Optimized and Non-optimized Emission Control Scenarios for Europe

Note prepared for the
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1 The Optimized Central Scenario F1

This note presents some initial scenario analysis to illustrate differences between optimized and non-optimized emission control scenarios. The starting point of the analysis is the central F1 scenario presented in IIASA's Sixth Interim Report to the European Commission (Amann et al., 1998). The emission levels of this F1 scenario are the outcome of a cost-optimization performed with the RAINS model, and reflect therefore the cost-minimal combination of emission controls to achieve the set of environmental targets presented in Table 1.1.

Table 1.1: Summary of the environmental targets for the central F1 scenario

	Central scenario (F1)
Acidification Gap closure on accumulated excess acidity Maximum excess deposition for the 2-percent of the most sensitive ecosystems	 95 % (850 eq/ha)
Health-related ozone Gap closure on AOT60 Maximum AOT60, to be achieved in 4 out of 5 years	 67 % 2.9 ppm.h
Vegetation-related ozone Gap closure on AOT40 Maximum excess AOT40, mean over five years	 33 % 10 ppm.h

Emission reductions and control costs of the central F1 scenario are presented in Table 1.2 and Table 1.3. Detailed information about the environmental improvements achieved by these emission reductions can be found in Amann *et al*., 1998.

Table 1.2: Emissions for the central scenario F1 compared to the REF case. Percentage changes relate to the year 1990.

	SO_2				NO_x				VOC				NH_3			
	REF		F1		REF		F1		REF		F1		REF		F1	
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*
Austria	42	*-55%*	42	*-55%*	113	*-41%*	94	*-51%*	208	*-41%*	133	*-62%*	67	*-13%*	67	*-13%*
Belgium	208	*-38%*	64	*-81%*	207	*-41%*	111	*-68%*	212	*-47%*	103	*-74%*	96	*-1%*	60	*-38%*
Denmark	90	*-51%*	48	*-74%*	136	*-50%*	136	*-50%*	86	*-47%*	86	*-47%*	72	*-6%*	70	*-9%*
Finland	116	*-50%*	116	*-50%*	162	*-41%*	162	*-41%*	112	*-47%*	112	*-47%*	31	*-23%*	31	*-23%*
France	489	*-61%*	256	*-80%*	1044	*-44%*	757	*-59%*	1242	*-48%*	866	*-64%*	798	*-1%*	727	*-10%*
Germany	608	*-88%*	453	*-91%*	1263	*-53%*	1062	*-60%*	1137	*-63%*	947	*-69%*	571	*-25%*	396	*-48%*
Greece	562	*12%*	562	*12%*	344	*0%*	338	*-2%*	205	*-39%*	202	*-40%*	74	*-8%*	74	*-8%*
Ireland	70	*-61%*	32	*-82%*	81	*-28%*	66	*-42%*	46	*-59%*	46	*-59%*	126	*-1%*	122	*-4%*
Italy	593	*-65%*	593	*-65%*	1186	*-42%*	879	*-57%*	1176	*-43%*	935	*-54%*	416	*-10%*	416	*-10%*
Luxembourg	4	*-71%*	4	*-71%*	10	*-55%*	5	*-77%*	8	*-58%*	5	*-74%*	7	*0%*	7	*0%*
Netherlands	74	*-63%*	53	*-74%*	312	*-42%*	261	*-52%*	241	*-51%*	154	*-69%*	136	*-42%*	106	*-55%*
Portugal	146	*-49%*	146	*-49%*	197	*-5%*	112	*-46%*	144	*-34%*	127	*-41%*	67	*-6%*	67	*-6%*
Spain	793	*-64%*	759	*-65%*	892	*-23%*	822	*-29%*	669	*-36%*	669	*-36%*	353	*0%*	353	*0%*
Sweden	67	*-44%*	67	*-44%*	200	*-41%*	181	*-46%*	287	*-42%*	235	*-52%*	48	*-21%*	48	*-21%*
UK	980	*-74%*	537	*-86%*	1186	*-58%*	1186	*-58%*	1351	*-49%*	1032	*-61%*	297	*-10%*	264	*-20%*
EU-15	4842	*-70%*	3731	*-77%*	7333	*-45%*	6171	*-53%*	7123	*-49%*	5651	*-60%*	3159	*-12%*	2807	*-22%*

Table 1.3: Emission control costs for the central scenario F1 compared to the REF case. Control costs in million ECU/year.

