Working Paper

Marginal and average costs of reducing nitrogen oxides and sulfur dioxide emissions in Europe

A contribution to internalizing the social costs of transport

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WP-92-050

July 1992

IIASA

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Foreword

Market prices not fully reflecting the social costs of production, transport and consumption lead to non-optimal allocation of resources. Internalization of the external costs of transport may create a more optimal allocation. For this, however, estimates of environmental damage costs are necessary. Based on the 'cost of avoiding environmental damage' method this paper estimates the marginal and average costs of reducing SO_2 and NO_x emissions in the EC/EFTA region.

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MARGINAL AND AVERAGE COSTS OF REDUCING NITROGEN OXIDES AND SULFUR EMISSIONS IN THE EC/EFTA REGION

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1 INTRODUCTION

One important element of economic integration in the European Community is the internalization of the social costs of production and transport. Insofar as market prices do not reflect the full social costs of production and transport this causes distortions in the allocation of resources. Consumption and production of goods and services can cause negative external impacts, such as damage to the environment as a result of pollution. If no compensation is given to the victims of these externalities, the costs of consumption and production will be higher than optimal from a social point of view. Internalizing the full social costs thus contributes to an optimal allocation of scarce resources. This, however, requires the estimation of the social damage caused by externalities such as pollution.

Many methods are available and have been applied to estimate the damage (compare Barde and Pearce, 1991; Cropper and Oates, 1991; Hufschmidt et al., 1988). One can distinguish direct and indirect techniques. Direct approaches use surveys which ask people to define trade-offs between environment and other goods. Indirect approaches attempt to infer from actual choices people make, such as where they live or they work, the value people place on a clean environment. Indirect methods can make use of:

- changes in values of output,
- losses of earnings,
- travel costs,
- wage differentials,
- replacement costs, and
- preventive expenditures or avoidance costs.

In the latter case peoples' expenditures for eradicating or reducing the adverse effects of pollution are used as indicators, e. g. for the liming of lakes to reduce negative impacts of acidification.

Costs of avoiding environmental damage, by means of controlling pollution at the source, can be used as an estimate of the economic value of environmental damage. The major advantage of that method is that estimation of pollution control costs is usually easier than the estimation of the damage. The disadvantage is that the method does not relate directly to actual damage, but assumes that the damage avoided by reducing pollution up to a certain level is higher than the costs of controlling pollution up to that level. In other words, marginal damage costs are assumed to be higher than marginal pollution control costs.

As part of a project on internalizing the social costs of transport, the Swedish NGO (Non-Governmental Organization) Secretariat on Acid Rain asked IIASA to estimate the costs of controlling sulfur and nitrogen oxides emissions in the EC/EFTA region (Kågeson, 1992). In order to allow further elaboration of this approach, this paper estimates costs of reducing sulfur dioxide and nitrogen oxide emissions in the EC/EFTA region. For this purpose the following data are produced:

1. Marginal and average costs of reducing NO_x emissions in the whole EC/EFTA region and for specific countries (Germany, Spain, United Kingdom, Italy, the Netherlands and France), by 30 % and 50% (compared to 1985) and according to the application of best available technologies (BAT). Cost estimates are given for the year 1990 and 2000.
2. Marginal and average costs of reducing SO_2 emissions in the whole EC/EFTA region and for specific countries (Germany, Spain, United Kingdom, Italy, the Netherlands and France), by 60 % and 80% (compared to 1980) and according to the application of best available technologies (BAT). Cost estimates are given for the year 1990 and 2000.

The results presented in this paper are extracted from version 6.0 of the RAINS (Regional Acidification INformation and Simulation) model, developed at the International

Institute for Applied Systems Analysis.

The remainder of the paper is as follows. Section 2 describes the method for calculating the average and marginal costs of controlling NO_x and SO_2 emissions. The resulting costs are presented and elucidated in Section 3.

