SIXTH INTERIM REPORT

Cost-effective Control of Acidification and Ground-Level Ozone

Part A: Methodology and Databases

Sixth Interim Report to the
European Commission, DG-XI

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This report constitutes Part A of the First Interim Report on the
Study Contract B4-3040/98/000228/MAR/B1
Economic Evaluation of a Directive on National Emission Ceilings for Certain
Atmospheric Pollutants.

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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, frequently 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.

It is generally expected that the current policies on emission reductions will greatly reduce the levels of tropospheric ozone. However, the measures will not be sufficient to eliminate the problem everywhere in Europe. To meet the environmental long-term targets aiming at the protection of human health and vegetation, as they are currently discussed in the context of the Commission's ozone strategy, additional- measures will be necessary. 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.

1.1 Structure of this Report

This Sixth Interim Report to the European Commission is a further step in a series of reports analyzing the features of cost-effective approaches to control European air quality. The first two Interim Reports focused on acidification-related aspects and provided input to the Commission's Acidification Strategy. The following Third and Fourth Interim Reports drew attention to ground-level ozone: The Third Report illustrated the different chemical and meteorological regimes of ozone formation prevailing in Europe and assessed the consequences on strategy development. The Fourth Report explored alternative principles of setting environmental targets and the implication on the distribution of costs and environmental benefits to different regions in Europe. The Fifth Interim Report examined the interaction of acidification and ground-level ozone.

Building on the various strategy elements developed in the preceding analyses, the Sixth Interim Report concentrates on a central emission reduction scenario for controlling acidification and ground-level ozone in the EU-15 and explores the sensitivity of the optimized emission reductions against variations in a range of important input assumptions.

This Sixth Interim Report is divided into three parts:

Part A describes the methodology of the analysis and reviews the present state of the databases used for the scenario calculations.

Part B presents the results of the model analysis and analyzes the sensitivity of optimized emission reductions against modified input assumptions.

Part C explores some of the monetized benefits of the emission reduction scenarios.

Part A provides a summary of the methodology selected for the integrated assessment exercise and reviews the latest status of the databases used for the analysis. Section 2 presents the main elements of the RAINS model (the emission database, estimates of emission control potentials and costs for SO_2, NO_x, NH_3 and VOC, the atmospheric source-receptor relationships, the critical loads database and the optimization methodology). The data sources (energy and agricultural projections) are described in Section 3. Section 4 presents model estimates for the emissions of 1990 and compares them with the expected impacts of current policies and with the maximum technical potential for emission control.

In Part A of this report, a gray bar on the right border of the page indicates the most important changes in the description of methodology and databases that have been introduced since the Fifth Interim Report. In addition to the changes marked by the gray bar, all tables and figures were updated, and references to the updated tables were changed in the text.

Detailed information and documentation of the cost curves and the optimization algorithm is available on the Internet under http://www.iiasa.ac.at/~rains.

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.

2.1 The General Approach for an Integrated Assessment

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 2.1.

The European implementation of the RAINS model incorporates databases on energy consumption for 38 regions in Europe, distinguishing 22 categories of fuel use in six economic sectors. The time horizon extends from the year 1990 up to the year 2010 (Bertok *et al*., 1993). Emissions of SO_2, NO_x, NH_3 and VOC for 1990 are estimated based on information collected by the CORINAIR'90 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*., 1997).

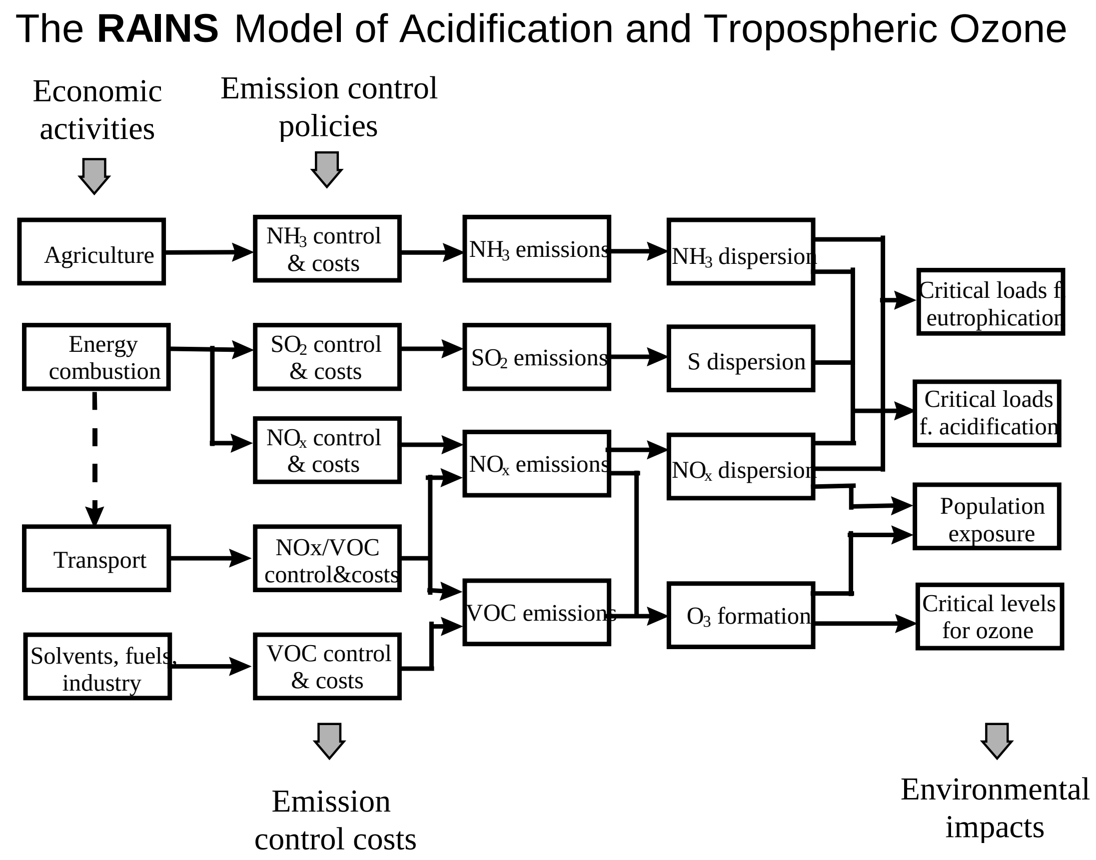

Figure 2.1: Schematic flowchart of the RAINS model framework

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 non-linear optimization module for tropospheric ozone has been recently completed and was used for this study.

2.2 Scenarios of Emission Generating Anthropogenic Activities

Inputs to the RAINS model include 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 six economic sectors. These energy balances are complemented by additional information relevant for emission projections, such as boiler types (e.g., dry bottom vs. wet bottom boilers), size distribution of plants, age structures, fleet composition of the vehicle stock, etc..

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. The projections of future agricultural activities currently implemented in the RAINS model have been compiled from a variety of national and international studies on the likely development of the agricultural system in Europe.

The forecast of the future development of VOC emission generating activities is linked to other information on general economic development. About half of the anthropogenic emissions of VOC originates from combustion and distribution of fossil fuels. Therefore, the information on projected levels of fuel consumption in the countries of the UN/ECE region contained in RAINS is used to estimate future emissions of VOC from relevant sources, i.e. traffic, stationary combustion, extraction and distribution of fuels. The development of the other VOC emitting sectors in the EU is based on information provided in the reports to the European Commission on the development of the EU energy system between 1995-2020 (Capros *et al*., 1997) and on information provided by national experts. The forecasts of GDP values in various industrial sectors, as well as population, were linked to the projected development in the sectors distinguished in the RAINS-VOC module. A similar exercise was performed for non-EU countries.

A detailed description of the actual projections used for this report is provided in Section 3.

2.3 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'90 emission inventory database and guidebook (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 energy and agricultural projections and the CORINAIR'90 emission inventory. The relations between CORINAIR/SNAP97 categories and the RAINS sectors are shown in Table 2.1 to Table 2.4. 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'90 data is only possible at a more aggregated level.

Considering the intended purposes of integrated assessment, the major criteria for aggregation are:

- Contribution to total emissions (compared to total European emissions and to emissions for a particular country). It was decided to aim for individual source categories in a share from 0.5 to 2 percent of total anthropogenic emissions;
- Possibility to define uniform activity rates and emission factors;
- Possibility to construct forecasts of future activity levels. Since the emphasis of the cost estimates is on future years, it is crucial that reasonable projections of the activity rates be constructed or derived;
- Availability and applicability of ‘similar’ control technologies;
- Availability of relevant data. As far as possible, emission related data should be compatible with the CORINAIR'90 emission inventory.

Table 2.1: RAINS sectors of the SO_2/NO_x modules for stationary sources and their relation to the main activity groups of the CORINAIR'90 inventory

RAINS sector		CORINAIR
Primary	**Secondary**	**SNAP97 code**
Power plants and district heating plants	- New boilers - Existing boilers, dry bottom - Existing boilers, wet bottom	0101, 0102
Fuel production and conversion (other than power plants)	- Combustion - Losses	0103, 0104, 0105, 05
Domestic	- Residential, commercial, institutional, agriculture	02
Industry	- Combustion in boilers, gas turbines and stationary engines	0301
	- Other combustion	03 excl. 0301[1]
	- Process emissions[2]	04
Non-energy use of fuels	- Use of fuels for non-energy purposes (feedstocks, lubricants, asphalt)	
Other emissions	- Other sources: (air traffic LTO cycles, waste treatment and disposal, agriculture	080501, 080502, 09, 10

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[1] Also processes with contact from SNAP code 0303 that are treated separately as process emissions are excluded.

[2] 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 in 'Industry-Other combustion'.

Table 2.2: Sectors in the RAINS module for mobile sources and their relation to the CORINAIR/SNAP97 codes

RAINS sector Primary	 Secondary	CORINAIR SNAP97 code
Road transport	-Heavy duty vehicles (trucks, buses and others)	0703
	- Light duty vehicles, four-stroke (cars, vans, motorcycles)	0701,02,04,05
	- Light duty vehicles, two-stroke (cars, motorcycles)	
	- Gasoline evaporation	0706
Off-road	- Other mobile sources and machinery with two-stroke engines	03, 08 excl. 0804 and 0805
	- Other mobile sources and machinery with four-stroke engines	
Maritime activities	- Medium vessels	080402,
	- Large vessels	080403

Table 2.3: Main activity groups distinguished in the RAINS NH_3 module and their relation to the CORINAIR'90 SNAP code

RAINS sector Primary	 Secondary	CORINAIR SNAP code
Livestock	Dairy cows	100501
	Other cattle	100502
	Pigs	100503, 100504
	Laying hens	100507
	Other poultry	100508, 100509
	Sheep and goats	100505
	Fur animals	100510
	Horses	100506
Fertilizer use	Agricultural cultures with fertilizers (except animal manure)	1001-100106
Fertilizer production	Production processes in inorganic chem. industry	040403-040408
Other industrial	Production processes- nitric acid	040402
Waste treatment and disposal	Waste treatment and disposal	0901-0904
Other	Various activities including stationary combustion, mobile sources and industrial processes	01, 02, 03, 04, 07, 08

Table 2.4: Sectors in the RAINS VOC module for stationary sources and their relation to the CORINAIR'90 SNAP codes

RAINS sector Primary	 Secondary	CORINAIR SNAP code
Solvent Use	Dry cleaning	060202
	Metal degreasing	060201
	Treatment of vehicles	060407,9
	Domestic solvent use (excluding paint)	060408
	Architectural painting	060103
	Domestic use of paints	060104
	Manufacture of automobiles	060101
	Other industrial use of paints	060102
	Products incorporating solvents	060307-11
	Products not incorporating solvents	060301-05
	Pharmaceutical industry	060306
	Printing industry	060403
	Application of glues, adhesives in industry	060405
	Preservation of wood	060406
	Other industrial use of solvents	060401,2,4
Chemical Industry	Inorganic chemical industry	040401-09
	Production processes in organic chemistry	040501-21
	Storage and handling of chemical products	040522
Refineries	Refineries - process	040101-03
	Refineries - storage	040104
Fuel Extraction and Distribution	Gaseous fuels	0503,0506
	Liquid fuels	0502,0504
Gasoline Distribution	Service stations	050503
	Transport and depots	050501,2
Stationary Combustion	Public power, co-generation, district heat	0101,0102
	Industrial combustion	0301-03
	Commercial and residential combustion	0200
Miscellaneous	Stubble and other agricultural waste burning	1003,0907
	Cultures with and without fertilizers	1001,1002
	Food and drink industry	040605-08
	Other industrial sources	0402,3,6,7
	Waste treatment and disposal	0901-04,6

2.3.1 Comparison of RAINS Emission Estimates for 1990 with other Inventories

As indicated above, RAINS generally uses information on emission factors provided by the CORINAIR’90 inventory. CORINAIR'90 is available for all EU countries as well as for eleven non-EU countries. Consequently, emission levels calculated by RAINS are usually in good agreement with the CORINAIR’90 inventory with differences typically below five percent.

In a few cases, however, RAINS deviates from the CORINAIR'90 database. This is mainly the case when, in the process of constructing the RAINS database, an inconsistency in CORINAIR'90 was detected, or when countries updated their CORINAIR'90 inventory.

Recent work on the emission database addressed the following issues:

- The updates of national emission inventories for 1990 recently received from Austria, Belgium, Denmark, France, Germany, Greece, Italy and UK were incorporated into the RAINS database.
- The treatment of coastal shipping. An attempt has been made to harmonize the treatment of emissions from coastal shipping. Coastal shipping is now included in the national emissions for the respective countries, and the emissions from international shipping are apportioned to separate categories for the various regional seas.

Table 2.5 compares the 1990 estimates for NO_x and VOC emissions incorporated into the RAINS model with the results from the CORINAIR'90 inventory and with the EMEP/UN-ECE database (UN/ECE, 1998).

It is important to mention that, when calculating ozone concentrations, the EMEP model internally determines natural and agricultural emissions of VOC as a function of temperature, land use, etc. On the other hand, the agricultural emissions are also fully included in the CORINAIR'90 estimates (sector 10). In order to avoid double-counting of these emissions for ozone calculations, the RAINS results presented later on exclude these emissions from the anthropogenic sources (and the cost curves). As a consequence, also the emission levels derived in the subsequent analyses of this report exclude these sources. In order to achieve emission fully comparable to the present CORINAIR methodology, natural and agricultural emissions of VOC must be added to the numbers presented for each scenario.

Close cooperation with several national experts made it possible to remove earlier inconsistencies between the national emission inventories and RAINS estimates. In all cases where national data were sufficiently documented, this revised information was used to improve the RAINS estimate. For some EU countries, however, there remain certain discrepancies between the revised national inventories for 1990 and the data reported by EMEP/UN-ECE, which can partly be explained by the delayed reporting procedures to EMEP/UN-ECE. It was important to confirm, as far as practically possible, that the supplied revisions of national emission inventories for the year 1990 are consistent with the general CORINAIR guidelines.

Compared to the Fifth Interim Report, the most important changes in the emission database occurred for France, Greece and Sweden, due to a different treatment of the emissions from

’Other mobile sources’. There remain for some non-EU countries a number of unresolved questions:

- There still exist major uncertainties about emissions from the countries of the former Soviet Union, for which no CORINAIR’90 inventory exercise was carried out. Using reported energy statistics, it is in some cases rather difficult to reconstruct the officially submitted emission data. As pointed out by Ryboshapko *et al*. (1996), data reported officially by the former Soviet Union did not always include small and dispersed sources in the residential and commercial sector. This approach is apparently still exercised by Yugoslavia, which reports only emissions from stationary sources to EMEP.
- Compared with CORINAIR’90, RAINS estimates of NO_x emissions in the Czech Republic are more than 30 percent lower. This is due to an extremely high emission factor used in 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. To some degree, also the 10 percent difference to Slovakia's NO_x estimate can be traced back to the same root.
- For Poland, the discrepancies between RAINS and CORINAIR'90 estimates are a result of high emission factors applied in the Polish CORINAIR'90 inventory for some industrial processes and for open burning of agricultural waste. In other non-EU countries the discrepancies are mainly due to uncertainties of their energy balances.

Also for the VOC estimates of the EU-15 countries, assistance of national experts helped to eliminate all major discrepancies mentioned in earlier reports, so that there is now a rather good agreement between the national inventories and the RAINS database (typically within ± ten percent). For non-EU countries, the following open questions remain:

- The CORINAIR'90 database for the Czech Republic does not include estimates for domestic solvent use, evaporative emissions from cars, industrial paint use;
- Hungary’s CORINAIR'90 database does not include emissions from the domestic use of paints;
- According to CORINAIR, Poland’s biggest single source of VOC emissions is the burning of stubble and other agricultural waste. Despite considerable uncertainties, the reported number seems to be too high by about one order of magnitude.
- The CORINAIR'90 database for Slovenia excludes several important emission sources for VOC, such as evaporative emissions from cars, dry cleaning, degreasing, domestic use of solvents and the storage of products in refineries.

The CORINAIR’94 emission inventory, of which parts became available recently, provides important additional information contributing to a better understanding of VOC emission sources. It is envisaged to further update the RAINS emission calculation using these new data.

Table 2.5: Comparison of RAINS 1990 emission estimates of NO_x and VOC with results from the CORINAIR'90 1990 inventory and the EMEP/UN-ECE databases (in kilotons).

		NO_x			VOC	
	RAINS	EMEP/ UN/ECE	CORINAIR '90[3]	RAINS	EMEP/ UN/ECE	CORINAIR' '90[3]
Albania	24	24	n.a.	30	32	n.a.
Austria	234	222	227	352	367	348
Belarus	402	285	n.a.	279	533	n.a.
Belgium	355	352	343	398	339/358	364
Bosnia-H	80	80	n.a.	46	101	n.a.
Bulgaria	354	376	361	198	187/217	189
Croatia	83	83	n.a.	79	105	97
Czech R.	522	742	773	322	435	253
Denmark	269	279	273	162	178	167
Estonia	84	93	72	44	23	50
Finland	278	300	269	213	209	207
France	1600	1590/1585	1899	2399	2393/2404	2424
Germany	2690	2654/2677	2980	3066	3181	2937
Greece	394	392	344	336	293	312
Hungary	214	238	191	206	205	148
Ireland	103	115	116	111	102	102
Italy	2038	2047	2041	2053	2080	2002
Latvia	117	90	93	51	63	47
Lithuania	152	158	158	104	111	108
Luxembourg	22	23	23	19	19	19
Netherlands	540	596/580	537	490	502	502
Norway	221	227	232	308	299	270
Poland	1209	1279	1445	709	797/831	971
Portugal	208	221	215	217	202/206	202
Moldova	87	39	n.a.	53	11	n.a.
Romania	518	546	546	483	568/616	571
Russia	3485	2675	n.a.	3332	3566	n.a.
Slovakia	207	227	227	143	149	150
Slovenia	60	57	57	60	35	35
Spain	1162	1188/1178	1247	1048	1051/1134	1044
Sweden	346	411/338	345	492	526	451
Switzerland	166	165	159	291	284/292	282
FYR Maced.	39	39	n.a.	20	7	n.a.
Ukraine	1888	1097	n.a.	1074	1079/1369	n.a.
UK	2800	2850/2762	2773	2663	2720/2552	2555
Yugoslavia	211	66[4]	n.a.	124	55	n.a.
Atlantic Sea	911	911	n.a.	0	n.a.	n.a.
Baltic Sea	80	80	n.a.	0	n.a.	n.a.
North Sea	639	639	n.a.	0	n.a.	n.a.
Total	24792	23419	n.a.	21973	22807	n.a.

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[3] Including the updates received from national experts. Anthropogenic sources only, i.e. excluding sector 10 and 11.

[4] Only stationary sources included

Table 2.6: Comparison of RAINS 1990 emission estimates of SO_2 and NH_3 with results from the CORINAIR'90 1990 inventory and the EMEP/UN-ECE databases (in kilotons).

		SO_2			NH_3	
	RAINS	EMEP/ UN/ECE	CORINAIR '90 3)	RAINS	EMEP/ UN/ECE	CORINAIR'90 3)
Albania	73	72	n.a.	32	31	n.a.
Austria	95	90	93	77	85/77	77
Belarus	845	637	n.a.	219	219/4	n.a.
Belgium	317	322	317	97	104	79
Bosnia-H	487	480	n.a.	31	31	n.a.
Bulgaria	1842	2020	2008	141	144	324
Croatia	178	180	n.a.	40	44/37	37
Czech R.	1877	1876	1863	107	105/136	91
Denmark	185	184	198	77	122	126
Estonia	276	239	275	29	29	29
Finland	227	260	227	40	35	41
France	1304	1300/1268	1232	805	700/807	807
Germany	5280	5263	5257	757	769	739
Greece	521	510/504	504	80	78	471
Hungary	913	1010	906	120	164	62
Ireland	172	178	178	127	126	126
Italy	1681	1678	1683	462	416	466
Latvia	122	57	115	43	44	38
Lithuania	213	222	223	80	84	84
Luxembourg	14	14	14	7	7	7
Netherlands	207	205	200	233	232/226	196
Norway	52	53	54	23	23	38
Poland	3001	3210	3273	505	508	539
Portugal	286	283	283	71	93	93
Moldova	197	231	n.a.	47	47	n.a.
Romania	1335	1311	1311	292	300	300
Russia	5046	4460	n.a.	1282	1191	n.a.
Slovakia	549	543	542	60	62	60
Slovenia	200	194	196	23	24	27
Spain	2190	2266	2206	352	353	331
Sweden	130	136/119	105	61	61	74
Switzerland	45	43	44	72	72	69
FYR Maced.	107	106	n.a.	17	17	n.a.
Ukraine	3708	2782	n.a.	729	729	n.a.
UK	3754	3764	3787	329	320/333	468
Yugoslavia	586	508[5]	n.a.	90	90	n.a.
Atlantic Sea	641	641	n.a.	0	0	n.a.
Baltic Sea	72	72	n.a.	0	0	n.a.
North Sea	439	439	n.a.	0	0	n.a.
Total	39215	37888	n.a.	7556	7459	n.a.

National SO_2 estimates different from EMEP/UN-ECE: Belgium 336 kt, UK 3782 kt
3) Including the updates received from national experts.

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[5] Only stationary sources included

For ammonia emissions, RAINS and CORINAIR/EMEP estimates differ for most of the EU-15 countries typically by less than five percent. Exceptions are Denmark and Portugal:

- The 1997 UN/ECE review of the RAINS ammonia data by Danish experts resulted in significant changes in the 1990 emission estimates for Denmark, which are now 30 percent lower than the Danish numbers originally submitted to CORINAIR'90.
- The Portuguese CORINAIR'90 database contains very high emission factors for fertilizer use. Applying internationally reported values (ECETOC, 1994) reduces the overall estimate by about 17 percent.

For the non-EU countries, major discrepancies (larger than 10 percent) remain only for Hungary. The difference can be traced back to the omission of emissions from pigs and fertilizer use. It is worth mentioning that for Hungary the estimate officially submitted to EMEP is nearly three times larger than the CORINAIR'90 value.

2.4 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. For each of these measures, the model 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. 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), Cofala *et al.* (1997), Klimont *et al.* (1998) 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, Rentz *et al.*, 1996). Country-specific information has been extracted from relevant national and international statistics (e.g., UN/ECE, 1996). The list of control options for NO_x, NH_3 and VOC 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.

2.4.1 Options for Reducing SO_2 Emissions and their Costs

The national potentials and costs of emission reductions are estimated based on a detailed database 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 2.7 to Table 2.9 present, for the major source categories, the available control options and the data applied 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. Compared with previous reports, the most important updates are:

- The reduction efficiency of limestone injection has been increased from 50 percent to 60 percent. Such reduction efficiencies are achieved in German plants equipped with this technology (UBA, 1998)
- Following the comments made by CONCAWE, the price differential for low sulfur heavy fuel oil includes was corrected to reflect modified assumptions on capacity utilization of desulfurization plants (CONCAWE, 1998). It should be stressed that also the new figure is based on a four percent real interest rate used for the economic analysis in the RAINS model.

Table 2.7: Emission control options for SO_2 in the power plant and industrial sector considered in RAINS

Sector/control option	Removal efficiency	Costs[6] Investment [1000 ECU/MW_{th}]	Operating and maintenance [%/year][7]
Retrofit of existing boilers (power plants)			
Limestone injection	60 %	30	4 %
Wet flue gas desulfurization (FGD) - boilers already retrofitted in the base year	90 %	69	4 %
Wet flue gas desulfurization (FGD) - boilers not yet retrofitted	95 %	69	4 %
Regenerative FGD	98 %	165	4 %
New boilers (power plants)			
Limestone injection	60 %	22	4 %
Wet flue gas desulfurization (FGD)	95 %	49	4 %
Regenerative FGD	98 %	119	4 %
Industrial boilers and furnaces			
Limestone injection	60 %	35	4 %
Wet flue gas desulfurization (FGD)	85 %	72	4 %

Table 2.8: Options for low sulfur fuels considered in RAINS

Fuel type	Price difference [ECU / GJ / %S][8]	Costs [ECU / t SO_2][9]
Hard coal and coke, 0.6 % S	0.28	397
Heavy fuel oil, 0.6 %S	0.20	463
Gas oil, 0.2% S	0.68	1440
Gas oil, 0.045% S	2.04	4330
Gas oil, 0.003 % S[10]	6.69	14200

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[6] Values are for typical hard coal fired boilers for each source category.

[7] Percent of investments per year

[8] Percent sulfur reduced compared to original fuel.

[9] Per ton of SO_2 removed. Calculated for the typical heating value of each fuel.

