Limiting Marginal Costs of Emission Reductions and Uniform per-capita Emission Scenarios

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1 Introduction

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

The main IIASA report prepared for the 23rd Meeting of the Task Force establishes the J1 scenario as the base case for the sensitivity analysis, taking into account recent updates to the databases, and presents results for a number of sensitivity studies. This companion report extends the range of sensitivity analyses, providing results for:

- Scenarios (J9 and J10) in which the effects of applying limits to the marginal costs are investigated;
- Scenarios (J11 and J12) which explore the effects on cost-effectiveness of allocating emission reductions on the basis of equal per capita emission rates.

2 The Central Scenario (J1)

The 22nd meeting of the Task Force on Integrated Assessment Modelling presented to the Working Group on Strategies a range of emission reduction scenarios with different environmental ambition levels. Out of the presented scenarios, the Working Group on Strategies at its 28th Session selected the 'medium ambition level' scenario G5/2 to guide the forthcoming negotiations on a second NO_x Protocol. The environmental targets of this scenario are summarized in Table 2.1. Note that these targets, with the exception of eutrophication, are identical to those underlying the H1 scenario developed for the European Commission.

Table 2.1: Summary of the environmental targets for the Central scenario J1

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

The optimization routine of the RAINS model was used to identify the cost-minimal allocation of emission controls to meet the environmental targets. The results of this analysis are presented in Table 2.2 to Table 2.7.

Table 2.2: NO_x and VOC emissions for the central scenario J1 compared to the REF case. Percentage changes relate to the year 1990.

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

Table 2.3: SO_2 and NH_3 emissions of the central scenario J1 compared to the REF case. Percentage changes relate to the year 1990.

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

Table 2.4: Control costs for NO_x, VOC and SO_2 of central scenario J1 compared to the REF case (in million EURO/year).

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

Table 2.5: Control costs for NH_3 and total costs of the central scenario J1 compared to the REF case (in million EURO/year).

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

Table 2.6: Ozone exposure indices for the REF and J1 scenarios

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

Table 2.7: Ecosystems with deposition above critical loads for the REF and J1 scenarios

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

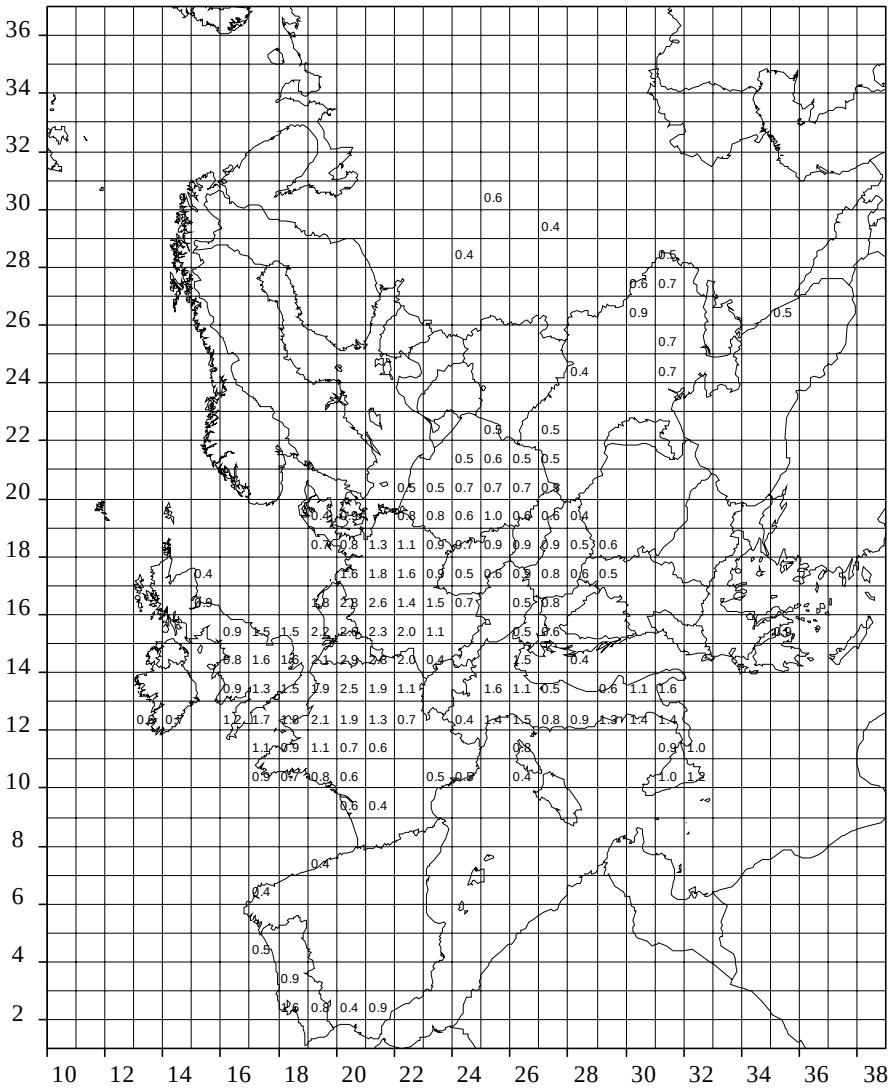

Figure 2.1: The AOT60 resulting from the emission reductions of the J1 scenario, second highest occurrence in the meteorological conditions of five years

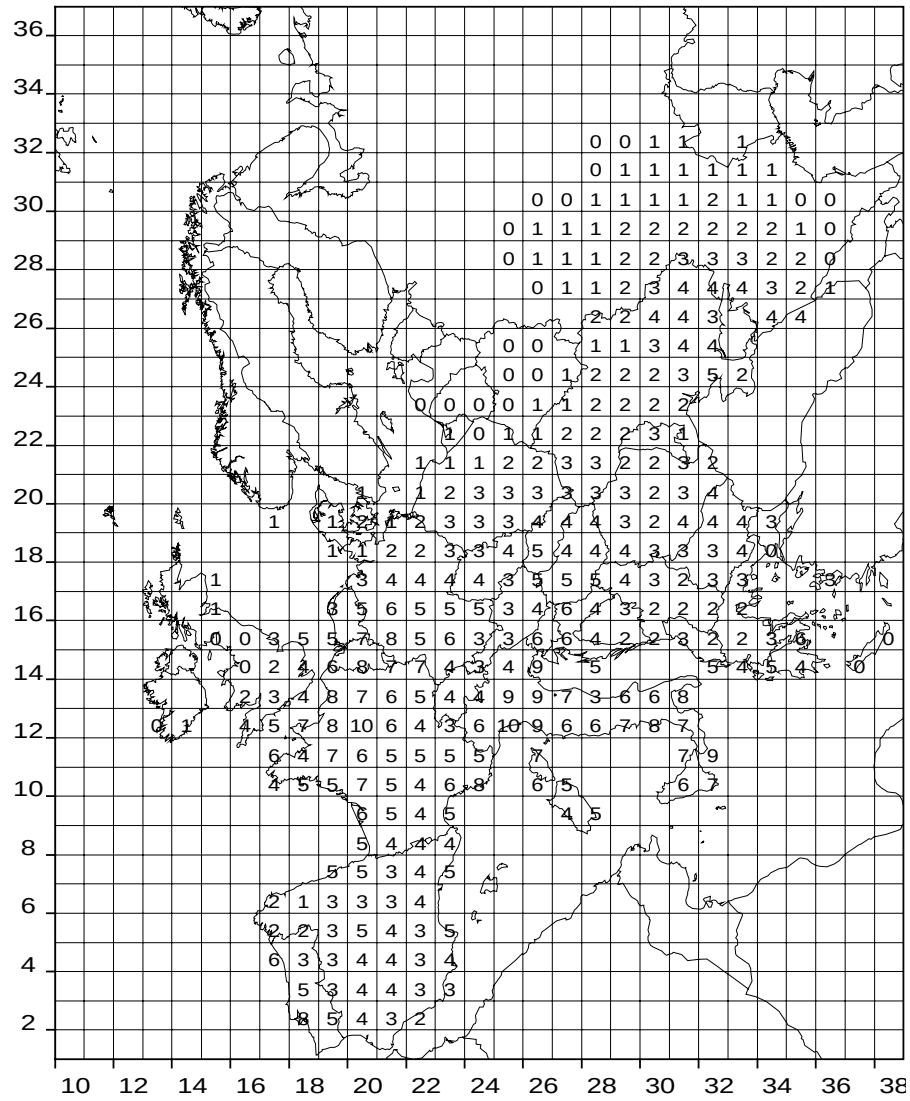

Figure 2.2: Excess AOT40 for the emissions of the J1 scenario (in ppm.hours)

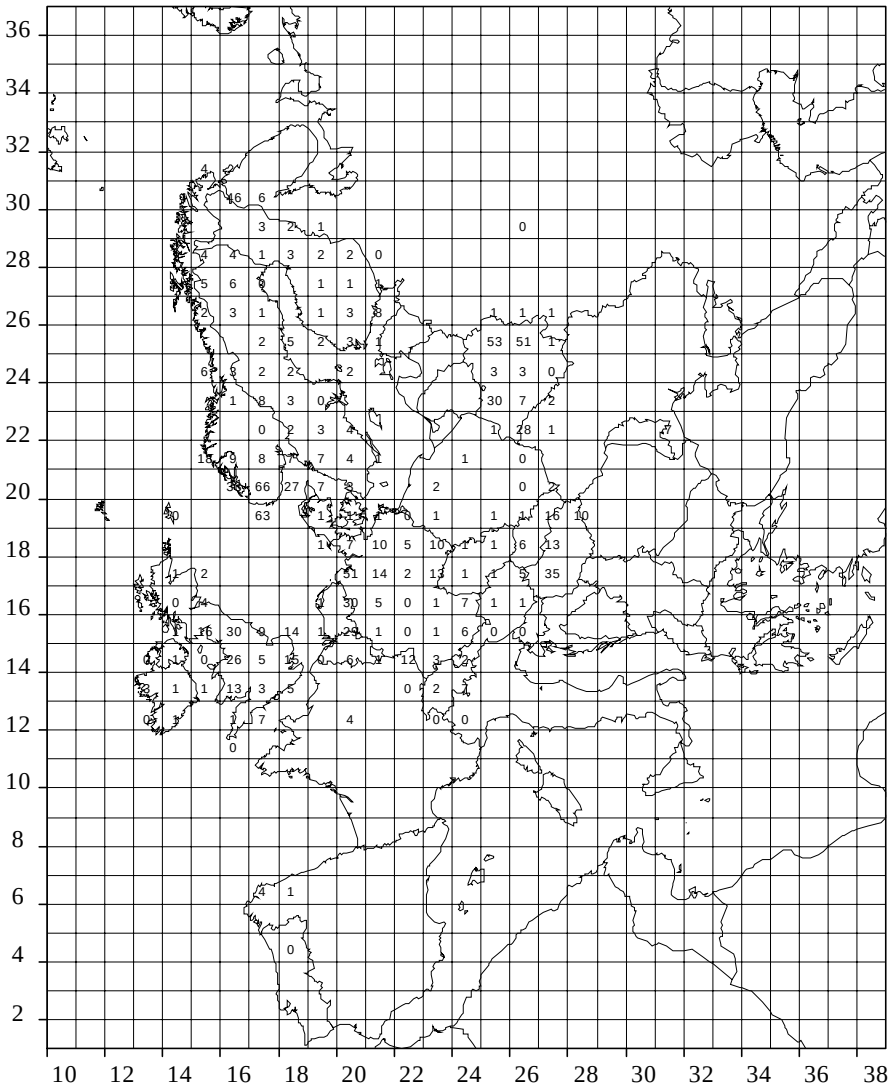

Figure 2.3: Percentage of ecosystems with acid deposition above their critical loads for the emissions of the J1 scenario

