Sensitivity Analyses for a Central Scenario to Control Acidification, Eutrophication and Ground-level Ozone in Europe

Report prepared for the
23rd Meeting of the UN/ECE Task Force on
Integrated Assessment Modelling

Markus Amann, Imrich Bertok, Janusz Cofala, Frantisek Gyarfas, Chris Heyes, Zbigniew Klimont, Marek Makowski, Wolfgang Schöpp, Sanna Syri

March 1999

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1 Introduction

At its 28th Session in January 1999, the UN/ECE Working Group on Strategies selected the 'G5/2' scenario presented in Amann *et al.*, 1998 as the guiding scenario for the negotiations on the revised NO_x Protocol of the Convention on Long-range Transboundary Air Pollution. Given this decision, the Task Force on Integrated Assessment Modelling was requested to perform a range of sensitivity analyses for this 'medium ambition level' scenario.

While the basic modelling approach and the databases remain in principle as described in Part A of Amann *et al*. (1998), this paper explores the robustness of emission ceilings for the environmental targets implied by the G5/2 scenario. Revisiting the environmental objectives of the G5/2 scenario, the J1 scenario of this report is established as the base case for the sensitivity analysis, taking into account recent updates to the databases (see Section 1.1). After this, Section 3 compares optimized emission ceilings for modified exogenous assumptions on economic drivers to the RAINS model:

- Scenario J2 illustrates implications of a 'post-Kyoto energy' projection (the J1 scenario is based on energy projections yielding increases in CO_2 emissions, which is in sharp contrast to the commitments of the Kyoto conference)
- To explore the response of optimized emission ceilings for a hypothetical opposite development, Scenario J3 assumes for all countries higher SO_2 emissions (and less potential for SO_2 reductions) than in the base case J1.
- The implications of uncertainties in livestock projections on emission reduction requirements are subject of two further test cases. Scenario J4 studies a 'low ammonia' agricultural projection (assuming 10 percent lower livestock numbers for all countries), while Scenario J5 assesses a sensitivity case, in which lower reduction potentials for ammonia emissions are assumed.

Section 4 analyzes the effects of revised critical loads data for Slovakia, which were recently submitted on an informal basis to the Coordination Centre for Effects. Section 5 illustrates the gains made by the cost-effectiveness concept by comparing the costs and environmental impacts of the J1 base case with those of a 'flat rate' emission reduction scenario and with an optimized scenario, in which the differences in national reduction requirements are reduced while maintaining the environmental targets of the J1 case.

Section 6 discusses the role of model uncertainties, based on assessments of the chairpersons of the various UN/ECE Working Groups (contained in the Annex).

1.1 Changes Since the Report for the 22nd Meeting of TFIAM

A description of the modelling approach and the databases is provided in Part A of the report prepared for the 22nd meeting of the Task Force on Integrated Assessment Modelling (Amann *et al.*, 1998). Since this report, the following changes were introduced into the database of the EU countries:

- Change of the REF scenario to reflect the Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel and amending Council Directive 93/12/EEC (OJ, 1998).

- Change of the REF scenario to reflect Directive 98/69/EC of the European Parliament and of the Council of 13 October 1998 relating to measures to be taken against air pollution from motor vehicles and amending Council Directive 70/220/EEC (OJ, 1998).
- Implementation of post-2005 standards for heavy-duty vehicles in the REF scenario reflecting the Common Position reached in December 1998 between the European Parliament and the Council on amending the Directive 88/77/EEC (on the approximation of laws of the Member States relating to the measures to be taken against the emissions of gaseous and particulate pollutants from diesel engines for use in vehicles). For the REF scenario the stricter standards were implemented in two stages (2005/2006 and 2008/2009), and the removal efficiencies have been changed according to the standards in the above document.
- Change of the REF scenario to limit the sulfur content of gas oil for stationary sources to 0.1 percent (Directive on sulfur in liquid fuels).
- Updates of the 'Current Reduction Plans' according to recent information provided by the UN/ECE in December 1998.
- Based on detailed discussion with French experts, the emission factors for France for off-road sources and maritime activities (seagoing ships) for 2010 have been revised.
- Modifications to the VOC databases for Ireland, UK, Sweden, Germany and France taking into account latest national information.

These changes, in particular the incorporation of the recent traffic-related decisions, lead in general to lower NO_x emissions for the REF scenario, but, due to the slower implementation schedule, to less overall NO_x reduction potential in the year 2010 than in the previous reports.

2 The Situation in 1990 and the Expected Impacts of the Current Policies

2.1 Emissions and Control Costs

A Reference scenario has been constructed in order to assess the likely environmental impacts of the current emission control strategies in the year 2010. The scenario takes into account national and international legislation as described in the CLE scenario. For the EU-15 countries, emissions resulting from the CLE case were replaced by officially announced emission ceilings (the so-called 'CRP' values), if they were lower than the CLE estimate.

Emissions and control costs for NO_x and VOC in this scenario are presented in Table 2.1. For Europe as a whole, the REF scenario results in a 35 percent cut of NO_x and a 37 percent cut of VOC emissions.

Table 2.1 also presents costs for NO_x and VOC reductions, given jointly for NO_x and VOC because control technologies used in the transport sector simultaneously reduce the emissions of the two pollutants. Emission control costs for NO_x and VOC emissions amount to 52 billion EURO/year, out of which 47 billion emerge in the EU-15 countries.

Emissions and control costs for SO_2 and NH_3 in REF scenario are presented in Table 2.2. The REF scenario implies a 71 percent decrease of SO_2 emissions of the EU-15 and a 55 percent cut in the non-EU countries. SO_2 control costs, calculated from the RAINS cost curves, reach 14 billion EURO/year, of which 75 percent occur in the EU countries. For ammonia, the overall reduction is about 12 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 projected for 2010. The total cost for ammonia reduction in the REF scenario is about 0.7 billion EURO/year.

Table 2.1: Emissions and control costs for NO_x and VOC for 1990 and the Reference (REF) scenario (emissions in kilotons, costs in million EURO/year).

	NO_x			VOC			Costs
	1990	REF	*Change*	1990	REF	*Change*	of REF
Austria	192	103	*-46%*	352	205	*-42%*	902
Belgium	351	191	*-46%*	374	193	*-48%*	1278
Denmark	274	128	*-53%*	182	85	*-53%*	484
Finland	276	152	*-45%*	213	110	*-48%*	642
France	1867	858	*-54%*	2382	1223	*-49%*	7383
Germany	2662	1184	*-56%*	3122	1137	*-64%*	10549
Greece	345	344	*0%*	336	267	*-21%*	1048
Ireland	113	70	*-38%*	110	55	*-50%*	477
Italy	2037	1130	*-45%*	2055	1159	*-44%*	7868
Luxembourg	22	10	*-55%*	19	7	*-63%*	71
Netherlands	542	280	*-48%*	490	233	*-52%*	1731
Portugal	208	177	*-15%*	212	144	*-32%*	1349
Spain	1162	847	*-27%*	1008	669	*-34%*	5658
Sweden	338	190	*-44%*	511	290	*-43%*	1125
UK	2839	1186	*-58%*	2667	1351	*-49%*	6695
EU-15	13226	6849	*-48%*	14031	7128	*-49%*	47258
Albania	24	36	*50%*	31	41	*32%*	0
Belarus	402	316	*-21%*	371	309	*-17%*	0
Bosnia-H.	80	60	*-25%*	51	48	*-6%*	1
Bulgaria	355	297	*-16%*	195	190	*-3%*	4
Croatia	82	91	*11%*	103	111	*8%*	1
Czech Rep.	546	296	*-46%*	442	305	*-31%*	568
Estonia	84	73	*-13%*	45	49	*9%*	0
Hungary	219	198	*-10%*	204	160	*-22%*	420
Latvia	117	118	*1%*	63	56	*-11%*	0
Lithuania	153	138	*-10%*	111	105	*-5%*	0
Norway	220	178	*-19%*	297	195	*-34%*	567
Poland	1217	879	*-28%*	797	807	*1%*	2487
Moldova	87	66	*-24%*	50	42	*-16%*	0
Romania	518	458	*-12%*	503	504	*0%*	2
Russia	3486	2653	*-24%*	3542	2787	*-21%*	21
Slovakia	219	132	*-40%*	151	140	*-7%*	331
Slovenia	60	36	*-40%*	55	40	*-27%*	93
Switzerland	163	79	*-52%*	278	144	*-48%*	831
FYR Macedonia	39	29	*-26%*	19	19	*0%*	1
Ukraine	1888	1433	*-24%*	1161	851	*-27%*	0
Yugoslavia	211	152	*-28%*	142	139	*-2%*	3
Non-EU	10170	7718	*-24%*	8609	7041	*-18%*	5332
Total	25025	16196	*-35%*	22640	14168	*-37%*	52590

Table 2.2: Emissions and control costs for SO_2 and NH_3 for 1990 and the Reference (REF) scenario (emissions in kilotons, costs in million EURO/year).

	SO_2 1990	SO_2 REF	Change	Costs of REF	NH_3 1990	NH_3 REF	*Change*	Costs of REF
Austria	93	40	*-57%*	191	77	67	*-13%*	0
Belgium	336	193	*-43%*	426	97	96	*-1%*	0
Denmark	182	90	*-51%*	138	77	72	*-6%*	0
Finland	226	116	*-49%*	247	40	31	*-23%*	0
France	1250	448	*-64%*	1276	807	777	*-4%*	0
Germany	5280	581	*-89%*	3264	757	571	*-25%*	0
Greece	504	546	*8%*	434	80	74	*-8%*	0
Ireland	178	66	*-63%*	132	127	126	*-1%*	9
Italy	1679	567	*-66%*	1776	462	432	*-6%*	0
Luxembourg	14	4	*-71%*	13	7	7	*0%*	15
Netherlands	201	73	*-64%*	340	233	136	*-42%*	517
Portugal	284	141	*-50%*	181	71	67	*-6%*	0
Spain	2189	774	*-65%*	809	352	353	*0%*	28
Sweden	119	67	*-44%*	316	61	48	*-21%*	113
UK	3805	980	*-74%*	1269	329	297	*-10%*	0
EU-15	16339	4687	*-71%*	10813	3578	3154	*-12%*	682
Albania	72	55	*-24%*	0	32	35	*9%*	0
Belarus	843	494	*-41%*	0	219	163	*-26%*	0
Bosnia-H.	487	415	*-15%*	0	31	23	*-26%*	0
Bulgaria	1842	846	*-54%*	153	141	126	*-11%*	0
Croatia	180	70	*-61%*	52	40	37	*-8%*	0
Czech Rep.	1873	366	*-80%*	411	107	108	*1%*	0
Estonia	275	175	*-36%*	0	29	29	*0%*	0
Hungary	913	546	*-40%*	166	120	137	*14%*	0
Latvia	121	104	*-14%*	0	43	35	*-19%*	0
Lithuania	213	107	*-50%*	0	80	81	*1%*	0
Norway	52	32	*-38%*	56	23	21	*-9%*	0
Poland	3001	1397	*-53%*	855	505	541	*7%*	0
Moldova	197	117	*-41%*	0	47	48	*2%*	0
Romania	1331	594	*-55%*	155	292	304	*4%*	0
Russia	5012	2344	*-53%*	694	1282	894	*-30%*	0
Slovakia	548	137	*-75%*	91	60	47	*-22%*	0
Slovenia	200	71	*-65%*	35	23	21	*-9%*	0
Switzerland	43	26	*-40%*	118	72	66	*-8%*	0
FYR Macedonia	107	81	*-24%*	0	17	16	*-6%*	0
Ukraine	3706	1488	*-60%*	328	729	649	*-11%*	0
Yugoslavia	585	269	*-54%*	88	90	82	*-9%*	0
Non-EU	21599	9732	*-55%*	3202	3980	3462	*-13%*	0
Total	39090	15571	*-60%*	14016	7558	6616	*-12%*	682

2.2 Environmental Effects

2.2.1 Ground-level Ozone

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

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

2.2.1.1 Health-related Ozone Exposure

Figure 2.1 displays the number of days on which the WHO health guideline value (60 ppb, eight-hours moving average) was exceeded with the 1990 emissions. The map shows the three-years average moving over the meteorological conditions of the five available year. Most frequent excess is calculated for Italy (about 60 days), while northern France experienced about 50 days and Germany 30-40 days. Spain and Portugal, Greece, Ireland and the UK are mainly between 10 and 20, while Scandinavia show typically below 10 days excess.

The emission controls calculated for the REF case (NO_x - 35 percent, VOC -37 percent compared to 1990, with higher reduction in the EU-15) are expected to have profound impacts on ozone exposure. The maximum number of violation is expected to decline to 42 in France and about 35 in Italy and Germany (Figure 2.2).

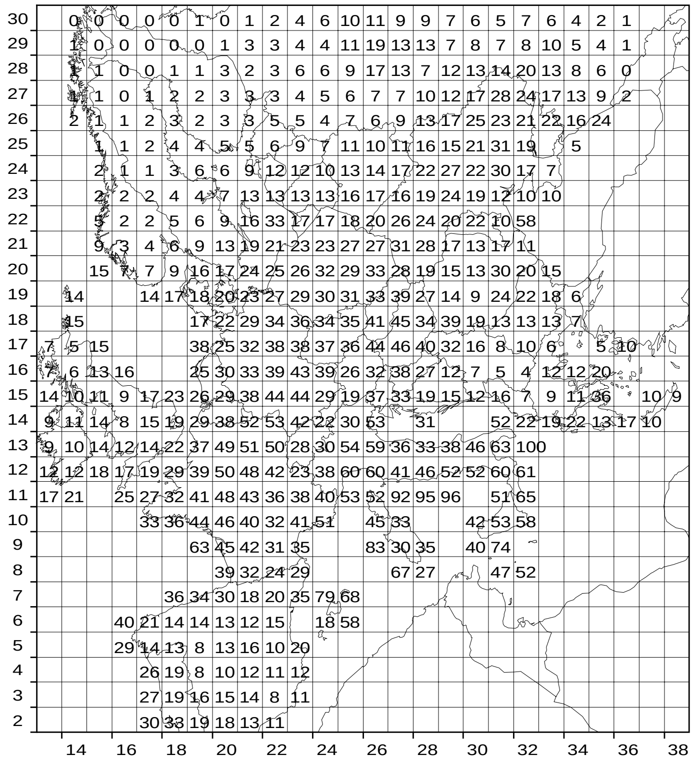

Figure 2.1: Number of days with ozone above 60 ppb, emissions of 1990, maximum of the three-years moving average over the five meteorological years

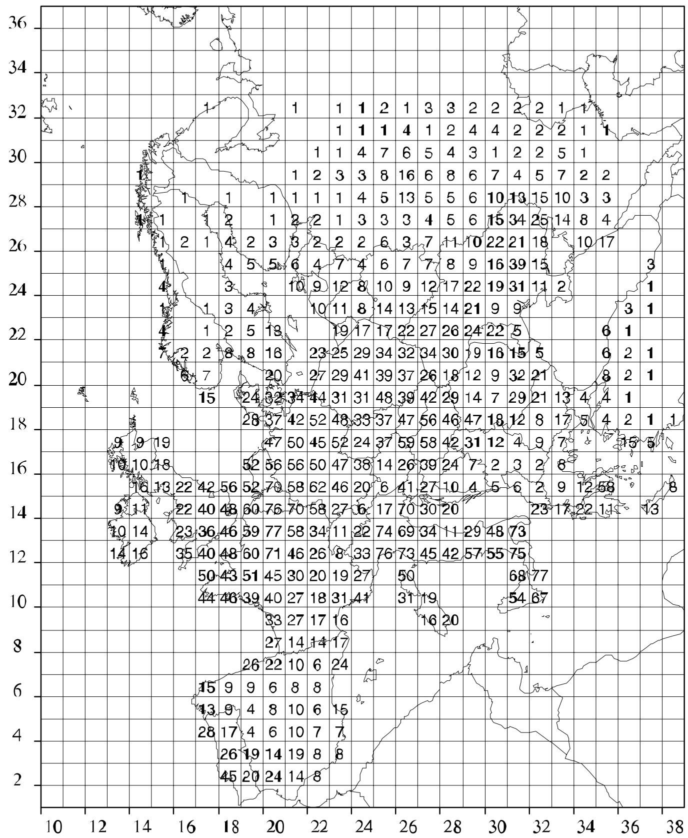

Figure 2.2: Number of days with ozone above 60 ppb, emissions of the REF case, maximum of the three-years moving average over the five meteorological years

Figure 2.3 illustrates that for the emissions of 1990 and using the meteorological conditions of five years, the second highest (rural) AOT60 of more than 6 ppm.hours occurred in northern France, Belgium and Germany. In many other parts of France, Germany and Benelux, the AOT60 was modeled in a range of 7-8 ppm.hours. Typical rural values in the UK and Austria were between 2 and 3 ppm.hours, while the highest AOT60 in Spain and Greece was between 1 and 2 ppm.hours. Portugal is estimated at 2 ppm.hours, while Scandinavia did not experience significant excess of the AOT60.

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

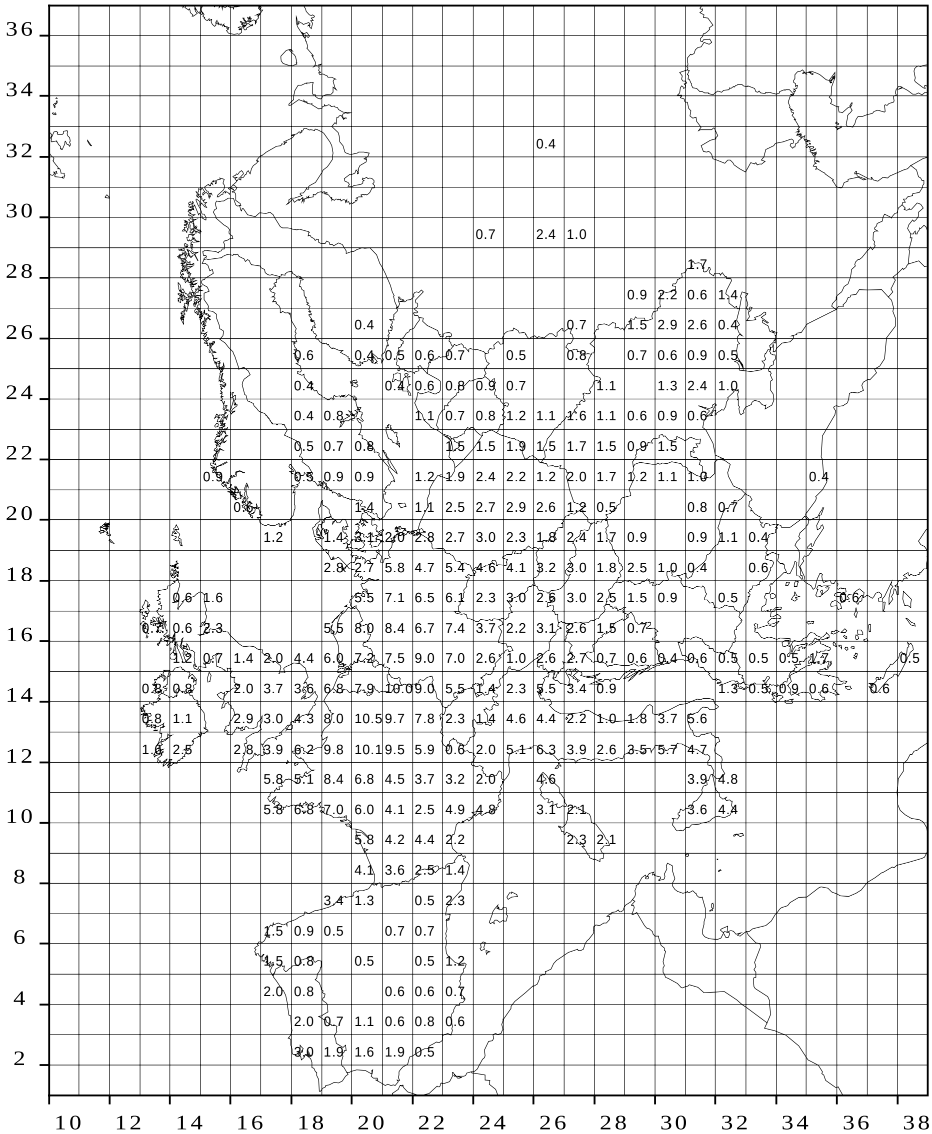

Figure 2.3: The AOT60 modelled for the emissions of 1990, second highest value of five years meteorologies (in ppm.hours)

Table 2.3 presents two different types of population exposure for the AOT60. The cumulative index reflects for each country the total exposure of a population and is expressed in person.ppm.hours. The RAINS model calculates these indices on a grid basis (using gridded data on AOT60 and population); in a second step these grid values are aggregated to the country level. The indices presented in this report use the AOT60 concentrations per grid, representing the rural ozone concentrations, and the total population per grid in 1990. Inaccuracies may occur for grids with major urban areas, where the rural ozone concentrations used for these analysis present an upper bound for the concentrations in the cities, and are lower than the concentrations occurring in the city plumes (Kindbom and Grennfelt, 1998). The ‘average’ indicator reflects the average exposure of a person in a country, calculated from gridded data. It is important to stress that these indices may not be used to derive estimates of health damage, for which more detailed information is deemed necessary. In the context of this report, these indices provide relative measures to enable a quick comparison of different scenarios.