[10] Only available for transport sources

Table 2.9: Emission control options for industrial process emissions of SO_2 considered in RAINS

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

2.4.2 Options for Reducing NO_x Emissions from Stationary Sources and their Costs

Table 2.10 to Table 2.15 present the measures for controlling NO_x emissions from stationary sources as contained in the RAINS database. Depending on the source category, the following main control options are assumed:

- Primary measures (low NO_x burners, re-burning, staged combustion). In the power plant sector this option is considered as a retrofit measure. For new installations, the use of primary measures is assumed by default at no extra costs.
- Selective catalytic (SCR) and non-catalytic (SNCR) reduction (always in combination with primary measures).

Table 2.10: Control options for NO_x emissions from the power plant sector considered in RAINS

Sector/control option	Removal efficiency [%]	Costs[11] Investment [kECU/MW_{th}]	 Operating and maintenance
Retrofits of existing boilers:			
Combustion modification and primary measures (CM)[12]			
Brown coal and lignite	65	6.8	-
Hard coal	50	3.9	-
Heavy fuel oil	65	4.7	-
Gas	65	5.0	-
CM + Select. Cat. Reduction (SCR)			
Brown coal and lignite	80	28.9	6 %/yr
Hard coal	80	23.0	6 %/yr
Heavy fuel oil	80	22.9	6 %/yr
Gas	80	24.7	6 %/yr
New boilers [13]			
SCR			
Brown coal and lignite	80	14.1	6 %/yr
Hard coal	80	12.2	6 %/yr
Heavy fuel oil	80	9.8	6 %/yr
Gas	80	12.9	6 %/yr

Table 2.11: Control options for NO_x emissions from the residential and commercial sector

Sector/control option	Removal efficiency [%]	Costs[14] Investment [1000 ECU/MW_{th}]	 Operating and maintenance [%/year][15]
Residential and commercial sector[16]			
Combustion modification, low-NO_x burners (CM)			
Heavy fuel oil	50	5.6	-
Medium distillates	30	12	-
Natural gas	50	16.3	-

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[11] Values are for typical boilers for each source category.

[12] Combination of various measures (e.g., low NO_x burners, overfire air, etc.)

[13] Low-NO_x burners are assumed by default; thus, new boilers have lower emission factors than the existing ones.

[14] Values are for typical boilers for each source category.

[15] Percent of investment cost per year.

[16] Weighted average for the residential and commercial sector. Unit control costs for gas and gas oil fired boilers in the commercial sector are 40 - 50 % lower.

Table 2.12: Control options for NO_x emissions from industrial boilers considered in RAINS

Sector/control option	**Removal efficiency [%]**	**Costs[17]**	
		Investment [1000 ECU/MW_{th}]	**Operating and maintenance [%/year][18]**
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	70	11.0	6
Hard coal	70	11.0	6
Heavy fuel oil	70	9.1	6
Gas	70	10.6	6
CM + Select. Cat. Reduction (SCR)			
Brown coal and lignite	80	26.0	6
Hard coal	80	25.3	6
Heavy fuel oil	80	18.5	6
Gas	80	21.4	6

Table 2.13: Control options for NO_x emissions from industrial processes

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

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[17] Values are for typical boilers for each source category.

[18] Percent of investment cost per year

2.4.3 Options for Reducing VOC Emissions from Stationary Sources and their Costs

Emissions of VOC originate both from mobile and stationary sources. Emission reduction measures for the mobile sources are described in the section on nitrogen oxides as they are the same as for controlling VOC emissions. The only exceptions are carbon canisters and oxidation catalysts for two-stroke gasoline engines. Although in reality they are installed in vehicles, they are included in the "stationary" part of the model, since they effect only VOC emissions.

There is a wide range of literature describing the available options for controlling VOC emissions from stationary sources, i.a., Jourdan and Rentz (1991), EPA (1994), OECD (1990, 1992). EEC (1990), ERM (1996), Hein *et al.* (1994), CONCAWE (1987-1990), KWS 2000 (1989-1997), VROM (1995a,b, 1997), IFARE (1998a,b).

Commonly employed methods for reducing VOC emissions from stationary sources include modification of the production process or storage tanks, improvement of the management practices (e.g., good housekeeping, leak monitoring and repair programs), solvent substitution, and finally add-on technologies, such as thermal or catalytic incineration, adsorption, absorption, condensation/refrigeration, and bio-oxidation. Major reduction measures and RAINS-VOC sectors to which they apply are listed in Table 2.14. Note that the listed efficiencies refer to the assumed technical efficiency of the option. In reality, the most efficient options in a sector often have only limited applicability.

The applicability of a given technology for the processes aggregated within a sector in the RAINS model is a very important element of the abatement module. There are many reasons for differences in applicability:

- In many cases the applicability will depend more on the characteristics of a specific source of emissions (e.g., drying oven) rather than on the type of the source category (e.g., automobile manufacturing/ surface coating);
- Some sectors (e.g., products incorporating solvents) include several processes (e.g., paint manufacture, ink manufacture) and the applicability of a selected technology depends on the parameters of the specific process;
- The size distribution of the installations considered in a given category;
- Reformulated products may not be available for all applications within a given source category;
- Variable parameters of emission streams, e.g., too low or too high concentrations of VOC in the stream gas or too low or high flow rates limiting the application of particular add-on techniques such as oxidation/incineration;
- Mixture of solvents used in the process, making some of the add-on technologies less effective or economic, e.g., carbon adsorption, condensation.

Table 2.14: Major categories of VOC abatement measures for stationary sources

Sector	*Technology*	*Efficiency [%]*	*Cost range [ECU/t VOC]*
Solvent use			
Dry Cleaning	Good housekeeping and adsorption	60	~600
	Closed circuit conventional or new machines	76/92	550/1200-4500
Metal degreasing	Basic emission management techniques	20	< 200
	Carbon adsorption	80	1300-2000
	Low temperature plasma process	98	1300-2300
	Conveyored degreaser with integrated adsorption	95	1700-2200
	Water based systems	99	2500-4000
Domestic solvent use	Substitution	~25	<4300
Non-industrial paint use	Water based paints	70-80	400-800
	High solids	40-60	1200-3000
Industrial paint use (car manufacturing)	Good housekeeping, application technique modification	20-45	<100
	Process modification and substitution	55-70	0.6-0.8/2-4*10^3
	Adsorption, incineration	95	1.5-1.8/3-7*10^3
Vehicle refinishing	Good housekeeping, application technique modification	15-30	< 0
	Housekeeping, application technique, substitution	72	300-800
Products incorporating solvents	Substitution	50	<50
	Basic emission management and end-of-pipe	95	600-900
Products not incorporating solvents	Solvent management plan and substitution	50	~200
	Basic emission management and end-of-pipe	60	1200-2500
Printing	Low solvent inks and enclosure	50-75	<30
	Water based inks	75-95	30-600
	Adsorption	75	150-1000
	Incineration	75	1000-10000
Glues and adhesives in industry	Good housekeeping	15	<50
	Substitution	85	350
	Incineration	80	~600
Preservation of wood	Double vacuum impregnation & dryer enclosure	40	~2800
	as above plus end-of-pipe	75	4300-7500
Other industrial use of solvents	Process modification and biofiltration	75	~600
	Water based coating (leather tanning)	~60	~350
	New agrochemical products	~40	~0
Chemical industry			
Organic chemical industry, processing and storage	Quarterly, monthly inspection and maintenance programs	60/70	~1600/~6000
	Flaring	85	~350
	Incineration	96	~800
	Internal floating covers and secondary seals	90	~2800
	Vapor recovery units	95-99	5600-6200
Pharmaceutical industry	Good housekeeping and end-of-pipe	85-90	2500-6000
Refineries	Quarterly, monthly inspection and maintenance programs	60/70	<50/300-1000
	Covers on oil/water separators	90	~200
	Flaring / Incineration	98/99	200-300
	Internal floating covers and secondary seals	85	<100
	Vapor recovery units (Stage IA)	95-99	500-2500
Liquid fuel extraction and distribution			
Fuel extraction, loading and transport	Venting alternatives and increased recovery	90	1800-2200
	Improved ignition system on flares	62	4500-5500
	Vapor balancing on tankers and loading facilities	78	50-200
Fuel distribution	Internal floating covers and secondary seals	85	<100
	Vapor recovery units (Stage IA)	95-99	500-2500
	Stage II	85	1500-3000
	Stage IB	95	200-800
Gasoline evaporation	Small carbon canister	85	50-500
2-stroke engines	Oxidation catalyst	80	900
Residential combustion	New boilers	80	100-500
	Catalyst	50	1000-7000
Miscellaneous			
Food and drink industry	End-of-pipe	90	10000
Agriculture	Ban on burning waste	100	60
Other industrial	Good housekeeping	20-60	<100
	Bitumen substitution (asphalt)	92	<50
Waste disposal	Improved landfills	20	400

2.4.4 Options for Reducing Emissions from Mobile Sources and their Costs

Also for mobile sources there exists a wide variety of fuel- and vehicle-related measures for reducing emissions. In order to keep the overall analysis manageable, RAINS aggregates individual measures into packages, following as far as possible the legislative proposals for emission standards discussed in the European context.

Table 2.15 presents the packages for controlling NO_x and VOC emissions for mobile sources as contained in the RAINS database. Data for mobile sources have been derived from various reports developed within the Auto/Oil program (EC, 1996b, Touche-Ross & Co., 1995) and from other national and international sources (i.a., Gorißen, 1992, HMSO, 1994, McArragher *et al*., 1994, Rodt *et al*., 1995, 1996, UN/ECE, 1994b, UN/ECE 1994c). The assistance of consultants participating in the Auto/Oil study helped to incorporate the suggested measures on fuel quality improvement and inspection and maintenance schemes into the RAINS model in a fully consistent way (Barrett, 1996).

The costs and control efficiencies of technologies used for the calculations presented in this report include the decisions of the Environment Council of October 1997 regarding the common positions on the quality of petrol and diesel fuels as well as on pollution control measures from motor vehicles (OJ 97/C 351/01, 1997a and OJ 97/C 351/02, 1997b). In particular, the following measures have been included in addition to the original Auto/Oil proposal:

- Change in petrol characteristics. For the year 2000, a reduction of the sulfur content to 150 ppm, of benzene to 1 percent and of aromatics to 42 percent. For 2005, further reductions to 50 ppm for sulfur and 35 percent for aromatics, as outlined in the indicative standards.
- Reduction of the maximum sulfur content in diesel oil to 50 ppm. It has been assumed that this low sulfur diesel fuel will be progressively introduced between 2005 and 2015. Additional costs of that fuel are allocated to the SO_2 control.
- For petrol cars, Stage 3 controls from the year 2000 and Stage 4 controls after 2005, taking into account the costs of the cold start test. Since the original proposal of the Auto/Oil programme for the increased durability of catalytic converters has not been accepted by the Commission (compare COM(96) 248, 1996), the unit costs of Stage 3 control have been corrected to reflect this change.
- Stage 4 controls for diesel cars, including the requirement for on-board diagnostic systems.
- Costs of Stage 4 controls have been reviewed and corrected taking into account information provided in Rodt *et al*. (1995, 1996).

The estimate of the effects of the Common Position on emission control efficiencies and costs is based on Auto/Oil data (EC, 1996; Touche & Ross, 1995) and on the information available in DG-XI (Mackowski, 1998).

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. Besides, Auto/Oil costs are in 1995 prices, while RAINS uses constant prices from 1990 as a basis for calculations.

The estimates of control efficiencies and costs for reducing emissions from ships are based on Norwegian sources (Klokk, 1995; Selvig, 1997).

Table 2.15: Control options for NO_x and VOC emissions from mobile sources

Fuel/vehicle type/control technology	**Removal efficiency NO_x/VOC [%]**	**Costs** **Investments [ECU/vehicle]**	 **Operating and maintenance [%/year]**[19]
Gasoline 4-stroke passenger cars and LDV[20]			
3-way catalytic converter - 1992 standards	75/75	250	30
3-way catalytic converter - 1996 standards	87/87	300	25
Advanced converter with maintenance schemes - EU 2000 standard	93/93	709	11
Advanced converter with maintenance schemes – possible EU post-2005 standard (**)	97/97	884	8
Diesel passenger cars and LDV			
Combustion modification - 1992 standards	31/31	150	34
Combustion modification - 1996 standards	50/50	275	19
Advanced combustion modification with maintenance schemes - EU 2000 standards	60/60	780	7
NO_x converter(**)	80/80	1027	5
Heavy duty vehicles - diesel			
Euro I - 1993 standards	33/36	600	42
Euro II - 1996 standards	43/47	1800	14
Euro III - EU 2000 standards with maintenance schemes	60/66	4047	6
Euro IV (NO_x converter) (**)	85/93	8047	3
Heavy duty vehicles – gasoline			
Catalytic converter	85/85	2750	7
Seagoing ships			
Combustion modifications – medium vessels[21]	40/0	115000	0
Combustion modifications – large vessels[22]	40/0	165000	0
SCR – large vessels	90/0	526000	4

(**) - Not yet commercially available. Preliminary cost estimates are based on Rodt (1995), Rodt *et al*. (1996), and UN/ECE (1994b, c).

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[19] Percent of investment cost per year.

[20] LDV - light duty vehicles.

[21] about 300 kW thermal

[22] about 2500 kW thermal

2.4.5 Options for Reducing Ammonia Emissions and their Costs

Ammonia emissions from livestock occur at four stages, i.e., in the animal house, 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 (Klaassen, 1991b, 1995; UN/ECE, 1996b; EEA, 1996; Menzi *et al*., 1997). 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), e.g., by treatment of ventilated air using biological scrubbers to convert the ammonia into nitrate or biological beds where ammonia is absorbed by organic matter. This option is applicable mainly for pigs and poultry;
- animal house 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);
- substitution of urea by ammonium nitrate for fertilizer application;
- stripping and absorption techniques in the chemical industry (e.g., during fertilizer production.

The removal efficiencies and costs of the control options are presented in Table 2.16 and Table 2.17. 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. An overview of national experience is available in the proceedings of the workshop on 'The Potential for Abatement of Ammonia Emissions from Agriculture and the Associated Costs' (Culham, UK, October, 1994; see ApSimon, 1994). More detailed information can be found in country reports, e.g., Menzi *et al.*, 1997; Zimmermann *et al.*, 1997 for Switzerland and Haan, Ogink, 1994; Hartog, Voermans, 1994; Holwerda *et al.*, 1995 for the Netherlands.

Table 2.16: Emission control options for NH_3 considered in the RAINS model and their assumed removal efficiencies

		Removal efficiency [%]			
Abatement option	**Application areas**	**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)[23]	Pigs, poultry	80		n.a,	n.a.
Animal house adaptation (SA)	Dairy cows, other cattle	45	60	n.a.	n.a.
	Pigs	50	60	n.a.	n.a.
	Laying hens	70	70	n.a.	n.a.
	Other poultry	80	70	n.a.	n.a.
Covered storage (CS - low/high)	Dairy cows, other cattle, pigs, poultry	n.a.	50/80	n.a.	n.a.
Low NH_3 application (LNA- low/high)	Dairy cows, other cattle, pigs, poultry, sheep [solid waste]	n.a.	n.a.	40/80	n.a.
	Dairy cows, other cattle, pigs [liquid manure]	n.a.	n.a.	30/70	n.a.
Urea substitution	Fertilizer use	80 - 93			
Stripping/ adsorption	Industry	50			

n.a.: not applicable

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[23] Although some countries indicated during the UN/ECE review process that this option is also available for cattle (because many animal houses are equipped with mechanical ventilation), it has not yet been implemented in RAINS.

Table 2.17: 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 place/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	40-60	35-38
	Laying hens	4.7		1.3-2.0	
	Other poultry	4.7		1.5-2.5	
Animal house adaptation	Dairy cows, Other cattle	450-550	400	90-110	75-90
	Pigs	90-94	89	18-20	
	Laying hens	0.8		0.2-0.25	
	Other poultry	1.8		0.28	
Covered storage - high efficiency	Dairy cows	150-350	100-220	20-50	10-20
	Other cattle	80-200	70-150	20-35	9-15
	Pigs	25-80	15-20	6-15	2-4
	Laying hens	0.4		0.05	
Covered storage - low efficiency	Dairy cows	50-100	30-60	10-20	5-7
	Other cattle	40-100	30-40	10-15	4-5
	Pigs	10-40	7-8	3-7	1-2
	Laying hens	0.2		0.03	
Low NH_3 application	Dairy cows	n.a.		40-70	
	Other cattle	n.a.		10-40	
	Pigs	n.a.		4-12	
	Laying hens	n.a.		0.1-0.15	
	Other poultry	n.a.		0.02-0.06	
	Sheep	n.a.		2-4	
Urea substitution	Fertilizer use	350-950 ECU/t NH_3 removed			
Stripping/adsorption	Industry	7000 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)

2.5 Atmospheric Source-Receptor Relationships

2.5.1 Modeling the Dispersion of Sulfur and Nitrogen Compounds in the Atmosphere

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 50 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).

2.5.2 Modeling Ozone Formation

The formation of ozone involves chemical reactions between NO_x and VOC driven by solar radiation and occurs on a regional scale in many parts of the world. The time scale of ozone production is such that ozone concentrations build up in polluted air over several days under suitable weather conditions, and this pollutant and its precursors can be transported over considerable distances and across national boundaries.

An integrated assessment model for ozone needs to be able to relate ozone exposure to changes in the emissions of ozone precursors. For application in an integrated assessment model for ozone, however, the source-receptor relationships need to be valid for a variety of spatial patterns of emission sources and for a range of emission levels, and not restricted to the present-day situation alone. For this reason, attempts to define these relationships solely on the basis of recent ozone measurement data are likely to prove inadequate. Instead, the ozone formation description needs to be based on mathematical models that have gained widespread international acceptance.

Within the framework of an integrated assessment model, source-receptor relationships must be computationally efficient to enable the numerous scenario runs for analyzing costs and benefits from a wide range of control strategies. Extended uncertainty and robustness analyses is necessary to derive solid conclusions from the model, taking into account the gaps and imperfections of the available databases and models. In many cases, methodologies for such analyses require sufficiently simple formulations of the underlying models. In addition, optimization analysis has proven to be a powerful feature in the integrated assessment process for the Second Sulfur Protocol. Optimization of the entire chain from the sources of emissions, over the costs for controlling them, up to the regional impacts on ozone levels, also requires sufficiently simple source-receptor relationships.

Most of the available models for ozone formation are process-oriented and contain a considerable degree of detail of the chemical mechanisms and meteorological factors relevant for ozone formation. Consequently, their computational complexity makes it impossible to use them directly within the framework of an integrated assessment model. In order to overcome this gap, an attempt has been made to construct a ‘reduced-form’ model, using statistical methods to summarize the reaction of a more complex ‘reference’ model.

To this end, the work was carried out in collaboration with EMEP’s Meteorological Synthesizing Centre-West, and the results of the EMEP ozone model (Simpson, 1993) provide the basis on which a 'reduced-form' model for the source-receptor relationships has been built. The EMEP model has been selected for this analysis, i.a., because (i) it has repeatedly undergone extensive peer review and its structure and results have been compared with other ozone models, and (ii) the EMEP model is readily available for calculating ozone levels over all of Europe over a time period of six months, and the calculation of the necessarily large number of scenarios is a practical proposition with this model.

2.5.3 Ozone Isopleth Diagrams

Before starting the development of the simplified model, the EMEP ozone model was used to investigate the relationships in different areas of Europe between mean boundary layer ozone concentrations and changes in the emissions of NO_x and VOCs. A convenient way to illustrate the results of these investigations is by means of ozone isopleth diagrams (Figure 2.2). Such diagrams have been most commonly used, particularly in North America, to show how maximum ozone concentrations depend on the initial concentrations of NO_x and VOCs on a particular day at a specific location. Lines of constant value, or isopleths, of the maximum ozone concentrations are constructed by connecting points having the same ozone concentration but corresponding to various initial conditions. Ozone isopleth diagrams in this form provide a concise representation of the effect of reducing initial NO_x and VOC concentrations on peak ozone concentrations. In the past, they have been used quantitatively to develop ozone control strategies as part of the U.S. EPA's empirical kinetic modeling approach (EKMA).

The isopleth diagrams used in this section are constructed rather differently, although there are obvious similarities in appearance. Firstly, the ozone statistic depicted by the isopleths is the mean, over the six-month summer period, of the early afternoon ozone concentrations calculated by the EMEP model. Secondly, in the version used here, ozone is shown as a function of the percentage reduction in emissions of NO_x and VOC across Europe. Thus, the top right-hand corner of each diagram represents the base case without any reduction in precursor emissions.

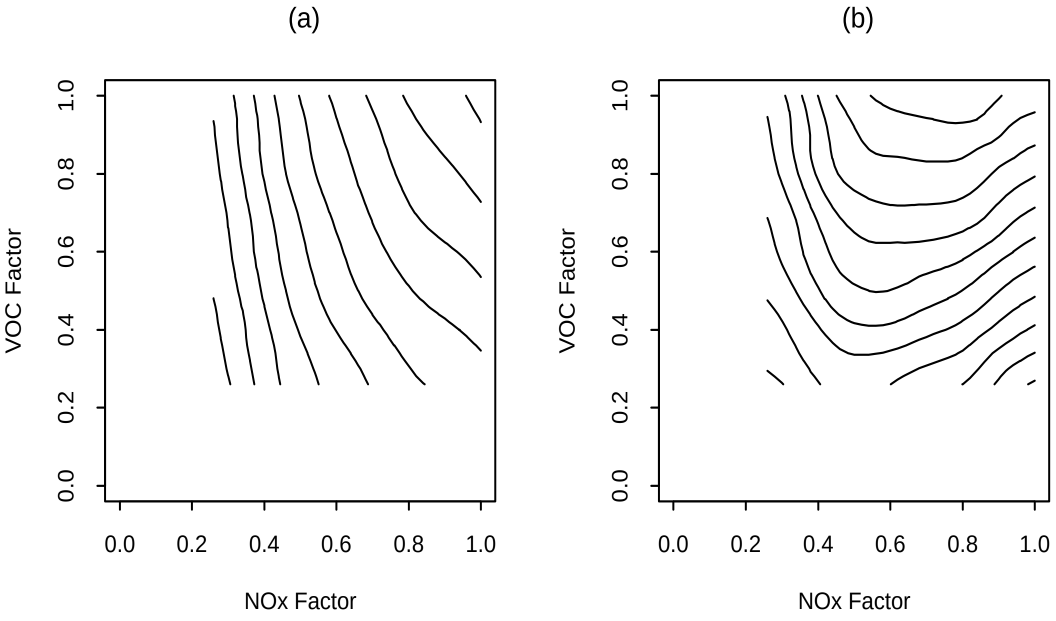

Figure 2.2: Typical patterns of ozone behavior in Europe. The left isopleth sketches the situation for a 'NO$_x$ limited region' in Europe, while the other illustrates the 'ozone hill' occurring in high-NO$_x$ areas.

For regions with comparably low emission densities, reductions in VOC emissions are seen to exert only a minor influence on mean ozone concentrations (Figure 2.2a). In these regions the NO_x / VOC ratio is relatively low and there is an ample supply of peroxy radicals (RO_2 and HO_2) to convert NO to NO_2 and, thus, lead to ozone production. Decreasing the available NO_x leads directly to a decrease in ozone. In these circumstances, ozone formation is limited by the availability of NO_x, and the atmospheric chemistry system is said to be NO_x-limited. In such regions, reductions in emissions of NO_x are likely to be effective in reducing ozone concentrations, but ozone is relatively insensitive to reductions of VOC, and to changes in the VOC species distribution, at constant NO_x.

In areas with sufficiently high emission densities, i.e., in the north-west of Europe, the isopleths form a ridge dividing the diagram into two areas (Figure 2.2b). On the left of the ridge, corresponding to the greatest reductions in NO_x emissions, the system tends towards the NO_x -limited case). On the right of the ridge, the NO_x / VOC ratio is relatively high and the NO_2 concentrations are sufficiently great that NO_2 competes with VOC for reaction with the OH radical. In this region of the diagram, reducing VOC emissions results in lower ozone concentrations; to a large extent, ozone shows a linear dependence on VOC emission changes (Simpson, 1992). However, ozone concentrations may be increased, at least initially, by NO_x reductions in the absence of concurrent reductions in VOC emissions.

2.5.4 A ‘Reduced Form’ Model of Ozone Formation

On the basis of the ideas outlined above a general formulation for the reduced-form "seasonal" model was developed. In subsequent sections the following abbreviations are used for model variables:

v_i - annual national emissions of non-methane VOCs from emitter country i
n_i - annual national emissions of NO_x from emitter country i
ev_j - "effective" emissions of VOCs, including natural sources, at receptor j
en_j - "effective" emissions of NO_x, including natural sources, at receptor j
evn_j - "effective" natural emissions of VOCs at receptor j
enn_j - "effective" natural emissions of NO_x at receptor j

The long-term ozone exposure at receptor j, AOT_j, is assumed to be a function of the non-methane VOC and NO_x emissions, v_i and n_i respectively, from each emitter country i, and the mean "effective" emissions (of NO_x and VOCs), en_j and ev_j, experienced at the receptor over the period in question. The general model formulation adopted is:

$$AOT_{lj} = k_j + \sum_{i=1}^{M}(a_{ij}v_i + b_{ij}n_i + c_{ij}n_i^2) + \alpha_j \overline{en_j}^2 + g(\overline{en_j},V) + \overline{en_j}\sum_{i=1}^{M} h_{ij}n_i \qquad (1)$$

where M is the number of emitter countries considered,

$$V = \{v1, v2, ..., vM\}, \qquad (2)$$

and the non-linear function $g()$ is given either by:

$$g(\overline{en_j},V) = \overline{en_j} \sum_{i=1}^{M} d_{ij}v_i \qquad (3)$$

or by:

$$g(\overline{en_j},V) = \beta_j \overline{en_j}\,\overline{ev_j} \qquad (4)$$

The mean "effective" emissions are given by:

$$\overline{en_j} = \sum_{i=1}^{M} \overline{E_{ij}} n_i + \overline{enn_j} \qquad (5)$$

$$\overline{ev_j} = \sum_{i=1}^{M} \overline{F_{ij}} v_i + \overline{evn_j} \qquad (6)$$

where E_{ij}, F_{ij} depend on the meteorology and are obtained from EMEP model calculations, and enn_j and evn_j represent the "effective" natural emissions of NO_x and VOCs, respectively.