2 METHOD OF COST CALCULATION AND DATA USED

2.1 Introduction

For the purpose of this study the Regional Acidification Information and Simulation (RAINS) model was used, developed at the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria. The RAINS model combines information on energy use and agricultural activity levels with emission coefficients for SO_2, NO_x and NH_3 to determine regional emission levels. Data on removal efficiencies of emission control technologies and costs are combined to assess the costs and emission reductions of abatement strategies. Results of the European Monitoring and Evaluation Program (EMEP), developed at the Meteorological Synthesizing Center-West (MSC-W) at the Norwegian Meteorological Institute, Oslo, are used to estimate the deposition of sulfur and nitrogen compounds. A comparison of deposition with maps of critical loads, established at the Coordination Center for Effects-West (CCE), Bilthoven, the Netherlands, allows for the evaluation of environmental impacts. In addition, dynamic simulation of the regional impacts of acid deposition on forest soils, lakes and silvicultural ecosystems is possible. The RAINS model is extensively documented in Alcamo et al. (1990). The paper employs the latest version (6.0) of the RAINS model.

2.2 Costs of controlling NO_x emissions

The RAINS model contains a sub-module to assess the potential for and costs of alternative NO_x abatement technologies. The evaluation is based in internationally reported performance and cost data of control devices (Amann, 1989 and 1990). The results of the cost estimates are not intended to predict costs for specific plants in individual countries. The main objective is the consistent international comparison of costs of different emission control strategies, based on different energy scenarios. The necessity to evaluate costs for 38 regions in Europe limits the level of detail that can be maintained.

Table 1 gives an overview of the control options included in the model and their removal efficiencies (%).

Table 1. Control options for NOx emissions and their removal efficiency (%)

STATIONARY SOURCES	Combustion Modifications (CM)	Selective Catalytic Reduction (SCR)	Combinations (CM+SCR)	Others
Power plants	50	80	90	
Coke plants and refineries	50	80	90	
Industry	50	80	90	
Process emissions				40-80
MOBILE SOURCES	EEC	US	US 85	US 91
Gasoline passenger cars	50	90		
Heavy duty trucks			25	40

For stationary sources (power plants, industry) the following control options are considered:

- combustion modification (CM), such as low NO_x burners and optimized boiler design,
- flue gas cleaning, i.e. selective catalytic reduction (SCR),
- combined NO_x control of the two above options (CM+SCR).

These options are considered for both new and existing plants and for various fuel types.

For mobile sources different techniques are available for gasoline and diesel cars. For gasoline cars two levels of control are considered:

- Moderate NO_x reductions (- 50%) reflecting the EEC-Luxembourg compromise for smaller cars (EEC). This involves engine modifications and uncontrolled catalytic converters,
- More demanding reductions to comply with the US standard through the application of three-way catalysts.

For heavy duty trucks two classes of measures are specified:

- A level of control reflecting US 1985 standards, to be met through incremental changes in existing technology (US'85)
- Control to meet the US 1991 standards, requiring in-cylinder emission control, electronically controlled fuel injection and maximum cooling of compressed air (US'91).

The estimation of costs of the different control options (for detail compare Amann, 1989) consists of two steps:

1. Unit costs for each technique in each country are calculated (in costs per ton NO_x controlled or in costs per unit of energy input).
2. These unit costs are combined with data on the volume and the structure of (future) energy consumption in each country to compile national cost functions for controlling emissions.

First, the unit costs are estimated on the basis of standard methods of investment analysis from a public policy perspective. The objective of the analysis is to calculate life cycle costs of reducing emissions from individual source types and to relate these costs to the emission reduction achieved. In order to calculate the life cycle costs, the following types of expenditures are distinguished: investments, annual costs depending on the investment and operating costs. Investments are annualized using (real) interest rates (4 percent) and the lifetime of the installation (depends on the sector: 30 years for power plants, 20 for industry and 10 for mobile sources). The unit costs in a country for a specific pollution control technology depend on two groups of parameters:

1. Technology-specific data that describe the typical economic and technical properties of control technologies, assumed to be equal for all countries: removal efficiency,

lifetime, the relation between investments and boiler size, the price of catalysts, additional retrofit costs and maintenance costs, lifetime of the catalyst, additional fuel consumption.

