

SEVENTH INTERIM REPORT

Cost-effective Control of Acidification and Ground-level Ozone

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**Seventh Interim Report to the
European Commission, DG-XI**

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Seventh Interim Report

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1 Introduction

There is substantial concern about the environmental impacts of air pollution on the local, regional and global scale. It has been shown that observed levels of various air pollutants can threaten human health, vegetation, wild life, and cause damage to materials. In order to limit the negative effects of air pollution, measures to reduce emissions from a variety of sources have been initiated.

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

Over the last decade several international agreements have been reached in Europe to reduce emissions in a harmonized way. Protocols under the Convention on Long-range Transboundary Air Pollution focus on reducing emissions of sulfur dioxide (SO₂), nitrogen oxides (NO_x) and volatile organic compounds (VOC). Several directives of the European Union prescribe emission standards for large combustion plants, for mobile sources, and limit the sulfur content in liquid fuels.

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

It is generally expected that the current policies on emission reductions will greatly reduce the levels of tropospheric ozone. However, the measures will not be sufficient to eliminate the problem everywhere in Europe. To meet the environmental long-term targets aiming at the protection of human health and vegetation, as they are currently discussed in the context of the Commission's ozone strategy, additional- measures will be necessary. Since most of the low-cost options for abating emissions are already adopted in the current strategies, further action aiming at the sustainability of Europe's ecosystems will have to embark on more costly measures. Cost-effectiveness will be an important argument for gaining acceptance of proposed policies.

1.1 Structure of this Report

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

Following the presentation of the Sixth Interim Report, the Commission requested a number of refinements to reflect recent policy decisions taken at the Commission. Consequently, this Seventh Interim Report revisits the central scenarios supporting the proposed emission ceilings, taking into account recent agreements on sulfur in heavy fuel oil, an improved quantitative interpretation of the results of the conciliation process between the European Commission and the European Parliament on the Auto/Oil proposal, and the Council decision on emission standards for heavy duty trucks. Furthermore, it reflects the recent decision of the UN/ECE Working Group on Strategies about the starting point of the negotiations on further emission reductions for the non-EU countries.

This report focuses on scenario results for the modified input assumptions. Descriptions of the general modeling approach, the database and the target setting principles can be found in Part A of the Sixth Interim Report (Amann et al., 1998). Up-to-date detailed information and documentation of the cost curves and the optimization algorithm is available on the Internet under <http://www.iiasa.ac.at/~rains>.

Section 2 reviews the starting point for the scenario analysis, i.e., the situation in 1990, the expected outcome of the current legislation and the theoretical case, if all available technical emission control measures were applied to the entire stock of emission sources.

Section 3 recalls the environmental interim targets for acidification and ground-level ozone developed in the earlier Interim Reports and presents the revised cost-optimized set of emission reductions to achieve the targets of the central H1 scenario of the Sixth Interim Report. The impacts of modified environmental ambition levels on optimized emission reductions are reported in Section 4, and Section 5 discusses the implications of extending the scope of emission controls beyond the EU-15 countries.

1.2 Changes Since the Sixth Interim Report

Since the Sixth Interim Report (Amann *et al.*, 1998), the following changes were introduced into the database:

- 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.
- For the non-EU countries, the REF scenario was changed to reflect the decisions taken at the UN/ECE Working Group on Strategies at their August 1998 session. Thereby, for non-EU countries, the CLE estimates are used as the starting point for the optimization.
- 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.
- Updates of the French and Dutch ammonia databases.
- For Denmark, the assumptions about the applicability of NO_x control for gas fired power stations were modified to incorporate additional information on size distribution, boiler types, etc. provided by national experts.
- For Belgium, the applicability of some SO₂ and NO_x control technologies were modified to reflect findings of the recent assessments performed by Belgium experts.
- For Germany, the national energy scenario was updated with the latest projections on power capacity expansion.
- Poland provided more information to update the VOC database.

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, the Expected Impacts of the Current Policies and the Maximum Technically Feasible Reductions

2.1 Projected Emissions and Control Costs

2.1.1 The Reference (REF) Scenario for the Year 2010

A Reference scenario has been constructed in order to assess the likely environmental impacts of the current emission control strategies in the year 2010. The scenario takes into account national and international legislation (the CLE case). For the EU-15 countries, emissions resulting from this 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 the EU-15, the revised REF scenario results in a 48 percent cut of NO_x and a 49 percent cut of VOC emissions, compared to 1990.

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. European emission control costs for NO_x and VOC emissions amount to 53 billion EURO/year, out of which 47 billion emerge in the EU-15 countries.

Emissions and control costs for SO₂ and NH₃ in REF scenario are presented in Table 2.2. The REF scenario implies a 71 percent decrease of SO₂ emissions of the EU-15 and a 55 percent cut in the non-EU countries. SO₂ control costs, calculated from the RAINS cost curves, reach 14 billion EURO/year, of which 77 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 of REF
	1990	REF	Change	1990	REF	Change	
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	23396	14567	-38%	22640	14169	-37%	52590

Table 2.2: Emissions and control costs for SO₂ and NH₃ for 1990 and the Reference (REF) scenario (emissions in kilotons, costs in million EURO/year).

	SO ₂			Costs of REF	NH ₃			Costs of REF
	1990	REF	Change		1990	REF	Change	
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%	196
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%	361
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	37938	14419	-62%	14016	7558	6616	-12%	361

2.1.2 Full Implementation of Current Control Technologies in the Year 2010

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

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

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

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

Table 2.3 lists the resulting emissions of NO_x and VOC for the REF and the 'ultimate' MFR scenarios. For all of Europe, the MFR scenario results in an 80 percent cut of NO_x emissions relative to 1990, and a 75 percent decline in VOC emissions. Total costs amount to more than 110 billion EURO/year.

Table 2.4 presents the same type of information for SO_2 and ammonia. For SO_2 , the achievable emission reductions for entire Europe are about 90 percent at costs of about 23 billion EURO/year. For ammonia, maximum reductions could cut the emissions by 42 percent compared to 1990 at costs of 22 billion EURO/year. An 11 percent reduction (0.8 million tons NH_3) is caused by the projected decline in livestock numbers; the remaining 31 percent (2.3 million tons NH_3) is calculated as the consequence of technical control measures.

Table 2.3: NO_x and VOC emissions for the REF case and the hypothetical maximum technically feasible reductions (MFR) scenario (percentage changes relate to the year 1990). Emission control costs for the MFR scenario in million EURO/yr

	NO _x emissions				VOC emissions				Costs
	REF		MFR _{ult}		REF		MFR _{ult}		NO _x & VOC
	kt	Change	kt	Change	kt	Change	kt	Change	MFR _{ult}
Austria	103	-46%	54	-72%	205	-42%	97	-72%	1496
Belgium	191	-46%	81	-77%	193	-48%	85	-77%	2101
Denmark	128	-53%	49	-82%	85	-53%	49	-73%	808
Finland	152	-45%	56	-80%	110	-48%	49	-77%	1026
France	858	-54%	383	-79%	1223	-49%	658	-73%	11734
Germany	1184	-56%	622	-77%	1137	-64%	644	-79%	15258
Greece	344	0%	127	-63%	267	-21%	100	-70%	2220
Ireland	70	-38%	27	-76%	55	-50%	30	-73%	716
Italy	1130	-45%	396	-81%	1159	-44%	617	-70%	12482
Luxembourg	10	-55%	4	-80%	7	-63%	5	-76%	110
Netherlands	280	-48%	127	-77%	233	-52%	136	-72%	2735
Portugal	177	-15%	51	-76%	144	-32%	68	-68%	2226
Spain	847	-27%	263	-77%	669	-34%	365	-64%	8798
Sweden	190	-44%	75	-78%	290	-43%	128	-74%	1899
UK	1186	-58%	521	-82%	1351	-49%	841	-68%	11063
EU-15	6849	-48%	2836	-79%	7128	-49%	3872	-72%	74672
Albania	36	50%	6	-74%	41	32%	9	-72%	165
Belarus	316	-21%	56	-86%	309	-17%	71	-81%	1071
Bosnia-H.	60	-25%	11	-86%	48	-6%	11	-79%	222
Bulgaria	297	-16%	61	-83%	190	-3%	37	-81%	1100
Croatia	91	11%	16	-81%	111	8%	25	-76%	416
Czech Rep.	296	-46%	78	-86%	305	-31%	102	-77%	1821
Estonia	73	-13%	13	-85%	49	9%	9	-80%	269
Hungary	198	-10%	50	-77%	160	-22%	50	-75%	1436
Latvia	118	1%	23	-81%	56	-11%	11	-82%	346
Lithuania	138	-10%	25	-83%	105	-5%	33	-70%	505
Norway	178	-19%	49	-78%	195	-34%	124	-58%	1063
Poland	879	-28%	266	-78%	807	1%	284	-64%	6974
Moldova	66	-24%	14	-84%	42	-16%	10	-80%	215
Romania	458	-12%	100	-81%	504	0%	126	-75%	1826
Russia	2653	-24%	527	-85%	2787	-21%	644	-82%	10431
Slovakia	132	-40%	42	-81%	140	-7%	57	-62%	1011
Slovenia	36	-40%	8	-87%	40	-27%	12	-78%	285
Switzerland	79	-52%	41	-75%	144	-48%	72	-74%	1270
FYR Maced.	29	-26%	5	-86%	19	0%	4	-79%	102
Ukraine	1433	-24%	325	-83%	851	-27%	165	-86%	4587
Yugoslavia	152	-28%	27	-87%	139	-2%	26	-82%	600
Non-EU	7718	-24%	1744	-83%	7041	-18%	1883	-78%	35715
Total	23396	-38%	4580	-80%	14169	-37%	5755	-75%	110387

Table 2.4: Emissions and control costs for REF and the Maximum technically feasible reductions (MFR) for SO₂ and NH₃. Percentage changes relate to the year 1990.

	SO ₂ emissions					NH ₃ emissions					
	REF		kt	MFR _{ult}		Costs	REF		kt	MFR _{ult}	
	kt	Change		Change	Costs		kt	Change		Change	Costs
Austria	40	-57%	30	-68%	207	67	-13%	48	-38%	362	
Belgium	193	-43%	60	-82%	627	96	-1%	57	-42%	496	
Denmark	90	-51%	19	-90%	268	72	-6%	40	-47%	693	
Finland	116	-49%	67	-71%	393	31	-23%	23	-43%	143	
France	448	-64%	165	-87%	1605	777	-4%	541	-33%	2217	
Germany	581	-89%	311	-94%	3719	571	-25%	353	-53%	1816	
Greece	546	8%	87	-83%	809	74	-8%	59	-26%	222	
Ireland	66	-63%	21	-88%	191	126	-1%	111	-13%	464	
Italy	567	-66%	194	-88%	2067	432	-6%	282	-39%	683	
Luxembourg	4	-71%	2	-84%	15	7	0%	7	-4%	15	
Netherlands	73	-64%	47	-76%	343	136	-42%	105	-55%	1072	
Portugal	141	-50%	29	-90%	285	67	-6%	46	-36%	374	
Spain	774	-65%	166	-92%	1251	353	0%	225	-36%	2043	
Sweden	67	-44%	52	-56%	423	48	-21%	44	-28%	230	
UK	980	-74%	286	-92%	2647	297	-10%	218	-34%	770	
EU-15	4687	-71%	1535	-91%	14850	3154	-12%	2156	-40%	11600	
Albania	55	-24%	7	-91%	44	35	9%	25	-23%	60	
Belarus	494	-41%	49	-94%	288	163	-26%	103	-53%	433	
Bosnia-H.	415	-15%	23	-95%	143	23	-26%	17	-45%	78	
Bulgaria	846	-54%	130	-93%	365	126	-11%	86	-39%	295	
Croatia	70	-61%	17	-91%	102	37	-8%	22	-46%	119	
Czech Rep.	366	-80%	100	-95%	582	108	1%	72	-33%	411	
Estonia	175	-36%	13	-95%	114	29	0%	16	-45%	88	
Hungary	546	-40%	286	-69%	331	137	14%	73	-40%	493	
Latvia	104	-14%	18	-85%	80	35	-19%	19	-56%	113	
Lithuania	107	-50%	22	-90%	84	81	1%	49	-38%	246	
Norway	32	-38%	17	-68%	67	21	-9%	17	-27%	108	
Poland	1397	-53%	367	-88%	2096	541	7%	367	-27%	1527	
Moldova	117	-41%	19	-90%	69	48	2%	29	-39%	127	
Romania	594	-55%	93	-93%	420	304	4%	206	-30%	834	
Russia	2344	-53%	539	-89%	1888	894	-30%	571	-55%	2943	
Slovakia	137	-75%	68	-88%	147	47	-22%	30	-50%	173	
Slovenia	71	-65%	10	-95%	79	21	-9%	12	-49%	64	
Switzerland	26	-40%	12	-72%	151	66	-8%	54	-25%	187	
FYR Maced.	81	-24%	5	-95%	71	16	-6%	11	-34%	43	
Ukraine	1488	-60%	368	-90%	1035	649	-11%	406	-44%	2126	
Yugoslavia	269	-54%	29	-95%	387	82	-9%	54	-40%	346	
Non-EU	9732	-55%	2193	-90%	8544	3462	-13%	2237	-44%	10813	
Total	14419	-62%	3728	-90%	23394	6616	-12%	4394	-42%	22413	

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

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 - 48 percent, VOC -49 percent compared to 1990) are expected to have profound impacts on ozone exposure. The maximum number of violations is expected to decline to 35 in France, about 30 in Italy and approximately 25 in Germany (Figure 2.2).

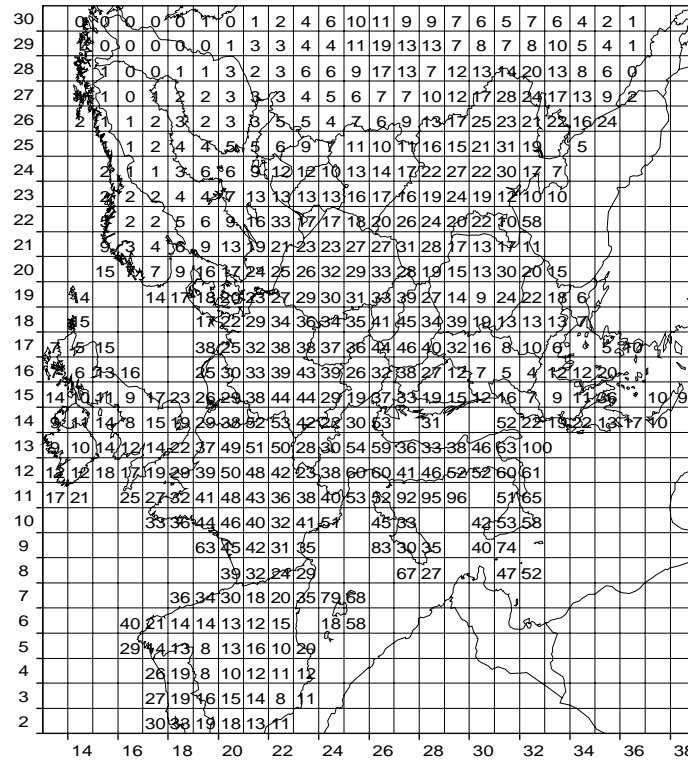


Figure 2.1: Number of days with ozone above 60 ppb, emissions of 1990, maximum of the three-years moving average over the five meteorological years

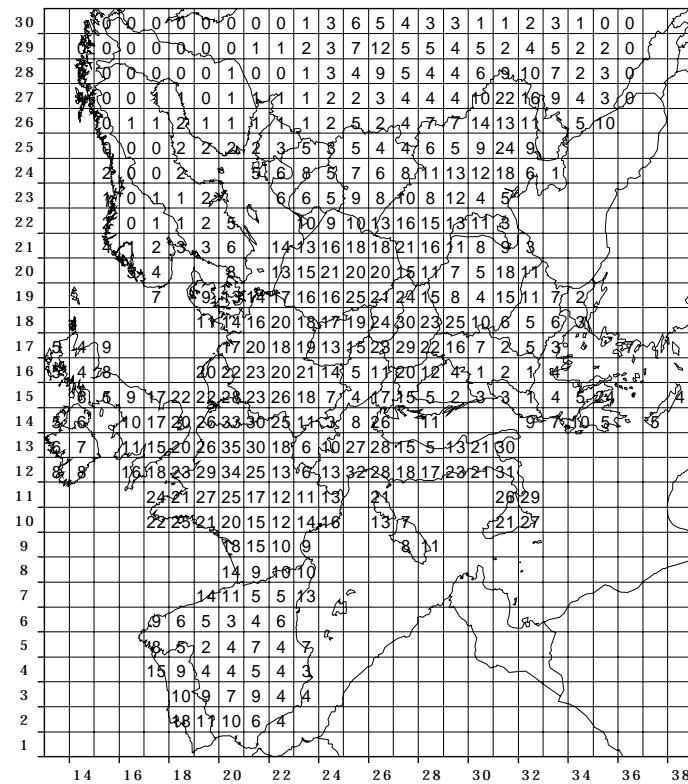


Figure 2.2: Number of days with ozone above 60 ppb, emissions of the REF case, maximum of the three-years moving average over the five meteorological years

For comparison, Figure 2.3 and Figure 2.4 present the situation for days exceeding a 90 ppb eight-hour mean concentration. While in 1990 the maximum was at about 10 days in the Benelux region, the frequency is expected to decline to not more than 3 days.

Figure 2.5 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.

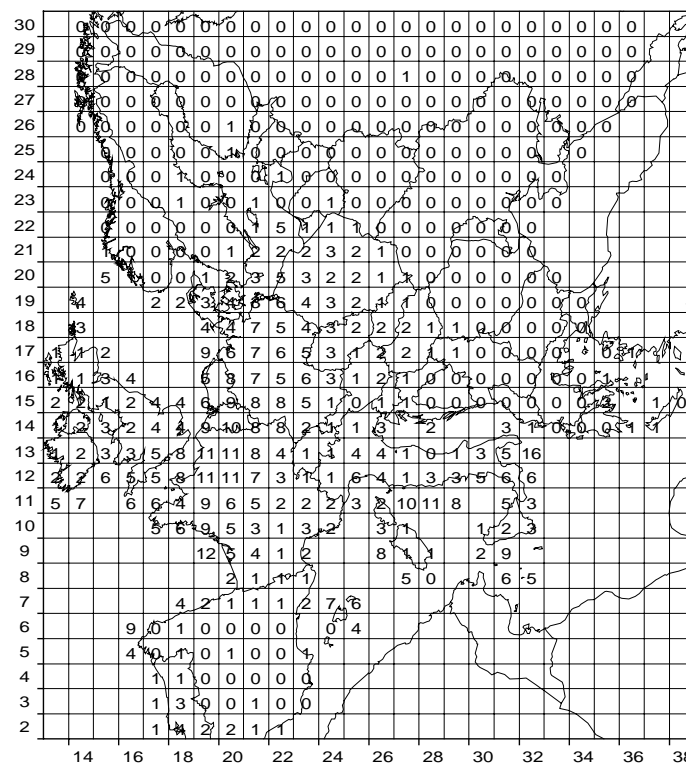


Figure 2.3: Number of days with ozone above 90 ppb, emissions of 1990, maximum of the three-years moving average over the five meteorological years

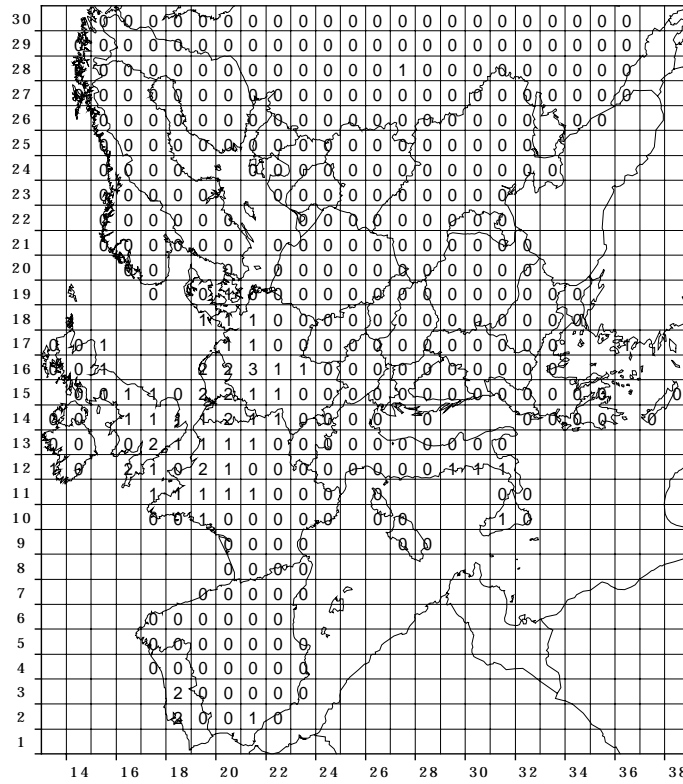


Figure 2.4: Number of days with ozone above 90 ppb, emissions of the REF case, maximum of the three-years moving average over the five meteorological years

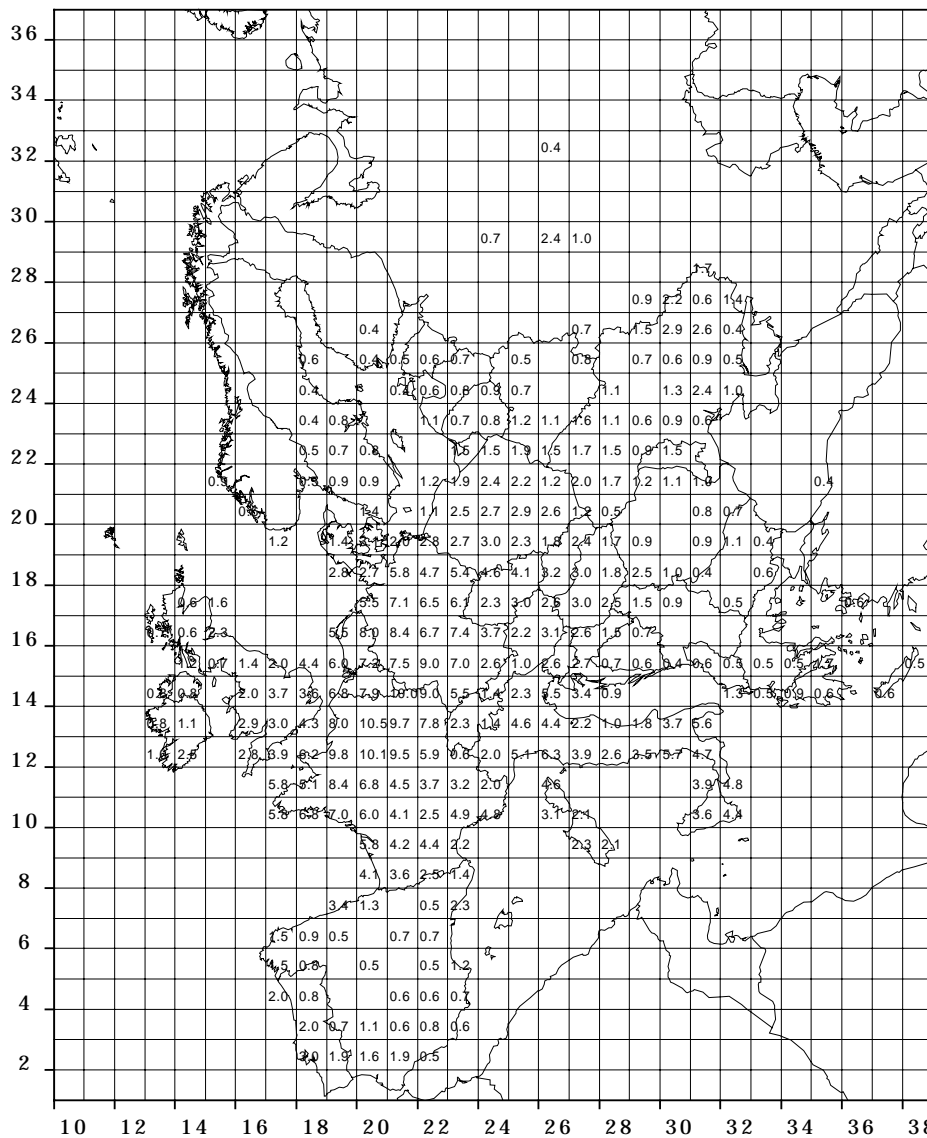


Figure 2.5: The AOT60 modelled for the emissions of 1990, second highest value of five years meteorologies (in ppm.hours)

Table 2.5 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.