	SO_2			NO_x/VOC			NH_3			Total		
	REF	F1	Total	REF	F1	Total	REF	F1	Total	REF	F1	Total
Austria	174	0	174	784	137	921	0	0	0	958	137	1095
Belgium	341	193	534	1000	856	1856	0	312	312	1341	1361	2702
Denmark	115	21	136	383	0	383	0	1	1	498	22	520
Finland	204	0	204	525	0	525	0	0	0	729	0	729
France	1004	123	1127	6180	1265	7445	0	65	65	7184	1453	8637
Germany	2146	554	2700	8704	1369	10073	0	1258	1258	10850	3181	14031
Greece	331	0	331	933	19	952	0	0	0	1264	19	1283
Ireland	108	19	127	410	10	420	9	49	58	527	77	604
Italy	1577	0	1577	6881	640	7521	12	0	12	8470	640	9110
Luxembourg	9	0	9	60	45	105	15	0	15	84	46	130
Netherlands	306	17	323	1486	246	1732	237	680	917	2029	944	2973
Portugal	152	0	152	1092	284	1376	0	0	0	1244	284	1528
Spain	678	13	691	4793	17	4810	28	0	28	5499	30	5529
Sweden	293	0	293	976	40	1016	113	0	113	1382	40	1422
UK	1148	238	1386	5934	643	6577	0	23	23	7082	904	7986
EU-15	8586	1178	9764	40140	5572	45712	413	2389	2802	49139	9139	58278

2 Non-optimized Scenarios

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

In order to explore the gains in cost-effectiveness achieved by the optimization approach for the F1 scenario, two alternative sets of scenarios are constructed:

- Scenario F12 constructs a 'flat rate' emission control scenario, in which the average reduction rates for the four pollutants of the F1 scenario are applied uniformly to all European countries. This note compares the changes in emission control costs against the changes in the environmental indicators for acidification and ground-level ozone (Section 2.1).
- Starting from the optimized F1 scenario and maintaining the environmental targets of this scenario, a series of scenarios (F13/1 to F13/4) explore the changes in emission control costs if the deviations from the average emission reduction levels (of the F12 scenario) were gradually restricted (Section 2.2).

2.1 A 'Flat-rate' Emission Control Scenario (F12)

The rationale for the illustrative 'flat rate' scenario is to fix - as far as possible - each country's emissions to the value corresponding to the average percentage reduction across all EU-15 countries that was obtained for the F1 scenario from the Sixth Interim Report (Amann et al., 1998). The average reductions from 1990 emission levels for each pollutant for the F1 scenario were as follows:

SO_2	-77 %
NO_x	-53 %
VOC	-60 %
NH_3	-22 %

For some combinations of countries and pollutants the EU-15 average emission reduction would lead to emission values which lay 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. Country/pollutant combinations where this was necessary may be identified in Table 2.1

2.1.1 Emissions, Costs and Environmental impacts

The emissions, costs and exposure indices obtained for this non-optimized "Average reduction" scenario F12 are summarized in Table 2.1 - Table 2.3.

Table 2.1 Emissions for the average reduction scenario F12. Percentage changes relate to the year 1990.

Country	NO_x		VOC		NH_3		SO_2	
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*
Austria	89	*-53%*	142	*-60%*	61	*-22%*	32	*-66%*
Belgium	164	*-53%*	160	*-60%*	76	*-22%*	77	*-77%*
Denmark	128	*-53%*	65	*-60%*	60	*-22%*	42	*-77%*
Finland	129	*-53%*	86	*-60%*	31	*-23%*	60	*-74%*
France	871	*-53%*	967	*-60%*	632	*-21%*	285	*-77%*
Germany	1172	*-56%*	1069	*-65%*	571	*-24%*	447	*-92%*
Greece	240	*-30%*	142	*-58%*	63	*-22%*	115	*-77%*
Ireland	53	*-53%*	45	*-60%*	111	*-13%*	41	*-77%*
Italy	951	*-53%*	828	*-60%*	363	*-22%*	383	*-77%*
Luxembourg	10	*-53%*	8	*-60%*	7	*-5%*	3	*-77%*
Netherlands	253	*-53%*	197	*-60%*	136	*-42%*	53	*-74%*
Portugal	99	*-52%*	122	*-44%*	56	*-21%*	65	*-77%*
Spain	542	*-53%*	494	*-53%*	277	*-21%*	500	*-77%*
Sweden	158	*-53%*	198	*-60%*	48	*-22%*	54	*-54%*
United Kingdom	1186	*-58%*	1074	*-60%*	258	*-21%*	869	*-77%*
EU-15	6044	*-54%*	5596	*-60%*	2749	*-23%*	3025	*-81%*

Table 2.2 Emission control costs above the EU6 REF case for the average reduction scenario F12, M.ECU/year.