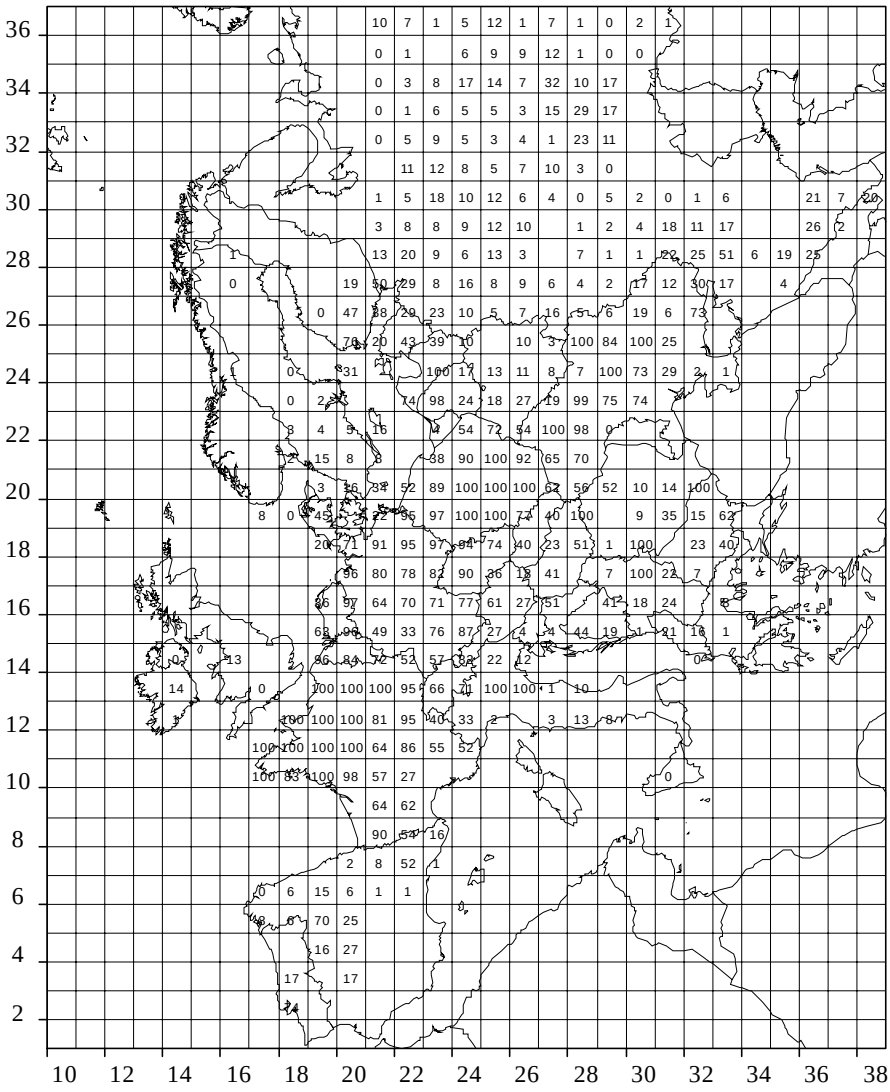

Figure 2.4: Percentage of ecosystems with nitrogen deposition above the critical loads for eutrophication for the emissions of the J1 scenario

2.1 Marginal costs of the J1 Scenario

Table 2.8: Marginal costs for the J1 scenario distinguishing the RAINS cost curves sectors (Euro/ton)

Country	Sectoral cost curve					
	SO_2	NH_3	NO_x Stationary sources	VOC Stationary sources	Non-road gasoline engines	Off-road machinery, diesel
Austria	1208	0	3147	2243		1827
Belgium	4927	18988	12292	6103	1114	1806
Denmark	422	762	623			
Finland						
France	1496	7573	4521	2025	4404	1309
Germany	4529	15795	3793	3392	3462	3705
Greece		92		277		
Ireland	512	16111	1446			
Italy	684	1217	1045	962		1245
Luxembourg	608	0	568	261		
Netherlands	1681	31772	1991	4116		2829
Portugal	0	1287	1085	2509		
Spain	326		500	541		
Sweden			790	768		1720
UK	1521	1132	0	3705	2915	
Albania		407				
Belarus		409	100			
Bosnia-H	324	413	249			
Bulgaria	125	1964	672	63		
Croatia	513	408	288	243		
Czech_R.	680	1695	1524	2184		2611
Estonia						
Hungary	4751	20670	2714	270		3341
Latvia						
Lithuania		409	101			
Norway	1321		521			
Poland	505	7247	1312	1549		
Moldova	428	408	100			
Romania	457	9137	1132			1984
Kaliningrad						
Kola-Karelia	359					
Russia_Rem						
St.Petersbu						
Slovakia	1254	2487	1598			1665
Slovenia	400	411	247			
Switzerland	483	1828	620	537		
Macedonia						
Ukraine	297	1800	287	62		
Yugoslavia	787	10455	787			

3 Limited Marginal Costs with Violations of the Environmental Targets (Scenario J9)

A sensitivity case was developed in which emission controls were limited to measures having marginal costs below a certain threshold. In practice, emission ceilings of the J1 scenario for countries and pollutants exceeding the imposed limit on marginal costs were revised to the level corresponding to the cost limit. Arbitrarily, the following limits were selected:

SO_2: 4000 EURO/ton
NO_x: 7000 EURO/ton
VOC: 5000 EURO/ton
NH_3: 25000 EURO/ton

The selected levels restrict SO_2 reductions in Belgium, Germany and Hungary, NO_x and VOC reductions in Belgium and ammonia control in the Netherlands. The revised emission levels are presented in Table 4.1. Overall, European SO_2 emissions would be 33.kt higher; NO_x would increase by 15 kt, VOC by 20 kt and ammonia by 9 kt compared to the J1 scenario. Total costs decline by 777 million EURO/year, i.e., by nine percent.

4 Limited Marginal Costs without Violations of the Environmental Targets (Scenario J10)

Alternatively, a scenario was constructed using the limits on marginal costs as listed above, but without allowing violations of the environmental targets of the J1 scenario. In practice, the optimization task of the J1 scenario was repeated with lower bounds on emissions derived from the marginal cost limits. This means that the optimization may use only measures with marginal costs below the limit. Excess exposure resulting from the restricted emission reduction potential must be compensated by additional reductions at other sources.

Maintaining the environmental targets while excluding most expensive emission controls from an optimized solution requires additional emission controls at other emission sources. For all of Europe, the 17 kt increase of Belgium emissions (close to the problem area) requires 419 kt additional reductions at more distant locations. 19 kt more emissions of VOC in Belgium imply 149 kt additional reductions in other countries. Relaxing ceilings for SO_2 emissions in Belgium, Germany and Hungary by a total of 32 kt has to be compensated by 813 kt additional reductions at other places. Although costs of the relaxed emission controls are high, the increase in control volume at sources more distant from the environmental problem area increases total emission control costs by almost 40 percent. As to be expected (and also intended), major cost savings occur in Belgium, Netherlands and Hungary, while many other countries experience significantly higher costs (e.g., France, UK, etc.; see Table 4.6).

Table 4.1: NO_x emissions for the central scenario J1 compared to the sensitivity cases with limited marginal costs. Percentage changes relate to the year 1990.

	J1 Central case		J9 Violation scenario		J10 Non-violation scenario	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	91	*-53%*	91	*-53%*	91	*-53%*
Belgium	127	*-64%*	144	*-59%*	144	*-59%*
Denmark	113	*-59%*	113	*-59%*	107	*-61%*
Finland	152	*-45%*	152	*-45%*	152	*-45%*
France	704	*-62%*	704	*-62%*	705	*-62%*
Germany	1081	*-59%*	1081	*-59%*	1014	*-62%*
Greece	344	*0%*	344	*0%*	344	*0%*
Ireland	55	*-51%*	55	*-51%*	49	*-57%*
Italy	901	*-56%*	901	*-56%*	903	*-56%*
Luxembourg	8	*-64%*	8	*-64%*	8	*-64%*
Netherlands	266	*-51%*	266	*-51%*	237	*-56%*
Portugal	144	*-31%*	144	*-31%*	177	*-15%*
Spain	726	*-38%*	726	*-38%*	660	*-43%*
Sweden	159	*-53%*	159	*-53%*	158	*-53%*
UK	1181	*-58%*	1181	*-58%*	907	*-68%*
EU-15	6054	*-54%*	6069	*-54%*	5656	*-57%*
Albania	36	*50%*	36	*50%*	36	*50%*
Belarus	290	*-28%*	290	*-28%*	290	*-28%*
Bosnia-H	53	*-34%*	53	*-34%*	54	*-33%*
Bulgaria	266	*-25%*	266	*-25%*	266	*-25%*
Croatia	87	*6%*	87	*6%*	84	*2%*
Czech Rep.	188	*-66%*	188	*-66%*	149	*-73%*
Estonia	73	*-13%*	73	*-13%*	73	*-13%*
Hungary	137	*-37%*	137	*-37%*	141	*-36%*
Latvia	118	*1%*	118	*1%*	118	*1%*
Lithuania	134	*-12%*	134	*-12%*	134	*-12%*
Norway	142	*-35%*	142	*-35%*	173	*-21%*
Poland	654	*-46%*	654	*-46%*	649	*-47%*
R.of Moldova	64	*-26%*	64	*-26%*	64	*-26%*
Romania	328	*-37%*	328	*-37%*	334	*-36%*
Russia	2653	*-24%*	2653	*-24%*	2653	*-24%*
Slovakia	115	*-47%*	115	*-47%*	115	*-47%*
Slovenia	34	*-43%*	34	*-43%*	34	*-43%*
Switzerland	76	*-53%*	76	*-53%*	75	*-54%*
FYR of Mac.	29	*-26%*	29	*-26%*	29	*-26%*
Ukraine	1222	*-35%*	1222	*-35%*	1222	*-35%*
Yugoslavia	132	*-37%*	132	*-37%*	132	*-37%*
Non-EU	6830	*-33%*	6830	*-33%*	6825	*-33%*
Total	14513	*-42%*	14528	*-42%*	14111	*-44%*

Table 4.2: VOC emissions for the central scenario J1 compared to the sensitivity cases with limited marginal costs. Percentage changes relate to the year 1990.