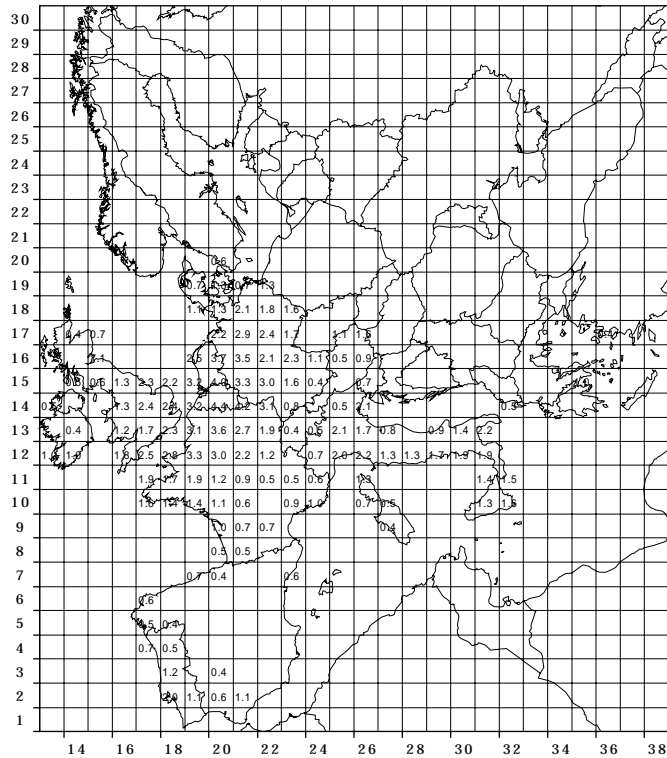


Figure 2.6: The AOT60 modelled for the emissions of the REF case, second highest value of five years meteorologies (in ppm.hours)

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 2.5: Population exposure indices for 1990, REF and the ultimate MFR scenario

	Cumulative population exposure index (million persons.ppm.hours)			Average population exposure index (ppm.hours)		
	1990	REF	MFR _{ult}	1990	REF	MFR _{ult}
	Austria	16	3	0	2.0	0.5
Belgium	71	34	7	6.5	3.1	0.6
Denmark	9	3	0	1.8	0.5	0.0
Finland	0	0	0	0.1	0.0	0.0
France	310	89	9	5.5	1.6	0.2
Germany	405	140	17	5.1	1.8	0.2
Greece	7	4	0	0.7	0.4	0.0
Ireland	3	1	0	0.8	0.3	0.0
Italy	183	63	0	3.2	1.1	0.0
Luxembourg	3	1	0	8.5	3.0	0.6
Netherlands	73	38	9	4.9	2.6	0.6
Portugal	16	8	0	1.6	0.8	0.0
Spain	35	7	0	0.9	0.2	0.0
Sweden	4	0	0	0.4	0.0	0.0
UK	125	77	12	2.2	1.3	0.2
EU-15	1259	466	53	3.5	1.3	0.1
Albania	1	0	0	0.4	0.0	0.0
Belarus	4	1	0	0.4	0.1	0.0
Bosnia-H	3	0	0	0.7	0.1	0.0
Bulgaria	4	1	0	0.4	0.1	0.0
Croatia	8	3	0	1.8	0.6	0.0
Czech Rep.	34	11	0	3.3	1.0	0.0
Estonia	0	0	0	0.2	0.0	0.0
Hungary	27	12	0	2.6	1.1	0.0
Latvia	1	0	0	0.4	0.1	0.0
Lithuania	2	0	0	0.6	0.1	0.0
Norway	1	0	0	0.1	0.0	0.0
Poland	91	36	0	2.4	0.9	0.0
R.of Moldova	3	1	0	0.7	0.2	0.0
Romania	17	6	0	0.8	0.3	0.0
Russia	21	7	0	0.2	0.1	0.0
Slovakia	15	6	0	2.8	1.1	0.0
Slovenia	4	1	0	2.2	0.7	0.0
Switzerland	14	2	0	2.1	0.3	0.0
FYR of Maced.	0	0	0	0.1	0.0	0.0
Ukraine	45	14	0	0.9	0.3	0.0
Yugoslavia	8	3	0	0.7	0.2	0.0
Non-EU	306	103	0	1.0	0.3	0.0
Total	1565	570	53	2.3	0.8	0.1

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

The explanation for this increase is related to the ozone formation chemistry. Put in a rather simplistic way, very high NO concentrations (in areas with high NO_x emissions) have, i.a., two effects: (a) they lead to the titration of ozone, i.e., the conversion of ozone and NO into NO₂, and (b) they cause a (partial) depletion of OH radicals. This resulting shortage of OH radicals at such high NO_x levels limits ozone production. Reducing NO_x emissions from such a high level will increase the available OH radicals, and more ozone will be produced, until NO_x emissions are so low that the ozone production will be limited by the available NO₂ molecules. As indicated in Part A of the Sixth Interim Report, reducing NO_x will lead for some time to increased ozone. Beyond a certain NO_x reduction level, however, ozone will decline again.

Figure 2.7 supports this explanation by illustrating the emission densities in 1990. It is important to realize that the emissions in the areas where the increase occurs (UK, Belgium, Netherlands, etc.) are up to a factor of 10 higher than in other industrialized European regions (compare e.g., southern Germany).

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

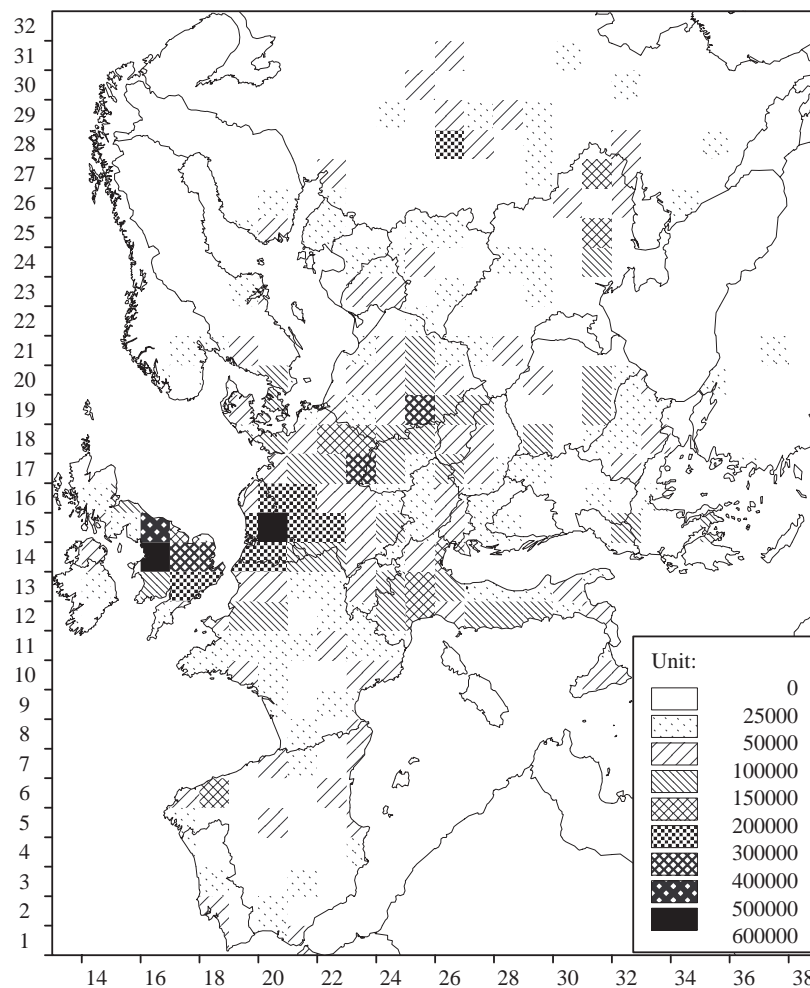


Figure 2.7: NO_x emissions per EMEP grid cell in 1990 (in tons)

2.2.1.2 Vegetation-related Ozone Exposure

Figure 2.8 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.

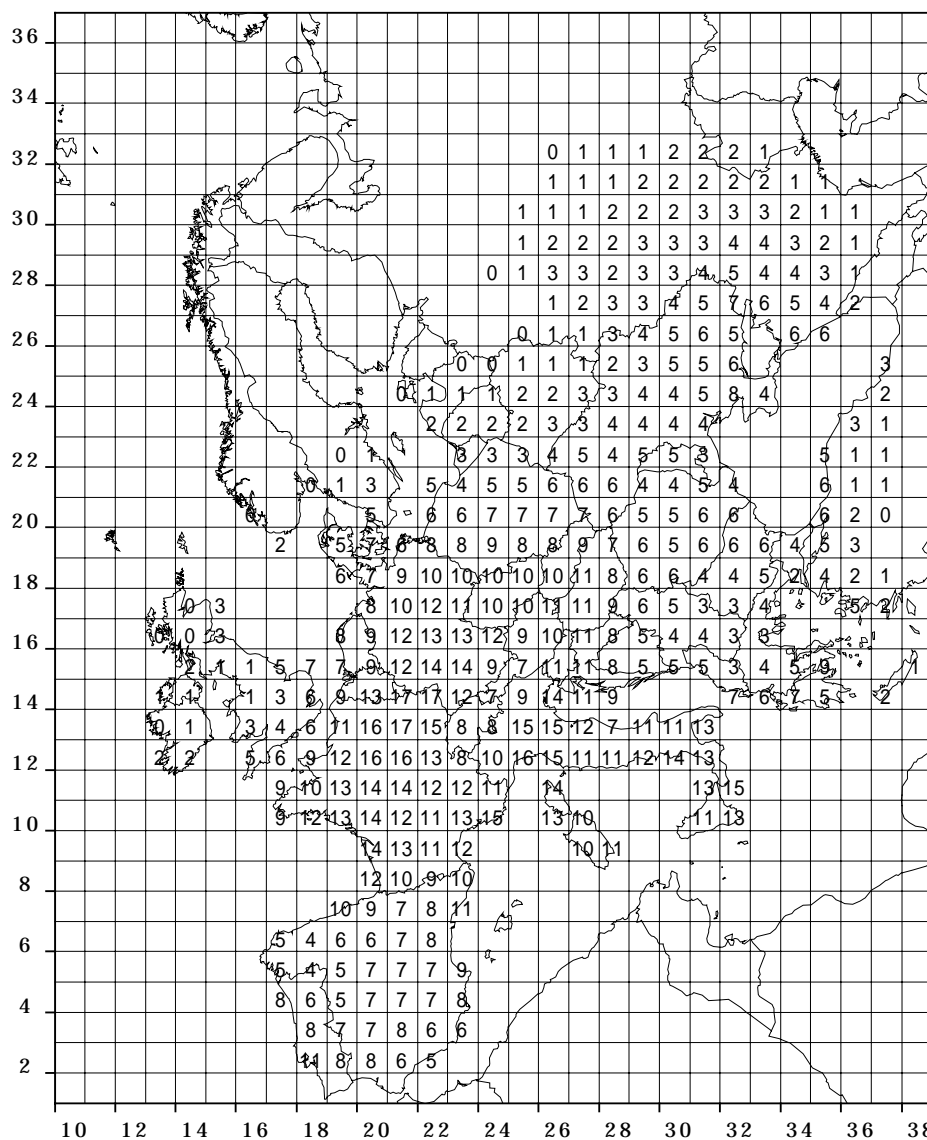


Figure 2.8: Excess AOT40 (above the critical level of 3 ppm.hours) for the emissions of 1990, in ppm.hours

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 2.9). Peak levels are in a range of 10-12 ppm.hours.

Table 2.6 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.

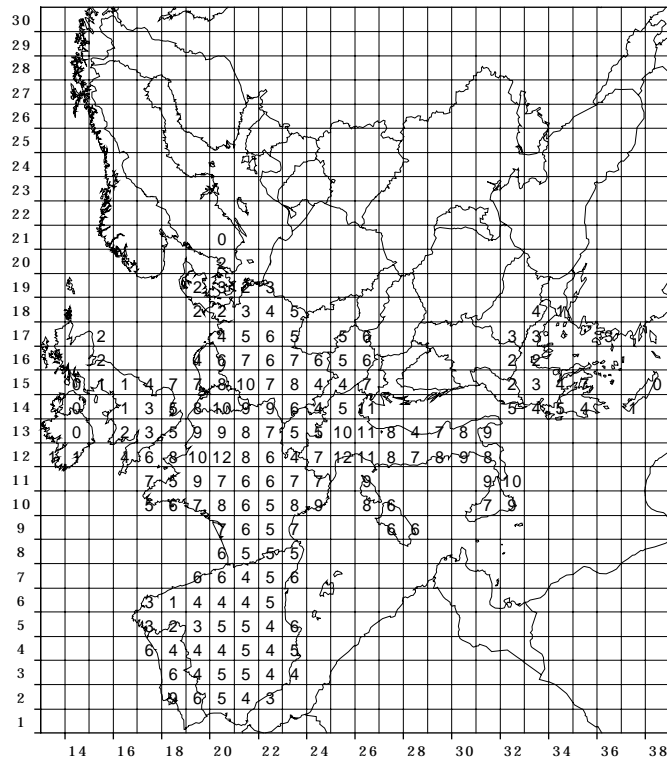


Figure 2.9: Excess AOT40 (above the critical level of 3 ppm.hours) for the emissions of the REF scenario, in ppm.hours

Table 2.6: Vegetation exposure indices for 1990, the REF and the ultimate MFR case

	Cumulative vegetation exposure index (1000 km ² .excess ppm.hours)			Average vegetation exposure index (excess ppm.hours)		
	1990	REF	MFR _{ult}	1990	REF	MFR _{ult}
	Austria	468	257	37	9.0	5.0
Belgium	177	141	82	11.4	9.1	5.3
Denmark	141	53	0	4.7	1.8	0.0
Finland	0	0	0	0.0	0.0	0.0
France	4158	2345	743	12.9	7.3	2.3
Germany	2344	1204	340	11.1	5.7	1.6
Greece	231	170	9	4.3	3.1	0.2
Ireland	25	8	0	1.1	0.3	0.0
Italy	1773	1186	422	11.3	7.5	2.7
Luxembourg	25	14	5	16.6	9.3	3.5
Netherlands	109	79	42	8.4	6.1	3.3
Portugal	379	274	24	6.5	4.7	0.4
Spain	2037	1281	99	6.6	4.2	0.3
Sweden	116	18	0	0.4	0.1	0.0
UK	192	153	72	2.3	1.9	0.9
EU-15	12174	7183	1875	6.5	3.8	1.0
Albania	0	0	0	0.0	0.0	0.0
Belarus	186	78	0	2.1	0.9	0.0
Bosnia-H	244	162	11	6.4	4.2	0.3
Bulgaria	344	281	0	4.6	3.8	0.0
Croatia	330	214	45	9.3	6.0	1.3
Czech Rep.	570	311	36	10.2	5.6	0.7
Estonia	2	0	0	0.1	0.0	0.0
Hungary	631	404	22	9.7	6.2	0.3
Latvia	43	6	0	1.0	0.1	0.0
Lithuania	75	23	0	1.8	0.6	0.0
Norway	3	1	0	0.0	0.0	0.0
Poland	1512	829	8	6.6	3.6	0.0
R.of Moldova	83	56	0	4.9	3.3	0.0
Romania	844	623	1	5.4	4.0	0.0
Russia	1733	983	0	0.9	0.5	0.0
Slovakia	342	215	11	9.6	6.0	0.3
Slovenia	139	94	25	10.7	7.2	1.9
Switzerland	155	85	25	8.7	4.8	1.4
FYR of Maced.	52	40	0	3.3	2.5	0.0
Ukraine	1759	1206	5	4.5	3.1	0.0
Yugoslavia	327	248	6	4.8	3.7	0.1
Non-EU	9373	5860	196	2.7	1.7	0.1
Total	21547	13043	2071	4.0	2.4	0.4

2.2.2 Acidification

Figure 2.10 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 2.7).

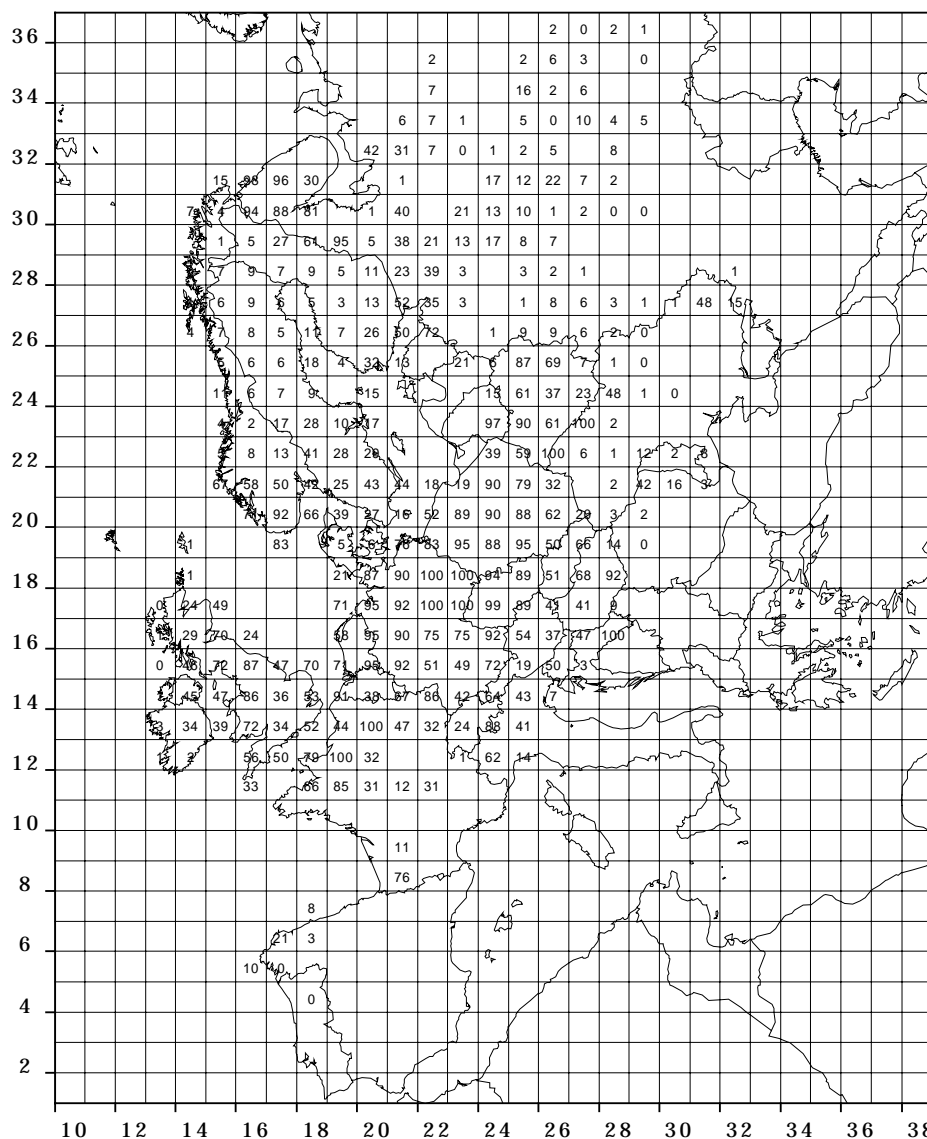


Figure 2.10: Percentage of ecosystems with acid deposition above their critical loads for acidification, 1990

The emission reductions anticipated in the REF scenario are expected to significantly improve the situation and to decrease the unprotected ecosystems to about 17 million hectares, out of which 6.4 million hectares are located in the EU-15 (Figure 2.11). 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.

