	*-4%*
Latvia	37	105	*-65%*	93	93	*0%*	28	28	*0%*
Lithuania	26	107	*-76%*	126	137	*-8%*	77	80	*-4%*
Norway	18	33	*-45%*	97	161	*-40%*	28	39	*-28%*
Poland	417	1397	*-70%*	821	821	*0%*	503	545	*-8%*
R. of Moldova	21	91	*-77%*	52	66	*-21%*	33	48	*-31%*
Romania	91	590	*-85%*	369	453	*-19%*	228	300	*-24%*
Russia	2110	2350	*-10%*	2658	2658	*0%*	894	894	*0%*
Slovakia	64	113	*-43%*	110	110	*0%*	53	53	*0%*
Slovenia	13	37	*-65%*	31	31	*0%*	20	20	*0%*
Switzerland	30	30	*0%*	78	78	*0%*	58	58	*0%*
FYRMacedonia	81	81	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	392	1486	*-74%*	1094	1094	*0%*	597	648	*-8%*
F.Yugoslavia	36	262	*-86%*	118	118	*0%*	83	83	*0%*
Non-EU	**4084**	**9407**	***-57%***	**6779**	**6952**	***-2%***	**3269**	**3484**	***-6%***
TOTAL	**6741**	**12677**	***-47%***	**12846**	**13539**	***-5%***	**5796**	**6035**	***-4%***

Table 4.28: Emission control costs for Scenario B4 ('50% gap closure' for all of Europe), in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B4	**B1**	***add.***	**B4**	**B1**	***add.***	**B4**	**B1**	***add.***	**B4**	**B1**	***add.***
Austria	259	259	0	625	625	0	0	0	0	884	884	0
Belgium	398	598	-200	888	888	0	73	193	-120	1359	1679	-320
Denmark	247	161	86	384	348	36	455	121	334	1086	630	456
Finland	159	159	0	449	449	0	0	0	0	608	608	0
France	1638	1638	0	4950	4950	0	248	36	212	6836	6624	212
Germany	3234	3234	0	7504	7941	-437	717	1435	-718	11455	12610	-1155
Greece	220	220	0	382	382	0	0	0	0	602	602	0
Ireland	155	155	0	245	202	43	194	194	0	594	551	43
Italy	2058	2058	0	5223	5223	0	291	400	-109	7572	7681	-109
Luxembourg	10	10	0	49	49	0	7	7	0	66	66	0
Netherlands	320	320	0	1488	1488	0	772	772	0	2580	2580	0
Portugal	165	165	0	790	790	0	0	0	0	955	955	0
Spain	434	385	49	3356	3342	14	0	0	0	3790	3727	63
Sweden	436	436	0	726	699	27	20	34	-14	1182	1169	13
United Kingdom	2702	1555	1147	5703	5198	505	234	143	91	8639	6896	1743
EU-15	**12435**	**11353**	**1082**	**32762**	**32574**	**188**	**3011**	**3335**	**-324**	**48208**	**47262**	**946**
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**

Table continued on next page

Table 4.28: Emission control costs for Scenario B4 ('50% gap closure' for all of Europe), in million ECU/year, continued

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B4	**B1**	***add.***	**B4**	**B1**	***add.***	**B4**	**B1**	***add.***	**B4**	**B1**	***add.***
Albania	0	0	0	7	7	0	0	0	0	7	7	0
Belarus	178	0	178	160	160	0	3	0	3	341	160	181
Bosnia-H	93	0	93	48	48	0	0	0	0	141	48	93
Bulgaria	339	155	184	4	4	0	0	0	0	343	159	184
Croatia	83	62	21	94	94	0	0	0	0	177	156	21
Czech R.	480	423	57	318	318	0	11	0	11	809	741	68
Estonia	77	0	77	0	0	0	0	0	0	77	0	77
Hungary	310	187	123	269	269	0	4	0	4	583	456	127
Latvia	30	0	30	19	19	0	0	0	0	49	19	30
Lithuania	54	0	54	2	0	2	2	0	2	58	0	58
Norway	126	50	76	570	411	159	78	0	78	774	461	313
Poland	1517	875	642	682	682	0	40	0	40	2239	1557	682
R. of Moldova	51	8	43	3	0	3	73	0	73	127	8	119
Romania	453	198	255	28	0	28	310	0	310	791	198	593
Russia	1076	987	89	19	19	0	0	0	0	1095	1006	89
Slovakia	154	120	34	185	185	0	0	0	0	339	305	34
Slovenia	67	58	9	69	69	0	0	0	0	136	127	9
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	22	22	0	0	0	0	22	22	0
Ukraine	974	463	511	128	128	0	42	0	42	1144	591	553
F.Yugoslavia	265	88	177	118	118	0	0	0	0	383	206	177
Non-EU	**6391**	**3738**	**2653**	**3249**	**3057**	**192**	**563**	**0**	**563**	**10203**	**6795**	**3408**
TOTAL	**19212**	**15091**	**4121**	**36171**	**35631**	**540**	**3574**	**3335**	**239**	**58957**	**54057**	**4900**

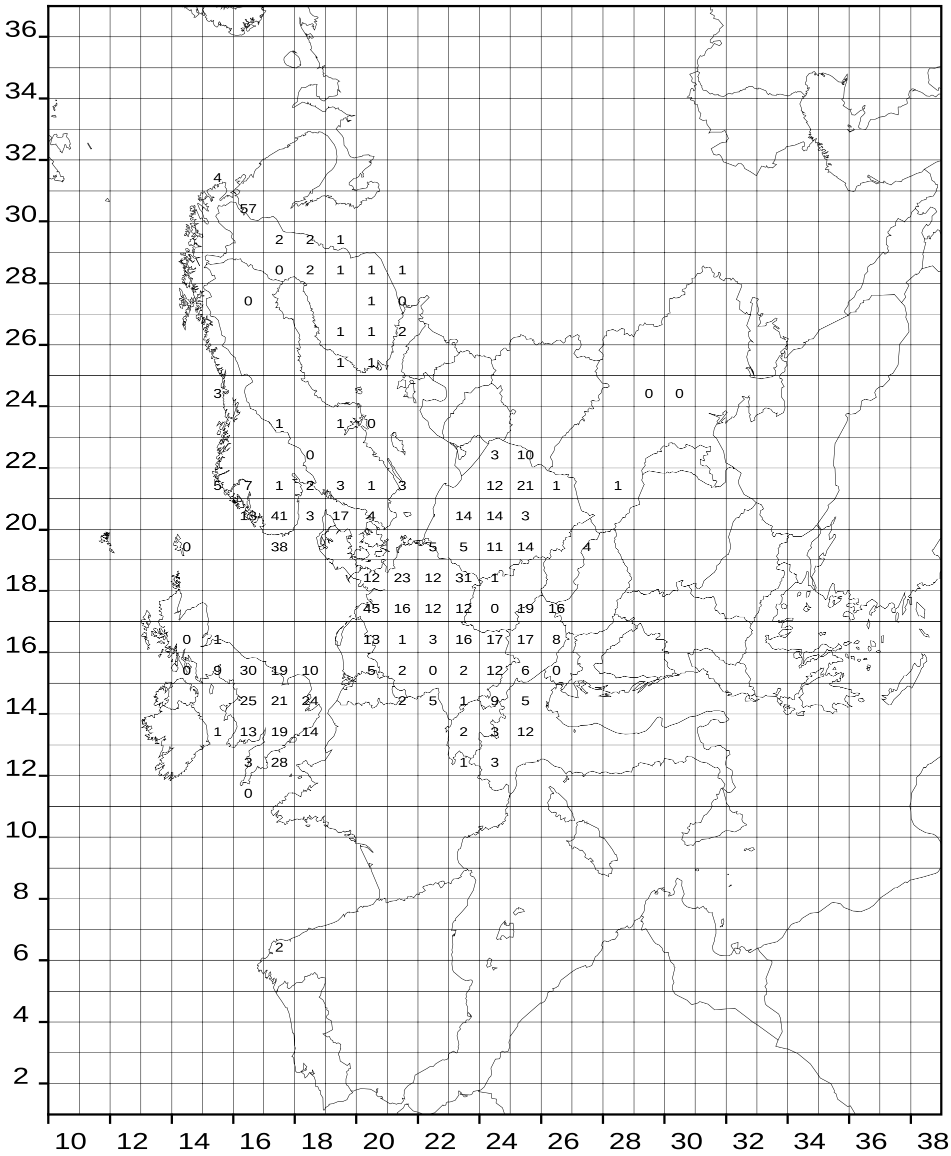

Figure 4.13: Percentage of ecosystems with deposition above their critical loads for acidity for Scenario B4 ('50% gap closure', ECE-wide context)

Table 4.29: Comparison of unprotected ecosystems for scenarios REF, B1 ('50% gap closure'), B2 (ships), B3 (measures in non-EU countries) and B4 (Europe-wide targets)