2. Country-specific data that account for specific conditions in individual countries: operating hours, boiler size, energy prices (electricity and fuels) and fuel consumption per vehicle.

In this way cost estimates for specific technologies are extrapolated by the model to reflect country-specific conditions. Table 2 gives an example result of the calculation of country-specific costs. For control technologies for mobile sources, Table 2 presents the average annual costs of reducing NO_x emissions per kg NO_x removed. In the calculation 50 percent of the costs of controlling emissions from gasoline vehicles (EEC standard or US) are attributed to the control of VOC emissions (reduction 50% for EEC, 90% for US-standard). Major differences in costs (expressed in DM of 1985) occur. The factors that come to the largest differences among countries are the annual fuel consumption per vehicle and the fuel prices for the additional energy consumption. For stationary sources similar differences in unit costs occur due to country specific factors.

Secondly, the unit costs of control are then used to create 'national cost functions' for controlling emissions. National circumstances result in variations in the costs for applying the same technology in different countries in Europe. Another source of difference is to be found in the structural differences between the volume and the structure of energy use (e.g. in the transport sector) that determine the potential for application of individual control options. To give one example: if a country increases the share of hydro-power at the expense of fossil fuel, NO_x emissions will be reduced. At the same time, however, the potential for further reducing emissions in the power plants sector by means of control technologies is restricted.

Table 2. Unit costs of controlling NO_x emissions from mobile sources (DM/kg NO_x) removed.

	Gasoline passenger cars		Heavy duty trucks	
Country:	EEC-norm	US	US '85	US'91
Austria	4.63	3.04	2.96	4.49
Belgium	4.99	3.34	3.05	4.55
Denmark	5.08	3.43	3.79	5.64
Finland	5.23	3.34	3.04	4.62
France	6.28	4.37	2.53	3.08
Germany, West	4.76	3.21	3.00	4.63
Germany, East	6.02	4.05	10.36	14.93
Greece	3.62	2.43	4.25	6.19
Ireland	3.54	2.26	3.56	5.35
Italy	7.12	4.92	3.25	4.83
Luxembourg	4.60	3.06	2.61	4.93
Netherlands	5.21	3.50	2.47	3.74
Norway	5.01	3.33	6.06	8.84
Portugal	7.89	5.44	2.72	4.12
Spain	6.69	4.62	3.78	5.58
Sweden	4.16	2.69	3.49	5.26
Switzerland	4.35	2.87	6.41	9.33
United Kingdom	4.17	2.78	4.17	6.16
EC/EFTA	3.54-7.89	2.26-5.44	2.53-10.36	3.08-14.93
Note: 50% of costs allocated to VOC reductions.				

