FIFTH INTERIM REPORT

Cost-effective Control of Acidification and Ground-Level Ozone

Part A: Methodology and Databases

Fifth Interim Report to the
European Commission, DG-XI

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Economic Evaluation of Air Quality Targets for Tropospheric Ozone.

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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 Fifth 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 Interim Report explored alternative principles of setting environmental targets and the implication on the distribution of costs and environmental benefits to different regions in Europe. This Fifth Interim Report carries the analysis further and studies, for a range of environmental targets, the robustness of the implied allocation of emission reductions against variations in important input assumptions.

This Fifth 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 a range of scenarios targeted at ground-level ozone and explores their robustness against changes in important input assumptions.

Part C addresses scenarios for acidification and eutrophication and assesses their interaction with ozone-focused strategies.

Part A and Part B formally constitute the Fifth Interim Report to the European Commission providing analysis for a Community ozone strategy. Part C is mainly prepared for the 22nd Session of the UN/ECE Task Force on Integrated Assessment Modelling (Helsinki, May 1998). Although produced for different organizations, Part A to C should be seen in conjunction as a harmonized attempt to analyze multi-pollutant/multi-effect emission control strategies on a pan-European scale, based on a common methodology and relying on one consistent data set as described in Part A.

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.

The most important changes in the database introduced since the last Interim Report are summarized in Section 3.5.

2 Methodology

The recent progress in quantifying the sensitivities of ecosystems adds an important feature to the analysis and the development of cost-effective strategies to achieve and maintain emission levels that do not endanger the sustainability of ecosystems. Integrated assessment models are tools to combine information and databases on the economic, physical and environmental aspects relevant for strategy development.

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).

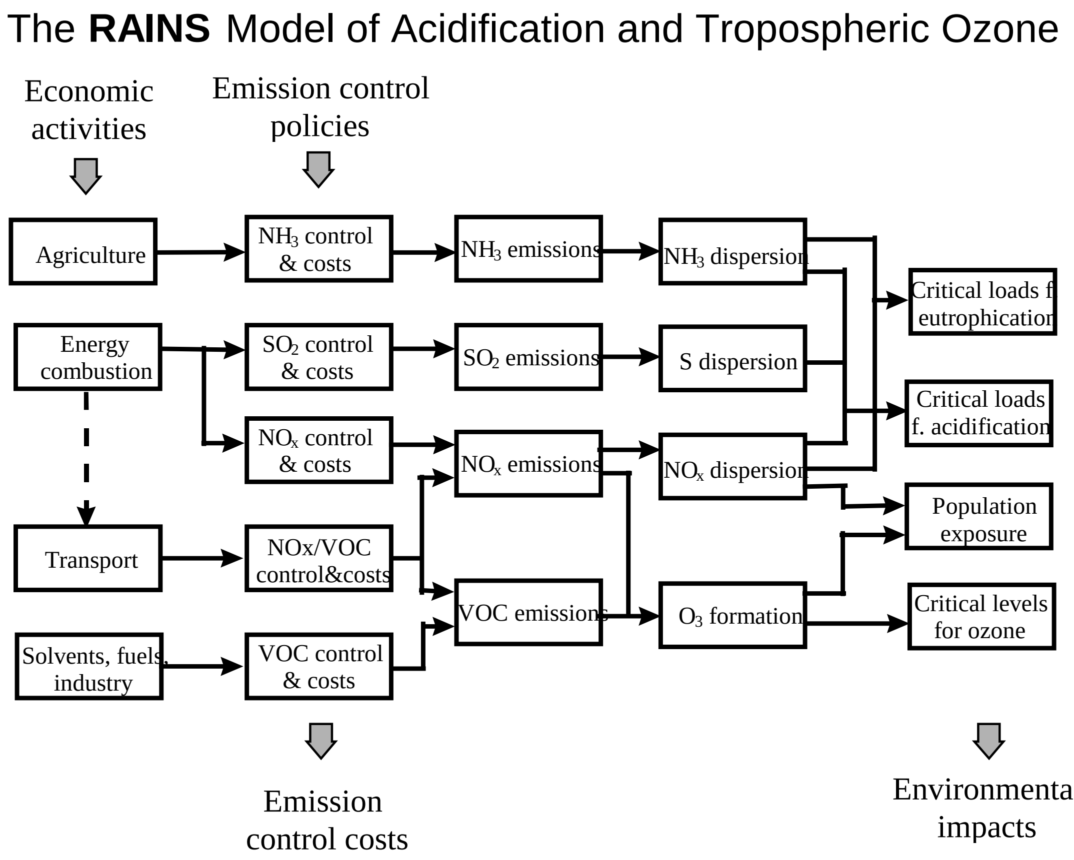

Figure 2.1: Schematic flowchart of the RAINS model framework

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, extraction 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). 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'90 categories and the RAINS sectors are shown in Table 2.1 to Table 2.3. 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**	**SNAP code**
Fuel production and conversion	Combustion	05
	Losses	05
Power plants and district heating plants	New boilers	01
	Existing boilers, dry bottom	
	Existing boilers, wet bottom	
Households	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

Table 2.2: Sectors in the RAINS module for mobile sources and their relation to the CORINAIR'90 SNAP codes

RAINS sector		**CORINAIR**
Primary	**Secondary**	**SNAP 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)	0701,02,04,05
	Gasoline evaporation	0706
Off-road	Machinery with two-stroke engines	0801
	Other machinery and land-based sources (four stroke), railways, airports	0801,02,05
Ships	Medium vessels	0803,0804
	Large vessels	0803, 0804

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

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

RAINS sector		CORINAIR
Primary	**Secondary**	**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

Table 2.4: 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

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 German update of the emission inventory received in April 1998;
- 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.

- The recent UN/ECE emission inventory provided by the Secretariat of the Convention on Long-range Transboundary Air Pollution (UN/ECE, 1997). This inventory presents new (national total) emission estimates for 1990 for Austria, Belgium and Denmark, which differ by up to 10 percent from numbers given in the earlier publication. The reasons for these changes will need to be clarified in the future and – if significant – incorporated into RAINS.
- The treatment of emissions from offshore oil platforms. There is still an inconsistency in the national reportings. Whereas the Norwegian inventory includes such emissions, they are not contained, e.g., in the UK database.

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 database (EMEP, 1997). 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).

While for most countries the RAINS estimates, which are based on international energy, agricultural and economic statistics, match the emission inventories from other sources rather closely, important inconsistencies remain in a few specific cases. Significant inconsistencies in NO_x and SO_2 estimates occur in the following cases:

- For Greece, the NO_x emissions reported in CORINAIR’90 are more than 20 percent higher than the figures given to EMEP and calculated by RAINS. In-depth analysis revealed that the Greek submission to CORINAIR'90 includes emissions from all marine bunker fuel purchased in Greece, whereas the energy balances used in RAINS exclude marine bunkering from gross inland energy consumption. In reality, only a small portion of fuel purchased by sea vessels in Greece is used in the Greek coastal zone. New assessments done in Greece (Ziros, 1998) report 1990 SO_2 emissions of 503 kt and NO_x at 344 kt, which is close to the RAINS estimates.
- There is new information on the treatment of ship emissions in the Swedish inventories, which could probably eliminate the discrepancies listed for the Swedish data in Table 2.5. Due to the short notice, however, it was not possible to incorporate the new information into the RAINS database in time for this report.
- There remain 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.

For VOC emissions, the differences between RAINS and CORINAIR'90 estimates for the majority of countries are typically within ten percent. Most of these differences result from corrections of obvious inconsistencies in the CORINAIR'90 database, which were identified in cooperation with national experts. For example, corrections were applied inter alia in the following cases:

- The CORINAIR'90 database for the Czech Republic does not include estimates for domestic solvent use, evaporative emissions from cars, industrial paint use;
- The CORINAIR’90 database for Finland does not include estimates for domestic solvent use, residential combustion, wood preservation, as well as from some of the chemical industries;
- Hungary’s CORINAIR'90 database does not include emissions from the domestic use of paints;
- Italy is the only country that reports emissions of VOC from animal breeding. These emissions constitute the third largest source of VOC emissions in this country, contributing some 15 percent.
- For France, the energy balances used for the RAINS database (the UN/ECE energy database) and for the CORINAIR'90 inventory disagree about the fuel wood consumption for residential heating. VOC emissions estimated by RAINS for France are therefore different from the CORINAIR'90 inventory.
- 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, which 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 database (in kilotons).

	NO$_x$			VOC		
	RAINS	EMEP	CORINAIR'90	RAINS	EMEP	CORINAIR'90[3]
Albania	24	24	n.a.	30	32	n.a.
Austria	234	222	227	432	418	404
Belarus	402	285	n.a.	279	533	n.a.
Belgium	355	352	343	336	332	364
Bosnia-H	80	80	n.a.	46	101	n.a.
Bulgaria	354	376	361	198	187	189
Croatia	83	83	n.a.	79	105	97
Czech R.	522	742	773	322	435	253
Denmark	269	279	273	162	175	167
Estonia	84	93	72	44	23	50
Finland	278	300	269	213	209	165
France	1600	1585	1585	2129	2393	2393
Germany	2690	2640	2980	2973	3155	2937
Greece	394	392	543	306	293	312
Hungary	214	238	191	206	205	148
Ireland	103	115	116	111	102	102
Italy	2038	2047	2041	1873	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	575	537	483	420	452
Norway	221	227	232	308	299	270
Poland	1209	1279	1445	709	797	971
Portugal	208	221	215	217	202	202
Moldova	87	39	n.a.	52	11	n.a.
Romania	518	546	546	483	568	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	1178	1247	1048	1051	1044
Sweden	346	411	345	435	526	451
Switzerland	166	165	159	290	284	282
FYR Macedonia	39	39	n.a.	20	7	n.a.
Ukraine	1888	1097	n.a.	1074	1079	n.a.
United Kingdom	2800	2897	2773	2673	2623	2602
Yugoslavia	211	66[4]	n.a.	124	66	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	24790	23419	n.a.	21363	22654	n.a.

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[3] 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 database (in kilotons).