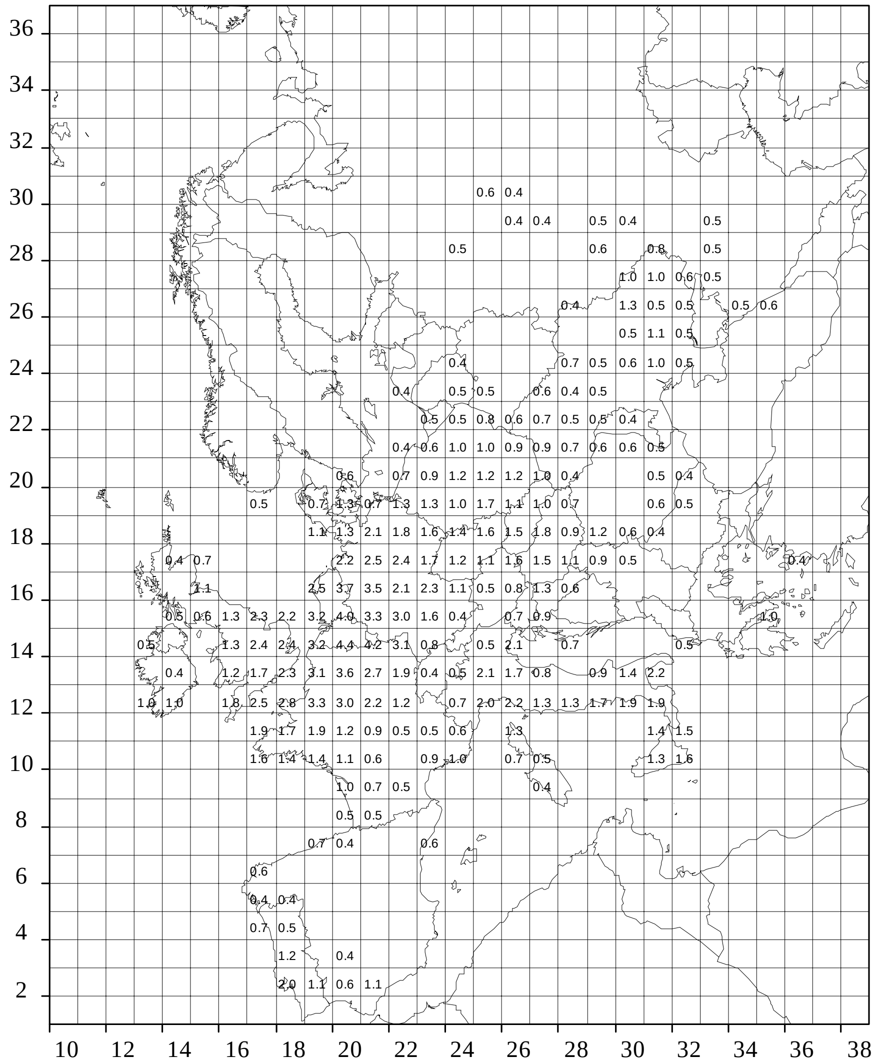

Figure 2.4: The AOT60 modelled for the emissions of the REF case, second highest value of five years meteorologies (in ppm.hours)

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

Table 2.3: Population exposure indices for 1990 and the REF scenario

	Cumulative population exposure index (million persons.ppm.hours)		Average population exposure index (ppm.hours)	
	1990	REF	1990	REF
Austria	16	3	2.0	0.5
Belgium	71	34	6.5	3.1
Denmark	9	3	1.8	0.5
Finland	0	0	0.1	0.0
France	311	89	5.5	1.6
Germany	404	140	5.1	1.8
Greece	7	4	0.7	0.4
Ireland	3	1	0.8	0.3
Italy	183	63	3.2	1.1
Luxembourg	3	1	8.5	3.0
Netherlands	73	38	4.9	2.6
Portugal	16	8	1.6	0.8
Spain	35	7	0.9	0.2
Sweden	4	0	0.4	0.0
UK	125	77	2.2	1.3
EU-15	1260	466	3.5	1.3
Albania	1	0	0.4	0.0
Belarus	4	1	0.4	0.1
Bosnia-H	3	0	0.7	0.1
Bulgaria	4	1	0.4	0.1
Croatia	8	3	1.8	0.6
Czech Rep.	34	11	3.3	1.0
Estonia	0	0	0.2	0.0
Hungary	27	12	2.6	1.1
Latvia	1	0	0.4	0.1
Lithuania	2	0	0.6	0.1
Norway	1	0	0.1	0.0
Poland	91	36	2.4	0.9
R.of Moldova	3	1	0.7	0.2
Romania	17	6	0.8	0.3
Russia	21	7	0.2	0.1
Slovakia	15	6	2.8	1.1
Slovenia	4	1	2.3	0.7
Switzerland	14	2	2.1	0.3
FYR of Maced.	0	0	0.1	0.0
Ukraine	45	14	0.9	0.3
Yugoslavia	8	3	0.7	0.2
Non-EU	305	103	1.0	0.3
Total	1566	570	2.3	0.8

2.2.1.2 Vegetation-related Ozone Exposure

Figure 2.5 displays the excess AOT40 (over the critical level of 3 ppm.hours) calculated for the emissions of the year 1990 using the five years mean meteorology. The map clearly shows that in most countries the critical level for vegetation was exceeded. The only exceptions occur in parts of the Scandinavian countries and of Russia. In an area extending from Paris over Belgium and Netherlands to Germany the excess AOT40 reached 16 ppm.hours, i.e., it exceeded the critical level by more than a factor of five. It is important to note that ozone levels in many areas, which do not experience significant excess of the AOT60, exceed the AOT40 criterion considerably. This applies particularly to the Mediterranean countries and some Alpine regions.

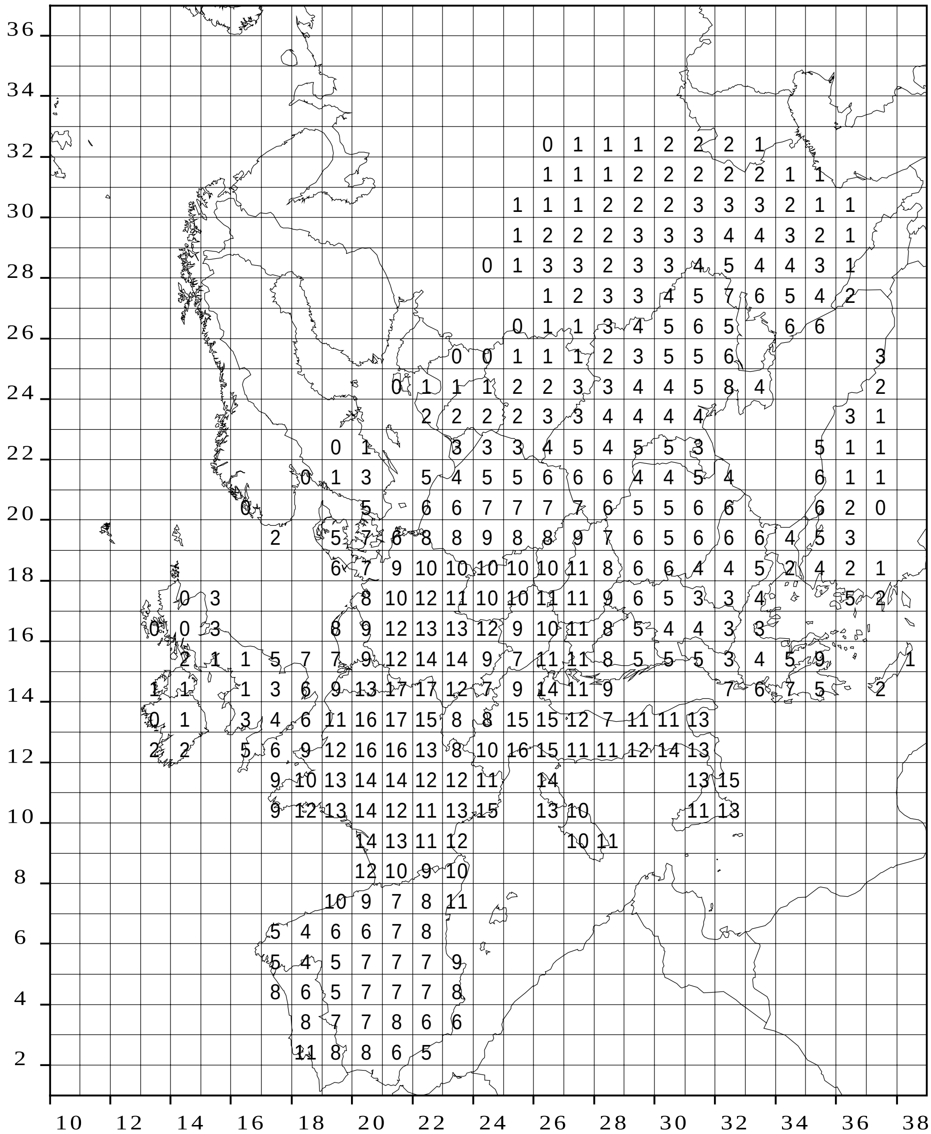

Figure 2.5: Excess AOT40 (above the critical level of 3 ppm.hours) for the emissions of 1990, in ppm.hours

The emission reductions of the Reference scenario will generally lead to a decline of the excess AOT40, but will not significantly increase the protected area (Figure 2.6). Peak levels are in a range of 10-12 ppm.hours.

Table 2.4 introduces two vegetation-related exposure indices. The cumulative vegetation exposure index is calculated as the excess AOT40 (i.e., the AOT40 in excess of the critical level of 3 ppm.hours) multiplied by the area of ecosystems that is exposed to the excess concentration. The index is calculated on a grid resolution, considering agricultural land, natural vegetation and forest areas. The average vegetation exposure index reflects the average excess AOT40 (over all grids in a country). The estimate of these indices is based on rural ozone concentrations.

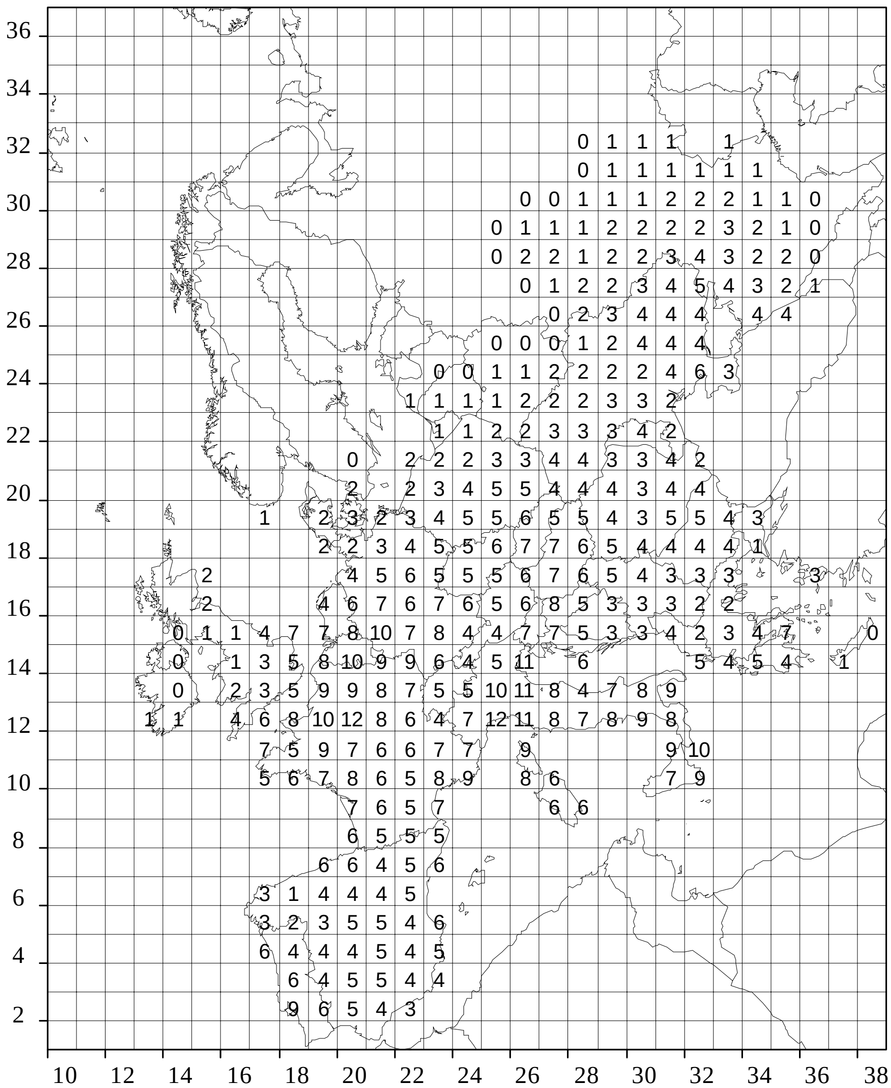

Figure 2.6: Excess AOT40 (above the critical level of 3 ppm.hours) for the emissions of the REF scenario, in ppm.hours

Table 2.4: Vegetation exposure indices for 1990 and the REF case

	Cumulative vegetation exposure index (1000 km^2.excess ppm.hours)		Average vegetation exposure index (excess ppm.hours)	
	1990	REF	1990	REF
Austria	468	257	9.0	5.0
Belgium	177	141	11.4	9.1
Denmark	160	53	5.3	1.8
Finland	0	0	0.0	0.0
France	4168	2345	12.9	7.3
Germany	2341	1204	11.0	5.7
Greece	245	170	4.5	3.1
Ireland	29	8	1.3	0.3
Italy	1852	1186	11.8	7.5
Luxembourg	25	14	16.5	9.3
Netherlands	110	79	8.5	6.1
Portugal	383	274	6.6	4.7
Spain	2088	1281	6.8	4.2
Sweden	163	18	0.5	0.1
UK	204	153	2.5	1.9
EU-15	12412	7183	6.6	3.8
Albania	0	0	0.0	0.0
Belarus	186	78	2.1	0.9
Bosnia-H	244	162	6.4	4.2
Bulgaria	357	281	4.8	3.8
Croatia	347	214	9.7	6.0
Czech Rep.	570	311	10.2	5.6
Estonia	2	0	0.1	0.0
Hungary	631	404	9.7	6.2
Latvia	42	6	1.0	0.1
Lithuania	77	23	1.8	0.6
Norway	4	1	0.0	0.0
Poland	1510	829	6.6	3.6
R.of Moldova	83	56	4.9	3.3
Romania	845	623	5.4	4.0
Russia	1764	983	0.9	0.5
Slovakia	341	215	9.6	6.0
Slovenia	139	94	10.7	7.2
Switzerland	155	85	8.7	4.8
FYR of Maced.	52	40	3.3	2.5
Ukraine	1776	1206	4.5	3.1
Yugoslavia	327	248	4.8	3.7
Non-EU	9453	5860	2.7	1.7
Total	21864	13043	4.1	2.4

2.2.2 Acidification

Figure 2.7 displays the percentage of ecosystems for which, for the emissions of 1990, acid deposition is calculated to exceed the critical loads. Least protection occurred in a band ranging from northern France over Germany to the Czech Republic and Poland. Overall, critical loads were exceeded in about 93 million hectares of ecosystems, out of which 37 million hectares were located in the EU-15 (see Table 2.5).

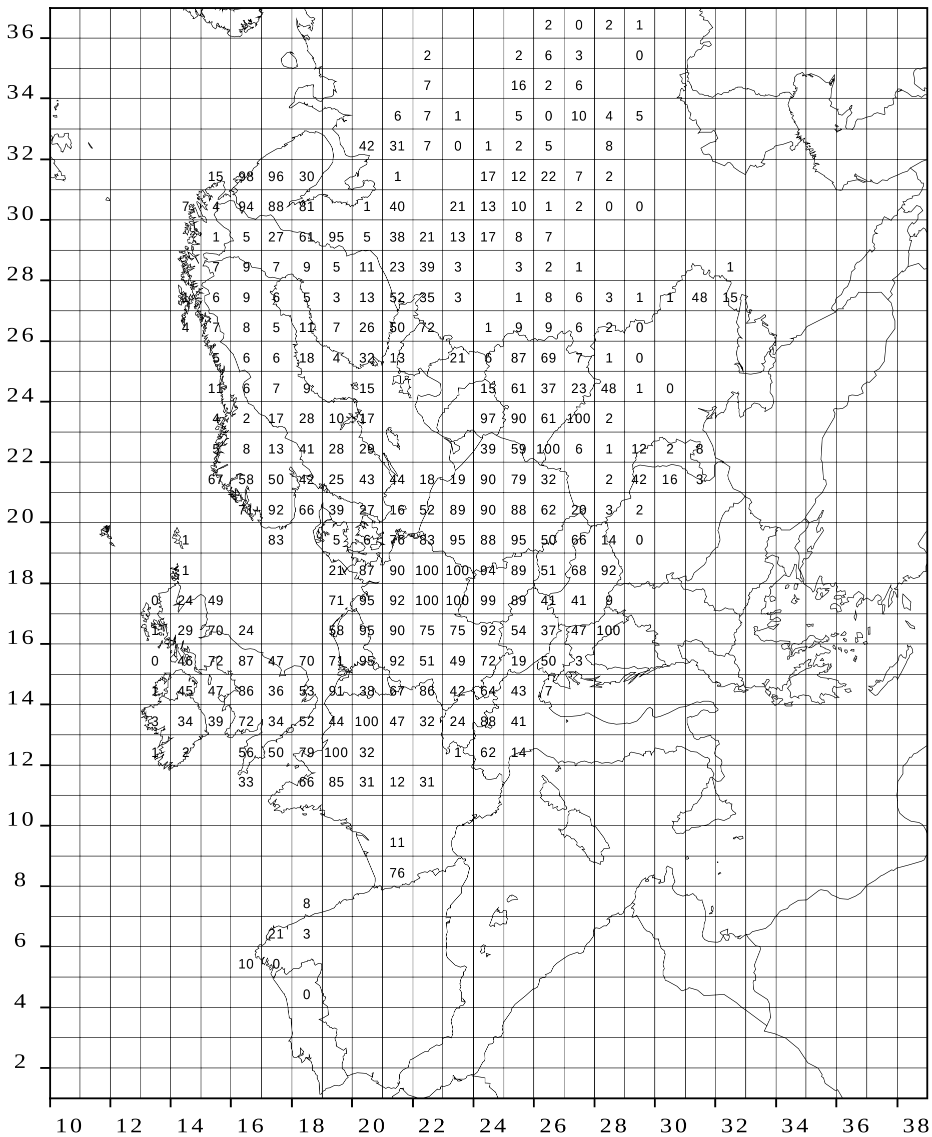

Figure 2.7: Percentage of ecosystems with acid deposition above their critical loads for acidification, 1990

The emission reductions anticipated in the REF scenario are expected to significantly improve the situation and to decrease the unprotected ecosystems to about 17.5 million hectares, out of which 6.4 million hectares are located in the EU-15 (Figure 2.8). There is clear indication that the overall area where critical loads are exceeded will decline, and many areas where the situation was not extreme will achieve full protection. On the other hand there are some regions (northern Germany, southern Norway, northern Sweden, Hungary, Kola) where the improvement will not exceed 10 to 30 percent.

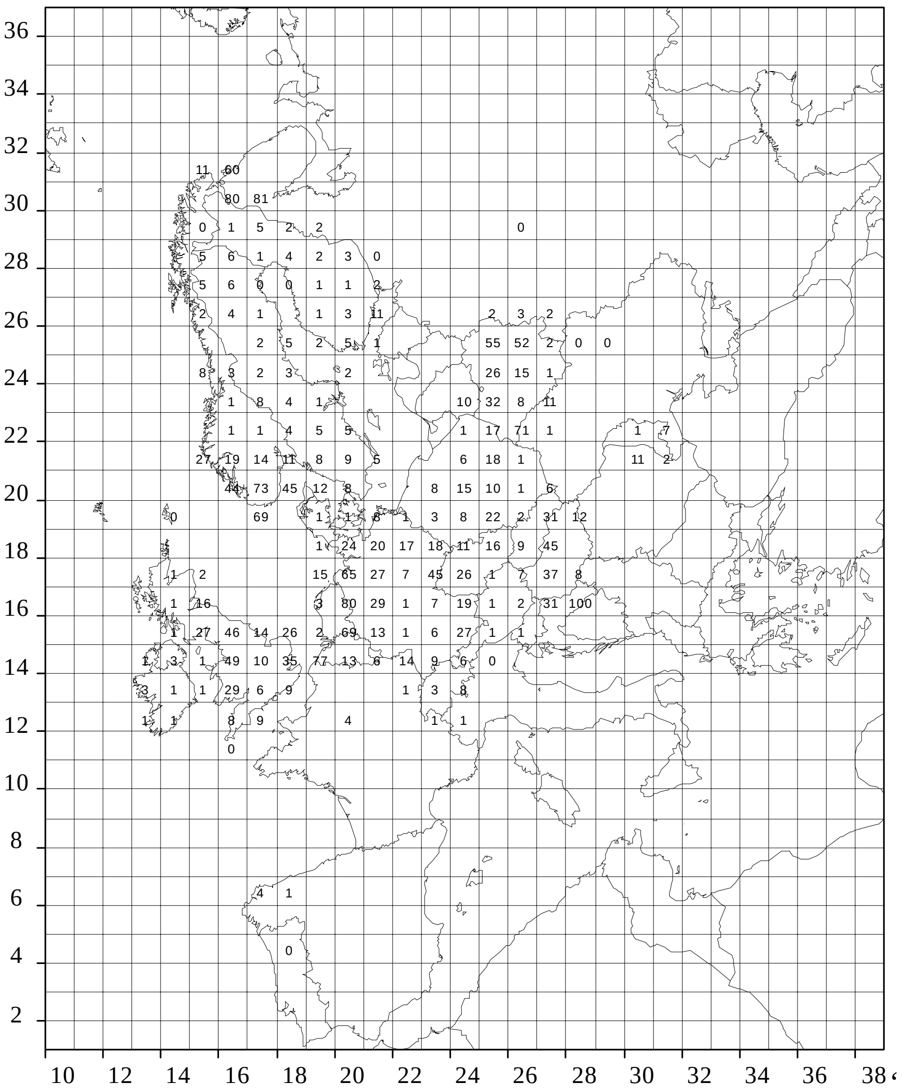

Figure 2.8: Percentage of ecosystems with acid deposition above their critical loads, REF case

Table 2.5: Ecosystems with acid deposition above their critical loads for acidification for 1990 and the REF scenario

	1000 hectares		Percent of ecosystems	
	1990	REF	1990	REF
Austria	2376	162	47.6	3.3
Belgium	410	155	58.4	22.1
Denmark	54	9	13.8	2.3
Finland	4725	1183	17.3	4.3
France	8191	218	25.8	0.7
Germany	8158	1617	79.5	15.8
Greece	0	0	0.0	0.0
Ireland	97	12	10.7	1.3
Italy	2065	74	19.6	0.7
Luxembourg	58	5	66.7	5.9
Netherlands	285	193	89.3	60.4
Portugal	1	1	0.0	0.0
Spain	78	17	0.9	0.2
Sweden	6348	1605	16.4	4.1
UK	4117	1182	43.0	12.3
EU-15	36963	6433	24.7	4.3
Albania	0	0	0.0	0.0
Belarus	2709	1048	53.9	20.9
Bosnia-H	132	131	9.1	9.1
Bulgaria	0	0	0.0	0.0
Croatia	7	0	2.7	0.0
Czech Rep.	2394	474	90.1	17.9
Estonia	314	11	16.6	0.6
Hungary	144	65	50.7	22.9
Latvia	128	0	4.7	0.0
Lithuania	817	78	43.1	4.1
Norway	5314	2573	24.0	11.6
Poland	12634	1357	72.8	7.8
R.of Moldova	84	29	7.1	2.4
Romania	231	51	3.7	0.8
Russia	27105	4073	7.9	1.2
Slovakia	1033	295	51.5	14.7
Slovenia	363	19	40.1	2.1
Switzerland	508	57	41.1	4.6
FYR of Maced.	0	0	0.0	0.0
Ukraine	2397	643	29.1	7.8
Yugoslavia	2	2	0.1	0.1
Non-EU	56315	10908	13.1	2.5
Total	93278	17341	16.1	3.0

2.2.3 Eutrophication

Figure 2.9 shows that in 1990 eutrophication was a wide-spread phenomenon in many parts of central Europe. The majority of grid cells in France, Germany, Poland, Romania and Bulgaria experienced excess deposition for all of their ecosystems. In the EU-15, critical loads for eutrophication were exceeded in more than 165 million hectares.

The emission reductions anticipated from the REF scenario will relieve the situation to some extent, but will still leave 116 million hectares unprotected (Figure 2.10). In many parts of mainland Europe they will not be sufficient to increase the unprotected ecosystems substantially. Statistics about individual countries are presented in Table 2.6.