	REF		B1		B2		B3		B4	
	1000 ha	**%**	**1000 ha**	**%**	**1000 ha**	**%**	**1000 ha**	**%**	**1000 ha**	**%**
Austria	943	19%	642	13%	650	13%	590	12%	534	11%
Belgium	117	19%	9	1%	25	4%	25	4%	9	2%
Denmark	38	4%	21	2%	20	2%	19	2%	12	1%
Finland	1211	4%	1144	4%	1147	4%	1122	4%	592	2%
France	82	1%	40	0%	46	0%	46	0%	33	0%
Germany	2541	29%	978	11%	1111	13%	977	11%	786	9%
Greece	0	0%	0	0%	0	0%	0	0%	0	0%
Ireland	4	1%	1	0%	1	0%	1	0%	0	0%
Italy	285	4%	103	2%	104	2%	101	2%	96	1%
Luxembourg	7	8%	2	2%	2	2%	2	2%	2	2%
Netherlands	121	38%	23	7%	27	9%	27	9%	24	7%
Portugal	0	0%	0	0%	0	0%	0	0%	0	0%
Spain	24	0%	10	0%	10	0%	10	0%	6	0%
Sweden	1235	3%	699	2%	764	2%	672	2%	268	1%
UK	2112	27%	809	10%	887	11%	890	11%	539	7%
EU-15	**8719**	**7%**	**4481**	**3%**	**4793**	**4%**	**4482**	**3%**	**2901**	**2%**
Albania	0	0%	0	0%	0	0%	0	0%	0	0%
Belarus	53	3%	52	3%	52	3%	47	3%	12	1%
Bosnia-H	0	0%	0	0%	0	0%	0	0%	0	0%
Bulgaria	0	0%	0	0%	0	0%	0	0%	0	0%
Croatia	1	0%	0	0%	0	0%	0	0%	0	0%
Czech R.	618	23%	267	10%	285	11%	200	8%	169	6%
Estonia	10	1%	8	0%	8	0%	8	0%	1	0%
Hungary	44	3%	40	3%	41	3%	36	2%	24	2%
Latvia	0	0%	0	0%	0	0%	0	0%	0	0%
Lithuania	12	1%	12	1%	12	1%	9	1%	1	0%
Norway	3539	11%	2373	7%	2397	8%	2330	7%	1550	5%
Poland	1930	30%	1655	26%	1670	26%	1161	18%	557	9%
R. of Moldova	0	1%	0	1%	0	1%	0	1%	0	0%
Romania	656	1%	647	1%	647	1%	619	1%	0	0%
Russia	4094	1%	3787	1%	3797	1%	3759	1%	841	0%
Slovakia	83	4%	79	4%	79	4%	63	3%	34	2%
Slovenia	47	5%	28	3%	28	3%	20	2%	13	1%
Switzerland	105	9%	32	3%	32	3%	32	3%	28	2%
FYRMacedonia	0	0%	0	0%	0	0%	0	0%	0	0%
Ukraine	104	1%	99	1%	99	1%	69	1%	6	0%
F.Yugoslavia	0	0%	0	0%	0	0%	0	0%	0	0%
Non-EU	**11298**	**3%**	**9079**	**2%**	**9149**	**2%**	**8353**	**2%**	**3238**	**1%**
TOTAL	**20017**	**4%**	**13560**	**2%**	**13942**	**2%**	**12835**	**2%**	**6139**	**1%**

4.4 Considering Acidification together with Other Environmental Problems

The initial analysis presented in the First Interim Report looked at cost-effective ways for achieving improvement of the acidification problem. It is obvious, however, that also other important environmental problems exist, some of them closely interrelated with the sources of acidifying emissions. As a consequence, a well-designed strategy to combat acidification should not look at this problem in isolation, but should consider also possible synergisms, trade-offs and side-impacts with other environmental problems.

For this Second Interim Report, work succeeded in introducing some basic aspects related to greenhouse gas emissions, ground-level ozone and eutrophication into the analysis of acidification-related strategies. Due to methodological reasons and the short time available for this report, the analysis used three different approaches for exploring possible interactions between an acidification strategy and these problem areas:

- The concern about emissions of greenhouse gases has been addressed by repeating the analysis of Scenario B1 based on an energy scenario in which CO_2 emissions of the EU-15 would be reduced by ten percent in comparison to the levels of 1990. This means that, for the purposes of this analysis, a strategy for controlling CO_2 emissions (and thereby the energy structure of the low CO_2 scenario) has been assumed as given; the optimization was then used to identify the optimal composition of acidification-induced emission reductions.
- Eutrophication of ecosystems is caused by emissions of nitrogen oxides and ammonia, both having direct impact on acidification. Therefore the analysis performed a simultaneous optimization of reductions of SO_2, NO_x and NH_3 emissions, with environmental targets specified both for acidification and eutrophication. This means that this work explored the optimal mix of measures for addressing both environmental problems, taking full account of existing synergisms.
- Finally, the problem of ground-level ozone has been introduced into the analysis by exploring the side-effects of the emission reductions of the B1 scenario on ground-level ozone in Europe, mainly with the aim of detecting possible trade-offs between acidification and ozone strategies. Within the given time it was not possible to study cost-effective approaches for solving both problems simultaneously. It should be mentioned, however, that in the meantime work at IIASA has continued in developing an ozone optimization module. It is planned to address this problem in the future.

4.4.1 Scenario B5: The Implications of a Community Strategy to Limit Greenhouse Gas Emissions

Earlier studies identified a potentially large interaction between acidification and greenhouse gas related emission reduction strategies. In order to assess the potential magnitude of this effect, a scenario was constructed in which the analysis of Scenario B1 (the ‘50% gap closure’ scenario) was repeated assuming an energy consumption pattern which achieves by the year 2010 a ten percent reduction of CO_2 emissions for the European Union.

For this analysis a ‘Low CO_2’ energy scenario was developed by the National Technical University of Greece (Athens) using the MIDAS energy model for the countries of the EU-15 (Kapros and Kokkolakis, 1996). It aims at reducing the EU-15’s CO_2 emissions by ten percent by 2010.

Table 4.30: Energy consumption of the low CO_2 scenario compared with the Modified Conventional Wisdom scenario for the EU-15 (Source: Kapros and Kokkolakis, 1996)

Source category/fuel	**Low CO_2 Scenario 2010 [PJ]**	**Modified Conventional Wisdom Scenario 2010 [PJ]**	**Difference %**
Stationary combustion sources:			
Total	46247	51741	*-11%*
- Coal	5195	8460	*-39%*
- Liquid fuels	10730	10819	*-1 %*
- Gaseous fuels	16811	19009	*-12 %*
- Other	13512	13453	*0%*
Mobile sources - total	11826	12958	*-9 %*
TOTAL	**58073**	**64699**	***-6%***

Table 4.31: Total primary energy consumption of the low CO_2 scenario compared with the Modified Conventional Wisdom scenario (in PJ)

Total energy consumption in the low CO_2 scenario is about ten percent lower than in the Modified Conventional Wisdom energy scenario (Table 4.30). Coal consumption decreases dramatically to only 60 percent of the level of the reference case, while the use of biomass, hydropower, nuclear and renewable energy sources increases in absolute terms and reaches a share of 23 percent of total primary energy consumption.

It is not surprising that such a dramatically different energy consumption pattern implies also a different cost-minimal allocation of measures to reduce acidifying emissions (Table 4.32 and Table 4.33). A closer look, however, reveals a systematic response towards changed structures of energy consumption.

One important, but obvious, factor causing differences in optimized emission levels is that the currently adopted elements of emission legislation (CLE) prescribing emission standards will result in modified volumes of emissions when the activity levels (e.g., fuel consumption) are changed. Since the REF scenario, which is used as an upper constraint for the optimization of national emissions, is partly determined by the results of the 'Current Legislation' (CLE), the emission levels of the optimal solution change accordingly if another energy scenario is adopted. In this particular case this phenomenon occurs for SO_2 emissions for Austria, Greece and Portugal, for which the CLE case for the low CO_2 scenario results in up to 16 percent lower SO_2 emissions compared to the Conventional Wisdom energy scenario. For NO_x, the CLE levels determine the optimal solution for Austria, Finland, Ireland, Luxembourg, Netherlands, Portugal, Spain and Sweden with up to 12 percent less emissions.

The second factor leading to changed emission levels relates to emission control costs. Due to the different structure of energy consumption of the low CO_2 scenario (i.e., the lower consumption of carbon containing fuels), costs for the reduction of acidifying emissions from the energy sector are lower in all countries than for the Conventional Wisdom scenario. This means that the same emission levels as in the B1 scenario could be achieved at lower cost, and there is even a potential for further reductions without an increase in the costs. Consequently, the cost-optimization can utilize this additional potential for relaxing some of the most expensive measures. This mechanism is nicely illustrated in the B5 scenario, where additional measures are taken in many countries (though at lower costs than in the B1 scenario) basically to compensate for less reductions of SO_2 emissions in Belgium and Ireland, of NO_x emissions in Denmark and the UK, and for some of the ammonia control. It is important to stress, however, that all countries face lower costs than in the B1 scenario. For the EU-15 as a whole, emission control costs of the low CO_2 scenario are nine percent lower.