	SO_2			NH_3		
	RAINS	EMEP	CORINAIR'90	RAINS	EMEP	CORINAIR'90
Albania	73	72	n.a.	31	31	n.a.
Austria	95	90	93	92	91	87
Belarus	845	637	n.a.	219	219	n.a.
Belgium	317	317	317	85	95	79
Bosnia-H	487	480	n.a.	31	31	n.a.
Bulgaria	1842	2020	2008	141	323	324
Croatia	178	180	n.a.	40	37	37
Czech R.	1877	1876	1863	115	105	91
Denmark	185	184	198	77	109	126
Estonia	276	239	275	29	29	29
Finland	227	260	227	42	35	41
France	1304	1298	1298	688	700	700
Germany	5328	5326	5257	739	759	739
Greece	521	510	640	77	78	471
Hungary	913	1010	906	120	176	62
Ireland	172	178	178	127	126	126
Italy	1681	1678	1683	397	416	383
Latvia	122	57	115	39	44	38
Lithuania	213	222	223	79	84	84
Luxembourg	14	14	14	7	7	7
Netherlands	207	205	200	233	236	196
Norway	52	53	54	23	23	38
Poland	3001	3210	3273	505	508	539
Portugal	286	283	283	77	93	93
Moldova	197	231	n.a.	47	47	n.a.
Romania	1335	1311	1311	290	300	300
Russia	5046	4460	n.a.	1283	1191	n.a.
Slovakia	549	543	542	60	62	60
Slovenia	200	195	196	23	27	27
Spain	2190	2266	2206	352	353	331
Sweden	130	136	105	62	61	74
Switzerland	45	43	44	58	62	69
FYR Macedonia	107	106	n.a.	17	17	n.a.
Ukraine	3708	2782	n.a.	729	729	n.a.
United Kingdom	3754	3756	3787	329	320	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.	7353	7614	n.a.

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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 Belgium, Denmark, Greece and Portugal:

- The difference for Belgium (about ten percent) is mainly a result of adjustments made in RAINS in order to take into account emissions from fertilizer use and other cattle which were not included in CORINAIR'90 for one of the Belgium regions.
- 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 Greek submission to CORINAIR'90 contains a very high estimate for emissions from fertilizer use (on an area basis, 100 times higher than emissions in, e.g., Germany). Correcting this single number to a reasonable range brings the total Greek emissions down to 84 kilotons, which is close to the EMEP and RAINS estimates.
- A similar inconsistency was detected in the Portuguese CORINAIR'90 database, Correcting the emission factor for fertilizer use to internationally reported values (ECETOC, 1994) reduces the overall estimate by about 17 percent.

For the non-EU countries major discrepancies (larger than 10 percent) occur only for the Czech Republic, Bulgaria, Hungary and Slovenia:

- The largest difference occurs for Bulgaria, where the CORINAIR'90 database contains an emission factor for dairy cows four to six times above the European average. In the meantime this mistake was detected by Bulgarian experts, so that the latest UN/ECE documents (UN/ECE, 1997) report for Bulgaria a corrected value of 144 kt, which is very close to RAINS estimate using the average European emission factor for Bulgarian cows.
- Differences for the Czech Republic, Hungary and Slovenia can be traced back to the omission of emissions from pigs and fertilizer use and to differences in livestock statistics. It is worth mentioning that for Hungary the estimate officially submitted to EMEP is nearly three times larger than the CORINAIR'90 value.

Many of the inconsistencies identified above were corrected for the CORINAIR'94 inventory, and some countries produced updates of their CORINAIR'90 submissions. Lack of time and missing access to the detailed revised 1990 information did not allow to incorporate this new information into the RAINS model to be used for this report.

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:

- Distinguishing boilers in existing power plants that are already equipped with wet flue gas desulfurization. The scrubbers installed at those plants were designed for less stringent emission standards than achievable today. Thus it was assumed that the control efficiency of these ‘old’ scrubbers is only at 90 percent rather than the 95 percent which is achievable for new installations and retrofits of presently uncontrolled plants.
- Decreasing of the average sulfur removal efficiency of wet scrubbers for industrial boilers and furnaces to 85 percent.
- Change in the price differential for low sulfur heavy fuel oil. The revised estimates are based on the data reported by CONCAWE (1993). The investments presented in the CONCAWE report were adapted to the four percent real interest rate used for the economic analysis in the RAINS model.
- Implementation of a third stage of desulfurization of gas oil (diesel) to 0.003 percent sulfur content. This stage is required to meet the sulfur limit of 50 ppm proposed for road transport by the European Council (Common Position, OJ 97/C 351/01, 1997a).

However, it is assumed that this desulfurization option for diesel oil is only meaningful for the transport sector. Costs of that step have been assessed based on reports of the Auto/Oil Programme (EC, 1996) and the estimates prepared by the European Commission (Mackowski, 1998).

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	50	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	50	22	4
Wet flue gas desulfurization (FGD)	95	49	4
Regenerative FGD	98	119	4
Industrial boilers and furnaces			
Limestone injection	50	35	4
Wet flue gas desulfurization (FGD)	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	410
Gas oil, 0.2% S	0.68	1440
Gas oil, 0.045% S	2.04	4330
Gas oil, 0.003 % S	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.

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[10] Investment [1000 ECU/MW_{th}]	Operating and maintenance [%/year][11]
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
Hard coal	80	23.0	6
Heavy fuel oil	80	22.9	6
Gas	80	24.7	6
New boilers [13]			
SCR			
Brown coal and lignite	80	14.1	6
Hard coal	80	12.2	6
Heavy fuel oil	80	9.8	6
Gas	80	12.9	6

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

[11] Percent of investments per year.

[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; 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) etc. .

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., printing, include several processes, such as rotogravure, flexography, lithography, letterpress, 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 abatement measures for stationary sources distinguished in the RAINS VOC model

Sector	*Technology*	*Efficiency [%]*	*Cost range [ECU/t VOC]*
Solvent use			
Dry Cleaning	Good housekeeping and adsorption	60	~600
	Closed circuit conventional or new machines	75/92	600/1200-4150
Metal degreasing	Basic emission management techniques	20	< 200
	Carbon adsorption	80	1400-2000
	Low temperature plasma process	98	1600-3300
	Conveyored degreaser with integrated adsorption	95	1800-2300
	Water based systems	95	2700-4500
Domestic solvent use	Substitution, propellant insert	30-50	3600-4300
Non-industrial paint use	Water based paints	80	600-850
	High solids	50-60	1850-2200
	Powder paints	100	1000-1300
Industrial paint use	Good housekeeping, application technique modification	20-45	<100
	Process modification and substitution	55-70	1000-2500
	Adsorption, incineration	95	1800-10000
Vehicle refinishing	Good housekeeping, application technique modification	15-30	< 0
	Housekeeping, application technique, water based paint	75	150-650
Products incorporating solvents	Substitution	50	<50
	Basic emission management and end-of-pipe	95	1200-2000
Products not incorporating solvents	Solvent management plan and substitution	50	~500
	Basic emission management and end-of-pipe	60	~1800
Printing	Good housekeeping	5	<50
	Water based inks	90	<100
	Adsorption, incineration	90	300-1700
Glues and adhesives in industry	Good housekeeping	15	<50
	Substitution	85	~500
	Incineration	80	800-1000
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
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	87	1500-2150
Refineries	Quarterly, monthly inspection and maintenance programs	60/70	<200/500-1500
	Covers on oil/water separators	90	100-300
	Internal floating covers and secondary seals	85	<400
	Vapor recovery units (Stage IA)	95-99	750-3700
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	70	50-200
Fuel distribution	Internal floating covers and secondary seals	85	<400
	Vapor recovery units (Stage IA)	95-99	750-3700
	Stage II	85	1300-1800
	Stage IB	95	300-450
Gasoline evaporation	Small carbon canister	85	100-500
Miscellaneous			
Food and drink industry	End-of-pipe	90	14000
Agriculture	Ban on burning waste	100	60
Other industrial	Good housekeeping	20	<100
	End-of-pipe	98	10000
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).

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

The main technical and economic characteristics of the control options are presented in Table 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.
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/yr]	
		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	100-200	13-30	9-15
	Other cattle	85-200	70-120	13-20	7-10
	Pigs	20-50	6-8	5-10	1.5
	Laying hens	0.4		0.06	
Covered storage - low efficiency	Dairy cows	50-100	30-60	10-15	5-7
	Other cattle	40-100	30-40	8-12	4-5
	Pigs	10-20	2.5-3.5	3-7	1
	Laying hens	0.2		0.03	
Low NH_3 application	Dairy cows	n.a.		45-70	
	Other cattle	n.a.		7-40	
	Pigs	n.a.		4-8	
	Laying hens	n.a.		0.1-0.15	
	Other poultry	n.a.		0.02-0.06	
	Sheep	n.a.		2-4	
Stripping/adsorption	Industry	625 ECU/t NH_3 removed			

n.a.: not applicable
* - Taking into account fixed and variable operating costs
** - The following stable sizes are assumed:

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

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.