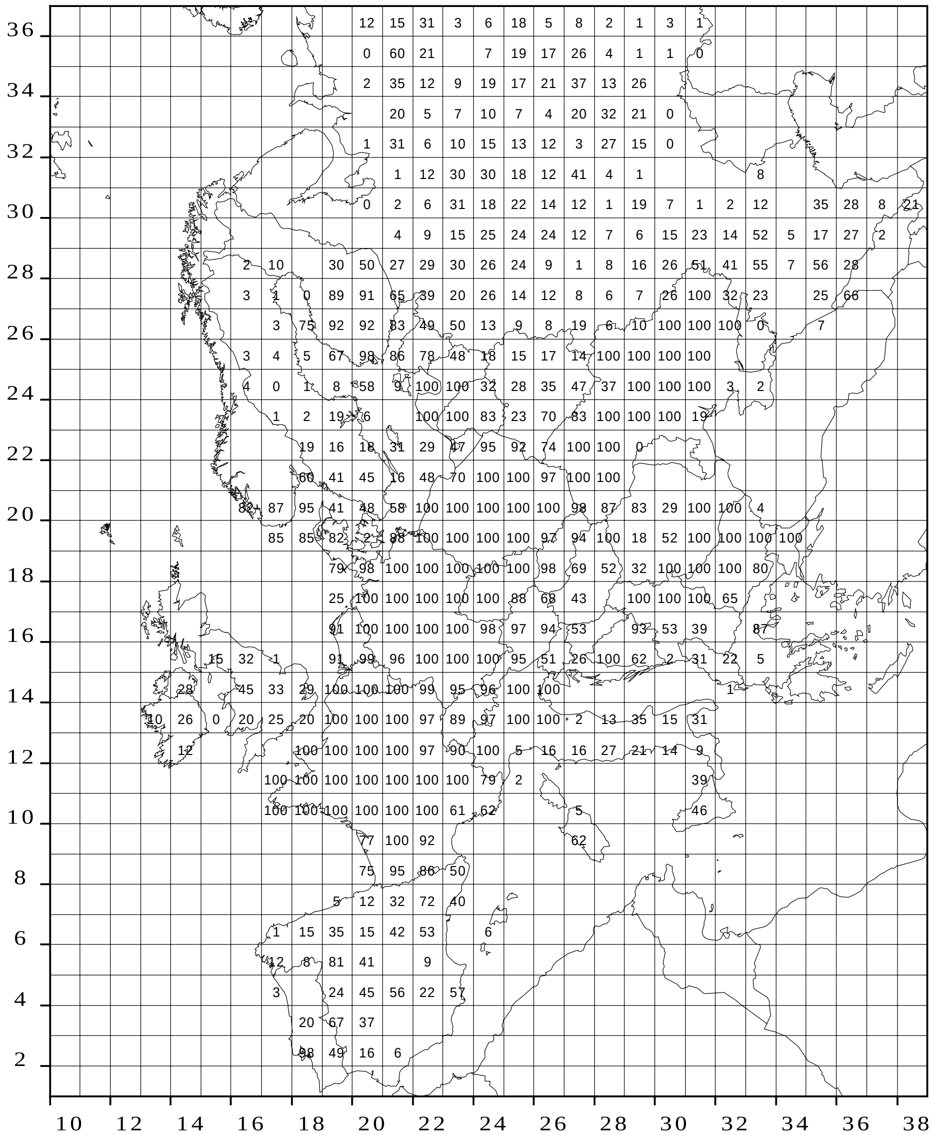

Figure 2.9: Percentage of ecosystems area with nitrogen deposition above their critical loads for eutrophication, for the emissions of 1990

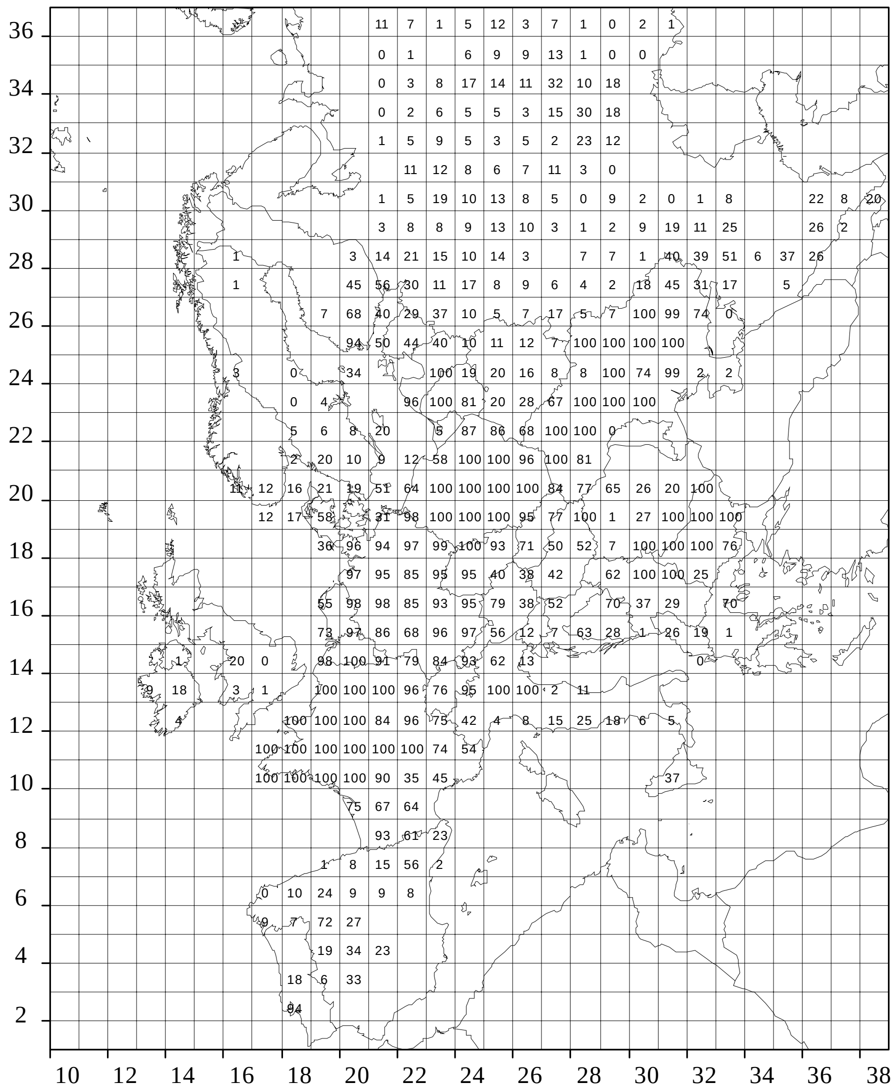

Figure 2.10: Percentage of ecosystems area with nitrogen deposition above their critical loads for eutrophication, for the emissions of the REF scenario

Table 2.6: Ecosystems with nitrogen deposition above their critical loads for eutrophication for 1990 and the REF case

	1000 hectares		Percent of ecosystems	
	1990	REF	1990	REF
Austria	5392	3441	90.3	57.6
Belgium	700	677	99.6	96.4
Denmark	197	119	62.7	37.6
Finland	7386	2538	44.8	15.4
France	29320	25160	92.3	79.2
Germany	10157	9184	99.0	89.5
Greece	295	236	12.0	9.6
Ireland	91	58	10.0	6.4
Italy	5921	3795	49.4	31.7
Luxembourg	88	80	100.0	91.3
Netherlands	312	291	97.8	91.0
Portugal	913	709	32.3	25.1
Spain	2390	1158	28.0	13.6
Sweden	2588	891	13.8	4.7
UK	1030	126	11.2	1.4
EU-15	66778	48461	55.3	40.2
Albania	240	200	22.6	18.8
Belarus	2049	1293	40.8	25.7
Bosnia-H	1104	725	76.2	50.0
Bulgaria	3964	3396	80.1	68.7
Croatia	70	18	25.9	6.8
Czech Rep.	2608	2312	98.2	87.0
Estonia	1296	738	68.5	39.0
Hungary	166	150	58.2	52.8
Latvia	2260	1553	83.2	57.2
Lithuania	1462	1357	77.1	71.6
Norway	2053	281	14.7	2.0
Poland	16875	16218	97.3	93.5
R.of Moldova	1	0	0.1	0.0
Romania	3450	2495	55.4	40.0
Russia	47704	26263	13.8	7.6
Slovakia	1874	1507	93.5	75.2
Slovenia	489	156	54.0	17.2
Switzerland	2105	1887	92.4	82.8
FYR of Maced.	242	158	22.7	14.9
Ukraine	6181	5331	75.0	64.7
Yugoslavia	2306	1994	67.6	58.5
Non-EU	98498	68032	23.2	16.0
Total	165276	116494	30.3	21.4

3 The Central Scenario (J1)

The 22nd meeting of the Task Force on Integrated Assessment Modelling presented to the Working Group on Strategies a range of emission reduction scenarios with different environmental ambition levels. Out of the presented scenarios, the Working Group on Strategies at its 28th Session selected the 'medium ambition level' scenario G5/2 to guide the forthcoming negotiations on a second NO_x Protocol. The environmental targets of this scenario are summarized in Table 3.1. Note that these targets, with the exception of eutrophication, are identical to those underlying the H1 scenario developed for the European Commission.

Table 3.1: Summary of the environmental targets for the Central scenario J1

	Central case J1 = Medium ambition (G5/2)
Acidification	
Gap closure on accumulated excess acidity	95 %
Gap closure on accumulated excess acidity for Norway	85 %
Maximum excess deposition for the 2-percent of the most sensitive ecosystems	(850 eq/ha)
Health-related ozone	
Gap closure on AOT60	67 %
Maximum AOT60, to be achieved in 4 out of 5 years	2.9 ppm.h
Vegetation-related ozone	
Gap closure on AOT40	33 %
Maximum excess AOT40, mean over five years	10 ppm.h
Eutrophication	
Gap closure on accumulated excess nitrogen deposition	60 %
Maximum excess deposition for the 2-percent of the most sensitive ecosystems	not specified

The optimization routine of the RAINS model was used to identify the cost-minimal allocation of emission controls to meet the environmental targets. The results of this analysis are presented in Table 3.2 to Table 3.7. Differences to the G5/2 scenario are explained by the changes introduced into the emission control database (see Section 1.1)

Table 3.2: NO_x and VOC emissions for the central scenario J1 compared to the REF case. Percentage changes relate to the year 1990.

	NO_x				VOC			
	REF		J1		REF		J1	
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*
Austria	103	*-46%*	91	*-53%*	205	*-42%*	142	*-60%*
Belgium	191	*-46%*	127	*-64%*	193	*-48%*	103	*-72%*
Denmark	128	*-53%*	113	*-59%*	85	*-53%*	85	*-53%*
Finland	152	*-45%*	152	*-45%*	110	*-48%*	110	*-48%*
France	858	*-54%*	704	*-62%*	1223	*-49%*	989	*-58%*
Germany	1184	*-56%*	1081	*-59%*	1137	*-64%*	995	*-68%*
Greece	344	*0%*	344	*0%*	267	*-21%*	261	*-22%*
Ireland	70	*-38%*	55	*-51%*	55	*-50%*	55	*-50%*
Italy	1130	*-45%*	901	*-56%*	1159	*-44%*	1030	*-50%*
Luxembourg	10	*-55%*	8	*-64%*	7	*-63%*	7	*-63%*
Netherlands	280	*-48%*	266	*-51%*	233	*-52%*	157	*-68%*
Portugal	177	*-15%*	144	*-31%*	144	*-32%*	102	*-52%*
Spain	847	*-27%*	726	*-38%*	669	*-34%*	648	*-36%*
Sweden	190	*-44%*	159	*-53%*	290	*-43%*	241	*-53%*
UK	1186	*-58%*	1181	*-58%*	1351	*-49%*	1101	*-59%*
EU-15	6849	*-48%*	6054	*-54%*	7128	*-49%*	6024	*-57%*
Albania	36	*50%*	36	*50%*	41	*32%*	41	*32%*
Belarus	316	*-21%*	290	*-28%*	309	*-17%*	298	*-20%*
Bosnia-H	60	*-25%*	53	*-34%*	48	*-6%*	48	*-6%*
Bulgaria	297	*-16%*	266	*-25%*	190	*-3%*	185	*-5%*
Croatia	91	*11%*	87	*6%*	111	*8%*	86	*-17%*
Czech Rep.	296	*-46%*	188	*-66%*	305	*-31%*	156	*-65%*
Estonia	73	*-13%*	73	*-13%*	49	*9%*	49	*9%*
Hungary	198	*-10%*	137	*-37%*	160	*-22%*	137	*-33%*
Latvia	118	*1%*	118	*1%*	56	*-11%*	56	*-11%*
Lithuania	138	*-10%*	134	*-12%*	105	*-5%*	105	*-5%*
Norway	178	*-19%*	142	*-35%*	195	*-34%*	195	*-34%*
Poland	879	*-28%*	654	*-46%*	807	*1%*	475	*-40%*
R.of Moldova	66	*-24%*	64	*-26%*	42	*-16%*	42	*-16%*
Romania	458	*-12%*	328	*-37%*	504	*0%*	500	*-1%*
Russia	2653	*-24%*	2653	*-24%*	2787	*-21%*	2723	*-23%*
Slovakia	132	*-40%*	115	*-47%*	140	*-7%*	140	*-7%*
Slovenia	36	*-40%*	34	*-43%*	40	*-27%*	40	*-27%*
Switzerland	79	*-52%*	76	*-53%*	144	*-48%*	144	*-48%*
FYR of Maced.	29	*-26%*	29	*-26%*	19	*0%*	19	*0%*
Ukraine	1433	*-24%*	1222	*-35%*	851	*-27%*	770	*-34%*
Yugoslavia	152	*-28%*	132	*-37%*	139	*-2%*	138	*-3%*
Non-EU	7718	*-24%*	6830	*-33%*	7041	*-18%*	6345	*-26%*
Total	16196	*-35%*	14513	*-42%*	14168	*-37%*	12370	*-45%*

Table 3.3: SO_2 and NH_3 emissions of the central scenario J1 compared to the REF case. Percentage changes relate to the year 1990.

	SO_2				NH_3			
	REF		J1		REF		J1	
	kt	Change	kt	Change	kt	Change	kt	Change
Austria	40	*-57%*	35	*-62%*	67	*-13%*	66	*-14%*
Belgium	193	*-43%*	76	*-77%*	96	*-1%*	60	*-38%*
Denmark	90	*-51%*	60	*-67%*	72	*-6%*	69	*-10%*
Finland	116	*-49%*	116	*-49%*	31	*-23%*	31	*-23%*
France	448	*-64%*	219	*-82%*	777	*-4%*	642	*-20%*
Germany	581	*-89%*	463	*-91%*	571	*-25%*	413	*-45%*
Greece	546	*8%*	546	*8%*	74	*-8%*	73	*-9%*
Ireland	66	*-63%*	36	*-80%*	126	*-1%*	116	*-9%*
Italy	567	*-66%*	290	*-83%*	432	*-6%*	356	*-23%*
Luxembourg	4	*-71%*	3	*-79%*	7	*0%*	7	*0%*
Netherlands	73	*-64%*	50	*-75%*	136	*-42%*	105	*-55%*
Portugal	141	*-50%*	141	*-50%*	67	*-6%*	65	*-8%*
Spain	774	*-65%*	747	*-66%*	353	*0%*	353	*0%*
Sweden	67	*-44%*	67	*-44%*	48	*-21%*	48	*-21%*
UK	980	*-74%*	499	*-87%*	297	*-10%*	264	*-20%*
EU-15	4687	*-71%*	3349	*-80%*	3154	*-12%*	2668	*-25%*
Albania	55	*-24%*	55	*-24%*	35	*9%*	32	*0%*
Belarus	494	*-41%*	494	*-41%*	163	*-26%*	140	*-36%*
Bosnia-H	415	*-15%*	162	*-67%*	23	*-26%*	22	*-29%*
Bulgaria	846	*-54%*	378	*-79%*	126	*-11%*	105	*-26%*
Croatia	70	*-61%*	23	*-87%*	37	*-8%*	29	*-28%*
Czech Rep.	366	*-80%*	283	*-85%*	108	*1%*	101	*-6%*
Estonia	175	*-36%*	175	*-36%*	29	*0%*	29	*0%*
Hungary	546	*-40%*	296	*-68%*	137	*14%*	77	*-36%*
Latvia	104	*-14%*	104	*-14%*	35	*-19%*	35	*-19%*
Lithuania	107	*-50%*	107	*-50%*	81	*1%*	72	*-10%*
Norway	32	*-38%*	18	*-65%*	21	*-9%*	21	*-9%*
Poland	1397	*-53%*	722	*-76%*	541	*7%*	468	*-7%*
R.of Moldova	117	*-41%*	38	*-81%*	48	*2%*	41	*-13%*
Romania	594	*-55%*	148	*-89%*	304	*4%*	227	*-22%*
Russia	2344	*-53%*	2186	*-56%*	894	*-30%*	894	*-30%*
Slovakia	137	*-75%*	92	*-83%*	47	*-22%*	39	*-35%*
Slovenia	71	*-65%*	14	*-93%*	21	*-9%*	16	*-30%*
Switzerland	26	*-40%*	23	*-47%*	66	*-8%*	63	*-13%*
FYR of Maced.	81	*-24%*	81	*-24%*	16	*-6%*	15	*-12%*
Ukraine	1488	*-60%*	1457	*-61%*	649	*-11%*	588	*-19%*
Yugoslavia	269	*-54%*	217	*-63%*	82	*-9%*	64	*-29%*
Non-EU	9732	*-55%*	7071	*-67%*	3462	*-13%*	3077	*-23%*
Total	15571	*-60%*	11572	*-70%*	6616	*-12%*	5745	*-24%*

Table 3.4: Control costs for NO_x, VOC and SO_2 of central scenario J1 compared to the REF case (in million EURO/year).

	NO_x and VOC			SO_2		
	REF	J1	TOTAL	REF	J1	TOTAL
Austria	902	70	972	191	5	196
Belgium	1278	452	1730	426	122	548
Denmark	484	8	492	138	13	151
Finland	642	0	642	247	0	247
France	7383	437	7820	1276	132	1408
Germany	10549	484	11033	3264	240	3504
Greece	1048	2	1050	434	0	434
Ireland	477	10	487	132	12	144
Italy	7868	245	8113	1776	87	1863
Luxembourg	71	2	73	13	0	13
Netherlands	1731	112	1843	340	19	359
Portugal	1349	57	1406	181	0	181
Spain	5658	42	5700	809	9	818
Sweden	1125	45	1170	316	0	316
UK	6695	353	7048	1269	295	1564
EU-15	47258	2318	49576	10813	935	11748
Albania	0	0	0	0	0	0
Belarus	0	3	3	0	0	0
Bosnia-H	1	2	3	0	55	55
Bulgaria	4	10	14	153	58	211
Croatia	1	5	6	52	18	70
Czech Rep.	568	235	803	411	36	447
Estonia	0	0	0	0	0	0
Hungary	420	112	532	166	113	279
Latvia	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0
Norway	567	12	579	56	10	66
Poland	2487	373	2860	855	283	1138
R.of Moldova	0	0	0	0	30	30
Romania	2	100	102	155	137	292
Russia	21	0	21	694	54	748
Slovakia	331	11	342	91	25	116
Slovenia	93	1	94	35	23	58
Switzerland	831	2	833	118	1	119
FYR of Maced.	1	0	1	0	0	0
Ukraine	0	44	44	328	8	336
Yugoslavia	3	6	9	88	27	115
Non-EU	5332	917	6249	3202	879	4081
Total	52590	3235	55825	14016	1814	15830

Table 3.5: Control costs for NH_3 and total costs of the central scenario J1 compared to the REF case (in million EURO/year).

	NH_3			TOTAL		
	REF	J1	TOTAL	REF	J1	TOTAL
Austria	0	1	1	1093	76	1169
Belgium	0	312	312	1704	886	2590
Denmark	0	2	2	623	22	645
Finland	0	0	0	889	0	889
France	0	367	367	8659	936	9595
Germany	0	842	842	13813	1567	15380
Greece	0	0	0	1482	2	1484
Ireland	9	146	155	618	168	786
Italy	0	85	85	9644	417	10061
Luxembourg	15	0	15	98	2	100
Netherlands	517	672	1189	2588	803	3391
Portugal	0	2	2	1530	59	1589
Spain	28	0	28	6495	51	6546
Sweden	113	0	113	1554	45	1599
UK	0	23	23	7964	671	8635
EU-15	682	2450	3132	58754	5704	64458
Albania	0	1	1	0	1	1
Belarus	0	9	9	0	12	12
Bosnia-H	0	1	1	1	58	59
Bulgaria	0	13	13	157	81	238
Croatia	0	3	3	52	26	78
Czech Rep.	0	9	9	979	280	1259
Estonia	0	0	0	0	0	0
Hungary	0	319	319	586	545	1131
Latvia	0	0	0	0	0	0
Lithuania	0	4	4	0	4	4
Norway	0	3	3	623	25	648
Poland	0	182	182	3342	838	4180
R.of Moldova	0	3	3	0	33	33
Romania	0	304	304	157	541	698
Russia	0	0	0	715	54	769
Slovakia	0	7	7	423	43	466
Slovenia	0	2	2	128	25	153
Switzerland	0	6	6	949	9	958
FYR of Maced.	0	1	1	1	1	2
Ukraine	0	30	30	328	82	410
Yugoslavia	0	94	94	92	128	220
Non-EU	0	991	991	8534	2787	11321
Total	682	3442	4124	67288	8490	75778

Table 3.6: Ozone exposure indices for the REF and J1 scenarios

	Population exposure index				Vegetation exposure index			
	Cumulative index		Average index		Cumulative index		Average index	
	REF	J1	REF	J1	REF	J1	REF	J1
Austria	3	1	0.5	0.2	257	194	5.0	3.7
Belgium	34	22	3.1	2.1	141	115	9.1	7.4
Denmark	3	1	0.5	0.2	53	30	1.8	1.0
Finland	0	0	0.0	0.0	0	0	0.0	0.0
France	89	54	1.6	1.0	2345	1865	7.3	5.8
Germany	140	91	1.8	1.1	1204	901	5.7	4.2
Greece	4	3	0.4	0.3	170	146	3.1	2.7
Ireland	1	0	0.3	0.1	8	3	0.3	0.1
Italy	63	40	1.1	0.7	1186	993	7.5	6.3
Luxembourg	1	1	3.0	2.1	14	11	9.3	7.4
Netherlands	38	26	2.6	1.8	79	63	6.1	4.8
Portugal	8	6	0.8	0.6	274	229	4.7	4.0
Spain	7	3	0.2	0.1	1281	1046	4.2	3.4
Sweden	0	0	0.0	0.0	18	7	0.1	0.0
UK	77	49	1.3	0.9	153	111	1.9	1.4
EU-15	466	298	1.3	0.8	7183	5714	3.8	3.1
Albania	0	0	0.0	0.0	0	0	0.0	0.0
Belarus	1	0	0.1	0.0	78	44	0.9	0.5
Bosnia-H	0	0	0.1	0.0	162	126	4.2	3.3
Bulgaria	1	0	0.1	0.0	281	228	3.8	3.0
Croatia	3	1	0.6	0.3	214	173	6.0	4.9
Czech Rep.	11	5	1.0	0.5	311	218	5.6	3.9
Estonia	0	0	0.0	0.0	0	0	0.0	0.0
Hungary	12	6	1.1	0.6	404	290	6.2	4.5
Latvia	0	0	0.1	0.0	6	2	0.1	0.0
Lithuania	0	0	0.1	0.0	23	9	0.6	0.2
Norway	0	0	0.0	0.0	1	1	0.0	0.0
Poland	36	18	0.9	0.5	829	529	3.6	2.3
R.of Moldova	1	0	0.2	0.1	56	43	3.3	2.5
Romania	6	1	0.3	0.0	623	458	4.0	2.9
Russia	7	5	0.1	0.0	983	861	0.5	0.4
Slovakia	6	3	1.1	0.6	215	153	6.0	4.3
Slovenia	1	1	0.7	0.4	94	78	7.2	5.9
Switzerland	2	1	0.3	0.1	85	70	4.8	3.9
FYR of Maced.	0	0	0.0	0.0	40	33	2.5	2.1
Ukraine	14	6	0.3	0.1	1206	971	3.1	2.5
Yugoslavia	3	1	0.2	0.1	248	195	3.7	2.9
Non-EU	103	48	0.3	0.2	5860	4481	1.7	1.3
Total	570	346	0.8	0.5	13043	10194	2.4	1.9

Table 3.7: Ecosystems with deposition above critical loads for the REF and J1 scenarios