For the initial stages of evaluating this model, an heuristic approach was taken to decide which terms, if any, could be dropped from the model. Such experiments led to the conclusion that the following linear regression model contained sufficient information for the present purpose:

$$AOT_{lj} = k_j + \sum_{i=1}^{M}(a_{ij}v_i + b_{ij}n_i + c_{ij}n_i^2) + \alpha_j \overline{en_j}^2 + \overline{en_j} \sum_{i=1}^{M} d_{ij}v_i \qquad (7)$$

In order to decide which emitter countries should be included in the model, the emitter countries were ranked (i) on the basis of their contribution to the "effective" NO_x emissions experienced at each receptor j, and (ii) by how great an ozone reduction was achieved for a given fractional VOC reduction. The most influential twelve countries were included in the equation, i.e. M was set equal to 12. This choice was based on an assessment of the EMEP model results for a small number of receptor sites, in an attempt to include in the simplified model all the most influential emitter countries (for a given receptor) yet exclude those which had very little effect.

The formulation of the reduced-form model given in Equation 7 above has been used in the construction of models for 598 European receptor grids.

It is of interest to relate the terms of Equation 7 to the physical and chemical processes that determine ozone formation in the atmosphere. Possible interpretations are:

k_j	includes the effects of background concentrations of O_3 and its precursors, and natural VOC emissions;
$a_{ij}v_i$	provides the linear country-to-grid contribution from VOC emissions in country i, allowing for meteorological effects;
$b_{ij}n_i$	provides the linear country-to-grid contribution from NO_x emissions in country i, allowing for meteorological effects;
$\alpha_j en_j^2$	takes account of the average non-linearity (in the O_3 / NO_x relationship) experienced along trajectories arriving at receptor j and any non-linear effects local to that receptor;
$c_{ij}n_i^2$	serves essentially as a correction term to allow for non-linearities occurring close to high NO_x emitter countries;
$d_{ij}en_jv_i$	allows for interactions between NO_x and VOCs along the trajectories.

The coefficients a_{ij}, b_{ij}, $c_{ij,\,,}$, d_{ij} and α_I are estimated by the linear regression, and n_i, v_i and en_j are used as variables. The coefficients a_{ij} and b_{ij} may also be regarded as a composite source-receptor matrix.

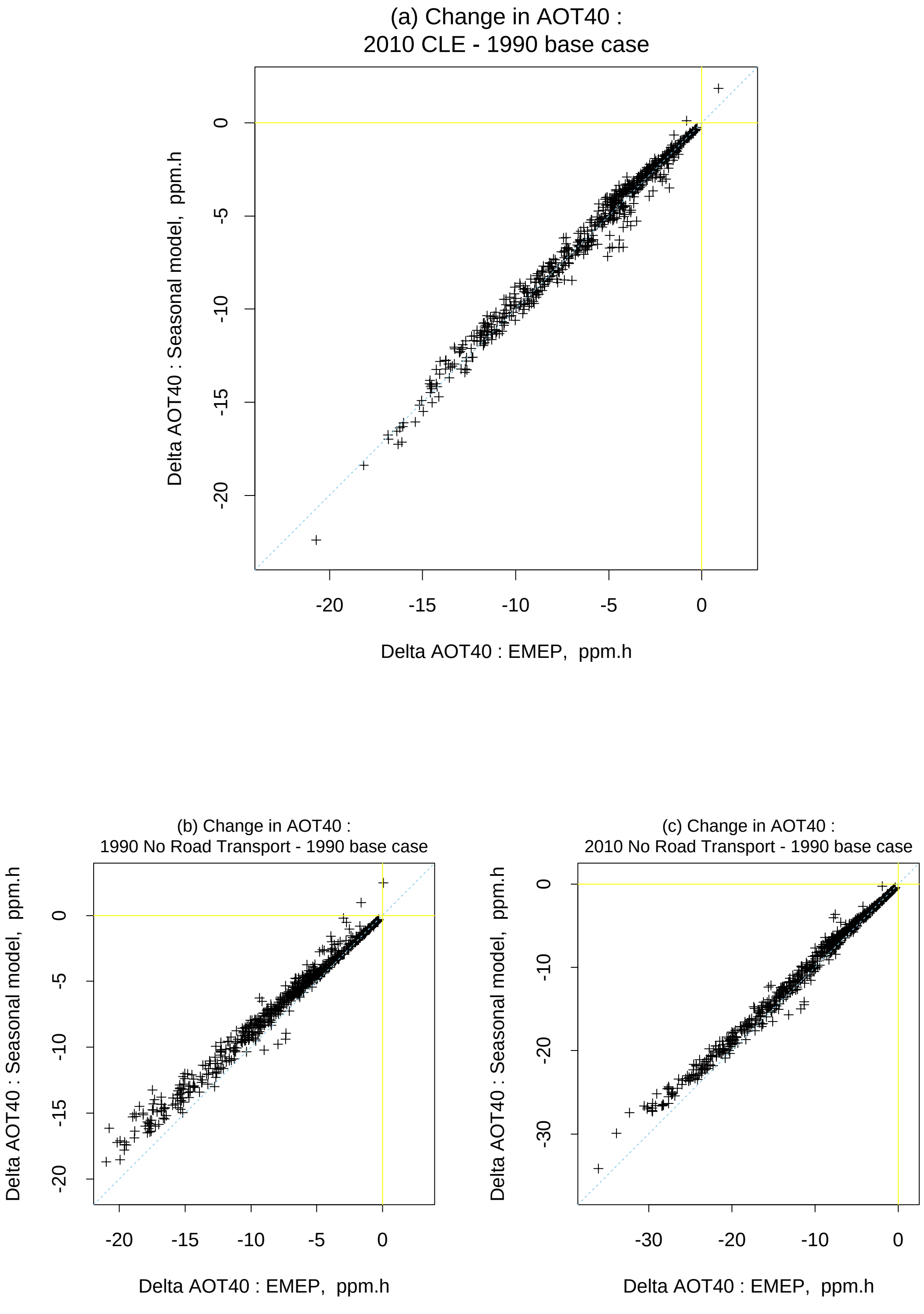

Figure 2.3: Comparison of the results from the reduced-form model for three scenarios with the corresponding EMEP model calculations

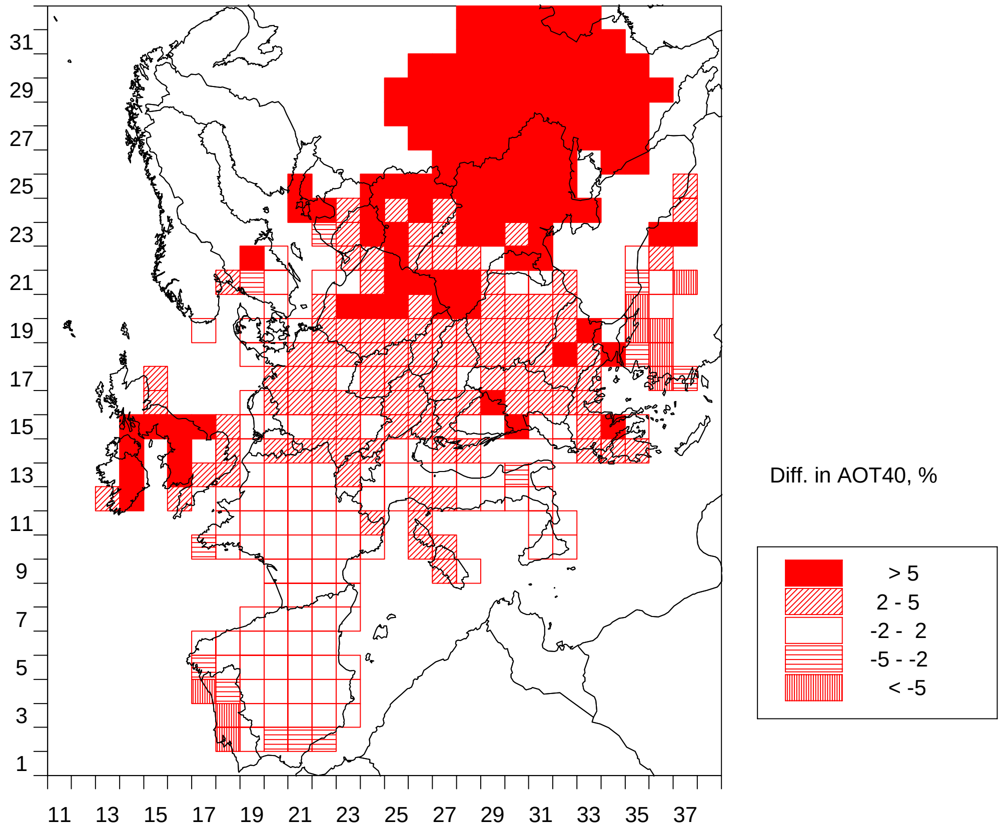

Figure 2.4: Spatial distribution of differences between a reduced-form and the full EMEP models for those receptor grids at which the 1990 base case AOT40 value for forests - as calculated using the 1995 version of the EMEP model - exceeds the critical level of 10 ppm.hours.

2.6 Critical loads and Critical Levels

2.6.1 The Concept of 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).

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.

2.6.2 The European Critical Loads Database

Following standardized methodologies, critical loads data are compiled on a national level. Each year the Coordination Center for Effects (CCE)) located at the Dutch National Institute for Public Health and the Environment (RIVM) invites countries to submit revised national critical loads calculations, so that the integrated assessment modeling groups participating in the LRTAP Convention may work with up-to-date critical loads data. The following paragraphs describe the status of the critical loads databases as of August 1998.

For the 1998 version of the critical loads databases, the number of countries which submitted data has increased to 24 (see Table 2.18 and Table 2.19). National focal centers have selected a variety of ecosystem types as receptors for calculating and mapping critical loads. For most ecosystem types (e.g., forests), critical loads are calculated for both acidity and eutrophication. Other receptor types, such as streams and lakes, have only critical loads for acidity, on the assumption that eutrophication does not occur in these ecosystems. For some receptors, like most semi-natural vegetation, only critical loads for nutrient nitrogen are computed, since the sensitivity to acidifying effects is less than the eutrophication effects.

Table 2.18 shows for the EU countries the ecosystem types and the number of individual ecosystems for which critical loads data were submitted by the national focal centers. Out of the 15 EU countries, 12 countries submitted critical load calculations to the CCE, providing details about 595,566 ecosystems. No data were supplied by Greece, Portugal and Luxembourg. Table 2.19 complements this information with the critical load statistics for the non-EU countries.

For those countries which did not provide their national critical loads estimates to the CCE, the European background database for critical loads (de Smet *et al.*, 1997) is employed. The European background database is constructed at the CCE by applying the consensus methodology for calculating critical loads to internationally published information, such as the 1994 digital soil map of the FAO and the RIVM European land use maps.

Figure 2.5 shows the fifth percentile of $CL_{max}(S)$ for the EMEP modeling domain.

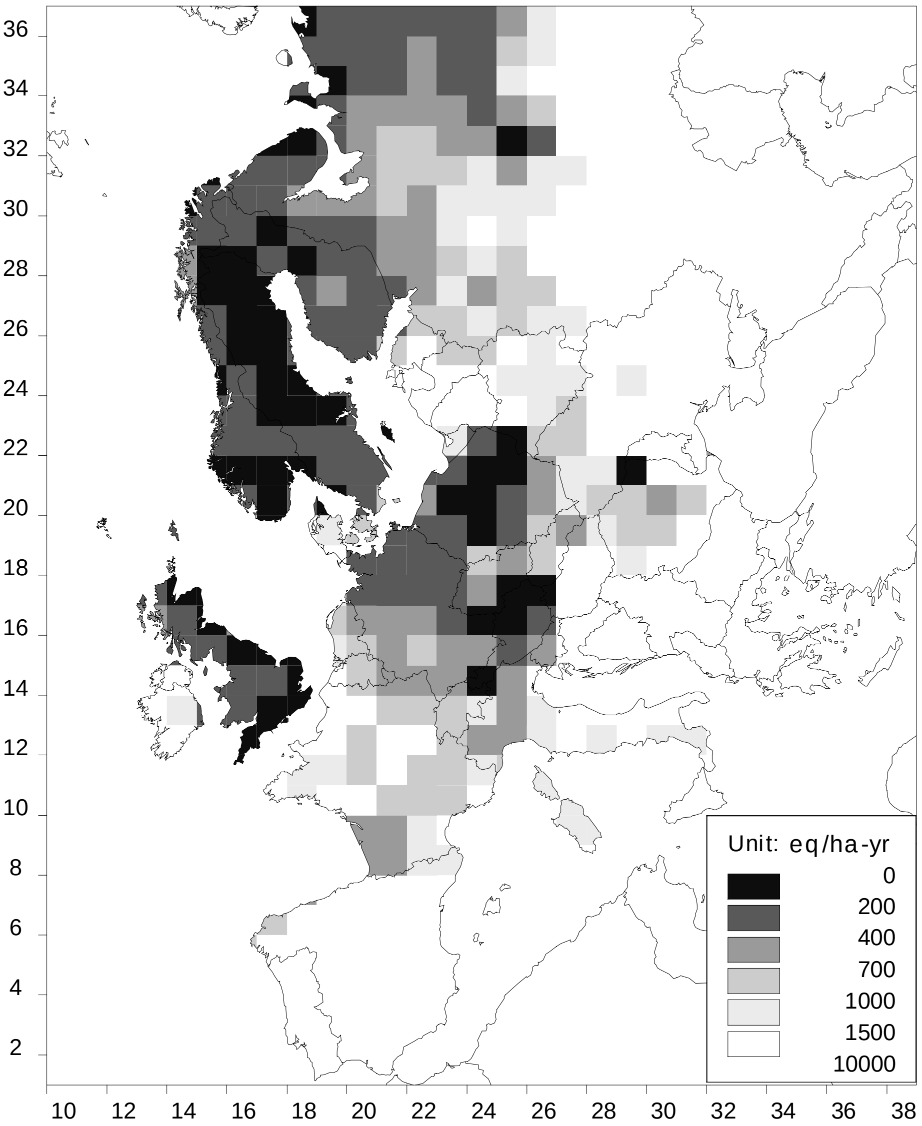

Figure 2.5: The fifth percentile of the critical loads for acidity ($CL_{max}(S)$)

Table 2.18: Types of ecosystems, number of critical loads and ecosystem cover (percentage of total land area) in the critical loads database submitted by EU countries (Status 1997) Source: Coordination Centre for Effects, Posch (1998)

Country	**Ecosystem type**	**Critial loads submitted**		**Land area covered by ecosystems with CL for acidity**
		No. of ecosystems	**Total ecosystems**	
Austria	Forest	6604	7901	71.2 %
	Oligotrophic bog	205		
	Alpine grassland	1092		
Belgium	Coniferous forest	835	2532	23.0 %
	Deciduous forest	1201		
	Mixed forest	490		
	Lake	6		
Denmark	Spruce	5463	18784	9.0 %
	Pine	1033		
	Beech	2814		
	Oak	447		
	Grass	9027		
Finland	Spruce	1004	4533	80.7 %
	Pine	1045		
	Deciduous forest	1034		
	Lake	1450		
France	Coniferous forest	28	591	58.4 %
	Deciduous forest	83		
	Mixed forest	302		
	Grassland (agricultural)	178		
Germany	Coniferous forest	227457	410277	28.7 %
	Deciduous forest	91937		
	Mixed forest	90883		
Ireland	Coniferous forest	10022	26303	9.8 %
	Deciduous forest	8933		
	Moors/Heathland	7348		
Italy	Boreal forest	41	502	39.8 %
	Temperate coniferous forest	22		
	Temperate deciduous forest	165		
	Mediterranian forest	110		
	Tundra	46		
	Acid grassland	118		

Table 2.18: Types of ecosystems, number of critical loads and ecosystem cover (percentage of total land area) in the critical loads database submitted by EU countries (Status 1997) Source: Coordination Centre for Effects, Posch (1998), continued

Country	**Ecosystem type**	**Critial loads submitted**		**Land area covered by ecosystems with CL for acidity**
		No. of ecosystems	**Total ecosystems**	
Netherlands	Coniferous forest	52949	127269	7.6 %
	Deciduous forest	74320		
Spain	Coniferous forest	2237	3409	17.1 %
	Deciduous forest	744		
	Mixed forest	428		
Sweden	Forest	1883	4261	86.9 %
	Lake	2378		
United Kingdom	Coniferous forest	29309	318258	39.2 %
	Deciduous forest	69747		
	Acid grassland	137228		
	Calcareous grassland	24976		
	Heathland	55553		
	Fresh water catchment	1445		
EU-15			890870	

Table 2.19: Types of ecosystems, number of critical loads and ecosystem area (percentage of total land area) in the critical loads database submitted by non-EU countries (Status 1997) Source: Coordination Centre for Effects, Posch (1998)

Country	**Ecosystem type**	**Critial loads submitted**		**Land area covered by ecosystems with CL for acidity**
		No. of ecosystems	**Total ecosystems**	
Belarus	Coniferous forest	234	555	24.2 %
	Deciduous forest	79		
	Grassland	242		
Bulgaria	Coniferous forest	29	84	44.6 %
	Deciduous forest	55		
Croatia	Coniferous forest	18	34	4.8 %
	Deciduous forest	16		
Czech Republic	Forest	29418	29418	33.7 %

Table 2.19: Types of ecosystems, number of critical loads and ecosystem area (percentage of total land area) in the critical loads database submitted by non-EU countries (Status 1997) Source: Coordination Centre for Effects, Posch (199, continued.

Country	**Ecosystem type**	**Critial loads submitted**		**Land area covered by ecosystems with CL for acidity**
		No. of ecosystems	**Total ecosystems**	
Estonia	Pine-podzol	32	140	41.8 %
	Pine-bog	22		
	Spruce-podzol	30		
	Spruce-alvar	15		
	Deciduous-podzol	12		
	Deciduous-wet	14		
	Bog	15		
Hungary	Unspecified forest	7	42	3.1 %
	Coniferous forest	5		
	Deciduous forest	8		
	Grassland / Reed / Marsh	12		
	Heath	4		
	Bog	4		
	Lake	2		
Moldova	Coniferous forest	15	141	35.6 %
	Deciduous forest	32		
	Grassland	94		
Norway	Forest	720	4635	99.0 %
	Lake/stream	2305		
	Semi-natural vegetation	1610		
Poland	Coniferous forest	1957	3914	55.5 %
	Deciduous forest	1957		
Russian Federation	Coniferous forest	4929	14251	74.2 %
	Deciduous forest	2983		
	Other	6339		
Slovakia	Coniferous forest	112440	320891	40.9 %
	Deciduous forest	208451		
Switzerland	Forest	8467	23937	58.0 %
	Alpine lakes	495		
	Semi-natural ecosystem	14975		
Total ECE			1322662	

2.6.3 Using Critical loads for Integrated Assessment Modelling

The European critical loads database as compiled by the Coordination Centre for Effects provides for each cell of the EMEP grid system the cumulative distribution function of the critical loads for all ecosystems of the grid cell. From this information it is possible to derive for each grid cell, for a given deposition value calculated from a certain emission control scenario, (a) the excess deposition for a selected ecosystem (e.g., for the two percentile) and (b) the percentage of ecosystems which experience deposition below their critical loads (i.e., the ecosystems protected against acidification).

Both measures have been used in the past to establish environmental interim targets on the way towards the full achievement of critical loads. The negotiations on the Second Sulfur Protocol of the Convention on Long-range Transboundary Air Pollution postulated for each grid cell a minimum ’60 percent gap closure’ between the deposition in 1980 and the critical load of the ’five percentile’ ecosystem. This strategy relied only on the critical load estimate of one single ecosystem, i.e., it ignored the five percent more sensitive ecosystems and the 94 percent less sensitive ecosystems in each grid cell.

Due to the methodological problems in adding up sulfur and nitrogen deposition, the multi-pollutant context of the EU Acidification Strategy motivated a move towards the second approach by using the percentage of protected ecosystems as the key environmental indicator for shaping the strategy. In practice, the central scenario aimed at a 50 percent reduction (’gap closure’) of the area of unprotected ecosystems in each grid cell, compared to the situation in 1990. Obviously, this criterion addresses the other dimension of the cumulative distribution function (i.e., the full range of ecosystems), but it ignores the extent to which ecosystems receive excess deposition.

Over the last few months, a new measure for evaluating ecosystems protection was developed. This new measure reflects the total excess deposition (above the critical loads) accumulated for all ecosystems in a grid cell (in acid equivalents per year). Starting from a given deposition, this ’accumulated exceedance’ (AE) is calculated by adding up (for each ecosystem) the sulfur and nitrogen reduction needed to achieve non-exceedance by taking the shortest path to the critical load function.

2.6.4 The AOT60 as a Surrogate Indicator for Risk to Human Health

The analysis presented in this report addresses the protection of human health and vegetation against elevated ozone exposure. The appropriate exposure measures for environmental long-term targets for these categories are discussed in detail in the Draft Position Paper on Ozone prepared by the Commission’s Services. For modeling and optimization purposes, however, the use of some of these original criteria proved to be complicated and impractical, and some surrogate indicators have been introduced instead. By no means the use of such surrogate indicators does question the original definition of the criteria. Furthermore, they must not be interpreted as actual damage estimates. The only reason for the surrogate indicators is to facilitate the modeling and optimization exercise.

Following the revised WHO Air Quality Guidelines for Europe (WHO 1997), the Draft Position Paper on Ozone prepared by the Commission's Services proposes a maximum eight-hour average concentration of 60 ppb (120 μg) as the long-term environmental objective for the EU ozone strategy[24]. The ultimate goal would be to eliminate all excess of this criterion.

The modeling of European abatement strategies for individual days over a multi-month period is a rather ambitious task and is not entirely feasible at the moment. In order to simplify the modeling task, and particularly to find a manageable approach for the reduced-form model implemented in the RAINS optimization, the target of no-exceedance of the WHO criterion (60 ppb as maximum eight hours mean concentrations) was converted into an AOT index, which could be handled in a similar way to the AOT40 for vegetation. As a result, an AOT60 (i.e., the cumulative excess exposure over 60 ppb, for practical reasons over a six-month period) of zero is considered as equivalent to the full achievement of the WHO criterion. Any violation of this WHO guideline will consequently result in an AOT60 of larger than zero.

It is important to stress that this AOT60 surrogate indicator has been introduced purely for practical modeling reasons. Given the current knowledge on health effects it is not possible to link any AOT60 value larger than zero with a certain risk to human health. The only possible interpretation is that if the AOT60 is above zero, the WHO criterion is exceeded at least once during the six-month period.

For the actual model exercise, the AOT60 of different emission control scenarios at a given site is calculated as a function of the emission levels of NO_x and VOC in the various European countries (see the description of the 'reduced form' model in Part A). The reduced-form model is derived from a statistical analysis of a large sample of results obtained with the full EMEP model. The EMEP model provides ozone levels at six-hourly intervals (0 GMT, 6 GMT, 12 GMT and 18 GMT) over a six months period. Following the findings of various studies for different parts of Europe (Künzle, 1995; Dumont 1998), the AOT60 has been calculated as the excess ozone over 60 ppb at 12 GMT and 18 GMT, accumulated over the entire period and multiplied by a factor of six.

2.6.5 The AOT40 as a Critical Threshold for Vegetation Protection

In the absence of accepted dose-response curves applicable at the large scale, the analysis in this report uses the concept of critical thresholds as developed within the framework of the UN/ECE Convention on Long-range Transboundary Air Pollution. The Working Group on Effects of this Convention established two long-term related critical levels:

- For agricultural crops and herbaceous plant communities (natural vegetation), the critical level is set at an AOT40 of 3 ppm.hours for the growing season and daylight hours, over a five-year period;
- For forest trees, a critical level of 10 ppm.hours for daylight hours, accumulated over a six-month growing season, is proposed.

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[24] The maximum is calculated from running eight-hour averages of the one-hour mean concentrations.

The AOT40 is calculated as the sum of the differences between the hourly ozone concentrations in ppb and 40 ppb for each hour when the concentration exceeds 40 ppb, using daylight hours only.

It has been shown elsewhere that for the currently prevailing European ozone regime the critical level for crops and natural vegetation is stricter than the critical level for forest trees. This means in other words, while the critical levels for forest trees are usually met when the critical level for crops and vegetation is achieved, the opposite statement does not hold. Based on this finding it has been decided to restrict the scenario analysis to the critical levels for crops and natural vegetation. If considered necessary, however, there are no methodological problems to prevent exploring scenarios for the achievement of the critical levels for forest trees separately.

For the regression analysis of the reduced-form ozone model, the AOT40 has been calculated from the results of the full EMEP model by multiplying the excess exposures over 40 ppb at 12GMT and 18 GMT, accumulated over a three months period, by a factor of six.