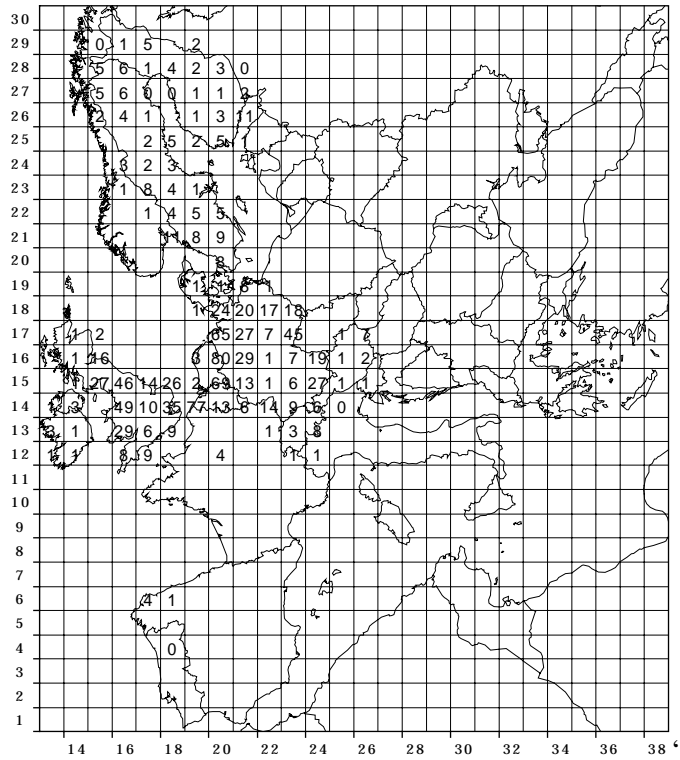


Figure 2.11: Percentage of ecosystems with acid deposition above their critical loads, REF case

Table 2.7: Ecosystems with acid deposition above their critical loads for acidification for 1990, REF and the ultimate MFR scenario

	1000 hectares			Percent of ecosystems		
	1990	REF	MFR _{ult}	1990	REF	MFR _{ult}
Austria	2376	162	35	47.6	3.3	0.7
Belgium	410	155	7	58.4	22.1	0.9
Denmark	54	9	1	13.8	2.3	0.4
Finland	4693	1183	152	17.2	4.3	0.6
France	8194	218	4	25.8	0.7	0.0
Germany	8158	1617	119	79.5	15.8	1.2
Greece	0	0	0	0.0	0.0	0.0
Ireland	97	12	6	10.7	1.3	0.7
Italy	2065	74	43	19.6	0.7	0.4
Luxembourg	58	5	0	66.7	5.9	0.1
Netherlands	285	193	30	89.3	60.4	9.5
Portugal	1	1	0	0.0	0.0	0.0
Spain	78	17	0	0.9	0.2	0.0
Sweden	6341	1605	457	16.4	4.1	1.2
UK	4117	1182	65	43.0	12.3	0.7
EU-15	36928	6433	919	24.7	4.3	0.6
Albania	0	0	0	0.0	0.0	0.0
Belarus	2709	1048	0	53.9	20.9	0.0
Bosnia-H	132	131	0	9.1	9.1	0.0
Bulgaria	0	0	0	0.0	0.0	0.0
Croatia	7	0	0	2.7	0.0	0.0
Czech Rep.	2394	474	12	90.1	17.9	0.5
Estonia	312	11	0	16.5	0.6	0.0
Hungary	144	65	10	50.7	22.9	3.6
Latvia	127	0	0	4.7	0.0	0.0
Lithuania	817	78	0	43.1	4.1	0.0
Norway	5313	2573	771	24.0	11.6	3.5
Poland	12634	1357	14	72.8	7.8	0.1
R.of Moldova	84	29	0	7.1	2.4	0.0
Romania	230	51	6	3.7	0.8	0.1
Russia	27072	4073	31	7.8	1.2	0.0
Slovakia	1033	295	110	51.5	14.7	5.5
Slovenia	363	19	3	40.1	2.1	0.3
Switzerland	508	57	26	41.1	4.6	2.1
FYR of Maced.	0	0	0	0.0	0.0	0.0
Ukraine	2397	643	5	29.1	7.8	0.1
Yugoslavia	2	2	0	0.1	0.1	0.0
Non-EU	56280	10908	989	13.1	2.5	0.2
Total	93209	17341	1909	16.1	3.0	0.3

2.2.3 Eutrophication

Figure 2.12 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 2.13). In many parts of mainland Europe they will not be sufficient to increase the unprotected ecosystems substantially. Statistics about individual countries are presented in Table 2.8.

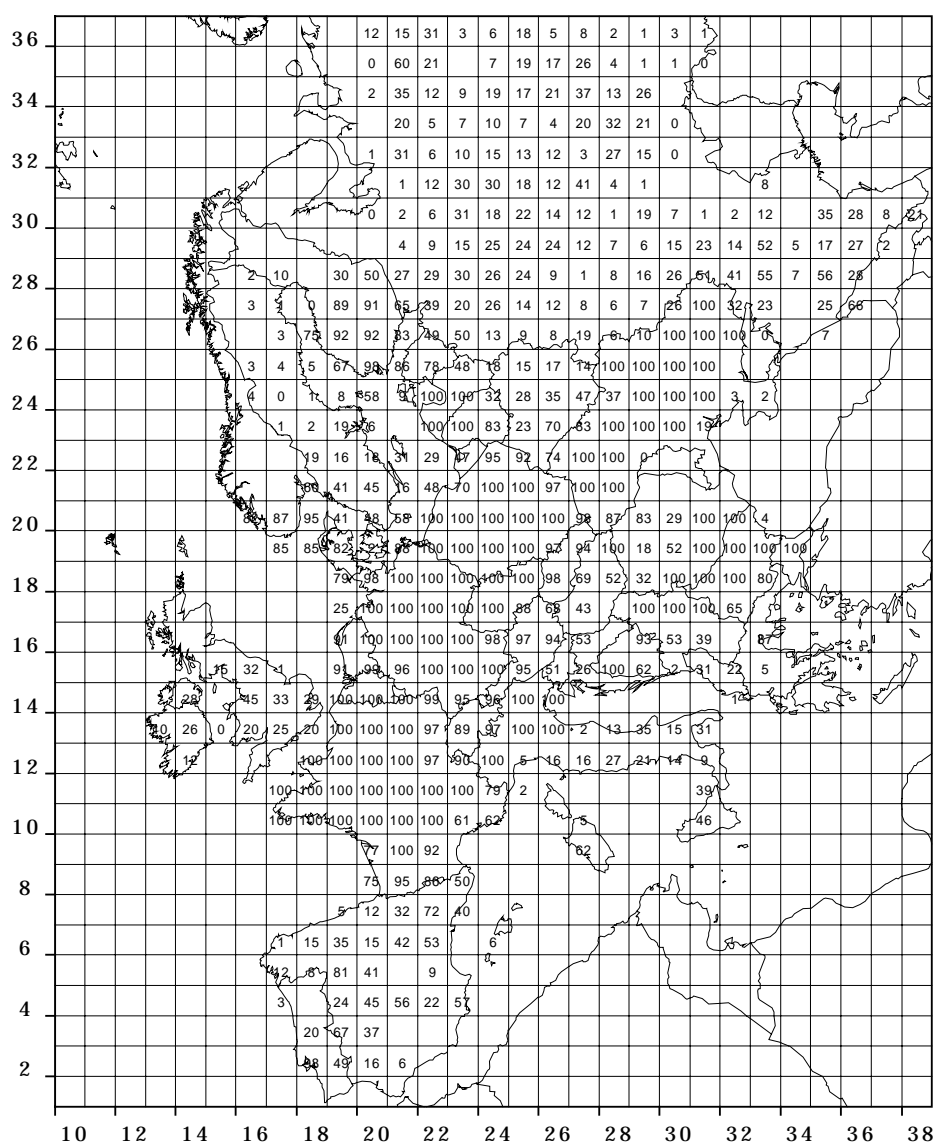


Figure 2.12: Percentage of ecosystems area with nitrogen deposition above their critical loads for eutrophication, for the emissions of 1990

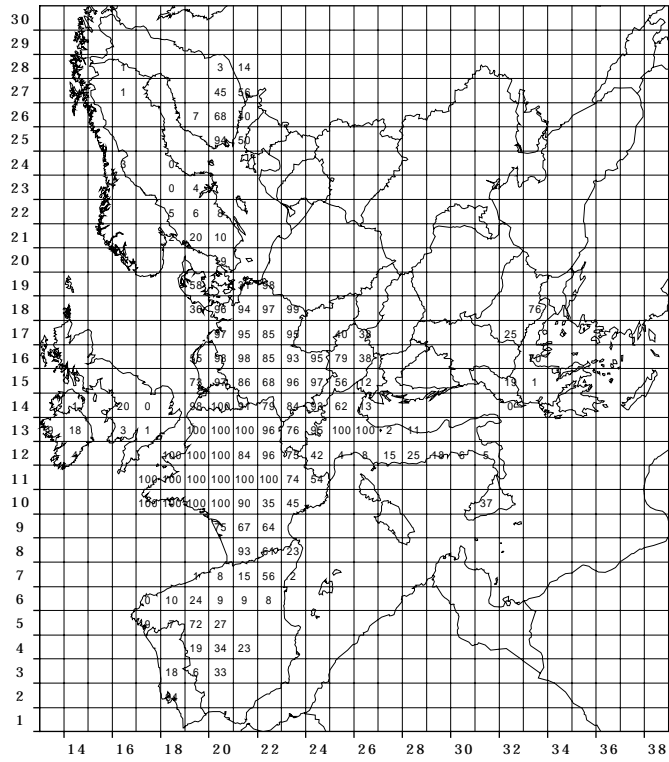


Figure 2.13: Percentage of ecosystems area with nitrogen deposition above their critical loads for eutrophication, for the emissions of the REF scenario

Table 2.8: Ecosystems with nitrogen deposition above their critical loads for eutrophication for 1990, the REF and the ultimate MFR case

	1000 hectares			Percent of ecosystems		
	1990	REF	MFR _{ult}	1990	REF	MFR _{ult}
Austria	5392	3441	572	90	58	9.6
Belgium	700	677	335	100	96	47.8
Denmark	197	119	4	63	38	1.3
Finland	7386	2538	10	45	15	0.1
France	29322	25160	13079	92	79	41.2
Germany	10157	9184	3590	99	90	35.0
Greece	295	236	8	12	10	0.3
Ireland	91	58	23	10	6	2.5
Italy	5921	3795	1382	49	32	11.5
Luxembourg	88	80	45	100	91	50.8
Netherlands	312	291	252	98	91	79.0
Portugal	913	709	0	32	25	0.0
Spain	2390	1158	8	28	14	0.1
Sweden	2588	891	64	14	5	0.3
UK	1030	126	0	11	1	0.0
EU-15	66782	48461	19372	55	40	16.1
Albania	240	200	60	23	19	5.7
Belarus	2049	1293	370	41	26	7.4
Bosnia-H	1104	725	115	76	50	8.0
Bulgaria	3964	3396	123	80	69	2.5
Croatia	70	18	0	26	7	0.0
Czech Rep.	2608	2312	491	98	87	18.5
Estonia	1296	738	30	69	39	1.6
Hungary	166	150	85	58	53	29.8
Latvia	2260	1553	90	83	57	3.3
Lithuania	1462	1357	74	77	72	3.9
Norway	2053	281	2	15	2	0.0
Poland	16875	16218	7726	97	93	44.5
R.of Moldova	1	0	0	0	0	0.0
Romania	3450	2495	1194	55	40	19.2
Russia	47704	26263	1254	14	8	0.4
Slovakia	1874	1507	241	93	75	12.0
Slovenia	489	156	44	54	17	4.9
Switzerland	2105	1887	823	92	83	36.1
FYR of Maced.	242	158	45	23	15	4.2
Ukraine	6181	5331	1808	75	65	22.0
Yugoslavia	2306	1994	945	68	58	27.7
Non-EU	98499	68032	15520	23	16	3.7
Total	165282	116494	34892	30	21	6.4

3 A Central Scenario for Reducing Acidification and Ground-level Ozone (Scenario H1)

3.1 Environmental Targets Derived from the Acidification and Ozone Strategies

It is demonstrated in Part A of this report that currently adopted emission controls are expected to significantly reduce harmful excess exposure to ground-level ozone and acidification by the year 2010. However, without further measures there will still be significant areas in Europe where health- and vegetation protection will not be achieved. It is furthermore a robust conclusion of the model analysis that the presently available technical emission control measures will not be sufficient to meet the no-damage levels everywhere in Europe within the next one or two decades without interfering with the 'business as usual' expectations on economic development and energy consumption.

Therefore, the acidification strategy of the EU and the recent discussions on the EU ozone strategy formulated environmental interim targets, which should guide the next step towards the full achievement of the environmental long-term objectives. Scenario H1 adopts these interim targets and explores, with the latest data set on energy use, emissions, control costs and critical loads, the cost-optimal allocation of emission reductions to simultaneously achieve the acidification and ozone targets.

For the individual environmental problems, the environmental constraints to be achieved by the optimized emission reductions can be summarized as follows:

For acidification:

The general target of the EU acidification strategy is to reduce in the year 2010 the area of ecosystems not protected against acidification everywhere by at least 50 percent compared to 1990. This results in about 4.3 million hectares of unprotected ecosystems in the EU15

In the optimization routine, a scenario based on a 95 percent gap closure of the accumulated excess acidity¹ which achieves the 50 percent area gap closure target was implemented. In order to increase the cost-effectiveness of the scenario, so that single ecosystems might not demand excessively expensive measures, some spatial flexibility in achieving the overall target was introduced. A balancing mechanism now allows limited violation of the targets at single grid cells, as long as they are compensated by additional improvements (in terms of accumulated excess acidity) in other grid cells in the same country.

¹ Acid deposition in excess of the critical loads, accumulated for all ecosystems in a grid cell. The purpose of using the accumulated excess is to avoid the focus on a specific ecosystem (percentile of the cumulative critical load distribution) and thus increase the robustness of the modeling results.

For health-relevant ozone exposure:

The principal interim target for moving towards the environmental long-term objective is a relative reduction of the AOT60 (the surrogate indicator for health-related excess ozone exposure) by two thirds between 1990 and 2010.

In order to minimize the influence of existing model uncertainties and to increase the robustness of the optimized solution, this 67 percent 'gap closure' is defined in relation to a model confidence interval. Furthermore, within certain limits, violations of these targets are allowed for individual grid cells or meteorological years, if the excess is compensated by additional improvements in other years or other grid cells in the same country (on a population-weighted basis).

In addition, highest excess ozone in the EU15 is addressed by introducing an absolute ceiling on the AOT60 of 2.9 ppm.hours.

In order to minimize the influence of rare and perhaps untypical meteorological conditions and to tailor the strategy for maximum effectiveness for the most frequent meteorological ozone regimes, this ceiling must be maintained under the meteorological conditions of four out of the five years, for which model analyses are available. This means that for each grid cell the meteorological conditions of the year in which improvements are most difficult to achieve is neglected.

For vegetation-relevant ozone exposure:

The general objective is to reduce the excess AOT40 (the indicator for vegetation-related excess ozone) by one third between 1990 and 2010.

The definition of the AOT40 relates to the average meteorological conditions over a five years period. Violations of the gap closure targets are allowed for individual grid cells, if the excess is compensated by additional improvements in other grid cells in the same country (on an ecosystems area-weighted basis).

In addition, the highest excess AOT40 in the EU15 is limited to an absolute ceiling of 10.0 ppm.hours.

Since the definition of the AOT40 already refers to the average meteorological conditions and considers extreme meteorological conditions only on a weighted basis, no exceptions are applied to this target.

Details on the target setting rules can be found in Section 5 of Part A of the Sixth Interim Report to the Commission (Amann *et al.*, 1998).

3.2 Main Input Assumptions

The main input assumptions for the H1 scenario relate to the energy development in the EU countries. It is assumed that energy consumption follows the 'baseline' scenario, i.e., the projections provided by Member States to the Commission or, if no national submissions were received, the 'Business as usual' scenario of DGXVII. For the non-EU countries, the 'Official Energy Pathway' of the UN/ECE database was used.

It is furthermore assumed that the current legislation on emission reductions will not be reversed. This means that for the EU countries the REF scenario is taken as the upper bound for emissions (i.e., the optimization may not result in higher emissions than produced by the REF scenario), and the cost curves for emission reductions consider only the measures not already taken by the REF scenario.

The same assumption on the REF as the minimum reduction level also holds for the non-EU countries. With the exception of the H4 scenario, however, no further emission reductions are assumed for the non-EU countries, so that in practice the emissions of these countries are fixed at the REF (i.e., the current legislation) level.

A further assumption relates to SO₂ and NO_x emissions from ships on the sea, which are kept uncontrolled throughout this report. It should be mentioned that the calculations in this report ignore, due to a complete lack of data, all VOC emissions from ships, and also SO₂ and NO_x emissions from the Mediterranean. Furthermore, the data for the Baltic Sea include merely the shipping into and out of the basin (EMEP, 1998)

For acidification, grid cells shared with non-EU countries, where (a) the low percentiles of critical loads (i.e., the sensitive ecosystems) are located in non-EU countries, or (b) the deposition is vastly dominated by emissions from non-EU countries, are excluded from the optimization. This applies to grid cells 24/13 on the Italian/Swiss border with low critical loads values in the Swiss Ticino, to grid cell 26/17 (Austria/Slovakia/Hungary) with most sensitive ecosystems in Slovakia, and to grid cells 16/30 and 17/30 at the Finnish/Russian border, where sulfur deposition results mainly from a few nickel smelters in the Russian part of the Kola peninsula.

3.3 Cost-minimal Emission Reductions

In order to simultaneously achieve the environmental targets outlined in Section 3.1, further emission reductions beyond the REF case are necessary for all four pollutants. For the EU-15, SO₂ emissions would be reduced from 71 percent to 78 percent (compared to 1990), NO_x emissions from 48 percent to 55 percent, VOC from 49 to 60 percent and ammonia from 12 to 21 percent (Table 3.1). This would increase total emission control costs from 58 billion EURO/year to 66 billion EURO, i.e., by 14 percent (Table 3.2). Out of this 7.5 billion EURO extra costs, 11 percent would be spent for additional SO₂ control, 60 percent for further measures to reduce NO_x and VOC, and 29 percent for ammonia.

The significant spatial differences in (a) the severity of the ozone and acidification problems and (b) in the extent to which emission controls are already implemented are the main factors explaining that additional measures for individual pollutants are not uniformly allocated across all Member States. Significant further SO₂ controls (increasing control costs by more

than 10 percent) emerge for Belgium, France, Ireland and the UK, while for the other countries the optimized measures are at or close to the REF case. Stricter NO_x and VOC controls are more widespread. Further NO_x and VOC measures are calculated for Austria, Belgium, France, Greece, Germany, Italy, Luxembourg, Netherlands, Portugal and Sweden; for Ireland and Spain only NO_x would be a priority, and for the UK further control of VOC emissions. Limitations to ammonia emissions emerge as important for Belgium, France, Germany, Ireland, Netherlands and the UK.

Table 3.1: Emissions for the central scenario H1 compared to the REF case. Percentage changes relate to the year 1990.

	SO ₂				NO _x				VOC				NH ₃			
	REF		H1		REF		H1		REF		H1		REF		H1	
	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change
Austria	40	-57%	40	-57%	103	-46%	91	-53%	205	-42%	129	-63%	67	-13%	67	-13%
Belgium	193	-43%	76	-77%	191	-46%	127	-64%	193	-48%	102	-73%	96	-1%	57	-41%
Denmark	90	-51%	77	-58%	128	-53%	127	-54%	85	-53%	85	-53%	72	-6%	71	-8%
Finland	116	-49%	116	-49%	152	-45%	152	-45%	110	-48%	110	-48%	31	-23%	31	-23%
France	448	-64%	218	-83%	858	-54%	679	-64%	1223	-49%	932	-61%	777	-4%	718	-11%
Germany	581	-89%	463	-91%	1184	-56%	1051	-61%	1137	-64%	924	-70%	571	-25%	413	-45%
Greece	546	8%	546	8%	344	0%	264	-23%	267	-21%	173	-49%	74	-8%	74	-8%
Ireland	66	-63%	28	-84%	70	-38%	59	-48%	55	-50%	55	-50%	126	-1%	123	-3%
Italy	567	-66%	566	-66%	1130	-45%	869	-57%	1159	-44%	962	-53%	432	-6%	430	-7%
Luxembourg	4	-71%	3	-79%	10	-55%	8	-64%	7	-63%	6	-68%	7	0%	7	0%
Netherlands	73	-64%	50	-75%	280	-48%	238	-56%	233	-52%	156	-68%	136	-42%	104	-55%
Portugal	141	-50%	141	-50%	177	-15%	144	-31%	144	-32%	102	-52%	67	-6%	67	-6%
Spain	774	-65%	746	-66%	847	-27%	781	-33%	669	-34%	662	-34%	353	0%	353	0%
Sweden	67	-44%	67	-44%	190	-44%	152	-55%	290	-43%	219	-57%	48	-21%	48	-21%
UK	980	-74%	497	-87%	1186	-58%	1181	-58%	1351	-49%	964	-64%	297	-10%	264	-20%
EU-15	4687	-71%	3637	-78%	6849	-48%	5922	-55%	7128	-49%	5581	-60%	3154	-12%	2826	-21%

Table 3.2: Emission control costs for the central scenario H1 compared to the REF case. Control costs in million EURO/year.

	SO ₂			NO _x /VOC			NH ₃			Total		
	REF	H1	Total	REF	H1	Total	REF	H1	Total	REF	H1	Total
Austria	191	0	191	902	119	1021	0	0	0	1093	119	1212
Belgium	426	127	553	1278	459	1737	0	467	467	1704	1053	2757
Denmark	138	5	143	484	0	484	0	0	0	623	6	629
Finland	247	0	247	642	0	642	0	0	0	889	0	889
France	1276	136	1412	7383	739	8122	0	41	41	8659	916	9575
Germany	3264	244	3508	10549	1048	11597	0	854	854	13813	2147	15960
Greece	434	0	434	1048	338	1386	0	0	0	1482	338	1820
Ireland	132	20	152	477	4	481	9	20	29	618	44	662
Italy	1776	0	1776	7868	403	8271	0	0	0	9644	403	10047
Luxembourg	13	1	14	71	4	75	15	0	15	98	4	102
Netherlands	340	19	359	1731	211	1942	196	741	937	2267	971	3238
Portugal	181	0	181	1349	57	1406	0	0	0	1530	57	1587
Spain	809	9	818	5658	13	5671	28	0	28	6495	22	6517
Sweden	316	0	316	1125	87	1212	113	0	113	1554	87	1641
UK	1269	299	1568	6695	1026	7721	0	23	23	7964	1348	9312
EU-15	10813	861	11674	47258	4508	51766	361	2146	2507	58433	7514	65947

3.4 Environmental Impacts of the H1 Scenario

In line with the environmental targets set to the optimization, all environmental indicators selected for the analysis experience a distinct improvement compared to the situation in 1990. The following graphs provide detailed information on the spatial distribution at which the improvements occur.

3.4.1 Acidification

For acidification, the overall target was a 50 percent gap closure in terms of unprotected ecosystems compared to 1990 or, phrased differently, a 50 percent reduction of the ecosystems with acid deposition above their critical loads. As explained in Section 3.1, a compensation mechanism was introduced in order to increase the cost-effectiveness of the overall strategy by relaxing the strict 50 percent gap closure targets for single grid cells where this improvement would be most costly to achieve. Figure 3.1 displays for the emissions of the H1 scenario the resulting gap closure (in terms of ecosystems area). The map clearly indicates that most grid cells achieve the minimum target of a 50 percent improvement, and many achieve even better results. There are, however, a number of areas where the gap closure remains below the nominal 50 percent target. In some of them, the compensation mechanism allows a violation of the target (grid cell 20/17 Netherlands/Germany), while in others the 95 percent gap closure of the accumulated excess acidity is still achieved (13/13 (Ireland), 18/6 (Spain), 23/17 (France/Italy/Switzerland) and four grid cells in central and northern Sweden²).

Table 3.3: Gap closure and percent of unprotected ecosystems for grid cells, where the original gap closure target is not achieved by the optimized emission reductions.

Grid cell	Country	Gap closure achieved by H1	Percent of ecosystems remaining unprotected in H1
13/13	IRE	20 %	3 %
15/27	SWE	12 %	5 %
15/28	SWE	34 %	5 %
16/24	SWE/NOR	47 %	1 %
16/27	SWE	36 %	6 %
16/28	SWE	39 %	6 %
16/30	FIN/RUS	16 %	80 %
17/30	FIN/RUS	8 %	81 %
18/6	SPA	49 %	1 %
20/17	D/NL	45 %	53 %
23/12	F/ITA/CH	44 %	1 %

² The 50 percent gap closure is also not achieved on the Finnish/Russian border (Kola). Due to the bilateral nature of this local problem and the limited extent to which it is linked to the EU emissions, no targets were specified for these grid cells in the EU-15 optimization runs.