	Acidification				Eutrophication			
	1000 hectares		Percent		1000 hectares		Percent	
	REF	J1	REF	J1	REF	J1	REF	J1
Austria	162	68	3.3	1.4	3441	2477	57.6	41.5
Belgium	155	52	22.1	7.4	677	572	96.4	81.4
Denmark	9	5	2.3	1.2	119	85	37.6	26.9
Finland	1183	756	4.3	2.8	2538	1738	15.4	10.5
France	218	84	0.7	0.3	25160	21632	79.2	68.1
Germany	1617	567	15.8	5.5	9184	7312	89.5	71.3
Greece	0	0	0.0	0.0	236	85	9.6	3.5
Ireland	12	8	1.3	0.9	58	29	6.4	3.2
Italy	74	51	0.7	0.5	3795	2508	31.7	20.9
Luxembourg	5	1	5.9	0.8	80	63	91.3	72.2
Netherlands	193	76	60.4	23.7	291	278	91.0	87.0
Portugal	1	1	0.0	0.0	709	580	25.1	20.5
Spain	17	17	0.2	0.2	1158	850	13.6	10.0
Sweden	1605	1166	4.1	3.0	891	620	4.7	3.3
UK	1182	636	12.3	6.6	126	62	1.4	0.7
EU-15	6433	3486	4.3	2.3	48461	38890	40.2	32.2
Albania	0	0	0.0	0.0	200	160	18.8	15.1
Belarus	1048	686	20.9	13.6	1293	924	25.7	18.4
Bosnia-H	131	0	9.1	0.0	725	460	50.0	31.7
Bulgaria	0	0	0.0	0.0	3396	1263	68.7	25.5
Croatia	0	0	0.0	0.0	18	10	6.8	3.6
Czech Rep.	474	81	17.9	3.0	2312	1983	87.0	74.6
Estonia	11	8	0.6	0.4	738	598	39.0	31.6
Hungary	65	37	22.9	13.0	150	125	52.8	44.1
Latvia	0	0	0.0	0.0	1553	1417	57.2	52.2
Lithuania	78	5	4.1	0.3	1357	894	71.6	47.2
Norway	2573	1928	11.6	8.7	281	35	2.0	0.3
Poland	1357	173	7.8	1.0	16218	14894	93.5	85.9
R.of Moldova	29	10	2.4	0.9	0	0	0.0	0.0
Romania	51	17	0.8	0.3	2495	1770	40.0	28.4
Russia	4073	1026	1.2	0.3	26263	23123	7.6	6.7
Slovakia	295	149	14.7	7.4	1507	939	75.2	46.8
Slovenia	19	4	2.1	0.4	156	87	17.2	9.6
Switzerland	57	35	4.6	2.8	1887	1468	82.8	64.4
FYR of Maced.	0	0	0.0	0.0	158	108	14.9	10.1
Ukraine	643	237	7.8	2.9	5331	3859	64.7	46.8
Yugoslavia	2	0	0.1	0.0	1994	1280	58.5	37.5
Non-EU	10908	4397	2.5	1.0	68032	55396	16.0	13.1
Total	17341	7883	3.0	1.4	116494	94287	21.4	17.3

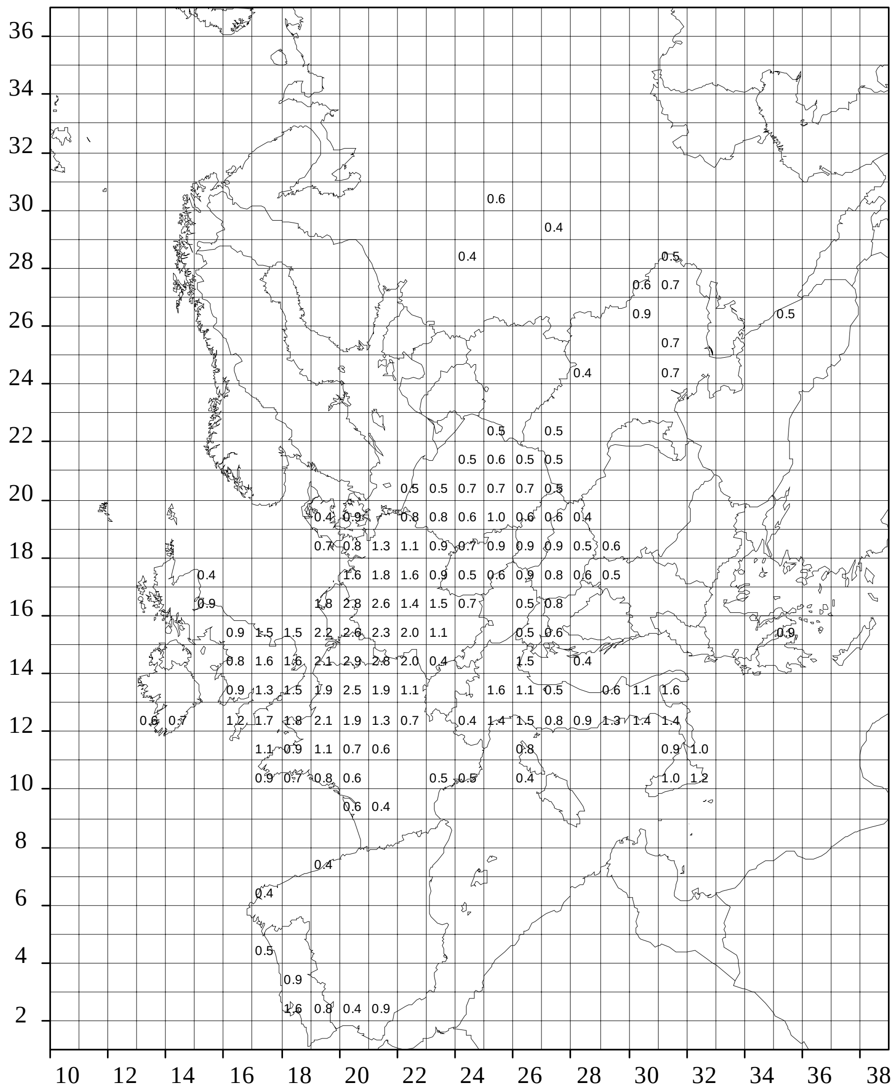

Figure 3.1: The AOT60 resulting from the emission reductions of the J1 scenario, second highest occurrence in the meteorological conditions of five years

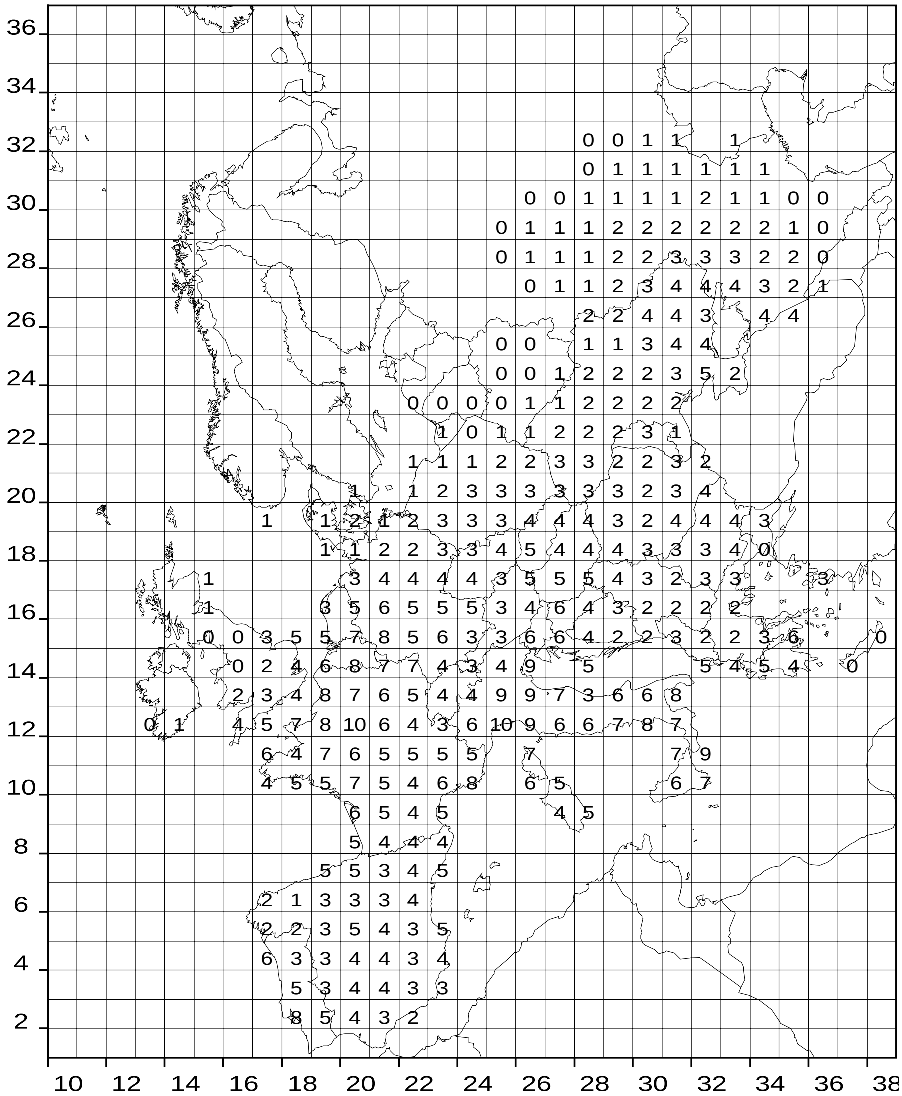

Figure 3.2: Excess AOT40 for the emissions of the J1 scenario (in ppm.hours)

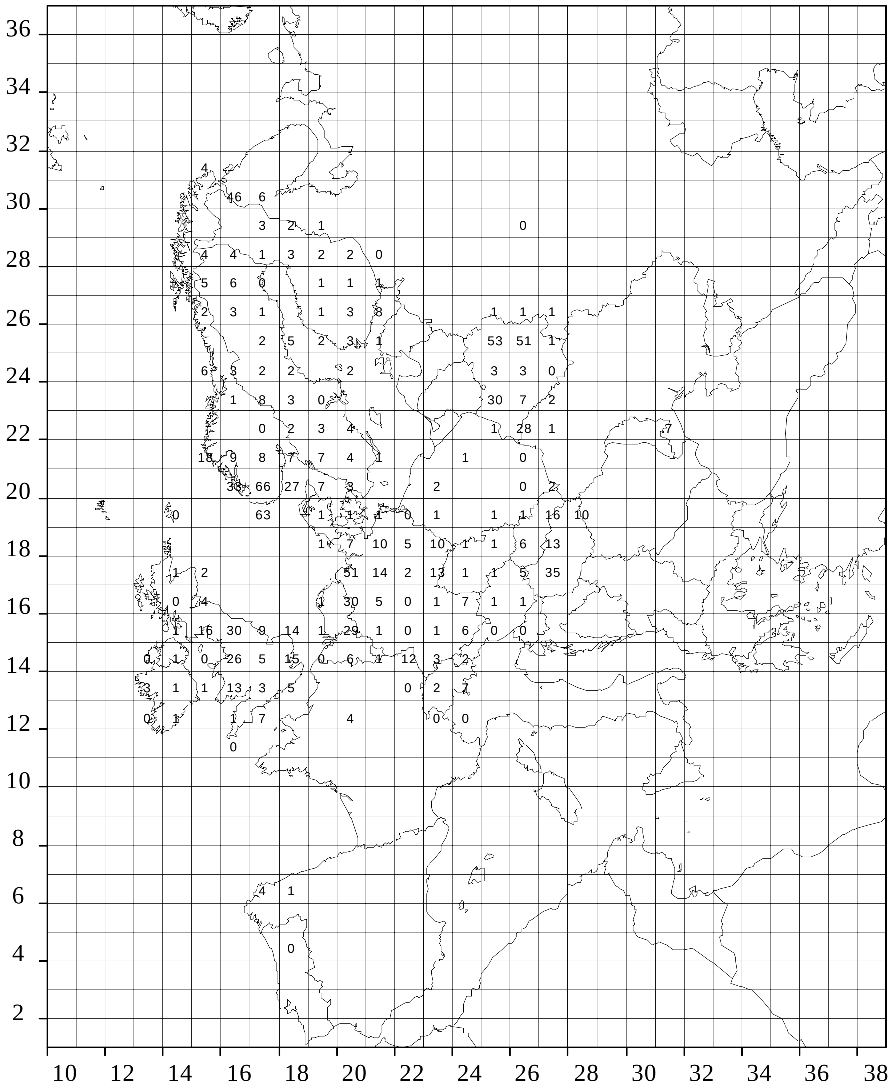

Figure 3.3: Percentage of ecosystems with acid deposition above their critical loads for the emissions of the J1 scenario

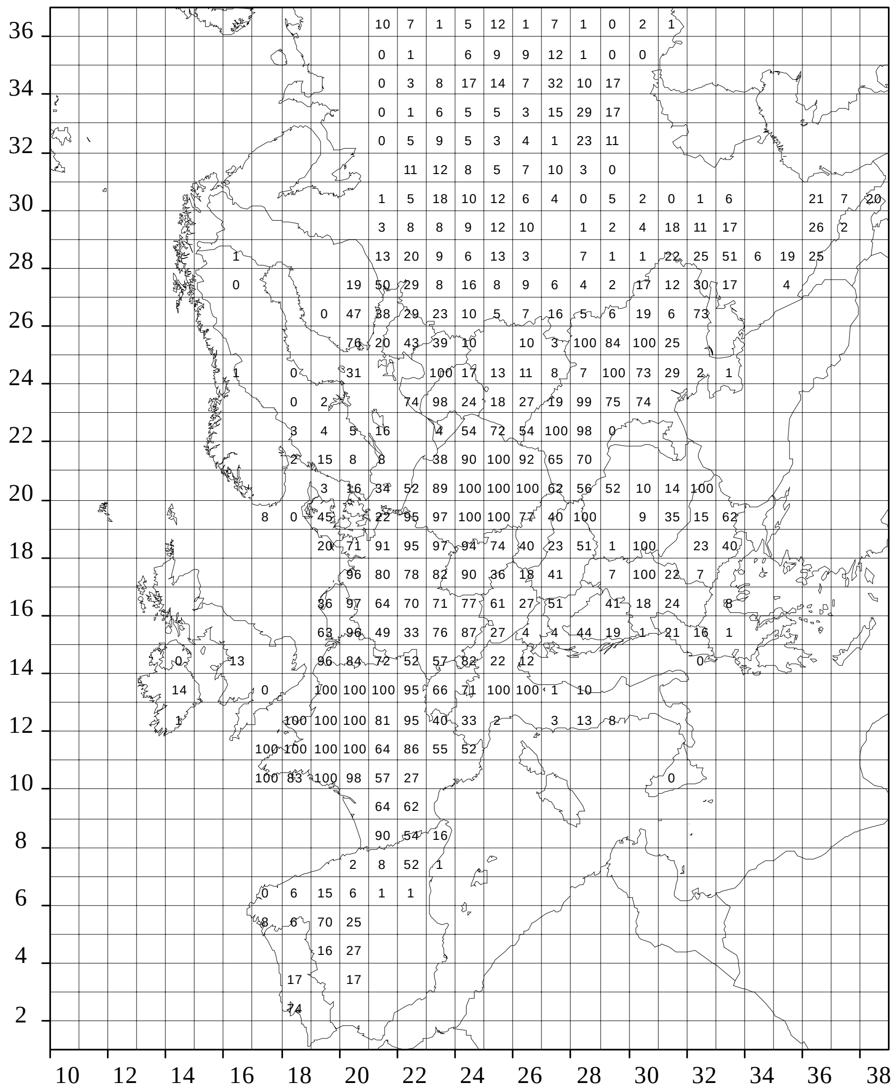

Figure 3.4: Percentage of ecosystems with nitrogen deposition above the critical loads for eutrophication for the emissions of the J1 scenario

4 Sensitivity Analysis 1: Modification of the Economic Drivers

4.1 Scenario J2: A 'Post-Kyoto' Energy Scenario

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. It must be kept in mind that the energy projection for the model domain underlying the J1 scenario by far fails to meet the Kyoto (Figure 4.1).

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

- The 'Official Energy Pathway' as reported in the UN/ECE database,
- for all EU countries, the 'Business as usual' energy scenario of DG-XVII,
- for the EU-15 a 'Low CO_2' energy scenario (Capros and Kokkolakis, 1996) derived from the earlier 'Conventional Wisdom' scenario of DG-XVII;
- for ten EU countries the national submissions to the Commission,
- for three EU countries 'Energy efficiency' scenarios developed by Gusbin *et al.* (1997), and
- for the Central and Eastern European country an 'Economic and Environmental Convergence' scenario developed by IIASA for a study for the European Environment Agency (Cofala *et al.*, 1998).

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. For the Member States of the European Union, this was done by selecting for each country, out of the available energy scenarios, the projection which comes in terms of CO_2 emissions closest (but not always exactly) to the Council decision of June 1998. For the non-EU countries (excluding Norway and Switzerland), an illustrative 'post-Kyoto' scenario was derived from the earlier IIASA study.

The scenario is also provisional since it implicitly assumes that the reductions for the three greenhouse gases would also hold for CO_2 emissions alone. Obviously, such an approach is not necessarily cost-effective, and countries 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.

Table 4.1: CO_2 emissions of the pre- and post-Kyoto energy scenarios compared to 1990 (in million tons)

	1990	Pre-Kyoto energy scenario 2010		Post-Kyoto energy scenario, 2010		EU/Kyoto agreement*)
Austria	58	59	*+1 %*	53	*-8 %*	*-13 %*
Belgium	110	133	*+21 %*	107	*-3 %*	*-7.5 %*
Denmark	54	51	*-5 %*	46	*-16 %*	*-21 %*
Finland	57	75	*+33 %*	49	*-14 %*	*0 %*
France	382	392	*+3 %*	369	*-3 %*	*0 %*
Germany	994	897	*-10 %*	816	*-18 %*	*-21 %*
Greece	76	140	*+83 %*	101	*+32 %*	*+25 %*
Ireland	26	44	*+71 %*	30	*+14 %*	*+13 %*
Italy	431	502	*+16 %*	400	*-7 %*	*-6.5 %*
Luxembourg	8.6	7.9	*-8 %*	7.6	*-11 %*	*-28 %*
Netherlands	164	211	*+28 %*	148	*-10 %*	*-6 %*
Portugal	42	62	*+47 %*	57	*+35 %*	*+27 %*
Spain	224	293	*+31 %*	256	*+14 %*	*+15 %*
Sweden	57	70	*+23 %*	70	*+23 %*	*+4 %*
UK	569	604	*+6 %*	515	*-9 %*	*-12.5 %*
EU-15	3250	3540	*9 %*	3020	*-7 %*	*-8 %*
Albania	6	7	*+13%*	11	*+85%*	-
Belarus	109	92	*-16%*	69	*-37%*	-
Bosnia-H	23	21	*-8%*	17	*-23%*	-
Bulgaria	84	80	*-5%*	59	*-29%*	*-8 %*
Croatia	20	22	*+11%*	21	*+3%*	*-5 %*
Czech_R.	150	120	*-20%*	85	*-43%*	*-8 %*
Estonia	33	27	*-19%*	19	*-43%*	*-8 %*
Hungary	66	83	*+26%*	72	*+9%*	*-6 %*
Latvia	24	21	*-10%*	15	*-37%*	*-8 %*
Lithuania	37	28	*-23%*	17	*-52%*	*-8 %*
Norway	26	39	*+47%*	39	*+47%*	*+1 %*
Poland	354	418	*+18%*	372	*+5%*	*-6 %*
R._of_Moldova	29	22	*-22%*	20	*-29%*	-
Romania	147	145	*-1%*	129	*-12%*	*-8 %*
Russia **)	1009	876	*-13%*	656	*-35%*	*0 %*
Slovakia	61	51	*-16%*	33	*-46%*	*-8 %*
Slovenia	14	14	*-6%*	13	*-10%*	*-8 %*
Switzerland	42	43	*+3%*	43	*+3%*	*-8 %*
FYRMacedonia	12	10	*-15%*	9	*-21%*	-
Ukraine	666	515	*-23%*	330	*-50%*	*0 %*
F.Yugoslavia	59	52	*-12%*	50	*-17%*	-
Non-EU	2972	2687	*-10%*	2081	*-30%*	

(*) Reduction commitments refer to all greenhouse gases.
Croatia, Czech Republic, Estonia, Latvia, Lithuania, Russian Federation, Slovakia, Slovenia, Ukraine - base year to be selected. Base year for Poland is 1988. Emissions of CO_2 in 1988 from fuel use - about 440 million tons. Base year for Romania is 1989.For all other countries the base year is 1990.
(**) only European part within the EMEP region

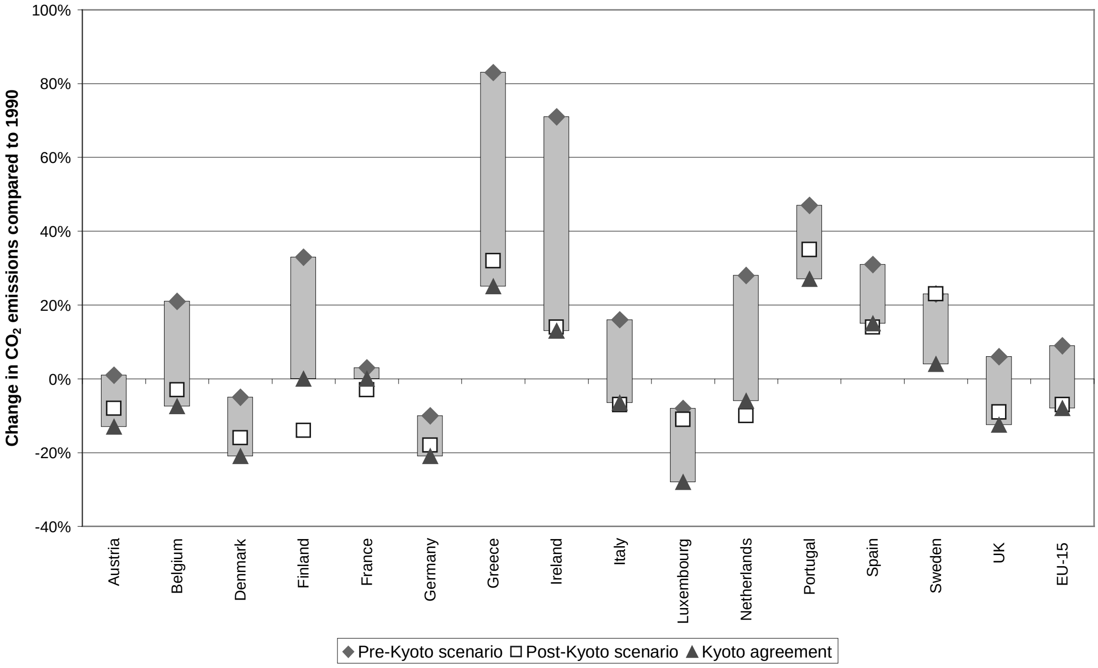

Figure 4.1: Comparison of the CO_2 emissions for the EU-15 between the pre-Kyoto energy scenario (used for J1), the post-Kyoto energy scenario (for J2) and the burden sharing agreement for reaching the Kyoto target. The grey bars illustrate the discrepancies between the J1 scenario and the Kyoto targets.

Results of the analysis are presented in Table 4.2 to Table 4.9. Most strikingly, total emission control costs in the ECE region decline from 8.5 to 4.8 billion EURO/year, i.e., by about 45 percent. Due to the less carbon-intensive energy structure of the post-Kyoto case, 60 percent less would be spent for SO_2 control, 44 percent less for NO_x and VOC reductions, and also the most expensive ammonia measures would not be necessary, so that also in the agricultural sector control costs were 35 percent lower. For the ECE region as a whole, remaining SO_2 emissions optimized for the post-Kyoto energy scenario are three percent lower than the J1 level, NO_x emissions six percent lower, VOC emissions two percent lower and ammonia emissions two percent higher. Due to the preliminary structure of the illustrative post-Kyoto energy projection no firm conclusions about results for individual countries should be drawn. However, it is interesting to note that there are some cases where a low CO_2 energy strategy emphasizing the use of renewable energy (wood burning) may result in higher VOC emissions.