2.7 Optimization

2.7.1 The Formulation of the Optimization Problem

The optimization mode of integrated assessment models can be a powerful tool in the search for cost-effective solutions to combat an air pollution problem. In the RAINS-acidification model, optimization techniques have been used to identify the cost-minimal allocation of resources in order to reduce the gap between current sulfur deposition and the ultimate targets of full critical loads achievement.

In the case of tropospheric ozone, a systematic search for cost-effectiveness appears even more attractive. The facts that several pollutants (NO_x and VOC emissions) are involved, and that important non-linearities between precursor emissions and ozone levels have been recognized, cut the likelihood of 'intuitive' solutions being identified in the scenario analysis mode.

The model distinguishes between a set of *I* sources of various types of air pollution and a set of *J* receptor areas for which various air quality targets are assessed.

Emissions are analyzed for sets of emitters that are located in a region *i*, which is typically a country. NO_x and VOC emitters are further subdivided into sectors in order to account for sectoral emission controls that reduce either NO_x or VOC or a linear combination of them.

2.7.1.1 Decision Variables

The main decision variables are the annual emissions of the following four polutants from either sectors or countries:

n_{is}	annual emissions of NO_x in sector *s* of country *i*,
v_{is}	annual emissions of VOC in sector *s* of country *i*,,
a_i	annual total emissions of NH_3, and
s_i	annual total emissions of SO_2.

Additionally, optional variables are considered for limited violations of air quality targets. For such scenarios, variables corresponding to each type of the considered air quality targets are defined for each receptor:

yl_j	violation of ozone exposure targets (surplus if $y_{lj} < 0$);
ya_j	violation of the acidification targets (surplus if $ya_j < 0$).

Each variable represents a violation of a given environmental target. Violations of targets are balanced with surpluses at selected other receptors (within the same country).

2.7.1.2 Auxiliary Variables

Auxiliary variables are introduced for total national emissions of NO_x (n_i), total national emissions of VOC (v_i) (summing up all sectoral emission in a country) and the mean effective emissions of NO_x experienced at the *j-th* receptor (en_{ij}).

2.7.1.3 Outcome Variables

One outcome variable represents the sum of the costs of emission reductions. Annual costs related to the reduction of one or several pollutants to a certain level are described by piece-wise linear functions:

$cs_i(s_i)$	for SO_2,
$ca_i(a_i)$	for NH_3,
$cn_i(n_i)$	for stationary NO_x sources,
$cv_i(v_i)$	or stationary sources of VOC emissions, and
$c_i(n_i,v_i)$	for simultaneous NO_x and VOC control at mobile sources.

For each cost function the domain is specified through upper and lower bounds of the arguments, which implicitly defines lower and upper bounds for total national emissions. These bounds may be tightened by an optional specification of bounds on total national or sectoral emission, e.g., to reflect upper limits to the emissions related to the CRP scenario.

For each receptor, the following outcome variables correspond to the various environmental targets. For AOT60, the outcome variable $aot60_i$ is related to the decision variables by

$$AOT60_j = k60_j + \sum_{i=1}^{M}(a60_{ij}v_i + b60_{ij}n_i + c60_{ij}n_i^2) + \alpha 60_j \overline{en}_j^2 + \overline{en}_j \sum_{i=1}^{M} d60_{ij}v_i$$

with $k60_j$, $a60_{ij}$, $b60_{ij}$, $c60_{ij}$, $\alpha 60_{ij}$ and $d60_ij$ as the receptor-specific coefficients of the reduced-form ozone model (see Section 2.5.4). A similar constraint is specified for the AOT40

$$AOT40_j = k40_j + \sum_{i=1}^{M}(a40_{ij}v_i + b40_{ij}n_i + c40_{ij}n_i^2) + \alpha 40_j \overline{en}_j^2 + \overline{en}_j \sum_{i=1}^{M} d40_{ij}v_i ,$$

where $k40_j$, $a40_{ij}$, $b40_{ij}$, $c40_{ij}$, $\alpha40_{ij}$ and $d40_j$ are the coefficients of the reduced-form ozone model.

For acidification, the outcome variables the type *l* (relating to the *l*-th segment of the piece-wise linear approximation of the accumulated excess function of the receptor grid *j*) is related to the decision variables via:

$$ac_{lj} = tns_{lj}(\sum_i tn_{ij} n_i + \sum_i ta_{ij} a_i) + tss_{lj} \sum_i ts_{ij} s_i + kn_j + ks_j$$

with tn_{ij}, ta_{ij}, ts_{in} are the transfer coefficients for NO_x, NH_3 and SO_2, respectively, kn_j and ks_j *the* background depositions for sulfur and nitrogen and tns_j and tss_j scaling coefficients to convert sulfur and nitrogen deposition into units of acidity of the critical loads functions. The coefficients tn_{ij}, ta_{ij}, ts_{in} kn_j and ks_j are obtained from the EMEP model; tns_{lj} and tss_j, are extracted from the critical loads database.

The accumulated excess of acidification (aac_j) is calculated by a piece-wise linear function PWL_j

$$aac_j = PWL_j ac(ac_j)$$

For eutrophication, the outcome variable is linked to the decision variables

$$eu_j = \sum_i tn_{ij} n_i + \sum_i ta_{ij} a_i + ke_j$$

2.7.1.4 Constraints

Each of the decision variables is implicitly bounded by a corresponding definition of the domain of the cost function

$n_{is}^{min} \le n_{is} \le n_{is}^{max}$,
$v_{is}^{min} \le v_{is} \le v_{s}^{max}$,.
$a_{i}^{min} \le a_{i} \le a_{i}^{max}$,
$s_{i}^{min} \le s_{i} \le s_{i}^{max}$

The $AOT_{(l=60/40)}$ at each receptor is constrained by

$$AOT_{lj} - y_{lj} \le AOT_{lj}^{max}$$

where AOT_{lj}^{max} is given by the user, and the accumulated excess acidity is constrained by

$$aac_j - ya_i \le aac_j^{max}$$

with aac_j^{max} specified by the user.

Optionally, violations fo targets can be balanced with surplusses of targets within restricted sets of receptors (Jm), where $m \in M$ is the index of a set of receptors. The balances are represented by the following constraints:

$$\sum_{j} wo_{lmj} y_{lj} \le tbo_{lm} \text{ , l=0}$$

$$\sum_{l} \sum_{j} wo_{lmj} y_{lj} \le \sum_{l} tbo_{lm}$$

$$\sum wa_{mj} ya_{j} \le tba_{m}$$

where wol_{mj} and wa_{mj} are given weighting coefficients, J_{m} are set of receptors and tbo_{lm}, and tba_{lm} are target balances for the m-th set of receptors.

2.7.1.5 Goal function

A composite goal function is used for a single criterion optimization of th enon-linear ozone model in order to meet the following goals

- minimization of total costs of emission reductions,
- minimization of violations of environmental targets.

Therefore, the goal function is formulated as

$$goal\_function = \sum_{i} (ca_{i}(a_{i}) + cs_{i}(s_{i}) + cn_{i}(n_{i}) + cv_{i}(v_{i}) + c_{i}(n_{i}, v_{i}) + penalty$$

The penalty term is defined by

$$penalty = \rho \sum_{l} \sum_{j} y_{lj}{}^{\xi} + \rho_{a} \sum ya_{j}{}^{\xi}$$

where ρ and ρ_{a} are a large positive penalty coefficients. The penalty term exponent ξ is equal to 1, of the corresponding lower bound is equal to 0.

2.7.2 Sectoral Cost Curves as Input to the Optimization

Inputs to the optimization package include cost curves providing, for the various pollutants under consideration, the costs of reducing emissions at the different source regions for a selected year.

The current implementation of the RAINS model contains modules for estimating emission control costs for SO_2, NO_x, NH_3 and VOC. These estimates can be expressed in terms of cost curves, providing - for a given emission source (country) - the least costs for achieving increasingly stringent emission reductions. They are compiled by ranking the available abatement options according to their marginal costs. Consequently, this methodology produces piece-wise linear curves, consisting typically of about 20-80 segments, depending on the pollutant.

For each of the pollutants (SO_2, NO_x, VOC, NH_3) and the countries, such piece-wise linear curves can be used as input to the optimization. Although the solvers used for this exercise are capable of dealing with piece-wise linear curves, for reasons of increased numerical stability a smoothed approximation of the cost curves has been developed and used. For this the original piece-wise linear information was smoothed at corners.

The selected functional form guarantees that the curve is, within the selected interval, convex and monotonically decreasing, and shows asymptotic behavior at the maximum control level. For NO_x, the maximum deviation from the piece-wise linear curve is typically within a range of ± five percent.

The cost curves have been submitted to the Parties of the Convention on Long-range Transboundary Air Pollution for review (NO_x and $_{NH3}$: December 1996, VOC: December 1997, SO_2: June 1998). Comments received from the Parties have been fully incorporated into the cost curves. The full documentation of the cost curves is available on the internet (http://iiasa.ac.at/~rains).

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. Part B of this report present analyses of emission control strategies for two alternative set of energy projections:

3.1.1 The 'Baseline' Energy Scenario used for this Report

The 'baseline' energy scenario reflects a kind of official 'business-as-usual' view of the energy development, compiled from a variety of national and international sources. For the EU-15 countries, the default projection is the pre-Kyoto 'Business as usual' (BAU) scenario of DG-XVII (Capros *et al*., 1997). In cases when countries officially reported alternative projections to the Commission, these national scenarios were used instead. For this Sixth Interim Report, the business-as-usual energy scenario has been replaced by national data for Austria, Belgium, Denmark, Finland, Germany, Greece, Ireland, Netherlands, Sweden and the UK. A national scenario has also been received from Italy on September 11, 1998, but lack of time prevented the timely implementation into the RAINS model.

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, 1996). Where necessary, missing forecast data have been constructed by IIASA based on a simple energy projection model. These forecasts (Table 3.3) are also the basis for the scenario calculations conducted for the negotiations of the Second NO_x Protocol under the Convention on Long-range Transboundary Air Pollution.

The energy scenario selected for this study projects for the 15 EU countries an increase of total energy consumption of 20 percent between 1990 and 2010. The demand for coal decreases by 30 percent. This decline is mainly compensated by a rapid increase in the demand for natural gas (72 percent by 2010) and for other fuels (nuclear, hydropower, renewable energy) by 24 percent (Table 3.2). 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 32 percent.

For the non-EU countries, the scenario projects a five percent drop in total primary energy consumption (Table 1.4). 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 22 and 33 percent, respectively. Consumption of natural gas will increase (by 11 percent). As in the EU countries, the demand for transport fuels will increase (by 7 percent over the period 1990 - 2010). In spite of a fast increase in car ownership, the growth 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: Projections of total primary energy consumption for the countries of the EU-15 for the 'Baseline' scenario. Energy use for air transport is not included.

	Data source	1990 [PJ]	2010 [PJ]	*Change 1990-2010*	GDP growth [%/year]
Austria	National	1242	1421	14%	1.9%
Belgium	National	1907	2436	28%	2.1%
Denmark	National	731	783	7%	2.2%
Finland	National	1233	1604	30%	3.0%
France	BAU	9141	11143	22%	2.0%
Germany	National	14534	14179	-2%	2.3%
Greece	National	911	1785	96%	2.8%
Ireland	National	409	698	71%	4.6%
Italy	BAU	6676	8455	27%	1.9%
Luxembourg	BAU	122	129	6%	2.3%
Netherlands	National	2737	3715	36%	3.3%
Portugal	BAU	699	1113	59%	3.0%
Spain	BAU	3612	5227	45%	2.6%
Sweden	National	2430	2581	6%	n.a.
UK	National	8544	9875	16%	n.a.
EU-15		54927	65146	16%	n.a.

Table 3.2: Energy projections for the EU-15 by source category and fuel type for the 'Baseline' scenario. (Energy use for air transport not included)

Source category/fuel	1990 [PJ]	2010 [PJ]	*Change 1990-2010*
Stationary combustion sources:			
Total	44657	51625	16%
- Coal	11561	8147	-30%
- Liquid fuels	11917	12045	1%
- Gaseous fuels	10603	18277	72%
- Other	10576	13156	24%
Mobile sources - total	10271	13521	32%
TOTAL	54927	65146	19%

Table 3.3: Projections of total primary energy consumption for the non-EU countries used for this study Energy use for air transport is not included.

	1990 [PJ]	2010 [PJ]	*Change 1990-2010*	GDP growth [%/year]
Albania	128	143	12%	1.5%
Belarus	1762	1553	-12%	0.5%
Bosnia-H.	311	297	-5%	-0.3%
Bulgaria	1296	1262	-3%	1.0%
Croatia	413	447	8%	1.4%
Czech Republic	1956	1765	-10%	1.6%
Estonia	423	366	-13%	0.5%
Hungary	1109	1350	22%	1.7%
Latvia	399	359	-10%	-1.1%
Lithuania	677	565	-17%	-0.7%
Norway	1591	1715	8%	2.0%
Poland	4202	4951	18%	3.0%
R. of Moldova	392	324	-17%	-2.2%
Romania	2425	2525	4%	1.2%
Russia	18237	16617	-9%	-0.4%
Slovakia	987	982	0%	1.4%
Slovenia	231	234	1%	3.6%
Switzerland	1119	1184	6%	1.3%
FYR Macedonia	151	138	-9%	0.5%
Ukraine	9970	8559	-14%	-1.0%
Yugoslavia	790	725	-8%	0.6%
Non-EU	48569	46062	-5%	0.6%

Table 3.4: Energy projections for the non-EU countries (Sources: UN/ECE, 1996a, RAINS estimates)

Source category/fuel	1990 [PJ]	2010 [PJ]	Change 1990-2010
Stationary combustion sources:			
Total	43986	41158	-6%
- Coal	11540	8947	-22%
- Liquid fuels	8543	5700	-33%
- Gaseous fuels	18198	20195	11%
- Other	5706	6316	11%
Mobile sources - total	4583	4904	7%
TOTAL	48569	46062	-5%

3.1.2 The Illustrative 'Low CO_2' Energy Scenario used for the Robustness Analysis

It has been demonstrated earlier that the level and the composition of energy use are important parameters determining the internationally optimized allocation of emission reductions. This aspect gains particular relevance in the light of the negotiation result of the Kyoto conference and the implied modifications to the 'business as usual' energy policies.

Since RAINS is not an energy model, it cannot answer the question about realistic or desirable energy strategies meeting the obligations of the Kyoto conference. Therefore, the model calculations exploring the impacts of such strategies on air pollution control policies have to rely on exogenously supplied energy pathways. To this end, there are a number of alternative energy projections implemented in the RAINS database, which could possibly be used for such an analysis:

- The 'Official Energy Pathway' as reported in the UN/ECE database,
- the 'Business as usual' energy scenario of DG-XVII,
- a 'Low CO_2' Energy scenario (Capros and Kokkolakis, 1996) derived from the earlier 'Conventional Wisdom' scenario of DG-XVII, as it was used for the Second Interim Report of this study (Amann *et al.,* 1996);
- for ten EU countries the national submissions to the Commission, and
- for three EU countries 'Energy efficiency' scenarios developed by Gusbin *et al.,* 1997.

For the purposes of this study, i.e., to conduct a provisional assessment of the possible impact of the Kyoto Protocol agreed in December 1997, an illustrative 'post-Kyoto scenario' has been compiled. This was done by selecting for each country, out of the four available energy scenarios listed above, the projection which comes in terms of CO_2 emissions closest (but not always exactly) to the Council decision of June 1998. Tthe scenario is also provisional since it implicitly assumes that the reductions agreed in June 1998 for the three greenhouse gases would also hold for CO_2 emissions alone. Obviously, such an approach is not necessarily cost-effective, and Member States might actually implement the Kyoto Protocol in different ways. Bearing this in mind, the only purpose of this scenario is to give an overall indication of the possible impact of the Kyoto agreement on the costs of an ozone strategy. In no way this scenario must be interpreted as a proposal by the European Commission or the consultant for implementing the greenhouse gas reduction target.

Table 3.5: CO_2 emissions in 1990 and for the different energy scenarios in 2010, million tons

	1990	Business as usual		National submissions		Low CO_2 (Conventional wisdom)		Energy efficiency scenario		'Kyoto' Scenario used for this study		Council decision June 1998
Austria	60	60	0%	59	-2%	**53**	**-11%**			53	-11%	-13%
Belgium	110	135	23%	134	22%	**90**	**-18%**	107	-3%	90	-18%	-7.5%
Denmark	55	58	6%	**51**	**-7%**	46	-17%			51	-7%	-21%
Finland	57	72	26%	75	33%	**49**	**-14%**			49	-14%	0%
France	375	393	5%			335	-11%	**369**	**-2%**	369	-2%	0%
Germany	994	907	-9%	882	-11%	**816**	**-18%**			816	-18%	-21%
Greece	77	96	26%	***95***	**24%**	78	2%			95	24%	25%
Ireland	27	38	42%	44	63%	**30**	**11%**			30	11%	13%
Italy	431	502	16%			**400**	**-7%**			400	-7%	-6.5%
Luxembourg	8.6	8	-8%			**8**	**-8%**			8	-8%	-28%
Netherlands	162	197	21%	197	22%	**148**	**-9%**			148	-9%	-6%
Portugal	42	62	47%			**57**	**35%**			57	35%	27%
Spain	224	293	31%			242	8%	**256**	**14%**	256	14%	15%
Sweden	57	73	30%	**70**	**24%**	83	46%			70	24%	4%
UK	576	581	1%	604	5%	**515**	**-11%**			515	-11%	-12.5%
EU-15	3255	3474	7%			2949	-9%			3007	-7%	-8%

Notes: CO_2 emissions are calculated using IPCC emission factors. For each country the energy pathway selected for the 'Kyoto' scenario of this study is underlined.

A comparison of fuel use in individual countries between the 'Baseline' and the 'Kyoto' scenarios is presented in Table 3.6. In the 'Kyoto' scenario, the increase in total energy demand is reduced from 19 percent in the 'Baseline' to only eight percent. The consumption of solid fuels declines by 54 instead of 39 percent, while liquid fuels increase by only five percent instead of 15 percent. Also the increase of the demand for gas is lower. As to be expected, the demand for other fuels (renewable, nuclear, hydro, biomass) is about 110 PJ higher than in the base line.

In the absence of alternative energy projections for the non-EU countries, the 'post Kyoto' sensitivity analysis had to be restricted to the EU-15 Member States. For the non-EU countries, the OEP scenario was used as default. Emissions of carbon dioxide for that scenario are presented in Table 3.7. Until 2010 these emissions decrease by 11 percent. This is partly due to the decrease in energy demand (particularly in the countries of the former Soviet Union), and partly due to changes in composition of fuel used (less coal and oil, more gas).

Table 3.6 Comparison of national energy demand in 1990 and in 2010 by fuel type for the ‘Baseline’ and the ‘Kyoto’ scenarios (in PJ). Percentage changes relate to 1990.

	Solid			Liquid			Gas			Other			Total		
Country	1990	Baseline’	’Kyoto’	1990	Baseline’	’Kyoto’	1990	Baseline’	’Kyoto’	1990	Baseline’	’Kyoto’	1990	Baseline’	’Kyoto’
Austria	143	75	80	420	427	463	252	375	237	428	544	560	1242	1421	1339
		-47%	*-44%*		*2%*	*10%*		*49%*	*-6%*		*27%*	*31%*		*14%*	*8%*
Belgium	354	295	215	737	928	778	416	733	600	400	481	528	1907	2436	2121
		-17%	*-39%*		*26%*	*6%*		*76%*	*44%*		*20%*	*32%*		*28%*	*11%*
Denmark	259	182	101	326	290	293	93	221	249	53	91	118	731	783	762
		-30%	*-61%*		*-11%*	*-10%*		*138%*	*168%*		*70%*	*123%*		*7%*	*4%*
Finland	218	347	99	412	412	402	125	237	256	478	608	672	1233	1604	1428
		59%	*-55%*		*0%*	*-2%*		*90%*	*105%*		*27%*	*40%*		*30%*	*16%*
France	683	323	304	3487	3915	3746	1352	1828	1640	3620	5078	4677	9141	11143	10367
		-53%	*-55%*		*12%*	*7%*		*35%*	*21%*		*40%*	*29%*		*22%*	*13%*
Germany	5139	3422	1940	5010	5485	6019	2686	3433	3906	1699	1839	1940	14534	14179	13805
		-33%	*-62%*		*9%*	*20%*		*28%*	*45%*		*8%*	*14%*		*-2%*	*-5%*
Greece	342	537	537	503	1048	1048	26	127	127	40	72	72	911	1785	1785
		57%	*57%*		*108%*	*108%*		*398%*	*398%*		*81%*	*80%*		*96%*	*96%*
Ireland	98	70	101	172	320	212	79	264	88	60	43	68	409	698	468
		-28%	*3%*		*86%*	*23%*		*237%*	*11%*		*-28%*	*13%*		*71%*	*15%*
Italy	519	459	331	3824	4214	3081	1752	2917	2752	582	866	931	6676	8455	7095
		-12%	*-36%*		*10%*	*-19%*		*66%*	*57%*		*49%*	*60%*		*27%*	*6%*
Luxembourg	31	20	20	40	38	35	34	46	44	16	26	24	122	129	123
		-36%	*-36%*		*-6%*	*-13%*		*34%*	*30%*		*61%*	*48%*		*6%*	*1%*
Netherlands	312	245	79	977	955	860	1372	2414	1672	76	102	166	2737	3715	2777
		-21%	*-75%*		*-2%*	*-12%*		*76%*	*22%*		*35%*	*120%*		*36%*	*1%*
Portugal	113	175	215	447	531	426	6	177	154	133	230	264	699	1113	1059
		54%	*90%*		*19%*	*-5%*		*2850%*	*2460%*		*73%*	*98%*		*59%*	*51%*
Spain	754	619	755	1833	2502	2067	259	981	663	765	1125	1081	3612	5227	4566
		-18%	*0%*		*36%*	*13%*		*279%*	*156%*		*47%*	*41%*		*45%*	*26%*
Sweden	84	163	163	621	697	697	43	72	72	1682	1649	1649	2430	2581	2581
		94%	*94%*		*12%*	*12%*		*68%*	*68%*		*-2%*	*-2%*		*6%*	*6%*
UK	2512	1216	548	3183	3502	3326	2110	4453	4252	738	704	1104	8544	9875	9231
		-52%	*-78%*		*10%*	*4%*		*111%*	*102%*		*-5%*	*50%*		*16%*	*8%*
EU-15	11561	8147	5488	21994	25264	23452	10603	18277	16713	10769	13459	13854	54927	65146	59507
		-30%	*-53%*		*15%*	*7%*		*72%*	*58%*		*25%*	*29%*		*19%*	*8%*

Table 3.7 CO_2 emissions for non-EU for the 'Official Energy Pathway', million tons CO_2

	1990	2010	Change
Albania	6	7	12%
Belarus	115	96	-16%
Bosnia-H.	23	21	-8%
Bulgaria	86	82	-5%
Croatia	21	24	10%
Czech Republic	158	124	-22%
Estonia	36	29	-20%
Hungary	68	85	25%
Latvia	24	22	-10%
Lithuania	39	29	-25%
Norway	31	33	7%
Poland	365	409	12%
R. of Moldova	29	22	-22%
Romania	153	150	-2%
Russia	1046	908	-13%
Slovakia	63	53	-16%
Slovenia	15	14	-6%
Switzerland	43	44	2%
FYR Macedonia	12	10	-15%
Ukraine	683	529	-23%
Yugoslavia	62	54	-13%
Non-EU	3078	2745	-11%

Note: CO_2 emissions are calculated using IPCC emission factors.

3.2 Forecast of Activity Levels for Mobile Sources

In order to maintain internal consistency between energy and transport projections, the analysis presented in this paper is based on a common set of forecasts, i.e., the traffic projections underlying the energy scenario(s) are used for the following analyses. This means that the numbers contained in the transport database reflect the change in fuel consumption and include already possible changes in fuel efficiency by cars. Assuming efficiency improvements for the overall fleet (such assumptions are made in the energy scenarios used for this report), the growth in actual transport volumes (mileage) will be larger than the increase in fuel consumption.

Table 3.8 shows the development of the demand for liquid fuels by transport sources. Energy demand is disaggregated for three transport categories: (i) road – light-duty vehicles (LDV), (ii) road – heavy-duty vehicles (HDV) and (iii) other (non-road) transport. In the 'Baseline' scenario, the overall motor fuel demand for road transport in the EU-15 increases by about 35 percent. There is a continuing trend towards a higher share of diesel for light duty vehicles (from 21 percent in 1990 to 31 percent in 2010). For 'Other transport', the consumption of liquid fuels increases only by eight percent, but a 33 percent increase in electricity use is assumed in this sector.

In the illustrative post 'Kyoto' scenario, road transport grows slower (+23 percent for light-duty vehicles, +21 percent for heavy-duty vehicles). Fuel demand for other transport decreases by nine percent compared to the 1990 level. It should be born in mind, however, that the illustrative 'Low CO_2' scenario is a combination of different energy pathways (low CO_2, Business as usual and national scenarios) compiled from different sources. Thus the national trends of the demand for liquid fuels differ substantially among countries.