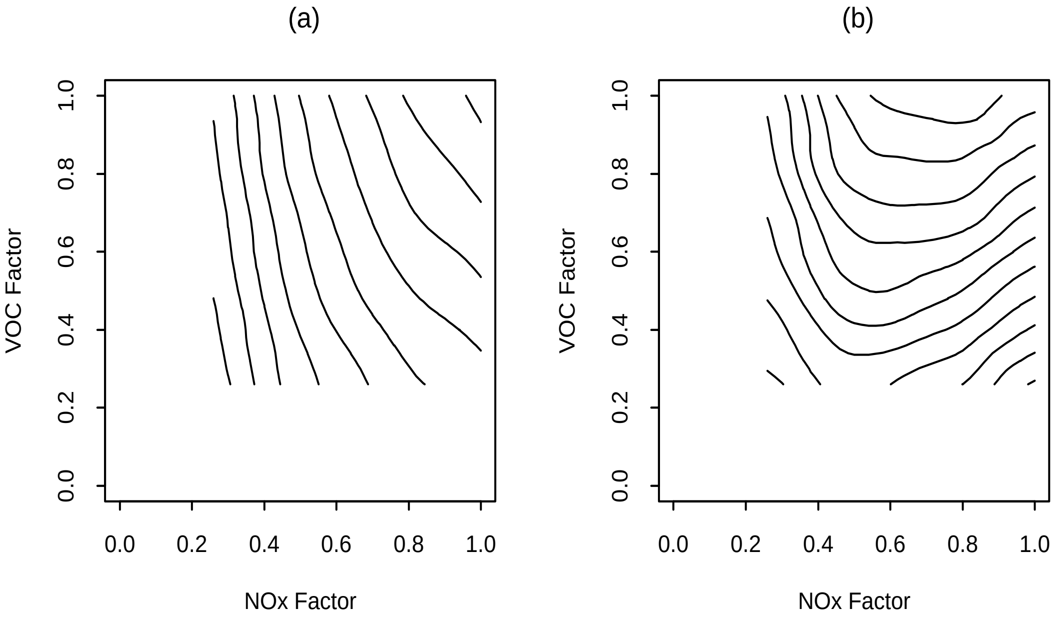

Figure 2.2: Typical patterns of ozone behaviour in Europe. The left isopleth sketches the situation for a 'NO$_x$ limited region' in Europe, while the other illustrates the 'ozone hill' occurring in high-NO$_x$ areas.

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.

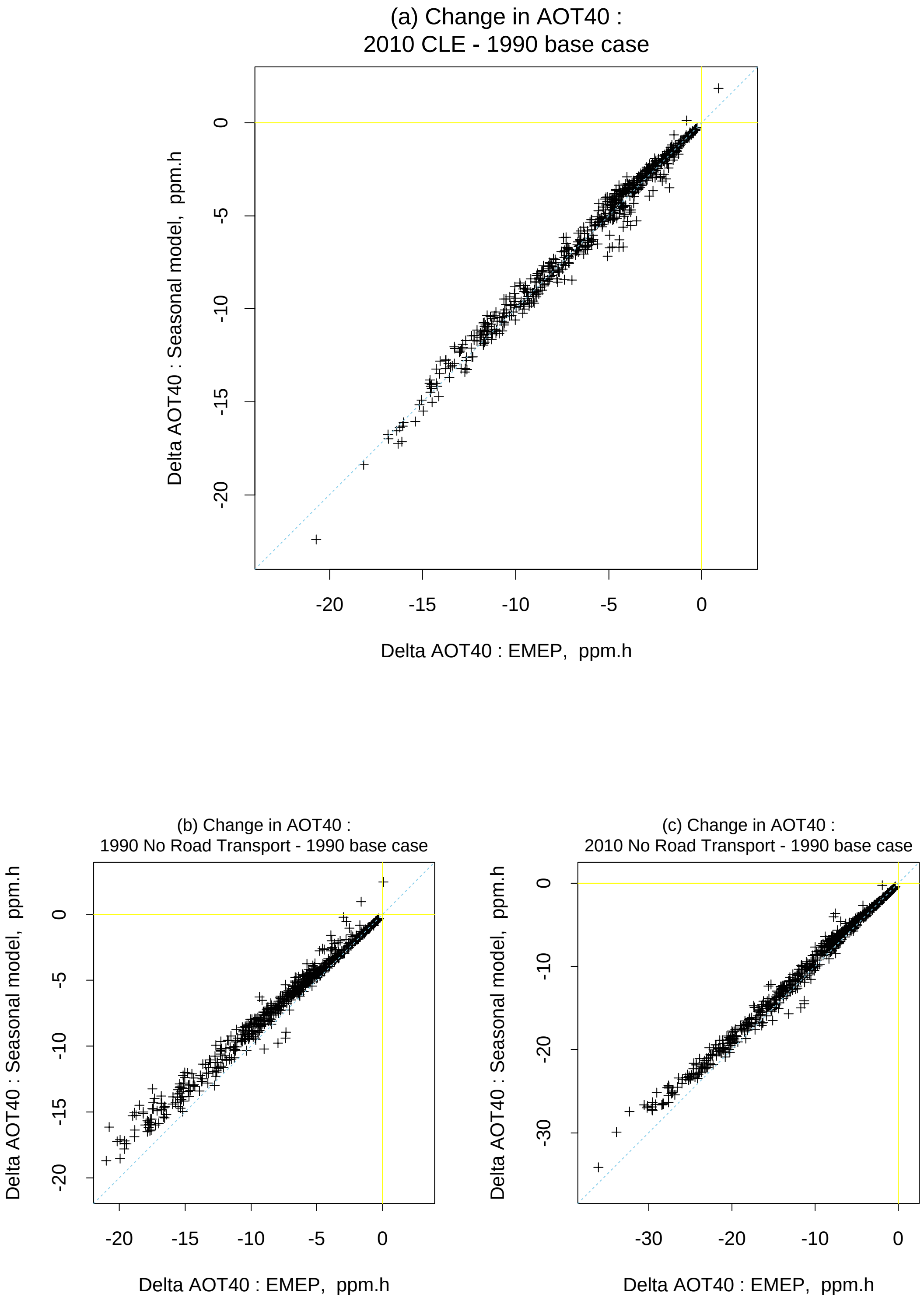

Figure 2.3: Comparison of the results from the reduced-form model for three scenarios with the corresponding EMEP model calculations

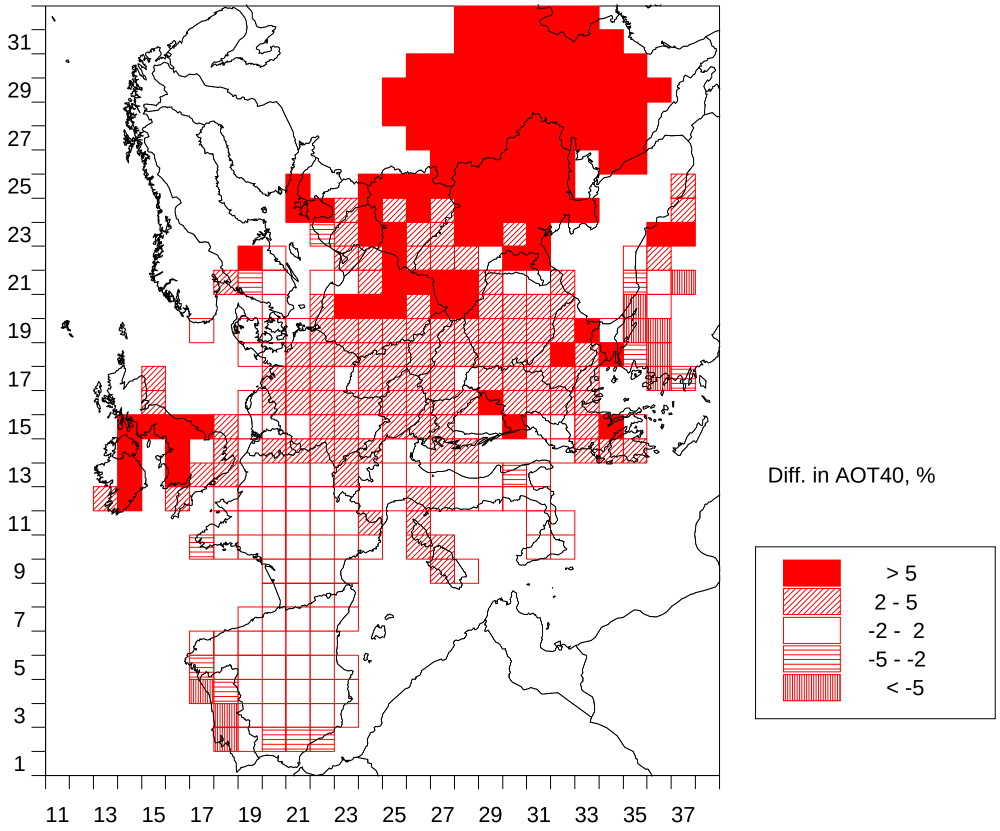

Figure 2.4: Spatial distribution of differences between a reduced-form and the full EMEP models for those receptor grids at which the 1990 base case AOT40 value for forests - as calculated using the 1995 version of the EMEP model - exceeds the critical level of 10 ppm.hours.

2.6 Critical loads for Acidification and Eutrophication

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

2.6.1 Using Critical loads for Integrated Assessment Modelling

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

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

To be able to compare critical loads with European deposition fields, the numerous critical load values and functions (currently more than 1.3 million, out of which 890.000 in the EU-15; mostly for forest soils, but also lakes and semi-natural vegetation, see Table 2.18 and Table 2.19) have to be aggregated in the 150km x 150km EMEP-grid. For single values this is done by computing a percentile of the cumulative distribution function of all critical load values within an EMEP-grid cell. As an example, Figure 2.5 shows the fifth percentile of $CL_{max}(S)$ for the EMEP modeling domain.