Although the changed allocation of emission reductions can be fully explained by their cost-effectiveness, the fact that optimal emission levels differ up to 30 percent (compared to Scenario B1) may raise questions for strategies relying solely on national emission ceilings. A closer look, however, reveals the variations as less dramatic for several reasons:

(i) If the 'hard' target emissions ceilings, i.e., those which are not automatically achieved by current legislation, are related to the present situation (e.g., to the levels of the year 1990), even the largest differences decrease to between five and seven percent, with the majority of cases below three percent (Figure 4.14 TO Figure 4.16).

(ii) The emission ceilings based on e.g., the Conventional Wisdom scenario would still achieve the 50 percent gap closure target for acidification, although possibly not at minimum costs for the EU-15 as a whole. Each country, however, would face less costs for controlling acidifying emissions than currently anticipated, which could in turn foster the implementation of the low CO_2 scenario.

(iii) A strategy aiming at a ten percent decrease of the CO_2 emissions within the next ten to 15 years implies a substantial redesign of current energy policies in Europe. If Europe-wide cost minimization for the control of acidification is still of interest, it is conceivable that the ceilings for acidifying emissions are also subject to revision within such a significant re-orientation process. In this context it is important to keep in mind that for most of the countries such an amendment would result in further tightened emission ceilings, i.e., would not reverse current planning. Only a few countries would experience reduced obligations. It may remain a political decision whether the gains to be made will be considered large enough to justify a reversal of existing policies, especially in the light of the longer-term target of the full achievement of critical loads. Such a target will require additional emission reductions that go in beyond the reductions of Scenario B1.

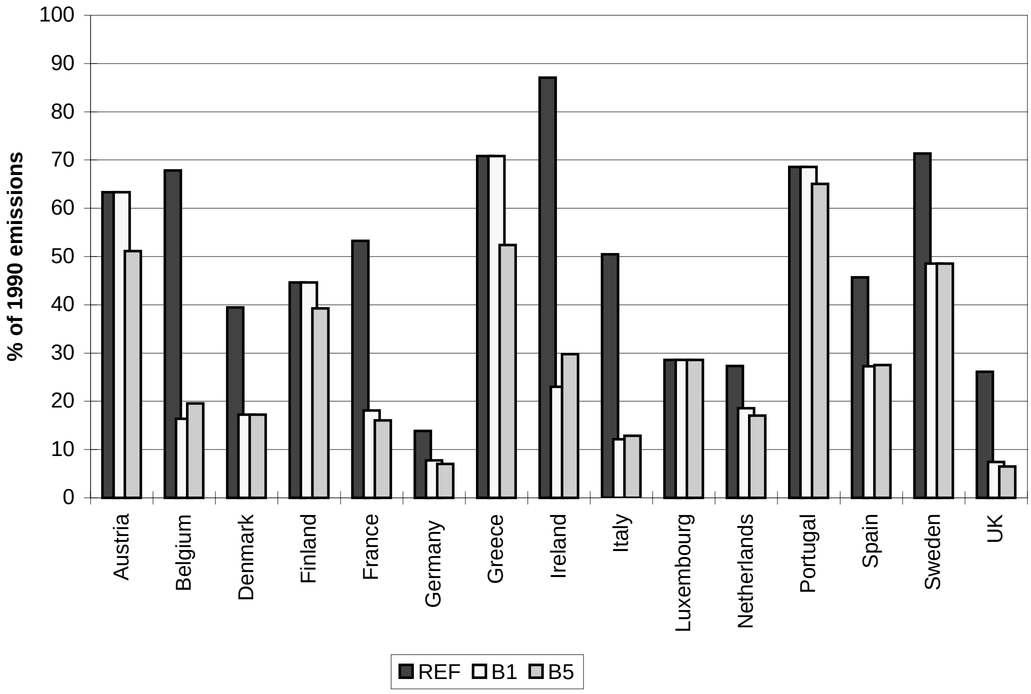

Figure 4.14: SO_2 emissions for the REF, the B1 ('50% gap closure') and the B5 (low CO_2) scenarios compared to the level of 1990

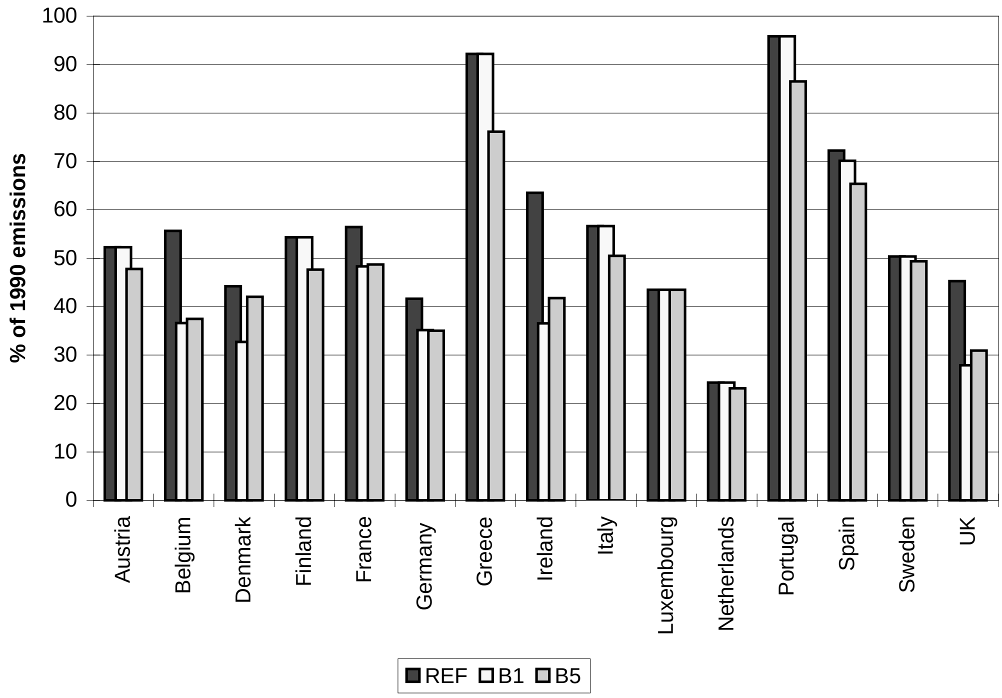

Figure 4.15: NO_x emissions for the REF, the B1 ('50% gap closure') and the B5 (low CO_2) scenarios compared to the level of 1990

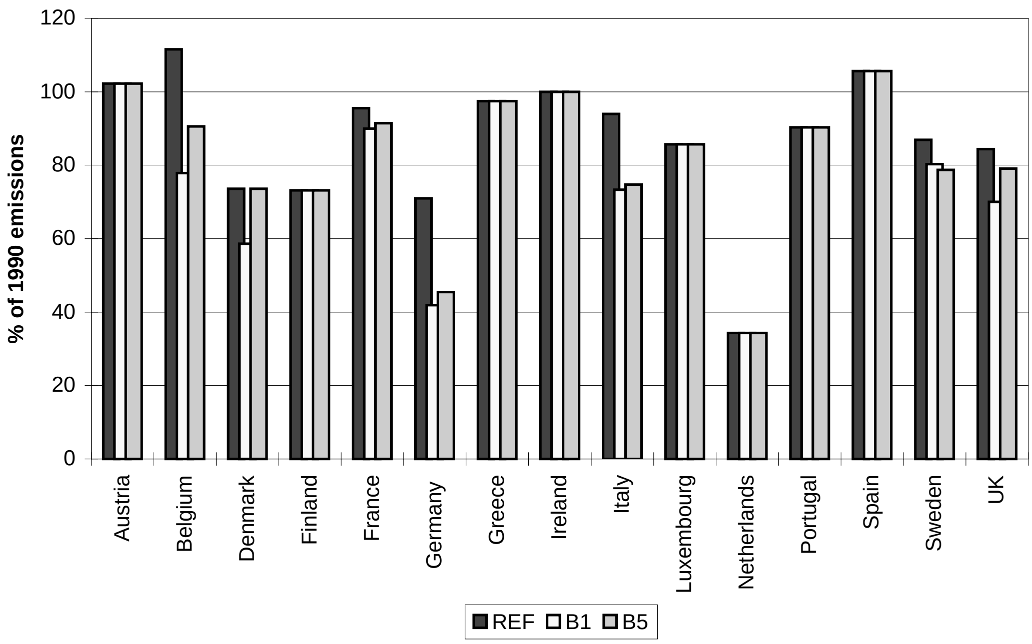

Figure 4.16: NH_3 emissions for the REF, the B1 ('50% gap closure') and the B5 (low CO_2) scenarios compared to the level of 1990

Table 4.32: Emissions of Scenario B5 (low CO_2 scenario) compared with those of the B1 scenario (in kilotons)