Table 3.8 Fuel consumption for light duty vehicles (cars, motorcycles, light duty trucks), 1990 and 2010 for the ’Baseline’ and the ’Kyoto’ scenario

	1990			Baseline 2010				Kyoto 2010			
	Gasoline	Diesel	Total	Gasoline	Diesel	Total		Gasoline	Diesel	Total	
Country	PJ	PJ	PJ	PJ	PJ	PJ	*Change*	PJ	PJ	PJ	*Change*
Austria	108	28	137	123	52	175	*28%*	132	36	168	*23%*
Belgium	120	85	204	117	165	282	*38%*	121	88	209	*2%*
Denmark	71	32	103	67	33	99	*-4%*	67	33	99	*-4%*
Finland	85	22	107	98	29	127	*19%*	105	26	131	*23%*
France	825	350	1175	957	602	1559	*33%*	749	700	1449	*23%*
Germany	1347	247	1594	1254	714	1968	*23%*	1502	494	1996	*25%*
Greece	108	7	114	240	14	254	*123%*	240	14	254	*123%*
Ireland	39	15	54	87	41	128	*137%*	49	16	65	*20%*
Italy	627	229	857	878	268	1146	*34%*	751	234	985	*15%*
Luxembourg	8	2	11	10	3	13	*25%*	9	3	12	*12%*
Netherlands	184	58	242	219	79	298	*23%*	155	51	206	*-15%*
Portugal	60	10	70	136	18	154	*121%*	115	16	131	*88%*
Spain	342	175	516	627	287	914	*77%*	538	220	757	*47%*
Sweden	177	18	195	236	22	258	*32%*	236	22	258	*32%*
UK	1088	91	1179	1019	438	1457	*24%*	1237	129	1366	*16%*
EU-15	5191	1367	6558	6069	2765	8834	*35%*	6005	2082	8086	*23%*

Notes:
Gasoline includes also liquefied petroleum gas (LPG).
Biomass- based fuels (ethanol, diester) are included as gasoline and diesel, respectively.

Table 3.9: Fuel consumption for heavy duty vehicles (trucks and buses), for 1990 and 2010 for the ’Baseline’ and the ’Kyoto’ scenario

	1990			Baseline 2010				Kyoto 2010			
	Gasoline	Diesel	Total	Gasoline	Diesel	Total		Gasoline	Diesel	Total	
Country	PJ	PJ	PJ	PJ	PJ	PJ	*Change*	PJ	PJ	PJ	*Change*
Austria	1	43	43	1	65	66	*53%*	1	76	77	*77%*
Belgium	5	58	63	5	85	90	*42%*	3	61	64	*1%*
Denmark	0	30	30	0	26	26	*-14%*	0	26	26	*-14%*
Finland	0	44	44	0	59	59	*35%*	0	49	49	*11%*
France	3	340	342	0	420	420	*23%*	0	487	487	*42%*
Germany	1	386	388	0	560	560	*44%*	0	367	367	*-5%*
‘Greece	0	53	53	0	116	116	*120%*	0	116	116	*120%*
Ireland	0	12	12	0	30	30	*157%*	0	15	15	*26%*
Italy	2	421	423	2	490	492	*16%*	1	427	429	*1%*
Luxembourg	0	3	3	0	3	3	*16%*	0	3	3	*5%*
Netherlands	0	87	88	0	146	146	*66%*	0	72	72	*-17%*
Portugal	0	59	59	0	108	108	*84%*	0	95	95	*62%*
Spain	24	147	171	18	265	283	*66%*	16	203	219	*28%*
Sweden	0	46	46	0	44	44	*-4%*	0	44	44	*-4%*
UK	0	344	344	0	492	492	*43%*	0	495	495	*44%*
EU-15	36	2072	2107	26	2908	2935	*39%*	22	2536	2557	*21%*

Notes:
Gasoline includes also liquefied petroleum gas (LPG).
Biomass- based fuels (ethanol, diester) are included as gasoline and diesel, respectively.

Table 3.10: Fuel consumption for ’Other transport’ (off-road, railways, inland waterways, coastal shipping), for 1990 and 2010 for the ’Baseline’ and the ’Kyoto’ scenario

	1990				Baseline 2010					Kyoto 2010				
	Gasoline	Diesel	H. fuel oil	Total	Gasoline	Diesel	H. fuel oil	Total		Gasoline	Diesel	H. fuel oil	Total	
Country	PJ	PJ	PJ	PJ	PJ	PJ	PJ	PJ	*Change*	PJ	PJ	PJ	PJ	*Change*
Austria	0	18	0	18	0	20	0	20	*12%*	0	24	2	27	*46%*
Belgium	0	14	0	14	0	14	0	15	*3%*	0	12	14	27	*84%*
Denmark	0	41	4	45	3	43	1	47	*4%*	3	43	1	47	*4%*
Finland	3	32	2	37	5	24	2	31	*-17%*	2	32	2	35	*-5%*
France	46	150	2	197	45	150	2	197	*0%*	9	98	2	109	*-45%*
Germany	31	194	0	224	28	147	0	175	*-22%*	32	182	0	214	*-5%*
Greece	19	52	10	80	34	96	19	149	*86%*	34	96	19	150	*87%*
Ireland	0	5	1	6	0	6	1	7	*29%*	0	5	2	7	*23%*
Italy	25	227	8	260	25	227	8	260	*0%*	18	227	8	253	*-3%*
Luxembourg	0	1	0	1	0	1	0	1	*0%*	0	1	0	1	*0%*
Netherlands	0	56	7	62	0	68	10	78	*25%*	0	48	0	48	*-23%*
Portugal	1	21	0	21	1	21	0	21	*0%*	1	21	0	21	*0%*
Spain	0	156	17	173	0	156	17	173	*0%*	0	156	17	173	*0%*
Sweden	6	63	2	72	11	63	2	77	*7%*	11	63	2	77	*7%*
UK	18	182	12	212	13	175	12	200	*-6%*	3	96	4	102	*-52%*
EU-15	149	1210	64	1423	166	1210	74	1450	*2%*	114	1103	72	1289	*-9%*

Note: Gasoline includes also liquefied petroleum gas (LPG).

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

The future rate of VOC emitting activities, such as industrial production, fuel consumption or transport services, are derived in RAINS by modifying the present activity levels according to exogeneously provided projections, e.g., for the year 2010. Unfortunately, reliable and consistent projections of future activity rates at the process level are hardly available; most economic long-term forecasts restrict themselves to a rather aggregated level of economic activities and rarely specify even the development of the main economic sectors. Therefore, the temporal changes of the activity rates are derived on the following four concepts:

- The change of the activity rates for processing, distribution and combustion of fossil fuels is linked to changes in fuel consumption provided by the energy scenario input to RAINS. Internal consistency with the energy scenario used for calculation of SO_2 and NO_x emissions is maintained.
- Some other activity rates (dry cleaning, use of solvents in households, vehicle treatment, food and drink industry) are linked to the economic growth and population development.
- The temporal development of a number of industrial activities (e.g., degreasing, paint use, solvent use in chemical industry, printing, other industrial solvent use) is related to changes in the sectoral gross domestic product (supplied with the energy scenario). In many cases statistics suggest that these activities grow slower than the GDP. To reflect this trend, sector-specific elasticities derived from statistics have been applied. Furthermore, comments from national experts on the development of several sectors were taken into account.
- In the absence of more information the activity rates for less important emission sectors are kept constant. This was typically done
    i. for sectors where current emissions estimates are very uncertain (e.g., agriculture, waste treatment),
    ii. where it is difficult to identify meaningful relations with other economic activities, and
    iii. for sectors where the increase in activity rates are expected to be offset by emission reductions induced by autonomous technical improvements.

3.4 Projections of Agricultural Livestock

3.4.1 The 'Baseline' Projection used for this Report

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; Pippatti, 1996; Henriksson, 1996; Riseth, 1990; Menzi, 1995; Menzi *et al.*, 1997; 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 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). The forecasts presented in this report are the result of the 1997 UN/ECE review, i.e., the original projections were modified as proposed by national experts.

Aggregated projections of livestock development as used for the further analysis in this report are presented in Table 3.11. In this table ‘cattle’ represents 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 the EU-15, Switzerland and Norway 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

- 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
- 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.

3.4.2 The Illustrative ’Low NH_3’ Scenario used for the Sensitivity Analysis

The agricultural policy in the European Union will have important implications for the achievement of the environmental targets analyzed in this study. In order to facilitate the analysis of the potential impacts of such policies and of the uncertainties associated with the forecasts of livestock, a so-called 'Low NH_3' was developed. This illustrative scenario is based on the simple assumption that, uniformly for all countries and all animal categories, the total livestock numbers will be ten percent lower than in the baseline forecast (i.e., 10 percent lower than the numbers presented in Table 3.11). Due to differences in livestock composition and emission factors among the countries, total ammonia emissions would decline between seven and nine percent.

This illustrative Low NH_3 scenario has not been reviewed by national experts and can only be seen as a tool for the sensitivity analysis.

Table 3.11: Projection of livestock up to the year 2010 (million animals)

	Cattle			Pigs			Poultry		
	1990	2010		1990	2010		1990	2010	
Austria	2.6	2.2	-15%	3.7	3.4	-7%	13.8	12.0	-13%
Belgium	3.1	2.8	-11%	6.4	7.2	12%	23.6	40.3	71%
Denmark	2.2	1.7	-23%	9.3	11.7	26%	16.2	17.4	7%
Finland	1.4	0.9	-33%	1.4	1.4	-2%	9.5	8.1	-14%
France	21.4	20.9	-3%	12.3	17.4	42%	271.7	317.3	17%
Germany	19.5	15.7	-19%	30.8	21.2	-31%	113.9	78.6	-31%
Greece	0.7	0.6	-20%	1.0	1.2	21%	27.7	33.0	19%
Ireland	7.0	7.4	6%	1.0	2.2	110%	9.0	13.2	46%
Italy	7.8	7.0	-11%	6.9	6.5	-7%	173.3	184.0	6%
Luxembourg	0.2	0.4	78%	0.1	0.1	-33%	0.1	0.1	-28%
Netherlands	4.9	4.8	-2%	13.9	11.2	-20%	93.8	79.5	-15%
Portugal	1.3	1.3	-2%	2.7	2.2	-17%	31.2	33.6	8%
Spain	5.1	6.0	17%	16.0	20.3	27%	44.9	83.1	85%
Sweden	1.7	1.8	5%	2.3	2.4	4%	12.6	12.6	0%
UK	12.1	10.4	-14%	7.5	7.8	5%	136.4	141.0	3%
EU-15	91.2	83.9	-8%	115.2	116.0	1%	978	1054	8%
Albania	0.6	0.8	21%	0.2	0.3	17%	5.0	8.4	68%
Belarus	7.2	4.3	-40%	5.2	4.0	-23%	49.8	43.3	-13%
Bosnia -H	0.9	0.7	-22%	0.6	0.6	-10%	9.0	8.0	-11%
Bulgaria	1.6	0.9	-41%	4.4	4.3	-2%	36.3	43.6	20%
Croatia	0.8	0.6	-27%	1.6	1.3	-17%	15.0	8.4	-44%
Czech Rep.	3.4	3.4	3%	4.6	5.8	26%	33.3	49.1	48%
Estonia	0.8	0.6	-28%	1.1	1.2	9%	7.0	7.8	11%
Hungary	1.6	1.6	-3%	9.7	7.9	-19%	58.6	63.5	8%
Latvia	1.5	0.7	-52%	1.6	1.5	-7%	11.0	7.6	-31%
Lithuania	2.4	2.2	-7%	2.7	2.8	2%	18.0	19.2	7%
Norway	1.0	0.7	-25%	0.7	0.8	10%	5.4	5.3	-2%
Poland	10.0	12.9	28%	19.5	23.8	22%	70.0	97.8	40%
R. Moldova	1.1	1.0	-13%	2.0	1.5	-27%	25.0	19.0	-24%
Romania	6.3	6.2	-2%	11.7	10.3	-12%	119.3	146.8	23%
Russia	42.2	27.3	-35%	30.5	30.5	0%	474.3	326.5	-31%
Slovakia	1.5	0.8	-44%	2.5	2.6	2%	16.5	22.0	34%
Slovenia	0.5	0.4	-22%	0.6	0.7	18%	13.5	12.9	-4%
Switzerland	1.9	1.7	-8%	1.8	1.4	-22%	6.5	6.5	0%
FYR Maced.	0.3	0.3	-1%	0.2	0.2	7%	22.0	22.0	0%
Ukraine	25.2	20.5	-19%	19.9	23.0	15%	255.1	260.0	2%
Yugoslavia	2.2	2.0	-8%	4.3	4.1	-5%	28.0	21.0	-25%
Non-EU	113.0	89.6	-21%	125.4	128.3	2%	1279	1199	-6%
Total	204.2	173.5	-15%	240.6	244.3	2%	2256	2253	-0%

Table 3.12: Projections of nitrogen fertilizer use (in 1000 tons N/year)

	Nitrogen fertilizer use		
	1990	2010	*Change*
Austria	137	109	*-20%*
Belgium	166	137	*-17%*
Denmark	395	261	*-34%*
Finland	228	180	*-21%*
France	2493	2457	*-1%*
Germany	2200	1801	*-18%*
Greece	428	294	*-31%*
Ireland	370	357	*-4%*
Italy	879	919	*5%*
Luxembourg	20	16	*-20%*
Netherlands	404	291	*-28%*
Portugal	150	144	*-4%*
Spain	1064	1052	*-1%*
Sweden	212	199	*-6%*
UK	1516	1298	*-14%*
EU-15	10662	9515	*-11 %*
Albania	73	60	*-18%*
Belarus	780	676	*-13%*
Bosnia -H	19	10	*-47%*
Bulgaria	453	530	*17%*
Croatia	114	190	*67%*
Czech Rep.	370	350	*-5%*
Estonia	110	151	*37%*
Hungary	359	639	*78%*
Latvia	143	221	*55%*
Lithuania	256	309	*21%*
Norway	111	92	*-17%*
Poland	671	855	*27%*
Moldova	123	228	*85%*
Romania	765	780	*2%*
Russia	3418	1994	*-42%*
Slovakia	217	180	*-17%*
Slovenia	88	103	*17%*
Switzerland	63	30	*-52%*
FYR Macedonia	6	3	*-50%*
Ukraine	1885	1599	*-15%*
Yugoslavia	146	145	*-1%*
Non-EU	10170	9145	*-10 %*
Total	20832	18660	*-10%*

3.5 Changes in the Database since the Fifth Interim Report

Since the Fifth Interim Report to the Commission a number of changes have been made to the database of the RAINS model. In addition to changes in the 1990 emission database used in RAINS (see 2.7.1.) the most important updates are as follows:

- Belgium, Germany, Greece and Ireland submitted officially national energy projections to the replace the 'Business as usual' scenario. Denmark and Netherlands decided to change their national scenarios, and Sweden proposed modifications to the previously submitted projection. All these changes were incorporated into the baseline energy scenario. Due to late submission, it was not possible to include the Italian projection in the analysis of this report.
- Austria, Belgium, Finland, France, Germany, Greece, Italy and the UK provided new country-specific parameters for the emission- and cost calculations and detailed information on the 'Current Legislation' scenario.
- The latest information on Current Reduction Plans provided by the UN/ECE secretariat (UN/ECE, 1998) was implemented in the database. As a consequence, the REF scenario was slightly changed.
- IIASA received comments on the SO_2 and NO_x modules from Norway and the Czech Republic. Due to time constraints, these comments could only be partially incorporated into the database for this report to the European Commission.
- Based on Finnish data, the sulfur content of fuel wood has been revised for all countries where no specific information is available. For 1990, this modification reduced total European (including non-EU countries) SO_2 emissions by 60 kt, i.e., by 0.2 percent.
- Cost estimates for low sulfur heavy fuel oil were revised to reflect the information provided by CONCAWE (CONCAWE 1998).
- The RAINS abatement technology database for ammonia was extended to include the substitution of urea by ammonium nitrate fertilizers.
- Based on the comments provided by UK and French experts (AEA Technology, CITEPA), several parameters in the VOC module have been adjusted. This includes the introduction of additional sectors (e.g., splitting printing into four sub-categories). Further extensions and modifications of the control technology database (e.g., adjustment of abatement options for printing, paint use, vehicle refinishing, refineries; introduction of options for leather tanning, agrochemicals production and road paving with asphalt).
- A detailed inventory of consumer products (domestic solvent use) and emission abatement possibilities provided by AEA Technology (Passant and Vincent, 1998) improved the description of this sector in RAINS and helped to determine the reduction potential.
- Following Swedish comments, control options (new boilers and catalysts) for residential combustion boilers (VOC) were introduced.
- Information provided by CONCAWE on average throughput of gasoline stations in several European countries was taken into account to derive country-specific abatement costs.
- Detailed information on the present penetration of Stage II vapor recovery installations and current legislation on further introduction of these systems provided by CONCAWE improved RAINS databases.

- The RAINS databases were updated to incorporate the final reports of the UN/ECE Task Forces on Control Technologies for Stationary Sources (VOC, NO_x) (IFARE 1998a,b). This resulted in modifications of several parameters (reduction efficiencies, investment and operating costs) for various sectors (e.g., refineries, degreasing operations, printing, etc.).

4 The Situation in 1990, the Expected Impacts of the Current Policies and the Maximum Technically Feasible Reductions

To establish a reference line against which the emission control scenarios of this report can be compared, the likely impacts of current emission abatement policies and regulations for the year 2010 are explored first. In order to capture the ‘dual-track’ approach adopted in Europe (regulations on emission standards for specific source categories and ceilings for national total emissions), two alternative scenarios were constructed that mimicked the implications of these approaches. While the ‘Current Reduction Plans’ (CRP) scenario incorporates officially adopted or internationally announced ceilings on national emissions, the ‘Current Legislation’ (CLE) scenario relies on an inventory of (present and already accepted future) legally binding emission control legislation for the European countries. Finally, for the further analysis a ‘Reference’ (REF) scenario was constructed that selected the more stringent emission ceiling for each country.

4.1 Emissions

4.1.1 The Current Reduction Plans (CRP) Scenario for the Year 2010

The ‘Current Reduction Plans’ (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 by UN/ECE, 1998 (indicated by (a) in Table 4.1). In cases where no projections were 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:

- If a future projection for 2000 or 2005 is available, the latest number has been used for the year 2010, case (b);
- if the country has signed the SO_2, 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, case (c);
- if neither applies, the value reported for 1990 in the UN/ECE, 1998 document is used, case (d);
- in special cases other rules have been used, which are explained below, case (e).

Table 4.1: Emissions for 1990 (as used by RAINS) and for the Current Reduction Plan (CRP) scenario (in kilotons)

Country	SO_2		NO_x		VOC		NH_3	
	1990	CRP	1990	CRP	1990	CRP	1990	CRP
Austria	93	60(c)	192	154(e)	352	266 (e)	77	77 (d)
Belgium	336	215(a)	351	309(c)	398	256 (c)	97	104 (d)
Denmark	185	90(b)	274	192(b)	162	136 (b)	77	103 (b)
Finland	232	116(b)	276	224(a)	213	150 (e)	40	34 (e)
France	1250	737(a)	1867	1276(c)	2399	1675 (c)	805	807 (e)
Germany	5280	650(a)	2662	1263(a)	3066	1750 (b)	757	769 (d)
Greece	504	570(a)	345	344(e)	336	205 (c)	80	78 (e)
Ireland	178	155(a)	113	115(a)	111	138 (a)	127	126 (a)
Italy	1679	1042(b)	2037	2060(b)	2053	1749 (c)	462	416 (d)
Luxembourg	14	4(b)	22	19(c)	19	13 (b)	7	7 (d)
Netherlands	201	98(c)	542	327(e)	490	247 (e)	233	136 (e)
Portugal	284	294(c)	208	221(d)	217	144 (c)	71	93 (d)
Spain	2189	2143(b)	1162	892(c)	1048	669 (c)	352	353 (d)
Sweden	119	87(a)	338	200(a)	492	290 (a)	61	48 (a)
UK	3805	980(a)	2839	1186(a)	2663	1351 (a)	329	333 (d)
EU-15	16348	7221	13226	8772	14017	9039	3576	3484
Albania	72	72(d)	24	36(e)	30	38 (e)	32	35 (e)
Belarus	843	480(a)	402	180(a)	279	321 (a)	219	219 (e)
Bosnia-H.	487	480(d)	80	80(e)	46	46 (e)	31	31 (e)
Bulgaria	1841	1127(a)	354	290(a)	198	192 (a)	141	126 (a)
Croatia	180	117(a)	83	83(a)	79	105 (d)	40	30 (a)
Czech Rep.	1873	376(a)	522	398(a)	322	435 (d)	107	136 (d)
Estonia	275	239(e)	84	93(e)	44	44 (e)	29	29 (e)
Hungary	913	650(a)	214	196(a)	206	145 (a)	120	150 (a)
Latvia	121	57(d)	117	90(d)	51	63 (d)	43	44 (d)
Lithuania	213	145(a)	152	110(a)	104	84 (a)	80	84 (a)
Norway	50	34(b)	220	158(c)	308	196 (b)	23	23 (d)
Poland	2999	1397(a)	1209	1345(c)	709	1300 (a)	505	508 (d)
R of Moldova	197	130(e)	87	34(a)	53	44 (e)	47	48 (e)
Romania	1331	1311(d)	518	546(d)	483	616 (d)	292	300 (d)
Russia	5012	4297(a)	3485	2675(d)	3332	3566 (d)	1282	1191 (d)
Slovakia	548	240(a)	207	225(d)	143	149 (d)	60	62 (d)
Slovenia	200	37(a)	60	31(a)	60	25 (a)	23	27 (a)
Switzerland	43	30(a)	163	113(a)	291	173 (a)	72	68 (a)
FYR Macedon.	107	106(d)	39	39(e)	20	20 (e)	17	17 (e)
Ukraine	3706	2310(a)	1888	1094(a)	1074	1369 (a)	729	649 (e)
Yugoslavia	585	1135(a)	211	211(e)	124	124 (e)	90	90 (e)
Non-EU	21595	14770	10118	7980	7956	9055	3980	3876
Atlantic Sea	640	640	910	910	n.a.	n.a.	n.a.	n.a.
Baltic Sea	72	72	80	80	n.a.	n.a.	n.a.	n.a.
North Sea	439	439	638	638	n.a.	n.a.	n.a.	n.a.
Total	39096	23142	24979	18381	21973	18094	7556	7351

Explanations for other sources indicated by case (e):

Austria (NO_x and VOC), Finland (NH_3, VOC), France (NH_3), Germany (NH_3), Netherlands (NO_x VOC, NH_3): The CRP values listed in UN/ECE (1998) were recently officially revised by the countries.

Greece (NO_x): Since no CRP value is provided to UN/ECE, the updated CORINAIR estimate for 1990 is used instead.

Greece (NH_3) - There is no official value for CRP available. The number given in the EMEP report No 98/1 for 1990 was used.

Albania (NO_x, NH_3, VOC) - No CRP values are provided in UN/ECE (1998). The emissions calculated by RAINS for 2010 are used.

Bosnia-Hercegovina (NO_x, VOC) - No CRP values are provided in UN/ECE (1998). The emissions calculated by RAINS for 1990 are used.

Belarus, Bosnia-Hercegovina, Estonia, FYR of Macedonia, Yugoslavia (NH_3) - No CRP values are provided in UN/ECE (1998). The numbers reported in EMEP (1998) for 1990 used.

Estonia, FYR of Macedonia (SO_2, NO_x) - No CRP values provided in UN/ECE (1998). EMEP estimates for 1990 used.

Estonia, FYR of Macedonia, Yugoslavia (VOC) - No CRP values provided in UN/ECE (1997). RAINS estimates for 1990 used.

Republic of Moldova ($NH_{3,}$ VOC) - The officially provided CRP value for 2010 of 0.15 kt NH_3 seems unrealistic. The value for VOC (7 kt) is also beyond MFR and therefore the RAINS 2010 estimates were used instead.

Ukraine (NH_3) - The officially provided CRP for 2010 of 9 kt NH_3 seems unrealistic. The RAINS 2010 estimate was used instead.

Yugoslavia (NO_x): No official value provided. RAINS 1990 value was used instead.

The CRP emissions used for this study are provided in Table 4.1. For the EU-15, the CRP emissions of SO_2 are 56 percent below 1990 level. Emissions of NO_x are reduced by 34 percent. For non-EU countries the emissions drop by 32 and 21 percent respectively. For the EU-15, the CRP emissions of VOC are 36 percent below the 1990 level, those of NH_3 only about 3 percent. For non-EU countries the situation is similar for ammonia, but the VOC emissions increase by nearly 14 percent. Overall, current reduction plans would result in a decrease of VOC and ammonia emissions in Europe by about 18 and 3 percent, respectively.

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

The Current Reduction Plans (CRP) scenario described above projects future emission levels in Europe based on officially announced national emission caps, e.g., as laid down in the Second Sulfur Protocol. This is contrasted by a Current Legislation (CLE) scenario, which explores the impacts of adopted national and international legislation for emission control, based on projections of future energy consumption.

For SO_2 and NO_x, the 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 - LCPD (OJ, 1988) and the directives on sulfur content of liquid fuels (gas oil - Johnson & Corcelle (1995), heavy fuel oil - COM(97)88, 1997)), 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) requires emission control according to 'Best Available Technology' (BAT) for new plants. It also requires the reduction of 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.

An inventory of national and international emission standards in Europe can be found in Bouscaren & Boucherau (1996). In addition, information on power plant emission standards has been taken from the survey of the IEA Coal Research (McConville, 1997). For countries of Central and Eastern Europe the environmental standards database developed by the Central European University (CEU, 1996) has also been used.

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

SO_2 and NO_x control measures assumed in the 'Current Legislation' scenario in individual countries or groups of countries are specified in Table 4.2. to Table 4.4 The control technologies assumed for major stationary emission sources in EU countries are presented in Table 4.7 and Table 4.8.