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

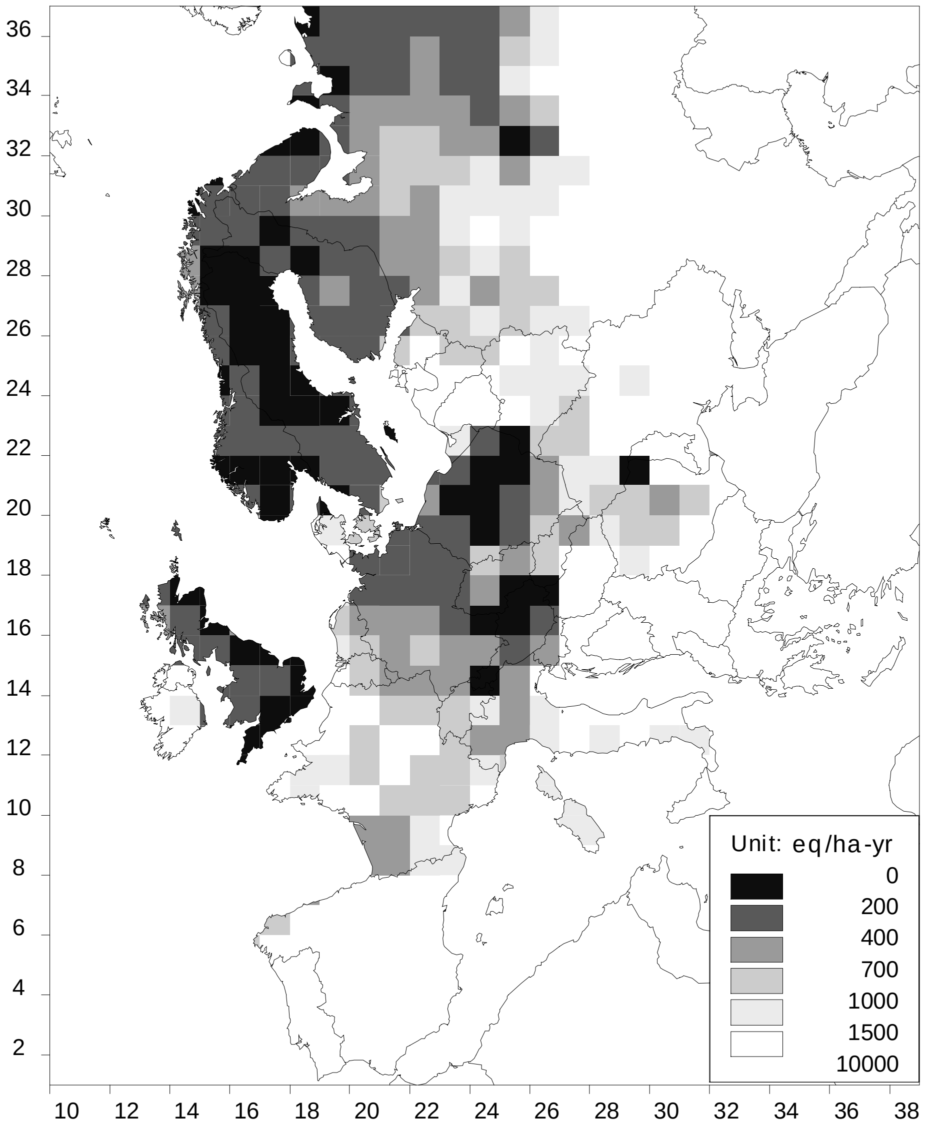

Figure 2.5: The fifth percentile of the critical loads for acidity ($CL_{max}(S)$)

Over the last few months, a new measure for evaluating ecosystems protection was developed. While in the past the analyses used either the excess deposition for a certain (single) percentile of critical loads or, alternatively, the percentage of ecosystems in each grid cell with acid deposition above the critical loads, the 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.

2.6.2 The European Critical Loads Database

Each year the Coordination Center for Effects (CCE) requests that countries 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 May 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.

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** **No. of ecosystems**	 **Total ecosystems**	**Land area covered by ecosystems with CL for acidity**
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	

2.7 Optimization

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.

Emissions are analyzed for sets of emitters that are located in a region, which is typically a country. NO_x and VOC emitters are further subdivided into sectors in order to account for measures that can be applied for sources that belong to one sector. In such a case emitters that belong to a particular sector emit either NO_x or VOC or a linear combination of them.

For simple cost-minimization, the optimization problem can be formulated as

$$\sum_{i=1}^{N} c_i(n_i, v_i) \longrightarrow \min \tag{8}$$

The country cost curves $c_i(n_i,v_i)$ are constructed from the sectoral cost curves $c_{is}(e_{is})$.

$$c_i(n_i, v_i) = \min \sum_{s=1}^{S} c_{is}(e_{is}) \tag{9}$$

constrained to

$$n_i = \sum_{s=1}^{S} n_{is} \tag{10}$$

$$v_i = \sum_{s=1}^{S} v_{is} \tag{11}$$

where s denotes the sector and :

e_{is} … sectoral emissions
$n_{i1}=e_{i1}$
$v_{i1}=0$
$n_{i2}=0$
$v_{i2}=e_{i2}$
$n_{is}=e_{is}$ $\quad s>2$
$v_{is}=\mu_{is} + \beta_{is}\, e_{is}$

The ozone exposure is defined by

$$AOT_{lj} = k_j + \sum_{i=1}^{M} (a_{ij} v_i + b_{ij} n_i + c_{ij} n_i^2) + \alpha_j \overline{en}_j^{\,2} + \overline{en}_j \sum_{i=1}^{M} d_{ij} v_i \tag{12}$$

and it is constrained at each receptor by

$$AOT_{lj} - y_{lj} \leq AOT_{lj}^{\max} \tag{13}$$

As will be shown later in ths report, a 'compensation mechanism has been developed allowing the optimization to exceed environmental targets at single grid cells as long as the excess is compensated by further reductions at other grids in the same country. Therefore, violations *y* of targets are constrained by corresponding lower and upper limits specified for each target type and for each grid:

$$y_{lj}^{\min} \leq y_{lj} \leq y_{lj}^{\max} \tag{14}$$

A grid is only allowed to violate the target, if another grid *j* in the same country *I* is compensating for this violation. Therefore, violations of targets have to be balanced (over receptors belonging to the ith country) with over-achievements of targets:

$$\sum_{l=1}^{L} \sum_{j=1}^{J} wo_{ijl}\, y_{lj} \leq 0 \tag{15}$$

with wo_{ijl} as the population or ecosystem densities in the grid.

2.7.1 Sectoral Cost Curves as Input to the Optimization

Inputs to the optimization package include cost curves (Equation 9) 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 30 segments.

For each of the pollutants (NO_x, VOC) and the countries, such piece-wise linear curves can be used as input to the optimization according to Equation 9. Although the solvers used for this exercise are capable of dealing with piece-wise linear constraints, 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.

In December 1996 the cost curves for NO_x and NH_3 have been submitted to the Parties of the Convention on Long-range Transboundary Air Pollution for review. The documentation of the VOC cost curves was distributed in early 1998. Comments received from the Parties will be fully incorporated into the cost curves in the near future. It is foreseen to present the cost curves for SO_2, together with a detailed documentation of the methodology used, to the Parties later in 1998.

2.7.2 Bounds to the Optimization

The sectoral emissions are implicitly bounded by a corresponding definition of the domain of the corresponding cost function that defines costs associated with reductions of emissions. This domain may be restricted by a specification of optional bounds (e.g., to take account of emission targets specified in the 'Current Reduction Plans). The total emissions of NO_x or VOC are bounded by given upper and lower bounds:

$$n_i^{\min} \leq n_i \leq n_i^{\max} \tag{16}$$

$$v_i^{\min} \leq v_i \leq v_i^{\max} \tag{17}$$

Additionally, the definition of cost functions of the type given in Equation 9 may contain linear constraints for n_i and v_i.. to reflect measures included in the Current Legislation scenario.

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 and C 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 Fifth Interim Report, the business-as-usual energy scenario has been replaced by national data for Austria, Denmark, Finland, Netherlands, Sweden and the UK. A national scenario has also been received from Greece, but lack of time prevented the timely implementation into the RAINS model. It is foreseen that the Greek projection as well as new information from the remaining EU countries, as far as available, will be implemented for the next report.

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 baseline 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 39 percent. This decline is mainly compensated by a rapid increase of the demand for natural gas (81 percent by 2010) and of other fuels (nuclear, hydropower, renewable energy) by 31 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 34 percent.

For the non-EU countries, the scenario projects a five percent drop in total primary energy consumption (Table 3.4). This is due to the sharp decrease in primary energy demand that occurred in the period 1990 - 1995 in the countries of the former Soviet Union and in other central and east European countries with economies in transition. The economic restructuring in those countries will allow further economic development while keeping the total primary energy demand until 2010 below the 1990 level. Consumption of coal and oil by stationary sources is predicted to decrease by 23 and 34 percent, respectively. Consumption of natural gas will increase by 12 percent. The demand for transport fuels will increase by seven percent in 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 scenario estimates the demand for goods transport remaining 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	1235	1421	15%	1.9%
Belgium	BAU	1907	2450	29%	2.1%
Denmark	National	757	765	1%	2.2%
Finland	National	1233	1620	31%	3.0%
France	BAU	8794	11143	27%	2.0%
Germany	BAU	14534	15087	4%	2.3%
Greece	BAU	898	1401	56%	2.8%
Ireland	BAU	409	576	41%	4.6%
Italy	BAU	6669	8448	27%	1.9%
Luxembourg	BAU	122	129	6%	2.3%
Netherlands	National	2711	3741	38%	3.3%
Portugal	BAU	699	1113	59%	3.0%
Spain	BAU	3612	5227	45%	2.6%
Sweden	National	2317	2462	6%	n.a.
UK	National	8526	9933	17%	n.a.
EU-15		54424	65518	20%	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	44379	52054	17%
- Coal	11620	7143	-39%
- Liquid fuels	12088	12627	4%
- Gaseous fuels	10406	18837	81%
- Other	10265	13447	31%
Mobile sources - total	10046	13464	34%
TOTAL	54424	65518	20%