Country	NO_x/VOC	NH_3	SO_2	Total	Diff from F1
Austria	132	28	20	180	43
Belgium	126	73	130	328	-1033
Denmark	54	84	29	167	145
Finland	43	0	142	185	185
France	488	579	106	1173	-280
Germany	527	0	652	1179	-2002
Greece	760	67	310	1137	1119
Ireland	46	455	14	515	438
Italy	862	64	90	1016	375
Luxembourg	0	0	3	3	-43
Netherlands	156	0	17	173	-771
Portugal	553	38	43	633	349
Spain	2020	397	116	2533	2503
Sweden	162	1	80	243	203
UK	478	52	47	577	-327
EU-15	6407	1839	1799	10044	905

Table 2.3: Cumulative exposure indices for the average reduction scenario F12

Country	Unprotected area – acid, 1000 ha		Population exposure index, 10^6 person ppm.hours		Vegetation exposure index, 10^3 km^2.excess ppm.hours	
	F12	Diff. from F1	F12	Diff. from F1	F12	Diff. from F1
Austria	119	25	2	0	219	12
Belgium	102	49	28	5	130	14
Denmark	7	2	2	1	40	4
Finland	1053	-77	0	0	0	0
France	103	13	71	16	2103	197
Germany	1183	492	117	20	1070	135
Greece	0	0	1	-1	127	-20
Ireland	9	0	0	0	4	1
Italy	56	-2	37	1	997	12
Luxembourg	3	2	1	0	13	2
Netherlands	156	80	32	5	71	8
Portugal	0	-1	4	-2	183	-43
Spain	7	-10	2	-2	790	-332
Sweden	1365	9	0	0	10	0
UK	891	211	58	10	116	14
EU-15	5056	796	356	54	5873	4

Compared to the F1 scenario, the average reduction scenario F12 would require increased control measures in Austria, Denmark, Finland, Greece, Ireland, Italy, Portugal, Spain and Sweden. In contrast, Belgium, France, Germany, Luxembourg, Netherlands and United Kingdom would benefit from reduced emission control costs. For the EU-15 as a whole, the average reduction scenario F12 would cost 905 million ECU more than F1, an increase of 10%.

Despite the increased costs, Table 2.3 shows that the average reduction scenario F12 would result in a lower environmental improvement – for the EU-15 as a whole – than the F1 scenario. For acidification, the countries where the largest increases in unprotected area would occur are Germany, UK, Netherlands and Belgium. Health-related ozone exposure, in terms of the cumulative population exposure index, would increase most in Germany, France, UK, Belgium and the Netherlands. For vegetation-related ozone exposure the largest increases would be found in France and Germany, with smaller changes in several other countries (see Table 2.3).

A graphical comparison of the changes in the environmental indicators in relation to emission control costs is provided in Figure 2.3 to Figure 2.5. From these graphs it is obvious that, for the EU-15 as a whole, flat-rate emission reductions of the F12 scenario result in a significantly lower cost-effectiveness for all three environmental problems considered (acidification, health-related and vegetation-related ozone exposure).

2.1.2 Non-Achievement of F1 Targets

Table 2.3 indicated how the environmental improvements that would be achieved by the flat-rate reduction scenario F12 compared with those expected from F1. It is also of interest to investigate which F1 targets would not be met by the average reduction scenario. Table 2.4 lists the grid cells at which the absolute ceilings set in the F1 scenario would be exceeded in the F12 scenario.

Table 2.4 Grid cells where the F1 absolute ceilings would not be achieved by the flat-rate F12 scenario.

Environmental measure	Grid cell	Country	Ceiling, ppm.hours	Flat-rate scenario, ppm.hours
Excess AOT40	20/12	FRA	10.0	10.78
	25/12	ITA		10.18
AOT60	20/13	FRA	2.9	2.99
	20/14	BEL/FRA		3.62
	20/15	NL/D/BEL		3.28
	20/16	NL/D		3.34
	21/14	LUX/FRA/D/NL		3.61
	21/16	D		3.06

In the F1 scenario, gap closure targets were specified in the context of a balancing mechanism in which individual grid targets could be exceeded provided that such target violation was compensated by additional improvements in other grid cells in the same country. Comparison of the average reduction scenario F12 with F1 in terms of meeting gap closure targets, therefore, needs to be carried out on a country basis. This is done in Table 2.5 which lists the mean exposure indices which would result from exactly meeting the full set of F1 targets, and indicates in which countries that (F1) level of environmental improvement would not be attained by the flat-rate reduction scenario.