4.2 Scenario J3: A 'High SO_2 ' Energy Scenario

A further sensitivity case was carried out hypothesizing the effects of higher SO_2 emissions on the optimized balanced of emission reductions. Higher SO_2 emissions could be caused by more combustion of sulfur containing fuels than foreseen in the J1 energy projection (although this would widen the gap to the Kyoto target), or by less efficient emission controls for SO_2 emissions than applied in the RAINS analysis.

For reasons for simplicity, the sensitivity study used for all countries revised SO_2 cost curves, which were derived by a scaling of the cost curves used for the J1 scenario by a factor of

1.05, so that both the REF and the MFR levels are five percent higher than in the original case.

The optimization shows only little impact on optimized emission levels. For the EU-15, overall SO_2 reductions are relieved by about one percent, compensated to some extent by slightly higher reductions in non-EU countries, where also in the J1 case a certain potential for less expensive measures remains. Changes for other pollutants are marginal. It is in the nature of the setup of this scenario that costs for SO_2 control are higher than in the base case.

4.3 Scenario J4: A ':Low Ammonia' Agricultural Scenario

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

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

The optimization shows a response similar to the 'low CO_2' scenario. Lower activity levels result in lower overall costs (in this specific case -27 percent), with cost savings for all pollutants. Costs for ammonia control are cut by about 50 percent, and for SO_2 and NO_x/VOC control by 14 and 12 percent, respectively.

4.4 Scenario J5: A 'High Ammonia' Agricultural Scenario

A further sensitivity case explored the response towards higher NH_3 emissions, either caused by larger livestock numbers than assumed for the J1 base case, or by less efficient emission control options. As for the high sulfur case (J3), the ammonia cost curves were scaled up by five percent for all countries.

The basic conclusions drawn from the high SO_2 case also hold for a high NH_3 situation: Despite higher costs implied by the modified cost curves, NH_3 emissions for all of Europe increase by only 56 kt or 0.74 percent, which is compensated by minor additional reductions of SO_2 and NO_x. .

Table 4.2: NO_x emissions for the central scenario J1 compared to the sensitivity cases with modified assumptions on economic drivers. Percentage changes relate to the year 1990.

	J1 Central case		J2 Post Kyoto		J3 High SO_2		J4 Low Ammonia		J5 High Ammonia	
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*
Austria	91	*-53%*	97	*-49%*	91	*-53%*	91	*-53%*	91	*-53%*
Belgium	127	*-64%*	113	*-68%*	127	*-64%*	133	*-62%*	127	*-64%*
Denmark	113	*-59%*	122	*-55%*	113	*-59%*	113	*-59%*	113	*-59%*
Finland	152	*-45%*	134	*-51%*	152	*-45%*	152	*-45%*	152	*-45%*
France	704	*-62%*	641	*-66%*	704	*-62%*	706	*-62%*	703	*-62%*
Germany	1081	*-59%*	952	*-64%*	1080	*-59%*	1115	*-58%*	1080	*-59%*
Greece	344	*0%*	306	*-11%*	344	*0%*	344	*0%*	344	*0%*
Ireland	55	*-51%*	45	*-60%*	55	*-51%*	60	*-47%*	43	*-62%*
Italy	901	*-56%*	899	*-56%*	901	*-56%*	902	*-56%*	901	*-56%*
Luxembourg	8	*-64%*	7	*-68%*	8	*-64%*	9	*-59%*	8	*-64%*
Netherlands	266	*-51%*	179	*-67%*	250	*-54%*	280	*-48%*	240	*-56%*
Portugal	144	*-31%*	137	*-34%*	144	*-31%*	177	*-15%*	177	*-15%*
Spain	726	*-38%*	717	*-38%*	726	*-38%*	758	*-35%*	726	*-38%*
Sweden	159	*-53%*	190	*-44%*	159	*-53%*	158	*-53%*	163	*-52%*
UK	1181	*-58%*	1051	*-63%*	1176	*-59%*	1181	*-58%*	1075	*-62%*
EU-15	6054	*-54%*	5589	*-58%*	6032	*-54%*	6179	*-53%*	5944	*-55%*
Albania	36	*50%*	32	*33%*	36	*50%*	36	*50%*	35	*46%*
Belarus	290	*-28%*	235	*-42%*	290	*-28%*	290	*-28%*	269	*-33%*
Bosnia-H	53	*-34%*	43	*-46%*	53	*-34%*	54	*-33%*	51	*-36%*
Bulgaria	266	*-25%*	211	*-41%*	266	*-25%*	249	*-30%*	260	*-27%*
Croatia	87	*6%*	74	*-10%*	84	*2%*	91	*11%*	81	*-1%*
Czech Rep.	188	*-66%*	168	*-69%*	188	*-66%*	197	*-64%*	172	*-68%*
Estonia	73	*-13%*	56	*-33%*	73	*-13%*	73	*-13%*	73	*-13%*
Hungary	137	*-37%*	138	*-37%*	131	*-40%*	141	*-36%*	131	*-40%*
Latvia	118	*1%*	78	*-33%*	118	*1%*	118	*1%*	117	*0%*
Lithuania	134	*-12%*	94	*-39%*	134	*-12%*	134	*-12%*	132	*-14%*
Norway	142	*-35%*	173	*-21%*	142	*-35%*	142	*-35%*	166	*-25%*
Poland	654	*-46%*	694	*-43%*	654	*-46%*	803	*-34%*	654	*-46%*
R.of Moldova	64	*-26%*	53	*-39%*	64	*-26%*	65	*-25%*	63	*-28%*
Romania	328	*-37%*	297	*-43%*	332	*-36%*	355	*-31%*	308	*-41%*
Russia	2653	*-24%*	2255	*-35%*	2653	*-24%*	2653	*-24%*	2653	*-24%*
Slovakia	115	*-47%*	84	*-62%*	115	*-47%*	118	*-46%*	108	*-51%*
Slovenia	34	*-43%*	33	*-45%*	33	*-45%*	34	*-43%*	33	*-45%*
Switzerland	76	*-53%*	76	*-53%*	76	*-53%*	76	*-53%*	76	*-53%*
FYR of Mac.	29	*-26%*	24	*-38%*	29	*-26%*	29	*-26%*	29	*-26%*
Ukraine	1222	*-35%*	981	*-48%*	1222	*-35%*	1242	*-34%*	1222	*-35%*
Yugoslavia	132	*-37%*	119	*-44%*	132	*-37%*	136	*-36%*	118	*-44%*
Non-EU	6830	*-33%*	5920	*-42%*	6825	*-33%*	7035	*-31%*	6752	*-34%*
Total	14513	*-42%*	13138	*-48%*	14487	*-42%*	14844	*-41%*	14326	*-43%*

Table 4.3: VOC emissions for the central scenario J1 compared to the sensitivity cases with modified assumptions on economic drivers. Percentage changes relate to the year 1990.

	J1 Central case		J2 Post Kyoto		J3 High SO_2		J4 Low Ammonia		J5 High Ammonia	
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*
Austria	142	*-60%*	200	*-43%*	142	*-60%*	142	*-60%*	151	*-57%*
Belgium	103	*-72%*	95	*-75%*	103	*-72%*	103	*-72%*	103	*-72%*
Denmark	85	*-53%*	85	*-53%*	85	*-53%*	85	*-53%*	85	*-53%*
Finland	110	*-48%*	125	*-41%*	110	*-48%*	110	*-48%*	110	*-48%*
France	989	*-58%*	907	*-62%*	939	*-61%*	1014	*-57%*	933	*-61%*
Germany	995	*-68%*	1031	*-67%*	995	*-68%*	997	*-68%*	995	*-68%*
Greece	261	*-22%*	249	*-26%*	261	*-22%*	263	*-22%*	261	*-22%*
Ireland	55	*-50%*	48	*-56%*	55	*-50%*	55	*-50%*	54	*-51%*
Italy	1030	*-50%*	1069	*-48%*	1048	*-49%*	1003	*-51%*	1055	*-49%*
Luxembourg	7	*-63%*	6	*-68%*	7	*-63%*	7	*-63%*	7	*-63%*
Netherlands	157	*-68%*	151	*-69%*	157	*-68%*	158	*-68%*	157	*-68%*
Portugal	102	*-52%*	106	*-50%*	102	*-52%*	100	*-53%*	100	*-53%*
Spain	648	*-36%*	669	*-34%*	653	*-35%*	632	*-37%*	645	*-36%*
Sweden	241	*-53%*	290	*-43%*	241	*-53%*	239	*-53%*	241	*-53%*
UK	1101	*-59%*	1108	*-58%*	1105	*-59%*	1068	*-60%*	1052	*-61%*
EU-15	6024	*-57%*	6138	*-56%*	6001	*-57%*	5974	*-57%*	5949	*-58%*
Albania	41	*32%*	34	*10%*	41	*32%*	41	*32%*	41	*32%*
Belarus	298	*-20%*	263	*-29%*	298	*-20%*	298	*-20%*	298	*-20%*
Bosnia-H	48	*-6%*	47	*-8%*	48	*-6%*	48	*-6%*	48	*-6%*
Bulgaria	185	*-5%*	177	*-9%*	184	*-6%*	182	*-7%*	188	*-4%*
Croatia	86	*-17%*	100	*-3%*	86	*-17%*	86	*-17%*	86	*-17%*
Czech Rep.	156	*-65%*	216	*-51%*	163	*-63%*	157	*-64%*	174	*-61%*
Estonia	49	*9%*	45	*0%*	49	*9%*	49	*9%*	49	*9%*
Hungary	137	*-33%*	159	*-22%*	136	*-33%*	138	*-32%*	137	*-33%*
Latvia	56	*-11%*	49	*-22%*	56	*-11%*	56	*-11%*	56	*-11%*
Lithuania	105	*-5%*	90	*-19%*	105	*-5%*	105	*-5%*	105	*-5%*
Norway	195	*-34%*	195	*-34%*	195	*-34%*	195	*-34%*	195	*-34%*
Poland	475	*-40%*	472	*-41%*	475	*-40%*	475	*-40%*	475	*-40%*
R.of Moldova	42	*-16%*	39	*-22%*	42	*-16%*	42	*-16%*	42	*-16%*
Romania	500	*-1%*	474	*-6%*	500	*-1%*	487	*-3%*	499	*-1%*
Russia	2723	*-23%*	2398	*-32%*	2723	*-23%*	2706	*-24%*	2723	*-23%*
Slovakia	140	*-7%*	126	*-17%*	140	*-7%*	140	*-7%*	140	*-7%*
Slovenia	40	*-27%*	40	*-27%*	40	*-27%*	40	*-27%*	40	*-27%*
Switzerland	144	*-48%*	144	*-48%*	144	*-48%*	144	*-48%*	143	*-49%*
FYR of Mac.	19	*0%*	19	*0%*	19	*0%*	19	*0%*	19	*0%*
Ukraine	770	*-34%*	715	*-38%*	768	*-34%*	756	*-35%*	797	*-31%*
Yugoslavia	138	*-3%*	134	*-6%*	138	*-3%*	136	*-4%*	136	*-4%*
Non-EU	6345	*-26%*	5936	*-31%*	6350	*-26%*	6300	*-27%*	6392	*-26%*
Total	12370	*-45%*	12074	*-47%*	12351	*-45%*	12274	*-46%*	12340	*-45%*

Table 4.4: SO_2 emissions for the central scenario J1 compared to the sensitivity cases with modified assumptions on economic drivers. Percentage changes relate to the year 1990.

	J1 Central case		J2 Post Kyoto		J3 High SO_2		J4 Low Ammonia		J5 High Ammonia	
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*
Austria	35	*-62%*	42	*-55%*	35	*-62%*	38	*-59%*	35	*-62%*
Belgium	76	*-77%*	75	*-78%*	80	*-76%*	77	*-77%*	76	*-77%*
Denmark	60	*-67%*	66	*-64%*	39	*-79%*	58	*-68%*	60	*-67%*
Finland	116	*-49%*	103	*-54%*	116	*-49%*	116	*-49%*	116	*-49%*
France	219	*-82%*	252	*-80%*	222	*-82%*	252	*-80%*	193	*-85%*
Germany	463	*-91%*	442	*-92%*	480	*-91%*	474	*-91%*	457	*-91%*
Greece	546	*8%*	363	*-28%*	546	*8%*	546	*8%*	546	*8%*
Ireland	36	*-80%*	72	*-60%*	38	*-79%*	46	*-74%*	36	*-80%*
Italy	290	*-83%*	277	*-84%*	289	*-83%*	316	*-81%*	261	*-84%*
Luxembourg	3	*-79%*	4	*-71%*	3	*-79%*	4	*-71%*	3	*-79%*
Netherlands	50	*-75%*	42	*-79%*	53	*-74%*	50	*-75%*	50	*-75%*
Portugal	141	*-50%*	138	*-51%*	141	*-50%*	141	*-50%*	141	*-50%*
Spain	747	*-66%*	747	*-66%*	747	*-66%*	746	*-66%*	747	*-66%*
Sweden	67	*-44%*	67	*-44%*	67	*-44%*	66	*-45%*	67	*-44%*
UK	499	*-87%*	429	*-89%*	520	*-86%*	582	*-85%*	497	*-87%*
EU-15	3349	*-80%*	3118	*-81%*	3376	*-79%*	3514	*-78%*	3286	*-80%*
Albania	55	*-24%*	47	*-35%*	55	*-24%*	55	*-24%*	55	*-24%*
Belarus	494	*-41%*	262	*-69%*	494	*-41%*	494	*-41%*	494	*-41%*
Bosnia-H	162	*-67%*	277	*-43%*	94	*-81%*	216	*-56%*	161	*-67%*
Bulgaria	378	*-79%*	776	*-58%*	397	*-78%*	378	*-79%*	378	*-79%*
Croatia	23	*-87%*	59	*-67%*	21	*-88%*	23	*-87%*	23	*-87%*
Czech Rep.	283	*-85%*	184	*-90%*	296	*-84%*	283	*-85%*	282	*-85%*
Estonia	175	*-36%*	107	*-61%*	175	*-36%*	175	*-36%*	175	*-36%*
Hungary	296	*-68%*	187	*-80%*	311	*-66%*	296	*-68%*	296	*-68%*
Latvia	104	*-14%*	49	*-60%*	104	*-14%*	104	*-14%*	104	*-14%*
Lithuania	107	*-50%*	51	*-76%*	107	*-50%*	107	*-50%*	107	*-50%*
Norway	18	*-65%*	32	*-38%*	19	*-63%*	18	*-65%*	25	*-52%*
Poland	722	*-76%*	1392	*-54%*	757	*-75%*	723	*-76%*	722	*-76%*
R.of Moldova	38	*-81%*	77	*-61%*	40	*-80%*	38	*-81%*	38	*-81%*
Romania	148	*-89%*	354	*-73%*	155	*-88%*	148	*-89%*	148	*-89%*
Russia	2186	*-56%*	1184	*-76%*	2185	*-56%*	2155	*-57%*	2201	*-56%*
Slovakia	92	*-83%*	47	*-91%*	97	*-82%*	92	*-83%*	92	*-83%*
Slovenia	14	*-93%*	71	*-65%*	15	*-93%*	14	*-93%*	14	*-93%*
Switzerland	23	*-47%*	24	*-44%*	24	*-44%*	26	*-40%*	22	*-49%*
FYR of Mac.	81	*-24%*	75	*-30%*	81	*-24%*	81	*-24%*	81	*-24%*
Ukraine	1457	*-61%*	621	*-83%*	1449	*-61%*	1445	*-61%*	1460	*-61%*
Yugoslavia	217	*-63%*	250	*-57%*	65	*-89%*	230	*-61%*	211	*-64%*
Non-EU	7071	*-67%*	6125	*-72%*	6940	*-68%*	7101	*-67%*	7089	*-67%*
Total	11572	*-70%*	10395	*-73%*	11468	*-71%*	11767	*-70%*	11527	*-71%*

Table 4.5: NH_3 emissions for the central scenario J1 compared to the sensitivity cases with modified assumptions on economic drivers. Percentage changes relate to the year 1990.

	J1 Central case		J2 Post Kyoto		J3 High SO_2		J4 Low Ammonia		J5 High Ammonia	
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*
Austria	66	*-14%*	66	*-14%*	66	*-14%*	61	*-21%*	67	*-13%*
Belgium	60	*-38%*	69	*-29%*	57	*-41%*	63	*-35%*	59	*-39%*
Denmark	69	*-10%*	71	*-8%*	69	*-10%*	63	*-18%*	72	*-6%*
Finland	31	*-23%*	31	*-23%*	31	*-23%*	28	*-30%*	31	*-23%*
France	642	*-20%*	657	*-19%*	643	*-20%*	627	*-22%*	645	*-20%*
Germany	413	*-45%*	460	*-39%*	412	*-46%*	418	*-45%*	416	*-45%*
Greece	73	*-9%*	73	*-9%*	73	*-9%*	67	*-16%*	74	*-8%*
Ireland	116	*-9%*	117	*-8%*	116	*-9%*	115	*-9%*	117	*-8%*
Italy	356	*-23%*	356	*-23%*	356	*-23%*	347	*-25%*	360	*-22%*
Luxembourg	7	*0%*	7	*0%*	7	*0%*	6	*-14%*	7	*0%*
Netherlands	105	*-55%*	105	*-55%*	104	*-55%*	96	*-59%*	109	*-53%*
Portugal	65	*-8%*	66	*-7%*	65	*-8%*	61	*-14%*	62	*-13%*
Spain	353	*0%*	353	*0%*	353	*0%*	353	*0%*	353	*0%*
Sweden	48	*-21%*	48	*-21%*	48	*-21%*	48	*-21%*	48	*-21%*
UK	264	*-20%*	264	*-20%*	264	*-20%*	244	*-26%*	264	*-20%*
EU-15	2668	*-25%*	2743	*-23%*	2663	*-26%*	2596	*-27%*	2683	*-25%*
Albania	32	*0%*	32	*0%*	32	*0%*	30	*-6%*	31	*-3%*
Belarus	140	*-36%*	157	*-28%*	140	*-36%*	143	*-35%*	147	*-33%*
Bosnia-H	22	*-29%*	22	*-29%*	22	*-29%*	20	*-35%*	23	*-26%*
Bulgaria	105	*-26%*	108	*-23%*	105	*-26%*	102	*-28%*	110	*-22%*
Croatia	29	*-28%*	29	*-28%*	29	*-28%*	27	*-33%*	30	*-25%*
Czech Rep.	101	*-6%*	105	*-2%*	101	*-6%*	96	*-10%*	107	*0%*
Estonia	29	*0%*	29	*0%*	29	*0%*	27	*-7%*	29	*0%*
Hungary	77	*-36%*	83	*-31%*	77	*-36%*	73	*-39%*	79	*-34%*
Latvia	35	*-19%*	35	*-19%*	35	*-19%*	33	*-23%*	35	*-19%*
Lithuania	72	*-10%*	77	*-4%*	72	*-10%*	72	*-10%*	74	*-8%*
Norway	21	*-9%*	21	*-9%*	21	*-9%*	18	*-22%*	21	*-9%*
Poland	468	*-7%*	477	*-6%*	469	*-7%*	454	*-10%*	468	*-7%*
R.of Moldova	41	*-13%*	45	*-4%*	41	*-13%*	40	*-15%*	42	*-11%*
Romania	227	*-22%*	240	*-18%*	227	*-22%*	225	*-23%*	231	*-21%*
Russia	894	*-30%*	894	*-30%*	894	*-30%*	819	*-36%*	894	*-30%*
Slovakia	39	*-35%*	39	*-35%*	39	*-35%*	38	*-37%*	41	*-32%*
Slovenia	16	*-30%*	18	*-22%*	16	*-30%*	16	*-30%*	17	*-26%*
Switzerland	63	*-13%*	63	*-13%*	63	*-13%*	60	*-17%*	66	*-8%*
FYR of Mac.	15	*-12%*	15	*-12%*	15	*-12%*	13	*-24%*	14	*-18%*
Ukraine	588	*-19%*	589	*-19%*	588	*-19%*	536	*-26%*	592	*-19%*
Yugoslavia	64	*-29%*	69	*-23%*	65	*-28%*	64	*-29%*	66	*-27%*
Non-EU	3077	*-23%*	3147	*-21%*	3080	*-23%*	2909	*-27%*	3117	*-22%*
Total	5745	*-24%*	5890	*-22%*	5743	*-24%*	5504	*-27%*	5801	*-23%*

Table 4.6: Control costs on top of the REF scenarios for SO_2, NO_x and VOC emissions for the central case and the sensitivity cases (in million EURO/year)

	NO_x & VOC					SO_2				
	J1 central	J2 post Kyoto	J3 high SO_2	J4 low NH_3	J5 high NH_3	J1 central	J2 post Kyoto	J3 high SO_2	J4 low NH_3	J5 high NH_3
Austria	70	2	70	70	48	5	0	7	1	5
Belgium	452	325	452	380	452	122	122	125	118	127
Denmark	8	0	8	8	8	13	0	33	15	13
Finland	0	0	0	0	0	0	0	8	0	0
France	437	449	537	373	555	132	91	155	83	209
Germany	484	315	487	387	493	240	134	250	191	251
Greece	2	1	2	1	2	0	0	4	0	0
Ireland	10	4	10	3	52	12	9	12	7	12
Italy	245	35	228	271	222	87	9	97	77	107
Luxembourg	2	13	2	1	5	0	0	0	0	0
Netherlands	112	63	156	87	196	19	49	19	19	19
Portugal	57	37	57	62	58	0	0	2	0	0
Spain	42	12	39	42	44	9	70	21	9	9
Sweden	45	0	45	50	40	0	0	4	0	0
UK	353	326	342	478	653	295	135	303	168	300
EU-15	2318	1583	2435	2212	2827	935	619	1042	689	1053
Albania	0	0	0	0	0	0	0	1	0	0
Belarus	3	1	3	3	8	0	0	6	0	0
Bosnia-H	2	1	2	1	4	55	0	78	38	55
Bulgaria	10	4	10	27	16	58	0	58	58	58
Croatia	5	4	6	3	10	18	0	22	18	18
Czech Rep.	235	85	220	213	240	36	0	36	35	36
Estonia	0	0	0	0	0	0	0	3	0	0
Hungary	112	29	136	97	136	113	51	113	113	113
Latvia	0	0	0	0	0	0	0	1	0	0
Lithuania	0	0	0	0	1	0	0	2	0	0
Norway	12	0	12	12	2	10	0	10	10	2
Poland	373	77	373	178	373	283	0	284	283	284
R.of Moldova	0	0	0	0	0	30	1	30	30	30
Romania	100	40	91	48	140	137	46	137	137	137
Russia	0	0	0	0	0	54	9	81	65	49
Slovakia	11	5	11	5	27	25	0	25	25	25
Slovenia	1	1	1	1	1	23	0	23	23	23
Switzerland	2	2	2	2	2	1	0	1	0	2
FYR of Mac.	0	0	0	0	0	0	0	2	0	0
Ukraine	44	3	44	39	42	8	0	31	11	7
Yugoslavia	6	6	6	4	31	27	0	150	17	32
Non-EU	917	260	919	633	1035	879	107	1094	863	871
Total	3235	1842	3354	2846	3863	1814	726	2162	1552	1924

Table 4.7: Control costs for NH_3 emissions and total costs on top of the REF scenario for the central case and the sensitivity cases (in million EURO/year)