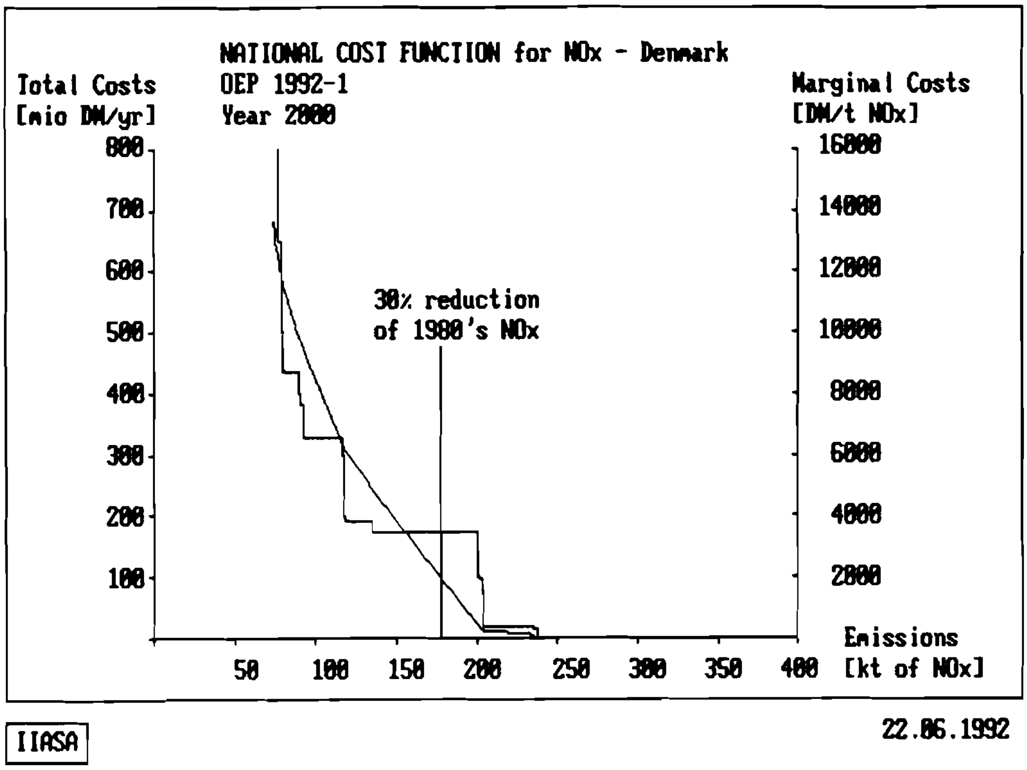
One way to combine these factors is to compile national cost curves. These functions display the lowest costs for achieving various national emission levels by applying the cost-optimal combination of abatement options. This is done by ranking the options according to their marginal costs and their individual potential for removal and can be performed for each sector and each fuel type. For this paper the results are based on official national energy use projections for the year 2000 and on data for the year 1990, as available mid March at the

UN/ECE (United Nations Economic Commission for Europe) and the IEA (IEA/OECD, 1991).

Figure 1 gives one example of such a national cost function for Denmark for the year 2000. Figure 1 shows both the total annual pollution control costs and the marginal costs (stepwise function) as function of the emissions remaining after control. The figure shows that unabated NO_x emissions in the year 2000 in Denmark are expected at nearly 250 kiloton. A 30 percent reduction compared to 1980 would cost some 200 million DM/year. The associated marginal costs would be slightly lower than 4000 DM/ton NO_x removed. Table 3 gives a more detailed picture of the separate control options that are part of the cost function for Denmark.

Table 3 shows in each row the following information: the control options, the volume of emission removed, the marginal costs, the per-unit costs (average costs of that specific measure), the total annual costs of that specific measure, the investments, the installed capacity, the volume of emissions remaining after abatement and, the total annual costs. The table for example shows that the US-1985 norm for heavy duty trucks (HDT) could remove 16 kiloton NO_x with marginal costs of 3789 DM/ton NO_x removed (unit costs would be the same). Application of the US-1991 norm for heavy duty trucks would be more expensive, but emissions could be reduced further by 9 kiloton. Although the average costs are only slightly higher than US-1985 standard (5642 DM/ton), the marginal costs are considerably higher (8730 DM/ton NO_x removed) because they are based on the additional costs of the US-1991 compared to the US-1985 norm divided by the additional removal efficiency (which is only 40%). Table 3 also shows that application of the best available control technology would reduce emission in Denmark from 237 kiloton NO_x in the year 2000 to 74 kiloton. The associated annual costs would be 681 million DM/year. The marginal costs would be 26615 DM/ton NO_x. The average costs would be 4178 DM/ton NO_x.

Figure 1. National cost function for controlling NO_x in Denmark (2000)



2.3 Costs of controlling SO_2 emissions

The method to construct national cost functions is the same for sulfur dioxide emissions as for nitrogen oxides (Amann and Kornai, 1987; Amann, 1990). Again regional and national potentials for emission control and the associated costs are estimated on the basis of detailed data on the most commonly used emission control technologies. The following techniques have been considered for controlling SO_2 emissions:

- the use of low sulfur fuels,
- fuel desulfurization,
- combustion modification such as lime stone injection and fluidized bed combustion),
- flue gas desulfurization (wet limestone scrubbing as well as regenerative processes), and the
- control of industrial process emissions (e.g. through a reduction of the sulfur content in the feed stock or the application of tail gas units for Claus plants in refineries).