	SO_2			NO_x			NH_3		
	B5	**B1**	***Change***	**B5**	**B1**	***Change***	**B5**	**B1**	***Change***
Austria	46[*)]	57	*-19%*	106[*)]	116	*-9%*	93	93	*0%*
Belgium	62	52	*19%*	132	129	*2%*	86	74	*16%*
Denmark	31	31	*0%*	113	88	*28%*	103	82	*26%*
Finland	102	116	*-12%*	143[*)]	163	*-12%*	30	30	*0%*
France	208	235	*-11%*	772	766	*1%*	640	630	*2%*
Germany	373	414	*-10%*	1076	1079	*0%*	345	318	*8%*
Greece	267[*)]	361	*-26%*	233[*)]	282	*-17%*	76	76	*0%*
Ireland	53	41	*29%*	48	42	*14%*	126	126	*0%*
Italy	216	204	*6%*	1034[*)]	1160	*-11%*	311	305	*2%*
Luxembourg	4	4	*0%*	10[*)]	10	*0%*	6	6	*0%*
Netherlands	35	38	*-8%*	133[*)]	140	*-5%*	81	81	*0%*
Portugal	184[*)]	194	*-5%*	186[*)]	206	*-10%*	84	84	*0%*
Spain	624	618	*1%*	770[*)]	826	*-7%*	373	373	*0%*
Sweden	66	66	*0%*	203[*)]	207	*-2%*	48	49	*-2%*
United Kingdom	244	279	*-13%*	835	753	*11%*	253	224	*13%*
EU-15	**2515**	**2710**	***-7%***	**5794**	**5967**	***-3%***	**2655**	**2551**	***4%***
Atlantic Sea	317	316	*0%*	349	349	*0%*	0	0	*0%*
Baltic	72	72	*0%*	80	80	*0%*	0	0	*0%*
North Sea	172	172	*0%*	191	191	*0%*	0	0	*0%*
SEA	**561**	**560**	***0%***	**620**	**620**	***0%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	184	184	*0%*	163	163	*0%*
Bosnia-H	410	410	*0%*	48	48	*0%*	23	23	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	126	126	*0%*
Croatia	69	69	*0%*	64	64	*0%*	38	38	*0%*
Czech R.	151	151	*0%*	226	226	*0%*	124	124	*0%*
Estonia	172	172	*0%*	72	72	*0%*	28	28	*0%*
Hungary	544	544	*0%*	196	196	*0%*	136	136	*0%*
Latvia	105	105	*0%*	93	93	*0%*	28	28	*0%*
Lithuania	107	107	*0%*	137	137	*0%*	80	80	*0%*
Norway	33	33	*0%*	161	161	*0%*	39	39	*0%*
Poland	1397	1397	*0%*	821	821	*0%*	545	545	*0%*
R. of Moldova	91	91	*0%*	66	66	*0%*	48	48	*0%*
Romania	590	590	*0%*	453	453	*0%*	300	300	*0%*
Russia	2350	2350	*0%*	2658	2658	*0%*	894	894	*0%*
Slovakia	113	113	*0%*	110	110	*0%*	53	53	*0%*
Slovenia	37	37	*0%*	31	31	*0%*	20	20	*0%*
Switzerland	30	30	*0%*	78	78	*0%*	58	58	*0%*
FYRMacedonia	81	81	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1486	1486	*0%*	1094	1094	*0%*	648	648	*0%*
F.Yugoslavia	262	262	*0%*	118	118	*0%*	83	83	*0%*
Non-EU	**9407**	**9407**	***0%***	**6952**	**6952**	***0%***	**3484**	**3484**	***0%***
TOTAL	**12483**	**12677**	***-2%***	**13366**	**13539**	***-1%***	**6139**	**6035**	***2%***

Explanation:
[*)] Emission level is the result of the application of current emission control legislation to the low CO_2 energy scenario

Table 4.33: Emission control costs for the B5 (low CO_2 scenario), in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B5	**B1**	***add.***	**B5**	**B1**	***add.***	**B5**	**B1**	***add.***	**B5**	**B1**	***add.***
Austria	203	259	*-56*	610	625	*-15*	0	0	*0*	813	884	*-71*
Belgium	322	598	*-276*	819	888	*-69*	55	193	*-138*	1196	1679	*-483*
Denmark	161	161	*0*	315	348	*-33*	41	121	*-80*	517	630	*-113*
Finland	77	159	*-82*	441	449	*-8*	0	0	*0*	518	608	*-90*
France	1496	1638	*-142*	4853	4950	*-97*	14	36	*-22*	6363	6624	*-261*
Germany	2865	3234	*-369*	7439	7941	*-502*	1314	1435	*-121*	11618	12610	*-992*
Greece	199	220	*-21*	374	382	*-8*	0	0	*0*	573	602	*-29*
Ireland	97	155	*-58*	181	202	*-21*	194	194	*0*	472	551	*-79*
Italy	1636	2058	*-422*	5243	5223	*20*	333	400	*-67*	7212	7681	*-469*
Luxembourg	10	10	*0*	49	49	*0*	7	7	*0*	66	66	*0*
Netherlands	250	320	*-70*	1422	1488	*-66*	772	772	*0*	2444	2580	*-136*
Portugal	145	165	*-20*	790	790	*0*	0	0	*0*	935	955	*-20*
Spain	357	385	*-28*	3336	3342	*-6*	0	0	*0*	3693	3727	*-34*
Sweden	321	436	*-115*	688	699	*-11*	37	34	*3*	1046	1169	*-123*
United Kingdom	992	1555	*-563*	4649	5198	*-549*	12	143	*-131*	5653	6896	*-1243*
EU-15	**9131**	**11353**	**-2222**	**31209**	**32574**	**-1365**	**2779**	**3335**	**-556**	**43119**	**47262**	***-4143***
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 4.33: Emission control costs for the B5 (low CO2 scenario), in million ECU/year, continued

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B5	**B1**	***add.***	**B5**	**B1**	***add.***	**B5**	**B1**	***add.***	**B5**	**B1**	***add.***
Albania	0	0	0	7	7	0	0	0	0	7	7	0
Belarus	0	0	0	160	160	0	0	0	0	160	160	0
Bosnia-H	0	0	0	48	48	0	0	0	0	48	48	0
Bulgaria	155	155	0	4	4	0	0	0	0	159	159	0
Croatia	62	62	0	94	94	0	0	0	0	156	156	0
Czech R.	423	423	0	318	318	0	0	0	0	741	741	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	187	187	0	269	269	0	0	0	0	456	456	0
Latvia	0	0	0	19	19	0	0	0	0	19	19	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	50	50	0	411	411	0	0	0	0	461	461	0
Poland	875	875	0	682	682	0	0	0	0	1557	1557	0
R. of Moldova	8	8	0	0	0	0	0	0	0	8	8	0
Romania	198	198	0	0	0	0	0	0	0	198	198	0
Russia	987	987	0	19	19	0	0	0	0	1006	1006	0
Slovakia	120	120	0	185	185	0	0	0	0	305	305	0
Slovenia	57	57	0	69	69	0	0	0	0	126	126	0
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	22	22	0	0	0	0	22	22	0
Ukraine	463	463	0	128	128	0	0	0	0	591	591	0
F.Yugoslavia	88	88	0	118	118	0	0	0	0	206	206	0
Non-EU	**3737**	**3737**	**0**	**3057**	**3057**	**0**	**0**	**0**	**0**	**6794**	**6794**	**0**
TOTAL	**12868**	**15090**	**-2222**	**34266**	**35631**	**-1365**	**2779**	**3335**	**-556**	**49913**	**54056**	**-4143**