	NH_3					Total				
	J1 central	J2 post Kyoto	J3 high SO_2	J4 low NH_3	J5 high NH_3	J1 central	J2 post Kyoto	J3 high SO_2	J4 low NH_3	J5 high NH_3
Austria	1	0	1	0	12	76	3	78	71	65
Belgium	312	147	467	133	467	886	595	1044	631	1046
Denmark	2	0	2	1	4	22	0	42	24	25
Finland	0	0	0	0	4	0	0	8	0	4
France	367	261	359	125	581	936	801	1052	581	1345
Germany	842	322	853	299	1219	1567	771	1591	877	1963
Greece	0	0	0	0	4	2	1	6	1	6
Ireland	146	122	145	7	356	168	134	167	17	421
Italy	85	84	84	58	120	417	128	409	406	450
Luxembourg	0	0	0	0	0	2	13	2	1	5
Netherlands	672	632	741	616	741	803	744	917	722	957
Portugal	2	1	2	0	18	59	38	61	62	76
Spain	0	0	0	0	30	51	82	60	51	83
Sweden	0	0	0	0	48	45	0	49	50	88
UK	23	23	23	22	87	671	484	669	668	1040
EU-15	2450	1592	2677	1261	3692	5704	3794	6154	4163	7573
Albania	1	1	1	1	2	1	1	2	1	2
Belarus	9	2	9	3	9	12	4	18	6	18
Bosnia-H	1	1	1	0	1	58	2	82	39	60
Bulgaria	13	7	13	7	13	81	12	81	92	86
Croatia	3	3	3	3	4	26	8	32	25	32
Czech Rep.	9	3	9	2	9	280	88	265	251	285
Estonia	0	0	0	0	1	0	0	3	0	1
Hungary	319	191	320	255	378	545	270	569	464	627
Latvia	0	0	0	0	1	0	0	1	0	1
Lithuania	4	2	4	2	4	4	2	6	2	5
Norway	3	0	3	18	9	25	0	25	40	14
Poland	182	115	173	45	342	838	192	830	505	999
R.of Moldova	3	1	3	2	3	33	2	33	32	34
Romania	304	187	304	111	417	541	273	533	295	695
Russia	0	0	0	0	17	54	9	81	65	66
Slovakia	7	7	7	3	8	43	13	44	33	61
Slovenia	2	1	2	1	2	25	2	25	24	26
Switzerland	6	6	6	1	6	9	8	9	2	10
FYR of Mac.	1	1	1	1	2	1	1	2	1	2
Ukraine	30	27	29	27	96	82	30	104	78	145
Yugoslavia	94	52	93	25	114	128	58	249	46	177
Non-EU	991	607	981	505	1441	2787	974	2994	2001	3347
Total	3442	2199	3657	1767	5133	8490	4767	9174	6164	10920

Table 4.8: Cumulative ozone exposure indices for the central case and the sensitivity cases

	Population exposure index					Vegetation exposure index				
	J1 central	J2 post Kyoto	J3 high SO_2	J4 low NH_3	J5 high NH_3	J1 central	J2 post Kyoto	J3 high SO_2	J4 low NH_3	J5 high NH_3
Austria	1	1	1	2	1	194	191	193	198	192
Belgium	22	22	22	23	22	115	115	115	115	115
Denmark	1	1	1	1	1	30	30	30	32	29
Finland	0	0	0	0	0	0	0	0	0	0
France	54	50	53	54	53	1865	1755	1853	1881	1845
Germany	91	84	90	94	89	901	871	899	920	894
Greece	3	3	3	3	3	146	129	146	146	145
Ireland	0	0	0	0	0	3	3	3	3	3
Italy	40	41	40	39	40	993	994	994	992	994
Luxembourg	1	1	1	1	1	11	10	11	11	11
Netherlands	26	25	26	26	26	63	65	63	62	63
Portugal	6	6	6	6	6	229	226	230	241	240
Spain	3	3	3	4	3	1046	1022	1045	1097	1064
Sweden	0	0	0	0	0	7	8	7	7	7
UK	49	50	49	49	48	111	116	111	108	110
EU-15	298	286	297	302	294	5714	5536	5699	5815	5710
Albania	0	0	0	0	0	0	0	0	0	0
Belarus	0	0	0	0	0	44	22	44	49	39
Bosnia-H	0	0	0	0	0	126	122	126	129	124
Bulgaria	0	0	0	0	0	228	196	229	229	225
Croatia	1	1	1	2	1	173	170	173	176	171
Czech Rep.	5	5	5	6	5	218	210	217	226	214
Estonia	0	0	0	0	0	0	0	0	0	0
Hungary	6	6	6	7	6	290	275	287	302	282
Latvia	0	0	0	0	0	2	1	2	3	2
Lithuania	0	0	0	0	0	9	2	9	11	7
Norway	0	0	0	0	0	1	1	1	1	1
Poland	18	17	18	20	17	529	498	527	584	518
R.of Moldova	0	0	0	0	0	43	34	43	44	42
Romania	1	0	1	1	1	458	402	458	480	443
Russia	5	2	5	5	4	861	611	860	868	857
Slovakia	3	3	3	4	3	153	140	151	159	148
Slovenia	1	1	1	1	1	78	77	78	78	77
Switzerland	1	0	1	1	0	70	68	70	70	69
FYR of Mac.	0	0	0	0	0	33	30	33	33	33
Ukraine	6	3	6	6	6	971	774	970	997	957
Yugoslavia	1	1	1	1	1	195	184	194	199	191
Non-EU	48	39	48	53	46	4481	3816	4472	4638	4402
Total	346	325	344	354	340	10194	9352	10171	10452	10112

Table 4.9: Ecosystems with deposition above critical loads for the central case and the sensitivity cases (1000 hectares)

	Acidification					Eutrophication				
	J1 central	J2 post Kyoto	J3 high SO_2	J4 low NH_3	J5 high NH_3	J1 central	J2 post Kyoto	J3 high SO_2	J4 low NH_3	J5 high NH_3
Austria	68	78	69	74	67	2477	2504	2471	2397	2491
Belgium	52	52	51	52	51	572	581	558	577	564
Denmark	5	5	5	5	5	85	84	84	72	86
Finland	756	673	757	644	775	1738	1486	1729	1613	1733
France	84	85	84	85	83	21632	21632	21627	21578	21885
Germany	567	585	588	604	558	7312	7504	7272	7464	7267
Greece	0	0	0	0	0	85	60	85	52	97
Ireland	8	9	8	9	8	29	29	29	29	29
Italy	51	51	51	51	50	2508	2498	2506	2360	2571
Luxembourg	1	1	1	1	1	63	63	63	63	63
Netherlands	76	75	76	76	76	278	276	278	276	278
Portugal	1	1	1	1	1	580	580	580	578	581
Spain	17	17	17	17	17	850	812	849	917	872
Sweden	1166	1142	1148	1170	1174	620	606	617	609	619
UK	636	547	650	639	604	62	58	62	55	58
EU-15	3486	3320	3504	3425	3469	38890	38775	38810	38641	39194
Albania	0	0	0	0	0	160	147	160	133	155
Belarus	686	116	688	687	565	924	940	924	937	937
Bosnia-H	0	0	0	0	0	460	440	458	438	483
Bulgaria	0	0	0	0	0	1263	1228	1263	1232	1615
Croatia	0	0	0	0	0	10	9	10	9	10
Czech Rep.	81	67	93	80	83	1983	1997	1977	1947	2019
Estonia	8	5	8	8	8	598	585	598	592	598
Hungary	37	36	37	37	37	125	125	125	125	126
Latvia	0	0	0	0	0	1417	1387	1415	1404	1418
Lithuania	5	0	5	5	0	894	894	894	895	899
Norway	1928	1950	1931	1900	1936	35	36	35	27	36
Poland	173	476	181	172	173	14894	14907	14895	14896	14906
R.of Moldova	10	10	10	10	10	0	0	0	0	0
Romania	17	17	17	17	17	1770	1770	1770	1769	1773
Russia	1026	1037	1027	636	1155	23123	20066	23121	21365	23094
Slovakia	149	138	151	151	149	939	916	935	937	952
Slovenia	4	4	4	4	4	87	87	87	85	87
Switzerland	35	36	35	36	35	1468	1472	1467	1445	1561
FYR of Mac.	0	0	0	0	0	108	101	108	93	106
Ukraine	237	303	242	238	238	3859	3763	3859	3736	3863
Yugoslavia	0	0	0	0	0	1280	1276	1280	1272	1287
Non-EU	4397	4196	4430	3981	4411	55396	52147	55380	53336	55926
Total	7883	7517	7934	7406	7880	94287	90921	94191	91977	95120

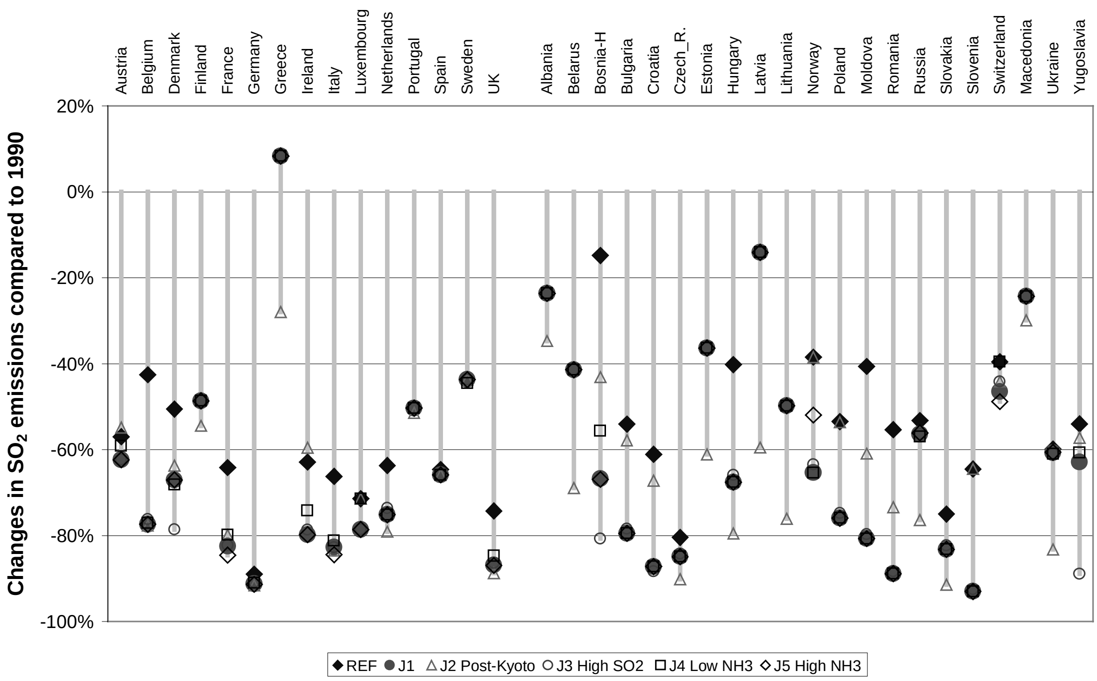

Figure 4.2: Changes in SO_2 emissions compared to 1990

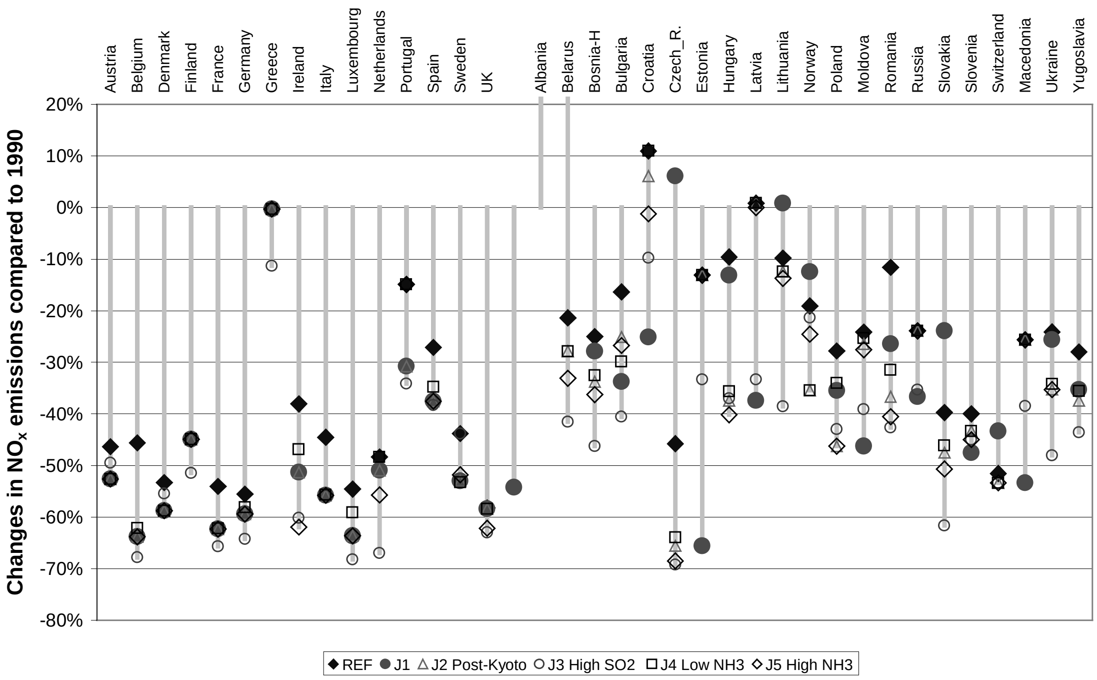

Figure 4.3: Changes in NO_x emissions compared to 1990

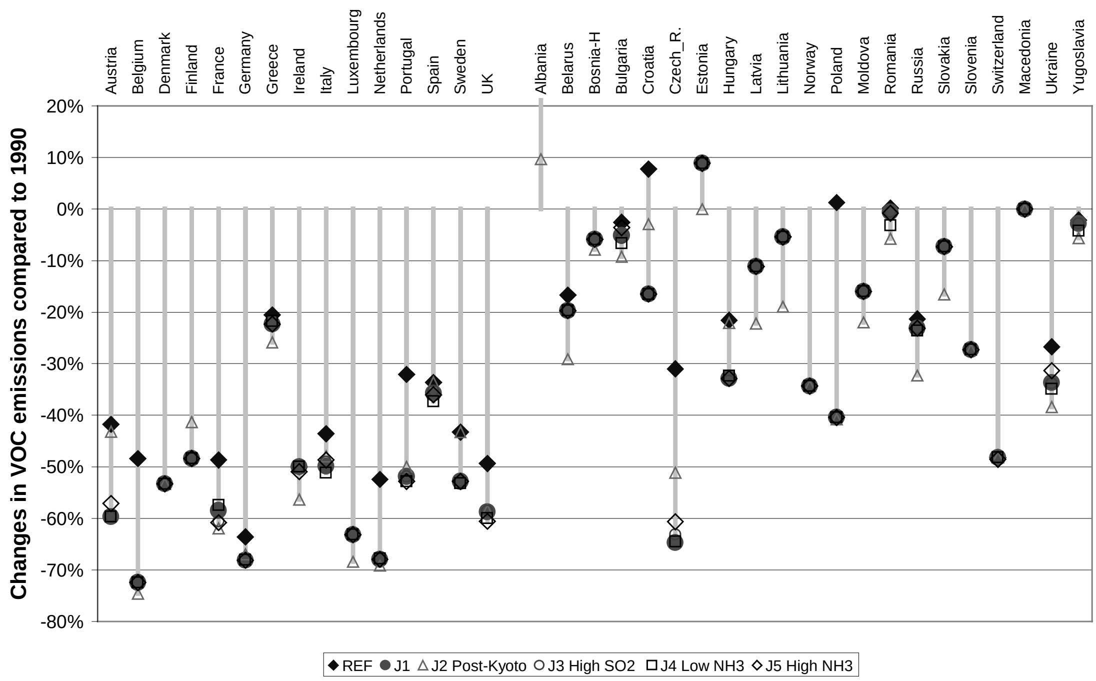

Figure 4.4: Changes in VOC emissions compared to 1990

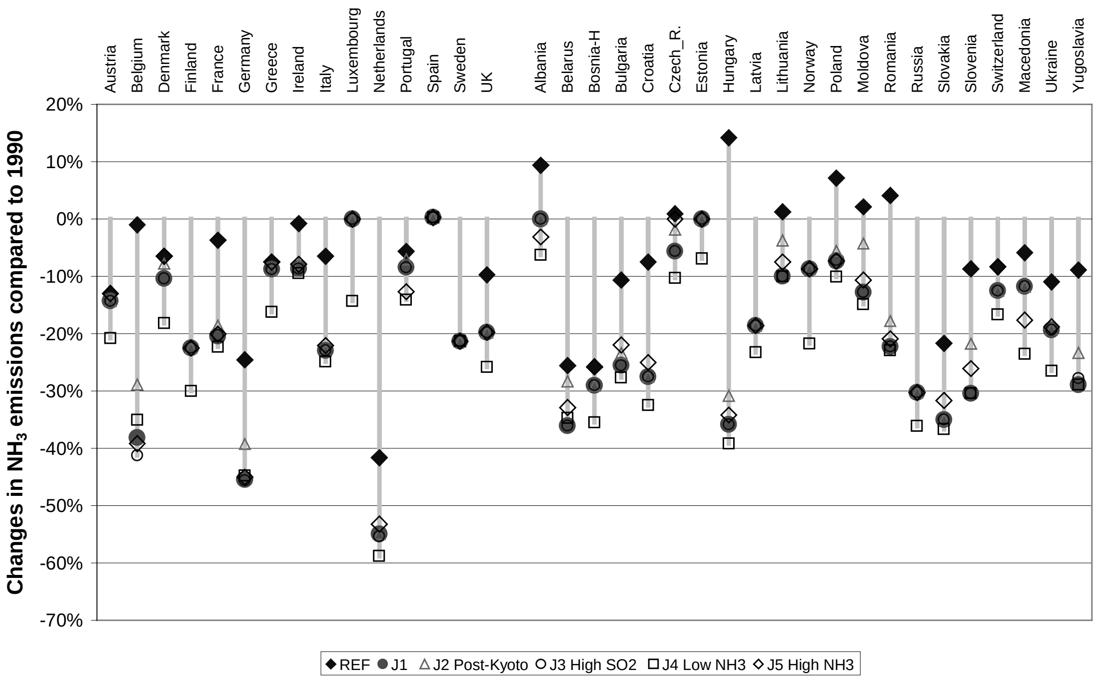

Figure 4.5: Changes in ammonia emissions compared to 1990

Summarizing the sensitivity analysis one can conclude that optimized emission reduction levels appear as robust towards (limited) increases in projected activity rates, reduced emission control potentials and increased costs for emission controls. Lower activity rates, however, do generally result in lower emission levels to relax most expensive emission controls. Cost savings for scenarios with low activity rates are substantial (-27 and -44 percent for the analyzed cases).

5 Sensitivity Analysis 2: Revised Critical Loads for Slovakia

After the final deadline for data submission on critical loads and the official approval of the critical load database by the UN/ECE Working Groups on Effects in August 1998, Slovakia indicated revisions to its critical loads database resulting in higher estimates for its most sensitive ecosystems. Since in the J1 scenario, which is based on the official critical load database, excess deposition in Slovakia is driving emission reductions in central Europe, a sensitivity analysis explored the implications of the proposed revisions in critical loads data.

As indicated in Table 5.1 to Table 5.3, higher critical loads in Slovakia would mainly relax SO_2 controls in Poland (-65 percent instead of -76 percent), in the south-eastern part of Europe (Yugoslavia, Slovenia, Bosnia, etc.), and to a minor extent in Slovakia, Hungary, Austria and Italy. It is interesting to note that less reductions in Polish SO_2 emissions have impacts on sensitive ecosystems in Germany and the Netherlands; higher sulfur deposition in this area would then be compensated by additional SO_2 controls in Denmark. Impacts on other pollutants are marginal. Total emission control costs would decline by about three percent.

Table 5.1: NO_x and VOC emissions for the sensitivity case with revised critical loads data for Slovakia compared to the J1 case. Percentage changes relate to the year 1990.

	NO_x				VOC			
	J1		J6		J1		J6	
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*
Austria	91	*-53%*	91	*-53%*	142	*-60%*	142	*-60%*
Belgium	127	*-64%*	127	*-64%*	103	*-72%*	103	*-72%*
Denmark	113	*-59%*	113	*-59%*	85	*-53%*	85	*-53%*
Finland	152	*-45%*	152	*-45%*	110	*-48%*	110	*-48%*
France	704	*-62%*	704	*-62%*	989	*-58%*	988	*-59%*
Germany	1081	*-59%*	1081	*-59%*	995	*-68%*	995	*-68%*
Greece	344	*0%*	344	*0%*	261	*-22%*	261	*-22%*
Ireland	55	*-51%*	55	*-51%*	55	*-50%*	55	*-50%*
Italy	901	*-56%*	901	*-56%*	1030	*-50%*	1034	*-50%*
Luxembourg	8	*-64%*	8	*-64%*	7	*-63%*	7	*-63%*
Netherlands	266	*-51%*	266	*-51%*	157	*-68%*	157	*-68%*
Portugal	144	*-31%*	144	*-31%*	102	*-52%*	102	*-52%*
Spain	726	*-38%*	726	*-38%*	648	*-36%*	648	*-36%*
Sweden	159	*-53%*	159	*-53%*	241	*-53%*	241	*-53%*
UK	1181	*-58%*	1181	*-58%*	1101	*-59%*	1101	*-59%*
EU-15	6054	*-54%*	6054	*-54%*	6024	*-57%*	6028	*-57%*
Albania	36	*50%*	36	*50%*	41	*32%*	41	*32%*
Belarus	290	*-28%*	290	*-28%*	298	*-20%*	298	*-20%*
Bosnia-H	53	*-34%*	53	*-34%*	48	*-6%*	48	*-6%*
Bulgaria	266	*-25%*	266	*-25%*	185	*-5%*	186	*-5%*
Croatia	87	*6%*	91	*11%*	86	*-17%*	86	*-17%*
Czech Rep.	188	*-66%*	188	*-66%*	156	*-65%*	156	*-65%*
Estonia	73	*-13%*	73	*-13%*	49	*9%*	49	*9%*
Hungary	137	*-37%*	137	*-37%*	137	*-33%*	137	*-33%*
Latvia	118	*1%*	118	*1%*	56	*-11%*	56	*-11%*
Lithuania	134	*-12%*	134	*-12%*	105	*-5%*	105	*-5%*
Norway	142	*-35%*	142	*-35%*	195	*-34%*	195	*-34%*
Poland	654	*-46%*	654	*-46%*	475	*-40%*	475	*-40%*
R.of Moldova	64	*-26%*	64	*-26%*	42	*-16%*	42	*-16%*
Romania	328	*-37%*	321	*-38%*	500	*-1%*	499	*-1%*
Russia	2653	*-24%*	2653	*-24%*	2723	*-23%*	2723	*-23%*
Slovakia	115	*-47%*	115	*-47%*	140	*-7%*	140	*-7%*
Slovenia	34	*-43%*	34	*-43%*	40	*-27%*	40	*-27%*
Switzerland	76	*-53%*	76	*-53%*	144	*-48%*	144	*-48%*
FYR of Maced.	29	*-26%*	29	*-26%*	19	*0%*	19	*0%*
Ukraine	1222	*-35%*	1222	*-35%*	770	*-34%*	772	*-34%*
Yugoslavia	132	*-37%*	132	*-37%*	138	*-3%*	138	*-3%*
Non-EU	6830	*-33%*	6827	*-33%*	6345	*-26%*	6348	*-26%*
Total	14513	*-42%*	14510	*-42%*	12370	*-45%*	12376	*-45%*

Table 5.2: SO_2 and NH_3 emissions for the sensitivity case with revised critical loads data for Slovakia compared to the J1 case. Percentage changes relate to the year 1990.