	J1 Central case		J9 Violation scenario		J10 No violation scenario	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	142	*-60%*	142	*-60%*	142	*-60%*
Belgium	103	*-72%*	122	*-67%*	122	*-67%*
Denmark	85	*-53%*	85	*-53%*	85	*-53%*
Finland	110	*-48%*	110	*-48%*	110	*-48%*
France	989	*-58%*	989	*-58%*	849	*-64%*
Germany	995	*-68%*	995	*-68%*	986	*-68%*
Greece	261	*-22%*	261	*-22%*	261	*-22%*
Ireland	55	*-50%*	55	*-50%*	54	*-51%*
Italy	1030	*-50%*	1030	*-50%*	1116	*-46%*
Luxembourg	7	*-63%*	7	*-63%*	5	*-74%*
Netherlands	157	*-68%*	157	*-68%*	156	*-68%*
Portugal	102	*-52%*	102	*-52%*	102	*-52%*
Spain	648	*-36%*	648	*-36%*	655	*-35%*
Sweden	241	*-53%*	241	*-53%*	227	*-56%*
UK	1101	*-59%*	1101	*-59%*	1021	*-62%*
EU-15	6024	*-57%*	6045	*-57%*	5893	*-58%*
Albania	41	*32%*	41	*32%*	41	*32%*
Belarus	298	*-20%*	298	*-20%*	298	*-20%*
Bosnia-H	48	*-6%*	48	*-6%*	48	*-6%*
Bulgaria	185	*-5%*	185	*-5%*	186	*-5%*
Croatia	86	*-17%*	86	*-17%*	100	*-3%*
Czech Rep.	156	*-65%*	156	*-65%*	133	*-70%*
Estonia	49	*9%*	49	*9%*	49	*9%*
Hungary	137	*-33%*	137	*-33%*	158	*-23%*
Latvia	56	*-11%*	56	*-11%*	56	*-11%*
Lithuania	105	*-5%*	105	*-5%*	105	*-5%*
Norway	195	*-34%*	195	*-34%*	195	*-34%*
Poland	475	*-40%*	475	*-40%*	446	*-44%*
R.of Moldova	42	*-16%*	42	*-16%*	42	*-16%*
Romania	500	*-1%*	500	*-1%*	501	*0%*
Russia	2723	*-23%*	2723	*-23%*	2723	*-23%*
Slovakia	140	*-7%*	140	*-7%*	140	*-7%*
Slovenia	40	*-27%*	40	*-27%*	40	*-27%*
Switzerland	144	*-48%*	144	*-48%*	143	*-49%*
FYR of Mac.	19	*0%*	19	*0%*	19	*0%*
Ukraine	770	*-34%*	770	*-34%*	787	*-32%*
Yugoslavia	138	*-3%*	138	*-3%*	138	*-3%*
Non-EU	6345	*-26%*	6345	*-26%*	6347	*-26%*
Total	12370	*-45%*	12390	*-45%*	12240	*-46%*

Table 4.3: SO_2 emissions for the central scenario J1 compared to the sensitivity cases with limited marginal costs. Percentage changes relate to the year 1990.

	J1 Central case		J9 Violation scenario		J10 Non-violation scenario	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	35	*-62%*	35	*-62%*	35	*-62%*
Belgium	76	*-77%*	82	*-76%*	82	*-76%*
Denmark	60	*-67%*	60	*-67%*	32	*-82%*
Finland	116	*-49%*	116	*-49%*	116	*-49%*
France	219	*-82%*	219	*-82%*	193	*-85%*
Germany	463	*-91%*	484	*-91%*	484	*-91%*
Greece	546	*8%*	546	*8%*	546	*8%*
Ireland	36	*-80%*	36	*-80%*	25	*-86%*
Italy	290	*-83%*	290	*-83%*	295	*-82%*
Luxembourg	3	*-79%*	3	*-79%*	3	*-79%*
Netherlands	50	*-75%*	50	*-75%*	50	*-75%*
Portugal	141	*-50%*	141	*-50%*	141	*-50%*
Spain	747	*-66%*	747	*-66%*	260	*-88%*
Sweden	67	*-44%*	67	*-44%*	67	*-44%*
UK	499	*-87%*	499	*-87%*	446	*-88%*
EU-15	3349	*-80%*	3375	*-79%*	2775	*-83%*
Albania	55	*-24%*	55	*-24%*	55	*-24%*
Belarus	494	*-41%*	494	*-41%*	494	*-41%*
Bosnia-H	162	*-67%*	162	*-67%*	216	*-56%*
Bulgaria	378	*-79%*	378	*-79%*	378	*-79%*
Croatia	23	*-87%*	23	*-87%*	23	*-87%*
Czech Rep.	283	*-85%*	283	*-85%*	275	*-85%*
Estonia	175	*-36%*	175	*-36%*	175	*-36%*
Hungary	296	*-68%*	301	*-67%*	301	*-67%*
Latvia	104	*-14%*	104	*-14%*	104	*-14%*
Lithuania	107	*-50%*	107	*-50%*	107	*-50%*
Norway	18	*-65%*	18	*-65%*	32	*-38%*
Poland	722	*-76%*	722	*-76%*	432	*-86%*
R.of Moldova	38	*-81%*	38	*-81%*	44	*-78%*
Romania	148	*-89%*	148	*-89%*	148	*-89%*
Russia	2186	*-56%*	2186	*-56%*	2202	*-56%*
Slovakia	92	*-83%*	92	*-83%*	92	*-83%*
Slovenia	14	*-93%*	14	*-93%*	14	*-93%*
Switzerland	23	*-47%*	23	*-47%*	26	*-40%*
FYR of Mac.	81	*-24%*	81	*-24%*	81	*-24%*
Ukraine	1457	*-61%*	1457	*-61%*	1435	*-61%*
Yugoslavia	217	*-63%*	217	*-63%*	230	*-61%*
Non-EU	7071	*-67%*	7078	*-67%*	6864	*-68%*
Total	11572	*-70%*	11605	*-70%*	10791	*-72%*

Table 4.4: NH_3 emissions for the central scenario J1 compared to the sensitivity cases with limited marginal costs. Percentage changes relate to the year 1990.

	J1 Central case		J9 Violation scenario		J10 Non-violation scenario	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	66	*-14%*	66	*-14%*	66	*-14%*
Belgium	60	*-38%*	60	*-38%*	60	*-38%*
Denmark	69	*-10%*	69	*-10%*	69	*-10%*
Finland	31	*-23%*	31	*-23%*	31	*-23%*
France	642	*-20%*	642	*-20%*	566	*-30%*
Germany	413	*-45%*	413	*-45%*	394	*-48%*
Greece	73	*-9%*	73	*-9%*	73	*-9%*
Ireland	116	*-9%*	116	*-9%*	118	*-7%*
Italy	356	*-23%*	356	*-23%*	356	*-23%*
Luxembourg	7	*0%*	7	*0%*	7	*0%*
Netherlands	105	*-55%*	114	*-51%*	114	*-51%*
Portugal	65	*-8%*	65	*-8%*	63	*-11%*
Spain	353	*0%*	353	*0%*	353	*0%*
Sweden	48	*-21%*	48	*-21%*	48	*-21%*
UK	264	*-20%*	264	*-20%*	238	*-28%*
EU-15	2668	*-25%*	2677	*-25%*	2556	*-29%*
Albania	32	*0%*	32	*0%*	32	*0%*
Belarus	140	*-36%*	140	*-36%*	140	*-36%*
Bosnia-H	22	*-29%*	22	*-29%*	22	*-29%*
Bulgaria	105	*-26%*	105	*-26%*	105	*-26%*
Croatia	29	*-28%*	29	*-28%*	29	*-28%*
Czech Rep.	101	*-6%*	101	*-6%*	101	*-6%*
Estonia	29	*0%*	29	*0%*	29	*0%*
Hungary	77	*-36%*	77	*-36%*	80	*-33%*
Latvia	35	*-19%*	35	*-19%*	35	*-19%*
Lithuania	72	*-10%*	72	*-10%*	75	*-6%*
Norway	21	*-9%*	21	*-9%*	21	*-9%*
Poland	468	*-7%*	468	*-7%*	477	*-6%*
R.of Moldova	41	*-13%*	41	*-13%*	41	*-13%*
Romania	227	*-22%*	227	*-22%*	227	*-22%*
Russia	894	*-30%*	894	*-30%*	894	*-30%*
Slovakia	39	*-35%*	39	*-35%*	40	*-33%*
Slovenia	16	*-30%*	16	*-30%*	18	*-22%*
Switzerland	63	*-13%*	63	*-13%*	66	*-8%*
FYR of Mac.	15	*-12%*	15	*-12%*	15	*-12%*
Ukraine	588	*-19%*	588	*-19%*	589	*-19%*
Yugoslavia	64	*-29%*	64	*-29%*	65	*-28%*
Non-EU	3077	*-23%*	3077	*-23%*	3102	*-22%*
Total	5745	*-24%*	5754	*-24%*	5658	*-25%*

Table 4.5: Control costs on top of the REF scenarios for SO_2, NO_x and VOC emissions for the central case and the sensitivity cases with limited marginal costs (in million EURO/year).