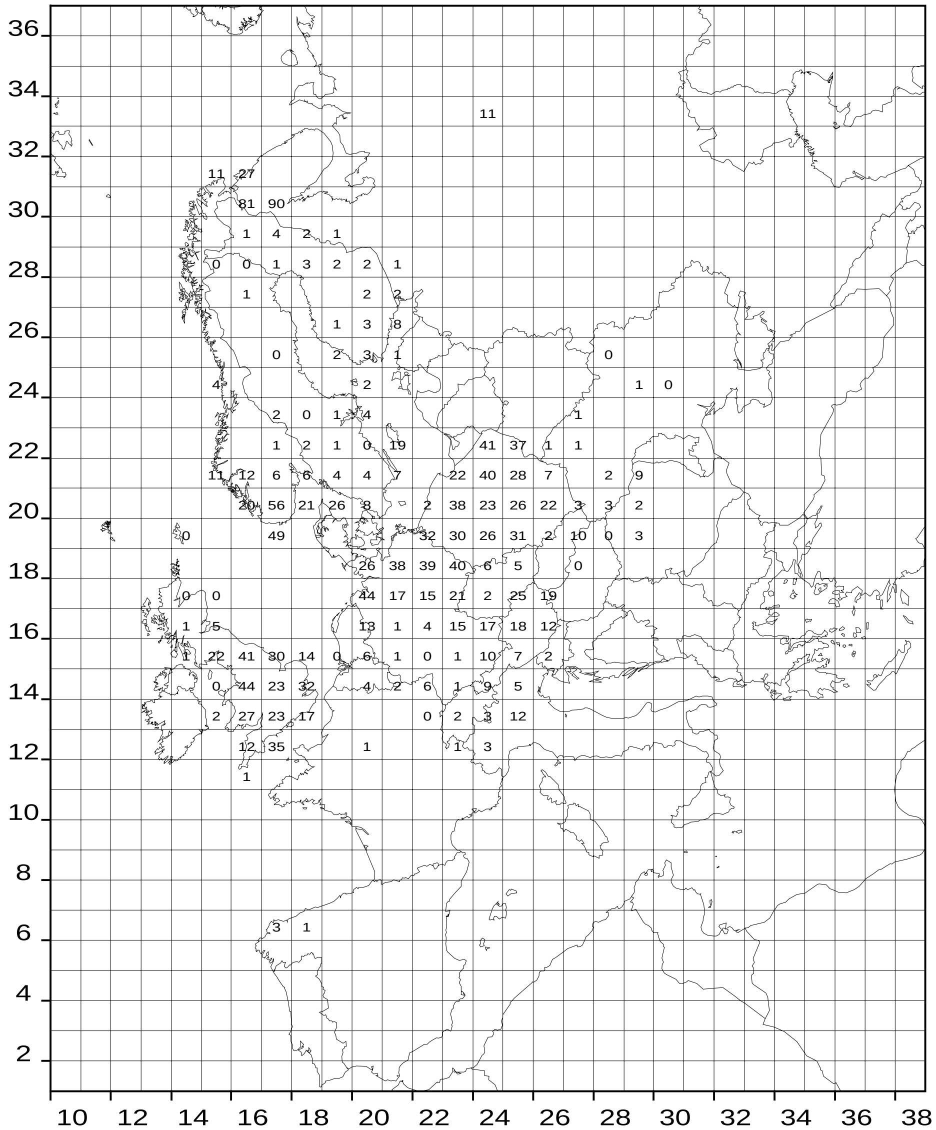

Figure 4.17: Percentage of ecosystems with acid deposition above their critical loads for the B5 (low CO_2) scenario

4.4.2 <u>Scenario B6:</u> Considering Acidification and Eutrophication Simultaneously

Emissions of nitrogen oxides and ammonia not only contribute to the acidification problem, but are also the major source for eutrophication of ecosystems. Although current policies are expected to decrease the area of ecosystems in the EU-15 with nitrogen deposition above their critical loads for eutrophication from 38 million hectares (34 percent) in 1990 to 21 million hectares (i.e., 19 percent) by 2010, and the B1 scenario focusing on acidification will lead to a further decline, more than 14 million hectares (13 percent of the ecosystems) will still remain unprotected. For comparison, this is twice the number of the ecosystems unprotected against acidification in the REF scenario, which, i.a., triggered the discussions on the acidification strategy. As displayed in Figure 4.4, eutrophication is mainly a problem in the central part of Europe, with protection levels in the REF scenario still as low as ten to 20 percent in the Benelux countries and about 50 percent in Germany and Austria.

Recently, the RAINS model has been extended by a multi-pollutant/multi-effect optimization, enabling the simultaneous optimization of strategies for acidification and eutrophication. As requested by a number of Member States of the European Union after presentation of the First Interim Report, this optimization module has been used to explore features of strategies aimed at a more comprehensive view of the current European environmental problems.

The analysis identified for a number of countries a series of shortcomings in the available databases on critical loads for eutrophication, so that at the present time the optimization results must be considered as provisional and no firm quantitative conclusions should be drawn.

Scenario B6 takes the 50 percent gap closure target for acidification (as for Scenario B1) as a starting point and adds a set of constraints on nitrogen deposition. Given the present database on critical loads for eutrophication, a full achievement of the critical loads is not possible even with the maximum technically feasible emission reductions. Unfortunately, since some countries did not supply the full information as required by the responsible bodies of the Convention on Long-range Transboundary Air Pollution, the construction of a gap closure target using the same philosophy as for acidification (i.e., based on the area of ecosystems) was not possible.

In order to construct a feasible and viable set of deposition targets for eutrophication for this Second Interim Report, another concept of 'gap closure' has been developed, defining the gap as the difference between the current (i.e., in the year 1990) and the maximum achievable protection level (i.e., resulting from the application of the EU-max scenario). It must be stressed that this concept has only been used for illustrative purposes in order to demonstrate possible interactions between acidification and eutrophication; in contrast to the acidification gap closure, however, it does not relate to the full achievements of critical loads and is therefore not directly related with sustainability criteria.

As an example assumption, the optimization targets for eutrophication were also set at a 50 percent closure of the gap (between the current and the maximum achievable protection level). A further complication arose from the fact that some countries (e.g., France) supplied for many grids only one single number as the critical load for all ecosystems. Since this ignores the different sensitivities of the ecosystems within grids (i.e., given a fixed nitrogen deposition all ecosystems within a grid are either protected or not), a meaningful gap closure cannot be constructed for such a degenerated database. Consequently, such grid cells have been eliminated from the analysis of Scenario B6.

All other assumptions (Modified Conventional Wisdom energy scenario, REF as minimum reductions for EU-15, emissions from non-EU countries fixed at the REF levels, no measures for ships) are identical to Scenario B1.

Table 4.34 presents the optimized emission levels of Scenario B6. It is in the logic of the process that setting limits on total nitrogen deposition triggers additional emission reductions for NO_x and ammonia emissions. In order to achieve the 50 percent gap closure target for eutrophication, NO_x emissions of

EU-15 countries would be eight percent lower than in Scenario B1; ammonia emissions would be reduced by a further 13 percent. Obviously, the lower nitrogen emissions also cause less acid deposition at the sensitive ecosystems. The cost-minimizing approach, therefore, consequently relaxes requirements for the reductions of sulfur emissions, ending up in 12 percent more SO_2 than in Scenario B1.

There is also a strong geographical aspect in the reactions towards the additional eutrophication constraint. In Denmark, Germany and Austria, but also in Portugal and Greece, reductions of NO_x and NH_3 are taken basically on top of the measures necessary for the acidification problem. In Sweden, the Benelux countries, France and Spain, the nitrogen reductions enable a relaxation of measures for SO_2. Countries without an eutrophication problem (e.g., UK and Ireland) benefit indirectly from the measures taken in the center of Europe and can weaken their own emission controls since, due to local measures at the hot spots, their long-range contribution to the continent causes less harm.

Imposing the 50 percent gap closure target on eutrophication pushes the extra abatement costs of the B1 scenario (on top of the REF scenario) up by 33 percent. Two billion ECU/year are spent for controlling ammonia emissions and a little less than 1.1 billion for further measures on NO_x. The multi-effect optimization, however, also identified possible relaxations of SO_2 control, resulting in a gross saving of about 800 million ECU/year (Table 4.35).

Using information contained in the present critical loads database, the area of ecosystems with nitrogen deposition above their critical loads for eutrophication shrinks from 14.6 million hectares in the B1 scenario (13 percent) to less than 9.5 million hectares (eight percent, Table 4.37). Furthermore, the nitrogen reductions in the center of Europe bring a side benefit on the acidification situation by decreasing acid deposition below the critical loads for additional 300,000 hectares (compared to Scenario B1, see Table 4.36).

Table 4.34: Emissions of Scenario B6 (Simultaneous optimization for acidification and eutrophication)

	SO_2			NO_x			NH_3		
	B6	**B1**	***Change***	**B6**	**B1**	***Change***	**B6**	**B1**	***Change***
Austria	57	57	*0%*	114	116	*-2%*	70	93	*-25%*
Belgium	69	52	*33%*	116	129	*-10%*	83	74	*12%*
Denmark	31	31	*0%*	75	88	*-15%*	82	82	*0%*
Finland	116	116	*0%*	163	163	*0%*	30	30	*0%*
France	310	235	*32%*	723	766	*-6%*	431	630	*-32%*
Germany	423	414	*2%*	1018	1079	*-6%*	292	318	*-8%*
Greece	361	361	*0%*	282	282	*0%*	72	76	*-5%*
Ireland	63	41	*54%*	52	42	*24%*	126	126	*0%*
Italy	315	204	*54%*	927	1160	*-20%*	305	305	*0%*
Luxembourg	4	4	*0%*	8	10	*-20%*	6	6	*0%*
Netherlands	46	38	*21%*	140	140	*0%*	81	81	*0%*
Portugal	194	194	*0%*	160	206	*-22%*	72	84	*-14%*
Spain	664	618	*7%*	761	826	*-8%*	280	373	*-25%*
Sweden	71	66	*8%*	185	207	*-11%*	48	49	*-2%*
United Kingdom	300	279	*8%*	753	753	*0%*	236	224	*5%*
EU-15	**3024**	**2710**	***12%***	**5477**	**5967**	***-8%***	**2214**	**2551**	***-13%***
Atlantic Sea	317	316	*0%*	349	349	*0%*	0	0	*0%*
Baltic	72	72	*0%*	80	80	*0%*	0	0	*0%*
North Sea	172	172	*0%*	191	191	*0%*	0	0	*0%*
SEA	**561**	**560**	***0%***	**620**	**620**	***0%***	**0**	**0**	***0%***
Albania	54	54	*0%*	30	30	*0%*	34	34	*0%*
Belarus	490	490	*0%*	184	184	*0%*	163	163	*0%*
Bosnia-H	410	410	*0%*	48	48	*0%*	23	23	*0%*
Bulgaria	835	835	*0%*	290	290	*0%*	126	126	*0%*
Croatia	69	69	*0%*	64	64	*0%*	38	38	*0%*
Czech R.	151	151	*0%*	226	226	*0%*	124	124	*0%*
Estonia	172	172	*0%*	72	72	*0%*	28	28	*0%*
Hungary	544	544	*0%*	196	196	*0%*	136	136	*0%*
Latvia	105	105	*0%*	93	93	*0%*	28	28	*0%*
Lithuania	107	107	*0%*	137	137	*0%*	80	80	*0%*
Norway	33	33	*0%*	161	161	*0%*	39	39	*0%*
Poland	1397	1397	*0%*	821	821	*0%*	545	545	*0%*
R. of Moldova	91	91	*0%*	66	66	*0%*	48	48	*0%*
Romania	590	590	*0%*	453	453	*0%*	300	300	*0%*
Russia	2350	2350	*0%*	2658	2658	*0%*	894	894	*0%*
Slovakia	113	113	*0%*	110	110	*0%*	53	53	*0%*
Slovenia	37	37	*0%*	31	31	*0%*	20	20	*0%*
Switzerland	30	30	*0%*	78	78	*0%*	58	58	*0%*
FYRMacedonia	81	81	*0%*	22	22	*0%*	16	16	*0%*
Ukraine	1486	1486	*0%*	1094	1094	*0%*	648	648	*0%*
F.Yugoslavia	262	262	*0%*	118	118	*0%*	83	83	*0%*
Non-EU	**9407**	**9407**	***0%***	**6952**	**6952**	***0%***	**3484**	**3484**	***0%***
TOTAL	**12992**	**12677**	***2%***	**13049**	**13539**	***-4%***	**5698**	**6035**	***-6%***