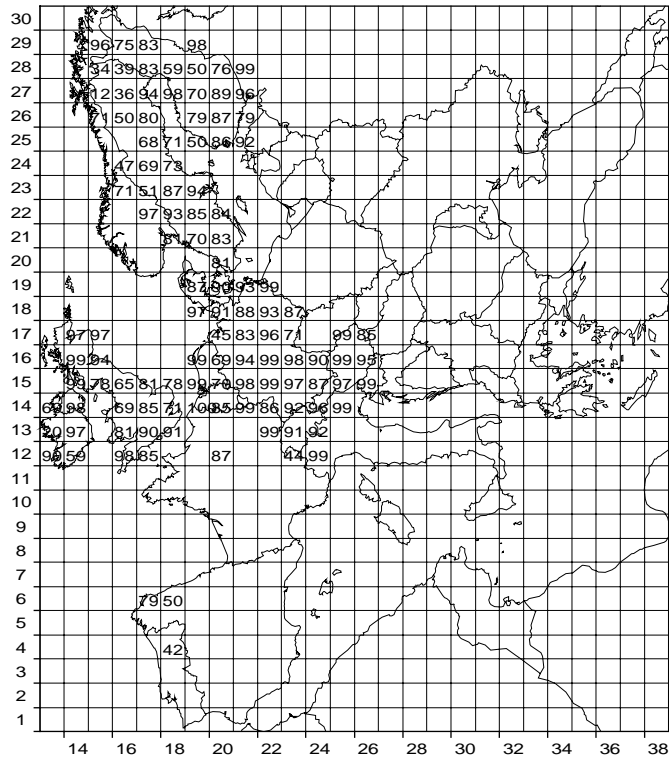


Figure 3.1: Gap closure in terms of unprotected ecosystems area (acidification) for the emissions of the H1 scenario. Areas left blank had no excess deposition in 1990.

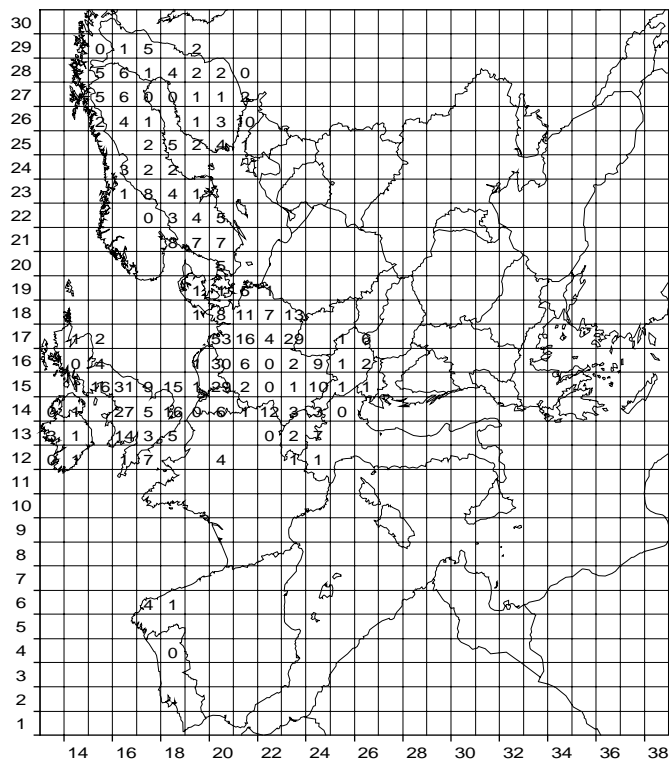


Figure 3.2: Percentage of ecosystems with acid deposition above their critical loads for the emissions of the H1 scenario

While the relative improvement (in terms of gap closure) is a practical means for setting environmental targets, it does not always provide an unequivocal picture of the actual environmental situation. Figure 3.2 presents for Scenario H1 the remaining percentage of ecosystems with acid deposition above their critical loads. Except for the Kola region, which is excluded from this analysis, the area with least protection on the German/Dutch border (53 percent) coincides with a failed 50 percent gap closure target. There are, however, regions in south-east Germany and the UK, where despite a gap closure of 60 to 80 percent still about 30 percent of the ecosystems receive acid deposition above their critical loads.

Another way of evaluating the ecological situation from a given emission pattern is to examine for a given percentile of the ecosystems the remaining excess deposition. For scenario H1 Figure 3.3 displays this information for the 2-percentile, i.e., for the ecosystem where two percent of the ecosystems in the same grid cell have lower critical loads and 98 percent of the ecosystems in the grid cell have higher critical loads. The map clearly indicates that, despite the significant emission reductions, there remain ecosystems where acid deposition is 500 to 1000 eq/ha above their critical loads, i.e., where the critical loads are exceeded by a factor of two and more. Such high levels of excess deposition would occur on the German/Dutch border, in southern UK and in some border grids between Italy/Switzerland, and Austria/Hungary. On the other hand, excess deposition in northern Sweden, where the gap closure is down to 12 percent, is comparatively low.

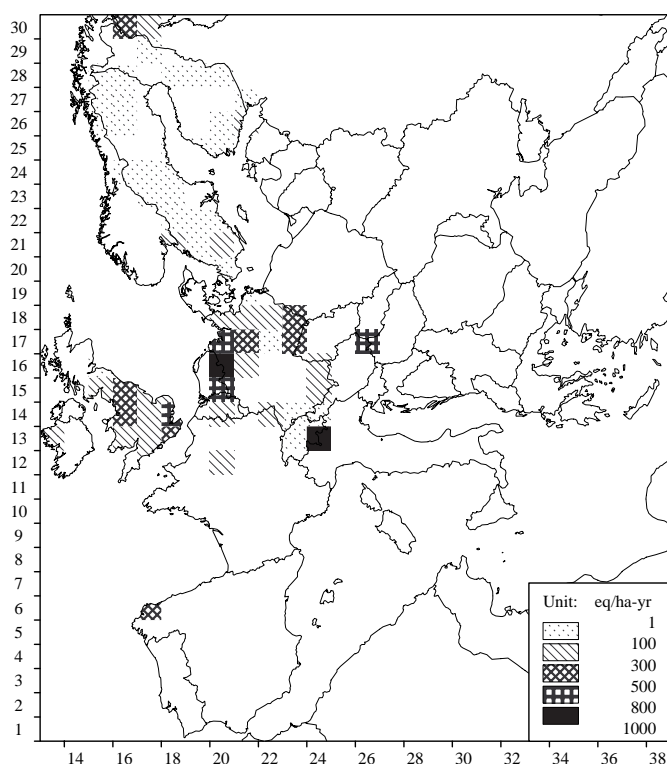


Figure 3.3: Excess deposition for the 2-percentile ecosystems for the emissions of the H1 scenario

Finally, Table 3.4 provides the country statistics of ecosystems protection. The emission reductions of the H1 scenario would reduce in the EU-15 the unprotected area from 6.4 million hectares in the REF case to 4.3 million hectares, a number, which is comparable to the ambition level put forward in the EU acidification strategy. On a national scale, least

ecosystems protection occurs in the Netherlands (with 24 percent of the ecosystems having acid deposition above critical loads), followed by Belgium, Germany and UK with about seven percent.

Table 3.4: Ecosystems with acid deposition above their critical loads for acidification for the H1 and the REF scenarios.

	1000 ha		Percent of ecosystems	
	REF	H1	REF	H1
Austria	162	99	3.3%	2.0%
Belgium	155	52	22.1%	7.4%
Denmark	9	6	2.3%	1.5%
Finland	1183	1150	4.3%	4.2%
France	218	88	0.7%	0.3%
Germany	1617	727	15.8%	7.1%
Greece	0	0	0.0%	0.0%
Ireland	12	9	1.3%	1.0%
Italy	74	58	0.7%	0.6%
Luxembourg	5	1	5.9%	0.9%
Netherlands	193	76	60.4%	23.7%
Portugal	1	1	0.0%	0.0%
Spain	17	17	0.2%	0.2%
Sweden	1605	1420	4.1%	3.7%
United Kingdom	1182	649	12.3%	6.8%
EU-15	6433	4351	4.3%	2.9%

3.4.2 Ground-level Ozone

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

- In order to present the improvements in generally understandable notions, maps indicate the remaining days on which the WHO health guideline (60 ppb) and the 90 ppb levels are exceeded. Two maps are provided: One map displays the highest value (number of days) out of the five years meteorological regimes (for 60 ppb), while the second present the maximum of the three-years moving averages over the five years (for both thresholds).
- 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 averaged over five years, in order to relate to the critical level for vegetation protection.

3.4.2.1 Number of Days with Ozone above 60 and 90 ppb

As to be expected from the stringency of the environmental targets, ozone exposure resulting from the H1 emissions is clearly lower than in 1990. If measured as three-year moving averages over the five years with data, the number of days with ozone above the WHO guideline value would decline, e.g., in northern France from about 55 in 1990, through 35 for REF, to about 25 in the H1 scenario. For Italy, exceedances decline from 60 to about 20 days, in Germany/Netherlands from 30-40 days down to 15-20 days (Figure 3.4). The maximum exceedance, if averaged over three years, declines for H1 from about 60 days³ in 1990 (at the German/French border and in Italy) to about 27 in the Benelux region.

As shown in Figure 3.6, the emission reductions of the H1 scenario would eliminate ozone in excess of 90 ppb (eight hours mean) almost entirely, at least if measured as the moving average over three years. Calculations suggest that only two grid cells in Germany and the Benelux region would experience more than one day with excess of the 90 ppb level.

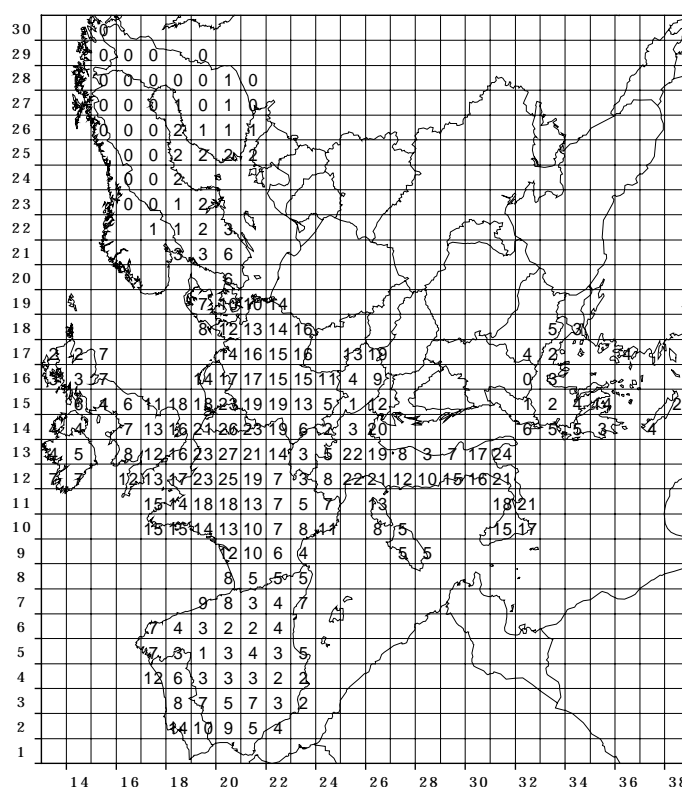


Figure 3.4: Number of days with excess of the WHO guideline value of 60 ppb resulting from the emissions of the H1 scenario, three-years moving average over five years.

³ for land-based grid cells only

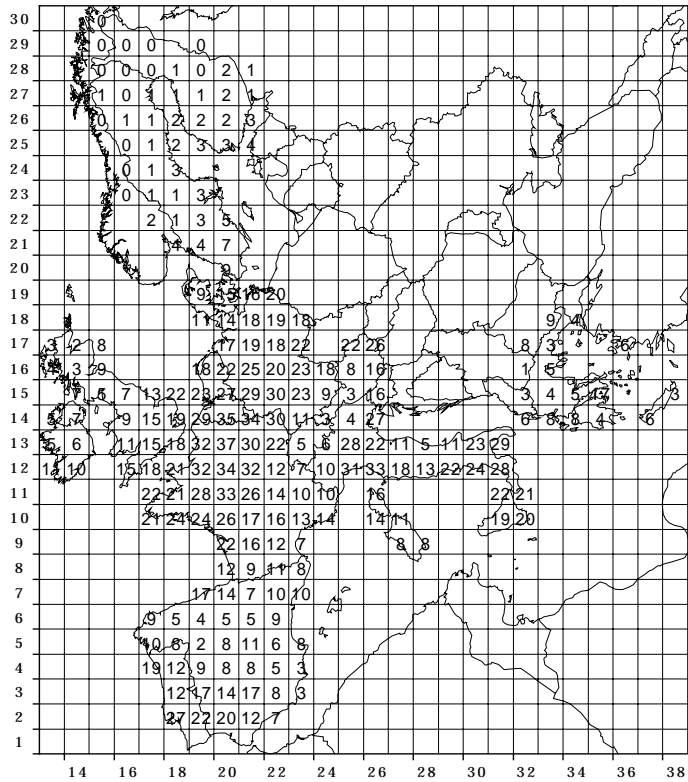


Figure 3.5: Number of days with excess of the WHO guideline value of 60 ppb resulting from the emissions of the H1 scenario, highest occurrence in five years meteorological conditions

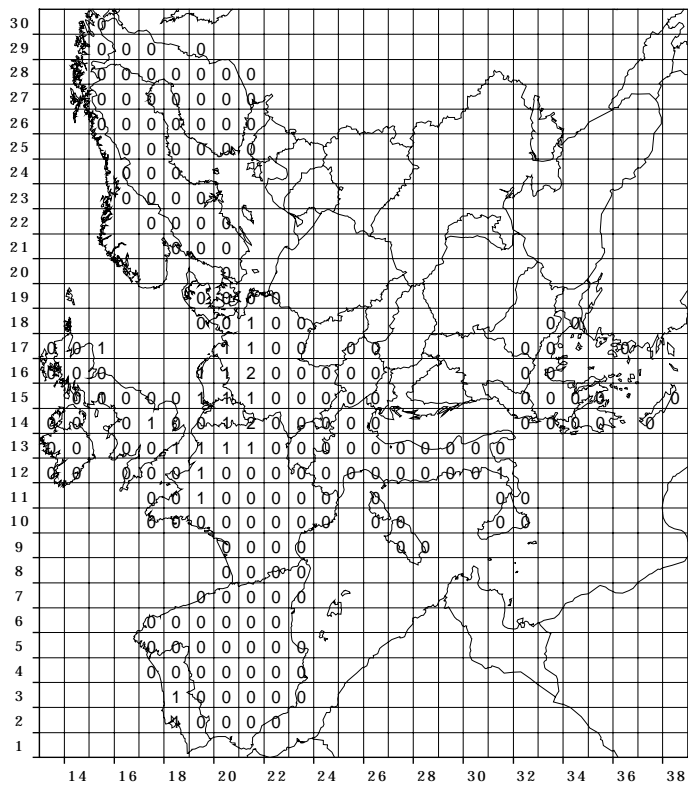


Figure 3.6: Number of days with ozone above 90 ppb for the emissions of the H1 scenario, mean of the three highest occurrences in five years

3.4.2.2 AOT60

For completeness, Figure 3.7 presents the AOT60 expressed as the second highest value from the five meteorological years. The map clearly indicates that only grid cells 20/14 and 21/14 at the Belgium/French border hit the absolute exposure limit of 2.9 ppm.hours, which was imposed on the optimization, while all other regions experience lower AOT60. It is further noteworthy that the spatial distribution of the AOT60 and the number of days with excess of 60 ppb do not fully coincide. While the number of days is comparable for the 'high ozone' areas north and south of the Alps, the regions north of the Alps have a higher AOT60 than in the Mediterranean countries. This indicates that the severity of the episodes (i.e., the degree to which the 60 ppb level is exceeded) is - and according to the model calculations will remain - higher in the north-western part of Europe.

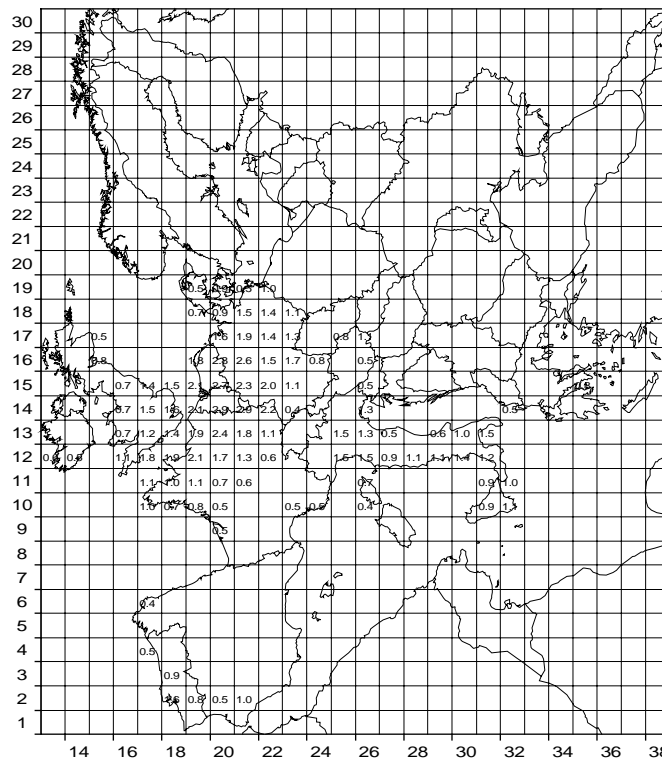


Figure 3.7: The AOT60 resulting from the emission reductions of the H1 scenario, second highest values of five years meteorologies (in ppm.hours)

Figure 3.8 displays the gap closure achieved in terms of AOT60 by the H1 scenario in comparison to 1990. The map clearly shows that, although a 67 percent improvement was set as the overall target, the compensation mechanism allows violations of these targets in Netherlands, UK, Spain and Portugal (these grid cells are cross-hatched in the map).

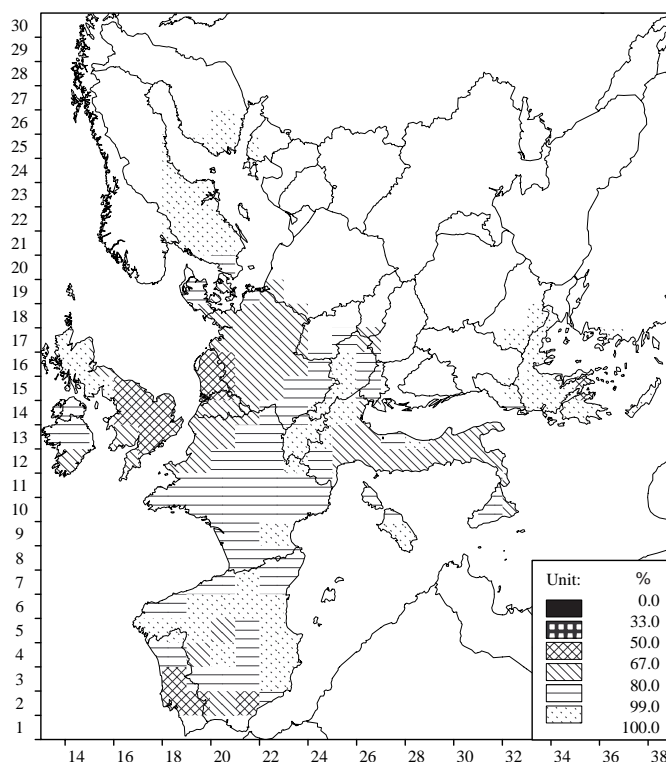


Figure 3.8: Percentage reduction of the AOT60 achieved by the H1 scenario, compared to 1990

Table 3.5 presents the population exposure indices for the REF and the H1 emissions. These indices are calculated by multiplying the AOT60 value of each grid cell with the population in the same grid belonging to the respective country. When interpreting results, the following aspects must be kept in mind:

- The indices are based on results of the reduced-form regression model, which has been constructed from calculations of the EMEP model. The EMEP model produces ozone levels for rural areas; these are usually higher than ozone levels observed within cities, but underestimate the levels occurring in the city plumes. Therefore, the presented values can provide only rough summary indications to enable quick comparisons of alternative scenarios on a highly aggregated basis. In-depth analyses with more detailed models are absolutely necessary to derive robust conclusions on the exposure of the population to ozone.
- As outlined before, the reduced-form model does not produce reliable results for AOT60 values below 0.4 ppm.hours. Therefore, low values of average exposure must be interpreted with care.

For the H1 scenario, the EU-15 average population exposure declines from 1.3 to 0.8 ppm.hours compared to the REF case. Compared to 1990, this relates to a 76 percent gap closure, if calculated against the model confidence interval. While on a grid basis a 67 percent improvement was specified as the minimum requirement (not taking into account the compensation mechanism), improvements on a country basis are always higher. Least overall gap closures occur in the UK, Belgium and Portugal.

Table 3.5: Population exposure indices for the REF and the H1 scenarios

	Cumulative population exposure index (million person ppm.hours)		Average population exposure index (excess ppm.hours)		Gap closure between 1990 and the model uncertainty range ¹⁾
	REF	H1	REF	H1	H1
Austria	3	2	0.5	0.3	-94%
Belgium	34	23	3.1	2.1	-72%
Denmark	3	1	0.5	0.3	-91%
Finland	0	0	0.0	0.0	-
France	89	53	1.6	0.9	-86%
Germany	140	99	1.8	1.3	-81%
Greece	4	2	0.4	0.2	-83%
Ireland	1	0	0.3	0.1	-94%
Italy	63	38	1.1	0.7	-87%
Luxembourg	1	1	3.0	2.1	-78%
Netherlands	38	27	2.6	1.8	-68%
Portugal	8	6	0.8	0.6	-72%
Spain	7	4	0.2	0.1	-94%
Sweden	0	0	0.0	0.0	-98%
United Kingdom	77	45	1.3	0.8	-71%
EU-15	466	300	1.3	0.8	-76%

Note ¹⁾: Reduction of ozone exposure exceeding the model confidence range of 0.4 ppm.hours)

3.4.2.3 AOT40

The excess AOT40 as a vegetation-related exposure criterion is presented in Figure 3.9. The emission reductions of the H1 scenario cut the highest excess exposure from 17 to about 10 ppm.hours (in excess of the critical level of 3 ppm.hours). The peak excess remains in France and northern Italy. Figure 3.10 highlights the AOT40 gap closures achieved in the various Member States. Evidently, the 33 percent target for individual grids is violated (and compensated by additional improvements) in the UK, the Benelux countries, Germany, Portugal and Greece.