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	1837	-6%	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	46134	-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	41230	-6%
- Coal	11540	8888	-23%
- Liquid fuels	8543	5671	-34%
- Gaseous fuels	18198	20371	12%
- Other	5706	6300	10%
Mobile sources - total	4583	4904	7%
TOTAL	48569	46134	-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 exogeneously 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 six 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 provisional arrangement reached at the March 97 Environment Council for sharing the EU target (see Table 3.5). It is important to stress that this arrangement is still provisional. The EU Ministers have agreed that the burden sharing would need to be revised in the light of the actual outcome of the Kyoto Conference, a process which is ongoing and not yet finalized. Furthermore, the scenario is also provisional since it implicitly assumes that the reductions agreed in March 1997 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		Initial Council Proposal March 97
Austria	60	60	0%	59	-2%	**53**	**-11%**			53	-11%	-25%
Belgium	110	135	23%			90	-18%	**107**	**-3%**	107	-3%	-10%
Denmark	55	58	6%	**45**	**-18%**	46	-17%			45	-18%	-25%
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%			**816**	**-18%**			816	-18%	-25%
Greece	77	**96**	**26%**	*95*	24%	78	2%			96	26%	25%
Ireland	27	38	42%			**30**	**11%**			30	11%	15%
Italy	431	502	16%			**400**	**-7%**			400	-7%	-7%
Luxembourg	8.6	8	-8%			**8**	**-8%**			8	-8%	-30%
Netherlands	162	197	21%	205	26%	**148**	**-9%**			148	-9%	-10%
Portugal	42	62	47%			**57**	**35%**			57	35%	40%
Spain	224	293	31%			242	8%	**256**	**14%**	256	14%	17%
Sweden	57	73	30%	**70**	**24%**	83	46%			70	24%	-5%
UK	576	581	1%	604	5%	**515**	**-11%**			515	-11%	-10%
EU-15	3255	3474	7%			2949	-9%			3019	-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 20 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 18 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 chagnes 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	145	75	80	445	428	460	252	375	239	394	544	560	1235	1422	1339
		-48%	-45%		-4%	3%		49%	-5%		38%	42%		15%	8%
Belgium	354	295	215	737	942	778	416	733	600	400	481	528	1907	2451	2121
		-17%	*-39%*		*28%*	*5%*		*76%*	*44%*		*20%*	*32%*		*29%*	*11%*
Denmark	255	101	101	339	294	294	96	249	249	67	121	121	757	766	766
		-60%	*-60%*		*-13%*	*-13%*		*160%*	*160%*		*82%*	*82%*		*1%*	*1%*
Finland	218	347	99	412	411	402	125	237	256	466	609	672	1221	1604	1428
		59%	*-55%*		*0%*	*-2%*		*90%*	*105%*		*27%*	*40%*		*30%*	*16%*
France	737	323	304	3433	3915	3745	1180	1828	1640	3444	5078	4677	8794	11143	10367
		-56%	-59%		14%	9%		55%	39%		47%	36%		27%	18%
Germany	5139	2567	1940	5010	6157	6024	2686	4488	3906	1699	1991	1940	14534	15202	13810
		-50%	*-62%*		*23%*	*20%*		*67%*	*45%*		*17%*	*14%*		*5%*	*-5%*
Greece	348	357	357	498	672	672	26	150	150	40	171	171	911	1350	1350
		3%	*3%*		*35%*	*35%*		*485%*	*485%*		*328%*	*328%*		*48%*	*48%*
Ireland	102	89	101	176	286	212	79	157	88	52	44	68	409	576	469
		-13%	*-1%*		*62%*	*20%*		*98%*	*11%*		*-15%*	*31%*		*41%*	*15%*
Italy	519	459	331	3817	4207	3081	1752	2917	2752	582	866	931	6669	8448	7095
		-12%	*-36%*		*10%*	*-19%*		*66%*	*57%*		*49%*	*60%*		*27%*	*6%*
Luxembourg	31	20	20	40	38	38	34	46	46	16	26	26	122	129	129
		-36%	*-36%*		*-7%*	*-7%*		*34%*	*34%*		*61%*	*61%*		*6%*	*6%*
Netherlands	312	308	79	951	1301	860	1372	1982	1672	75	151	166	2711	3742	2777
		-1%	*-75%*		*37%*	*-10%*		*44%*	*22%*		*101%*	*121%*		*38%*	*2%*
Portugal	113	175	215	447	531	424	6	177	154	131	230	264	697	1113	1056
		54%	*90%*		*19%*	*-5%*		*2850%*	*2460%*		*76%*	*102%*		*60%*	*51%*
Spain	754	619	755	1833	2502	2067	259	981	663	765	1125	1081	3612	5227	4565
		-18%	*0%*		*36%*	*13%*		*279%*	*156%*		*47%*	*41%*		*45%*	*26%*
Sweden	84	166	166	621	697	697	43	72	72	1569	1527	1527	2317	2462	2462
		98%	*98%*		*12%*	*12%*		*68%*	*68%*		*-3%*	*-3%*		*6%*	*6%*
UK	2520	1216	548	3175	3502	3326	2110	4453	4252	721	762	1104	8526	9933	9231
		-52%	*-78%*		*10%*	*5%*		*111%*	*102%*		*6%*	*53%*		*16%*	*8%*
EU-15	11631	7116	5311	21936	25884	23080	10435	18842	16739	10421	13725	13837	54423	65568	58966
		-39%	*-54%*		*18%*	*5%*		*81%*	*60%*		*32%*	*33%*		*20%*	*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 39 percent. There is a continuing trend towards a higher share of diesel for light duty vehicles (from 21 percent in 1990 to 29 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 (+22 percent for light-duty vehicles, +23 percent for heavy-duty vehicles). Fuel demand for other transport increases by only one 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	114	29	143	123	36	159	*11%*	132	36	168	*17%*
Belgium	120	85	205	173	123	296	*45%*	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	807	390	1197	993	633	1626	*36%*	749	700	1449	*21%*
Germany	1347	247	1594	1631	624	2254	*41%*	1507	494	2001	*26%*
Greece	108	7	114	210	19	229	*100%*	210	19	229	*100%*
Ireland	40	15	55	50	22	73	*33%*	49	16	65	*19%*
Italy	627	229	857	878	268	1146	*34%*	751	234	985	*15%*
Luxembourg	8	2	11	10	3	13	*25%*	10	3	13	*25%*
Netherlands	196	52	248	262	70	332	*34%*	155	51	206	*-17%*
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	5190	1403	6592	6514	2625	9139	*39%*	5981	2087	8068	*22%*

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	59	60	1	80	81	35%	1	76	77	28%
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	0	289	289	0	441	441	52%	0	487	487	68%
Germany	1	386	388	0	464	464	20%	0	367	367	-5%
Greece	0	53	53	0	94	94	79%	0	94	94	79%
Ireland	0	10	10	0	20	20	99%	0	15	15	45%
Italy	2	421	423	2	490	492	16%	1	427	429	1%
Luxembourg	0	3	3	0	3	3	16%	0	3	3	16%
Netherlands	0	74	74	0	132	133	78%	0	72	72	-3%
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	34	2023	2056	27	2803	2829	38%	22	2515	2536	23%

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	24	2	26	0	22	0	22	*-16%*	0	24	2	26	*-1%*
Belgium	0	14	0	14	0	14	0	14	*0%*	0	12	14	27	*83%*
Denmark	0	41	4	45	3	43	1	47	*4%*	3	43	1	47	*4%*
Finland	0	35	2	37	5	24	2	31	*-17%*	1	33	2	35	*-5%*
France	9	98	2	108	9	98	2	108	*0%*	9	98	2	109	*0%*
Germany	31	194	0	224	78	223	0	302	*34%*	32	182	0	214	*-4%*
Greece	19	52	10	80	2	71	18	92	*15%*	2	71	18	92	*15%*
Ireland	0	5	0	5	0	5	0	5	*0%*	0	5	0	5	*1%*
Italy	18	227	8	253	18	227	8	253	*0%*	18	227	8	253	*0%*
Luxembourg	0	1	0	1	0	1	0	1	*0%*	0	1	0	1	*0%*
Netherlands	0	44	0	44	0	67	0	67	*52%*	0	48	0	49	*10%*
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	1	106	3	110	3	96	4	103	*-6%*	3	96	4	103	*-7%*
EU-15	85	1080	49	1214	131	1130	54	1315	*8%*	81	1079	70	1229	*1%*

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.
- 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*

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.

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

	Cows			Pigs			Poultry		
	1990	2010		1990	2010		1990	2010	
Austria	2.6	2.2	-15%	3.7	3.4	-7%	13.1	12.0	-9%
Belgium	3.1	2.8	-11%	6.4	7.2	12%	23.6	40.3	71%
Denmark	2.2	1.7	-23%	9.3	11.7	26%	16.2	17.4	7%
Finland	1.4	0.9	-33%	1.4	1.4	-2%	9.5	8.1	-14%
France	21.4	20.9	-3%	12.3	17.4	42%	236.0	279.3	18%
Germany	19.5	15.7	-19%	30.8	21.2	-31%	113.9	78.6	-31%
Greece	0.7	0.6	-20%	1.0	1.2	21%	27.7	33.0	19%
Ireland	7.0	7.4	6%	1.0	2.2	110%	9.0	13.2	46%
Italy	8.2	7.0	-15%	8.8	8.2	-7%	160.6	172.5	7%
Luxembourg	0.2	0.4	78%	0.08	0.05	-33%	0.07	0.05	-28%
Netherlands	4.9	4.8	-2%	13.9	11.2	-20%	93.8	79.5	-15%
Portugal	1.3	1.3	-2%	2.7	2.2	-17%	31.2	33.6	8%
Spain	5.1	6.0	17%	16.0	20.3	27%	44.9	83.1	85%
Sweden	1.7	1.8	5%	2.3	2.4	4%	12.6	12.6	0%
UK	12.1	10.4	-14%	7.5	7.8	5%	136.4	141.0	3%
EU-15	91.6	83.9	-8%	117.1	117.8	1%	929	1000	8%
Albania	0.6	0.8	21%	0.2	0.3	17%	5.0	8.4	68%
Belarus	7.2	4.3	-40%	5.2	4.0	-23%	49.8	43.3	-13%
Bosnia -H	0.9	0.7	-22%	0.6	0.6	-10%	9.0	8.0	-11%
Bulgaria	1.6	0.9	-41%	4.4	4.3	-2%	36.3	43.6	20%
Croatia	0.8	0.6	-27%	1.6	1.3	-17%	15.0	8.4	-44%
Czech Rep.	3.4	3.4	3%	4.6	5.8	26%	33.3	49.1	48%
Estonia	0.8	0.6	-28%	1.1	1.2	9%	7.0	7.8	11%
Hungary	1.6	1.6	-3%	9.7	7.9	-19%	58.6	63.5	8%
Latvia	1.5	0.7	-52%	1.6	1.5	-7%	11.0	7.6	-31%
Lithuania	2.4	2.2	-7%	2.7	2.8	2%	18.0	19.2	7%
Norway	1.0	0.7	-25%	0.7	0.8	10%	5.4	5.3	-2%
Poland	10.0	12.9	28%	19.5	23.8	22%	70.0	97.8	40%
R. Moldova	1.1	1.0	-13%	2.0	1.5	-27%	25.0	19.0	-24%
Romania	6.3	6.2	-2%	11.7	10.3	-12%	119.3	146.8	23%
Russia	42.2	27.3	-35%	30.5	30.5	0%	474.3	326.5	-31%
Slovakia	1.6	0.8	-44%	2.5	2.6	2%	16.5	22.0	34%
Slovenia	0.5	0.4	-22%	0.6	0.7	18%	13.5	12.9	-4%
Switzerland	1.9	1.7	-8%	1.8	1.4	-22%	6.5	6.5	0%
FYR Macedonia	0.3	0.3	-1%	0.2	0.2	7%	22.0	22.0	0%
Ukraine	25.2	20.5	-19%	19.9	23.0	15%	255.1	260.0	2%
Yugoslavia	2.2	2.0	-8%	4.3	4.1	-5%	28.0	21.0	-25%
Non-EU	113.0	89.6	-21%	125.4	128.3	2%	1279	1199	-6%
Total	204.6	173.5	-15%	242.5	246.1	2%	2207	2203	-0%