	NO_x & VOC			SO_2		
	J1 central	J9 Violation scenario	J10 Non-violation scenario	J1 central	J9 Violation scenario	J10 Non-violation scenario
Austria	70	70	70	5	5	5
Belgium	452	179	179	122	93	93
Denmark	8	8	16	13	13	37
Finland	0	0	0	0	0	0
France	437	437	819	132	132	211
Germany	484	484	874	240	113	113
Greece	2	2	2	0	0	0
Ireland	10	10	25	12	12	29
Italy	245	245	173	87	87	83
Luxembourg	2	2	7	0	0	1
Netherlands	112	112	208	19	19	19
Portugal	57	57	45	0	0	0
Spain	42	42	109	9	9	255
Sweden	45	45	63	0	0	0
UK	353	353	1304	295	295	464
EU-15	2318	2046	3895	935	778	1311
Albania	0	0	0	0	0	0
Belarus	3	3	3	0	0	0
Bosnia-H	2	2	1	55	55	38
Bulgaria	10	10	10	58	58	58
Croatia	5	5	3	18	18	18
Czech Rep.	235	235	523	36	36	47
Estonia	0	0	0	0	0	0
Hungary	112	112	91	113	92	92
Latvia	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0
Norway	12	12	0	10	10	0
Poland	373	373	466	283	283	588
R.of Moldova	0	0	0	30	30	27
Romania	100	100	88	137	137	137
Russia	0	0	0	54	54	48
Slovakia	11	11	11	25	25	25
Slovenia	1	1	1	23	23	23
Switzerland	2	2	5	1	1	0
FYR of Mac.	0	0	0	0	0	0
Ukraine	44	44	43	8	8	14
Yugoslavia	6	6	6	27	27	17
Non-EU	917	917	1251	879	857	1131
Total	3235	2963	5145	1814	1635	2442

Table 4.6: Control costs for NH_3 emissions and total costs on top of the REF scenario for the central case and the two marginal costs scenarios (in million EURO/year)

	NH_3			Total costs				
	J1 Central scenario	J9 Violation scenario	J10 Non-violation scenario	J1 Central scenario	J9 Violation scenario		J10 Non-violation	
						Diff. to J1		Diff. to J1
Austria	1	1	1	76	76	0	76	*0*
Belgium	312	312	310	886	584	-302	583	*-303*
Denmark	2	2	2	22	22	0	54	*+32*
Finland	0	0	0	0	0	0	0	*0*
France	367	367	947	936	936	0	1977	*+1041*
Germany	842	842	1262	1567	1439	-128	2249	*+682*
Greece	0	0	0	2	2	0	2	*0*
Ireland	146	146	107	168	168	0	161	*-7*
Italy	85	85	84	417	417	0	341	*-76*
Luxembourg	0	0	0	2	2	0	9	*+7*
Netherlands	672	345	345	803	476	-327	572	*-231*
Portugal	2	2	6	59	59	0	51	*-8*
Spain	0	0	0	51	51	0	364	*+313*
Sweden	0	0	0	45	45	0	63	*+18*
UK	23	23	195	671	671	0	1963	*+1292*
EU-15	2450	2125	3259	5704	4949	-755	8465	*+2761*
Albania	1	1	1	1	1	0	1	*0*
Belarus	9	9	9	12	12	0	12	*0*
Bosnia-H	1	1	1	58	58	0	40	*-18*
Bulgaria	13	13	13	81	81	0	81	*0*
Croatia	3	3	3	26	26	0	25	*-1*
Czech Rep.	9	9	9	280	280	0	578	*+298*
Estonia	0	0	0	0	0	0	0	*0*
Hungary	319	319	245	545	523	-22	428	*-117*
Latvia	0	0	0	0	0	0	0	*0*
Lithuania	4	4	3	4	4	0	3	*-1*
Norway	3	3	0	25	25	0	0	*-25*
Poland	182	182	115	838	838	0	1168	*+330*
R.of Moldova	3	3	3	33	33	0	30	*-3*
Romania	304	304	305	541	541	0	529	*-12*
Russia	0	0	0	54	54	0	48	*-6*
Slovakia	7	7	3	43	43	0	39	*-4*
Slovenia	2	2	1	25	25	0	24	*-1*
Switzerland	6	6	0	9	9	0	5	*-4*
FYR of Mac.	1	1	1	1	1	0	1	*0*
Ukraine	30	30	27	82	82	0	85	*+3*
Yugoslavia	94	94	90	128	128	0	113	*-15*
Non-EU	991	991	830	2787	2765	-22	3212	*+425*
Total	3442	3116	4089	8490	7713	-777	11676	*+3186*

Table 4.7: Cumulative ozone exposure indices for the central case and the differences for the marginal cost scenarios

	Population exposure index			Vegetation exposure index		
	J1 central	J9 Violation scenario (diff. to J1)	J10 Non-violation scenario (diff. to J1)	J1 central	J9 Violation scenario	J10 Non-violation scenario
Austria	1	0	0	194	+1	-7
Belgium	22	+1	0	115	+1	0
Denmark	1	0	0	30	0	-4
Finland	0	0	0	0	0	0
France	54	+1	-3	1865	+12	-55
Germany	91	+2	-7	901	+7	-44
Greece	3	0	0	146	0	1
Ireland	0	0	0	3	0	0
Italy	40	0	+2	993	0	10
Luxembourg	1	0	0	11	0	0
Netherlands	26	+1	0	63	+1	0
Portugal	6	0	0	229	0	6
Spain	3	0	0	1046	2	-49
Sweden	0	0	0	7	0	-1
UK	49	+1	-3	111	+1	+1
EU-15	298	+6	-12	5714	+25	-142
Albania	0	0	0	0	0	0
Belarus	0	0	0	44	0	-3
Bosnia-H	0	0	0	126	0	0
Bulgaria	0	0	0	228	0	-1
Croatia	1	0	1	173	0	-1
Czech Rep.	5	0	-2	218	+1	-15
Estonia	0	0	0	0	0	0
Hungary	6	0	0	290	0	-4
Latvia	0	0	0	2	0	-1
Lithuania	0	0	0	9	0	-2
Norway	0	0	0	1	0	0
Poland	18	0	-2	529	+1	-41
R.of Moldova	0	0	0	43	0	-1
Romania	1	0	0	458	0	-3
Russia	5	0	0	861	0	-5
Slovakia	3	0	0	153	0	-5
Slovenia	1	0	0	78	0	-1
Switzerland	1	0	-1	70	0	-2
FYR of Mac.	0	0	0	33	0	0
Ukraine	6	0	0	971	0	-12
Yugoslavia	1	0	0	195	0	-2
Non-EU	48	0	-4	4481	+2	-96
Total	346	+6	-17	10194	+27	-238

Table 4.8: Ecosystems with acid deposition above critical loads for the central case and the differences for the marginal cost scenarios (in 1000 ha)

	Acidification			Eutrophication		
	J1 central	J9 Violation scenario (diff. to J1)	J10 Non-violation scenario (diff. to J1)	J1 central	J9 Violation scenario (diff. to J1)	J10 Non-violation scenario (diff. to J1)
Austria	162	+2	-5	2477	+5	-126
Belgium	155	+4	-1	572	+7	-50
Denmark	9	0	-1	85	0	-9
Finland	1183	+1	2	1738	+9	-84
France	218	+1	-5	21632	+6	-1830
Germany	1617	+40	-86	7312	+53	-566
Greece	0	0	0	85	0	0
Ireland	12	0	0	29	0	0
Italy	74	0	-1	2508	+2	-14
Luxembourg	5	0	0	63	+1	-4
Netherlands	193	+11	0	278	+2	-1
Portugal	1	0	0	580	0	0
Spain	17	0	-17	850	+1	-118
Sweden	1605	+9	-128	620	+3	-35
UK	1182	+2	-256	62	+1	-61
EU-15	6433	+72	-497	38890	+91	-2899
Albania	0	0	0	160	0	0
Belarus	1048	+1	-200	924	+1	-5
Bosnia-H	131	0	0	460	0	-6
Bulgaria	0	0	0	1263	0	-1
Croatia	0	0	0	10	0	0
Czech Rep.	474	+5	-23	1983	+6	-100
Estonia	11	0	0	598	0	-3
Hungary	65	0	0	125	0	+1
Latvia	0	0	0	1417	+1	-11
Lithuania	78	0	-5	894	0	3
Norway	2573	+9	-88	35	0	-2
Poland	1357	+3	-58	14894	+10	-36
R.of Moldova	29	0	0	0	0	0
Romania	51	0	0	1770	0	-1
Russia	4073	+1	+96	23123	+7	-85
Slovakia	295	+1	-5	939	+1	-4
Slovenia	19	0	0	87	0	0
Switzerland	57	0	-1	1468	+3	-20
FYR of Mac.	0	0	0	108	0	0
Ukraine	643	+1	-92	3859	+1	-5
Yugoslavia	2	0	0	1280	0	-1
Non-EU	10908	+22	-376	55396	+31	-273
Total	17341	+94	-873	94287	+121	-3172

5 Uniform Per Capita Emission Scenarios

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

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

Scenario J11 constructs a 'flat rate' per capita emission scenario, in which the average per capita emission rates for the four pollutants of the J1 scenario are applied uniformly to all European countries. Starting from the optimized J1 scenario and maintaining the environmental targets of this scenario, another scenario J12 explores the changes in emission control costs if the deviations from the average per capita emission levels (of the J11 scenario) were reduced as much as possible.

5.1 A 'Flat-rate' Per Capita Emission Scenario (J11)

The rationale for the illustrative 'flat rate' scenario is to fix - as far as possible - each country's emissions to the value corresponding to the average per capita emission rates across Europe that were obtained for the J1 scenario. The average per capita emission rates for each pollutant for the J1 scenario are as follows:

SO_2	15.5 kg capita^{-1} year^{-1}
NO_x	19.1 kg capita^{-1} year^{-1}
VOC	18.3 kg capita^{-1} year^{-1}
NH_3	8.5 kg capita^{-1} year^{-1}

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

The emissions, costs and exposure indices obtained for this non-optimized "flat-rate" scenario J11 are summarized in Table 5.1 - Table 5.8.

Table 5.1: NO_x emissions for the flat-rate per capita emission scenarios. Percentage changes relate to the year 1990.