Table 4.2: Measures assumed for the 'Current Legislation' (CLE) scenario for SO_2 emissions in EU countries

Stationary and mobile sources:

- Emission standards for new plant from the Large Combustion Plant Directive - LCPD (OJ, 1988) and from the Second Sulfur Protocol (UN/ECE, 1994a) also taking into account a proposal for a revision of the LCPD adopted by the Commission on 8.7.98 (COM(98) 415 final.
- Limits on sulfur content of gas oil for stationary and mobile sources and for heavy fuel oil as in the appropriate directives (Johnson & Corcelle, 1995, COM(97)88, 1997)
- National emission standards on stationary sources if stricter than the international standards. Control measures for stationary sources included in the CLE scenario for individual countries of the EU are shown in Table 4.7.

Table 4.3: Measures assumed for the ’Current Legislation’ (CLE) scenario for SO_2 emissions in the non-EU countries

Stationary and mobile sources:

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

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

Other countries in Central and Eastern Europe – no control

Table 4.4: Measures assumed for the 'Current Legislation' (CLE) scenario for the control of NO_x emissions in the non-EU countries

Stationary sources:

- Czech Republic, Croatia, Hungary, Norway, Poland, Slovak Republic, Slovenia, Switzerland, Romania, Yugoslavia – controls according to national emission standards on new and existing sources
- Other countries in Central and Eastern Europe – no control[25]

Mobile sources:

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

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

Table 4.5: Measures assumed for the 'Current Legislation' (CLE) scenario for NO_x emissions in the countries of the European Union

Stationary sources:

- Emission standards for new plant and emission ceilings for existing plant from the Large Combustion Plant Directive - LCPD (OJ, 1988). These standards require implementation of primary emission measures (combustion modification) on large boilers in the power plant sector and in industry.) A proposal for a revision of the LCPD adopted by the Commission on 8.7.98 (COM(98) 415 final is also taken into account.
- National emission standards on stationary sources – if stricter than in the LCPD. Control measures for stationary sources included in the CLE scenario for individual countries of the EU are shown in Table 4.8.

Mobile sources:

- EU standards for cars and light commercial vehicles (LCV) (Directive 70/220/EC du Conseil, du 20 mars 1970, concernant le rapprochement des législations des États membres relatives au mesures à prendre contre la pollution de l'air par les gaz provenant des moteurs à allumage commandé équipant les véhicules à moteur, OJ 76, 6.4.70, p. 1, as amended by 96/69/EC, OJ L 282, 1.11.96, p. 1)
- EU standards for heavy duty vehicles (HDV) according to Council Directive 88/77/EC of 3 December 1987 on the approximation of the laws of the Member States relating to the measures to be taken against the emission of gaseous pollutants from diesel engines for use in vehicles, OJ L 36, 9.2.88, p. 33, as amended by 96/1/EC, OJ L 40, 17.2.96
- EU standards for non-road machinery engines (Directive 97/68/EC of the European Parliament and the Council of 16 December 1997 on the approximation of laws of the Member States relating to measures against the emissions of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery, OJ L 59, 27.2.98, p. 1-85, as well as for mopeds and motorcycles (Directive 97/24/EC of the European Parliament and the Council of 17 June 1997 on certain components and characteristics of tow or three-wheel motor vehicles, OJ L 226, 18.8.97, p. 1)
- From 2000 - fuel quality and emission standards (for LDV, LCV, HDV) and improved inspection/maintenance, as resulting from the Auto/Oil Programme (Communication from the Commission to the European Parliament and the Council on a future strategy for the control of atmospheric emissions from road transport taking into account the results from the Auto/Oil Programme (COM(96) 248, 18.6.1996), amended by the agreement resulting from conciliation between Council and European Parliament related to LDV, LCV, fuels (PE-CONS 3619/98, PE-CONS 3620/98) and by COM(97) 627, 3.12.97, on HDV-emissions. These standards are assumed to be implemented in the EU-15 as well as in Norway and in Switzerland.

Table 4.6: Measures assumed for the 'Current Legislation' (CLE) scenario for VOC emissions for EU countries

Stationary sources:

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

Mobile sources:

- All directives and legislation acts aimed at a reduction of emissions from mobile sources mentioned for NO_x also apply to NMVOC
- Passenger cars - small canister according to the Council Directive 91/441/EEC of 26 June 1991 amending directive 70/220/CEE on the approximation of the laws of the Member States relating to measures to be taken against air pollution by emissions from motor vehicles, OJ L 242, 30.8.91, p. 1 - 6 (EC, 1991)

For VOC, the CLE scenario assumes the implementation of the Solvent Directive of the EU (COM(96)538) as proposed by the Commission. Furthermore, the obligations of the VOC Protocol of the Convention on Long-range Transboundary Air Pollution (UN/ECE, 1994d) were incorporated. For mobile sources, the measures pertaining to the regulations on carbon canisters of Directive 91/441/EEC complemented by the proposed amendment of Dir. 70/220 in the Auto/Oil 1 package are assumed to be fully implemented. Emissions from non-road mobile machinery engines are subject to Directive 97/68/EC. It was further assumed that VOC emissions from gasoline distribution will be controlled through the Stage-I measures in all the EU countries (reflecting the Directive 94/63/EC). Additionally, Stage-II controls were assumed for several countries (Table 4.6).

For constructing the CLE scenario the emission control measures listed above were combined with the future level of energy consumption as projected by the 'Baseline' energy scenario. Table 4.9 and Table 4.10 compare the emission estimates for the year 1990 with the CRP and the CLE scenarios. For the EU-15 countries, total SO_2 emissions in the CLE scenario are 31 percent and NO_x emissions 11 percent below the CRP values. In the non-EU countries, CLE emissions of SO_2 are 33 percent lower than in the CRP case. CLE for VOC emissions is 15 percent below CRP, and for NH_3 6 percent.

There is clear evidence that official long-term emission targets presented to international organizations are not always consistent 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. Some 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 most official country submissions to the UN/ECE used for the CRP scenario.

Table 4.7: SO_2 abatement technologies for the power plant and industrial sources assumed in the 'Current Legislation' (CLE) scenario for the EU countries

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 3		Stage 3	
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 1		Stage 1	
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	-	LSHF
100 - 500 300 - 500	LSCO/FGD(2)	FGD	-	LSHF
>500 >500	FGD	FGD	-	LSHF
Industrial processes:	-		-	
Germany(6):				
50 - 100	LSCO	LSHF	LSCO	LSHF
100 - 300	FGD	FGD	FGD	FGD
> 300	FGD	FGD	FGD	FGD
Industrial processes:	Stage 2		Stage 2	
Greece:				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	-	LSHF
100 - 500 300 - 500	LSCO/FGD(2)	LSHF	-	LSHF
>500 >500	FGD	FGD	-	LSHF
Industrial processes:	-		-	
Ireland(6)				
Coal Oil				
50 - 100 50 - 300	LSCO	LSHF	LSCO	LSHF
100 - 500 300 - 500	LSCO/FGD(2)	FGD	LSCO	LSHF
>500 >500	FGD	FGD	LSCO	LSHF
Industrial processes:	-		-	

Table 4.7: SO_2 abatement technologies for the power plant and industrial sources assumed in the ’Current Legislation’ (CLE) scenario for the EU countries, continued

Country		New plants		Existing plants	
Capacity class, MW_{th}		Coal	Oil	Coal	Oil
Italy:					
Coal	Oil				
50 - 100	50 - 300	LSCO	LSHF	-	LSHF
100 - 500	300 - 500	LSCO/FGD(2)	LSHF	-	LSHF
>500	>500	FGD	FGD	FGD	LSHF
Industrial processes:		Stage 1		Stage 1	-
Luxembourg(6):					
Coal	Oil				
50 - 100	50 - 300	LSCO	LSHF	-	LSHF
100 - 500	300 - 500	LSCO/FGD(2)	FGD	-	FGD
>500	>500	FGD	FGD	-	FGD
Industrial processes:		-		-	
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	-	LSHF
100 - 500	300 - 500	LSCO/FGD(2)	LSHF	-	LSHF
>500	>500	FGD	FGD	-	LSHF
Industrial processes:		-		-	
Spain:					
Coal	Oil				
50 - 100	50 - 300	LSCO	LSHF	-	LSHF
100 - 500	300 - 500	LSCO/FGD(2)	LSHF	-	LSHF
>500	>500	FGD	FGD	-	LSHF
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	LSHF
100 - 500	300 - 500	LSCO/FGD(2)	FGD	LSCO	LSHF
>500	>500	FGD	FGD	FGD	FGD
Industrial processes:		-		-	

(1) Lignite/hard coal
(2) Below 300 MW_{th}/above 300 MW_{th}
(3) Includes also sources below 50 MW_{th}
(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 4.8: NO$_x$ abatement technologies for the power plant and industrial sources assumed in the 'Current Legislation' (CLE) scenario for the EU countries

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/SCR	CM/SCR	SCR	CM	CM
Luxembourg:						
>50	CM	CM	CM	CM	CM	CM
Industrial processes:		Stage 1			Stage 1	
Netherlands:						
<300(3)	SCR	SCR	SCR	CM	CM	CM
>300	SCR	SCR	SCR	CM/SCR	CM	CM
Industrial processes:		Stage 2			Stage 2	

Table 4.8: NO_x abatement technologies for the power plant and industrial sources assumed in the 'Current Legislation' (CLE) scenario for the EU countries, 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(4)	CM(4)	CM(4)
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) 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 4.9: NO_x and VOC emissions of the Current Legislation (CLE) scenario for the year 2010 compared with the values for 1990 (RAINS estimates) and Current Reduction Plans (CRP), in kilotons. The underlined numbers are further used for the Reference scenario.

	NO_x (kt)			VOC (kt)		
	1990	CRP	CLE	1990	CRP	CLE
Austria	192	154	113	352	266	209
Belgium	351	309	207	398	256	212
Denmark	274	192	136	162	136	86
Finland	276	224	162	213	150	112
France	1867	1276	1044	2399	1675	1242
Germany	2662	1263	1316	3066	1750	1137
Greece	345	344	459	336	205	288
Ireland	113	105	81	111	138	46
Italy	2037	2060	1186	2053	1749	1176
Luxembourg	22	19	10	19	13	8
Netherlands	542	327	312	490	247	241
Portugal	208	221	197	217	144	185
Spain	1162	892	916	1048	669	789
Sweden	338	200	200	492	290	287
United Kingdom	2839	1186	1439	2663	1351	1652
EU-15	13226	8772	7778	14017	9039	7668
Albania	24	36	36	30	38	38
Belarus	402	180	315	279	321	241
Bosnia-H.	80	80	60	46	46	43
Bulgaria	354	290	295	198	192	197
Croatia	83	83	91	79	105	88
Czech Rep.	522	351	231	322	435	225
Estonia	84	93	73	44	44	49
Hungary	214	196	198	206	145	172
Latvia	117	90	118	51	63	43
Lithuania	152	110	138	104	84	91
Norway	220	158	151	308	196	293
Poland	1209	1345	810	709	1300	759
Moldova	87	34	66	53	44	44
Romania	518	546	458	483	616	508
Russia	3485	2675	2797	3332	3566	2718
Slovakia	207	225	112	143	149	141
Slovenia	60	31	36	60	25	51
Switzerland	163	113	89	291	173	234
FYR Macedonia	39	39	29	20	20	21
Ukraine	1888	1094	1425	1074	1369	846
Yugoslavia	211	211	152	124	124	123
Non-EU	10118	7980	7680	7956	9055	6924
Total[1])	24979	18381	17087	21973	18094	14592

1) including emissions from sea regions

Table 4.10: SO_2 and NH_3 emissions of the Current Legislation (CLE) scenario for the year 2010 compared with the values for 1990 (RAINS estimates) and Current Reduction Plans (CRP), in kilotons. The underlined numbers are further used for the Reference scenario.

	SO_2 (kt)			NH_3 (kt)		
	1990	CRP	CLE	1990	CRP	CLE
Austria	93	60	42	77	77	67
Belgium	336	215	208	97	104	96
Denmark	185	90	97	77	103	72
Finland	232	116	124	40	34	31
France	1250	737	489	805	807	798
Germany	5280	650	609	757	769	572
Greece	504	570	562	80	78	74
Ireland	178	155	70	127	126	130
Italy	1679	1042	593	462	416	432
Luxembourg	14	4	9	7	7	9
Netherlands	201	98	74	233	136	196
Portugal	284	294	146	71	93	67
Spain	2189	2143	793	352	353	383
Sweden	119	67	69	61	48	61
United Kingdom	3805	980	1099	329	333	297
EU-15	16348	7221	4983	3576	3484	3283
Albania	72	72	55	32	35	35
Belarus	843	480	494	219	219	163
Bosnia-H.	487	480	415	31	31	23
Bulgaria	1841	1127	846	141	126	126
Croatia	180	117	70	40	30	37
Czech Rep.	1873	376	368	107	136	108
Estonia	275	239	175	29	29	29
Hungary	913	653	546	120	150	137
Latvia	121	57	104	43	44	35
Lithuania	213	145	107	80	84	81
Norway	50	34	27	23	23	21
Poland	2999	1397	1514	505	508	541
Moldova	197	130	117	47	48	48
Romania	1331	1311	594	292	300	304
Russia	5012	4297	2344	1282	1191	894
Slovakia	548	240	137	60	62	47
Slovenia	200	37	76	23	27	21
Switzerland	43	30	36	72	68	66
FYR Macedonia	107	106	81	17	17	16
Ukraine	3706	2310	1488	729	649	649
Yugoslavia	585	1135	269	90	90	82
Non-EU	21595	14770	9861	3980	3867	3462
Total[1])	39096	23142	15996	7556	7351	6745

1) including emissions from sea regions

4.1.3 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 Plans- and the Current Legislation-scenarios (Table 4.9, Table 4.10).

Emissions and control costs for NO_x and VOC in this scenario are presented in Table 4.11. For EU-15 as a whole, the REF scenario results in a 45 percent cut of NO_x and a 49 percent cut of VOC emissions. While for some non-EU countries the emissions in the REF scenario increase in comparison to the 1990 level, overall emissions are lower by 31 percent for NO_x and by 17 percent for VOC.

Table 4.11 also presents costs for NO_x and VOC reductions, given jointly for NO_x and VOC because control technologies used in the transport sector reduce jointly the emissions of the two pollutants. Emission control costs for NO_x and VOC emissions amount to almost 41.5 billion ECU/year in the EU. The annual cost to achieve the REF emissions in the non-EU countries is estimated at 2.3 billion ECU/year. For VOC major reductions originate in the EU-15 countries, 84 percent of total VOC reduced in REF.

Emissions and control costs for SO_2 and NH_3 in REF scenario are presented in Table 4.12. The REF scenario implies a 70 percent decrease of SO_2 emissions of the EU-15 and a 55 percent cut in the non-EU countries. SO_2 control costs, calculated from the RAINS cost curves, reach 11.4 billion ECU/year, of which 75 percent occur in the EU countries. For ammonia, the overall reduction is about 134 percent compared to 1990, and it is evenly distributed between EU and non-EU countries. In many countries reductions are achieved due to decline in the number of animals (compare Table 3.11) projected for 2010. The total cost for ammonia reduction in the REF scenario is about 0.4 billion ECU/year.

Table 4.11: Emissions and control costs for NO_x and VOC for 1990 and the Reference (REF) scenario (emissions in kilotons, costs in million ECU/year).

	NO_x			VOC			Costs
	1990	REF	Change	1990	REF	*Change*	of REF
Austria	192	113	-41%	352	208	-41%	784
Belgium	351	207	-41%	398	212	-47%	1050
Denmark	274	136	-50%	162	86	-47%	383
Finland	276	162	-41%	213	112	-47%	525
France	1867	1044	-44%	2399	1242	-48%	6180
Germany	2662	1263	-53%	3066	1137	-63%	9890
Greece	345	344	0%	336	205	-39%	933
Ireland	113	81	-28%	111	46	-59%	410
Italy	2037	1186	-42%	2053	1176	-43%	6881
Luxembourg	22	10	-55%	19	8	-58%	60
Netherlands	542	312	-42%	490	241	-51%	1486
Portugal	208	197	-5%	217	144	-34%	1092
Spain	1162	892	-23%	1048	669	-36%	4793
Sweden	338	200	-41%	492	287	-42%	976
UK	2839	1186	-58%	2663	1351	-49%	5934
EU-15	13226	7333	-45%	14017	7123	-49%	41376
Albania	24	36	50%	30	37	23%	0
Belarus	402	180	-55%	279	231	-17%	210
Bosnia-H.	80	60	-25%	46	43	-7%	1
Bulgaria	354	290	-18%	198	192	-3%	4
Croatia	83	83	0%	79	87	10%	6
Czech Rep.	522	231	-56%	322	224	-30%	492
Estonia	84	73	-13%	44	44	0%	1
Hungary	214	196	-8%	206	144	-30%	424
Latvia	117	90	-23%	51	40	-22%	31
Lithuania	152	110	-28%	104	84	-19%	29
Norway	220	151	-31%	308	196	-36%	495
Poland	1209	810	-33%	709	754	6%	1217
Moldova	87	34	-61%	52	41	-21%	46
Romania	518	458	-12%	483	505	5%	0
Russia	3485	2675	-23%	3332	2696	-19%	16
Slovakia	207	112	-46%	143	141	-1%	325
Slovenia	60	31	-48%	60	25	-58%	125
Switzerland	163	89	-45%	291	173	-41%	715
FYR Macedonia	39	29	-26%	20	20	0%	1
Ukraine	1888	1094	-42%	1074	836	-22%	139
Yugoslavia	211	152	-28%	124	121	-2%	3
Non-EU	10118	6983	-31%	7954	6635	-17%	2301
Total[26]	24973	15945	-39%	21971	13758	-37%	43677

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[26] Including ship emissions

Table 4.12: Emissions and control costs for SO_2 and NH_3 for 1990 and the Reference (REF) scenario (emissions in kilotons, costs in million ECU/year).

	SO_2 1990	SO_2 REF	Change	Costs of REF	NH_3 1990	NH_3 REF	*Change*	Costs of REF
Austria	93	42	-55%	174	77	67	-13%	0
Belgium	336	208	-38%	341	97	96	-1%	0
Denmark	185	90	-51%	115	77	72	-6%	0
Finland	232	116	-50%	204	40	31	-23%	0
France	1250	489	-61%	1004	805	798	-1%	0
Germany	5280	608	-88%	2146	757	571	-25%	0
Greece	504	562	12%	331	80	74	-8%	0
Ireland	178	70	-61%	108	127	126	-1%	9
Italy	1679	593	-65%	1577	462	416	-10%	12
Luxembourg	14	4	-71%	9	7	7	0%	15
Netherlands	201	74	-63%	306	233	136	-42%	237
Portugal	284	146	-49%	152	71	67	-6%	0
Spain	2189	793	-64%	678	352	353	0%	28
Sweden	119	67	-44%	293	61	48	-21%	113
UK	3805	980	-74%	1148	329	297	-10%	0
EU-15	16348	4842	-70%	8586	3576	3159	-12%	413
Albania	72	55	-24%	0	32	35	9%	0
Belarus	843	480	-43%	4	219	163	-26%	0
Bosnia-H.	487	415	-15%	0	31	23	-26%	0
Bulgaria	1841	846	-54%	126	141	126	-11%	0
Croatia	180	70	-61%	52	40	30	-25%	3
Czech Rep.	1873	368	-80%	293	107	108	1%	0
Estonia	275	175	-36%	0	29	29	0%	0
Hungary	913	546	-40%	144	120	137	14%	0
Latvia	121	57	-53%	15	43	35	-19%	0
Lithuania	213	107	-50%	0	80	81	1%	0
Norway	50	27	-46%	62	23	21	-9%	0
Poland	2999	1397	-53%	739	505	508	1%	16
Moldova	197	117	-41%	0	47	48	2%	0
Romania	1331	594	-55%	132	292	300	3%	1
Russia	5012	2344	-53%	691	1282	894	-30%	0
Slovakia	548	137	-75%	80	60	47	-22%	0
Slovenia	200	37	-82%	41	23	21	-9%	0
Switzerland	43	30	-30%	72	72	66	-8%	0
FYR Macedonia	107	81	-24%	0	17	16	-6%	0
Ukraine	3706	1488	-60%	325	729	649	-11%	0
Yugoslavia	585	269	-54%	47	90	82	-9%	0
Non-EU	21595	9638	-55%	2822	3980	3418	-14%	20
Total[27]	39096	14480	-62%	11408	7556	6577	-13%	433

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[27] Including ship emissions

4.1.4 Full Implementation of Current Control Technologies in the Year 2010

A further scenario, the Maximum Feasible Reductions (MFR) scenario has been constructed to illustrate the potential of a full application of current control technologies and to quantify possible progress towards the ultimate target of full achievement of the environmental long-term targets.

Based on the baseline energy scenario, the MFR scenario presented in this report simulates the hypothetical case with a complete implementation of the currently available most efficient emission control technologies to the entire stock of emission sources. In contrast to the assumptions in the previous reports, constraints imposed by current legislation and historically observed turnover rates of the capital stock are ignored in this 'ultimate' MFR scenario. However, by definition, changes to the structure and the levels of economic activities and energy consumption, e.g., as reactions to excessive emission control costs or the effects of non-technical instruments to control emissions, are excluded.

It is important to stress that this hypothetical 'maximum potential' scenario assumes a complete penetration of the presently best available emission control techniques. This implies that also presently installed equipment that has lower reduction efficiencies will be replaced by more efficient measures, and that this replacement might occur before the end of its normal technical lifetime.

It is important to mention that the analysis presented in this report includes the potential for further emission reductions from mobile sources beyond measures agreed upon in the Auto/Oil 1 Programme. At the present time it was not possible to incorporate the preliminary findings of the Auto/Oil 2 Programme. Given this situation, the emission control potential and the costs assumed in this report for these measures have to be considered as purely illustrative and should in no way prejudge the final outcome of the Auto-Oil 2 activities.

In reality, however, the limited turnover of capital stock is an important factor determining the achievable emission reductions. The methodology for deriving the cost curves in the RAINS model takes full account of these limitations and distinguishes different emission control efficiencies for the several vintages of emission control equipment (e.g., for flue gas desulfurization and mobile sources). Furthermore, the cost curves constructed by RAINS exclude early retirement of already existing equipment. Consequently, these cost curves which were used in the subsequent optimization analyses do not reflect the full theoretical potential for reducing emissions.

Table 4.13 lists the resulting emissions of NO_x and VOC for the REF and the 'ultimate' MFR scenarios. For the EU-15 as a whole, the MFR scenario produces a 79 percent cut of NO_x emissions relative to 1990, and a 68 percent decline in VOC emissions. Costs on top of REF amount to more than 55 billion ECU/year. For the interpretation of model results in the following sections it is important to realize that in the Mediterranean countries Greece, Portugal and Spain the full application of control technology will result in significantly smaller emission reductions (about 50 percent) compared to 1990 than in the other EU countries (about 70 percent). This is due to lower turnover of vehicle stock in those countries as well as due to higher economic growth assumed in the Baseline energy scenario. For the non-EU countries the emissions of NO_x and VOC also decrease (by 83 percent and 63 percent respectively). Costs for that group of countries amount to 26 billion ECU/year.

Table 4.14 presents the same type of information for SO_2 and ammonia. For SO_2, the achievable emission reductions are about 91 percent. However, control costs (on top of the costs of the REF scenario are 54 billion ECU/year for the EU countries and 23 billion ECU/year for other counties in Europe. For ammonia, maximum reductions could cut the emissions by 42 percent compared to 1990 at costs of 21 billion ECU/year. An 11 percent reduction (0.8 million tons NH_3) is caused by the projected decline in livestock numbers; the remaining 31 percent (2.3 million tons NH_3) is calculated as the consequence of technical control measures.