	SO_2				NH_3			
	J1		J6		J1		J6	
	kt	Change	kt	Change	kt	Change	kt	Change
Austria	35	*-62%*	39	*-58%*	66	*-14%*	66	*-14%*
Belgium	76	*-77%*	76	*-77%*	60	*-38%*	59	*-39%*
Denmark	60	*-67%*	32	*-82%*	69	*-10%*	69	*-10%*
Finland	116	*-49%*	116	*-49%*	31	*-23%*	31	*-23%*
France	219	*-82%*	219	*-82%*	642	*-20%*	643	*-20%*
Germany	463	*-91%*	463	*-91%*	413	*-45%*	412	*-46%*
Greece	546	*8%*	546	*8%*	73	*-9%*	73	*-9%*
Ireland	36	*-80%*	36	*-80%*	116	*-9%*	116	*-9%*
Italy	290	*-83%*	295	*-82%*	356	*-23%*	356	*-23%*
Luxembourg	3	*-79%*	3	*-79%*	7	*0%*	7	*0%*
Netherlands	50	*-75%*	50	*-75%*	105	*-55%*	104	*-55%*
Portugal	141	*-50%*	141	*-50%*	65	*-8%*	65	*-8%*
Spain	747	*-66%*	747	*-66%*	353	*0%*	353	*0%*
Sweden	67	*-44%*	66	*-45%*	48	*-21%*	48	*-21%*
UK	499	*-87%*	497	*-87%*	264	*-20%*	264	*-20%*
EU-15	3349	*-80%*	3328	*-80%*	2668	*-25%*	2667	*-25%*
Albania	55	*-24%*	55	*-24%*	32	*0%*	32	*0%*
Belarus	494	*-41%*	480	*-43%*	140	*-36%*	140	*-36%*
Bosnia-H	162	*-67%*	308	*-37%*	22	*-29%*	22	*-29%*
Bulgaria	378	*-79%*	378	*-79%*	105	*-26%*	105	*-26%*
Croatia	23	*-87%*	53	*-71%*	29	*-28%*	29	*-28%*
Czech Rep.	283	*-85%*	283	*-85%*	101	*-6%*	101	*-6%*
Estonia	175	*-36%*	175	*-36%*	29	*0%*	29	*0%*
Hungary	296	*-68%*	312	*-66%*	77	*-36%*	80	*-33%*
Latvia	104	*-14%*	104	*-14%*	35	*-19%*	35	*-19%*
Lithuania	107	*-50%*	107	*-50%*	72	*-10%*	71	*-11%*
Norway	18	*-65%*	18	*-65%*	21	*-9%*	20	*-13%*
Poland	722	*-76%*	1047	*-65%*	468	*-7%*	468	*-7%*
R.of Moldova	38	*-81%*	38	*-81%*	41	*-13%*	41	*-13%*
Romania	148	*-89%*	147	*-89%*	227	*-22%*	227	*-22%*
Russia	2186	*-56%*	2185	*-56%*	894	*-30%*	894	*-30%*
Slovakia	92	*-83%*	100	*-82%*	39	*-35%*	39	*-35%*
Slovenia	14	*-93%*	71	*-65%*	16	*-30%*	18	*-22%*
Switzerland	23	*-47%*	22	*-49%*	63	*-13%*	61	*-15%*
FYR of Maced.	81	*-24%*	81	*-24%*	15	*-12%*	15	*-12%*
Ukraine	1457	*-61%*	1352	*-64%*	588	*-19%*	587	*-19%*
Yugoslavia	217	*-63%*	255	*-56%*	64	*-29%*	64	*-29%*
Non-EU	7071	*-67%*	7572	*-65%*	3077	*-23%*	3078	*-23%*
Total	11572	*-70%*	12052	*-69%*	5745	*-24%*	5744	*-24%*

Table 5.3: Control costs for the sensitivity case with revised critical loads data for Slovakia compared to the J1 case (in million EURO/year).

	NO_x & VOC		SO_2		NH_3		Total	
	J1	J6	J1	J6	J1	J6	J1	J6
Austria	70	70	5	0	1	0	76	71
Belgium	452	452	122	123	312	350	886	925
Denmark	8	8	13	37	2	2	22	46
Finland	0	0	0	0	0	0	0	0
France	437	437	132	133	367	365	936	935
Germany	484	485	240	241	842	846	1567	1572
Greece	2	2	0	0	0	0	2	2
Ireland	10	10	12	12	146	146	168	168
Italy	245	241	87	84	85	85	417	410
Luxembourg	2	2	0	0	0	0	2	2
Netherlands	112	112	19	19	672	677	803	808
Portugal	57	57	0	0	2	2	59	59
Spain	42	42	9	9	0	0	51	51
Sweden	45	45	0	0	0	0	45	45
UK	353	352	295	299	23	23	671	675
EU-15	2318	2315	935	958	2450	2495	5704	5769
Albania	0	0	0	0	1	1	1	1
Belarus	3	3	0	4	9	9	12	15
Bosnia-H	2	2	55	20	1	1	58	23
Bulgaria	10	10	58	58	13	13	81	81
Croatia	5	3	18	5	3	3	26	11
Czech Rep.	235	235	36	35	9	9	280	279
Estonia	0	0	0	0	0	0	0	0
Hungary	112	112	113	65	319	257	545	434
Latvia	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	4	4	4	4
Norway	12	12	10	10	3	13	25	35
Poland	373	373	283	119	182	181	838	673
R.of Moldova	0	0	30	30	3	3	33	33
Romania	100	113	137	137	304	306	541	556
Russia	0	0	54	54	0	0	54	55
Slovakia	11	11	25	15	7	7	43	33
Slovenia	1	1	23	0	2	1	25	2
Switzerland	2	2	1	2	6	16	9	19
FYR of Maced.	0	0	0	0	1	1	1	1
Ukraine	44	44	8	39	30	32	82	115
Yugoslavia	6	6	27	5	94	96	128	107
Non-EU	917	927	879	598	991	952	2787	2478
Total	3235	3243	1814	1556	3442	3447	8490	8246

6 Sensitivity Analysis 3: Uniform Emission Reduction Scenarios

It has been shown by earlier work that cost-effectiveness implies differentiated requirements for emission reductions, taking into account regional differences in environmental sensitivities, differences in the potential and the costs for further emission controls, and in meteorological conditions. The presently observed variations of these factors in Europe lead to the fact, however, that the burden for additional emission control measures imposed by cost-optimized strategies on individual European countries might show certain variations.

In order to explore the gains in cost-effectiveness achieved by the optimization approach for the J1 scenario, two alternative scenarios are constructed:

Scenario J7 constructs a 'flat rate' emission control scenario, in which the average reduction rates for the four pollutants of the J1 scenario are applied uniformly to all European countries. Starting from the optimized J1 scenario and maintaining the environmental targets of this scenario, another scenario J8 explores the changes in emission control costs if the deviations from the average emission reduction levels (of the J7 scenario) were reduced as much as possible.

6.1 A 'Flat-rate' Emission Control Scenario (J7)

The rationale for the illustrative 'flat rate' scenario is to fix - as far as possible - each country's emissions to the value corresponding to the average percentage reduction across all EU-15 countries that was obtained for the J1 scenario. The average reductions from 1990 emission levels for each pollutant for the J1 scenario are as follows:

SO_2	-73 %
NO_x	-45 %
VOC	-45 %
NH_3	-24 %

For some combinations of countries and pollutants the EU-15 average emission reduction would lead to emission values which lie outside the range available for control. In such cases the emissions for this sensitivity scenario were set to the relevant bound, i.e. "MFR" or REF, as appropriate.

The emissions, costs and exposure indices obtained for this non-optimized "flat-rate" scenario H9 are summarized in Table 6.1 - Table 6.6.

Table 6.1: NO_x emissions for the flat rate emission control scenarios.. Percentage changes relate to the year 1990.

	J1 Central case		J7 Uniform		J8 Reduced var.	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	91	*-53%*	103	*-46%*	96	*-50%*
Belgium	127	*-64%*	191	*-46%*	150	*-57%*
Denmark	113	*-59%*	128	*-53%*	127	*-54%*
Finland	152	*-45%*	152	*-45%*	152	*-45%*
France	704	*-62%*	858	*-54%*	648	*-65%*
Germany	1081	*-59%*	1184	*-56%*	953	*-64%*
Greece	344	*0%*	248	*-28%*	254	*-26%*
Ireland	55	*-51%*	62	*-45%*	62	*-45%*
Italy	901	*-56%*	1122	*-45%*	988	*-51%*
Luxembourg	8	*-64%*	10	*-55%*	10	*-55%*
Netherlands	266	*-51%*	280	*-48%*	256	*-53%*
Portugal	144	*-31%*	114	*-45%*	115	*-45%*
Spain	726	*-38%*	640	*-45%*	646	*-44%*
Sweden	159	*-53%*	186	*-45%*	175	*-48%*
UK	1181	*-58%*	1186	*-58%*	1181	*-58%*
EU-15	6054	*-54%*	6464	*-51%*	5811	*-56%*
Albania	36	*50%*	16	*-33%*	16	*-33%*
Belarus	290	*-28%*	221	*-45%*	222	*-45%*
Bosnia-H	53	*-34%*	44	*-45%*	44	*-45%*
Bulgaria	266	*-25%*	195	*-45%*	197	*-45%*
Croatia	87	*6%*	45	*-45%*	45	*-45%*
Czech Rep.	188	*-66%*	296	*-46%*	278	*-49%*
Estonia	73	*-13%*	46	*-45%*	47	*-44%*
Hungary	137	*-37%*	120	*-45%*	120	*-45%*
Latvia	118	*1%*	65	*-44%*	65	*-44%*
Lithuania	134	*-12%*	84	*-45%*	84	*-45%*
Norway	142	*-35%*	125	*-43%*	129	*-41%*
Poland	654	*-46%*	670	*-45%*	651	*-47%*
R.of Moldova	64	*-26%*	48	*-45%*	48	*-45%*
Romania	328	*-37%*	286	*-45%*	287	*-45%*
Russia	2653	*-24%*	1920	*-45%*	2006	*-42%*
Slovakia	115	*-47%*	121	*-45%*	120	*-45%*
Slovenia	34	*-43%*	33	*-45%*	33	*-45%*
Switzerland	76	*-53%*	79	*-52%*	78	*-52%*
FYR of Mac.	29	*-26%*	21	*-46%*	21	*-46%*
Ukraine	1222	*-35%*	1039	*-45%*	1049	*-44%*
Yugoslavia	132	*-37%*	116	*-45%*	116	*-45%*
Non-EU	6830	*-33%*	5592	*-45%*	5656	*-44%*
Total	14513	*-42%*	13685	*-45%*	13097	*-48%*

Table 6.2: VOC emissions for the flat rate emission control scenarios. Percentage changes relate to the year 1990.

	J1 Central case		J7 Uniform		J8 Reduced var.	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	142	*-60%*	192	*-45%*	173	*-51%*
Belgium	103	*-72%*	193	*-48%*	145	*-61%*
Denmark	85	*-53%*	85	*-53%*	85	*-53%*
Finland	110	*-48%*	110	*-48%*	110	*-48%*
France	989	*-58%*	1223	*-49%*	976	*-59%*
Germany	995	*-68%*	1137	*-64%*	912	*-71%*
Greece	261	*-22%*	184	*-45%*	184	*-45%*
Ireland	55	*-50%*	55	*-50%*	55	*-50%*
Italy	1030	*-50%*	1123	*-45%*	1037	*-50%*
Luxembourg	7	*-63%*	7	*-63%*	7	*-63%*
Netherlands	157	*-68%*	233	*-52%*	194	*-60%*
Portugal	102	*-52%*	116	*-45%*	116	*-45%*
Spain	648	*-36%*	551	*-45%*	560	*-44%*
Sweden	241	*-53%*	279	*-45%*	266	*-48%*
UK	1101	*-59%*	1351	*-49%*	957	*-64%*
EU-15	6024	*-57%*	6838	*-51%*	5774	*-59%*
Albania	41	*32%*	17	*-45%*	17	*-45%*
Belarus	298	*-20%*	203	*-45%*	203	*-45%*
Bosnia-H	48	*-6%*	28	*-45%*	28	*-45%*
Bulgaria	185	*-5%*	107	*-45%*	107	*-45%*
Croatia	86	*-17%*	56	*-46%*	56	*-46%*
Czech Rep.	156	*-65%*	241	*-45%*	225	*-49%*
Estonia	49	*9%*	25	*-44%*	25	*-44%*
Hungary	137	*-33%*	111	*-46%*	111	*-46%*
Latvia	56	*-11%*	34	*-46%*	34	*-46%*
Lithuania	105	*-5%*	61	*-45%*	61	*-45%*
Norway	195	*-34%*	162	*-45%*	163	*-45%*
Poland	475	*-40%*	436	*-45%*	426	*-47%*
R.of Moldova	42	*-16%*	27	*-46%*	27	*-46%*
Romania	500	*-1%*	275	*-45%*	278	*-45%*
Russia	2723	*-23%*	1935	*-45%*	1951	*-45%*
Slovakia	140	*-7%*	82	*-46%*	82	*-46%*
Slovenia	40	*-27%*	30	*-45%*	30	*-45%*
Switzerland	144	*-48%*	144	*-48%*	143	*-49%*
FYR of Mac.	19	*0%*	10	*-47%*	10	*-47%*
Ukraine	770	*-34%*	634	*-45%*	636	*-45%*
Yugoslavia	138	*-3%*	77	*-46%*	78	*-45%*
Non-EU	6345	*-26%*	4696	*-45%*	4692	*-45%*
Total	12370	*-45%*	11534	*-49%*	10466	*-54%*

Table 6.3: SO_2 emissions of the flat rate emission control scenarios. Percentage changes relate to the year 1990.

	J1 Central case		J7 Uniform		J8 Reduced var.	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	35	*-62%*	31	*-67%*	31	*-67%*
Belgium	76	*-77%*	92	*-73%*	75	*-78%*
Denmark	60	*-67%*	50	*-73%*	50	*-73%*
Finland	116	*-49%*	71	*-69%*	73	*-68%*
France	219	*-82%*	343	*-73%*	238	*-81%*
Germany	463	*-91%*	468	*-91%*	444	*-92%*
Greece	546	*8%*	138	*-73%*	141	*-72%*
Ireland	36	*-80%*	49	*-72%*	48	*-73%*
Italy	290	*-83%*	461	*-73%*	397	*-76%*
Luxembourg	3	*-79%*	4	*-71%*	4	*-71%*
Netherlands	50	*-75%*	55	*-73%*	50	*-75%*
Portugal	141	*-50%*	78	*-73%*	78	*-73%*
Spain	747	*-66%*	601	*-73%*	586	*-73%*
Sweden	67	*-44%*	53	*-55%*	54	*-55%*
UK	499	*-87%*	980	*-74%*	493	*-87%*
EU-15	3349	*-80%*	3475	*-79%*	2762	*-83%*
Albania	55	*-24%*	20	*-72%*	20	*-72%*
Belarus	494	*-41%*	232	*-72%*	232	*-72%*
Bosnia-H	162	*-67%*	134	*-72%*	130	*-73%*
Bulgaria	378	*-79%*	506	*-73%*	492	*-73%*
Croatia	23	*-87%*	49	*-73%*	48	*-73%*
Czech Rep.	283	*-85%*	366	*-80%*	280	*-85%*
Estonia	175	*-36%*	75	*-73%*	76	*-72%*
Hungary	296	*-68%*	296	*-68%*	296	*-68%*
Latvia	104	*-14%*	33	*-73%*	33	*-73%*
Lithuania	107	*-50%*	59	*-72%*	59	*-72%*
Norway	18	*-65%*	17	*-67%*	17	*-67%*
Poland	722	*-76%*	824	*-73%*	701	*-77%*
R.of Moldova	38	*-81%*	54	*-73%*	54	*-73%*
Romania	148	*-89%*	366	*-73%*	330	*-75%*
Russia	2186	*-56%*	1377	*-73%*	1402	*-72%*
Slovakia	92	*-83%*	137	*-75%*	111	*-80%*
Slovenia	14	*-93%*	55	*-73%*	54	*-73%*
Switzerland	23	*-47%*	12	*-72%*	12	*-72%*
FYR of Mac.	81	*-24%*	29	*-73%*	29	*-73%*
Ukraine	1457	*-61%*	1018	*-73%*	1015	*-73%*
Yugoslavia	217	*-63%*	161	*-72%*	154	*-74%*
Non-EU	7071	*-67%*	5818	*-73%*	5544	*-74%*
Total	11572	*-70%*	10446	*-73%*	9458	*-76%*

Table 6.4: NH_3 emissions for the central scenario J1 compared to the flat rate emission control scenarios. Percentage changes relate to the year 1990.

	J1 Central case		J7 Uniform		J8 Reduced var.	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	66	*-14%*	59	*-23%*	59	*-23%*
Belgium	60	*-38%*	74	*-24%*	64	*-34%*
Denmark	69	*-10%*	58	*-25%*	60	*-22%*
Finland	31	*-23%*	31	*-23%*	31	*-23%*
France	642	*-20%*	613	*-24%*	601	*-26%*
Germany	413	*-45%*	570	*-25%*	444	*-41%*
Greece	73	*-9%*	61	*-24%*	61	*-24%*
Ireland	116	*-9%*	111	*-13%*	113	*-11%*
Italy	356	*-23%*	351	*-24%*	346	*-25%*
Luxembourg	7	*0%*	7	*0%*	7	*0%*
Netherlands	105	*-55%*	136	*-42%*	104	*-55%*
Portugal	65	*-8%*	54	*-24%*	54	*-24%*
Spain	353	*0%*	268	*-24%*	274	*-22%*
Sweden	48	*-21%*	46	*-25%*	47	*-23%*
UK	264	*-20%*	250	*-24%*	249	*-24%*
EU-15	2668	*-25%*	2689	*-25%*	2513	*-30%*
Albania	32	*0%*	25	*-22%*	25	*-22%*
Belarus	140	*-36%*	163	*-26%*	163	*-26%*
Bosnia-H	22	*-29%*	23	*-26%*	23	*-26%*
Bulgaria	105	*-26%*	107	*-24%*	107	*-24%*
Croatia	29	*-28%*	30	*-25%*	30	*-25%*
Czech Rep.	101	*-6%*	81	*-24%*	82	*-23%*
Estonia	29	*0%*	22	*-24%*	22	*-24%*
Hungary	77	*-36%*	91	*-24%*	75	*-38%*
Latvia	35	*-19%*	33	*-23%*	33	*-23%*
Lithuania	72	*-10%*	61	*-24%*	61	*-24%*
Norway	21	*-9%*	18	*-22%*	18	*-22%*
Poland	468	*-7%*	384	*-24%*	403	*-20%*
R.of Moldova	41	*-13%*	36	*-23%*	36	*-23%*
Romania	227	*-22%*	222	*-24%*	226	*-23%*
Russia	894	*-30%*	891	*-30%*	891	*-30%*
Slovakia	39	*-35%*	45	*-25%*	45	*-25%*
Slovenia	16	*-30%*	17	*-26%*	17	*-26%*
Switzerland	63	*-13%*	55	*-24%*	55	*-24%*
FYR of Mac.	15	*-12%*	13	*-24%*	13	*-24%*
Ukraine	588	*-19%*	554	*-24%*	566	*-22%*
Yugoslavia	64	*-29%*	68	*-24%*	68	*-24%*
Non-EU	3077	*-23%*	2938	*-26%*	2959	*-26%*
Total	5745	*-24%*	5627	*-26%*	5471	*-28%*

Table 6.5: Control costs on top of the REF scenarios for SO_2, NO_x and VOC emissions for the flat rate emission control scenarios (in million EURO/year)

	NO_x & VOC			SO_2		
	J1 Central	J7 Uniform	J8 Reduced var	J1 Central	J7 Uniform	J8 Reduced var.
Austria	70	3	18	5	18	18
Belgium	452	0	88	122	68	154
Denmark	8	0	0	13	22	22
Finland	0	0	0	0	106	88
France	437	0	1003	132	38	105
Germany	484	0	2166	240	282	331
Greece	2	490	408	0	203	197
Ireland	10	2	2	12	6	6
Italy	245	21	147	87	30	51
Luxembourg	2	0	0	0	0	0
Netherlands	112	0	76	19	11	19
Portugal	57	141	136	0	27	27
Spain	42	288	259	9	57	61
Sweden	45	4	13	0	80	43
UK	353	0	1071	295	0	310
EU-15	2318	949	5387	935	948	1433
Albania	0	89	88	0	15	15
Belarus	3	96	95	0	93	93
Bosnia-H	2	26	26	55	64	65
Bulgaria	10	181	176	58	42	44
Croatia	5	146	147	18	6	6
Czech Rep.	235	23	38	36	0	40
Estonia	0	54	54	0	42	42
Hungary	112	231	241	113	113	113
Latvia	0	128	127	0	33	33
Lithuania	0	129	128	0	20	20
Norway	12	198	127	10	16	16
Poland	373	492	614	283	232	305
R.of Moldova	0	16	16	30	23	23
Romania	100	340	330	137	52	60
Russia	0	1133	887	54	333	322
Slovakia	11	57	58	25	0	10
Slovenia	1	8	8	23	6	7
Switzerland	2	0	1	1	34	34
FYR of Mac.	0	15	15	0	28	28
Ukraine	44	283	263	8	155	156
Yugoslavia	6	60	60	27	72	77
Non-EU	917	3705	3497	879	1379	1509
Total	3235	4654	8885	1814	2327	2943

Table 6.6: Control costs for NH_3 emissions and total costs on top of the REF for the flat rate emission control scenarios (in million EURO/year)

	NH_3			Total		
	J1 Central	J7 Uniform	J8 Reduced var.	J1 Central	J7 Uniform	J8 Reduced var.
Austria	1	38	39	76	60	75
Belgium	312	95	235	886	163	477
Denmark	2	120	91	22	142	112
Finland	0	0	0	0	106	88
France	367	586	682	936	624	1790
Germany	842	1	535	1567	283	3033
Greece	0	95	84	2	788	689
Ireland	146	455	216	168	463	224
Italy	85	96	113	417	147	311
Luxembourg	0	0	0	2	0	0
Netherlands	672	0	741	803	11	837
Portugal	2	51	49	59	220	212
Spain	0	497	421	51	841	741
Sweden	0	33	25	45	117	81
UK	23	95	108	671	95	1489
EU-15	2450	2164	3340	5704	4061	10161
Albania	1	56	53	1	160	155
Belarus	9	0	0	12	189	188
Bosnia-H	1	0	0	58	90	91
Bulgaria	13	10	9	81	232	229
Croatia	3	3	3	26	154	157
Czech Rep.	9	160	152	280	184	230
Estonia	0	6	6	0	103	103
Hungary	319	94	385	545	438	738
Latvia	0	1	1	0	162	161
Lithuania	4	58	55	4	207	203
Norway	3	74	71	25	287	214
Poland	182	1056	655	838	1779	1574
R.of Moldova	3	21	21	33	60	60
Romania	304	385	323	541	777	712
Russia	0	5	5	54	1472	1214
Slovakia	7	1	1	43	58	69
Slovenia	2	1	1	25	15	16
Switzerland	6	105	105	9	139	140
FYR of Mac.	1	7	7	1	50	50
Ukraine	30	134	87	82	572	507
Yugoslavia	94	57	54	128	189	191
Non-EU	991	2234	1995	2787	7319	7002
Total	3442	4398	5336	8490	11380	17163

Table 6.7: Cumulative ozone exposure indices for the flat rate emission control scenarios

	Population			Vegetation		
	J1 Central	J7 Uniform	J8 Reduced var.	J1 Central	J7 Uniform	J8 Reduced var.
Austria	1	2	1	194	232	193
Belgium	22	32	22	115	138	115
Denmark	1	2	1	30	45	30
Finland	0	0	0	0	0	0
France	54	83	50	1865	2278	1763
Germany	91	130	89	901	1133	873
Greece	3	2	2	146	110	105
Ireland	0	1	0	3	7	3
Italy	40	55	41	993	1107	988
Luxembourg	1	1	1	11	14	11
Netherlands	26	36	26	63	76	62
Portugal	6	5	5	229	210	205
Spain	3	4	2	1046	963	901
Sweden	0	0	0	7	12	7
UK	49	73	44	111	152	96
EU-15	298	426	284	5714	6476	5350
Albania	0	0	0	0	0	0
Belarus	0	0	0	44	22	18
Bosnia-H	0	0	0	126	125	111
Bulgaria	0	0	0	228	178	172
Croatia	1	2	1	173	175	158
Czech Rep.	5	9	6	218	269	220
Estonia	0	0	0	0	0	0
Hungary	6	6	5	290	292	261
Latvia	0	0	0	2	1	0
Lithuania	0	0	0	9	2	1
Norway	0	0	0	1	1	1
Poland	18	24	17	529	593	481
R.of Moldova	0	0	0	43	32	30
Romania	1	0	0	458	399	371
Russia	5	2	2	861	460	477
Slovakia	3	4	3	153	161	143
Slovenia	1	1	1	78	85	76
Switzerland	1	2	0	70	83	68
FYR of Mac.	0	0	0	33	25	24
Ukraine	6	2	2	971	747	715
Yugoslavia	1	1	0	195	183	167
Non-EU	48	53	39	4481	3834	3494
Total	346	479	323	10194	10310	8844

Compared to the J1 scenario, the flat-rate scenario J7 would require increased control measures in Denmark, Finland, Greece, Ireland, Portugal, Spain and Sweden and in most non-EU countries. In contrast, Austria, Belgium, France, Germany, Italy, Luxembourg, Netherlands and United Kingdom, and the Czech Republic, Hungary and Slovenia would experience reduced emission control costs. For the ECE as a whole, the flat-rate scenario J7 would cost 2.9 billion EURO more than J1, an increase of 34 percent.