Table 4.35: Emission control costs for Scenario B6 (Simultaneous optimization for acidification and eutrophication), in million ECU/year

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B6	**REF**	***add.***	**B6**	**REF**	***add.***	**B6**	**REF**	***add.***	**B6**	**REF**	***add.***
Austria	259	259	*0*	628	625	*3*	103	0	*103*	990	884	*106*
Belgium	398	598	*-200*	970	888	*82*	73	193	*-120*	1441	1679	*-238*
Denmark	161	161	*0*	384	348	*36*	121	121	*0*	666	630	*36*
Finland	159	159	*0*	449	449	*0*	0	0	*0*	608	608	*0*
France	1525	1638	*-113*	5079	4950	*129*	1336	36	*1300*	7940	6624	*1316*
Germany	3182	3234	*-52*	8460	7941	*519*	1907	1435	*472*	13549	12610	*939*
Greece	220	220	*0*	382	382	*0*	2	0	*2*	604	602	*2*
Ireland	127	155	*-28*	184	202	*-18*	194	194	*0*	505	551	*-46*
Italy	1888	2058	*-170*	5438	5223	*215*	400	400	*0*	7726	7681	*45*
Luxembourg	10	10	*0*	55	49	*6*	7	7	*0*	72	66	*6*
Netherlands	260	320	*-60*	1488	1488	*0*	772	772	*0*	2520	2580	*-60*
Portugal	165	165	*0*	828	790	*38*	37	0	*37*	1030	955	*75*
Spain	361	385	*-24*	3378	3342	*36*	357	0	*357*	4096	3727	*369*
Sweden	412	436	*-24*	726	699	*27*	37	34	*3*	1175	1169	*6*
United Kingdom	1420	1555	*-135*	5198	5198	*0*	73	143	*-70*	6691	6896	*-205*
EU-15	**10547**	**11353**	**-806**	**33647**	**32574**	**1073**	**5419**	**3335**	**2084**	**49613**	**47262**	***2351***
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 4.35: Emission control costs for Scenario B6 (Simultaneous optimization for acidification and eutrophication), continued

	SO_2			NO_x			NH_3			TOTAL COSTS		
	B6	**B1**	***add.***	**B6**	**B1**	***add.***	**B6**	**B1**	***add.***	**B6**	**B1**	***add.***
Albania	0	0	0	7	7	0	0	0	0	7	7	0
Belarus	0	0	0	160	160	0	0	0	0	160	160	0
Bosnia-H	0	0	0	48	48	0	0	0	0	48	48	0
Bulgaria	155	155	0	4	4	0	0	0	0	159	159	0
Croatia	62	62	0	94	94	0	0	0	0	156	156	0
Czech R.	423	423	0	318	318	0	0	0	0	741	741	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	187	187	0	269	269	0	0	0	0	456	456	0
Latvia	0	0	0	19	19	0	0	0	0	19	19	0
Lithuania	0	0	0	0	0	0	0	0	0	0	0	0
Norway	50	50	0	411	411	0	0	0	0	461	461	0
Poland	875	875	0	682	682	0	0	0	0	1557	1557	0
R. of Moldova	8	8	0	0	0	0	0	0	0	8	8	0
Romania	198	198	0	0	0	0	0	0	0	198	198	0
Russia	987	987	0	19	19	0	0	0	0	1006	1006	0
Slovakia	120	120	0	185	185	0	0	0	0	305	305	0
Slovenia	57	57	0	69	69	0	0	0	0	126	126	0
Switzerland	64	64	0	504	504	0	0	0	0	568	568	0
FYRMacedonia	0	0	0	22	22	0	0	0	0	22	22	0
Ukraine	463	463	0	128	128	0	0	0	0	591	591	0
F.Yugoslavia	88	88	0	118	118	0	0	0	0	206	206	0
Non-EU	**3737**	**3737**	**0**	**3057**	**3057**	**0**	**0**	**0**	**0**	**6794**	**6794**	**0**
TOTAL	**14284**	**15090**	**-806**	**36704**	**35631**	**1073**	**5419**	**3335**	**2084**	**56407**	**54056**	**2351**

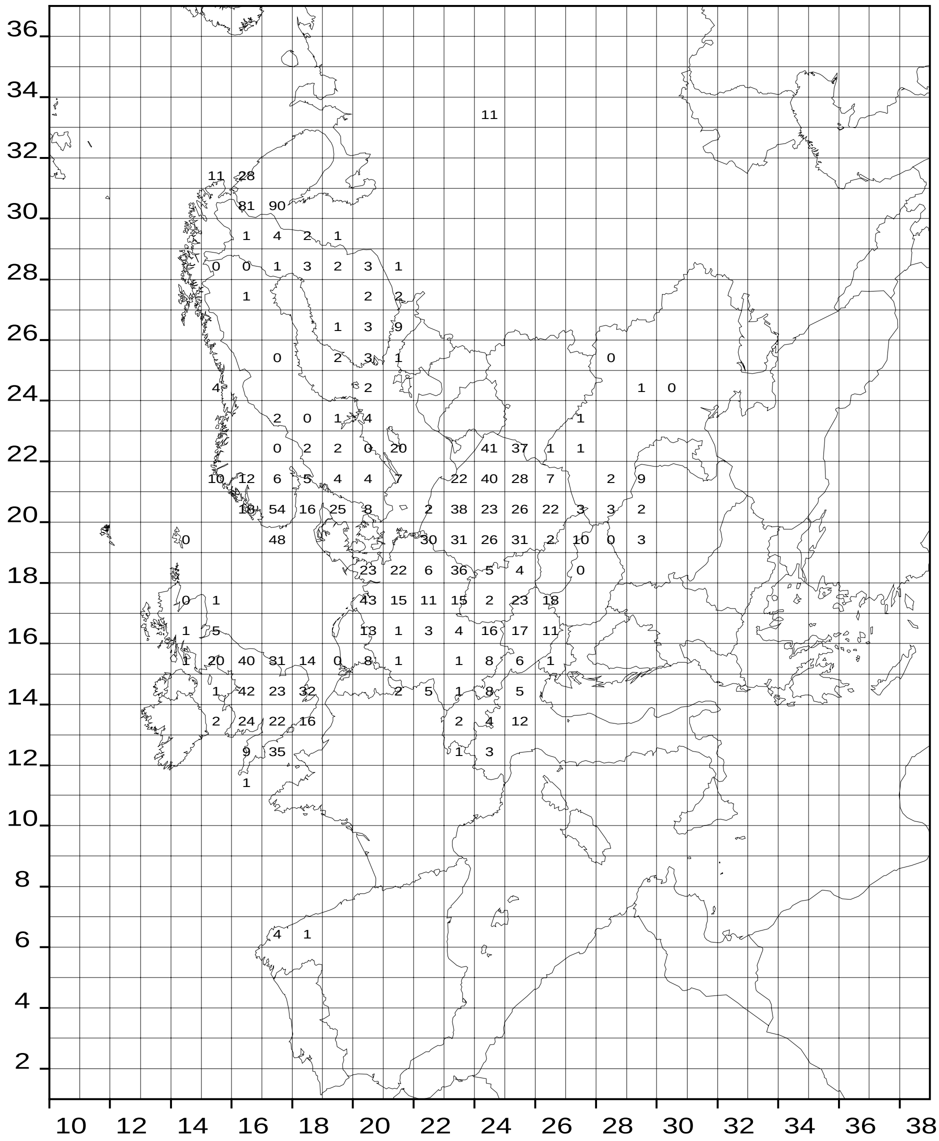

Figure 4.18: Percentage of ecosystems with acid deposition above their critical loads for acidification for Scenario B6