The vegetation exposure indices are presented in Table 3.6. Highest average excess exposure occurs in Belgium, France, Italy and Luxembourg, and the overall gap closure (in terms of these exposure indices) reaches 53 percent. It is noteworthy that, in absolute terms, France, Germany, Spain and Italy will continue to have the highest cumulative exposure for their ecosystems.

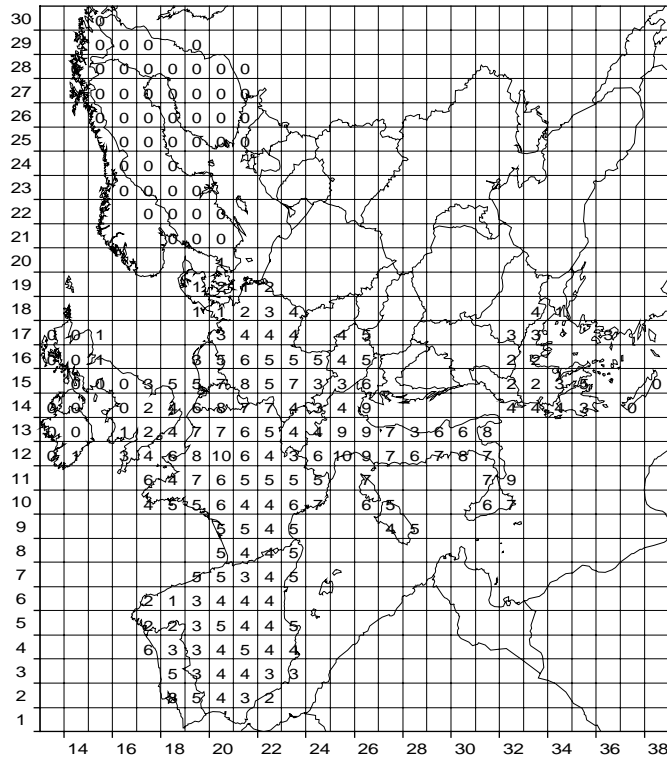


Figure 3.9: Excess AOT40 (above 3 ppm.hours) for the emissions of the H1 scenario (in ppm.hours)

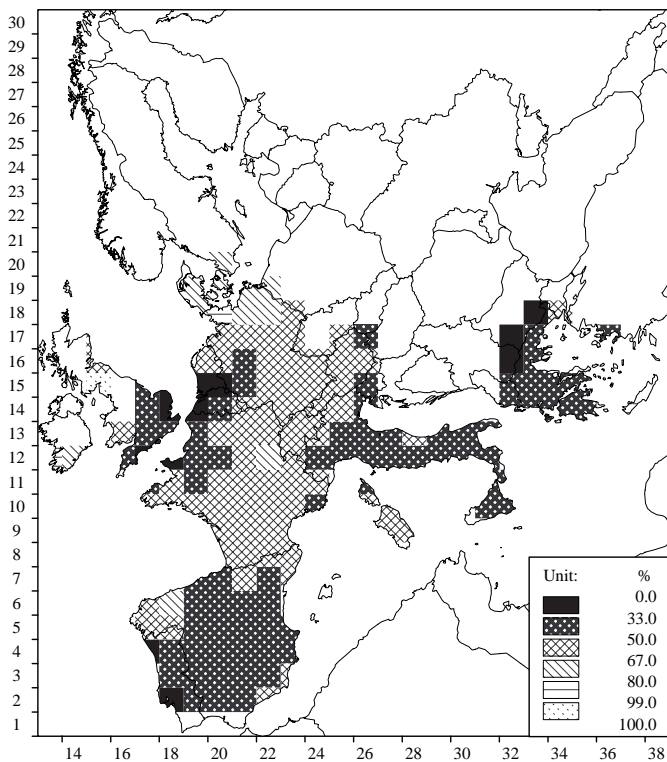


Figure 3.10: Percentage reduction of the excess AOT40 achieved by the H1 scenario compared to 1990

Table 3.6: Vegetation exposure indices for the REF and the H1 scenarios

	Cumulative vegetation exposure index (1000 km ² .excess ppm.hours)		Average vegetation exposure index (excess ppm.hours)		Change compared to 1990
	REF	H1	REF	H1	H1
Austria	257	213	5.0	4.1	-55%
Belgium	141	115	9.1	7.4	-35%
Denmark	53	36	1.8	1.2	-74%
Finland	0	0	0.0	0.0	-
France	2345	1816	7.3	5.6	-56%
Germany	1204	943	5.7	4.4	-60%
Greece	170	137	3.1	2.5	-41%
Ireland	8	3	0.3	0.1	-88%
Italy	1186	996	7.5	6.3	-44%
Luxembourg	14	11	9.3	7.3	-56%
Netherlands	79	63	6.1	4.8	-42%
Portugal	274	233	4.7	4.0	-39%
Spain	1281	1093	4.2	3.6	-46%
Sweden	18	9	0.1	0.0	-92%
United Kingdom	153	96	1.9	1.2	-50%
EU-15	7183	5765	3.8	3.1	-53%

3.4.3 Eutrophication

Although no specific environmental targets were introduced for eutrophication, the NO_x and ammonia emission reductions taken for the sake of acidification and ground-level ozone have an influence on the eutrophication situation. Figure 3.11 presents the percentage of ecosystems, which still receive nitrogen deposition above their critical loads despite the emission reductions of the H1 scenario. A comparison with the situation in the year 1990 clearly indicates that, when using the 'protected area' criterion, there is in some regions only little improvement observable. To some extent this low improvement can be linked to insufficient emission reductions; another factor having significant impact on the 'protected area' measure is the distribution of critical loads supplied by the countries to the Coordination Centre for Effects. While for acidification the mapping work conducted by national experts resulted in relatively large variations of critical loads within each grid cell (ranging from low critical loads for most sensitive ecosystems to significantly higher critical loads for others), for eutrophication some countries provided only a very small number of samples with negligible variation of sensitivities within grid cells. Obviously, such minor differences in sensitivities might be caused by ecological factors or by insufficient knowledge to firmly quantify possible differences in environmental sensitivities.

In the context of an area gap closure approach, however, this missing spread of critical loads distribution can only lead to 'flip/flop' solutions, i.e., either everything is unprotected, or everything is protected. Intermediate gap closures cannot be realized.

The recently developed 'accumulated excess' concept overcomes this problem by offering a continuous measure for excess deposition. The gap closure, expressed in accumulated excess deposition above the critical loads for eutrophication of all ecosystems in each grid cell is presented in Figure 3.12. In areas with high nitrogen deposition in the Benelux region, improvements range up to 70 percent; for northern Italy with a comparable situation the gap closure is only 34 percent, while for France the lowest relative improvements range between 30 and 40 percent. Overall, the average improvement in the EU-15 is in the range of about 50 percent.

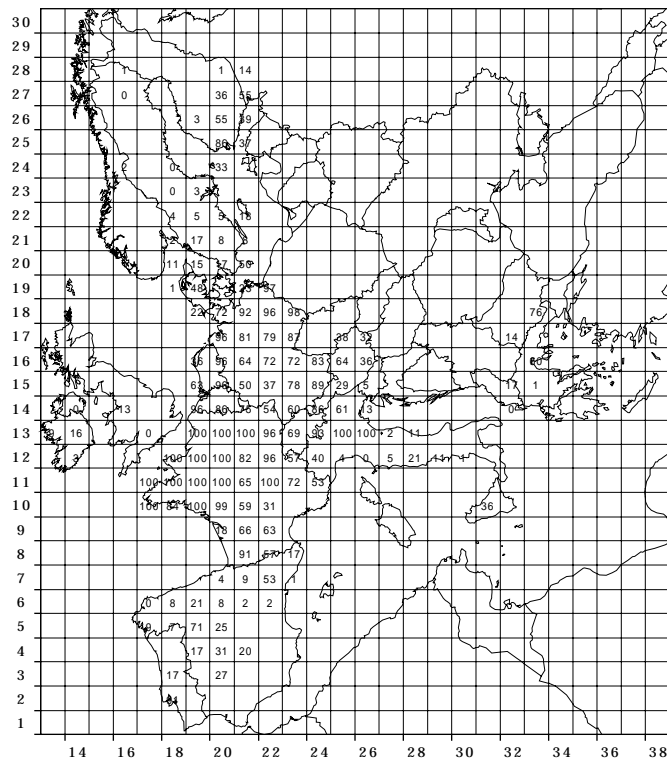


Figure 3.11: Percentage of ecosystems with nitrogen deposition above their critical loads for the emissions of the H1 scenario

Figure 3.13 displays the excess nitrogen deposition for the 'two percentile' ecosystems. Peak excess deposition occurs on the German/Dutch border and in northern Italy, where it exceeds the critical loads for these ecosystems by a factor of two and more.

Finally, Table 3.7 presents the country statistics for ecosystems protection. Compared to 1990, the H1 scenario would reduce the unprotected ecosystems from 66 million hectares to 42 million hectares, i.e., by 29 percent. Despite this improvement, about 35 percent of all ecosystems in the EU would still receive nitrogen deposition above the critical loads for eutrophication.

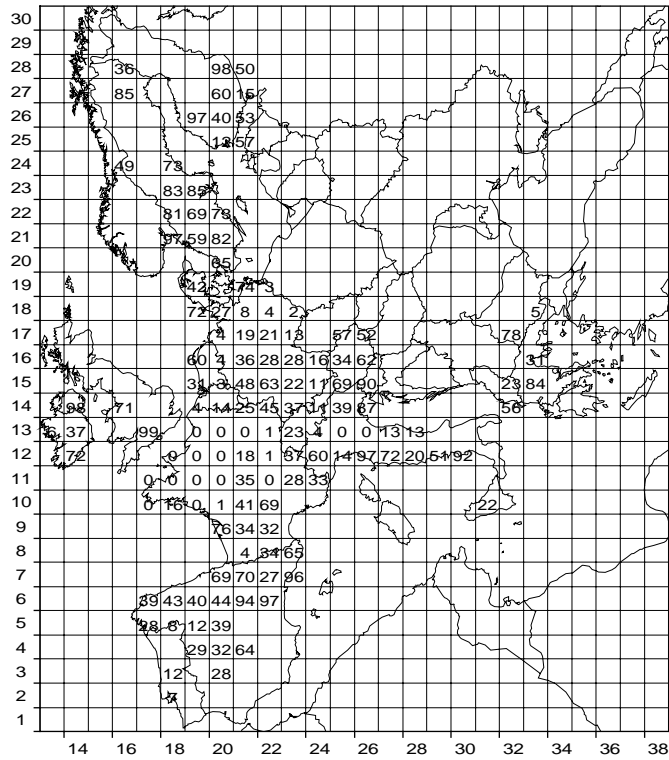


Figure 3.12: Gap closure in terms of unprotected ecosystems area (for eutrophication) achieved by the emission reductions of the H1 scenario

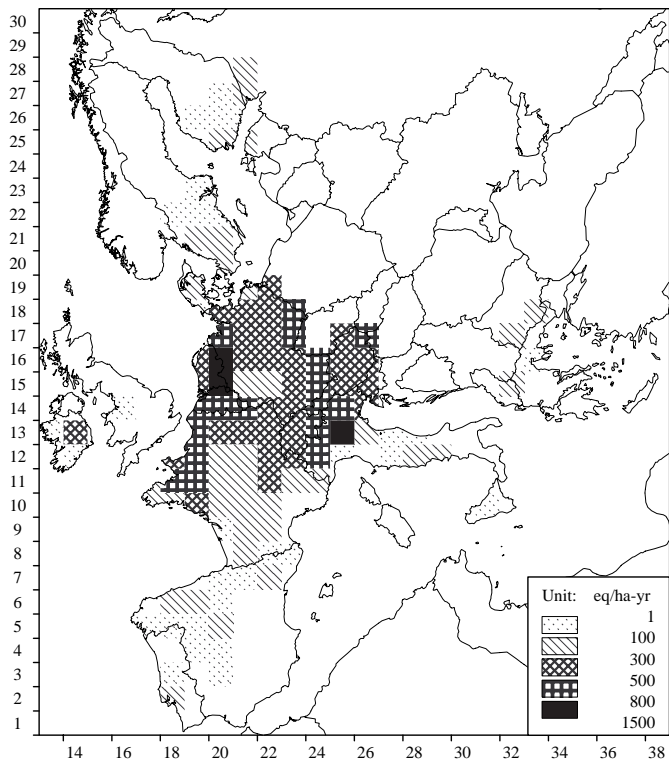


Figure 3.13: Excess nitrogen deposition for the 2-percentile ecosystems for the emissions of the H1 scenario

Table 3.7: Ecosystems with nitrogen deposition above their critical loads for eutrophication for the H1 and the REF scenarios.

	1000 ha		Percent of ecosystems	
	REF	H1	REF	H1
Austria	3441	2773	57.6%	46.5%
Belgium	677	586	96.4%	83.4%
Denmark	119	91	37.6%	28.9%
Finland	2538	2163	15.4%	13.1%
France	25160	22524	79.2%	70.9%
Germany	9184	7474	89.5%	72.9%
Greece	236	211	9.6%	8.6%
Ireland	58	54	6.4%	5.9%
Italy	3795	3452	31.7%	28.8%
Luxembourg	80	66	91.3%	75.1%
Netherlands	291	278	91.0%	87.0%
Portugal	709	683	25.1%	24.2%
Spain	1158	964	13.6%	11.3%
Sweden	891	737	4.7%	3.9%
United Kingdom	126	64	1.4%	0.7%
EU-15	48461	42117	40.2%	34.9%

3.4.4 'Binding Effects'

Although the non-linear optimization routine, which is used to identify the cost-minimal allocation of emission reductions, is a highly complex mathematical procedure, the results obtained by such an optimization can subsequently be analyzed according to a number of criteria in order to gain insight into which factors (e.g., cost curves) and (environmental) constraints drive a particular solution.

A key explanatory factor which explains at least parts of the cost-optimized solution is the set of environmental targets which are most difficult to attain by the emission reductions and which therefore 'drive' the optimized solution. Figure 3.14 displays for which areas which of the environmental constraints (on acidification, AOT60 and AOT40) are most difficult to attain and are therefore, together with their interaction with other pollutants, responsible for stringency and the overall balance of optimized emission reductions. The map indicates that the targets specified for acidification are driving forces at the German/Dutch border, in Ireland and to a limited extent in Spain. Health-related ozone targets dominate the need for measures in the UK, France, the Benelux countries, in some parts of Germany and in Portugal. Vegetation related ozone targets are drivers for Mediterranean countries. It is important to mention that the dominance of a particular type of constraint in a region does not imply that there are no other problems in this region; the only conclusion is that the targets selected for a particular problem are more difficult to attain than the targets for other problems.

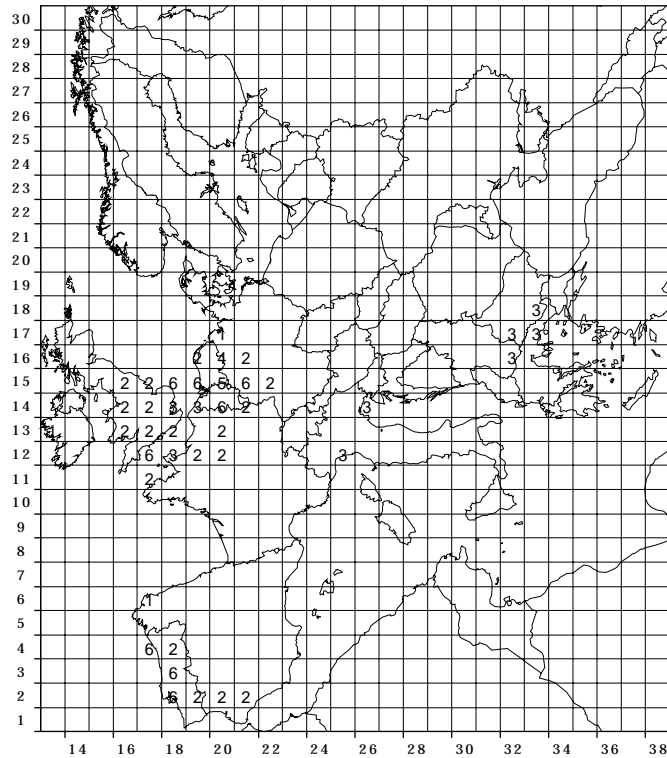


Figure 3.14: The environmental constraints which are most difficult to achieve in the various parts of Europe (1 ..acidification, 2 .. AOT60, 3 .. AOT40, 4 .. acidification and AOT60, 5 .. acidification and AOT60 and AOT40, 6 .. AOT60 and AOT40)

3.5 Comparison of Per-capita Emission Control Costs against Environmental Indices

The optimization analysis follows an effect-based rationale by identifying the cost-minimal set of emission controls to achieve the imposed environmental targets. Therefore, all measures are justified by actual environmental improvements; emission controls that would not improve the environment in a cost-effective way are not selected by the optimization. It is in the nature of the effect-based rationale, however, that other allocation criteria (e.g., equity across countries and/or economic sectors) are not in order to ensure the overall cost-effectiveness.

The analysis presented in this section provides an initial assessment of the international distribution of emission control costs implied by the H1 scenario. Additional analysis of the costs and of some monetized benefits and their international distribution is the subject of Part B of this report.

For reasons of simplicity, total emission control costs were selected as the criterion against which the international distribution will be compared. This measure enables one to easily add up the efforts for the four pollutants without the need for defining necessarily arbitrary weights for the individual pollutants. Furthermore, in order to adjust for the differences in individual countries, total abatement costs were related to the 1997 population of the countries.

The resulting per-capita costs (both of the REF case, white boxes, and the H1 case (filled boxes) - on the y-axis - were then plotted against the average exposure indices for acidification, ozone population exposure, and ozone vegetation exposure of the REF scenario (on the x-axis). It is important to note that these graphs present total emission control costs (for all three environmental problems), although the environmental indices on the x-axis can only relate to one individual problem.

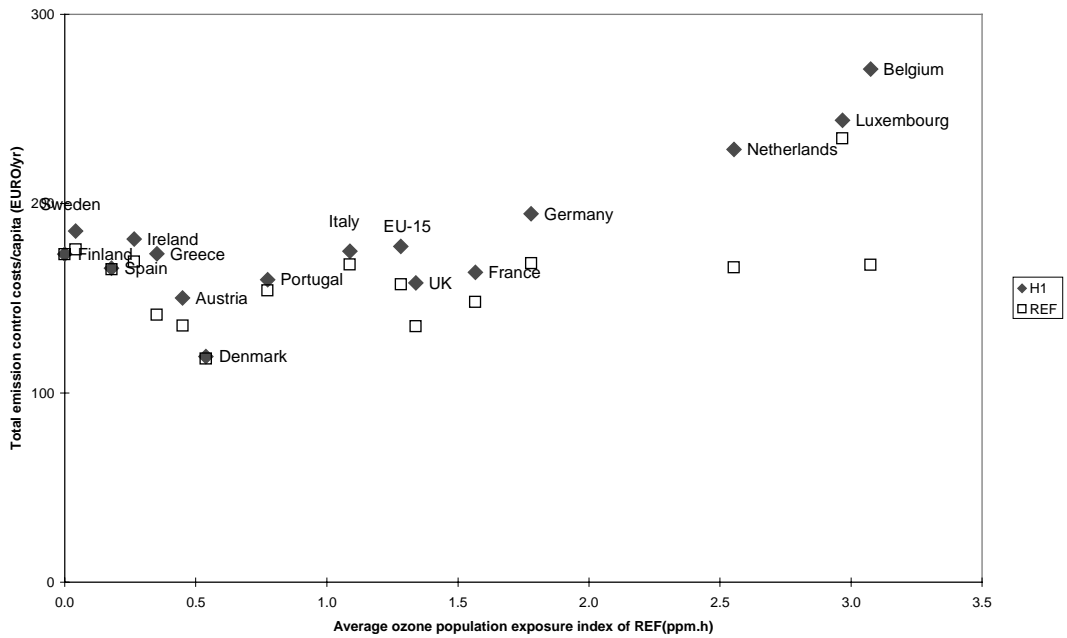


Figure 3.15: Total per-capita emission control costs of the REF and H1 scenarios (for SO₂, NO_x, VOC and NH₃ emissions) plotted against the average ozone population exposure indices of the REF case

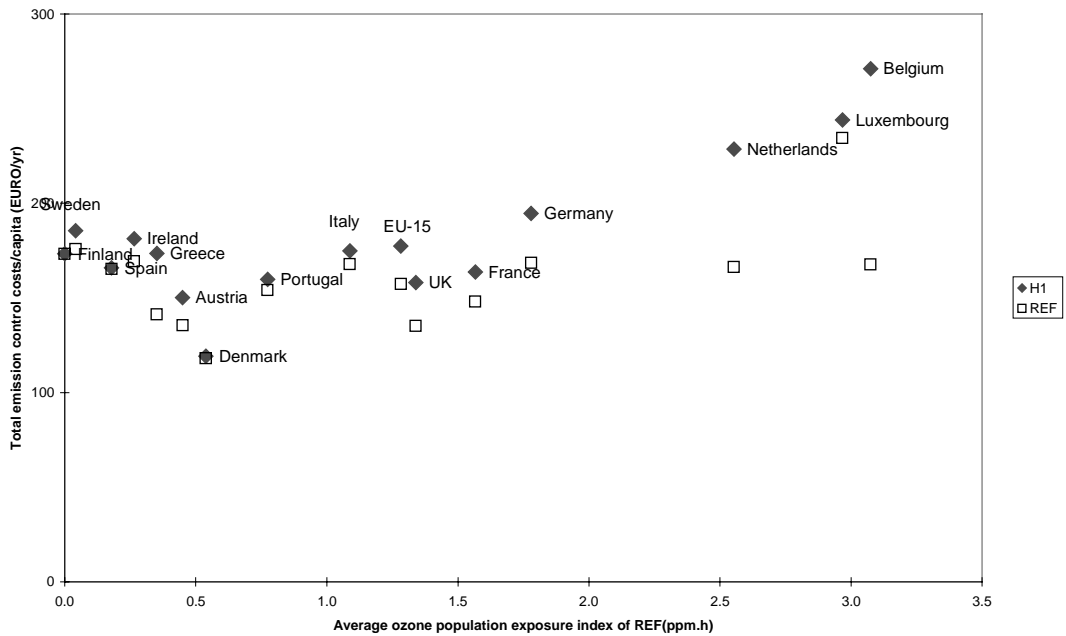


Figure 3.15 plots the per-capita emission control costs (for all four pollutants) of the REF and the H1 cases against the average population exposure indices. There is clear evidence that⁴, the per-capita emission control costs for the REF case stay within a relatively narrow band, independent of the actual severity of the environmental problem. The low per-capita costs for Denmark can be explained by the fact that, in contrast so most other countries, Denmark submitted a 'low CO₂' energy scenario as the basis for the calculations. For the H1 scenario, however, countries with a more severe ozone problem are charged with higher additional costs.

A similar graph is presented in Figure 3.16 for vegetation-related ozone exposure. Again, also when evaluated against this criterion, REF costs show no relation to the environmental problem; in the H1 scenario, higher costs are related to higher ozone exposure. Figure 3.17 presents the analysis for acidification with similar results.