Table 3. National cost function for controlling NO_x emissions in Denmark (2000)

Control option			NO_x remov. (kt)	Marginal costs (DM/ton NO_x)	Unit costs (DM/ton NO_x)	Annual costs (mio DM/yr)	Invest-ments (mio DM)	Remaining NO_x (kt)	Total annual costs (mio DM)
Unabated No_x								237	0
CM	CONV	HF	0	243	243	0	1	237	0
CM	IND	HC	2	300	300	0	9	234	0
CM	IND	HF	0	324	324	0	1	234	0
CM	PP old DB	HC	29	352	352	10	116	204	11
CM	PP old DB	HF	1	1446	1446	2	22	203	13
CM	PP old DB	GAS	1	1928	1928	3	35	201	16
PROCESS-EM. 40 %			1	2000	2000	3		200	19
Gasoline cars, US-N			64	3428	3428	222		135	242
HDT, US-Norm 1985			16	3789	3789	62		118	304
CM+SCR	PP new DB	HC	1	3959	1759	4	21	117	309
CM+SCR	CONV	HF	0	5649	2646	2	12	117	311
PROCESS-EM. 60 %			0	6000	6000	4		116	316
CM+SCR	PP old DB	HC	23	6555	3109	155	818	92	472
CM+SCR	IND	HC	1	7650	3567	14	88	90	487
CM+SCR	IND	HF	0	8003	3737	2	16	90	489
HDT, US-Norm 1991			9	8730	5642	86		80	576
PROCESS-EM. 80 %			0	10000	10000	8		79	584
CM+SCR	PP new DB	HF	0	10020	4453	1	7	79	585
CM+SCR	PP new DB	GAS	2	12946	5754	37	270	76	623
CM+SCR	PP old DB	HF	1	20272	9813	22	152	75	645
CM+SCR	PP old DB	GAS	1	26615	12900	35	238	74	681

CM combustion modification
SCR selective catalytic reduction
CONV conversion sector (refineries + coke plants)
IND industry
PP power plants
HDT heavy duty trucks
DB dry bottom boiler
HF heavy fuel oil
HC hard coal
BC brown coal
GAS natural gas

The economic evaluation is restricted to the above typical add-on technologies; costs of structural changes such as fuel switching and energy conservation are not included in this analysis. The cost evaluation is based on the international operating experience of pollution control equipment in Europe. A free and competitive market for the exchange of emission control technology is assumed throughout Europe. As for NO_x, the cost evaluation makes use of technology-specific and country-specific elements (Amann, 1990). Important country-specific elements are the sulfur content of the fuels, annual operating hours of plants and boiler size (Amann and Sϕrensen, 1991), and the projected pattern of energy consumption.

3 AVERAGE AND MARGINAL COSTS OF REDUCING NO_X AND SO_2 EMISSIONS

3.1 Introduction

This section shows the results of the following calculation:

1. Marginal and average costs of reducing NO_x emissions for all countries in the EC/EFTA region by 30 % and 50% (compared to 1985) and according to the application of best available technologies (BAT). Cost estimates are given for the year 1990 and 2000.
2. Marginal and average costs of reducing SO_2 emissions in all countries in the EC/EFTA region, by 60 % and 80% (compared to 1980) and according to the application of best available technologies (BAT). Cost estimates are given for the year 1990 and 2000.

3.2 Average and marginal costs of controlling NO_x emissions

Section 2 shows that an important factor that determines the costs of controlling emissions is the volume and structure of energy consumption in a country. This is certainly the case if we are interested in reducing emissions with a similar percentage over a given base year since in some countries energy consumption might increase much further than in other countries. Consequently, the volume of emissions that has to be removed, and the associated costs, might differ considerable among countries. Table 4 gives the development of NO_x emissions over time for a number of cases, compared to 1985:

- 30% cut-back compared to 1985,
- 50% cut-back compared to 1985,
- BAT in 1990,
- BAT in 2000,
- uncontrolled emissions in 1990 and
- uncontrolled emissions in 2000.