Table 4.36: Ecosystems not protected against acidification for the Scenarios REF, B1 and B6

	REF		B1		B6	
	1000 ha	**%**	**1000 ha**	**%**	**1000 ha**	**%**
Austria	943	19%	642	13%	585	12%
Belgium	117	19%	9	1%	11	2%
Denmark	38	4%	21	2%	20	2%
Finland	1211	4%	1144	4%	1146	4%
France	82	1%	40	0%	31	0%
Germany	2541	29%	978	11%	672	8%
Greece	0	0%	0	0%	0	0%
Ireland	4	1%	1	0%	1	0%
Italy	285	4%	103	2%	99	2%
Luxembourg	7	8%	2	2%	2	2%
Netherlands	121	38%	23	7%	27	9%
Portugal	0	0%	0	0%	0	0%
Spain	24	0%	10	0%	15	0%
Sweden	1235	3%	699	2%	696	2%
UK	2112	27%	809	10%	885	11%
EU-15	**8719**	**7%**	**4481**	**3%**	**4190**	**3%**
Albania	0	0%	0	0%	0	0%
Belarus	53	3%	52	3%	52	3%
Bosnia-H	0	0%	0	0%	0	0%
Bulgaria	0	0%	0	0%	0	0%
Croatia	1	0%	0	0%	0	0%
Czech R.	618	23%	267	10%	234	9%
Estonia	10	1%	8	0%	8	0%
Hungary	44	3%	40	3%	39	2%
Latvia	0	0%	0	0%	0	0%
Lithuania	12	1%	12	1%	12	1%
Norway	3539	11%	2373	7%	2354	7%
Poland	1930	30%	1655	26%	1645	26%
R. of Moldova	0	1%	0	1%	0	1%
Romania	656	1%	647	1%	646	1%
Russia	4094	1%	3787	1%	3788	1%
Slovakia	83	4%	79	4%	78	4%
Slovenia	47	5%	28	3%	24	3%
Switzerland	105	9%	32	3%	31	3%
FYRMacedonia	0	0%	0	0%	0	0%
Ukraine	104	1%	99	1%	98	1%
F.Yugoslavia	0	0%	0	0%	0	0%
Non-EU	**11298**	**3%**	**9079**	**2%**	**9011**	**2%**
TOTAL	**20017**	**4%**	**13560**	**2%**	**13201**	**2%**

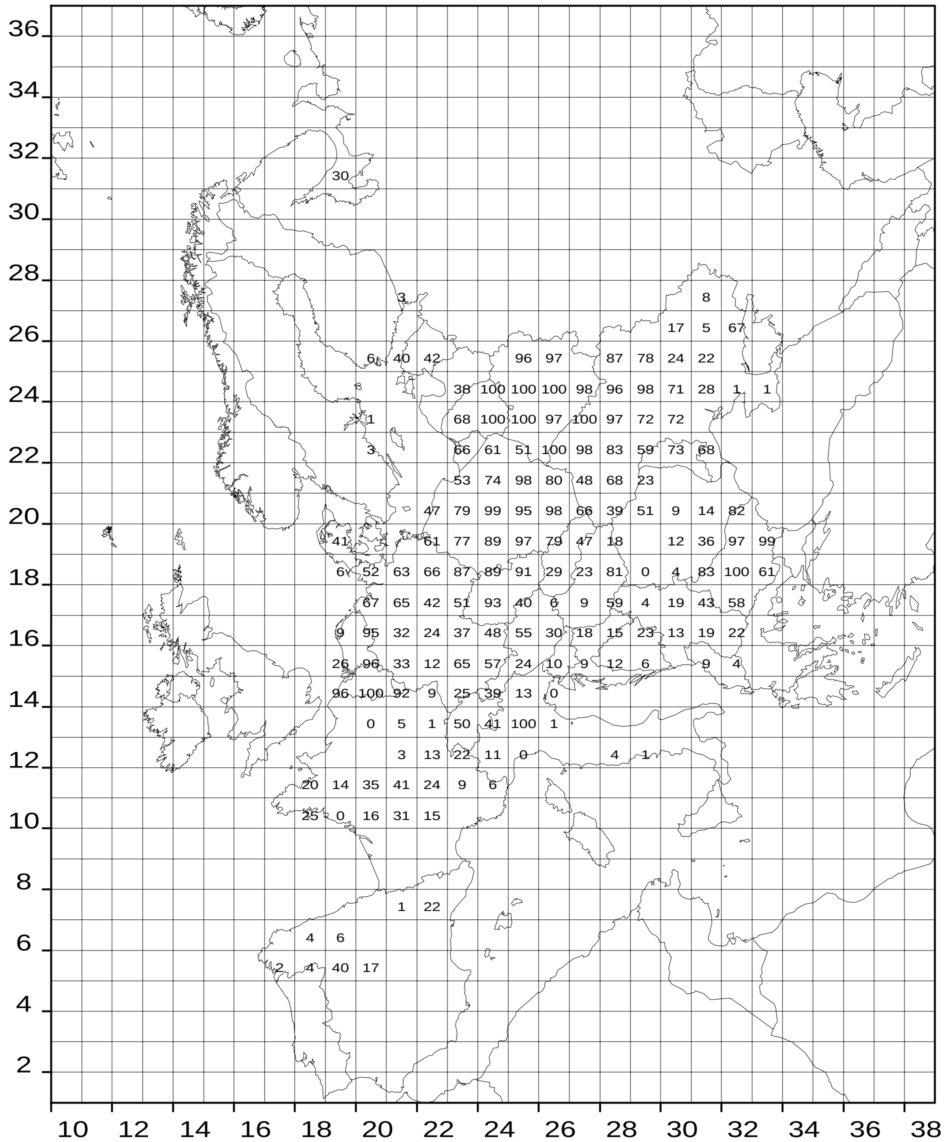

Figure 4.19: Percentage of ecosystems with nitrogen deposition above their critical loads for eutrophication for Scenario B6

Table 4.37: Ecosystems not protected against eutrophication

	REF		B1		B6	
	1000 ha	**%**	**1000 ha**	**%**	**1000 ha**	**%**
Austria	3019	62%	2376	49%	1687	35%
Belgium	599	97%	578	93%	572	92%
Denmark	358	37%	205	21%	198	20%
Finland	769	2%	260	1%	192	1%
France	6093	42%	4511	31%	1646	11%
Germany	7098	82%	4436	51%	3891	45%
Greece	91	4%	91	4%	88	4%
Ireland	0	0%	0	0%	0	0%
Italy	1193	18%	669	10%	601	9%
Luxembourg	85	97%	82	94%	80	92%
Netherlands	271	85%	257	80%	256	80%
Portugal	277	10%	164	6%	6	0%
Spain	1180	14%	996	12%	198	2%
Sweden	100	1%	17	0%	12	0%
United Kingdom	42	1%	0	0%	0	0%
EU-15	**21175**	**19%**	**14642**	**13%**	**9425**	**8%**
Albania	69	7%	68	6%	65	6%
Belarus	1571	83%	1564	82%	1561	82%
Bosnia-H	329	23%	276	19%	223	15%
Bulgaria	2685	71%	2675	71%	2633	70%
Croatia	455	28%	305	19%	193	12%
Czech R.	2319	87%	2022	76%	1910	72%
Estonia	508	27%	502	27%	501	27%
Hungary	624	39%	515	32%	406	25%
Latvia	509	19%	434	16%	390	14%
Lithuania	1656	87%	1589	84%	1576	83%
Norway	276	5%	0	0%	0	0%
Poland	5666	89%	5273	82%	5133	80%
R. of Moldova	2	20%	2	20%	2	20%
Romania	1097	2%	1056	2%	1040	2%
Russia	169	0%	144	0%	138	0%
Slovakia	1139	57%	1032	52%	925	47%
Slovenia	221	24%	167	18%	121	13%
Switzerland	1244	59%	948	45%	853	40%
FYRMacedonia	243	23%	241	23%	228	21%
Ukraine	5429	66%	5311	64%	5294	64%
F.Yugoslavia	706	21%	678	20%	653	19%
Non-EU	**26917**	**7%**	**34310**	**6%**	**33294**	**6%**
TOTAL	**48092**	**11%**	**48952**	**10%**	**42719**	**8%**

4.4.3 Side-impacts on Ground-level Ozone

Unfortunately this Section could not be finalized in time for the delivery of the Report and will be distributed later.