	J1 Central case		J11 Uniform		J12 Reduced var.	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	91	*-53%*	103	*-46%*	97	*-49%*
Belgium	127	*-64%*	191	*-46%*	133	*-62%*
Denmark	113	*-59%*	98	*-64%*	98	*-64%*
Finland	152	*-45%*	95	*-66%*	98	*-64%*
France	704	*-62%*	858	*-54%*	648	*-65%*
Germany	1081	*-59%*	1184	*-56%*	951	*-64%*
Greece	344	*0%*	248	*-28%*	254	*-26%*
Ireland	55	*-51%*	67	*-41%*	67	*-41%*
Italy	901	*-56%*	1100	*-46%*	916	*-55%*
Luxembourg	8	*-64%*	7	*-68%*	7	*-68%*
Netherlands	266	*-51%*	280	*-48%*	236	*-56%*
Portugal	144	*-31%*	177	*-15%*	177	*-15%*
Spain	726	*-38%*	713	*-39%*	666	*-43%*
Sweden	159	*-53%*	164	*-51%*	156	*-54%*
UK	1181	*-58%*	1095	*-61%*	1057	*-63%*
EU-15	6054	*-54%*	6380	*-52%*	5561	*-58%*
Albania	36	*50%*	36	*50%*	36	*50%*
Belarus	290	*-28%*	195	*-51%*	197	*-51%*
Bosnia-H	53	*-34%*	60	*-25%*	59	*-26%*
Bulgaria	266	*-25%*	172	*-52%*	171	*-52%*
Croatia	87	*6%*	90	*10%*	89	*9%*
Czech Rep.	188	*-66%*	198	*-64%*	183	*-66%*
Estonia	73	*-13%*	30	*-64%*	31	*-63%*
Hungary	137	*-37%*	198	*-10%*	194	*-11%*
Latvia	118	*1%*	59	*-50%*	64	*-45%*
Lithuania	134	*-12%*	71	*-54%*	72	*-53%*
Norway	142	*-35%*	125	*-43%*	129	*-41%*
Poland	654	*-46%*	729	*-40%*	702	*-42%*
R.of Moldova	64	*-26%*	66	*-24%*	66	*-24%*
Romania	328	*-37%*	443	*-14%*	431	*-17%*
Russia	2653	*-24%*	1971	*-43%*	2029	*-42%*
Slovakia	115	*-47%*	101	*-54%*	100	*-54%*
Slovenia	34	*-43%*	36	*-40%*	36	*-40%*
Switzerland	76	*-53%*	79	*-52%*	77	*-53%*
FYR of Mac.	29	*-26%*	29	*-26%*	29	*-26%*
Ukraine	1222	*-35%*	967	*-49%*	977	*-48%*
Yugoslavia	132	*-37%*	152	*-28%*	151	*-28%*
Non-EU	6830	*-33%*	5808	*-43%*	5821	*-43%*
Total	14513	*-42%*	13817	*-45%*	13012	*-48%*

Table 5.2: VOC emissions for the flat-rate per capita emission scenarios. Percentage changes relate to the year 1990.

	J1 Central case		J11 Uniform		J12 Reduced var.	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	142	*-60%*	142	*-60%*	129	*-63%*
Belgium	103	*-72%*	193	*-48%*	147	*-61%*
Denmark	85	*-53%*	85	*-53%*	85	*-53%*
Finland	110	*-48%*	92	*-57%*	92	*-57%*
France	989	*-58%*	1038	*-56%*	860	*-64%*
Germany	995	*-68%*	1137	*-64%*	912	*-71%*
Greece	261	*-22%*	184	*-45%*	185	*-45%*
Ireland	55	*-50%*	55	*-50%*	55	*-50%*
Italy	1030	*-50%*	1056	*-49%*	1070	*-48%*
Luxembourg	7	*-63%*	7	*-63%*	7	*-63%*
Netherlands	157	*-68%*	233	*-52%*	196	*-60%*
Portugal	102	*-52%*	144	*-32%*	112	*-47%*
Spain	648	*-36%*	669	*-34%*	578	*-43%*
Sweden	241	*-53%*	174	*-66%*	179	*-65%*
UK	1101	*-59%*	1051	*-61%*	953	*-64%*
EU-15	6024	*-57%*	6260	*-55%*	5556	*-60%*
Albania	41	*32%*	41	*32%*	41	*32%*
Belarus	298	*-20%*	188	*-49%*	188	*-49%*
Bosnia-H	48	*-6%*	48	*-6%*	48	*-6%*
Bulgaria	185	*-5%*	165	*-15%*	165	*-15%*
Croatia	86	*-17%*	86	*-17%*	86	*-17%*
Czech Rep.	156	*-65%*	190	*-57%*	178	*-60%*
Estonia	49	*9%*	29	*-36%*	29	*-36%*
Hungary	137	*-33%*	160	*-22%*	160	*-22%*
Latvia	56	*-11%*	42	*-33%*	47	*-25%*
Lithuania	105	*-5%*	68	*-39%*	68	*-39%*
Norway	195	*-34%*	135	*-55%*	138	*-54%*
Poland	475	*-40%*	700	*-12%*	662	*-17%*
R.of Moldova	42	*-16%*	42	*-16%*	42	*-16%*
Romania	500	*-1%*	426	*-15%*	426	*-15%*
Russia	2723	*-23%*	1861	*-47%*	1891	*-47%*
Slovakia	140	*-7%*	97	*-36%*	97	*-36%*
Slovenia	40	*-27%*	36	*-35%*	36	*-35%*
Switzerland	144	*-48%*	124	*-55%*	124	*-55%*
FYR of Mac.	19	*0%*	19	*0%*	19	*0%*
Ukraine	770	*-34%*	836	*-28%*	836	*-28%*
Yugoslavia	138	*-3%*	139	*-2%*	139	*-2%*
Non-EU	6345	*-26%*	5431	*-37%*	5421	*-37%*
Total	12370	*-45%*	11691	*-48%*	10977	*-52%*

Table 5.3: SO_2 emissions of the flat-rate per capita emission scenarios flat-rate per capita emission scenarios. Percentage changes relate to the year 1990.

	J1 Central case		J11 Uniform		J12 Reduced var.	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	35	*-62%*	40	*-57%*	40	*-57%*
Belgium	76	*-77%*	169	*-50%*	105	*-69%*
Denmark	60	*-67%*	79	*-57%*	79	*-57%*
Finland	116	*-49%*	77	*-66%*	78	*-65%*
France	219	*-82%*	448	*-64%*	281	*-78%*
Germany	463	*-91%*	581	*-89%*	444	*-92%*
Greece	546	*8%*	155	*-69%*	158	*-69%*
Ireland	36	*-80%*	54	*-70%*	54	*-70%*
Italy	290	*-83%*	566	*-66%*	300	*-82%*
Luxembourg	3	*-79%*	4	*-71%*	4	*-71%*
Netherlands	50	*-75%*	73	*-64%*	50	*-75%*
Portugal	141	*-50%*	141	*-50%*	141	*-50%*
Spain	747	*-66%*	577	*-74%*	550	*-75%*
Sweden	67	*-44%*	67	*-44%*	67	*-44%*
UK	499	*-87%*	886	*-77%*	422	*-89%*
EU-15	3349	*-80%*	3918	*-76%*	2773	*-83%*
Albania	55	*-24%*	50	*-31%*	50	*-31%*
Belarus	494	*-41%*	158	*-81%*	158	*-81%*
Bosnia-H	162	*-67%*	70	*-86%*	68	*-86%*
Bulgaria	378	*-79%*	145	*-92%*	156	*-92%*
Croatia	23	*-87%*	70	*-61%*	69	*-62%*
Czech Rep.	283	*-85%*	267	*-86%*	267	*-86%*
Estonia	175	*-36%*	24	*-91%*	25	*-91%*
Hungary	296	*-68%*	296	*-68%*	296	*-68%*
Latvia	104	*-14%*	42	*-65%*	42	*-65%*
Lithuania	107	*-50%*	58	*-73%*	58	*-73%*
Norway	18	*-65%*	32	*-38%*	32	*-38%*
Poland	722	*-76%*	590	*-80%*	504	*-83%*
R.of Moldova	38	*-81%*	67	*-66%*	67	*-66%*
Romania	148	*-89%*	359	*-73%*	340	*-74%*
Russia	2186	*-56%*	1632	*-67%*	1656	*-67%*
Slovakia	92	*-83%*	91	*-83%*	91	*-83%*
Slovenia	14	*-93%*	30	*-85%*	29	*-86%*
Switzerland	23	*-47%*	26	*-40%*	25	*-42%*
FYR of Mac.	81	*-24%*	33	*-69%*	33	*-69%*
Ukraine	1457	*-61%*	782	*-79%*	786	*-79%*
Yugoslavia	217	*-63%*	162	*-72%*	159	*-73%*
Non-EU	7071	*-67%*	4983	*-77%*	4910	*-77%*
Total	11572	*-70%*	10053	*-74%*	8835	*-77%*

Table 5.4: NH_3 emissions for the central scenario J1 compared to the flat-rate per capita emission scenarios. Percentage changes relate to the year 1990.

	J1 Central case		J11 Uniform		J12 Reduced var.	
	kt	*Change*	kt	*Change*	kt	*Change*
Austria	66	*-14%*	66	*-14%*	65	*-16%*
Belgium	60	*-38%*	93	*-4%*	79	*-19%*
Denmark	69	*-10%*	44	*-43%*	47	*-39%*
Finland	31	*-23%*	31	*-23%*	31	*-23%*
France	642	*-20%*	526	*-35%*	530	*-34%*
Germany	413	*-45%*	571	*-25%*	407	*-46%*
Greece	73	*-9%*	74	*-8%*	74	*-8%*
Ireland	116	*-9%*	111	*-13%*	113	*-11%*
Italy	356	*-23%*	432	*-6%*	390	*-16%*
Luxembourg	7	*0%*	7	*0%*	7	*0%*
Netherlands	105	*-55%*	127	*-45%*	104	*-55%*
Portugal	65	*-8%*	67	*-6%*	63	*-11%*
Spain	353	*0%*	318	*-10%*	319	*-9%*
Sweden	48	*-21%*	48	*-21%*	48	*-21%*
UK	264	*-20%*	297	*-10%*	290	*-12%*
EU-15	2668	*-25%*	2811	*-21%*	2566	*-28%*
Albania	32	*0%*	28	*-13%*	28	*-13%*
Belarus	140	*-36%*	103	*-53%*	108	*-51%*
Bosnia-H	22	*-29%*	23	*-26%*	23	*-26%*
Bulgaria	105	*-26%*	86	*-39%*	88	*-38%*
Croatia	29	*-28%*	37	*-8%*	37	*-8%*
Czech Rep.	101	*-6%*	88	*-18%*	88	*-18%*
Estonia	29	*0%*	16	*-45%*	16	*-45%*
Hungary	77	*-36%*	88	*-27%*	77	*-36%*
Latvia	35	*-19%*	23	*-47%*	23	*-47%*
Lithuania	72	*-10%*	49	*-39%*	50	*-38%*
Norway	21	*-9%*	21	*-9%*	21	*-9%*
Poland	468	*-7%*	368	*-27%*	389	*-23%*
R.of Moldova	41	*-13%*	37	*-21%*	37	*-21%*
Romania	227	*-22%*	206	*-29%*	209	*-28%*
Russia	894	*-30%*	836	*-35%*	838	*-35%*
Slovakia	39	*-35%*	45	*-25%*	45	*-25%*
Slovenia	16	*-30%*	17	*-26%*	17	*-26%*
Switzerland	63	*-13%*	58	*-19%*	55	*-24%*
FYR of Mac.	15	*-12%*	16	*-6%*	16	*-6%*
Ukraine	588	*-19%*	431	*-41%*	463	*-36%*
Yugoslavia	64	*-29%*	82	*-9%*	64	*-29%*
Non-EU	3077	*-23%*	2659	*-33%*	2690	*-32%*
Total	5745	*-24%*	5470	*-28%*	5256	*-30%*

Table 5.5: Control costs on top of the REF scenario for SO_2, NO_x and VOC emissions for the flat-rate per capita emission scenarios (in million EURO/year).