Table 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	1885	1545	*-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	10347	9259	*-11 %*
Albania	73	60	*-18 %*
Belarus	780	676	*-13 %*
Bosnia -H	19	10	*-47 %*
Bulgaria	453	530	*17 %*
Croatia	114	190	*67 %*
Czech Rep.	441	580	*32 %*
Estonia	110	151	*37 %*
Hungary	359	639	*78 %*
Latvia	143	221	*55 %*
Lithuania	256	309	*21 %*
Norway	111	92	*-17 %*
Poland	671	855	*27 %*
Moldova	123	228	*85 %*
Romania	765	780	*2 %*
Russia	3418	1994	*-42 %*
Slovakia	147	150	*2 %*
Slovenia	88	102	*16 %*
Switzerland	63	30	*-52 %*
FYR Macedonia	6	3	*-50 %*
Ukraine	1885	1599	*-15 %*
Yugoslavia	146	145	*-1 %*
Non-EU	6206	4497	*-28 %*
Total	16553	13756	*-17%*

3.5 Changes in the Database since the Fourth Interim Report

Since the Fourth 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:

- For a number of EU countries (Austria, Denmark, Finland, Netherlands, Sweden, UK) the 'Business as usual' energy scenario has been replaced by national projections officially submitted to the Commission. These scenarios were used for the baseline analysis in this report. Due to the limited time available it was not possible to implement the Greek submission in a consistent way.
- Cost estimates for low sulfur heavy fuel oil were revised to reflect the information provided by CONCAWE (CONCAWE 1993).
- SO_2 control costs were revised to take proper account of increased costs for further emission reductions at already controlled emission sources. In practice, a new category (existing 'already controlled power stations) was introduced in the model. This is important for countries, which have implemented comprehensive retrofit programs to their power plant sector. The full information on methodology and data used for the construction of the national SO_2 control cost curves will be made available to the Parties of the Convention and on the Internet in due course.
- The latest information on Current Reduction Plans provided by the UN/ECE secretariat (UN/ECE, 1997) was implemented in the database. As a consequence, the REF scenario was slightly changed.
- In response to comments made by Norwegian experts, the VOC control cost curve for Norway was revised to more accurately reflect the potential for emission control from extraction and distribution of liquid and gaseous fuels.
- A number of changes were introduced to the cost curves for NH_3 emissions:
    - The comments received from the 1997 UN/ECE country review of the cost curves were incorporated into the model.
    - Removal efficiencies for emission control technologies were modified to reflect the conclusions of the 1997 meeting of the UN/ECE Expert Group on Ammonia Abatement in Reggio Emilia, Italy, the latest proposal for the Technical Annex on Ammonia Abatement Techniques to the UN/ECE 'Protocol on Nitrogen Oxides and Related Substances' as well as comments from national experts received during the 1997 UN/ECE review.
    - The number of animal categories and control options considered in RAINS has been extended to account for solid and liquid manure systems. This applies to dairy cows, other cattle and pigs.
    - Using new information on investment and operating costs of covered storage facilities in the Netherlands, Switzerland and Denmark the investment functions for 'covered storage (CS high/low)' techniques in RAINS were updated;
    - The responses of national agricultural experts to a questionnaire prepared by the UK Imperial College were used to validate several parameters in the RAINS model. These parameters (e.g., the proportion of liquid and solid waste generated, time animals spend grazing, excretion rates, etc.) influence reduction potentials and control costs.

4 Emissions 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 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, 1997 (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, 1997 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	95	60(b)	234	87(e)	432	270(e)	92	77(d)
Belgium	317	215(a)	355	309(c)	336	259(c)	85	104(d)
Denmark	185	90(b)	269	192(b)	162	136(b)	77	103(b)
Finland	227	116(b)	278	224(a)	213	108(a)	42	34(a)
France	1304	737(a)	1600	1276(c)	2129	1750(c)	688	700(d)
Germany	5328	740(b)	2690	2130(b)	2973	1749(b)	739	759(d)
Greece	521	570(a)	394	392(e)	306	205(c)	77	78(e)
Ireland	172	155(a)	103	115(d)	111	138(a)	127	126(a)
Italy	1681	1042(b)	2038	2060(b)	1873	1701(c)	397	416(d)
Luxembourg	14	4(b)	22	19(b)	19	13(b)	7	6(b)
Netherlands	207	56(a)	540	270(e)	483	196(b)	233	93(e)
Portugal	286	294(a)	208	221(d)	217	144(c)	77	93(d)
Spain	2190	2143(b)	1162	892(b)	1048	669(c)	352	353(d)
Sweden	130	87(b)	346	254(a)	435	287(b)	62	53(a)
UK	3754	980(b)	2800	1186(a)	2673	1276(a)	329	320(a)
EU-15	16412	7289	13039	9627	13410	8901	3385	3315
Albania	73	72(d)	24	36(e)	30	38(e)	31	34(e)
Belarus	845	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	1842	1127(a)	354	290(a)	198	192(a)	141	126(a)
Croatia	178	117(a)	83	83(a)	79	105(d)	40	37(d)
Czech Rep.	1877	632(a)	522	398(b)	322	435(d)	115	105(d)
Estonia	276	239(d)	84	93(e)	44	44(e)	29	29(e)
Hungary	913	653(a)	214	196(a)	206	145(a)	120	150(a)
Latvia	122	57(d)	117	90(d)	51	63(d)	39	44(d)
Lithuania	213	145(a)	152	110(a)	104	84(a)	79	84(a)
Norway	52	34(b)	221	161(b)	308	196(b)	23	23(d)
Poland	3001	1397(a)	1209	1345(b)	709	1300(a)	505	508(d)
R of Moldova	197	130(a)	87	34(a)	53	44(e)	47	48(e)
Romania	1335	1311(d)	518	546(d)	483	616(d)	290	300(d)
Russia	5046	4297(a)	3485	1995(a)	3332	3566(d)	1283	1191(d)
Slovakia	549	240(a)	207	227(d)	143	149(d)	60	62(d)
Slovenia	200	37(a)	60	31(a)	60	25(a)	23	27(a)
Switzerland	45	30(a)	166	113(a)	291	173(a)	58	68(a)
FYR Macedon.	107	106(d)	39	39(e)	20	20(e)	17	17(e)
Ukraine	3708	2310(a)	1888	1094(a)	1074	1369(a)	729	649(e)
Yugoslavia	586	1135(a)	211	211(e)	124	124(e)	90	90(e)
Non-EU	21651	15030	10122	7352	7954	9054	3968	3842
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	39215	23471	24790	18608	21364	17955	7353	7157

Explanations for other sources indicated by case (e):

Austria (NO_x) - The CRP value officially submitted to UN/ECE (70 kt) is not feasible with the emission control measures assumed in RAINS. Instead, the RAINS estimate of MFR emissions (79 kt) relaxed by 10 percent was used for the calculations in this report.

Austria (VOC) - The CRP value officially submitted to UN/ECE is 124 kt for the year 2005. This level of emission reduction is not feasible with the measures considered in RAINS; therefore the VOC protocol value was used instead.

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

Greece (NH_3) - There is no official value for CRP available. The number given in the EMEP report No 97/1 for 1990 was used.

Netherlands (NO_x) - The CRP value officially submitted to UN/ECE for 2010 (120 kt) is not achievable with the emission control measures assumed in RAINS. An interim target (270 kt) was suggested to IIASA by the Dutch Ministry of Environment.

Netherlands (VOC) - The CRP value officially submitted to UN/ECE for 2010 is 120 kt. It is not feasible in the model to reduce emissions down to this level; the reported value for 2000 was used instead.

Netherlands (NH_3) - The officially reported value of 50 kt for 2010 is not feasible in RAINS. The maximum feasible reduction as calculated by RAINS (93 kt) was used.

Albania (NO_x, NH_3, VOC) - No CRP values are provided in UN/ECE (1997). The emissions calculated in RAINS for 2010 are used.

Bosnia-Hercegovina (NO_x, NH_3, VOC) - No CRP values are provided in UN/ECE (1997). The emissions calculated in RAINS for 1990 are used.

Belarus, Estonia, FYR of Macedonia, Yugoslavia (NH_3) - No CRP values are provided in UN/ECE (1997). The numbers reported in EMEP (1997) for 1990 used.

Estonia, FYR of Macedonia (NO_x) - No CRP values provided in UN/ECE (1997). 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) - 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 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 26 percent. For non-EU countries the emissions drop by 31 and 27 percent respectively. For the EU-15, the CRP emissions of VOC are 34 percent below the 1990 level, those of NH_3 only about 2 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 16 and 3 percent, respectively.

4.2 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.

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 'Common Positions' of the Council on the envisaged legislation referred to by this Communication and the Commission’s proposal on emissions from HDV (COM(97) 627) is also taken into account. This includes vehicle-related measures like improved catalytic converters, engine modifications and on-board diagnostic systems. Furthermore, the impacts of the envisaged improved inspection and maintenance practices and the changes in fuel quality are incorporated. The pace of the implementation of the vehicle-related measures depends on the turnover of vehicle stock and has been based on modeling work performed for the Auto/Oil 1 study.