Table 2.5 Non-achievement of the F1 country balance targets by the average reduction scenario F12.

Country	Accumulated excess acidity, equivalents/hectare/year		Average population exposure index, excess ppm.hours		Average vegetation exposure index, excess ppm.hours	
	F1 target	%Excess	F1 target	%Excess	F1 target	%Excess
Austria	3.22		0.21		5.01	
Belgium	31.48		1.77	23%	7.47	12%
Denmark	1.44		0.26		1.80	
Finland	0.06		0.00		0.00	
France	0.73		1.13		7.63	
Germany	29.27		1.20		5.69	
Greece	0.00		0.11		2.76	
Ireland	0.08	(106%)	0.09		0.38	
Italy	0.29		0.73		7.27	
Luxembourg	12.00		1.83	20%	9.97	
Netherlands	85.52	41%	1.44	22%	5.16	5%
Portugal	0.00		0.38		4.37	
Spain	0.24		0.10		4.31	
Sweden	0.92		0.02		0.06	
UK	16.69	25%	0.57	16%	1.45	
EU-15	3.97		0.79		3.86	

The F1 acidification targets would not be met in the UK and the Netherlands; the AOT60 targets would not be achieved in Belgium, Luxembourg, the Netherlands and UK; and in Belgium and the Netherlands the F1 AOT40 targets would also be exceeded. It is worth noting that in several cases where the F1 targets would not be met those targets are themselves relatively high in comparison with the corresponding targets in other countries.

2.2 Reducing the Variation in Emission Reductions while achieving the F1 Targets

Another series of scenarios was developed with the aim of keeping emission reductions as uniform as possible within the EU-15 countries but at the same time ensuring that the F1 targets would be achieved.

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

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

where z denotes the vector of the decision variables (emissions relative to 1990) and $\check{z}$ the vector of the 'target' emission levels (relative to 1990). For the particular case of the F13 scenarios, the emission levels of the F12 scenario was used as the target level.

Depending on the weight ε given to the regularization, the optimization balances the deviations from these target levels against the overall emission control costs. With sufficiently small regularization coefficients, the optimization ends up with the emission levels of the original F1 scenario, while an increase of this coefficient will ultimately push all emission reductions to the target levels of the F12 scenario (if these achieved the F1 targets).

To this end, four scenarios (F13/1 to F13/4) were carried out with values for ε of 1, 10, 100 and 1000, respectively. Figure 2.2 display the changes in national emission control costs for these four scenarios. For sake of brevity, only the extreme scenario F13/4 is presented here in more detail (Table 2.6. to Table 2.8).

2.2.1 Emissions, Costs and Environmental Impacts

Table 2.6 shows the emissions of the F13/4 scenario. Comparison with Table 2.1 shows where it proves necessary for some countries to make greater emission reductions than the average in order to ensure that the F1 targets are met. For NH_3, for example, the results suggest that the Netherlands, Germany and Belgium are required to make above-average emission reductions if the F1 targets are to be achieved.

Table 2.6 Emissions for the F13/4 scenario. Percentage changes relate to the year 1990.

Country	NO_x		VOC		NH_3		SO_2	
	kt	*Change*	kt	*Change*	kt	*Change*	kt	*Change*
Austria	87	*-55%*	131	*-63%*	61	*-21%*	32	*-65%*
Belgium	131	*-63%*	119	*-70%*	69	*-29%*	64	*-81%*
Denmark	113	*-59%*	63	*-61%*	62	*-20%*	42	*-77%*
Finland	117	*-58%*	73	*-65%*	31	*-23%*	63	*-73%*
France	727	*-61%*	828	*-65%*	628	*-22%*	234	*-81%*
Germany	995	*-63%*	901	*-71%*	445	*-41%*	423	*-92%*
Greece	246	*-29%*	147	*-56%*	63	*-21%*	118	*-76%*
Ireland	50	*-56%*	40	*-64%*	113	*-11%*	40	*-77%*
Italy	904	*-56%*	846	*-59%*	364	*-21%*	387	*-77%*
Luxembourg	8	*-62%*	6	*-66%*	7	*-5%*	3	*-77%*
Netherlands	234	*-57%*	163	*-67%*	105	*-55%*	53	*-74%*
Portugal	102	*-51%*	124	*-43%*	56	*-21%*	65	*-77%*
Spain	577	*-50%*	519	*-51%*	281	*-20%*	493	*-77%*
Sweden	152	*-55%*	190	*-61%*	48	*-21%*	56	*-53%*
United Kingdom	1115	*-61%*	971	*-64%*	256	*-22%*	472	*-88%*
EU-15	5559	*-58%*	5122	*-63%*	2588	*-28%*	2547	*-84%*