⁴ The numbers for Luxembourg should be treated with care; due to the very small numbers numerical and statistical artifacts are not negligible.

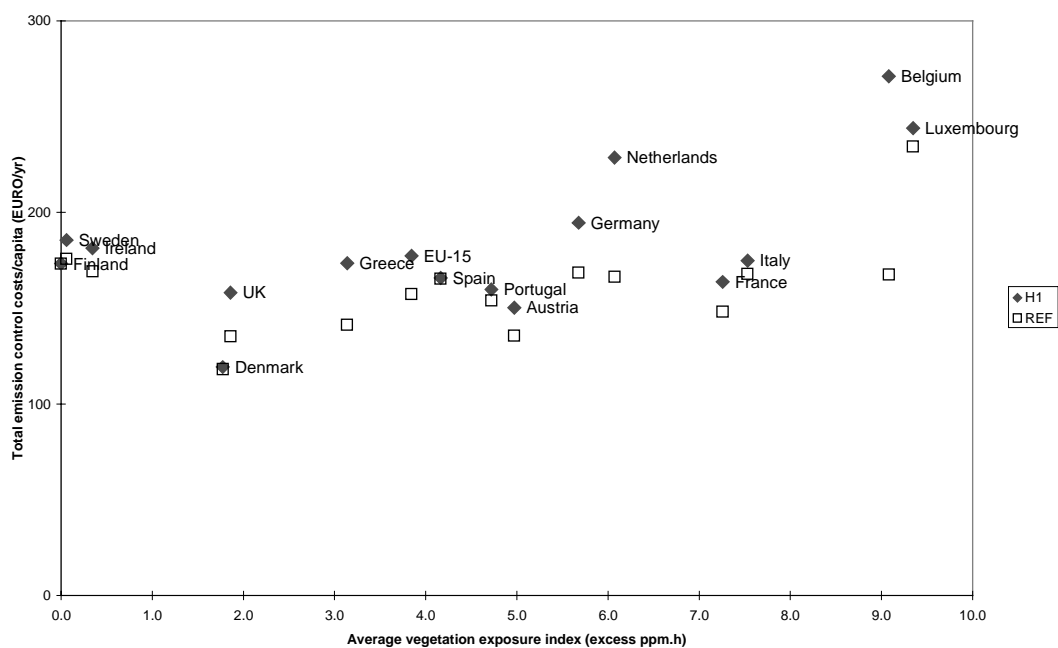


Figure 3.16: Total per-capita emission control costs of the REF and H1 scenarios (for SO₂, NO_x, VOC and NH₃ emissions) plotted against the average vegetation ozone exposure indices of the REF scenario

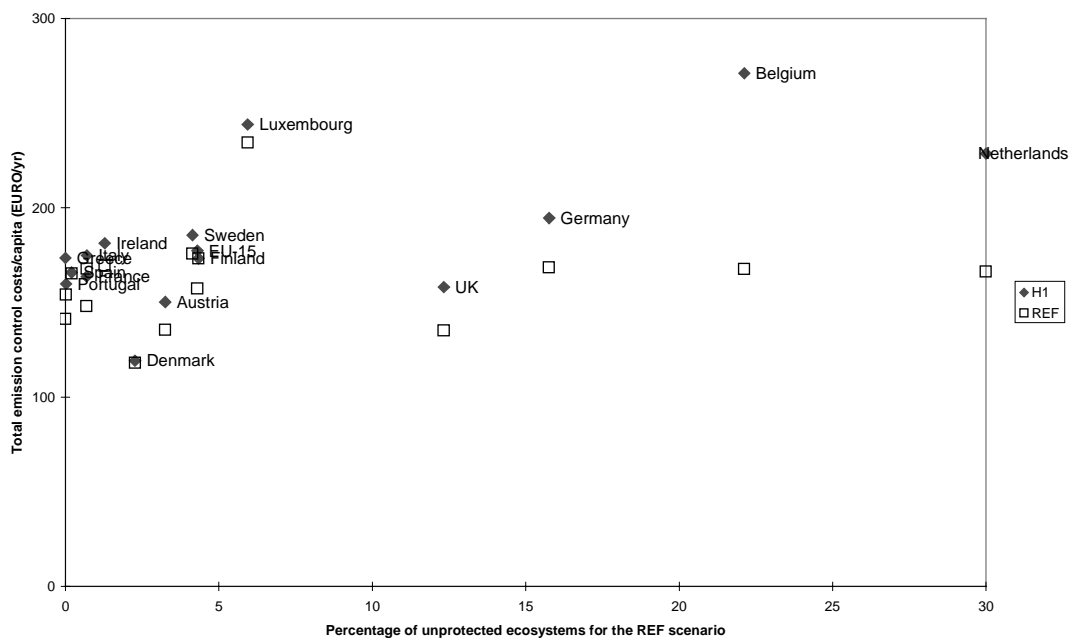


Figure 3.17: Total per-capita emission control costs of the REF and H1 scenarios (for SO₂, NO_x, VOC and NH₃ emissions) plotted against the percentage of unprotected ecosystems (acidification) for the REF scenario

4 Variation of Ambition Levels (Scenarios H2 and H3)

Two scenarios were calculated with modified environmental ambition levels. For the 'low ambition' case (H2), the lower targets identified in the Fifth Interim Reports were adopted, while for the 'high ambition case' (H3), the AOT60 ceiling of the F5 scenario had to be relaxed due to feasibility considerations. Compared to the central H1 case, the low ambition scenario H2 generally lower gap closure percentages and lower exposure ceilings were selected. For H3, the acidification gap closure target of H1 was maintained, while a stricter emission ceiling was introduced. For ozone, both gap closure and ceiling targets were tightened (Table 4.1).

Table 4.1: Summary of the environmental targets for the scenarios with modified ambition levels

	Low ambition (H2)	Central scenario (H1)	High ambition (H3)
Acidification			
Gap closure on accumulated excess acidity	90 %	95 %	95 %
Maximum excess deposition for the 2-percent of the most sensitive ecosystems	(900 eq/ha)	(850 eq/ha)	800 eq/ha
Health-related ozone			
Gap closure on AOT60	60 %	67 %	70 %
Maximum AOT60, to be achieved in 4 out of 5 years	3.0 ppm.h	2.9 ppm.h	2.8 ppm.h
Vegetation-related ozone			
Gap closure on AOT40	30 %	33 %	35 %
Maximum excess AOT40, mean over five years	10.5 ppm.h	10 ppm.h	9.5 ppm.h
Eutrophication			
Gap closure on accumulated excess nitrogen deposition		(50 %)	(50%)
Maximum excess deposition for the 2-percent of the most sensitive ecosystems	(1400 eq/ha)	(1300 eq/ha)	(1000 eq/ha)

Results of the analyses are provided in Table 4.2 to Table 4.4 (emissions and costs) and Table 4.5 to Table 4.8 (environmental indices). With 7.5 billion EURO/year the overall costs of the central scenario H1 lie well within the range spanned by the low ambition (4.2 billion EURO/year) and the high ambition (16.2 billion EURO/year). There are interesting differences in emission controls: For SO₂, modifying the environmental ambition level changes total EU-15 emission by -4/+3 percent; for NO_x, variations range from -2 to + 6 percent. For VOC, only ±1-2 percent differences occur, and ammonia could be 5 percent lower or 8 percent higher than in the central scenario.

Table 4.2: NO_x and VOC emissions for the variations in the ambition. Percentage changes relate to the year 1990.

	NO _x								VOC							
	REF		H2		H1		H3		REF		H2		H1		H3	
	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change
Austria	103	-46%	92	-52%	91	-53%	89	-54%	205	-42%	129	-63%	129	-63%	129	-63%
Belgium	191	-46%	127	-64%	127	-64%	127	-64%	193	-48%	103	-72%	102	-73%	101	-73%
Denmark	128	-53%	128	-53%	127	-54%	96	-65%	85	-53%	85	-53%	85	-53%	84	-54%
Finland	152	-45%	152	-45%	152	-45%	151	-45%	110	-48%	110	-48%	110	-48%	110	-48%
France	858	-54%	706	-62%	679	-64%	633	-66%	1223	-49%	1015	-57%	932	-61%	771	-68%
Germany	1184	-56%	1081	-59%	1051	-61%	930	-65%	1137	-64%	925	-70%	924	-70%	912	-71%
Greece	344	0%	253	-27%	264	-23%	317	-8%	267	-21%	169	-50%	173	-49%	188	-44%
Ireland	70	-38%	63	-44%	59	-48%	46	-59%	55	-50%	55	-50%	55	-50%	54	-51%
Italy	1130	-45%	900	-56%	869	-57%	842	-59%	1159	-44%	962	-53%	962	-53%	893	-57%
Luxembourg	10	-55%	7	-68%	8	-64%	6	-73%	7	-63%	5	-74%	6	-68%	5	-74%
Netherlands	280	-48%	280	-48%	238	-56%	213	-61%	233	-52%	157	-68%	156	-68%	152	-69%
Portugal	177	-15%	177	-15%	144	-31%	144	-31%	144	-32%	113	-47%	102	-52%	102	-52%
Spain	847	-27%	847	-27%	781	-33%	587	-49%	669	-34%	669	-34%	662	-34%	642	-36%
Sweden	190	-44%	158	-53%	152	-55%	147	-57%	290	-43%	219	-57%	219	-57%	215	-58%
UK	1186	-58%	1181	-58%	1181	-58%	859	-70%	1351	-49%	1023	-62%	964	-64%	953	-64%
EU-15	6849	-48%	6152	-53%	5922	-55%	5185	-61%	7128	-49%	5739	-59%	5581	-60%	5310	-62%

Table 4.3: SO₂ and NH₃ emissions for the variations in the ambition levels of the scenarios with different ambition levels. Percentage changes relate to the year 1990.

	SO ₂								NH ₃							
	REF		H2		H1		H3		REF		H2		H1		H3	
	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change
Austria	40	-57%	40	-57%	40	-57%	33	-65%	67	-13%	67	-13%	67	-13%	66	-14%
Belgium	193	-43%	82	-76%	76	-77%	75	-78%	96	-1%	80	-18%	57	-41%	57	-41%
Denmark	90	-51%	90	-51%	77	-58%	25	-86%	72	-6%	71	-8%	71	-8%	65	-16%
Finland	116	-49%	116	-49%	116	-49%	116	-49%	31	-23%	31	-23%	31	-23%	31	-23%
France	448	-64%	318	-75%	218	-83%	163	-87%	777	-4%	771	-4%	718	-11%	530	-34%
Germany	581	-89%	514	-90%	463	-91%	444	-92%	571	-25%	513	-32%	413	-45%	366	-52%
Greece	546	8%	546	8%	546	8%	546	8%	74	-8%	74	-8%	74	-8%	74	-8%
Ireland	66	-63%	28	-84%	28	-84%	23	-87%	126	-1%	126	-1%	123	-3%	123	-3%
Italy	567	-66%	566	-66%	566	-66%	295	-82%	432	-6%	432	-6%	430	-7%	430	-7%
Luxembourg	4	-71%	4	-71%	3	-79%	2	-86%	7	0%	7	0%	7	0%	7	0%
Netherlands	73	-64%	50	-75%	50	-75%	50	-75%	136	-42%	119	-49%	104	-55%	104	-55%
Portugal	141	-50%	141	-50%	141	-50%	141	-50%	67	-6%	67	-6%	67	-6%	67	-6%
Spain	774	-65%	744	-66%	746	-66%	197	-91%	353	0%	353	0%	353	0%	346	-2%
Sweden	67	-44%	67	-44%	67	-44%	66	-45%	48	-21%	48	-21%	48	-21%	48	-21%
UK	980	-74%	718	-81%	497	-87%	422	-89%	297	-10%	293	-11%	264	-20%	224	-32%
EU-15	4687	-71%	4026	-75%	3637	-78%	2600	-84%	3154	-12%	3051	-15%	2826	-21%	2537	-29%

Table 4.4: Emission control costs for the variations in the ambition levels, in million EURO/year.

Costs	SO ₂				NO _x /VOC				NH ₃				Total			
	REF total	H2 low	H1 central	H3 high	REF total	H2 low	H1 central	H3 high	REF total	H2 low	H1 central	H3 high	REF total	H2 low	H1 central	H3 high
		on top of REF				on top of REF				on top of REF				on top of REF		
Austria	191	0	0	7	902	117	119	129	0	0	0	0	1093	117	119	136
Belgium	426	93	127	154	1278	455	459	499	0	43	467	467	1704	591	1053	1120
Denmark	138	0	5	61	484	0	0	37	0	0	0	25	623	0	6	123
Finland	247	0	0	0	642	0	0	0	0	0	0	0	889	0	0	0
France	1276	47	136	348	7383	374	739	2455	0	0	41	1467	8659	421	916	4270
Germany	3264	60	244	331	10549	929	1048	2584	0	111	854	1460	13813	1100	2147	4376
Greece	434	0	0	0	1048	449	338	119	0	0	0	0	1482	449	338	119
Ireland	132	20	20	40	477	1	4	36	9	3	20	20	618	24	44	96
Italy	1776	0	0	83	7868	313	403	648	0	0	0	0	9644	313	403	731
Luxembourg	13	0	1	3	71	11	4	30	15	0	0	0	98	11	4	33
Netherlands	340	19	19	19	1731	88	211	495	196	247	741	741	2267	354	971	1255
Portugal	181	0	0	0	1349	21	57	57	0	0	0	0	1530	21	57	57
Spain	809	10	9	303	5658	0	13	295	28	0	0	7	6495	10	22	605
Sweden	316	0	0	0	1125	73	87	116	113	0	0	0	1554	73	87	117
UK	1269	92	299	580	6695	647	1026	2138	0	2	23	445	7964	741	1348	3163
EU-15	10813	342	861	1931	47258	3479	4508	9639	361	406	2146	4632	58433	4227	7514	16202

Table 4.5: Ecosystems with acid deposition above their critical loads for acidification for the central scenario H1 and for the scenarios with modified ambition levels

Ambition	1000 ha				Percent of ecosystems			
	REF	H2 Low	H1 Central	H3 High	REF	H2 Low	H1 Central	H3 High
Austria	162	122	99	78	3.3	2.5	2.0	1.6
Belgium	155	99	52	24	22.1	14.0	7.4	3.4
Denmark	9	7	6	4	2.3	1.8	1.5	1.1
Finland	1183	1164	1150	1130	4.3	4.3	4.2	4.1
France	218	111	88	38	0.7	0.4	0.3	0.1
Germany	1617	1110	727	515	15.8	10.8	7.1	5.0
Greece	0	0	0	0	0.0	0.0	0.0	0.0
Ireland	12	9	9	8	1.3	1.0	1.0	0.9
Italy	74	62	58	52	0.7	0.6	0.6	0.5
Luxembourg	5	4	1	0	5.9	4.3	0.9	0.5
Netherlands	193	134	76	63	60.4	41.8	23.7	19.8
Portugal	1	1	1	1	0.0	0.0	0.0	0.0
Spain	17	17	17	0	0.2	0.2	0.2	0.0
Sweden	1605	1494	1420	1236	4.1	3.9	3.7	3.2
UK	1182	926	649	288	12.3	9.7	6.8	3.0
EU-15	6433	5259	4351	3437	4.3	3.5	2.9	2.3

Table 4.6: Ozone population exposure for the central scenario H1 and for the scenarios with modified ambition levels

Ambition	Cumulative population exposure index (million.persons.ppm.h)				Average population exposure index (ppm.h)			
	REF	H2 Low	H1 Central	H3 High	REF	H2 Low	H1 Central	H3 High
Austria	3	2	2	2	0.5	0.3	0.3	0.3
Belgium	34	24	23	21	3.1	2.2	2.1	1.9
Denmark	3	2	1	1	0.5	0.3	0.3	0.2
Finland	0	0	0	0	0.0	0.0	0.0	0.0
France	89	56	53	45	1.6	1.0	0.9	0.8
Germany	140	102	99	88	1.8	1.3	1.3	1.1
Greece	4	2	2	2	0.4	0.2	0.2	0.2
Ireland	1	0	0	0	0.3	0.1	0.1	0.1
Italy	63	40	38	33	1.1	0.7	0.7	0.6
Luxembourg	1	1	1	1	3.0	2.2	2.1	1.8
Netherlands	38	28	27	25	2.6	1.9	1.8	1.7
Portugal	8	6	6	5	0.8	0.6	0.6	0.5
Spain	7	4	4	1	0.2	0.1	0.1	0.0
Sweden	0	0	0	0	0.0	0.0	0.0	0.0
UK	77	49	45	42	1.3	0.9	0.8	0.7
EU-15	466	317	300	267	1.3	0.9	0.8	0.7

Table 4.7: Ozone vegetation exposure indices for the central scenario H1 and for the scenarios with modified ambition levels

Ambition	Cumulative vegetation exposure index (1000 km ² ppm.h)				Average vegetation exposure index (ppm.h)			
	REF	H2	H1	H3	REF	H2	H1	H3
		Low	Central	High		Low	Central	High
Austria	257	217	213	201	5.0	4.2	4.1	3.9
Belgium	141	117	115	113	9.1	7.5	7.4	7.3
Denmark	53	38	36	29	1.8	1.3	1.2	1.0
Finland	0	0	0	0	0.0	0.0	0.0	0.0
France	2345	1897	1816	1658	7.3	5.9	5.6	5.1
Germany	1204	966	943	883	5.7	4.6	4.4	4.2
Greece	170	136	137	145	3.1	2.5	2.5	2.7
Ireland	8	4	3	2	0.3	0.2	0.1	0.1
Italy	1186	1017	996	945	7.5	6.5	6.3	6.0
Luxembourg	14	11	11	10	9.3	7.4	7.3	6.8
Netherlands	79	63	63	63	6.1	4.9	4.8	4.9
Portugal	274	254	233	215	4.7	4.4	4.0	3.7
Spain	1281	1197	1093	865	4.2	3.9	3.6	2.8
Sweden	18	10	9	7	0.1	0.0	0.0	0.0
UK	153	102	96	101	1.9	1.2	1.2	1.2
EU-15	7183	6029	5765	5237	3.8	3.2	3.1	2.8

Table 4.8: Ecosystems with nitrogen deposition above their critical loads for eutrophication for the central scenario H1 and for the scenarios with modified ambition levels

Ambition	1000 ha				Percent of ecosystems			
	REF	H2	H1	H3	REF	H2	H1	H3
		Low	Central	High		Low	Central	High
Austria	3441	3172	2773	2583	58	53	46	43
Belgium	677	644	586	471	96	92	83	67
Denmark	119	99	91	57	38	32	29	18
Finland	2538	2291	2163	1858	15	14	13	11
France	25160	23936	22524	17884	79	75	71	56
Germany	9184	8489	7474	6283	90	83	73	61
Greece	236	206	211	219	10	8	9	9
Ireland	58	57	54	47	6	6	6	5
Italy	3795	3557	3452	3338	32	30	29	28
Luxembourg	80	75	66	54	91	86	75	62
Netherlands	291	284	278	271	91	89	87	85
Portugal	709	708	683	578	25	25	24	20
Spain	1158	1097	964	487	14	13	11	6
Sweden	891	813	737	589	5	4	4	3
UK	126	98	64	0	1	1	1	0
EU-15	48461	45527	42117	34720	40	38	35	29

The cost-effectiveness ratio of the sensitivity scenarios are presented for the various environmental indicators in Figure 4.1 to Figure 4.3. For completeness, the graphs also include the Reference scenario and the 'ultimate' maximum feasible emission reduction case. It should be noted that the ultimate MFR estimate is of hypothetical value, since it would require fundamental changes in the stock of presently existing plants.