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)
- Limits on sulfur content of gas oil for stationary and mobile sources and for heavy fuel oil as in the appropriate directives (- compare 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[24]

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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[24] 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.
- 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 Common Positions of the Council related to LDV, LCV, fuels and by COM(97) 627, 3.12.97, on HDV-emissions. These standards are assumed to be implemented in the EU-15 as well as in Norway and in Switzerland.

Table 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, Germany, Netherlands, Sweden and Switzerland

Mobile sources:

- All directives and legislation acts aimed at a reduction of emissions form 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), unless in some countries there already exist more stringent regulations requesting Stage-II control.

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 and NO_x emissions in the CLE scenario are 25 percent below the CRP values. In the non-EU countries, CLE emissions of SO_2 are 35 percent lower than in the CRP case. 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. However, most of the differences in the estimates for the EU countries can be explained by the stricter emission standards for mobile sources resulting from the Auto/Oil program. Whereas these new plans are considered in the CLE scenario, they are not yet taken into account in 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	New plants		Existing plants	
Capacity class, MW$_{th}$	Coal	Oil	Coal	Oil
Austria				
10 - 50	FGD	LSHF	LSCO	LSHF
50 - 300	FGD	FGD	FGD/LSCO(1)	LSHF
> 300	FGD	FGD	FGD	FGD
Industrial processes:	Stage 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 1		Stage 1	
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 Capacity class, MW_{th}		New plants		Existing plants	
		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 1		Stage 1	
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 Capacity class, MW_{th}	New plants Coal	 Oil	 Gas	Existing plants 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	-

Lignite/hard coal
- Standard slightly below of what is achievable with CM
- Includes also sources below 50 MWth
- 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	234	87	114	432	270	340
Belgium	355	309	204	336	259	195
Denmark	269	192	133	162	136	86
Finland	278	224	170	213	108	107
France	1600	1276	822	2129	1750	1181
Germany	2690	2130	1226	2973	1449	1445
Greece	394	392	339	306	205	249
Ireland	103	115	73	111	138	46
Italy	2038	2060	1195	1873	1701	1082
Luxembourg	22	19	11	19	13	8
Netherlands	540	270	292	483	196	208
Portugal	208	221	199	217	144	175
Spain	1162	892	922	1048	669	788
Sweden	346	254	198	435	287	195
United Kingdom	2800	1186	1268	2673	1276	1333
EU-15	13039	9627	7164	13410	8901	7437
Albania	24	36	36	30	38	38
Belarus	402	180	315	279	321	240
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	398	231	322	435	224
Estonia	84	93	73	44	44	49
Hungary	214	196	207	206	145	172
Latvia	117	90	118	51	63	43
Lithuania	152	110	138	104	84	91
Norway	221	161	153	308	196	293
Poland	1209	1345	831	709	1300	759
Moldova	87	34	66	53	43	43
Romania	518	546	458	483	616	508
Russia	3485	1995	2797	3332	3566	2718
Slovakia	207	227	113	143	149	141
Slovenia	60	31	38	60	25	51
Switzerland	166	113	89	291	173	234
FYR Macedonia	39	39	29	20	20	21
Ukraine	1888	1094	1425	1074	1369	845
Yugoslavia	211	211	152	124	124	123
Non-EU	10122	7352	7714	7954	9054	6924
Total	24790	18608	16508	21364	17955	14361

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	95	60	45	92	77	80
Belgium	317	215	195	85	104	82
Denmark	185	90	73	77	103	72
Finland	227	116	178	42	34	33
France	1304	737	532	688	700	670
Germany	5328	740	753	739	759	557
Greece	521	570	375	77	78	72
Ireland	172	155	95	127	126	130
Italy	1681	1042	603	397	416	366
Luxembourg	14	4	9	7	6	8
Netherlands	207	56	89	233	93	196
Portugal	286	294	151	77	93	73
Spain	2190	2143	802	352	353	382
Sweden	130	87	100	62	53	62
United Kingdom	3754	980	1427	329	320	298
EU-15	16412	7289	5428	3385	3315	3081
Albania	73	72	56	31	34	34
Belarus	845	480	495	219	219	163
Bosnia-H.	487	480	415	31	31	23
Bulgaria	1842	1127	846	141	126	126
Croatia	178	117	71	40	37	38
Czech Rep.	1877	632	178	115	105	125
Estonia	276	239	175	29	29	29
Hungary	913	653	547	120	150	137
Latvia	122	57	105	39	44	29
Lithuania	213	145	107	79	84	81
Norway	52	34	37	23	23	21
Poland	3001	1397	1518	505	508	541
Moldova	197	130	117	47	48	48
Romania	1335	1311	599	289	300	301
Russia	5046	4297	2371	1283	1191	895
Slovakia	549	240	119	60	62	51
Slovenia	200	37	76	23	27	20
Switzerland	45	30	39	58	68	53
FYR Macedonia	107	106	81	17	17	16
Ukraine	3708	2310	1492	729	649	649
Yugoslavia	586	1135	269	90	90	83
Non-EU	21651	15029	9711	3968	3842	3462
Total	39215	23470	16292	7353	7157	6543

4.3 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.

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 46 percent cut of NO_x and a 47 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 37 percent for NO_x and by 16 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 40 billion ECU/year in the EU. The annual cost to achieve this reduction in the non-EU countries is estimated at 5 billion ECU/year. For VOC major reductions originate in the EU-15 countries, 83 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 56 percent cut in the non-EU countries. SO_2 control costs, calculated from the RAINS cost curves, reach 10.6 billion ECU/year, of which 73 percent occur in the EU countries. For ammonia, the overall reduction is about 14 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 1.15 billion ECU/year, of which about 90 percent occur in the Netherlands, where very strict Current Reduction Plans lead to maximum feasible reduction achievable in RAINS model.

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	234	87	-63%	432	270	*-37%*	954
Belgium	355	204	-42%	336	195	*-42%*	1146
Denmark	269	133	-51%	162	86	*-47%*	379
Finland	278	170	-39%	213	107	*-50%*	513
France	1600	822	-49%	2129	1181	*-45%*	6573
Germany	2690	1226	-54%	2973	1445	*-51%*	8907
Greece	394	339	-14%	306	205	*-33%*	719
Ireland	103	73	-29%	111	46	*-59%*	240
Italy	2038	1195	-41%	1873	1082	*-42%*	6533
Luxembourg	22	11	-52%	19	8	*-59%*	60
Netherlands	540	270	-50%	483	196	*-59%*	1686
Portugal	208	199	-4%	217	144	*-34%*	1080
Spain	1162	892	-23%	1048	669	*-36%*	4813
Sweden	346	198	-43%	435	195	*-55%*	926
UK	2800	1186	-58%	2673	1276	*-52%*	5294
EU-15	13039	7003	-46%	13410	7104	*-47%*	39822
Albania	24	36	51%	30	38	*28%*	0
Belarus	402	180	-55%	279	240	*-14%*	209
Bosnia-H.	80	60	-25%	46	43	*-5%*	1
Bulgaria	354	290	-18%	198	192	*-3%*	4
Croatia	83	83	1%	79	88	*12%*	5
Czech Rep.	522	231	-56%	322	224	*-30%*	487
Estonia	84	73	-13%	44	44	*0%*	2
Hungary	214	196	-8%	206	144	*-30%*	420
Latvia	117	90	-23%	51	43	*-14%*	34
Lithuania	152	110	-28%	104	84	*-19%*	32
Norway	221	153	-31%	308	196	*-36%*	492
Poland	1209	831	-31%	709	759	*7%*	1190
Moldova	87	34	-61%	53	43	*-17%*	46
Romania	518	458	-12%	483	508	*5%*	0
Russia	3485	1995	-43%	3332	2718	*-18%*	832
Slovakia	207	113	-45%	143	141	*-1%*	325
Slovenia	60	31	-49%	60	25	*-59%*	130
Switzerland	166	89	-46%	291	173	*-40%*	717
FYR Macedonia	39	29	-26%	20	20	*0%*	1
Ukraine	1888	1094	-42%	1074	845	*-21%*	138
Yugoslavia	211	152	-28%	124	123	*-1%*	3
Non-EU	10122	6327	-37%	7954	6694	*-16%*	5068
Total[25]	24790	14960	-40%	21364	13798	*-35%*	44890

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[25] 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		Costs		NH_3		Costs
	1990	REF	Change	of REF	1990	REF	*Change*	of REF
Austria	95	45	-53%	164	92	77	*-16%*	7
Belgium	317	195	-38%	264	85	82	*-4%*	0
Denmark	185	73	-60%	88	77	72	*-7%*	0
Finland	227	116	-49%	217	42	33	*-23%*	0
France	1304	532	-59%	1017	688	670	*-3%*	0
Germany	5328	740	-86%	1822	739	557	*-25%*	0
Greece	521	375	-28%	251	77	72	*-7%*	0
Ireland	172	95	-45%	84	127	126	*-1%*	18
Italy	1681	603	-64%	1497	397	366	*-8%*	0
Luxembourg	14	4	-71%	9	7	6	*-11%*	14
Netherlands	207	56	-73%	275	233	93	*-60%*	960
Portugal	286	151	-47%	145	77	73	*-6%*	0
Spain	2190	802	-63%	647	352	353	*0%*	49
Sweden	130	87	-33%	223	62	53	*-15%*	17
UK	3754	980	-74%	973	329	298	*-10%*	0
EU-15	16412	4854	-70%	7676	3385	2931	*-13%*	1065
Albania	73	56	-24%	0	31	34	*10%*	0
Belarus	845	480	-43%	4	219	163	*-26%*	0
Bosnia-H.	487	415	-15%	0	31	23	*-25%*	0
Bulgaria	1842	846	-54%	107	141	126	*-11%*	0
Croatia	178	71	-60%	46	40	37	*-8%*	0
Czech Rep.	1877	178	-91%	363	115	105	*-8%*	53
Estonia	276	175	-37%	0	29	29	*-1%*	0
Hungary	913	547	-40%	144	120	137	*14%*	0
Latvia	122	57	-53%	15	39	29	*-26%*	0
Lithuania	213	107	-50%	0	79	81	*1%*	0
Norway	52	34	-35%	50	23	21	*-8%*	0
Poland	3001	1397	-53%	771	505	508	*1%*	29
Moldova	197	117	-41%	0	47	48	*2%*	0
Romania	1335	599	-55%	144	289	300	*4%*	0
Russia	5046	2371	-53%	646	1283	895	*-30%*	0
Slovakia	549	119	-78%	85	60	51	*-15%*	0
Slovenia	200	37	-81%	48	23	20	*-11%*	0
Switzerland	45	30	-33%	78	58	53	*-9%*	0
FYR Macedonia	107	81	-24%	0	17	16	*-7%*	0
Ukraine	3708	1492	-60%	315	729	649	*-11%*	0
Yugoslavia	586	269	-54%	86	90	83	*-8%*	0
Non-EU	21651	9477	-56%	2902	3968	3407	*-14%*	82
Total[26]	39215	15483	-61%	10579	7353	6338	*-14%*	1147

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[26] Including ship emissions

4.4 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 technology and to quantify possible progress towards the ultimate target of full achievement of the long-term environmental targets discussed within the context of the EU ozone strategy and the UN/ECE Convention on Long-range Transboundary Air Pollution.