Table 4.13: NO$_x$ and VOC emissions for the REF case and the hypothetical maximum technically feasible reductions (MFR) scenario (percentage changes relate to the year 1990). Emission control costs for the MFR scenario (in million ECU/yr)

	NO$_x$ emissions				VOC emissions				Costs
	REF		MFR$_{ult}$		REF		MFR$_{ult}$		NO$_x$&VOC
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	MFR$_{ult}$
Austria	113	*-41%*	54	*-72%*	208	*-41%*	111	*-68%*	1911
Belgium	207	*-41%*	81	*-77%*	212	*-47%*	97	*-76%*	2556
Denmark	136	*-50%*	49	*-82%*	86	*-47%*	51	*-69%*	1026
Finland	162	*-41%*	56	*-80%*	112	*-47%*	59	*-72%*	1309
France	1044	*-44%*	383	*-79%*	1242	*-48%*	735	*-69%*	15709
Germany	1263	*-53%*	601	*-77%*	1137	*-63%*	720	*-77%*	19348
Greece	344	*0%*	127	*-63%*	205	*-39%*	144	*-57%*	2860
Ireland	81	*-28%*	27	*-76%*	46	*-59%*	34	*-69%*	947
Italy	1186	*-42%*	396	*-81%*	1176	*-43%*	727	*-65%*	16963
Luxembourg	10	*-55%*	4	*-80%*	8	*-58%*	4	*-79%*	134
Netherlands	312	*-42%*	127	*-77%*	241	*-51%*	148	*-70%*	3449
Portugal	197	*-5%*	51	*-76%*	144	*-34%*	88	*-59%*	2981
Spain	892	*-23%*	263	*-77%*	669	*-36%*	440	*-58%*	11276
Sweden	200	*-41%*	75	*-78%*	287	*-42%*	159	*-68%*	2413
UK	1186	*-58%*	521	*-82%*	1351	*-49%*	902	*-66%*	14231
EU-15	7333	*-45%*	2815	*-79%*	7123	*-49%*	4419	*-68%*	97113
Albania	36	*50%*	6	*-74%*	37	*23%*	17	*-43%*	114
Belarus	180	*-55%*	56	*-86%*	231	*-17%*	79	*-72%*	1103
Bosnia-H.	60	*-25%*	11	*-86%*	43	*-7%*	15	*-67%*	191
Bulgaria	290	*-18%*	61	*-83%*	192	*-3%*	74	*-63%*	867
Croatia	83	*0%*	16	*-81%*	87	*10%*	34	*-57%*	350
Czech Rep.	231	*-56%*	78	*-85%*	224	*-30%*	86	*-73%*	1764
Estonia	73	*-13%*	13	*-85%*	44	*0%*	16	*-64%*	225
Hungary	196	*-8%*	50	*-77%*	144	*-30%*	92	*-55%*	1611
Latvia	90	*-23%*	23	*-80%*	40	*-22%*	17	*-67%*	320
Lithuania	110	*-28%*	25	*-83%*	84	*-19%*	49	*-53%*	431
Norway	151	*-31%*	51	*-77%*	196	*-36%*	105	*-66%*	1280
Poland	810	*-33%*	244	*-80%*	754	*6%*	380	*-46%*	5318
Moldova	34	*-61%*	14	*-84%*	41	*-21%*	18	*-65%*	198
Romania	458	*-12%*	100	*-81%*	505	*5%*	167	*-65%*	1174
Russia	2675	*-23%*	528	*-85%*	2696	*-19%*	1185	*-64%*	7785
Slovakia	112	*-46%*	40	*-81%*	141	*-1%*	67	*-53%*	1126
Slovenia	31	*-48%*	8	*-87%*	25	*-58%*	20	*-67%*	366
Switzerland	89	*-45%*	41	*-75%*	173	*-41%*	115	*-60%*	1676
FYR Maced.	29	*-26%*	5	*-86%*	20	*0%*	7	*-65%*	93
Ukraine	1094	*-42%*	327	*-83%*	836	*-22%*	355	*-67%*	3553
Yugoslavia	152	*-28%*	27	*-87%*	121	*-2%*	40	*-68%*	522
Non-EU	6983	*-31%*	1725	*-83%*	6635	*-17%*	2936	*-63%*	28088
Total	14316	*-39%*	4703	*-81%*	13758	*-37%*	7355	*-67%*	125201

Note: Total for NO$_x$ includes sea regions.

Table 4.14: Emissions and control costs (on top of REF) for REF and the Maximum technically feasible reductions (MFR) for SO_2 and NH_3. Percentage changes relate to the year 1990.

	SO_2 emissions					NH_3 emissions				
	REF		MFR_{ult}			REF		MFR_{ult}		
	kt	*Change*	kt	*Change*	Costs	kt	*Change*	kt	*Change*	Costs
Austria	42	*-55%*	30	*-68%*	1025	67	*-13%*	48	*-38%*	349
Belgium	208	*-38%*	60	*-82%*	1739	60	*-38%*	57	*-41%*	467
Denmark	90	*-51%*	19	*-90%*	687	70	*-9%*	40	*-48%*	693
Finland	116	*-50%*	67	*-71%*	862	31	*-23%*	23	*-43%*	143
France	489	*-61%*	165	*-87%*	9774	727	*-10%*	541	*-33%*	2084
Germany	608	*-88%*	301	*-94%*	12689	396	*-48%*	353	*-53%*	1763
Greece	562	*12%*	87	*-83%*	1955	74	*-8%*	59	*-26%*	199
Ireland	70	*-61%*	21	*-88%*	644	122	*-4%*	111	*-13%*	455
Italy	593	*-65%*	194	*-88%*	10703	416	*-10%*	282	*-39%*	598
Luxembourg	4	*-71%*	2	*-84%*	103	7	*0%*	7	*0%*	0
Netherlands	74	*-63%*	47	*-76%*	2435	106	*-55%*	105	*-55%*	836
Portugal	146	*-49%*	29	*-90%*	2035	67	*-6%*	46	*-35%*	353
Spain	793	*-64%*	166	*-92%*	7841	353	*0%*	226	*-36%*	1816
Sweden	67	*-44%*	52	*-56%*	1359	48	*-21%*	44	*-28%*	109
UK	980	*-74%*	286	*-92%*	9069	264	*-20%*	218	*-34%*	741
EU-15	4842	*-70%*	1524	*-91%*	62920	2807	*-22%*	2159	*-40%*	10604
Albania	55	*-24%*	7	*-91%*	114	35	*9%*	25	*-22%*	56
Belarus	480	*-43%*	49	*-94%*	893	163	*-26%*	103	*-53%*	433
Bosnia-H.	415	*-15%*	23	*-95%*	190	23	*-26%*	17	*-45%*	74
Bulgaria	846	*-54%*	130	*-93%*	863	126	*-11%*	86	*-39%*	262
Croatia	70	*-61%*	17	*-91%*	344	30	*-25%*	22	*-45%*	110
Czech Rep.	368	*-80%*	101	*-95%*	1272	108	*1%*	72	*-33%*	411
Estonia	175	*-36%*	13	*-95%*	224	29	*0%*	16	*-45%*	83
Hungary	546	*-40%*	286	*-69%*	1187	137	*14%*	73	*-39%*	440
Latvia	57	*-53%*	18	*-85%*	289	35	*-19%*	19	*-56%*	113
Lithuania	107	*-50%*	22	*-90%*	402	81	*1%*	49	*-39%*	246
Norway	27	*-46%*	18	*-64%*	785	21	*-9%*	17	*-26%*	104
Poland	1397	*-53%*	362	*-88%*	4101	508	*1%*	368	*-27%*	1438
Moldova	117	*-41%*	19	*-90%*	152	48	*2%*	29	*-38%*	127
Romania	594	*-55%*	93	*-93%*	1174	300	*3%*	206	*-29%*	763
Russia	2344	*-53%*	539	*-89%*	7769	894	*-30%*	571	*-55%*	2943
Slovakia	137	*-75%*	68	*-88%*	801	47	*-22%*	30	*-50%*	173
Slovenia	37	*-82%*	10	*-95%*	241	21	*-9%*	12	*-48%*	60
Switzerland	30	*-30%*	12	*-72%*	961	66	*-8%*	54	*-25%*	187
FYR Maced.	81	*-24%*	5	*-95%*	92	16	*-6%*	11	*-35%*	43
Ukraine	1488	*-60%*	368	*-90%*	3414	649	*-11%*	406	*-44%*	2126
Yugoslavia	269	*-54%*	13	*-98%*	519	82	*-9%*	54	*-40%*	326
Non-EU	9638	*-55%*	2174	*-90%*	25787	3418	*-14%*	2240	*-44%*	10517
Total	14480	*-62%*	3698	*-79%*	89226	6225	*-18%*	4399	*-42%*	21121

Note: Total for SO_2 includes sea regions.

4.2 Environmental Effects

4.2.1 Acidification

Figure 4.1 displays the percentage of ecosystems for which, for the emissions of 1990, acid deposition is calculated to exceed the critical loads. Least protection occurred a band ranging from northern France over Germany to the Czech Republic and Poland. Overall, critical loads were exceeded in about 95 million hectares of ecosystems, out of which 37 million hectares were located in the EU-15 (see Table 4.15).

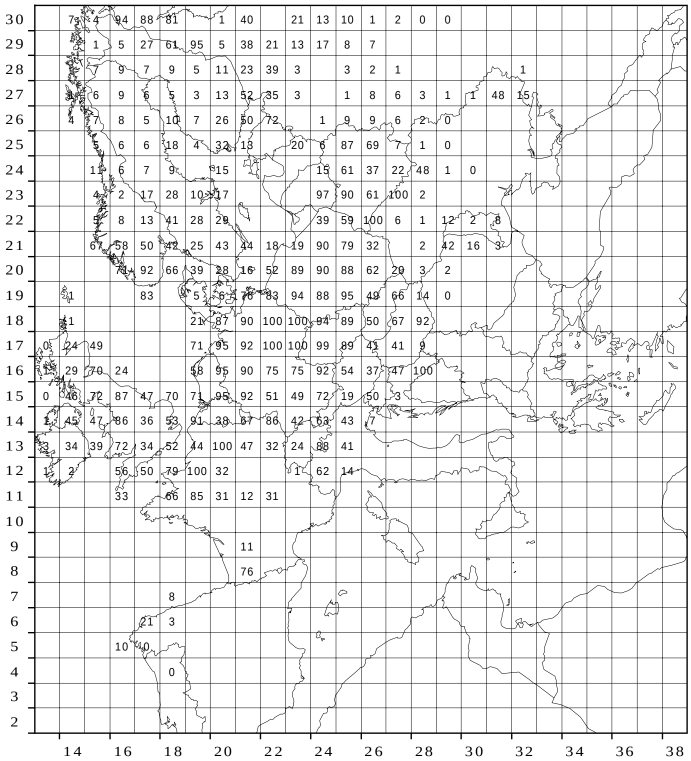

Figure 4.1: Percentage of ecosystems with acid deposition above their critical loads for acidification, 1990

The emission reductions anticipated in the REF scenario are expected to significantly improve the situation and to decrease the unprotected ecosystems to abut 21 million hectares, out of which 6.6 million hectares are located in the EU-15 (Figure 4.2). There is clear indication that the overall area where critical loads are exceeded will decline, and many areas where the situation was not extreme will achieve full protection. On the other hand there are some regions (northern Germany, southern Norway, northern Sweden, Hungary, Kola) where the improvement will not exceed 10 to 30 percent.

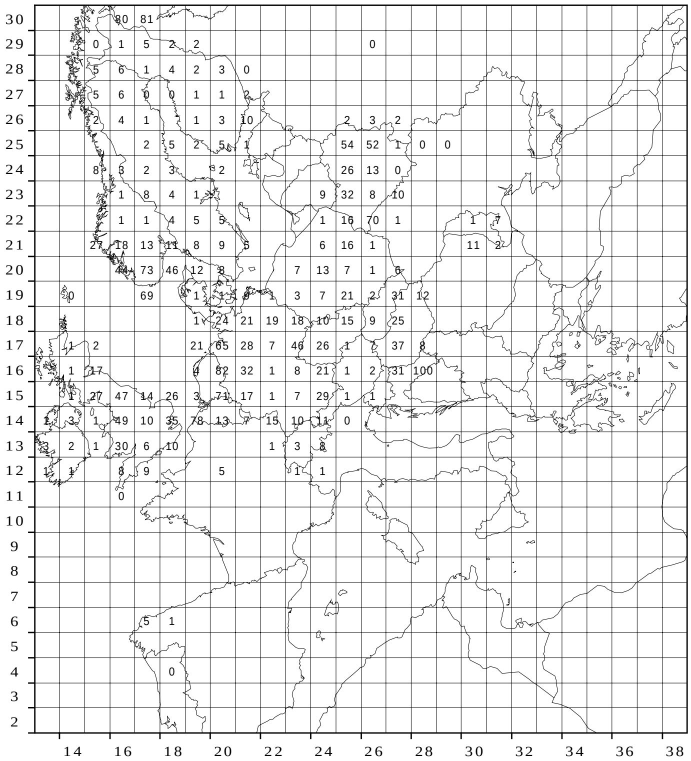

Figure 4.2: Percentage of ecosystems with acid deposition above their critical loads, REF case

Table 4.15: Ecosystems with acid deposition above their critical loads for acidification for 1990, the REF and the MFR_{ult} case.

	1000 ha			Percent of ecosystems		
	1990	REF	MFR_{ult}	1990	REF	MFR_{ult}
Austria	2373	189	35	47.5%	3.8%	0.7%
Belgium	410	162	6	58.3%	23.1%	0.9%
Denmark	54	9	1	13.9%	2.3%	0.3%
Finland	4722	1166	151	17.3%	4.3%	0.6%
France	8191	226	4	25.8%	0.7%	0.0%
Germany	8156	1750	117	79.5%	17.1%	1.1%
Greece	0	0	0	0.0%	0.0%	0.0%
Ireland	97	12	6	10.7%	1.4%	0.7%
Italy	2064	87	43	19.5%	0.8%	0.4%
Luxembourg	58	6	0	66.7%	6.7%	0.1%
Netherlands	285	198	30	89.3%	61.9%	9.3%
Portugal	1	1	0	0.0%	0.0%	0.0%
Spain	78	18	0	0.9%	0.2%	0.0%
Sweden	6344	1599	456	16.4%	4.1%	1.2%
United Kingdom	4117	1200	65	43.0%	12.5%	0.7%
EU-15	36950	6623	914	24.7%	4.4%	0.6%

4.2.2 Ground-level Ozone

There are several statistics against which improvement in ozone exposure could be evaluated. This report provides the following analyses:

- In order to present the improvements in generally understandable notions, maps indicate the remaining days on which the WHO health guideline (60 ppb) and the 90 ppb levels are exceeded. For each of these criteria, two maps are provided: one map displays the highest value (number of days) out of the five years meteorological regimes, while the second presents the maximum of the three-years moving averages over the five years.
- The second series of maps shows the AOT60 values, which were used as a surrogate health-risk indicator for the optimization. For the AOT60, the second highest value out of the five years meteorologies is presented.
- The third series of maps presents the excess AOT40 over the critical level of 3000 ppb.hours, in order to relate to the critical level for vegetation protection.

4.2.2.1 Health-related Ozone Exposure

Figure 4.3 displays the number of days on which the WHO health guideline value (60 ppb, eight-hours moving average) was exceeded with the 1990 emissions. The map shows the three-years average moving over the meteorological conditions of the five available year. Most frequent excess is calculated for Italy (about 60 days), while northern France experienced about 50 days and Germany 30-40 days. Spain and Portugal, Greece, Ireland and the UK are mainly between 10 and 20, while Scandinavia show typically below 10 days excess.

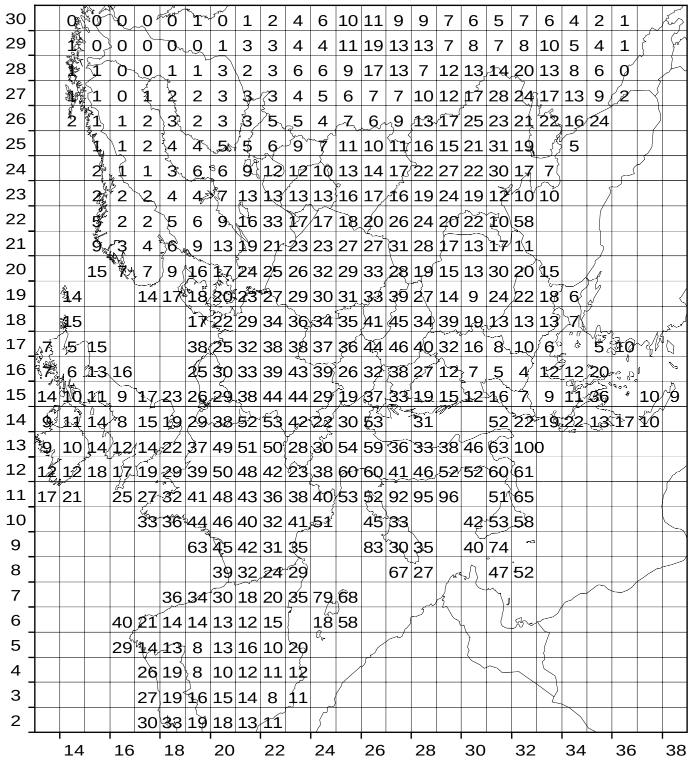

Figure 4.3: Number of days with ozone above 60 ppb, emissions of 1990, maximum of the three-years moving average over the five meteorological years

The emission controls calculated for the REF case (NO_x - 45 percent, VOC -49 percent compared to 1990) are expected to have profound impacts on ozone exposure. The maximum number of violation is expected to decline to 42 in France and about 35 in Italy and Germany (Figure 4.2).

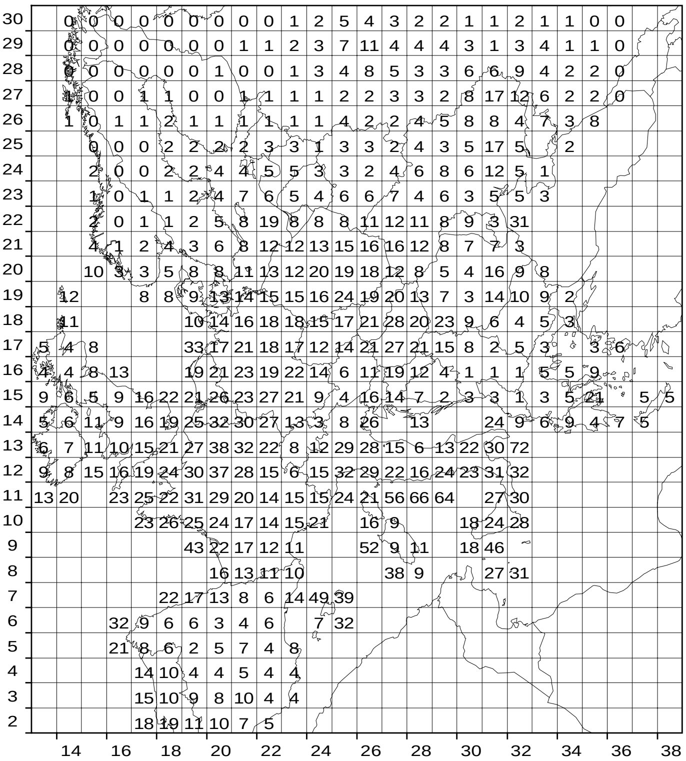

Figure 4.4: Number of days with ozone above 60 ppb, emissions of the REF case, maximum of the three-years moving average over the five meteorological years

For comparison, Figure 4.5 and Figure 4.6 present the situation for days exceeding a 90 ppb eight-hour mean concentration. While in 1990 the maximum was at about 14 days in the Benelux region, the frequency is expected to decline allover the EU-15 to not more than 4 days.

Figure 4.7 illustrates that for the emissions of 1990 and using the meteorological conditions of five years, the second highest (rural) AOT60 of more than 6 ppm.hours occurred in northern France, Belgium and Germany. In many other parts of France, Germany and Benelux, the AOT60 was modeled in a range of 7-8 ppm.hours. Typical rural values in the UK and Austria were between 2 and 3 ppm.hours, while the highest AOT60 in Spain and Greece was between 1 and 2 ppm.hours. Portugal is estimated at 2 ppm.hours, while Scandinavia did not experience significant excess of the AOT60.

It is interesting to note that there is not a 1:1 relationship between the AOT60 and the number of days across all regions in Europe, indicating that the amount by which the 60 ppb criterion is exceeded varies over Europe. Whereas the highest AOT60 is expected for the northern part of Europe (France/Belgium/Germany), large numbers of days exceeding the 60 ppb threshold are also found in Italy, where the AOT60 is typically 20 to 30 percent lower than in northern Europe. A detailed analysis of the available monitoring results is presented in van Hout (1998). This phenomenon underlines the observation that ozone exposure shows different temporal characteristics in different parts of Europe, a fact which is important to take into account when designing emission control strategies.

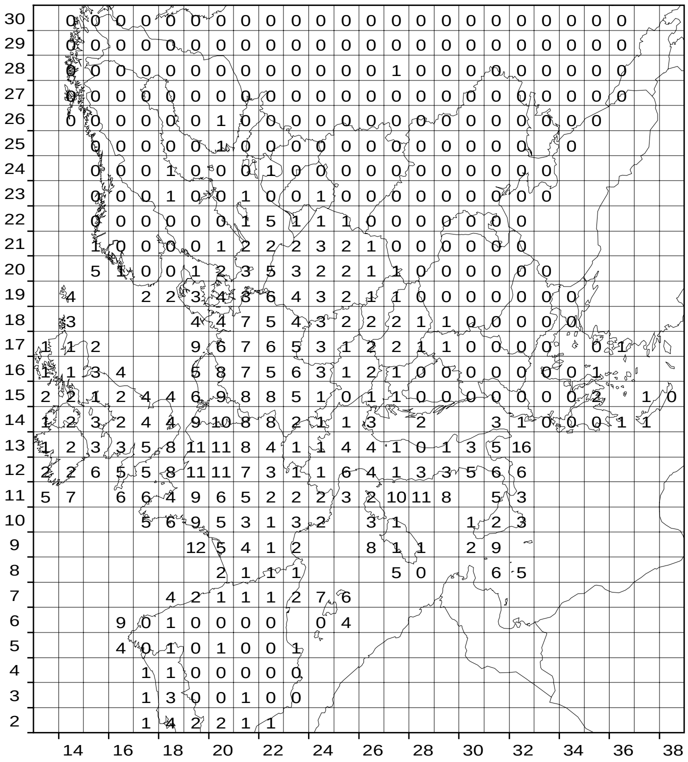

Figure 4.5: Number of days with ozone above 90 ppb, emissions of 1990, maximum of the three-years moving average over the five meteorological years

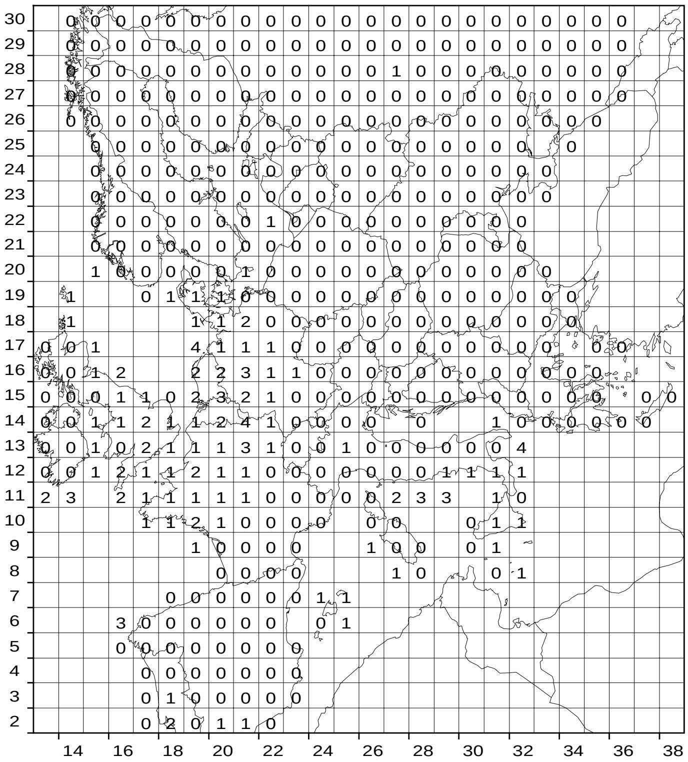

Figure 4.6: Number of days with ozone above 90 ppb, emissions of the REF case, maximum of the three-years moving average over the five meteorological years

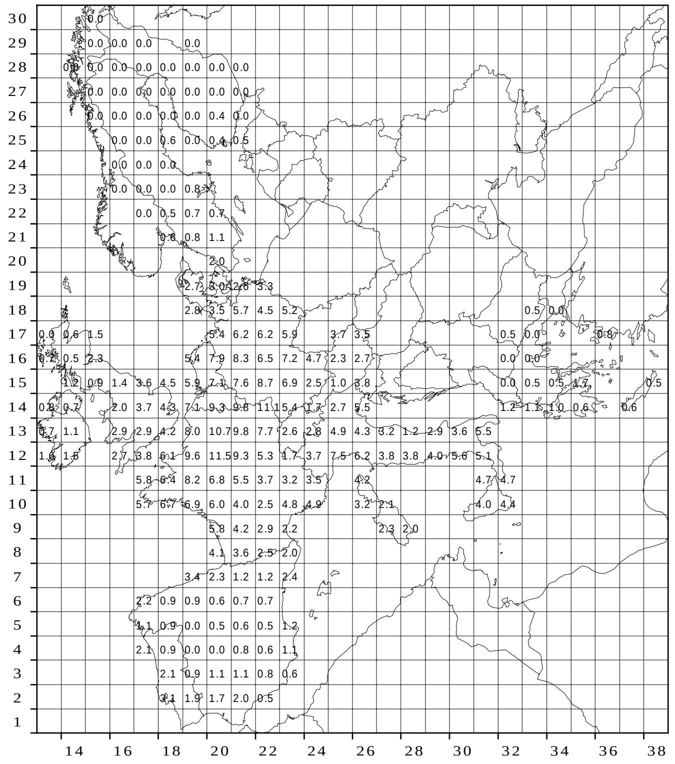

Figure 4.7: The AOT60 modelled for the emissions of 1990, second highest value of five years meteorologies (in ppm.hours)

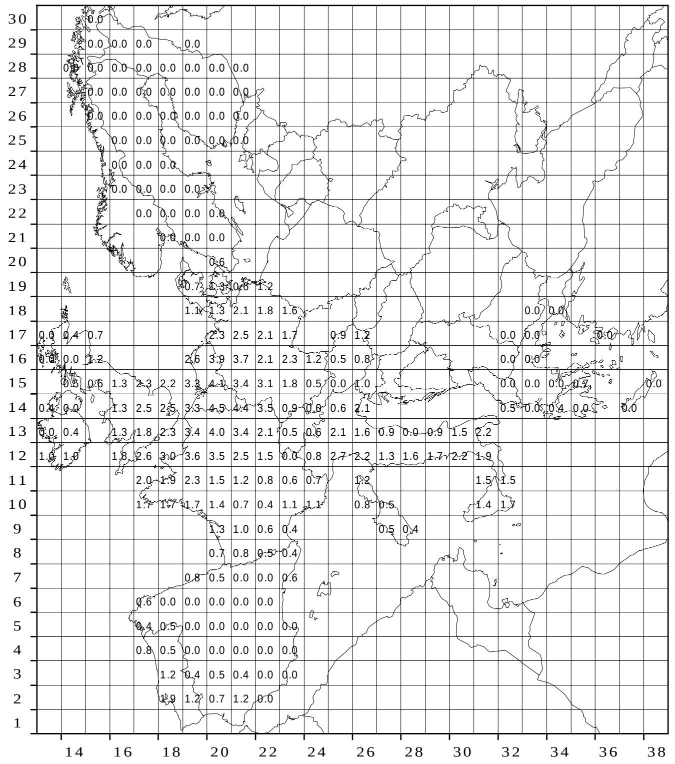

Figure 4.8: The AOT60 modelled for the emissions of the REF case, second highest value of five years meteorologies (in ppm.hours)

Table 4.16 presents two different types of population exposure for the AOT60. The cumulative index reflects for each country the total exposure of a population and is expressed in person.ppm.hours. The RAINS model calculates these indices on a grid basis (using gridded data on AOT60 and population); in a second step these grid values are aggregated to the country level. The indices presented in this report use the AOT60 concentrations per grid, representing the rural ozone concentrations, and the total population per grid in 1990. Inaccuracies may occur for grids with major urban areas, where the rural ozone concentrations used for these analysis present an upper bound for the concentrations in the cities, and are lower than the concentrations occurring in the city plumes (Kindbom and Grennfelt, 1998). The 'average' indicator reflects the average exposure of a person in a country, calculated from gridded data. It is important to stress that these indices may not be used to derive estimates of health damage, for which more detailed information is deemed necessary. In the context of this report, these indices provide relative measures to enable a quick comparison of different scenarios.