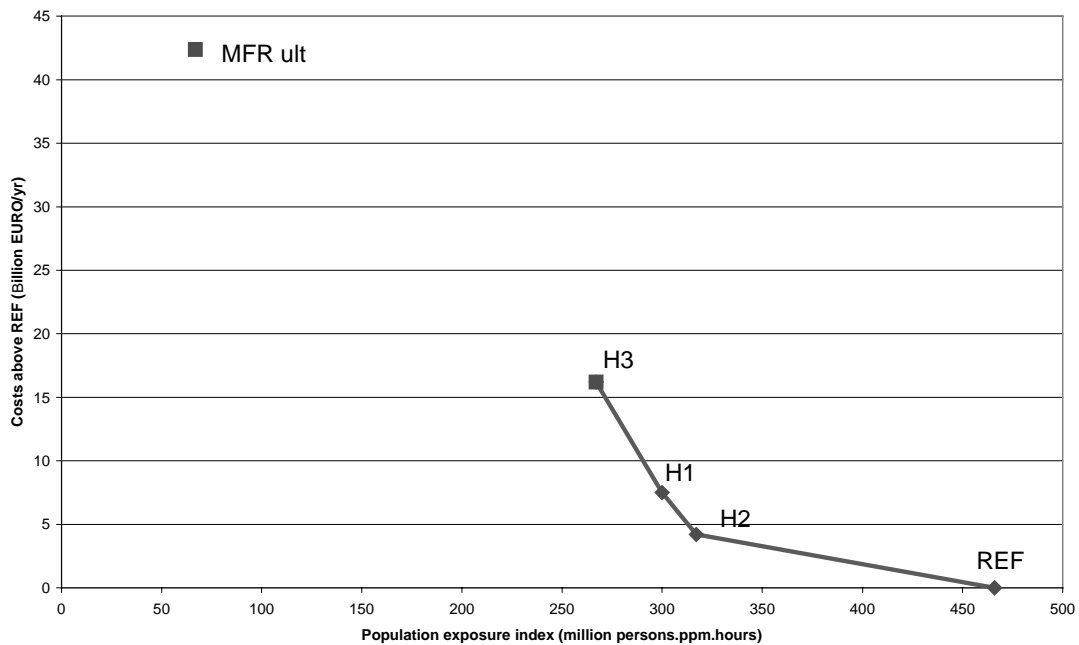


Figure 4.1: Cost-effectiveness of the scenarios with modified environmental ambition levels in relation to changes of the cumulative population exposure index

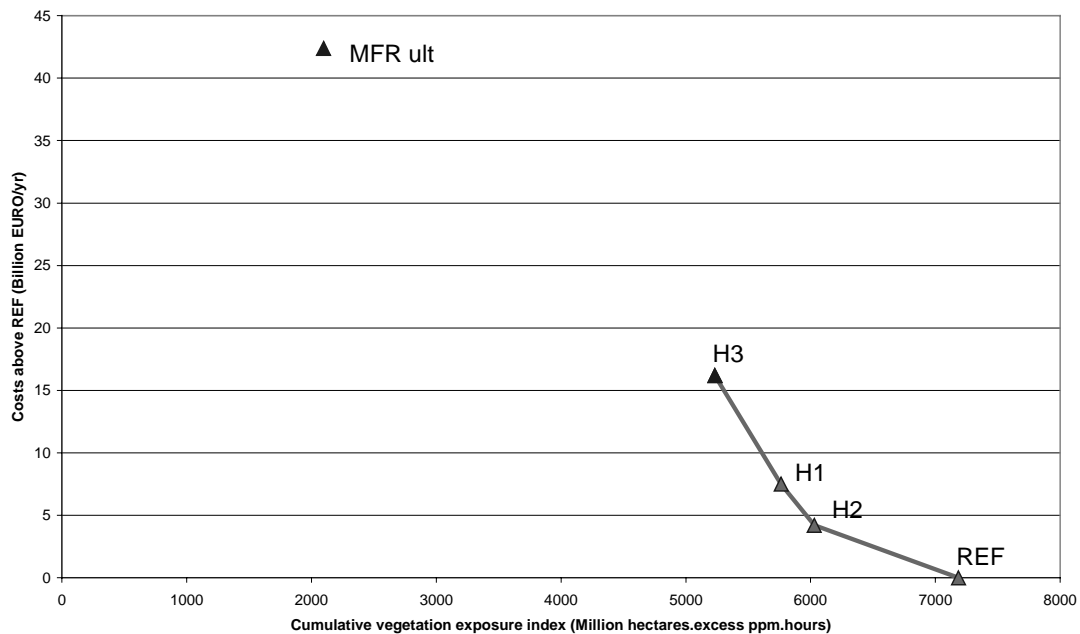


Figure 4.2: Cost-effectiveness of the scenarios with modified environmental ambition levels in relation to changes of the cumulative vegetation exposure index

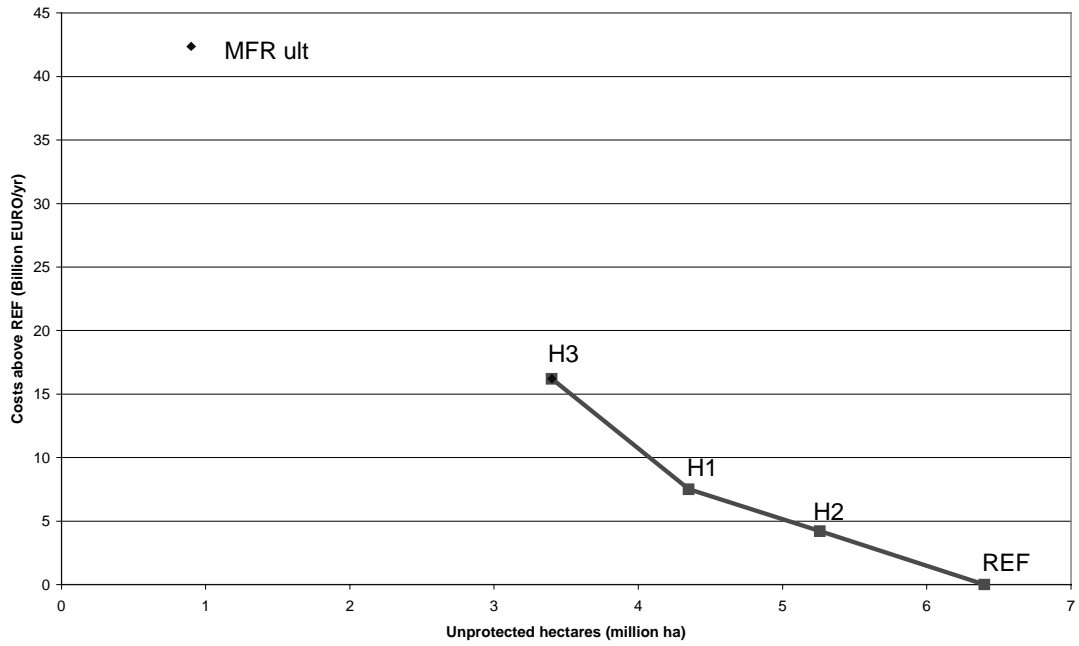


Figure 4.3: Cost-effectiveness of the scenarios with modified environmental ambition levels in relation to the ecosystems area unprotected against acidification

5 ECE-wide Targets and Measures (Scenario H4)

Scenario H4 explores the changes in emission ceilings and control costs for the EU-15, if the strategy with the same targets as in the H1 scenario included the entire European ECE-region. This means that the targets of the H1 scenario are applied Europe-wide, and emission controls in all ECE member states are considered in the optimization.

The extension of the geographical scope means that environmental targets are specified for all land-based grid cells in the ECE. For the EU-15 this implies that border grid cells, which were excluded in the earlier EU-15 scenarios (i.e., the Kola region, grid 24/13 at the Italian/Swiss border, and grid 26/17 at the Austrian/Slovakian/Hungarian border) are now included. Following the recent discussions at the UN/ECE level, acidification targets for two grid cells in southern Norway were set at an 85 percent gap closure in terms of accumulated excess acidity.

The results of the joint (multi-effect/multi-pollutant) optimization clearly indicate that there is a certain degree of interaction between the emissions of the EU-15 and the non-EU countries. Depending on the selected ambition level, this interaction could work in both directions. Given the particular environmental targets, emission reductions in the non-EU countries reduce the required efforts in the EU-15 (costs decline from 7.5 billion EURO/year to 5.6 billion EURO/year, i.e. by 25 percent). Most interestingly, the overall costs for all countries incurred in the H4 scenario are slightly lower than the costs of the H1 case, which relate to the EU-15 only.

Significant cost savings would occur for countries at the EU border (Austria, Germany, Greece), where additional reductions would shift to neighboring non-EU countries. Via the atmospheric long-range transport, these reductions relieve background pollution also for France, Netherlands, Sweden and the UK, so that the most expensive measures in these countries could be relaxed. Due to sensitive ecosystems in Switzerland, however, further reductions would be necessary in Italy.

Most of the cost-savings occur for further NO_x and VOC controls, while in the EU-15 abatement costs for sulfur slightly increase (due to the sensitive ecosystems in Switzerland and Slovakia),

It is further interesting to note that about two thirds of the additional costs of the non-EU countries occur in 'first round' accession countries (the Czech Republic, Hungary, Poland, and Slovenia).

Detailed results are presented in Table 5.1 to Table 5.10.

Table 5.1: NO_x emissions for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4). Percentage changes relate to the year 1990.

	REF		H1 Central case, EU15		H4 ECE wide	
	kt	Change	kt	Change	kt	Change
Austria	103	-46%	91	-53%	91	-53%
Belgium	191	-46%	127	-64%	127	-64%
Denmark	128	-53%	127	-54%	113	-59%
Finland	152	-45%	152	-45%	152	-45%
France	858	-54%	679	-64%	705	-62%
Germany	1184	-56%	1051	-61%	1095	-59%
Greece	344	0%	264	-23%	344	0%
Ireland	70	-38%	59	-48%	58	-49%
Italy	1130	-45%	869	-57%	902	-56%
Luxembourg	10	-55%	8	-64%	8	-64%
Netherlands	280	-48%	238	-56%	266	-51%
Portugal	177	-15%	144	-31%	144	-31%
Spain	847	-27%	781	-33%	758	-35%
Sweden	190	-44%	152	-55%	163	-52%
United Kingdom	1186	-58%	1181	-58%	1181	-58%
EU-15	6849	-48%	5922	-55%	6107	-54%
Albania	36	50%	36	50%	36	50%
Belarus	316	-21%	316	-21%	305	-24%
Bosnia-H.	60	-25%	60	-25%	57	-29%
Bulgaria	297	-16%	297	-16%	252	-29%
Croatia	91	11%	91	11%	91	11%
Czech Rep.	296	-46%	296	-46%	197	-64%
Estonia	73	-13%	73	-13%	73	-13%
Hungary	198	-10%	198	-10%	142	-35%
Latvia	118	1%	118	1%	118	1%
Lithuania	138	-10%	138	-10%	138	-10%
Norway	178	-19%	178	-19%	142	-35%
Poland	879	-28%	879	-28%	803	-34%
Moldova	66	-24%	66	-24%	66	-24%
Romania	458	-12%	458	-12%	369	-29%
Russia	2653	-24%	2653	-24%	2653	-24%
Slovakia	132	-40%	132	-40%	118	-46%
Slovenia	36	-40%	36	-40%	34	-43%
Switzerland	79	-52%	79	-52%	76	-53%
FYR Macedonia	29	-26%	29	-26%	29	-26%
Ukraine	1433	-24%	1433	-24%	1333	-29%
Yugoslavia	152	-28%	152	-28%	152	-28%
Non-EU	7718	-24%	7718	-24%	7184	-29%
Total	14567	-38%	13640	-42%	13291	-43%

Table 5.2: VOC emissions for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4). Percentage changes relate to the year 1990.

	REF		H1 Central case, EU15		H4 ECE wide	
	kt	Change	kt	Change	kt	Change
Austria	205	-42%	129	-63%	142	-60%
Belgium	193	-48%	102	-73%	103	-72%
Denmark	85	-53%	85	-53%	85	-53%
Finland	110	-48%	110	-48%	110	-48%
France	1223	-49%	932	-61%	972	-59%
Germany	1137	-64%	924	-70%	987	-68%
Greece	267	-21%	173	-49%	265	-21%
Ireland	55	-50%	55	-50%	55	-50%
Italy	1159	-44%	962	-53%	1006	-51%
Luxembourg	7	-63%	6	-68%	7	-63%
Netherlands	233	-52%	156	-68%	157	-68%
Portugal	144	-32%	102	-52%	102	-52%
Spain	669	-34%	662	-34%	645	-36%
Sweden	290	-43%	219	-57%	241	-53%
United Kingdom	1351	-49%	964	-64%	1084	-59%
EU-15	7128	-49%	5581	-60%	5959	-58%
Albania	41	32%	41	32%	41	32%
Belarus	309	-17%	309	-17%	298	-20%
Bosnia-H.	48	-6%	48	-6%	48	-6%
Bulgaria	190	-3%	190	-3%	175	-10%
Croatia	111	8%	111	8%	97	-6%
Czech Rep.	305	-31%	304	-31%	186	-58%
Estonia	49	9%	49	9%	49	9%
Hungary	160	-22%	160	-22%	139	-32%
Latvia	56	-11%	56	-11%	56	-11%
Lithuania	105	-5%	105	-5%	105	-5%
Norway	195	-34%	195	-34%	195	-34%
Poland	807	1%	807	1%	475	-40%
Moldova	42	-16%	42	-16%	42	-16%
Romania	504	0%	504	0%	464	-8%
Russia	2787	-21%	2786	-21%	2675	-24%
Slovakia	140	-7%	140	-7%	140	-7%
Slovenia	40	-27%	40	-27%	40	-27%
Switzerland	144	-48%	144	-48%	144	-48%
FYR Macedonia	19	0%	19	0%	19	0%
Ukraine	851	-27%	851	-27%	756	-35%
Yugoslavia	139	-2%	139	-2%	137	-4%
Non-EU	7041	-18%	7041	-18%	6283	-27%
Total	14169	-37%	12622	-44%	12242	-46%

Table 5.3: SO₂ emissions for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4). Percentage changes relate to the year 1990.

	REF		H1 Central case, EU15		H4 ECE wide	
	kt	Change	kt	Change	kt	Change
Austria	40	-57%	40	-57%	34	-63%
Belgium	193	-43%	76	-77%	76	-77%
Denmark	90	-51%	77	-58%	34	-81%
Finland	116	-49%	116	-49%	116	-49%
France	448	-64%	218	-83%	219	-82%
Germany	581	-89%	463	-91%	457	-91%
Greece	546	8%	546	8%	546	8%
Ireland	66	-63%	28	-84%	28	-84%
Italy	567	-66%	566	-66%	261	-84%
Luxembourg	4	-71%	3	-79%	3	-79%
Netherlands	73	-64%	50	-75%	50	-75%
Portugal	141	-50%	141	-50%	141	-50%
Spain	774	-65%	746	-66%	747	-66%
Sweden	67	-44%	67	-44%	66	-45%
United Kingdom	980	-74%	497	-87%	496	-87%
EU-15	4687	-71%	3637	-78%	3276	-80%
Albania	55	-24%	55	-24%	55	-24%
Belarus	494	-41%	494	-41%	494	-41%
Bosnia-H.	415	-15%	415	-15%	77	-84%
Bulgaria	846	-54%	846	-54%	378	-79%
Croatia	70	-61%	70	-61%	20	-89%
Czech Rep.	366	-80%	366	-80%	282	-85%
Estonia	175	-36%	175	-36%	175	-36%
Hungary	546	-40%	546	-40%	296	-68%
Latvia	104	-14%	104	-14%	104	-14%
Lithuania	107	-50%	107	-50%	107	-50%
Norway	32	-38%	32	-38%	18	-65%
Poland	1397	-53%	1397	-53%	721	-76%
Moldova	117	-41%	117	-41%	42	-79%
Romania	594	-55%	594	-55%	148	-89%
Russia	2344	-53%	2344	-53%	2155	-57%
Slovakia	137	-75%	137	-75%	92	-83%
Slovenia	71	-65%	71	-65%	14	-93%
Switzerland	26	-40%	26	-40%	23	-47%
FYR Macedonia	81	-24%	81	-24%	81	-24%
Ukraine	1488	-60%	1488	-60%	1460	-61%
Yugoslavia	269	-54%	269	-54%	62	-89%
Non-EU	9732	-55%	9732	-55%	6804	-68%
Total	14419	-62%	13369	-65%	10080	-73%

Table 5.4: NH₃ emissions for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4). Percentage changes relate to the year 1990.

	REF		H1 Central case, EU15		H4 ECE wide	
	kt	Change	kt	Change	kt	Change
Austria	67	-13%	67	-13%	66	-14%
Belgium	96	-1%	57	-41%	57	-41%
Denmark	72	-6%	71	-8%	69	-10%
Finland	31	-23%	31	-23%	31	-23%
France	777	-4%	718	-11%	718	-11%
Germany	571	-25%	413	-45%	413	-45%
Greece	74	-8%	74	-8%	74	-8%
Ireland	126	-1%	123	-3%	124	-2%
Italy	432	-6%	430	-7%	362	-22%
Luxembourg	7	0%	7	0%	7	0%
Netherlands	136	-42%	104	-55%	104	-55%
Portugal	67	-6%	67	-6%	67	-6%
Spain	353	0%	353	0%	353	0%
Sweden	48	-21%	48	-21%	48	-21%
United Kingdom	297	-10%	264	-20%	264	-20%
EU-15	3154	-12%	2826	-21%	2757	-23%
Albania	35	9%	35	9%	35	9%
Belarus	163	-26%	163	-26%	163	-26%
Bosnia-H.	23	-26%	23	-26%	22	-29%
Bulgaria	126	-11%	126	-11%	126	-11%
Croatia	37	-8%	37	-8%	29	-28%
Czech Rep.	108	1%	108	1%	105	-2%
Estonia	29	0%	29	0%	29	0%
Hungary	137	14%	137	14%	77	-36%
Latvia	35	-19%	35	-19%	35	-19%
Lithuania	81	1%	81	1%	81	1%
Norway	21	-9%	21	-9%	21	-9%
Poland	541	7%	541	7%	515	2%
Moldova	48	2%	48	2%	48	2%
Romania	304	4%	304	4%	274	-6%
Russia	894	-30%	894	-30%	894	-30%
Slovakia	47	-22%	47	-22%	39	-35%
Slovenia	21	-9%	21	-9%	17	-26%
Switzerland	66	-8%	66	-8%	63	-13%
FYR Macedonia	16	-6%	16	-6%	16	-6%
Ukraine	649	-11%	649	-11%	649	-11%
Yugoslavia	82	-9%	82	-9%	76	-16%
Non-EU	3462	-13%	3462	-13%	3313	-17%
Total	6616	-12%	6288	-17%	6070	-20%

Table 5.5: Emission control costs for SO₂ and NO_x for the EU-wide central scenario H1 and the sensitivity case with measures in all ECE countries (H4), in million EURO/year.

Costs	REF	SO ₂		NO _x & VOC		
		H1	H4	REF total	H1 on top of REF	H4 on top of REF
Austria	191	0	5	902	119	70
Belgium	426	127	124	1278	459	452
Denmark	138	5	35	484	0	8
Finland	247	0	0	642	0	0
France	1276	136	133	7383	739	465
Germany	3264	244	248	10549	1048	472
Greece	434	0	0	1048	338	1
Ireland	132	20	20	477	4	5
Italy	1776	0	107	7868	403	268
Luxembourg	13	1	0	71	4	2
Netherlands	340	19	19	1731	211	112
Portugal	181	0	0	1349	57	57
Spain	809	9	9	5658	13	29
Sweden	316	0	0	1125	87	40
United Kingdom	1269	299	302	6695	1026	417
EU-15	10813	861	1004	47258	4508	2397
Albania	0	0	0	0	0	0
Belarus	0	0	0	0	0	1
Bosnia-H.	0	0	82	1	0	1
Bulgaria	153	0	58	4	0	25
Croatia	52	0	22	1	0	1
Czech Rep.	411	0	36	568	0	149
Estonia	0	0	0	0	0	0
Hungary	166	0	113	420	0	94
Latvia	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0
Norway	56	0	10	567	0	12
Poland	855	0	284	2487	0	177
Moldova	0	0	28	0	0	0
Romania	155	0	137	2	0	33
Russia	694	0	65	21	0	1
Slovakia	91	0	25	331	0	5
Slovenia	35	0	23	93	0	1
Switzerland	118	0	1	831	0	2
FYR Macedonia	0	0	0	1	0	0
Ukraine	328	0	7	0	0	13
Yugoslavia	88	0	150	3	0	0
Non-EU	3202	0	1042	5332	0	515
Total	14016	861	2047	52590	4508	2912

Table 5.6: Emission control costs (on top of REF) for NH₃ and total costs for the EU-wide central scenario H1 and the sensitivity cases with measures in all ECE countries (H4), in million EURO/year.

Costs	REF	NH ₃		REF total	TOTAL	
		H1	H4		H1	H4
		on top of REF			on top of REF	
Austria	0	0	1	1093	119	76
Belgium	0	467	467	1704	1053	1043
Denmark	0	0	2	623	6	44
Finland	0	0	0	889	0	0
France	0	41	41	8659	916	640
Germany	0	854	845	13813	2147	1565
Greece	0	0	0	1482	338	1
Ireland	9	20	18	618	44	43
Italy	0	0	77	9644	403	452
Luxembourg	15	0	0	98	4	2
Netherlands	196	741	699	2267	971	830
Portugal	0	0	0	1530	57	57
Spain	28	0	0	6495	22	38
Sweden	113	0	0	1554	87	40
United Kingdom	0	23	23	7964	1348	742
EU-15	361	2146	2172	58433	7514	5574
Albania	0	0	0	0	0	0
Belarus	0	0	0	0	0	1
Bosnia-H.	0	0	0	1	0	83
Bulgaria	0	0	0	157	0	83
Croatia	0	0	3	52	0	26
Czech Rep.	0	0	2	979	0	188
Estonia	0	0	0	0	0	0
Hungary	0	0	319	586	0	526
Latvia	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0
Norway	0	0	3	623	0	25
Poland	0	0	6	3342	0	467
Moldova	0	0	0	0	0	28
Romania	0	0	6	157	0	176
Russia	0	0	0	715	0	66
Slovakia	0	0	7	423	0	38
Slovenia	0	0	2	128	0	25
Switzerland	0	0	6	949	0	9
FYR Macedonia	0	0	0	1	0	0
Ukraine	0	0	0	328	0	20
Yugoslavia	0	0	2	92	0	152
Non-EU	0	0	356	8534	0	1913
Total	361	2146	2528	66967	7514	7487

Table 5.7: Ecosystems with acid deposition above their critical loads, comparison of the joint scenario H1 (limited to the EU countries) with the ECE-wide scenario H4

	1000 ha			Percent of ecosystems		
	REF	H1	H4	REF	H1	H4
Austria	162	99	70	3.3	2.0	1.4
Belgium	155	52	52	22.1	7.4	7.4
Denmark	9	6	4	2.3	1.5	1.2
Finland	1183	1150	653	4.3	4.2	2.4
France	218	88	87	0.7	0.3	0.3
Germany	1617	727	585	15.8	7.1	5.7
Greece	0	0	0	0.0	0.0	0.0
Ireland	12	9	9	1.3	1.0	1.0
Italy	74	58	51	0.7	0.6	0.5
Luxembourg	5	1	1	5.9	0.9	0.8
Netherlands	193	76	76	60.4	23.7	23.7
Portugal	1	1	1	0.0	0.0	0.0
Spain	17	17	17	0.2	0.2	0.2
Sweden	1605	1420	1148	4.1	3.7	3.0
United Kingdom	1182	649	643	12.3	6.8	6.7
EU-15	6433	4351	3395	4.3	2.9	2.3
Albania	0	0	0	0.0	0.0	0.0
Belarus	1048	1033	574	20.9	20.5	11.4
Bosnia-H.	131	131	0	9.1	9.1	0.0
Bulgaria	0	0	0	0.0	0.0	0.0
Croatia	0	0	0	0.0	0.0	0.0
Czech Rep.	474	285	92	17.9	10.7	3.5
Estonia	11	10	8	0.6	0.5	0.4
Hungary	65	54	37	22.9	18.9	13.0
Latvia	0	0	0	0.0	0.0	0.0
Lithuania	78	77	0	4.1	4.1	0.0
Norway	2573	2239	1891	11.6	10.1	8.6
Poland	1357	1117	202	7.8	6.4	1.2
Moldova	29	29	10	2.4	2.4	0.9
Romania	51	51	17	0.8	0.8	0.3
Russia	4073	4060	634	1.2	1.2	0.2
Slovakia	295	261	150	14.7	13.0	7.5
Slovenia	19	19	4	2.1	2.1	0.4
Switzerland	57	40	36	4.6	3.2	2.9
FYR Macedonia	0	0	0	0.0	0.0	0.0
Ukraine	643	636	265	7.8	7.7	3.2
Yugoslavia	2	2	0	0.1	0.1	0.0
Non-EU	10908	10043	3919	2.5	2.3	0.9
Total	17341	14394	7315	3.0	2.5	1.3

Table 5.8: Population exposure indices, comparison of the joint scenario H1 (limited to the EU countries) with the ECE-wide scenario H4