	NO_x & VOC			SO_2		
	J1 Central	J11 Uniform	J12 Reduced var.	J1 Central	J11 Uniform	J12 Reduced var.
Austria	70	51	104	5	0	0
Belgium	452	0	189	122	9	48
Denmark	8	32	32	13	5	5
Finland	0	98	77	0	74	72
France	437	127	1321	132	0	67
Germany	484	0	2193	240	0	331
Greece	2	489	411	0	164	158
Ireland	10	0	0	12	4	4
Italy	245	74	191	87	0	82
Luxembourg	2	9	9	0	0	0
Netherlands	112	0	150	19	0	19
Portugal	57	0	23	0	0	0
Spain	42	44	193	9	65	73
Sweden	45	397	346	0	0	0
UK	353	625	1241	295	33	580
EU-15	2318	1946	6479	935	354	1440
Albania	0	0	0	0	1	1
Belarus	3	172	169	0	125	124
Bosnia-H	2	0	0	55	85	85
Bulgaria	10	229	233	58	182	157
Croatia	5	4	4	18	0	0
Czech Rep.	235	141	199	36	86	86
Estonia	0	114	109	0	73	73
Hungary	112	0	1	113	113	113
Latvia	0	192	143	0	22	22
Lithuania	0	170	167	0	21	21
Norway	12	310	175	10	0	0
Poland	373	131	174	283	422	513
R.of Moldova	0	0	0	30	18	18
Romania	100	12	14	137	53	57
Russia	0	1021	870	54	286	273
Slovakia	11	89	93	25	32	32
Slovenia	1	2	2	23	16	17
Switzerland	2	21	21	1	0	0
FYR of Mac.	0	0	0	0	26	26
Ukraine	44	408	384	8	256	255
Yugoslavia	6	0	0	27	71	73
Non-EU	917	3013	2758	879	1887	1946
Total	3235	4959	9238	1814	2240	3386

Table 5.6: Control costs for NH_3 emissions and total costs on top of the REF for flat-rate per capita emission scenarios (in million EURO/year).

	NH_3			Total		
	J1 Central	J11 Uniform	J12 Reduced var.	J1 Central	J11 Uniform	J12 Reduced var.
Austria	1	2	2	76	53	106
Belgium	312	4	50	886	12	287
Denmark	2	539	395	22	575	432
Finland	0	0	0	0	173	148
France	367	1592	1468	936	1719	2856
Germany	842	0	1250	1567	0	3775
Greece	0	0	0	2	654	569
Ireland	146	455	219	168	460	224
Italy	85	0	43	417	74	315
Luxembourg	0	0	0	2	9	9
Netherlands	672	108	741	803	108	910
Portugal	2	0	5	59	0	27
Spain	0	101	97	51	210	363
Sweden	0	0	0	45	397	346
UK	23	0	4	671	658	1825
EU-15	2450	2801	4274	5704	5100	12193
Albania	1	10	11	1	11	12
Belarus	9	433	274	12	729	566
Bosnia-H	1	0	0	58	85	86
Bulgaria	13	262	213	81	673	604
Croatia	3	0	0	26	4	4
Czech Rep.	9	86	85	280	312	370
Estonia	0	83	80	0	270	262
Hungary	319	124	314	545	237	428
Latvia	0	33	32	0	247	198
Lithuania	4	246	212	4	437	400
Norway	3	0	0	25	310	175
Poland	182	1455	954	838	2007	1641
R.of Moldova	3	12	11	33	29	29
Romania	304	764	634	541	829	705
Russia	0	34	33	54	1340	1175
Slovakia	7	1	1	43	122	126
Slovenia	2	2	2	25	20	20
Switzerland	6	45	104	9	66	126
FYR of Mac.	1	0	0	1	26	26
Ukraine	30	1334	846	82	1998	1485
Yugoslavia	94	0	105	128	71	179
Non-EU	991	4922	3912	2787	9822	8616
Total	3442	7723	8186	8490	14922	20809

Table 5.7: Cumulative ozone exposure indices for the flat-rate per capita emission scenarios.

	Population			Vegetation		
	J1 Central	J11 Uniform	J12 Reduced var.	J1 Central	J11 Uniform	J12 Reduced var.
Austria	1	2	1	194	227	192
Belgium	22	30	22	115	133	115
Denmark	1	2	1	30	38	27
Finland	0	0	0	0	0	0
France	54	76	48	1865	2195	1730
Germany	91	121	83	901	1085	858
Greece	3	2	2	146	122	116
Ireland	0	1	0	3	5	3
Italy	40	52	41	993	1098	998
Luxembourg	1	1	1	11	13	10
Netherlands	26	34	26	63	73	63
Portugal	6	7	6	229	262	234
Spain	3	5	3	1046	1133	973
Sweden	0	0	0	7	8	5
UK	49	61	44	111	123	99
EU-15	298	394	278	5714	6516	5425
Albania	0	0	0	0	0	0
Belarus	0	0	0	44	20	16
Bosnia-H	0	0	0	126	148	135
Bulgaria	0	0	0	228	205	196
Croatia	1	2	2	173	197	181
Czech Rep.	5	7	5	218	260	216
Estonia	0	0	0	0	0	0
Hungary	6	9	8	290	348	318
Latvia	0	0	0	2	0	0
Lithuania	0	0	0	9	2	1
Norway	0	0	0	1	1	0
Poland	18	25	19	529	622	518
R.of Moldova	0	0	0	43	40	38
Romania	1	3	2	458	512	479
Russia	5	2	2	861	484	495
Slovakia	3	4	4	153	175	157
Slovenia	1	1	1	78	86	78
Switzerland	1	1	0	70	78	65
FYR of Mac.	0	0	0	33	32	30
Ukraine	6	4	3	971	805	774
Yugoslavia	1	2	2	195	218	202
Non-EU	48	62	47	4481	4234	3902
Total	346	456	326	10194	10750	9327

Compared to the J1 scenario, the flat-rate scenario J11 would require increased control measures in Denmark, Finland, France, Greece, Ireland, Luxembourg, Spain and Sweden and in most non-EU countries. In contrast, Austria, Belgium, Germany, Italy, Netherlands and

Portugal, and Croatia, Hungary and Yugoslavia would experience reduced emission control costs. For the ECE as a whole, the flat-rate scenario J11 would cost 6.4 billion EURO more than J1, an increase of 76 percent.

Table 5.7 and Table 5.8 show how the flat-rate scenario J11 compares with the J1 scenario in terms of environmental improvement. Increased exposure to ozone throughout Europe is expected under the J11 scenario. The area unprotected against acidification generally increases within the EU area, with improvements in some parts of Eastern Europe.

Health-related ozone exposure, in terms of the cumulative population exposure index, would increase by 32 percent, particularly in the high-ozone area of Germany, France, UK, Belgium and the Netherlands. For vegetation-related ozone exposure the largest increases would be found in France, Germany and Italy. For acidification, 4.3 instead of 3.5 million hectares in the EU would remain unprotected (+23 percent), while additional measures in the eastern part of Europe achieve some additional environmental benefits there.

A graphical comparison of the changes in the environmental indicators in relation to emission control costs is provided in Figure 5.1 to Figure 5.3. From these graphs it is obvious that, for the ECE as a whole, flat-rate per capita emissions of the J11 scenario result in a significantly lower cost-effectiveness for two of the environmental problems considered (vegetation- and health-related ozone exposure).

5.2 A Scenario with Reduced Variability in National Per Capita Emissions (J12)

Another scenario was developed with the aim of keeping per capita emissions as uniform as possible within the ECE but at the same time ensuring that the J1 targets would be achieved.

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

$$\varepsilon \parallel z - \breve{z} \parallel^2$$

where z denotes the vector of the decision variables (emissions relative to 1990) and $\breve{z}$ the vector of the 'target' emission levels (relative to 1990). For the particular case of the J12 scenario, the emission levels of the J11 scenario were used as the target level.

Depending on the weight ε given to the regularization, the optimization balances the deviations from these target levels against the overall emission control costs. With sufficiently small regularization coefficients, the optimization ends up with the emission levels of the original J1 scenario, while an increase of this coefficient would ultimately push all emission reductions to the target levels of the J12 scenario (if these achieved the J1 targets).

Table 5.1 to Table 5.6 show the emissions and costs of the J12 scenario. Comparison with J11 shows where it proves necessary for some countries to make greater emission reductions than the per capita average in order to ensure that the environmental targets of J1 are met. For $NH_{3,}$ for example, the results suggest that Germany, Netherlands, Belgium and Italy are required to make above-average emission reductions if the J1 targets are to be achieved.

Compared to the J1 scenario, only Belgium, Italy, Portugal, Croatia, Hungary, Moldova and Slovenia would benefit from reduced emission costs in the J12 scenario. The overall costs (above REF) to the ECE countries are 145% higher than in J1, i.e., they increase by 12.3 billion EURO.

Table 5.8: Ecosystems with deposition above critical loads (1000 hectares) for the flat-rate per capita emission scenarios.