The interpretation of BAT used here is that maximum technically feasible reduction is employed. Such an interpretation does not necessarily coincide with current practice (e.g. in Germany).

Table 4 shows that in some countries NO_x uncontrolled emissions in the year 2000 would be higher than in 1985 (Austria, Belgium, Finland, France, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, United Kingdom). In other countries, a stabilization can be expected (Germany, West and East, Norway, Sweden and Switzerland), and in a few cases (e.g. Denmark) emissions would even decline. These changes are solely due to changes in the volume and structure of the projected energy consumption in 2000 compared to 1980. This has considerable impact on the cost to reach a flat rate reduction: Since Denmark's unabated NO_x emissions are expected to decline, Denmark will have to reduce emissions less than e.g. Spain and Portugal, where the expected growth in energy consumption is considerable. Due to this growth in emissions, neither Spain nor Portugal will be able to reduce emissions by 50 percent compared to 1985, even if all technically feasible measures (BAT) would be applied.

The differences in energy consumption patterns partly explain why average as well as marginal costs for a given flat rate reduction differ among countries (Table 5, marginal and average costs of reducing NO_x emissions by 30 percent (compared to 1985!) in the year 1990; Table 6, same result for the year 2000).

Table 4. NO_x emissions in the EC/EFTA region (kton NO_x)

	Official NO_x 1985	30%	50%	BAT 1990	BAT 2000	Unabated 1990	Unabated 2000
Austria	232	162	116	99	115	288	295
Belgium	420	294	210	167	196	474	546
Denmark	258	181	129	80	74	262	237
Finland	251	176	126	100	117	268	288
France	1615	1131	808	728	722	2049	2010
Germany, West	2959	2071	1480	952	924	3199	2942
Germany, East	670	469	335	208	156	782	610
Greece	297	208	149	101	143	354	464
Ireland	91	64	46	41	42	127	122
Italy	1595	1117	798	694	708	1904	1982
Luxembourg	34	24	17	12	12	39	39
Netherlands	544	381	272	229	256	675	660
Norway	203	142	102	68	81	181	210
Portugal	166	116	83 [1)]	83	101	242	280
Spain	950	665	475 [1)]	437	583	1257	1602
Sweden	394	276	197	125	142	359	406
Switzerland	201	140	100	69	63	236	214
United Kingdom	2402	1681	1201	747	785	2725	2687
EC/EFTA	13282	9297	6641	4940	5220	15421	15594

1) 50 % in 200 not feasible

Table 5 indicates that in the EC/EFTA region marginal costs are expected to vary between 2425 and 5502 DM/ton for a 30% reduction, 2688 and 8582 DM/ton for a 50% reduction and 10000 and 28453 DM/ton NO_x when 'Best Available Technologies' (BAT) would be applied. Average costs (total annual costs divided by the total volume of emissions reduced) for the EC/EFTA region would be 2493 DM/ton (30% reduction), 2918 DM/ton (50% reduction) and 3846 DM/ton NO_x (BAT). Note that a 50 percent reduction is not feasible in Portugal and Spain since without abatement emissions strongly increase. For 1990, Table 5 shows that marginal costs for a 30 percent cut-back are relatively high in

Spain and Portugal compared to e.g. Denmark. The major factor here is that emissions in these two countries increase considerably from 1985 to 1990. In order to bring emissions down to a level of 30% reduction (of 1985!) Portugal and Spain will also have to take fairly expensive measures. This is in contrast to Denmark where emissions decrease between 1985 and 2000. In some countries marginal costs for a 30% and a 50% cut-back are the same (Sweden and Switzerland), because the same measures can be applied (in this case US-standards for gasoline cars) to achieve both the 30% and the 50% cut-back. In other countries (Norway e.g.) this measure (US-norm gasoline cars) is sufficient to attain a 30% reduction, but more expensive measures (US-norm 1985 for heavy duty trucks) need to be taken to meet the 50% reduction.