4.5 Exploring the Robustness of the Optimized 50% Gap Closure Scenario against Uncertainties in the Critical Loads Database

4.5.1 The Relevance of the 'Binding' Grid Cells

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

		Scenario					
EMEP grid number	**Location**	**B1 50% gap closure**	**B2 Ships**	**B3 Non-EU**	**B4 Europe -wide targets**	**B5 Low CO_2**	**B6 Acid/ Eutro.**
BINDING FOR ACIDIFICATION:							
18/06	Spain	0.06	0.10	0.09	-	-	0.16
20/17	Germany/Netherlands (Hannover/Groningen)	74.41	54.34	58.16	0.47	31.95	22.17
21/22	Sweden (Gotland)	7.00	0.04	-	-	8.69	7.09
22/18	Germany (Berlin)	-	0.13	-	-	0.65	-
25/13	Italy (Milano)	3.52	3.53	3.53	3.50	3.54	3.04
Grid cells outside the EU-15:							
17/19	Southern Norway	-	-	-	129.71	-	-
17/20	Southern Norway	-	-	-	2.05	-	-
29/21	Romania/Ukraine	-	-	-	12.00	-	-
BINDING FOR EUTROPHICATION:							
18/05	Spain	-	-	-	-	-	4.10
19/05	Spain/Portugal	-	-	-	-	-	6.99
18/11	France	-	-	-	-	-	6.74
23/18	Germany	-	-	-	-	-	68.77
25/16	Austria	-	-	-	-	-	0.87
28/13	Italy	-	-	-	-	-	2.67
32/15	Greece	-	-	-	-	-	1.44

Table 4.38 shows that for all scenarios a number of binding grids cells well-distributed over the EU countries occur, indicating that the optimized solution is not driven by a single ecosystem, but determined by a balanced spread of targets over Europe.

Taking Scenario B1 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 island of 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, France, UK and 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 Spanish grid cell emissions from Spain. The targets on acid deposition selected for the current set of scenarios do not have a limiting influence on emissions of Austria, Portugal and Greece.

This situation does not significantly change for the other scenarios where the environmental targets are kept constant (i.e., Scenarios B2 (ships), B3 (measures also in non-EU countries) and B5 (the low CO_2 scenario)). Extending the gap closure target to all European ecosystems (Scenario B4), the targets for southern Norway turn out to be most difficult to attain, superseding the limiting role of some of the grid cells within the EU-15 countries.

When constraints on total nitrogen deposition are added (i.e., for the acidification/eutrophication Scenario B6), seven additional grid cells determine the necessary reductions of NO_x and NH_3 emissions. Grids binding for acidification retain their limiting role.

4.5.2 Some Sensitivity Runs for the Binding Grid Cells

It has been explained before that changes in the optimization results will only occur when deposition targets of the binding grids are changed (unless a limit is tightened so much that it becomes binding). A sensitivity analysis should therefore primarily focus on the binding grids.

Experience with the optimization shows that, although removing or relaxing one of the targets of binding grids 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.

Ignoring Single Binding Grid Cells

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 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.

Another experimental run carried out for the Second Interim Report explored the impacts of eliminating the targets for the Gotland grid (21/22), i.e., the Scandinavian grid for which the 50 percent gap closure is most difficult to attain and the grid with the second-highest marginal costs. Results from the optimization show that in such a case additional abatement costs on top of the REF scenario decline by five percent. There are only a few countries with emission changes compared to the B1 scenario. The only significant differences occur for Swedish emissions of SO_2 (-29 percent instead of -51 percent), and NH_3 (-13 percent instead of -20 percent), and Belgian NO_x emissions (-63 percent instead of -67 percent).

A further test case excluded the binding grid cell in northern Italy. As a result, the emissions of all three pollutants from Italy remained at the same level as in the REF scenario, with resulting cost-savings for that country. A side-effect was that emissions of SO2 in the UK and Denmark were somewhat lowered, causing increased costs in these countries. The net result was reduced costs by about 700 million ECU/year and lower ecosystems' protection (4.7 million hectares unprotected). Specifically for Italy, the unprotected area increased from 103,000 hectares to 246,000 hectares. Some impact could also be noted in surrounding countries, such as Austria, where the unprotected ecosystems increased compared to the main scenario.

Using the 95 Percentile Instead of the 98 Percentile as Optimization Target

A third sensitivity run acknowledges the fact that the substitution of the 100 percentile of the critical loads by the 98 percentile for use as an optimization target is to a certain extent an arbitrary step (see Section 4.2.1). To explore the magnitude of changes if another percentile is selected, a scenario was constructed in which the optimization targets of the 98 percentile values were replaced by the 95 percentiles. Also in this case the optimized abatement schedule turns out as rather robust: the only difference to Scenario B1 occurs for Spanish SO_2 emissions, which are then reduced by only by 68 percent instead of 73 percent compared to 1990.

Using Modified Critical Loads Data for the UK

A fourth case recognized the announcement of revised critical loads data for the UK. Although the revised data set was not available in time to be used for this Second Interim Report, an 'interim set' with significantly higher critical loads than those officially submitted to UN/ECE in January 1996 was made available to IIASA. These interim critical loads, however, are considered by the UK as too high compared to the final data.

It can be derived from Table 4.38, that with the updated database employed for this Second Interim Report, but still using the low critical loads data officially submitted in 1995, the grid cell 16/14, which was a binding grid in the optimization runs for the First Interim Report, does not turn out any more as binding. The reason for this is that, compared to the First Interim Report, the RAINS ammonia emission database for the UK was modified to reflect the latest official UK estimates supplied by the Ministry of Agriculture, Fisheries and Food. This means that, compared to the earlier runs, UK ammonia emissions for 1990 were reduced from 486 kt (derived from the CORINAIR'90 inventory) to 320 kt. While keeping the (old) critical loads constant, the assumption of 34 percent lower ammonia emissions in the UK eliminated the calculated excess deposition of the critical loads at the UK grid 16/14 (as well as in all other UK grids) for Scenario B1.

Obviously, increasing the critical loads data (e.g., to the levels of the 'interim' critical loads) relaxes this situation further, and can never lead to binding grid cells in the UK. Consequently, there will be no change in optimization results from increased critical loads estimates in the UK. Although the overall reduction levels for the UK in Scenario B1 are not very different from the '50% gap closure' scenario of the First Interim Report (with the obvious exception of ammonia), the marginal reductions in the UK are, with the present data set, driven by transboundary impacts on sensitive ecosystems on the continent rather than by UK ecosystems. This conclusion will also hold for an eventual set of 'final' critical loads, provided that these estimates are not lower than the current (very low) data.

5. 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 EU-15 in the year 1990) are expected to decline to seven percent as a result of current policy; however, THIS still leaves 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, a scenario was constructed to explore a possible cost-effective solution for further moving towards the full achievement of critical loads. Since full achievement of critical loads means bringing down the area of unprotected ecosystems to zero, an interim target has been defined, aimed at a reduction of the unprotected ecosystems in each grid cell of the EU-15 by 50 percent. 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 should be reduced by 52 percent below the levels envisaged as a result of current policy; NO_x is reduced by 14 percent, and ammonia by 15 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 amount to seven billion ECU/year, which is 18 percent higher than the costs of current policy. On the other hand, sustainability can be reached for an additional 4.2 million hectares out of the nine million hectares remaining unprotected by current policy.

The report examines the robustness of the optimized solution against alternative approaches (i.e., extending measures to emission sources outside the direct control of the European Union), against a possible interaction with strategies addressing other environmental problems (e.g., climate change policies, eutrophication and tropospheric ozone), and against uncertainties in the underlying databases on critical loads in Europe.

It has been demonstrated in the First Interim Report that, while keeping the environmental targets the same(i.e., the ‘50% 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., 25 percent of the additional costs on top of current legislation. Limiting such measures to the use of heavy fuel oil with a maximum sulfur content of 1.5 percent and restricting such a strategy to the Baltic and the North Sea exhausts obviously only a fraction of the cost-effective potential. The cost-saving ratio for the subset of measures of 13 ECU saved per ECU spent is, however, significantly higher than for the other measures.

Two other scenarios explore the possible role of measures in countries outside the EU. The first scenario shows that, while keeping a limited focus on the ecosystems within the EU-15, further measures in non-EU countries could substitute the most expensive controls inside the EU-15 and thereby generate net savings of about 500 million ECU/year. The second scenario illustrates the effects of a pan-European solution, e.g. by extending the 50 percent gap closure target to all European ecosystems. Emission reductions calculated for the EU gap closure scenario (B1) can be considered as an interim step for such a pan-European solution.

Three further scenarios assess the interaction with strategies to address other environmental problems (climate change, eutrophication, ground-level ozone). The analysis concludes that a single policy considering several problems simultaneously may achieve significant cost savings.

A strategy for reducing CO_2 emissions in Europe will decrease costs for controlling acidifying emissions substantially. For utilizing the full cost-saving potential of an optimized approach, however, national emission ceilings may have to be adjusted to take full advantage of the modified energy policies.

Provisional analysis suggests that a simultaneous consideration of acidification and eutrophication could be advantageous. Further reductions of NO_x and NH_3 emissions necessary to satisfy constraints on nitrogen deposition can relax expensive measures for reducing SO_2 emissions.

Finally, the report concludes that some of the most important uncertainties in the estimates of critical loads for acidification do not significantly modify the present optimization results for the ‘50% gap closure’ scenario.

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 economic activities can reduce emission control costs substantially, in countries with economies in transition by more than 50 percent. In principle, this observation is valid also for the EU countries: As demonstrated in this report, emission control costs for the low CO_2 scenario are nine percent lower than for the ‘Modified Conventional Wisdom’ energy scenario, while achieving the same deposition targets. However, although such factors have a 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.

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