	Acidification			Eutrophication		
	J1 central	J11 uniform	J12	J1 central	J11 uniform	J12
Austria	68	117	62	2477	2989	2287
Belgium	52	118	55	572	633	565
Denmark	5	6	4	85	18	13
Finland	756	289	277	1738	1164	982
France	84	108	80	21632	19658	18693
Germany	567	1227	481	7312	8676	6596
Greece	0	0	0	85	48	47
Ireland	8	9	8	29	28	28
Italy	51	62	50	2508	3566	2553
Luxembourg	1	4	1	63	69	58
Netherlands	76	177	77	278	286	276
Portugal	1	1	1	580	691	578
Spain	17	9	7	850	477	425
Sweden	1166	1126	897	620	574	483
UK	636	1029	617	62	95	67
EU-15	3486	4281	2618	38890	38972	33653
Albania	0	0	0	160	130	121
Belarus	686	2	1	924	597	595
Bosnia-H	0	0	0	460	590	501
Bulgaria	0	0	0	1263	1200	730
Croatia	0	0	0	10	17	11
Czech Rep.	81	125	53	1983	2028	1805
Estonia	8	2	2	598	479	462
Hungary	37	38	37	125	130	127
Latvia	0	0	0	1417	719	566
Lithuania	5	0	0	894	594	553
Norway	1928	2055	1736	35	33	24
Poland	173	161	105	14894	13449	12885
R.of Moldova	10	10	10	0	0	0
Romania	17	17	17	1770	1706	1699
Russia	1026	54	54	23123	16534	16639
Slovakia	149	156	143	939	1037	931
Slovenia	4	4	4	87	98	87
Switzerland	35	44	33	1468	1615	1312
FYR of Mac.	0	0	0	108	93	79
Ukraine	237	16	12	3859	3249	3252
Yugoslavia	0	0	0	1280	1818	1174
Non-EU	4397	2686	2206	55396	46116	43554
Total	7883	6967	4824	94287	85087	77207

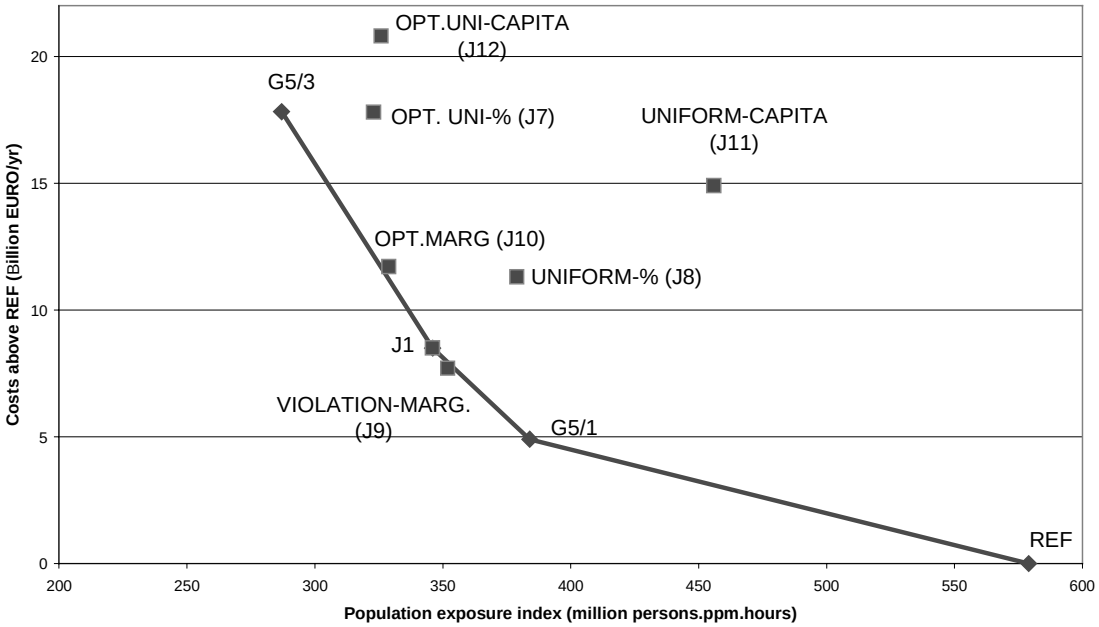

Figure 5.1: Cost-effectiveness of the 'flat rate' reduction scenarios in relation to the population exposure index

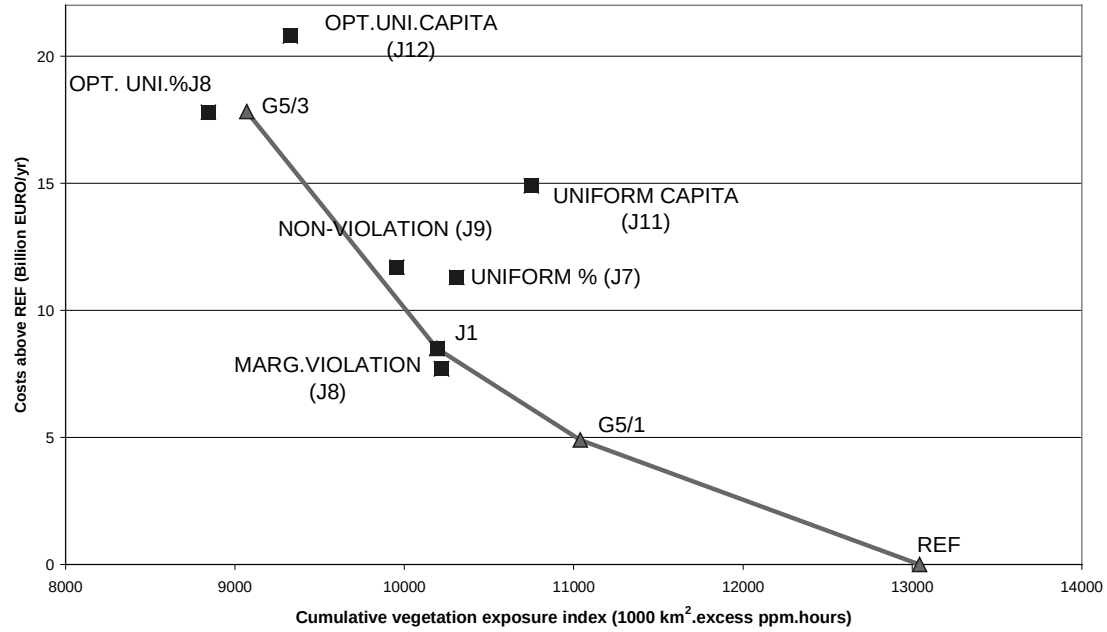

Figure 5.2: Cost-effectiveness of the 'flat rate' reduction scenarios in relation to the vegetation exposure index

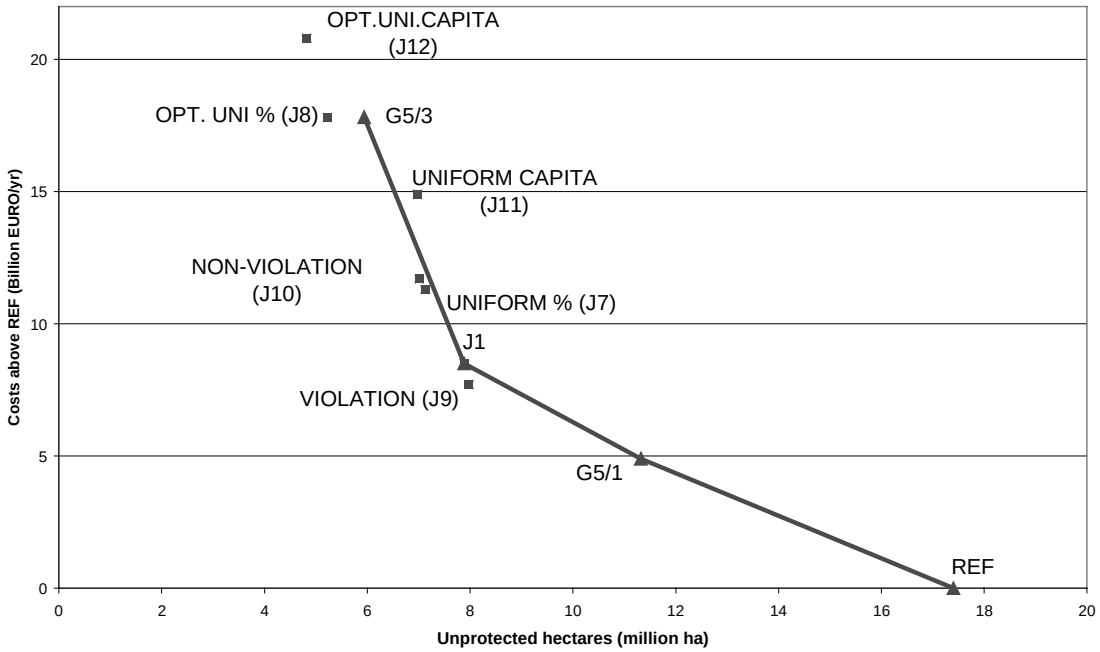

Figure 5.3: Cost-effectiveness of the 'flat rate' reduction scenarios in relation to the area of ecosystems not protected against acidification

6 ANNEX 1: Further Analysis of the H1 Scenario

6.1 Sectoral Emission Control costs of the H1 scenario

Table 6.1: Control costs for SO_2 emissions per sector for the H1 scenario on top of REF (million EURO/yr)

	PP new	PP ex	IND	DOM	TRA	AGRI	TOTAL
Austria	0	0	0	0	0	0	0
Belgium	12	28	59	27	0	0	126
Denmark	0	6	0	0	0	0	6
Finland	0	0	0	0	0	0	0
France	0	3	121	4	9	0	138
Germany	10	2	103	126	0	0	242
Greece	0	0	0	0	0	0	0
Ireland	1	13	5	1	1	0	21
Italy	0	0	0	0	0	0	0
Luxembourg	0	0	1	0	0	0	1
Netherlands	0	0	14	0	5	0	19
Portugal	0	0	0	0	0	0	0
Spain	0	9	0	0	0	0	9
Sweden	0	0	0	0	0	0	0
UK	0	55	184	16	60	0	315
EU-15	23	117	486	174	76	0	875

Table 6.2: Control costs for NO_x emissions per sector for the H1 scenario (million EURO/year)

	PP new	PP ex	IND	DOM	TRA	AGRI	TOTAL
Austria	6	0	8	4	5	0	22
Belgium	2	20	127	66	5	0	220
Denmark	0	0	0	0	0	0	0
Finland	0	0	0	0	0	0	0
France	20	24	258	75	44	0	420
Germany	41	75	116	60	81	0	373
Greece	17	0	41	10	126	0	194
Ireland	0	1	2	1	0	0	4
Italy	64	8	100	30	40	0	243
Luxembourg	0	0	1	0	0	0	2
Netherlands	2	37	29	37	19	0	124
Portugal	4	2	7	0	0	0	13
Spain	0	8	1	0	0	0	9
Sweden	7	2	13	0	18	0	40
UK	0	0	0	0	3	0	3
EU-15	163	177	703	282	342	0	1667

Table 6.3: Control costs for VOC emissions from stationary sources per sector for the H1 scenario (million EURO/year)