Compared to the F1 scenario, only Belgium and Luxembourg would benefit from reduced emission costs in the F13/4 scenario (Table 2.7). The overall costs (above REF) to the EU countries are some 6.6 billion ECU greater than in F1, a 72% increase (Figure 2.1).

The cumulative exposure indices for the F13/4 scenario, shown in Table 2.8, suggest that in many cases the F13/4 scenario would achieve a similar environmental improvement to that of the F1 scenario, with further improvements in some measures in a number of countries, as might be hoped for given the considerable additional costs involved.

The overall cost-effectiveness of these scenarios is graphically displayed in Figure 2.3 to Figure 2.5.

Table 2.7 Emission control costs above the EU6 REF case for the F13/4 scenario, M.ECU/year.

Country	NO_x/VOC	NH_3	SO_2	Total	Diff from F1
Austria	216	27	15	258	121
Belgium	487	146	193	826	-535
Denmark	84	60	30	173	151
Finland	90	0	110	199	199
France	1897	606	219	2721	1269
Germany	2627	531	708	3866	685
Greece	624	63	300	987	969
Ireland	66	215	15	296	219
Italy	1004	63	88	1155	514
Luxembourg	10	0	3	13	-33
Netherlands	381	836	17	1234	290
Portugal	412	36	42	489	205
Spain	1040	354	119	1513	1482
Sweden	243	0	32	275	235
UK	1236	64	419	1719	815
EU-15	10417	3000	2308	15725	6586

Table 2.8 Cumulative exposure indices for the F13/4 scenario.

Country	Unprotected area – acid, 1000 ha		Population exposure index, 10^6 person ppm.hours		Vegetation exposure index, 10^3 km^2.excess ppm.hours	
	F13/4	Diff. from F1	F13/4	Diff. from F1	F13/4	Diff. from F1
Austria	87	-7	2	0	198	-9
Belgium	52	-1	22	-1	116	0
Denmark	5	0	1	0	30	-6
Finland	1030	-100	0	0	0	0
France	84	-6	51	-4	1798	-108
Germany	694	3	91	-6	905	-30
Greece	0	0	1	-1	125	-22
Ireland	8	-1	0	0	3	0
Italy	53	-5	33	-3	952	-33
Luxembourg	1	0	1	0	11	0
Netherlands	76	0	26	-1	63	0
Portugal	0	-1	5	-1	188	-38
Spain	7	-10	1	-3	801	-321
Sweden	1242	-114	0	0	7	-3
UK	557	-123	44	-4	98	-4
EU-15	3895	-365	278	-24	5293	-576