	Cumulative population exposure index (million persons.ppm.h)			Average population exposure index (ppm.h)		
	REF	H1	H4	REF	H1	H4
Austria	3	2	2	0.5	0.3	0.2
Belgium	34	23	23	3.1	2.1	2.1
Denmark	3	1	1	0.5	0.3	0.3
Finland	0	0	0	0.0	0.0	0.0
France	89	53	54	1.6	0.9	1.0
Germany	140	99	93	1.8	1.3	1.2
Greece	4	2	3	0.4	0.2	0.3
Ireland	1	0	0	0.3	0.1	0.1
Italy	63	38	39	1.1	0.7	0.7
Luxembourg	1	1	1	3.0	2.1	2.1
Netherlands	38	27	27	2.6	1.8	1.8
Portugal	8	6	6	0.8	0.6	0.6
Spain	7	4	4	0.2	0.1	0.1
Sweden	0	0	0	0.0	0.0	0.0
United Kingdom	77	45	49	1.3	0.8	0.9
EU-15	466	300	301	1.3	0.8	0.8
Albania	0	0	0	0.0	0.0	0.0
Belarus	1	1	0	0.1	0.1	0.0
Bosnia-H.	0	0	0	0.1	0.1	0.0
Bulgaria	1	1	0	0.1	0.1	0.0
Croatia	3	2	2	0.6	0.4	0.3
Czech Rep.	11	8	6	1.0	0.8	0.6
Estonia	0	0	0	0.0	0.0	0.0
Hungary	12	10	7	1.1	1.0	0.7
Latvia	0	0	0	0.1	0.0	0.0
Lithuania	0	0	0	0.1	0.1	0.0
Norway	0	0	0	0.0	0.0	0.0
Poland	36	29	21	0.9	0.8	0.5
Moldova	1	1	0	0.2	0.1	0.1
Romania	6	5	2	0.3	0.2	0.1
Russia	7	6	5	0.1	0.1	0.1
Slovakia	6	5	4	1.1	1.0	0.7
Slovenia	1	1	1	0.7	0.4	0.4
Switzerland	2	0	1	0.3	0.1	0.1
FYR Macedonia	0	0	0	0.0	0.0	0.0
Ukraine	14	13	8	0.3	0.3	0.2
Yugoslavia	3	2	1	0.2	0.2	0.1
Non-EU	103	86	57	0.3	0.3	0.2
Total	570	385	358	0.8	0.6	0.5

Table 5.9: Vegetation exposure indices, comparison of the joint scenario H1 (limited to the EU countries) with the ECE-wide scenario H4

	Cumulative vegetation exposure index (100 km ² .ppm.h)			Average vegetation exposure index (ppm.h)		
	REF	H1	H4	REF	H1	H4
Austria	257	213	198	5.0	4.1	3.8
Belgium	141	115	115	9.1	7.4	7.4
Denmark	53	36	32	1.8	1.2	1.1
Finland	0	0	0	0.0	0.0	0.0
France	2345	1816	1867	7.3	5.6	5.8
Germany	1204	943	915	5.7	4.4	4.3
Greece	170	137	147	3.1	2.5	2.7
Ireland	8	3	3	0.3	0.1	0.1
Italy	1186	996	993	7.5	6.3	6.3
Luxembourg	14	11	11	9.3	7.3	7.4
Netherlands	79	63	63	6.1	4.8	4.8
Portugal	274	233	231	4.7	4.0	4.0
Spain	1281	1093	1074	4.2	3.6	3.5
Sweden	18	9	7	0.1	0.0	0.0
United Kingdom	153	96	109	1.9	1.2	1.3
EU-15	7183	5765	5766	3.8	3.1	3.1
Albania	0	0	0	0.0	0.0	0.0
Belarus	78	69	54	0.9	0.8	0.6
Bosnia-H.	162	143	130	4.2	3.7	3.4
Bulgaria	281	270	229	3.8	3.6	3.1
Croatia	214	205	178	6.0	5.8	5.0
Czech Rep.	311	263	227	5.6	4.7	4.1
Estonia	0	0	0	0.0	0.0	0.0
Hungary	404	370	305	6.2	5.7	4.7
Latvia	6	4	3	0.1	0.1	0.1
Lithuania	23	17	12	0.6	0.4	0.3
Norway	1	1	1	0.0	0.0	0.0
Poland	829	721	590	3.6	3.2	2.6
Moldova	56	54	46	3.3	3.2	2.7
Romania	623	594	489	4.0	3.8	3.1
Russia	983	960	889	0.5	0.5	0.5
Slovakia	215	196	161	6.0	5.5	4.5
Slovenia	94	82	78	7.2	6.2	6.0
Switzerland	85	68	70	4.8	3.9	3.9
FYR Macedonia	40	36	33	2.5	2.3	2.1
Ukraine	1206	1166	1034	3.1	3.0	2.6
Yugoslavia	248	230	198	3.7	3.4	2.9
Non-EU	5860	5449	4726	1.7	1.6	1.4
Total	13043	11214	10492	2.4	2.1	2.0

Table 5.10: Ecosystems with nitrogen deposition above their critical loads for eutrophication, comparison of the central scenario H1 (limited to the EU countries) with the ECE-wide scenario H4

	1000 ha			Percent of ecosystems		
	REF	H1	H4	REF	H1	H4
Austria	3441	2773	2537	58	46	43
Belgium	677	586	589	96	83	84
Denmark	119	91	86	38	29	27
Finland	2538	2163	1988	15	13	12
France	25160	22524	22514	79	71	71
Germany	9184	7474	7479	90	73	73
Greece	236	211	193	10	9	8
Ireland	58	54	54	6	6	6
Italy	3795	3452	2589	32	29	22
Luxembourg	80	66	66	91	75	76
Netherlands	291	278	278	91	87	87
Portugal	709	683	682	25	24	24
Spain	1158	964	934	14	11	11
Sweden	891	737	691	5	4	4
United Kingdom	126	64	64	1	1	1
EU-15	48461	42117	40744	40	35	34
Albania	200	185	183	19	17	17
Belarus	1293	1261	1225	26	25	24
Bosnia-H.	725	672	525	50	46	36
Bulgaria	3396	3256	2716	69	66	55
Croatia	18	17	10	7	6	4
Czech Rep.	2312	2199	2107	87	83	79
Estonia	738	679	669	39	36	35
Hungary	150	147	128	53	52	45
Latvia	1553	1542	1504	57	57	55
Lithuania	1357	1353	1342	72	71	71
Norway	281	58	52	2	0	0
Poland	16218	16062	15609	93	93	90
Moldova	0	0	0	0	0	0
Romania	2495	2442	2011	40	39	32
Russia	26263	25877	24778	8	8	7
Slovakia	1507	1424	1054	75	71	53
Slovenia	156	110	89	17	12	10
Switzerland	1887	1674	1568	83	73	69
FYR Macedonia	158	138	133	15	13	13
Ukraine	5331	5303	4982	65	64	60
Yugoslavia	1994	1910	1778	58	56	52
Non-EU	68032	66311	62463	16	16	15
Total	116494	108428	103208	21	20	19

6 Conclusions

This report presents a central emission control scenario to achieve the environmental targets that were discussed in the context of the EU acidification and ozone strategies. In particular, the scenario aims at reducing

- the area of ecosystems not protected against acidification by half,
- the health-relevant excess ozone exposure by two thirds, and
- the vegetation-relevant excess ozone exposure by one third.

Additional targets control the highest ozone levels in the European Union.

Based on a 'business as usual' pre-Kyoto energy projection and a 'pre-CAP reform' agricultural scenario, the optimized set of emission reductions to achieve these targets would cut SO₂ and NO_x emissions by seven percent below the 'current legislation' case, VOC by 11 percent and ammonia emissions by nine percent. These measures would increase total emission control costs by 7.5 billion EURO/year, i.e., by 14 percent compared to the Reference (current legislation) case. Of the additional costs, 11 percent would be allocated to SO₂ control, 63 percent to NO_x and VOC control, and 26 percent for ammonia.

If a strategy to achieve the same environmental targets included also countries outside the present EU-15 (while aiming for the same environmental improvements also for these regions), control costs for the EU-15 would drop by 25 percent. About two thirds of the costs for measures in non-EU countries are allocated to the 'first-round' accession candidates.

The robustness of the optimized emission ceilings against changes in exogeneous input assumptions was analyzed in detail in the Sixth Interim Report. The national emission levels resulting from this central scenario were subjected to several sensitivity analyses, exploring the implications of

- single-effect strategies (ground-level ozone and acidification individually),
- variations in the environmental ambition levels,
- modifications of the main economic drivers (a low CO₂ ' energy and an 'low NH₃ ' agricultural projection), and
- the involvement of emission sources from international maritime transport.

The analysis showed that in all cases the emission ceilings of the central scenario are within the range spanned by the various sensitivity cases. More importantly, in many cases they are at the upper end of the ranges, i.e., none of the sensitivity cases resulted in higher emissions.

It has been further shown in the Sixth Report that modified input assumptions on the main economic drivers (energy scenarios and agricultural projections) have a profound impact on the costs for achieving the environmental targets (-40 percent for a low CO₂ scenario), but do not significantly change emission levels calculated from the baseline scenario.

While the sensitivity of optimized emission levels towards changes in input assumptions could be assessed for the above-mentioned cases, lack of supporting information and of resources prevented a systematic quantitative assessment of the impact of model and data uncertainties on the optimization results. In-depth studies on certain aspects support the

qualitative conclusion that, for a number of reasons, the present model results (emission reductions) are conservative in the sense that they might not be sufficient to fully achieve the specified environmental targets in reality.

7 References

Amann M., Bertok I., Cofala J., Gyarfas F., Heyes C., Klimont Z., Makowski M., Schöpp W., Syri S. (1998) *Cost-effective control of acidification and ground-level ozone*. Sixth Interim Report to the European Commission, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

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8 Annex 1: Emissions and Control Costs of Single-effect Scenarios

8.1 Three Ambition Levels for Ground-level ozone (H5)

Three sensitivity cases explore the emission reductions for achieving the ozone related targets of the Scenarios H2, H1 and H3.

Table 8.1: NO_x and VOC emissions for variations in ambition levels for ground-level ozone (Scenarios H5/1, H5/2 and H5/3). Percentage changes relate to the year 1990.

	NO _x								VOC							
	REF		H5/1		H5/2		H5/3		REF		H5/1		H5/2		H5/3	
	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change
Austria	103	-46%	91	-53%	91	-53%	89	-54%	205	-42%	129	-63%	129	-63%	123	-65%
Belgium	191	-46%	127	-64%	127	-64%	127	-64%	193	-48%	103	-72%	102	-73%	101	-73%
Denmark	128	-53%	128	-53%	128	-53%	128	-53%	85	-53%	85	-53%	85	-53%	83	-54%
Finland	152	-45%	152	-45%	152	-45%	152	-45%	110	-48%	110	-48%	110	-48%	110	-48%
France	858	-54%	706	-62%	682	-63%	648	-65%	1223	-49%	1015	-57%	932	-61%	849	-64%
Germany	1184	-56%	1086	-59%	1086	-59%	1071	-60%	1137	-64%	925	-70%	924	-70%	916	-71%
Greece	344	0%	253	-27%	261	-24%	291	-16%	267	-21%	168	-50%	173	-49%	179	-47%
Ireland	70	-38%	70	-38%	70	-38%	66	-42%	55	-50%	55	-50%	55	-50%	55	-50%
Italy	1130	-45%	900	-56%	863	-58%	839	-59%	1159	-44%	962	-53%	962	-53%	811	-61%
Luxembourg	10	-55%	7	-68%	6	-73%	6	-73%	7	-63%	5	-74%	5	-74%	5	-74%
Netherlands	280	-48%	280	-48%	280	-48%	280	-48%	233	-52%	157	-68%	153	-69%	153	-69%
Portugal	177	-15%	160	-23%	144	-31%	129	-38%	144	-32%	113	-47%	102	-52%	102	-52%
Spain	847	-27%	847	-27%	803	-31%	726	-38%	669	-34%	669	-34%	657	-35%	645	-36%
Sweden	190	-44%	158	-53%	158	-53%	152	-55%	290	-43%	219	-57%	219	-57%	216	-58%
UK	1186	-58%	1181	-58%	1181	-58%	1181	-58%	1351	-49%	1023	-62%	974	-63%	957	-64%
EU-15	6849	-48%	6148	-54%	6032	-54%	5886	-55%	7128	-49%	5738	-59%	5581	-60%	5303	-62%

Table 8.2: SO₂ and NH₃ emissions for variations in ambition levels for ground-level ozone (Scenarios H5/1, H5/2 and H5/3). Percentage changes relate to the year 1990.

	SO ₂								NH ₃							
	REF		H5/1		H5/2		H5/3		REF		H5/1		H5/2		H5/3	
	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change
Austria	40	-57%	40	-57%	40	-57%	40	-57%	67	-13%	67	-13%	67	-13%	67	-13%
Belgium	193	-43%	193	-43%	193	-43%	193	-43%	96	-1%	96	-1%	96	-1%	96	-1%
Denmark	90	-51%	90	-51%	90	-51%	90	-51%	72	-6%	72	-6%	72	-6%	72	-6%
Finland	116	-49%	116	-49%	116	-49%	116	-49%	31	-23%	31	-23%	31	-23%	31	-23%
France	448	-64%	448	-64%	448	-64%	448	-64%	777	-4%	777	-4%	777	-4%	777	-4%
Germany	581	-89%	581	-89%	581	-89%	581	-89%	571	-25%	571	-25%	571	-25%	571	-25%
Greece	546	8%	546	8%	546	8%	546	8%	74	-8%	74	-8%	74	-8%	74	-8%
Ireland	66	-63%	66	-63%	66	-63%	66	-63%	126	-1%	126	-1%	126	-1%	126	-1%
Italy	567	-66%	566	-66%	566	-66%	566	-66%	432	-6%	432	-6%	432	-6%	432	-6%
Luxembourg	4	-71%	4	-71%	4	-71%	4	-71%	7	0%	7	0%	7	0%	7	0%
Netherlands	73	-64%	73	-64%	73	-64%	73	-64%	136	-42%	136	-42%	136	-42%	136	-42%
Portugal	141	-50%	141	-50%	141	-50%	141	-50%	67	-6%	67	-6%	67	-6%	67	-6%
Spain	774	-65%	774	-65%	774	-65%	774	-65%	353	0%	353	0%	353	0%	353	0%
Sweden	67	-44%	67	-44%	67	-44%	67	-44%	48	-21%	48	-21%	48	-21%	48	-21%
UK	980	-74%	980	-74%	980	-74%	980	-74%	297	-10%	297	-10%	297	-10%	297	-10%
EU-15	4687	-71%	4687	-71%	4687	-71%	4687	-71%	3154	-12%	3154	-12%	3154	-12%	3154	-12%

Table 8.3: Emission control costs for variations in ambition levels for ground-level ozone (Scenarios H5/1, H5/2 and H5/3), in million EURO/year.

Costs	SO ₂				NO _x /VOC				NH ₃				Total			
	REF	H5/1	H5/2	H5/3	REF	H5/1	H5/2	H5/3	REF	H5/1	H5/2	H5/3	REF	H5/1	H5/2	H5/3
	total	Low ambition	Central ambition	High ambition	total	Low ambition	Central ambition	High ambition	total	Low ambition	Central ambition	High ambition	total	Low ambition	Central ambition	High ambition
	on top of REF				on top of REF				on top of REF				on top of REF			
Austria	191	0	0	0	902	118	120	169	0	0	0	0	1093	118	120	169
Belgium	426	0	0	0	1278	455	459	499	0	0	0	0	1704	455	459	499
Denmark	138	0	0	0	484	0	0	1	0	0	0	0	623	0	0	1
Finland	247	0	0	0	642	0	0	0	0	0	0	0	889	0	0	0
France	1276	0	0	0	7383	373	719	1366	0	0	0	0	8659	373	719	1366
Germany	3264	0	0	0	10549	918	933	1140	0	0	0	0	13813	918	933	1140
Greece	434	0	0	0	1048	455	363	202	0	0	0	0	1482	455	363	202
Ireland	132	0	0	0	477	0	0	0	9	0	0	0	618	0	0	0
Italy	1776	0	0	0	7868	313	420	971	0	0	0	0	9644	313	420	971
Luxembourg	13	0	0	0	71	12	30	30	15	0	0	0	98	12	30	30
Netherlands	340	0	0	0	1731	89	140	140	196	0	0	0	2267	89	140	140
Portugal	181	0	0	0	1349	22	57	98	0	0	0	0	1530	22	57	98
Spain	809	0	0	0	5658	0	10	44	28	0	0	0	6495	0	10	44
Sweden	316	0	0	0	1125	73	73	92	113	0	0	0	1554	73	73	92
UK	1269	0	0	0	6695	648	957	1071	0	0	0	0	7964	648	957	1071
EU-15	10813	0	0	0	47258	3476	4280	5823	361	0	0	0	58433	3476	4280	5823

8.2 Three Ambition Levels for Acidification (H6)

This annex provides optimization results for three scenarios with different ambition levels for acidification, corresponding to the acidification targets of the H2, H1 and H3 scenarios.

Table 8.4: NO_x and VOC emissions for variations in ambition levels for acidification (Scenarios H6/1, H6/2 and H6/3). Percentage changes relate to the year 1990.

	NO _x								VOC							
	REF		H6/1		H6/2		H6/3		REF		H6/1		H6/2		H6/3	
	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change
Austria	103	-46%	103	-46%	103	-46%	100	-48%	205	-42%	205	-42%	205	-42%	205	-42%
Belgium	191	-46%	167	-52%	144	-59%	127	-64%	193	-48%	193	-48%	192	-49%	192	-49%
Denmark	128	-53%	128	-53%	127	-54%	97	-65%	85	-53%	85	-53%	85	-53%	84	-54%
Finland	152	-45%	152	-45%	152	-45%	152	-45%	110	-48%	110	-48%	110	-48%	110	-48%
France	858	-54%	855	-54%	738	-60%	675	-64%	1223	-49%	1223	-49%	1220	-49%	1218	-49%
Germany	1184	-56%	1180	-56%	1138	-57%	965	-64%	1137	-64%	1137	-64%	1136	-64%	1129	-64%
Greece	344	0%	344	0%	344	0%	344	0%	267	-21%	267	-21%	267	-21%	267	-21%
Ireland	70	-38%	63	-44%	58	-49%	46	-59%	55	-50%	55	-50%	55	-50%	54	-51%
Italy	1130	-45%	1130	-45%	1130	-45%	1063	-48%	1159	-44%	1159	-44%	1159	-44%	1159	-44%
Luxembourg	10	-55%	10	-55%	9	-59%	8	-64%	7	-63%	7	-63%	7	-63%	7	-63%
Netherlands	280	-48%	276	-49%	237	-56%	198	-63%	233	-52%	233	-52%	232	-53%	232	-53%
Portugal	177	-15%	177	-15%	177	-15%	168	-19%	144	-32%	144	-32%	144	-32%	144	-32%
Spain	847	-27%	847	-27%	803	-31%	726	-38%	669	-34%	669	-34%	669	-34%	669	-34%
Sweden	190	-44%	190	-44%	190	-44%	167	-51%	290	-43%	290	-43%	290	-43%	290	-43%
UK	1186	-58%	1186	-58%	1094	-61%	816	-71%	1351	-49%	1351	-49%	1351	-49%	1341	-50%
EU-15	6849	-48%	6808	-49%	6444	-51%	5651	-57%	7128	-49%	7128	-49%	7120	-49%	7102	-49%

Table 8.5: SO₂ and NH₃ emissions for variations in ambition levels for acidification (Scenarios H6/1, H6/2 and H6/3). Percentage changes relate to the year 1990.

	SO ₂								NH ₃							
	REF		H6/1		H6/2		H6/3		REF		H6/1		H6/2		H6/3	
	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change	kt	Change
Austria	40	-57%	40	-57%	40	-57%	37	-60%	67	-13%	67	-13%	67	-13%	66	-14%
Belgium	193	-43%	82	-76%	76	-77%	75	-78%	96	-1%	80	-18%	57	-41%	57	-41%
Denmark	90	-51%	90	-51%	72	-60%	27	-85%	72	-6%	71	-8%	71	-8%	68	-12%
Finland	116	-49%	116	-49%	116	-49%	116	-49%	31	-23%	31	-23%	31	-23%	31	-23%
France	448	-64%	318	-75%	193	-85%	163	-87%	777	-4%	771	-4%	682	-15%	555	-31%
Germany	581	-89%	514	-90%	462	-91%	444	-92%	571	-25%	513	-32%	413	-45%	373	-51%
Greece	546	8%	546	8%	546	8%	546	8%	74	-8%	74	-8%	74	-8%	74	-8%
Ireland	66	-63%	28	-84%	28	-84%	23	-87%	126	-1%	125	-2%	124	-2%	124	-2%
Italy	567	-66%	566	-66%	566	-66%	295	-82%	432	-6%	432	-6%	430	-7%	430	-7%
Luxembourg	4	-71%	4	-71%	3	-79%	2	-86%	7	0%	7	0%	7	0%	7	0%
Netherlands	73	-64%	50	-75%	50	-75%	50	-75%	136	-42%	114	-51%	104	-55%	104	-55%
Portugal	141	-50%	141	-50%	141	-50%	141	-50%	67	-6%	67	-6%	67	-6%	67	-6%
Spain	774	-65%	744	-66%	746	-66%	198	-91%	353	0%	353	0%	353	0%	353	0%
Sweden	67	-44%	67	-44%	67	-44%	66	-45%	48	-21%	48	-21%	48	-21%	48	-21%
UK	980	-74%	718	-81%	496	-87%	422	-89%	297	-10%	290	-12%	264	-20%	229	-30%
EU-15	4687	-71%	4026	-75%	3604	-78%	2607	-84%	3154	-12%	3043	-15%	2790	-22%	2586	-28%

Table 8.6: Emission control costs for variations in ambition levels for acidification (Scenarios H6/1, H6/2 and H6/3), in million EURO/year.

Costs	SO ₂				NO _x /VOC				NH ₃				Total			
	REF	H6/1	H6/2	H6/3	REF	H6/1	H6/2	H6/3	REF	H6/1	H6/2	H6/3	REF	H6/1	H6/2	H6/3
	total	Low ambition	Central ambition	High ambition	total	Low ambition	Central ambition	High ambition	total	Low ambition	Central ambition	High ambition	total	Low ambition	Central ambition	High ambition
	on top of REF			on top of REF			on top of REF			on top of REF			on top of REF			
Austria	191	0	0	3	902	0	0	1	0	0	0	0	1093	0	0	4
Belgium	426	93	129	154	1278	10	66	220	0	43	467	467	1704	146	662	841
Denmark	138	0	8	48	484	0	0	36	0	0	0	6	623	0	8	90
Finland	247	0	0	0	642	0	0	0	0	0	0	0	889	0	0	0
France	1276	47	209	348	7383	1	104	460	0	0	135	1104	8659	48	448	1912
Germany	3264	60	246	331	10549	1	63	1295	0	111	860	1385	13813	172	1170	3011
Greece	434	0	0	0	1048	0	0	0	0	0	0	0	1482	0	0	0
Ireland	132	20	20	40	477	1	5	36	9	6	14	11	618	27	40	87
Italy	1776	0	0	83	7868	0	0	11	0	0	0	0	9644	0	0	94
Luxembourg	13	0	1	3	71	0	1	4	15	0	0	0	98	0	1	7
Netherlands	340	19	19	19	1731	2	123	618	196	342	741	741	2267	363	883	1379
Portugal	181	0	0	0	1349	0	0	1	0	0	0	0	1530	0	0	1
Spain	809	10	9	301	5658	0	4	31	28	0	0	0	6495	10	13	332
Sweden	316	0	0	0	1125	0	0	10	113	0	0	0	1554	0	0	10
UK	1269	92	301	580	6695	0	98	1605	0	4	23	314	7964	96	422	2499
EU-15	10813	342	942	1911	47258	15	464	4328	361	506	2241	4028	58433	863	3647	10267