	Fuel process. & distr.	Solvents use in industry	Industr. paint use	Other industry	Domestic	Energy	Transport (2-stroke)	Total
Austria	10	57	5	4	20	0	3	104
Belgium	19	40	54	101	18	0	8	240
Denmark	0	0	0	0	0	0	0	0
Finland	0	0	0	0	0	0	0	0
France	64	131	49	8	12	0	55	328
Germany	20	333	196	46	90	0	7	737
Greece	21	10	2	0	5	0	28	66
Ireland	0	0	0	0	0	0	0	0
Italy	9	29	9	10	5	0	99	172
Luxembourg	0	1	0	0	0	0	0	2
Netherlands	12	24	23	22	1	0	9	113
Portugal	16	20	4	2	3	0	2	48
Spain	0	4	0	0	0	0	0	4
Sweden	12	8	3	9	0	0	13	48
UK	209	402	64	142	159	0	28	1147
EU-15	391	1060	410	344	313	0	253	3009

Table 6.4: Control costs for NH_3 emissions per sector for the H1 scenario

	PP new	PP ex	IND	DOM	TRA	AGRI	TOTAL
Austria	0	0	0	0	0	0	0
Belgium	0	0	0	0	0	467	467
Denmark	0	0	0	0	0	0	0
Finland	0	0	0	0	0	0	0
France	0	0	0	0	0	41	41
Germany	0	0	0	0	0	854	854
Greece	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	20	20
Italy	0	0	0	0	0	0	0
Luxembourg	0	0	0	0	0	0	0
Netherlands	0	0	0	0	0	741	741
Portugal	0	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0
Sweden	0	0	0	0	0	0	0
UK	0	0	0	0	0	23	23
EU-15	0	0	0	0	0	2146	2146

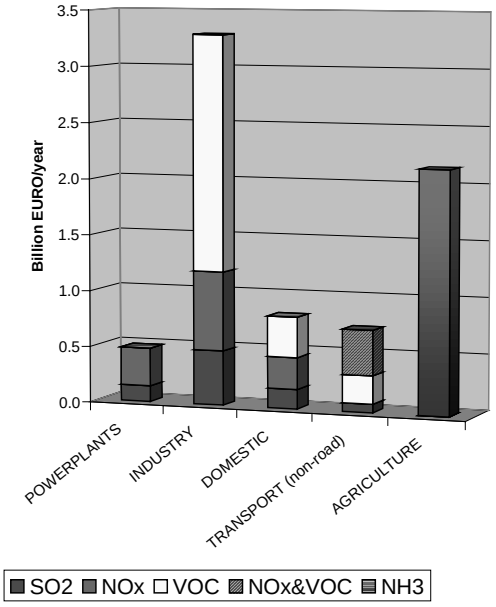

Figure 6.1: Control costs of the H1 scenario (on top of REF) by sector

6.2 Groups of measures taken in the H1 scenario

O = fully implemented.in CLE
o = partially implemented in CLE
N.A. = category not applied to the country in concern
* = fuel/sector combinations do not appear in the given energy pathway

Table 6.5: Controls for SO_2 emissions in the electricity sector for the H1 scenario

	AUS	BEL	DK	FIN	France	GER	GRE	IRE	ITA	LUX	NL	POR	SPAIN	SWE	UK
New powerplants, low sulfur fuels															
OS															
HF < 1 %				O											
MD < 0.1 %		X				X									
New powerplants, limestone injection and FBC															
HC															
BC				o											
OS								x							
New powerplants, FGD															
HC	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
BC	O	O	O		O	o	O	O	O	O	O	O	O	O	O
OS	O	X		o		O								o	
HF	O	O	O		O	O		O	o	O	o	O	O	O	O
New powerplants, high eff. FGD															
HC		x													
BC						o/x									
HF															
Existing powerplants, low sulfur fuels															
HC		o			X								x		o/X
HF < 1 %			x	O											X
MD < 0.1 %		X				X									
Existing powerplants, limestone injection															
HC						o									
BC					O	o									
OS															
Existing powerplants, FGD															
HC	O	X		O		o		X	O		O			O	o
BC	o					o								O	
OS	o	X												o	
HF	o	X				O					o			O	o

Table 6.6: Controls for SO_2 emissions in the industrial sector for the H1 scenario

Fuel	AUS	BEL	DK	FIN	France	GER	GRE	IRE	ITA	LUX	NL	POR	SPAIN	SWE	UK
Industry, low sulfur fuels															
HC			o	O	o	o/X				o			o	o	
DC															
HF < 1 %		X			X			X		O					X
MD < 0.1 %		X				X									
Industry, Combustion modification															
HC											X				
BC	o					O									
Industry, FGD															
HC	o	X	o	O	o/X	o		o	o	o	o			o	o/X
BC	o	X			o	X				o				o	o
OS	o*													o	
HF		X	O		X	o/X		X		o				o	X
INDUSTRIAL PROCESSES															
Sage 1		o	O						O						
Stage 2	O			O		O				O					
Stage 3		X			X	X		X		o/x	O			O	X

Table 6.7: Control measures for SO_2 emissions for the conversion and transport sectors for the H1 scenario

	AUS	BEL	DK	FIN	France	GER	GRE	IRE	ITA	LUX	NL	POR	SPAIN	SWE	UK
CON/ lsfuel	**Conversion sector, low sulfur fuels**														
HC				o	o					o*			o/X		o
DC															
HF < 1 %		X			X	X									X
MD < 0.1 %		X				X									
	Conversion sector, combustion modification														
HC		X				O									
BC						O									
	Conversion sector, FGD														
HC	o		o	o	X			o	o		o			o	X
BC	O*				o					o*				o	o*
OS	o*					o								o*	
HF	o		O	O		X		X		o*	X			o	X
	Residential & commercial sector, low sulfur fuels														
HC	O	X	O	O	X	X		X						O	X
DC	O	X			X	X								O	X
HF < 1 %		X		O	X	X		X							X
MD < 0.1 %		X				X									
	Off-road transport and machinery, low sulfur fuel														
HF < 1 %		X		O											
MD < 0.1 %		X													
	Inland and coastal shipping, low sulfur fuels														
HF					X	o		X			X			o	X
MD					X			X			o/X			O	X

Table 6.8: NO_x control measures for the power plant sector in the H1 scenario

Fuel	AUS	BEL	DK	FIN	France	GER	GRE	IRE	ITA	LUX	NL	POR	SPAIN	SWE	UK
	New powerplants, SCR														
HC	o/X	o/X	o	O	X	o/X	O		o/X		o*	X		O	
BC	o*			o*		o/X	O				o*			X	
OS		X			X										
HF	o/X	o/X	o*	o		o*	O		o/X		o	X		o/X	
GAS	o/X	o/X		o	X	o/X			o/x		o/X			O	
	Existing powerplants, combustion modification														
HC		o	o	O	O	O	O	X	O	O*	O	X	o/X	o	o
BC	O		O*	o	O*	o	O			O*	O*		o*	O	o*
OS	X	X	X		X	O		X	X	O*	O	X		o/X	
HF	o	o		o	O*	O	O		o/X	O*	O*	X		O	o
MD		X			X	o/X	O		X						
LF						o/X			X					X	
GAS	o	o/X		o	O	o	O	X	o/X	O	O	X	X	O	
	Existing powerplants, SCR														
HC	O	X	o		x	O	X		O		X			o/X	
BC	O					o									
OS															
HF	o	X				O	X								
GAS	o					o									

Table 6.9: NO_x control options for the industrial sector in the H1 scenario

Sector / Technology Fuel	AUS	BEL	DK	FIN	France	GER	GRE	IRE	ITA	LUX	NL	POR	SPAIN	SWE	UK
	Industry, Combustion modifications														
HC	O		X		o	o	O	o/X	o	o	O			o	o
DC	O				o	o				o	O			o	o
OS	X	X			X	O	O	X	X		X	X		o/X	
HF	O	o		o	o	o	O	o/X	o	o	O*	o/X	o	o	o
MD	X				X	O	O	X	X	X		X		X	
LF	X	X				O	O		X		X	X		X	X
GAS	O	o			o	O	O	X	o/X	o/X	O	o/X	o	o/X	o
	Industry, SCR and SNCR														
HC	X	X		o	X	X			o/X		X	x		X	
BC	X	X		o		X			X						
OS															
HF	X	X		o	X	o/X			X	x				X	
GAS	x	X		o	X	o/x					x				
	Industrial process emissions														
Stage 1		o	O	O			O	x	X	O				o/X	
Stage 2	O				X	O					O	X			
Stage 3		x								X					

Table 6.10: NO_x control options for the conversion and residential sectors for the H1 scenario

Sector / Technology	AUS	BEL	DK	FIN	France	GER	GRE	IRE	ITA	LUX	NL	POR	SPAIN	SWE	UK
	Conversion sector, combustion modifications														
HC	O				o	o		o	o	o*	O		X	o/X	o
DC	O*				o*	o				o*	O*			o*	o*
OS												X*			
HF	O	o	o/X		o	o	O	o/X		o*	O	o/X	o/X	o/X	o
MD	X	X			X	O		X	X			X			
LF	X	X				O	O		X			X			X
GAS	O	o			o	O	O		o/X	o*	O	o/X	o	o	o/X
	Conversion sector, SCR and SNCR														
HC	X	X		o	X	o/X			o/X		X				
BC				o*											
OS															
HF	X	X			X	o/X	O		X		X				
GAS		X		o	X	o/X									
	Commercial sector, combustion modifications														
HC															
DC															
OS															
HF	X	X			X	O	O	X	X			X			x
MD		X					x								
LF		X					X								
GAS	X	X			X		O		X	X					
	Residential sector, combustion modifications														
HC															
DC															
OS															
HF															
MD		X													
LF		X													
GAS															

Sector	AUS	BEL	DK	FIN	France	GER	GRE	IRE	ITA	LUX	NL	POR	SPAIN	SWE	UK
	Road transport, heavy duty trucks and buses														
MD EUR4	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
LF LFHDCC	X	X							X	X	X				
	Other transport (agricultural tractors, rail, off-road machinery)														
HF CM		X							X					X	
MD EUR2	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
MD EUR3															
MD EUR4	X	X			X	X	X		X	X	X			X	
LF LFHDCC	X				X	X	X							x	
	Road transport, cars and, light duty trucks														
MD MDLDEC	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
MD MDLDNX	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
LF LFCC4	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
GAS GLDCC	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
	Other transport, national sea traffic														
HF CM															
HF SCR					X		O	X			X				X
MD CM							O	X	X		X			X	X
MD SCR					X				X					X	X