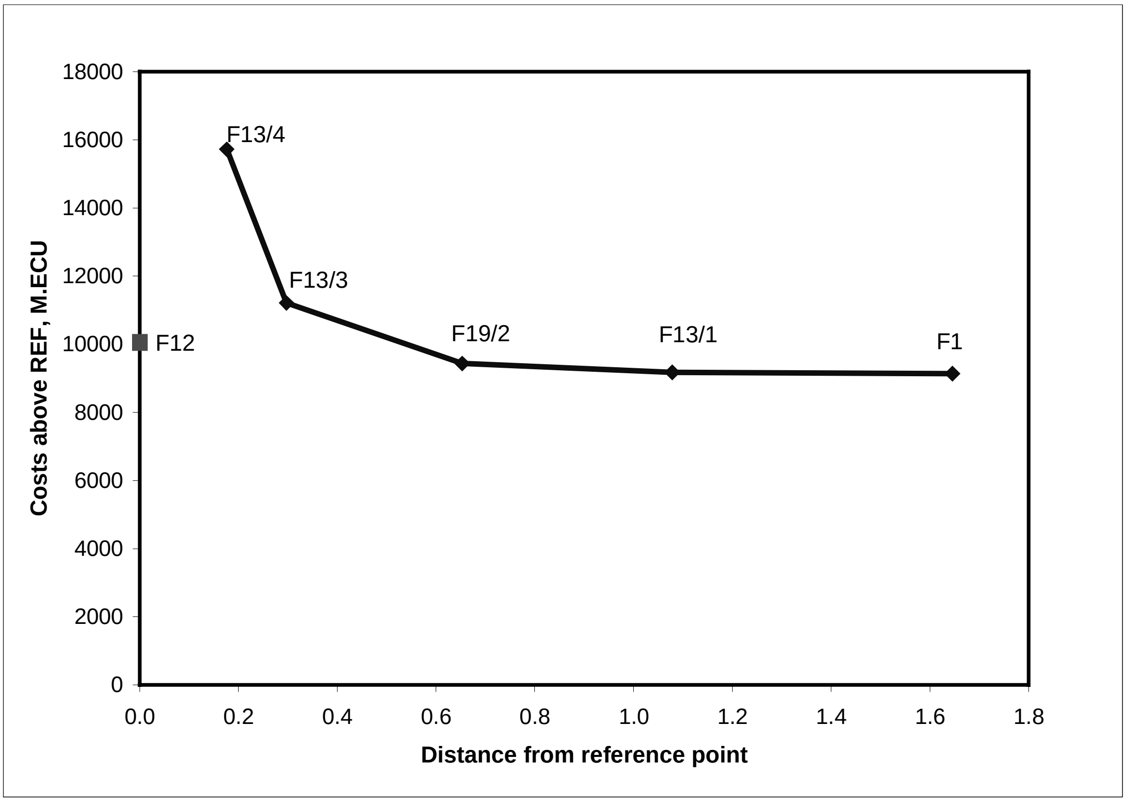

Figure 2.1: Emission control costs (above REF) of the average reduction scenario (F12) and the sensitivity runs F13 compared to those of the central scenarios

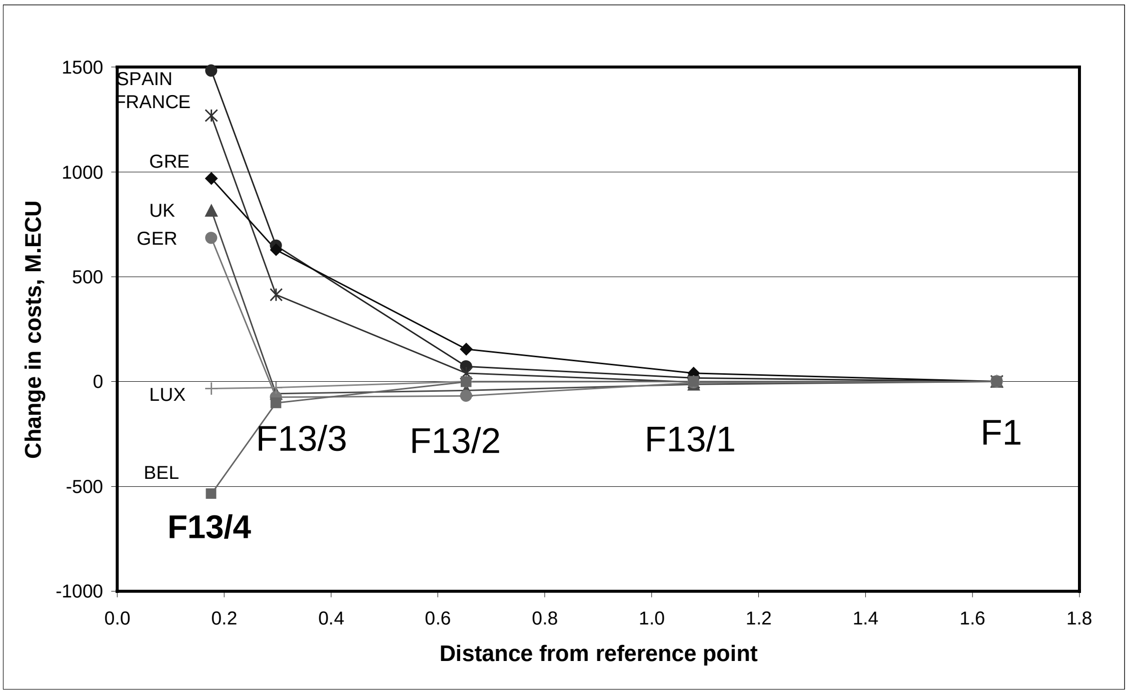

Figure 2.2: Change in emission control costs for the sensitivity runs F13/1 to F13/4