Table 4.16: Population exposure indices for 1990, the REF and for the MFR_{ult} case

	Cumulative population exposure index (million person ppm.hours)			Average population exposure index (excess ppm.hours)		
	1990	REF	MFR_{ult}	1990	REF	MFR_{ult}
Austria	15	3	0	2.0	0.4	0.0
Belgium	70	35	8	6.4	3.2	0.8
Denmark	9	3	0	1.7	0.5	0.0
Finland	0	0	0	0.1	0.0	0.0
France	306	102	11	5.4	1.8	0.2
Germany	394	145	20	5.0	1.8	0.3
Greece	7	3	0	0.7	0.3	0.0
Ireland	3	1	0	0.7	0.3	0.0
Italy	181	65	0	3.1	1.1	0.0
Luxembourg	3	1	0	8.3	3.2	0.6
Netherlands	71	39	10	4.8	2.6	0.7
Portugal	17	8	0	1.7	0.8	0.0
Spain	36	8	0	1.0	0.2	0.0
Sweden	3	0	0	0.4	0.0	0.0
United Kingdom	123	79	16	2.1	1.4	0.3
EU-15	1238	493	67	3.4	1.4	0.2

As shown in the table, in 1990 the average exposure was highest in Luxembourg, Belgium, France, Germany and the Netherlands; the highest cumulative exposure (due to the large population) occurred in Germany, France, Italy and the UK. The cumulative exposure of the population in the EU-15 countries is expected to decline by 58 percent as a result of the current policy. Larger improvements occur in Austria (-81 percent) and the Scandinavian countries (60-70 percent), while for the UK and Netherlands a decrease in AOT60 by about 40 percent could be expected.

It is important to mention that there are some areas where, despite - or because of - the anticipated emission reductions of the REF scenario, for individual years the AOT60 is expected to slightly increase as a result of current policy. Using mean meteorology, however, masks the increase occurring in individual years.

The explanation for this increase is related to the ozone formation chemistry. Put in a rather simplistic way, very high NO concentrations (in areas with high NO_x emissions) have, i.a., two effects: (a) they lead to the titration of ozone, i.e., the conversion of ozone and NO into NO_2, and (b) they cause a (partial) depletion of OH radicals. This resulting shortage of OH radicals at such high NO_x levels limits ozone production. Reducing NO_x emissions from such a high level will increase the available OH radicals, and more ozone will be produced, until NO_x emissions are so low that the ozone production will be limited by the available NO_2 molecules. As indicated in Section 2.5.3, reducing NO_x will lead for some time to increased ozone. Beyond a certain NO_x reduction level, however, ozone will decline again.

Figure 4.9 supports this explanation by illustrating the emission densities in 1990. It is important to realize that the emissions in the areas where the increase occurs (UK, Belgium, Netherlands, etc.) are up to a factor of 10 higher than in other industrialized European regions (compare e.g., southern Germany).

It is also important to realize that this ozone increase disappears for the maximum feasible emission reductions. This means that sufficiently high NO_x reductions (which are considered as technically feasible) can overcome the temporary ozone increase everywhere.

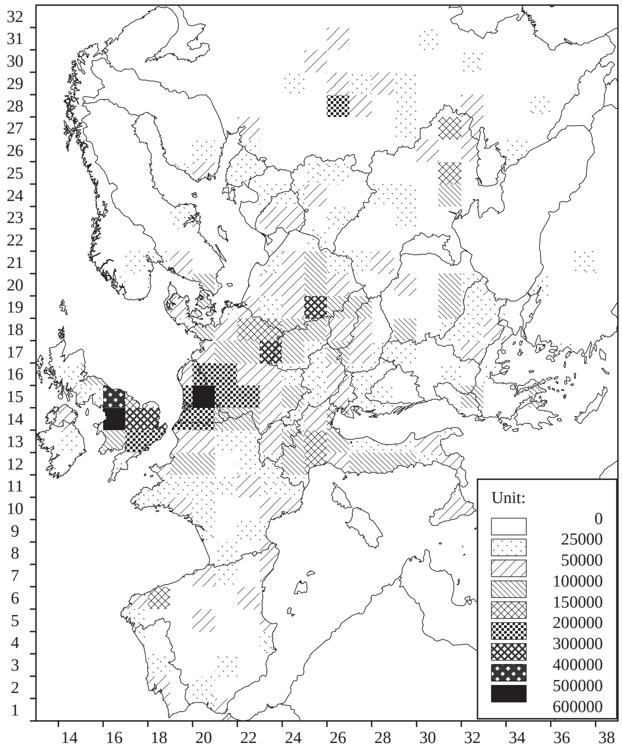

Figure 4.9: NO_x emissions per EMEP grid cell in 1990 (in tons)

4.2.2.2 Vegetation-related Ozone Exposure

Figure 4.10 displays the excess AOT40 (over the critical level of 3 ppm.hours) calculated for the emissions of the year 1990 using the five years mean meteorology. The map clearly shows that in most countries of the EU-15 the critical level for vegetation was exceeded. The only exceptions are parts of the Scandinavian countries. In an area extending from Paris over

Belgium and Netherlands to Germany the excess AOT40 reached 16 ppm.hours, i.e., it exceeded the critical level by more than a factor of five. It is important to note that ozone levels in many areas, which do not experience significant excess of the AOT60, exceed the AOT40 criterion considerably. This applies particularly to the Mediterranean countries and some Alpine regions.

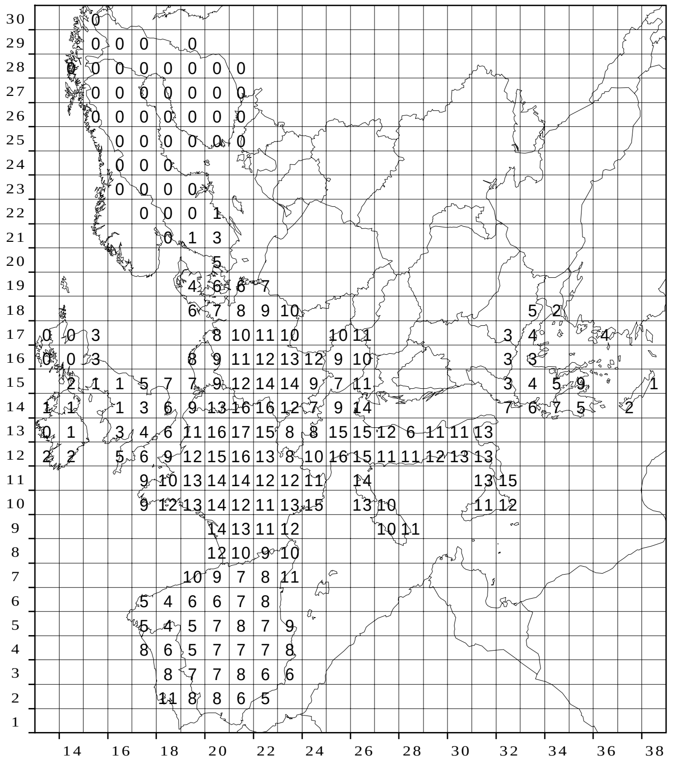

Figure 4.10: Excess AOT40 (above the critical level of 3 ppm.hours) for the emissions of 1990, in ppm.hours

The emission reductions of the Reference scenario will generally lead to a decline of the excess AOT40, but will not significantly increase the protected area (Figure 4.11). Peak levels are in a range of 10-12 ppm.hours.

Table 4.17 introduces two vegetation-related exposure indices. The cumulative vegetation exposure index is calculated as the excess AOT40 (i.e., the AOT40 in excess of the critical level of 3 ppm.hours) multiplied by the area of ecosystems that is exposed to the excess concentration. The index is calculated on a grid resolution, considering agricultural land, natural vegetation and forest areas. The average vegetation exposure index reflects the average excess AOT40 (over all grids in a country). The estimate of these indices is based on rural ozone concentrations.

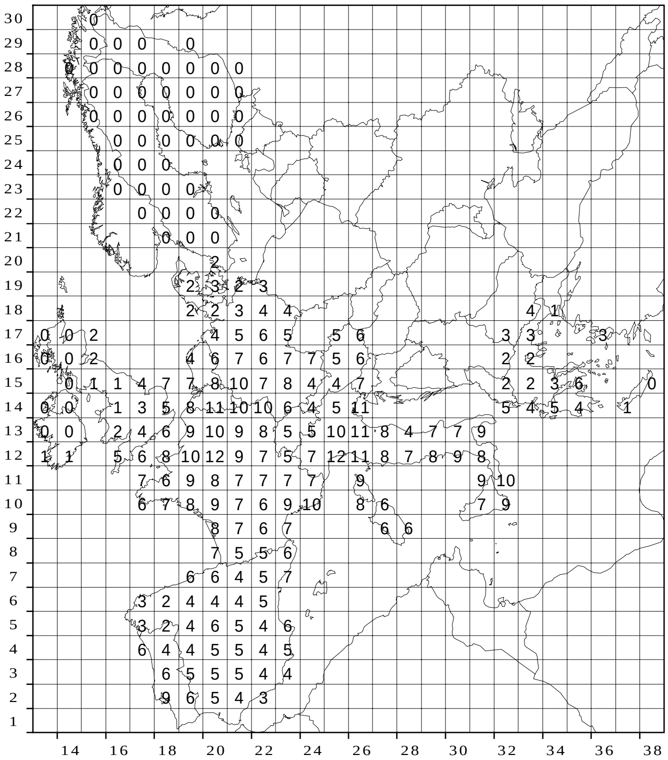

Figure 4.11: Excess AOT40 (above the critical level of 3 ppm.hours) for the emissions of the REF scenario, in ppm.hours

Table 4.17: Vegetation exposure indices for 1990 and the REF case

	Cumulative vegetation exposure index (million hectares.excess ppm.hours)			Average vegetation exposure index (excess ppm.hours)		
	1990	REF	MFR$_{ult}$	1990	REF	MFR$_{ult}$
Austria	460	260	47	8.9	5.0	0.9
Belgium	176	144	86	11.4	9.3	5.6
Denmark	136	54	0	4.5	1.8	0.0
Finland	0	0	0	0.0	0.0	0.0
France	4154	2565	809	12.9	7.9	2.5
Germany	2298	1231	377	10.8	5.8	1.8
Greece	228	161	15	4.2	3.0	0.3
Ireland	25	9	0	1.1	0.4	0.0
Italy	1758	1207	468	11.2	7.7	3.0
Luxembourg	25	15	6	16.5	10.0	3.8
Netherlands	107	79	46	8.2	6.1	3.5
Portugal	384	281	32	6.6	4.9	0.6
Spain	2058	1359	123	6.7	4.4	0.4
Sweden	110	19	0	0.4	0.1	0.0
United Kingdom	191	157	82	2.3	1.9	1.0
EU-15	12110	7541	2090	6.5	4.0	1.1

4.2.3 Eutrophication

Figure 4.12 shows that in 1990 eutrophication was a wide-spread phenomenon in may parts of central Europe. The majority of grid cells in France, Germany, Poland, Romania and Bulgaria experienced excess deposition for all of their ecosystems. In the EU-15, critical loads for eutrophication were exceeded in more than 66 milllion hectares.

The emission reductions anticipated from the REF scenario will relieve the situation to some extent, but will still leave 50 million hectares unprotected (Figure 4.13). In many parts of mainland Europe they will not be sufficient to increase the unprotected ecosystems substantially. Statistics about individual countries are presented in Table 4.18.

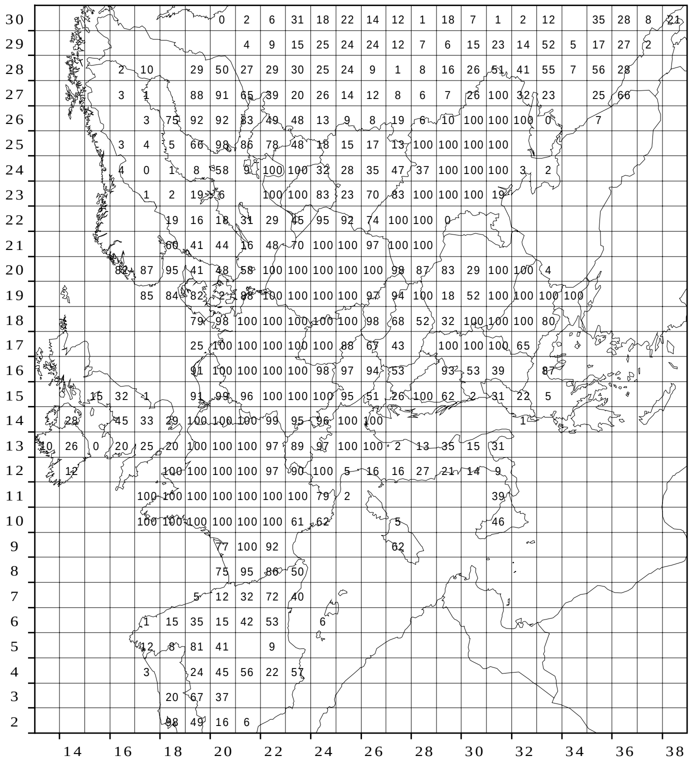

Figure 4.12: Percentage of ecosystems area with nitrogen deposition above their critical loads for eutrophication, for the emissions of 1990

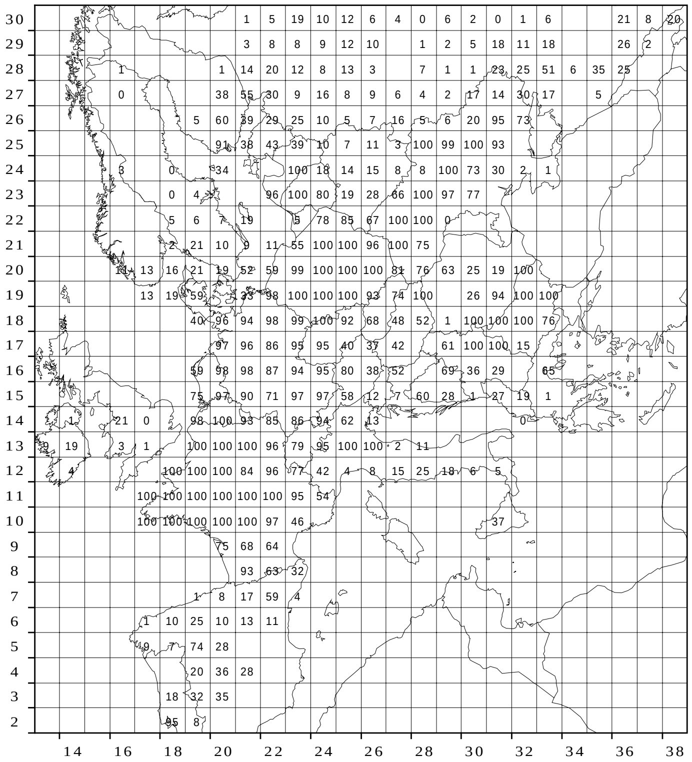

Figure 4.13: Percentage of ecosystems area with nitrogen deposition above their critical loads for eutrophication, for the emissions of the REF scenario

Table 4.18: Ecosystems with nitrogen deposition above their critical loads for eutrophication for 1990 and the REF case

	1000 ha			Percent of ecosystems		
	1990	REF	MFR$_{ult}$	1990	REF	MFR$_{ult}$
Austria	5379	3499	568	90.1%	58.6%	9.5%
Belgium	700	683	335	99.6%	97.3%	47.7%
Denmark	197	122	4	62.6%	38.7%	1.3%
Finland	7376	2292	3	44.7%	13.9%	0.0%
France	29319	26563	13075	92.3%	83.6%	41.2%
Germany	10156	9324	3561	99.0%	90.9%	34.7%
Greece	295	226	8	12.0%	9.2%	0.3%
Ireland	91	59	23	10.0%	6.5%	2.5%
Italy	5920	3806	1381	49.4%	31.8%	11.5%
Luxembourg	88	82	44	100.0%	93.2%	50.7%
Netherlands	312	293	252	97.8%	91.6%	79.0%
Portugal	913	760	0	32.3%	26.9%	0.0%
Spain	2389	1344	8	28.0%	15.8%	0.1%
Sweden	2581	886	63	13.7%	4.7%	0.3%
United Kingdom	1030	128	0	11.2%	1.4%	0.0%
EU-15	66746	50065	19326	55.3%	41.5%	16.0

5 The Selection of Environmental Interim Targets

The assessment in the preceding section clearly demonstrates that the occurrence of and the reduction potential for ground-level ozone and acidification show distinct spatial differences over Europe. Furthermore, there is robust evidence that the presently available technical emission control measures will not be sufficient to meet the environmental long-term targets (the no-damage levels) everywhere in Europe within the next one or two decades without interfering with the 'business as usual' expectations on economic development and energy consumption. In such a situation the choice of an equitable environmental interim target becomes crucial for deriving a balanced emission control strategy.

The analysis of the Fourth Interim Report identified two basic concepts for setting interim targets, i.e., prioritizing measures in highly polluted areas by imposing uniform absolute exposure limits over the entire area as one principle, and postulating equal relative improvements in relation to the situation in a base year (the gap closure concept) as the alternative option. It was clearly shown that these two different conceptual approaches imply fundamentally different spatial distributions of environmental benefits and emission abatement efforts over Europe. Discussions concluded that a combination of both principles could most likely lead to internationally acceptable solutions and should be further explored.

Earlier analysis (see, e.g., Amann *et al.*, 1997) demonstrated that the optimal allocation of emission controls may be strongly influenced by the need to exactly meet specific environmental targets at a few single grid cells, while for the majority of grid cells the targets are usually over-achieved. The sensitivity of the optimization results towards modifications of the environmental targets of these 'binding grids' was the subject of numerous discussions in the past. It was argued that the requirement to achieve stringent targets in isolated areas could possibly imply unbalanced high costs without yielding adequate benefits. This concern is even more pronounced when the targets are not related to absolute exposure levels, but to interim targets on the way towards the ultimate environmental objective.

Both the Council Conclusions on the Acidification Strategy (8387/97 ENV 146 PRO-COOP45 - COM(97) 88 final) and the UN/ECE Working Group on Strategies (EB.AIR/WG.5/54) requested the analysis of alternative concepts, where environmental targets for single ecosystems are not allowed to drive the overall optimization system to extreme solutions.

The following paragraphs provide a brief description of the two types of targets applied in the scenario analysis and outline the rationales and mechanisms for relaxing the influence of small receptor areas on the overall optimization result.

5.1 Equal Relative Improvements: Gap Closure Targets

In a situation with significant spatial differences in environmental excess pollution, an obvious possibility for defining interim targets is to postulate equal relative improvements in comparison to a reference situation. In the international context, such a target setting approach was adopted for the Second Sulfur Protocol of the UN/ECE Convention on Long-range Transboundary Air Pollution, where for all areas a target of a '60 percent gap closure' of the excess sulfur deposition (i.e., sulfur deposition above the critical loads) was established. The advantage of such an approach is that it implies general progress towards the full achievement of the ultimate environmental targets even in areas, which experience comparably little excess pollution, and thereby achieves a wide-spread distribution of environmental benefits.

5.1.1 The Definition of the ’Gap’

Earlier analysis revealed that in certain situations the original definition of the ’gap’ (the difference between present and absolute ’no-damage’ levels) could push areas with comparatively low exposure to costly emission reductions, while less burden would be placed on more polluted regions. This occurs typically in areas where background concentrations resulting, e.g., from natural sources, constitute a large fraction of the total exposure. At such places a target specified as a certain relative improvement requires therefore higher reductions in anthropogenic emissions than in highly polluted regions, where the relative contribution of natural background is negligible.

It is important to recall that model uncertainties are, for a number of reasons, largest for just these low pollution levels. In order to maximize the robustness of results obtained from the currently available models and not to let model results below this limit influence the actual strategy development, a ’model confidence interval’ was introduced. The ’gap to be closed’ by the optimization is now defined as the difference between the current situation and this model confidence interval. In practice, the lower model confidence range was set for the AOT60 to 0.4 ppm.hours and for acidification for each grid cell to the accumulated excess deposition resulting from natural and hemispheric background plus five aeq/hectare.

5.1.2 Limiting the Influence of Single Environmental Receptors on the Optimization Result

In order to limit the potential influence of small and perhaps untypical environmental receptor areas on optimized Europe-wide emission controls and to increase the overall cost-effectiveness of strategies, a mechanism was developed to tolerate lower improvements at a few places without discarding the overall environmental ambition levels.

This ’compensation mechanism’ allows a (limited) violation of environmental targets at single grid cells or single years as long as this excess is compensated by additional improvements in other years or at other grid cells within the same country. The compensation considers differences in the stock at risk over grid cells and puts more relative emphasis on densely populated areas or regions with large natural ecosystems. A weighting mechanism requires that excess exposure (AOT60, AOT40 or accumulated excess acidity) must be compensated on a population- or vegetation-adjusted basis, e.g., a small excess of AOT60 in a big city by larger improvements in less populated rural areas. In practice, this weighting mechanisms assure that for each country the (population/vegetation/area-) exposure indices of the optimized solution (applying the compensation mechanism) will not deteriorate as a result of the compensation.

In order to avoid a possible inequitable treatment of large and small countries implied by the compensation mechanism, a (uniform) maximum compensation potential was introduced. This means that environmental targets may only be violated up to a certain amount, which is independent of the country. Experiments showed that such a violation limit was best defined in terms of a uniform 'minimum' gap closure, compared to other relative or absolute measures.

In practice, the 'gap closure' optimization with compensation proceeds along the following steps, which are here explained for the example of the AOT60 optimization:

- For each grid cell, a 'soft' target is determined. This soft target is either the AOT60 of the base year (1990) reduced by *x* percent (for a *x* percent gap closure) or the AOT60 resulting from the REF scenario, whichever is lower.
- The AOT60 after the optimization may exceed the soft target in a grid, if the excess AOT60 (weighted by the population in the grid) is fully compensated by over-achievements of the soft targets at other grids in the same country (again population-weighted).
- The AOT60 after the optimization may not exceed, however,
  (a) the absolute AOT60 target (except in the worst year); this guarantees that the absolute AOT60 target is maintained after the compensation;
  (b) the AOT60 of the REF scenario. This prohibits a deterioration of the environmental situation compared to the REF (no further measures) case;
  (c) and it must satisfy a minimum gap closure of *y* percent (to prevent unlimited compensation).
- For the AOT60, the country balances (of the excess population exposure indices) extend not only over all grids of a country, but also over all five meteorological years. This means that (a) for the gap closure approach the worst meteorological year is also considered in the optimization, and (b) that excess in some years may be compensated by additional improvements in other years.
- In addition, a lower cut-off for the AOT60 of 0.4 ppm.hours is introduced. This means that the minimum target is set at 0.4 ppm.hours, and that improvements below the model confidence interval of 0.4 ppm.hours are not allowed to compensate violations at other grids. The major argument for this cut-off is that possible model artifacts should not be allowed to drive the optimization solution, nor should they justify violations of environmental targets at other grid cells.

The country balances ensure that for each country the exposure indices will be reduced at least by the percentage of the selected gap closure, or phrased differently, that the desired 'gap closure' is achieved for the country population exposure indices rather than for individual grid cells.

5.2 Uniform Exposure Ceilings

As an alternative principle to drive environmental improvements, general exposure ceilings to be achieved throughout the modeling domain could be introduced. In such a case the overall move towards the environmental long-term targets is steered by the needs for the most polluted areas. Uniform exposure ceilings proved as practical tools to exert additional pressure for environmental improvements in the most polluted areas.

For ozone however, model results for five different meteorological years demonstrated that actual ozone levels do not only depend on the levels of precursor emissions, but also to a significant degree on the specific meteorological condition. Emission control strategies addressing an extreme situation might therefore look rather different than strategies tailored towards the improvement of typical situations. For the purposes of strategy development, it was decided to exclude the ’most difficult’ situations from the analysis, when considering the uniform ozone limit target. In practice, the strategy should be constructed in such a way that it would meet the absolute AOT targets in four out of five years. It is important to stress that the major motivation for this ’four out of five’ principle in the context of strategy development is the concern to avoid reliance on the model performance for extreme (and perhaps rare) situations. By no means should this principle prejudge the selection of meaningful criteria against which the compliance should be checked.

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