For the year 2000 the results are somewhat different (Table 6). Marginal costs per ton NO_x removed vary between 2000 and 8582 DM/ton for a reduction of 30%, between 2873 and 12210 for a reduction of 50% and between 10000 and 28453 DM/ton for the application of 'Best Available Technologies'. Average costs gradually increase from 2797 DM/ton NO_x (30% reduction) to 3114 DM/ton (50% reduction) and up to 3980 DM/ton NO_x (BAT). Remarkably, the costs of BAT also differ among countries, because the marginal costs of the same technology for the same sector and the same fuel type differ due to country specific circumstances (see Section 2), which leads to different average costs and as a result different marginal costs.

In summary, differences in the volume and structure of future energy consumption patterns, as well as differences in country specific circumstances (such as boiler sizes, operating hours, average fuel consumption and fuel prices) lead to differences in average costs and, consequently, in marginal costs for reducing emissions by the same percentage over a given base year.

Table 5. Marginal and average costs per ton NO_x removed in 1990 (DM/ton NO_x)

Country	Marginal costs			Average costs		
	30% over 1985	50% over 1985	BAT	30% over 1985	50% over 1985	BAT
Austria	3036	7046	12210	2444	3070	3757
Belgium	3340	7044	11565	2289	3061	3818
Denmark	3428	3789	26615	1941	2571	3940
Finland	3339	7621	12039	2102	3025	4065
France	4371	5918	17081	3354	3815	4120
Germany, West	3210	4825	15034	1927	2379	3505
Germany, East	4568	7156	22555	930	2727	4401
Greece	2425	6754	10000	1622	2414	3478
Ireland	3558	8329	12170	1912	2908	3314
Italy	4921	7473	11748	3261	3994	4366
Luxembourg	3057	3057	11681	2303	2591	3741
Netherlands	3501	6220	11491	2424	3102	3614
Norway	3329	6055	21283	2931	3233	5000
Portugal	5502	n.f.	12006	3736	n.f.	4428
Spain	4621	8582	11640	3361	4192	4429
Sweden	2688	2688	16365	2079	2377	3376
Switzerland	2873	2873	22903	2791	2814	3617
United Kingdom	2775	4174	28435	1879	1314	3402
EC/EFTA	2425-	2688-	10000-	2493	2918	3846
	5502	8582	28453			

BAT: best available technology
n.f: not feasible

Table 6. Marginal and average costs per ton NO_x removed in 2000 (DM/ton NO_x)

Country	Marginal costs			Average costs		
	30% over 1985	50% over 1985	BAT	30% over 1985	50% over 1985	BAT
Austria	3036	12210	12210	2511	3832	3833
Belgium	3340	10000	11565	2508	3565	3843
Denmark	3428	3789	26615	1507	2454	4178
Finland	3339	9884	12039	2271	3772	4082
France	4371	5918	13121	3482	3879	4164
Germany, West	3210	3210	15034	1722	2322	3562
Germany, East	2000	4568	22555	433	2200	5073
Greece	5777	9423	10000	2460	3439	3558
Ireland	3558	8329	12170	1973	3163	3488
Italy	4921	7473	11748	3441	4090	4404
Luxembourg	3057	3057	11681	2237	2591	3704
Netherlands	3501	8469	11491	2539	3420	3681
Norway	3329	6055	27963	3078	3714	5271
Portugal	6456	12006	12006	4237	n.f.	4547
Spain	8582	11640	11640	4096	n.f	4488
Sweden	2688	3488	21407	2120	2407	3413
Switzerland	2873	2873	22903	2743	2778	3675
United Kingdom	2775	4174	28435	1992	2392	3614
EC/EFTA	2000-	2873-	10000-	2797	3114	3980
	8582	12210	28453			

BAT: best available technology
n.f: not feasible

3.3 Average and marginal costs of controlling $S0_2$ emissions

Tables 7 to 9 present the results of the analysis for SO_2 emissions. Table 7 shows the development of SO_2 emissions in comparison to the base year 1980:

- the 1980 emissions,
- the emissions required with a 60 and a 80 percent reduction over 1980,
- the emissions that can be achieved by BAT in 1990 and 2000 as well as
- the development of the unabated emissions in 1990 and 2000.