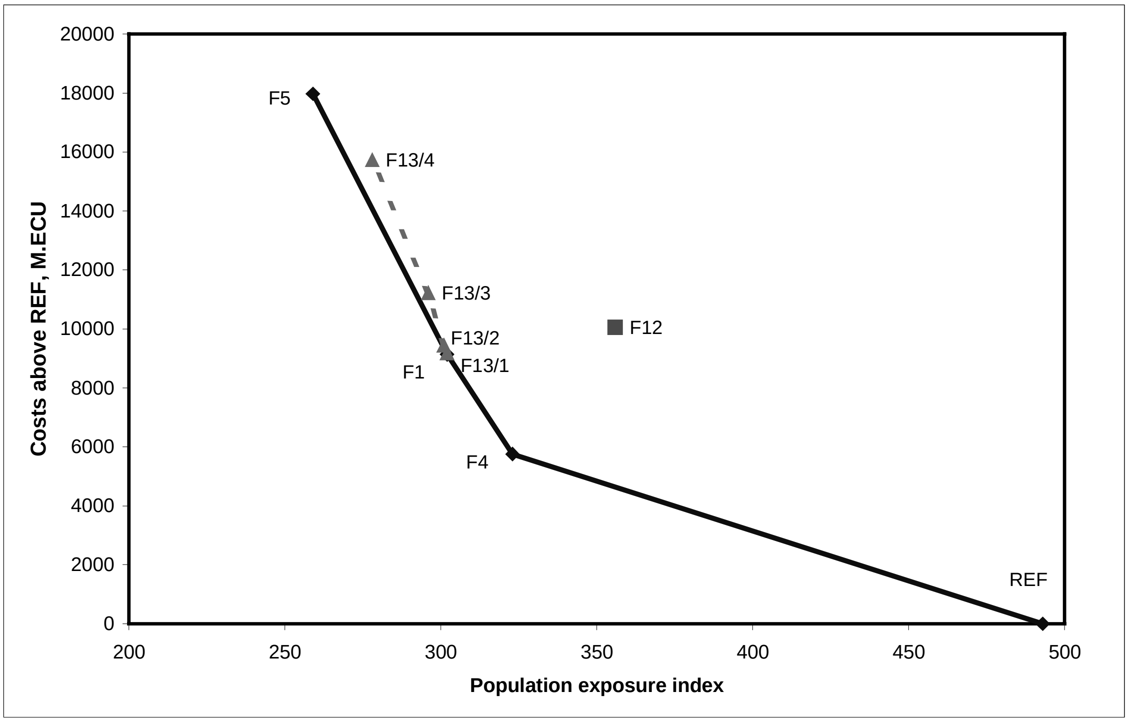

Figure 2.3: Cost-effectiveness in terms of the population exposure index for the average reduction scenario (F12) and the sensitivity runs (F13) compared to the central scenarios