Table 6.7 and Table 6.8 show that the flat-rate scenario J7 would result in a generally lower environmental improvement – for the ECE as a whole – than the J1 scenario.

Health-related ozone exposure, in terms of the cumulative population exposure index, would increase by 38 percent, particularly in the high-ozone area of Germany, France, UK, Belgium and the Netherlands. For vegetation-related ozone exposure the largest increases would be found in France and Germany. For acidification, 4.1 instead of 3.5 million hectares in the EU would remain unprotected (+17 percent), while additional measures in the eastern Europe achieve additional environmental benefits there.

A graphical comparison of the changes in the environmental indicators in relation to emission control costs is provided in Figure 6.2 to Figure 6.4. From these graphs it is obvious that, for the ECE as a whole, flat-rate emission reductions of the J7 scenario result in a significantly lower cost-effectiveness for two of the environmental problems considered (vegetation- and health-related ozone exposure).

6.2 A Scenario with Reduced Variability in National Emission Reductions (J8)

Another scenario was developed with the aim of keeping emission reductions as uniform as possible within the EU-15 countries but at the same time ensuring that the J1 targets would be achieved.

In practice, the mathematical optimization problem was extended by a 'regularization' term, which puts a (quadratic) penalty on each deviation of an optimized emission reduction level from an exogeneously specified 'target' emission level. The goal function of the optimization problem as presented in Section 2.7.1.5 in Part A of the Sixth Interim Report is extended by a regularization term

$$\varepsilon \, \| z - \breve{z} \|^2$$

where z denotes the vector of the decision variables (emissions relative to 1990) and $\breve{z}$ the vector of the 'target' emission levels (relative to 1990). For the particular case of the J8 scenarios, the emission levels of the J7 scenario was used as the target level.

Depending on the weight ε given to the regularization, the optimization balances the deviations from these target levels against the overall emission control costs. With sufficiently small regularization coefficients, the optimization ends up with the emission levels of the original J1 scenario, while an increase of this coefficient would ultimately push all emission reductions to the target levels of the J8 scenario (if these achieved the J1 targets).

Table 6.1 to Table 6.6 show the emissions of the J8 scenario. Comparison with J7 shows where it proves necessary for some countries to make greater emission reductions than the average in order to ensure that the environmental targets of J1 are met. For NH_3, for example, the results suggest that the Netherlands, Germany and Belgium are required to make above-average emission reductions if the J1 targets are to be achieved.

Compared to the J1 scenario, only Belgium, Luxembourg, Italy, Slovenia and the Czech Republic would benefit from reduced emission costs in the J8 scenario. The overall costs (above REF) to the ECE countries are twice as high as in J1, i.e., they increase by 8.6 billion EURO.

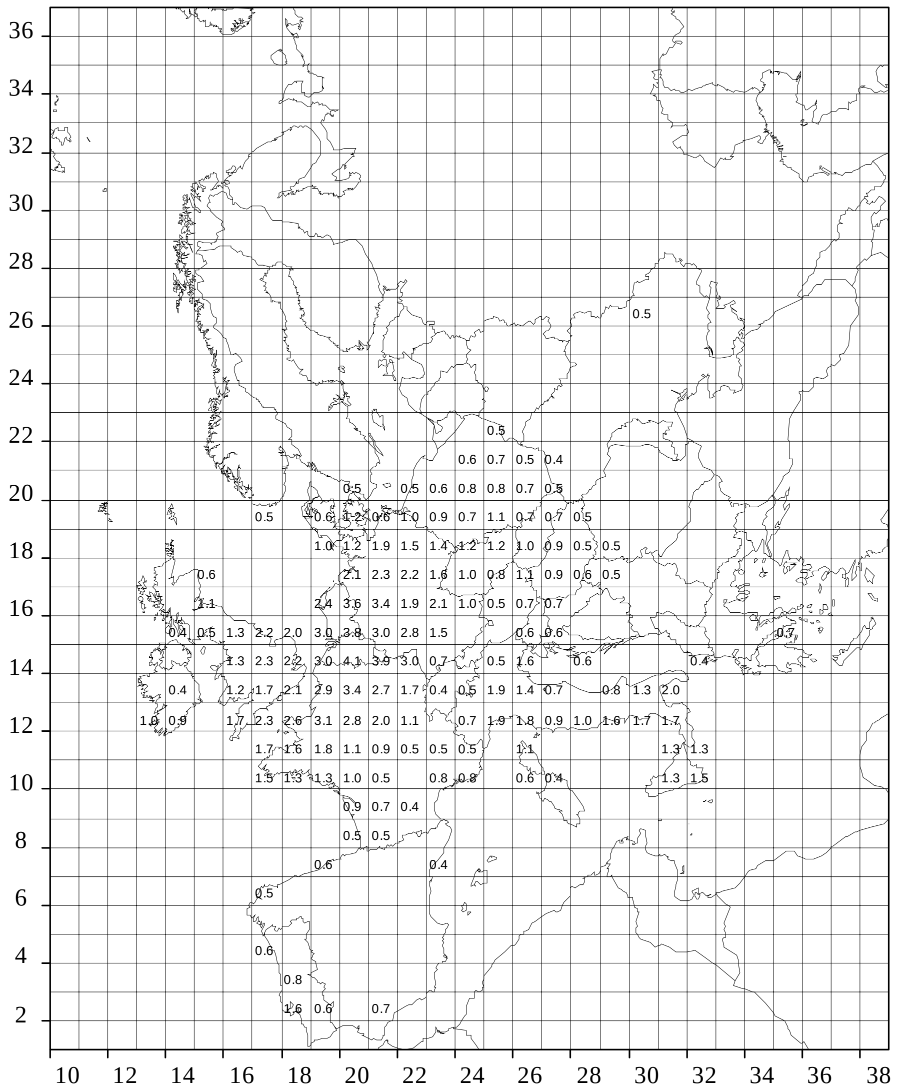

Figure 6.1: AOT60 (second highest occurrence in meteorological conditions of five years) for the emissions of the uniform J7 scenario

Table 6.8: Ecosystems with deposition above critical loads (1000 hectares)

	Acidification			Eutrophication		
	J1 central	J7 uniform	J8	J1 central	J7 uniform	J8
Austria	68	108	67	2477	2860	2280
Belgium	52	106	51	572	628	563
Denmark	5	6	4	85	72	58
Finland	756	360	335	1738	1457	1381
France	84	105	81	21632	21182	20447
Germany	567	1142	551	7312	8763	7236
Greece	0	0	0	85	47	46
Ireland	8	9	8	29	28	28
Italy	51	56	51	2508	2671	2345
Luxembourg	1	4	1	63	70	61
Netherlands	76	163	76	278	287	277
Portugal	1	0	0	580	349	356
Spain	17	10	9	850	204	173
Sweden	1166	1124	925	620	667	566
UK	636	944	565	62	58	56
EU-15	3486	4136	2726	38890	39344	35874
Albania	0	0	0	160	109	105
Belarus	686	72	41	924	894	884
Bosnia-H	0	0	0	460	496	445
Bulgaria	0	0	0	1263	1114	884
Croatia	0	0	0	10	10	9
Czech Rep.	81	170	66	1983	2016	1845
Estonia	8	3	3	598	560	554
Hungary	37	38	37	125	129	125
Latvia	0	0	0	1417	1230	1187
Lithuania	5	0	0	894	850	840
Norway	1928	2015	1746	35	43	26
Poland	173	208	140	14894	13925	13573
R.of Moldova	10	10	10	0	0	0
Romania	17	17	17	1770	1730	1717
Russia	1026	111	109	23123	18565	18731
Slovakia	149	173	154	939	1031	931
Slovenia	4	4	4	87	89	85
Switzerland	35	39	33	1468	1522	1363
FYR of Mac.	0	0	0	108	83	80
Ukraine	237	221	136	3859	3663	3586
Yugoslavia	0	0	0	1280	1269	1158
Non-EU	4397	3084	2497	55396	49328	48128
Total	7883	7220	5222	94287	88672	84002

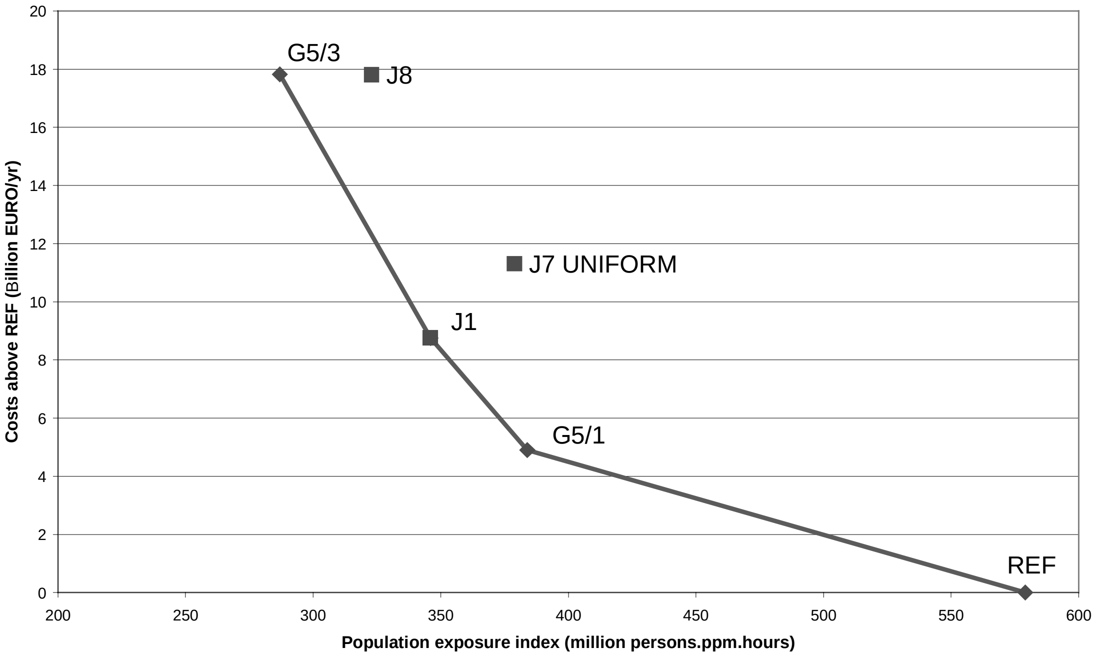

Figure 6.2: Cost-effectiveness of the 'flat rate' reduction scenarios in relation to the population exposure index

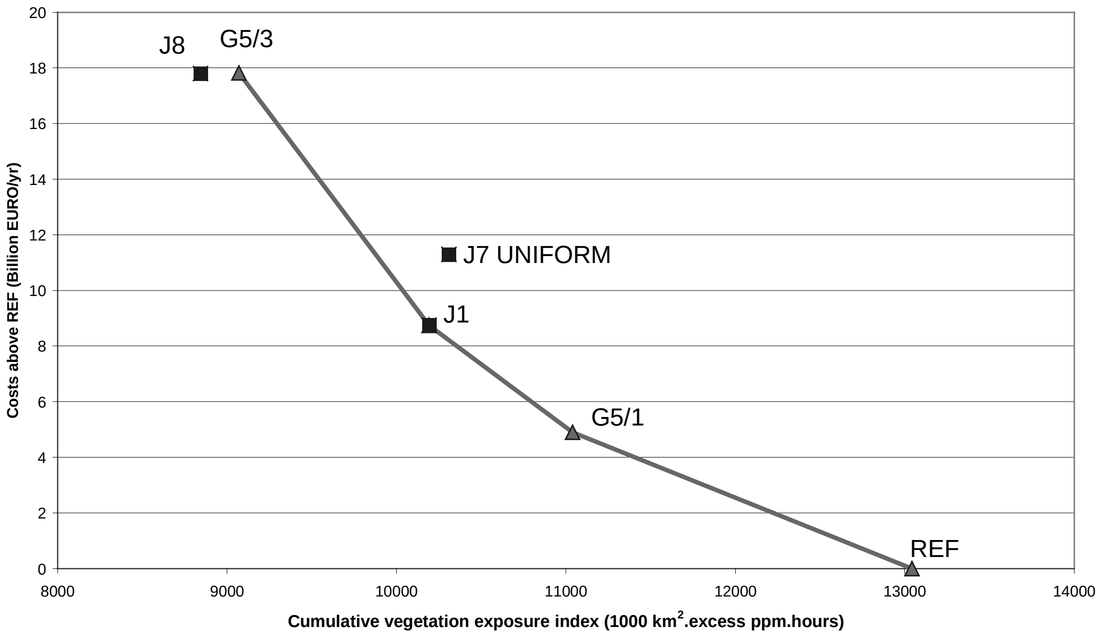

Figure 6.3: Cost-effectiveness of the 'flat rate' reduction scenarios in relation to the vegetation exposure index

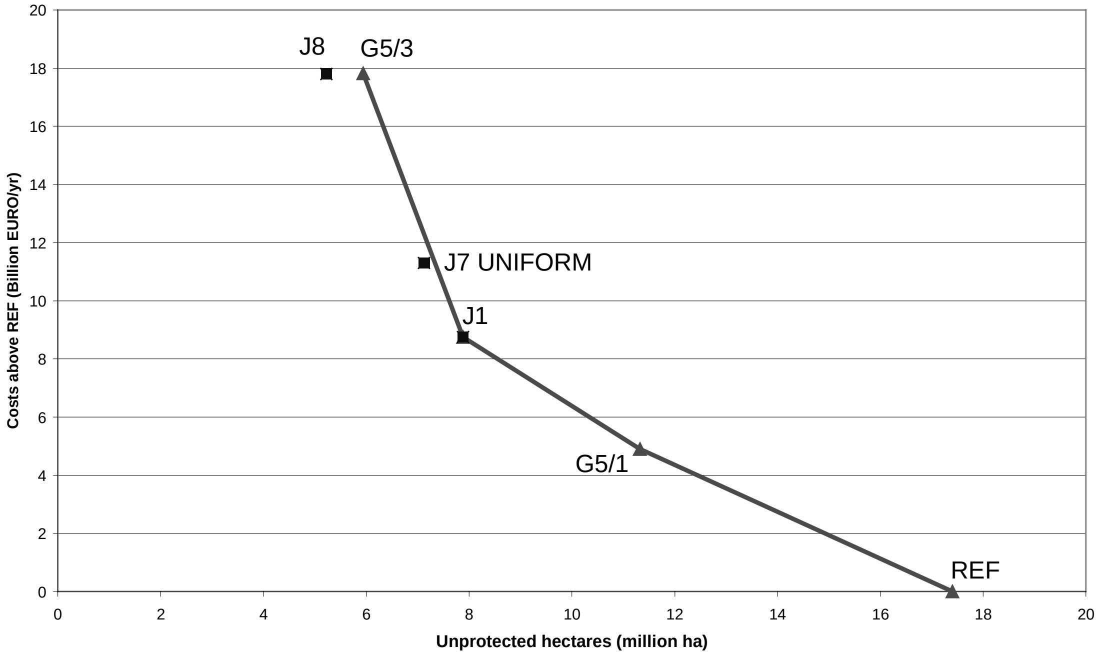

Figure 6.4: Cost-effectiveness of the 'flat rate' reduction scenarios in relation to the area of ecosystems not protected against acidification

7 Uncertainties in the Model Calculations

The sensitivity of the optimization results against changes in important input assumptions was extensively explored in preceding sections of this report. Besides the uncertainties in the input assumptions, however, there exists a wide range of uncertainties associated with the present model setup and the available databases. Unfortunately, a systematic quantification of the sensitivity of the optimization results in relation to these model and data uncertainties is much more complicated to conduct and would require substantial time and resources. Nevertheless, some qualitative considerations about the possible influence of such uncertainties can be provided.

Without any doubt there exist considerable uncertainties in almost all parts of the model framework, e.g., in the emission inventories, the estimates of emission control potentials, the atmospheric dispersion calculations and in the estimate of environmental sensitivities. However, a systematic analysis of the importance of these uncertainties requires as a starting point a quantification of the uncertainties of all the input data. One would need, e.g., concrete numbers about the accuracy of individual emission estimates (on a sectoral level), about the accuracy of dispersion calculations, which must be compared against monitoring data which are in themselves of uncertain quality, and about the precision of the critical loads/critical levels estimates, which can only be determined against long-term monitoring data. At the moment, such quantitative information is not available for most of the input elements of the model.

In such a situation an overall uncertainty analysis could only explore the theoretical influence of the individual uncertainties on the final model output, without actually quantifying the importance of the individual elements and the confidence range of model results.

As a general rule, uncertainties with a symmetric distribution (e.g., if the central value is more or less in the middle of the possible range) result in most cases also in symmetric distributions of the model output[1]. In other words, if the probability distribution of input data is symmetric around the central value, than also the output variable will be in the center of the distribution. Translated into the specific air quality optimization problem, if the present input data are assumed to represent the central value with some symmetric probability distribution around it, then also the output will be a central value, with some probability for lower results and a comparable probability for higher results. An exact quantification of the confidence intervals (σ) cannot be provided without further information.

In the specific case of emission limits for individual sources calculated to meet environmental targets, however, there is additional information available to interpret possible variations within the confidence intervals. Since there exists some kind of physical mass balance between overall emissions and environmental exposure, possible variations of the individual emissions are not independent of each other. It is obvious that the environmental targets will not be met, if all emission sources simultaneously move to, e.g., the upper ends of their individual confidence intervals. Consequently, when interpreting possible deviations from the central values, some kind of mechanism must guarantee that less emission reductions at some sources (countries) are compensated by additional reductions in other countries.

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[1] At least for the calculations performed within RAINS.

This line of thought, however, does not hold in case of unsymmetrical probability distributions, i.e., if estimates are associated with a systematic bias. In such a case such a bias might feed through the entire chain from environmental targets via dispersion calculations to emission control potentials and costs, so that also the final optimization result might be biased. It is therefore important to scrutinize the various model parts and databases against possible biases. For the calculations presented above, some potential biases have been identified:

- It has been shown that in some cases the steady-state approach for estimating critical loads suggests higher (less sensitive) threshold values than would result from a dynamic analysis (FOEFL, 1997).
- It has been demonstrated that the selected spatial scale of critical loads mapping influences the distribution of critical loads estimates (Barkman, 1997). Higher spatial resolution captures smaller ecosystems with extreme (low or high) sensitivities, which are not considered if the analysis is done on a highly aggregated level. As a consequence, higher spatial resolution of the mapping exercise decreases the critical loads of the low percentiles and increases the critical loads for the high percentiles, if compared to a more aggregated analysis. In most countries the present-day mapping is typically performed with a spatial resolution of 1-3 kilometers.
- A similar effect also occurs for the atmospheric dispersion calculations, which are presently carried out with a 150 x 150 km resolution. The atmospheric models try to capture the average conditions for each grid, which implies that there are some areas with lower deposition, but also some areas with higher deposition than predicted by the model. For ground-level ozone, the EMEP model is designed to estimate rural ozone concentrations. It is clear from the model design, that it necessarily overestimates ozone concentrations in city centers, but at the same time it systematically underestimates ozone levels in the suburbs (Moussioupoulos *et al*., 1998, EMEP, 1998)). A finer resolution of the atmospheric calculations would yield certain areas with higher ozone than currently estimated.
- Furthermore, the model calculations presented in this report assume a constant level of background concentration originating from hemispheric scale emissions. Thereby, the analysis ignores the hemispheric feedback of European emission reductions on background concentrations in Europe, but perhaps more importantly, it also ignores the potential for dramatic increases of emissions, e.g., in south-east Asia (see also Hov *et al*., 1993).
- There is also a demonstrated bias in the estimates of the emission control potentials and costs. Numerous studies proved that exclusion of non-technical measures from the analysis underestimates the existing reduction potential and systematically overestimates the costs. The general phenomenon is described in Rentz *et al.,* 1994, For a case study on France see Rentz *et al.,* 1992.

In conclusion it can be stated that, according to current information, there is a chance that for a number of reasons the emission reductions calculated by RAINS are at the minimum level required to really meet the environmental targets. A more conservative treatment, e.g., of the environmental sensitivities would probably call for stricter measures.

A conclusion from the sensitivity analysis presented in this paper is that optimized emission ceilings appear generally as robust against higher activity rates, but would decline for scenarios with lower rates of economic. This is of particular importance for the specific analysis based on a pre-Kyoto scenario, which is incompatible with the existing decisions for meeting the Kyoto targets on controlling the amount of greenhouse gases.

As mentioned before, a systematic assessment of the role of individual model and data uncertainties is a complex matter and would require more time and resources than available for this study. Standard techniques for estimating the propagation of individual uncertainties through a chain of calculation steps (as is the case for the optimization) typically require several 10,000 - 100,000 model runs. A single non-linear optimization, e.g., for the F8 scenario presented in this report, might consume about 72 hours of CPU time on IIASA's fastest workstation, which illustrates the technical difficulties of performing standard methods of uncertainty analysis.

Despite these theoretical and practical difficulties, however, several precautionary measures were taken to limit the influence of the most uncertain model elements in the optimization results. As described in Part A, the environmental targets were selected in such a way that the confidence ranges in model performance are taken into account. Furthermore, extreme values in critical loads estimates (the low percentiles) were disregarded when setting the environmental targets, and the revised cost-curve routine excludes measures with questionable cost-effectiveness (e.g., retrofits of already controlled plants, etc.).

It remains to the user of the analysis to interpret the optimization results along the known but still unquantified uncertainties. In order to minimize the potential flaw from theoretically possible model biases, it is clear that more trust should be put in the relative changes (e.g., percent change compared to the base year) than in absolute numbers on resulting emission levels.

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