The MFR scenario simulates the complete implementation of currently available emission control technologies taking into account constraints imposed by current legislation and historically observed turnover rates of the capital stock when determining the application potential of the presently available emission control options.

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 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. Unfortunately, at the present time the in-depth analysis of the Auto/Oil 2 Programme has not yet reached the phase where definite findings could be presented. 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 outcome of the ongoing Auto-Oil 2 activities.

The MFR scenario for the year 2010 considers the historically observed turnover of the capital stock. This means that the scenario assumes for the year 2010 a certain fraction of the emission sources (car fleet, etc.) equipped with emission controls according to the regulations of the time when they entered into service. This is of particular relevance for the transport sector, where the fleet vintage coming in operation between 2000 and 2005 and complying with the year 2000 emission standards will still be in operation in the year 2010. The potential for more stringent controls is therefore limited only to cars built after 2005. As a consequence, emission levels could be even lower in later years when the most advanced control options penetrate the entire car fleet.

Table 4.13 lists the resulting emissions of NO_x and VOC for the REF and MFR scenarios. For the EU-15 as a whole, the MFR scenario produces a 68 percent cut of NO_x emissions relative to 1990, and a 65 percent decline in VOC emissions. Costs on top of REF amount to more than 24 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 68 percent and 63 percent respectively). Costs for that group of countries amount to 21 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 90 percent. However, control costs (on top of the costs of the REF scenario are 4.9 billion ECU/year for the EU countries and 4.8 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 19.1 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: Emissions and control costs (on top of REF) for REF and the Maximum technically feasible reductions (MFR). Percentage changes relate to the year 1990.

	NO$_x$ emissions				VOC emissions				Costs
	REF		MFR		REF		MFR		10^6
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	ECU/yr
Austria	87	-63%	76	-67%	270	*-37%*	259	-40%	268
Belgium	204	-42%	107	-70%	195	*-42%*	99	-71%	895
Denmark	133	-51%	85	-68%	86	*-47%*	56	-65%	270
Finland	170	-39%	88	-68%	107	*-50%*	74	-65%	375
France	822	-49%	502	-69%	1181	*-45%*	812	-62%	3069
Germany	1226	-54%	775	-71%	1445	*-51%*	905	-70%	5638
Greece	339	-14%	189	-52%	205	*-33%*	147	-52%	740
Ireland	73	-29%	32	-69%	46	*-59%*	30	-73%	186
Italy	1195	-41%	707	-65%	1082	*-42%*	690	-63%	3520
Luxembourg	11	-52%	5	-76%	8	*-59%*	5	-74%	47
Netherlands	270	-50%	176	-67%	196	*-59%*	138	-71%	1025
Portugal	199	-4%	99	-52%	144	*-34%*	114	-47%	573
Spain	892	-23%	540	-54%	669	*-36%*	504	-52%	2134
Sweden	198	-43%	128	-63%	195	*-55%*	149	-66%	534
UK	1186	-58%	653	-77%	1276	*-52%*	724	-73%	4203
EU-15	7003	-46%	4161	-68%	7104	*-47%*	4706	-65%	23477
Albania	36	51%	14	-40%	38	*28%*	17	-43%	117
Belarus	180	-55%	108	-73%	240	*-14%*	80	-71%	653
Bosnia-H.	60	-25%	21	-74%	43	*-5%*	15	-67%	188
Bulgaria	290	-18%	113	-68%	192	*-3%*	75	-62%	895
Croatia	83	1%	35	-58%	88	*12%*	34	-57%	299
Czech Rep.	231	-56%	126	-76%	224	*-30%*	86	-73%	876
Estonia	73	-13%	25	-70%	44	*0%*	17	-61%	210
Hungary	196	-8%	111	-48%	144	*-30%*	93	-55%	571
Latvia	90	-23%	55	-53%	43	*-14%*	17	-66%	194
Lithuania	110	-28%	56	-63%	84	*-19%*	49	-53%	314
Norway	153	-31%	107	-52%	196	*-36%*	106	-66%	384
Poland	831	-31%	433	-64%	759	*7%*	380	-46%	2657
Moldova	34	-61%	24	-73%	43	*-17%*	18	-65%	106
Romania	458	-12%	173	-67%	508	*5%*	168	-65%	1702
Russia	1995	-43%	1021	-71%	2718	*-18%*	1190	-64%	7227
Slovakia	113	-45%	74	-64%	141	*-1%*	67	-53%	360
Slovenia	31	-49%	21	-66%	25	*-59%*	20	-67%	91
Switzerland	89	-46%	61	-63%	173	*-40%*	115	-60%	429
FYR Maced.	29	-26%	10	-73%	20	*0%*	7	-65%	85
Ukraine	1094	-42%	557	-70%	845	*-21%*	357	-67%	3147
Yugoslavia	152	-28%	54	-75%	123	*-1%*	40	-68%	496
Non-EU	6327	-37%	3200	-68%	6694	*-16%*	2951	-63%	21001
Total	14960	-40%	8623	-65%	13798	*-35%*	7657	-64%	44608

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			REF		MFR		
	kt	*Change*	kt	*Change*	Costs	kt	*Change*	kt	*Change*	Costs
Austria	45	-53%	36	-62%	30	77	*-16%*	52	*-44%*	333
Belgium	195	-38%	56	-82%	327	82	*-4%*	49	*-42%*	454
Denmark	73	-60%	20	-89%	134	72	*-7%*	39	*-50%*	677
Finland	116	-49%	65	-71%	164	33	*-23%*	23	*-46%*	111
France	532	-59%	213	-84%	245	670	*-3%*	434	*-37%*	1920
Germany	740	-86%	364	-93%	1446	557	*-25%*	328	*-56%*	1898
Greece	375	-28%	58	-89%	216	72	*-7%*	52	*-33%*	131
Ireland	95	-45%	30	-83%	102	126	*-1%*	106	*-17%*	332
Italy	603	-64%	203	-88%	432	366	*-8%*	290	*-27%*	792
Luxembourg	4	-71%	2	-83%	6	6	*-11%*	6	*-11%*	0
Netherlands	56	-73%	44	-79%	49	93	*-60%*	93	*-60%*	0
Portugal	151	-47%	36	-87%	117	73	*-6%*	52	*-33%*	153
Spain	802	-63%	183	-92%	511	353	*0%*	235	*-33%*	1750
Sweden	87	-33%	60	-54%	194	53	*-15%*	44	*-30%*	157
UK	980	-74%	251	-93%	921	298	*-10%*	219	*-34%*	699
EU-15	4854	-70%	1621	-90%	4894	2931	*-13%*	2021	*-40%*	9406
Albania	56	-24%	6	-91%	46	34	*10%*	26	*-14%*	55
Belarus	480	-43%	43	-95%	327	163	*-26%*	112	*-49%*	421
Bosnia-H.	415	-15%	24	-95%	146	23	*-25%*	15	*-50%*	70
Bulgaria	846	-54%	135	-93%	219	126	*-11%*	97	*-31%*	225
Croatia	71	-60%	18	-90%	42	37	*-8%*	28	*-32%*	97
Czech Rep.	178	-91%	96	-95%	135	105	*-8%*	80	*-30%*	289
Estonia	175	-37%	15	-95%	114	29	*-1%*	19	*-33%*	86
Hungary	547	-40%	289	-68%	145	137	*14%*	92	*-23%*	405
Latvia	57	-53%	18	-85%	70	29	*-26%*	19	*-53%*	101
Lithuania	107	-50%	20	-91%	99	81	*1%*	53	*-33%*	217
Norway	34	-35%	20	-62%	39	21	*-8%*	16	*-29%*	91
Poland	1397	-53%	383	-87%	1117	508	*1%*	346	*-31%*	1312
Moldova	117	-41%	18	-91%	72	48	*2%*	33	*-30%*	115
Romania	599	-55%	106	-92%	219	300	*4%*	206	*-29%*	632
Russia	2371	-53%	607	-88%	922	895	*-30%*	555	*-57%*	2875
Slovakia	119	-78%	69	-87%	44	51	*-15%*	39	*-36%*	140
Slovenia	37	-81%	12	-94%	20	20	*-11%*	14	*-38%*	50
Switzerland	30	-33%	15	-67%	70	53	*-9%*	42	*-28%*	121
FYR Maced.	81	-24%	5	-95%	73	16	*-7%*	10	*-43%*	29
Ukraine	1492	-60%	390	-89%	583	649	*-11%*	398	*-45%*	2090
Yugoslavia	269	-54%	28	-95%	311	83	*-8%*	54	*-40%*	301
Non-EU	9477	-56%	2317	-89%	4812	3407	*-14%*	2254	*-43%*	9722
Total	15483	-61%	4215	-89%	10070	6338	*-14%*	4275	*-42%*	19128

Note: Total for SO_2 includes sea regions.

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