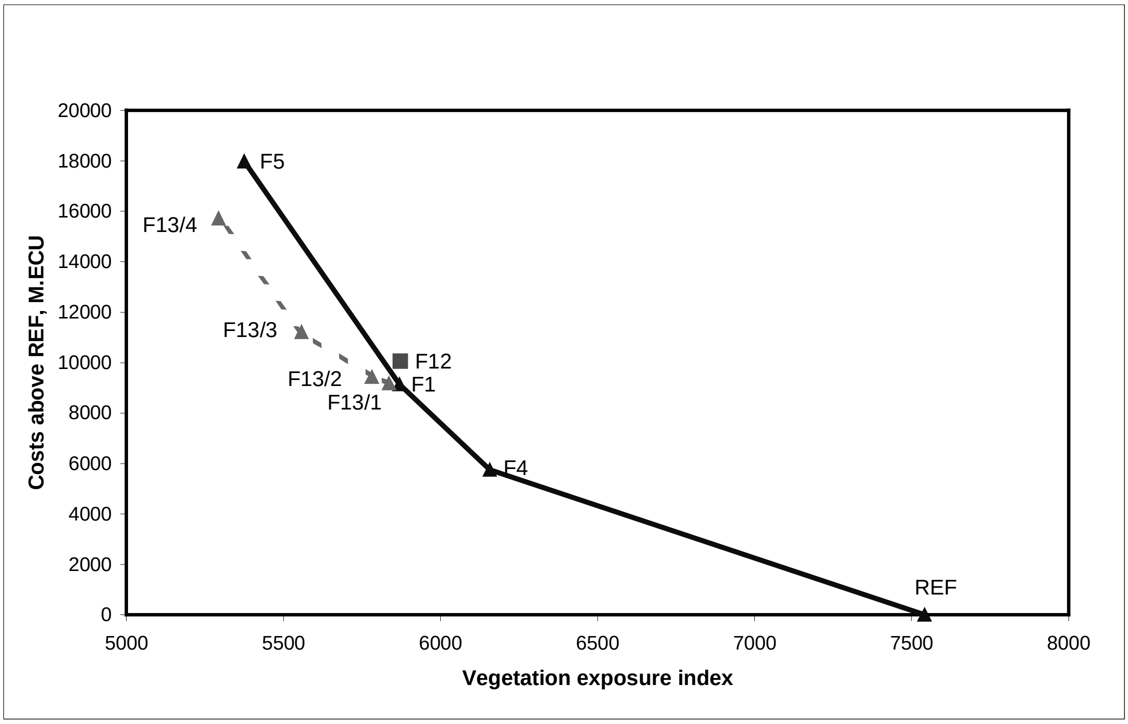

Figure 2.4: Cost-effectiveness in terms of the vegetation exposure index for the average reduction scenario (F12) and the sensitivity runs (F13) compared to the central scenarios

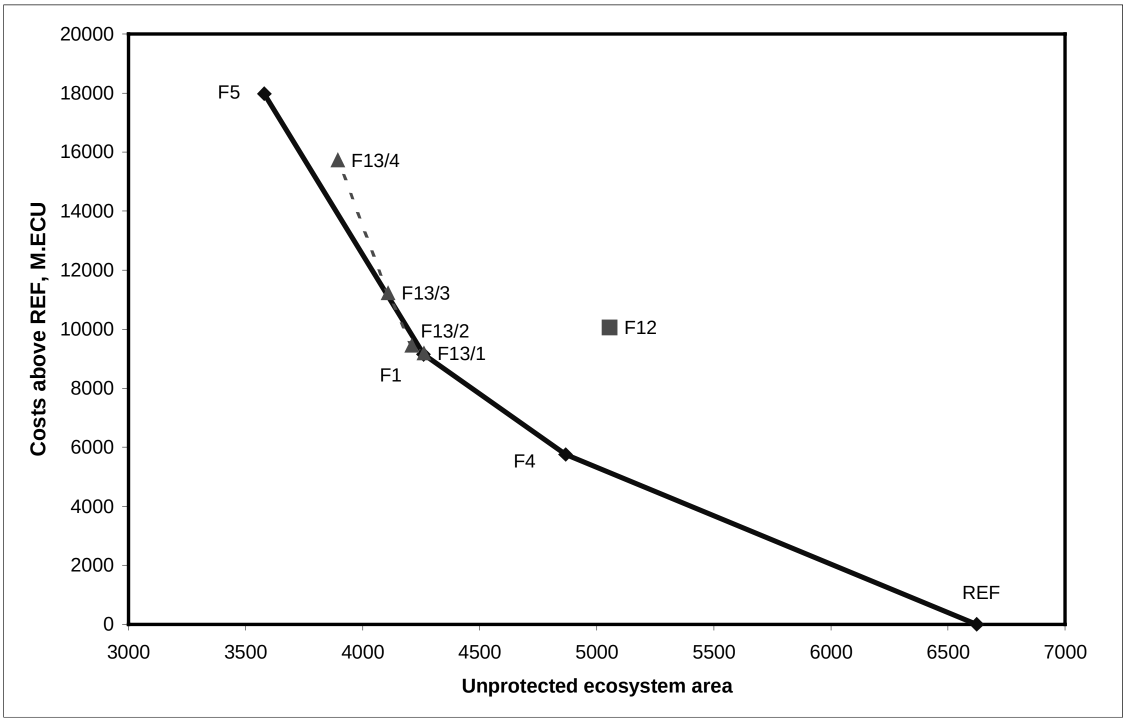

Figure 2.5: Cost-effectiveness in terms of the ecosystems protection (acidification) for the average reduction scenario (F12) and the sensitivity runs (F13) compared to the central scenarios

3 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