There will be considerable differences in the development of unabated emissions over time among the different countries due to differences in the growth and the structure of energy consumption. Although in most countries uncontrolled SO_2 emissions are expected to decrease (i.e. Germany-East due to closing down of brown coal fired power plants), in some countries the decrease is more rapid than in others. In Greece, unabated emissions would more than double up to the year 2000.

Table 8 shows the marginal and average costs (expressed in DM/ton SO_2 removed, in constant prices of 1985) of reducing SO_2 emissions in the year 1990 for all EC/EFTA countries. The marginal costs are the costs incurred for removing the last ton of SO_2 to meet the required reduction in emissions. Marginal costs of reducing emissions by 60 % vary between 295 and 5817 DM/ton SO_2. For an 80% reduction, marginal costs vary between 1720 and 8670 DM/ton. Application of Best Available Technologies (in this case, generally, the application of regenerative flue gas desulfurization) would lead to extremely high marginal costs between 107812 and 924529 DM/ton SO_2. This is mainly caused by the fact that the removal efficiency of the regenerative FGD process is only slightly higher (4 percent) than that of a traditional (limestone-based) FGD process (95 % removal). Note that a SO_2 reduction of 80 percent is not feasible in Switzerland.

Table 7. SO_2 emissions in the EC/EFTA region

	Official SO_2 1980	60%	80%	BAT 1990	BAT 2000	Unabated 1990	Unabated 2000
Austria	390	156	78	38	44	335	346
Belgium	828	331	166	44	52	499	681
Denmark	448	179	90	22	21	286	253
Finland	584	234	117	38	53	461	498
France	3338	1335	668	132	125	1645	1432
Germany, West	3194	1278	639	212	224	2527	2271
Germany, East	4264	1706	853	647	226	4494	2363
Greece	400	160	80	64	74	738	907
Ireland	222	89	44	20	18	165	170
Italy	3800	1520	760	182	167	3280	2900
Luxembourg	24	10	5	0	0	16	13
Netherlands	466	186	93	38	47	404	448
Norway	142	57	28	24	27	105	104
Portugal	266	106	53	19	17	358	332
Spain	3250	1300	650	132	166	2437	2952
Sweden	514	206	103	62	83	319	412
Switzerland	126	50	25	48	43	76	78
United Kingdom	4842	1937	968	389	386	3857	3333
EC/EFTA	27098	10839	5420	2111	1773	22002	19493

Table 8. Marginal and average costs per ton SO_2 removed in 1990 (DM/ton SO_2)

Country	Marginal costs			Average costs		
	60% over 1980	80% over 1980	BAT	60% over 1980	80% over 1980	BAT
Austria	1805	4265	172471	1291	1930	3279
Belgium	1284	4250	526792	900	1692	4389
Denmark	1391	3955	373945	918	1828	3027
Finland	1287	5281	107812	950	1284	2849
France	798	3369	196770	781	1333	3699
Germany, West	1866	3607	492098	1470	2049	4200
Germany, East	712	2767	131641	706	759	1177
Greece	1805	8670	126672	1024	1421	1898
Ireland	1289	3390	116909	1010	1517	2862
Italy	730	3073	576521	726	903	2079
Luxembourg	3973	8670	924529	1875	4018	15063
Netherlands	3973	4160	506214	1305	2156	4227
Norway	1805	5458	124299	1017	1880	3210
Portugal	1961	3973	209831	1172	1470	2714
Spain	295	1720	325910	294	531	1617
Sweden	1350	2860	270209	891	1383	2977
Switzerland	5817	n.f.	203006	2188	n.f.	4536
United Kingdom	1268	2065	499674	747	1094	1813
EC/EFTA	295-	1720-	107812-	829	1144	2355
	5817	8670	924529			

BAT: best available technology
n.f: not feasible

Table 9. Marginal and average costs per ton SO_2 removed in 2000 (DM/ton SO_2)

Country	Marginal costs			Average costs		
	60% over 1980	80% over 1980	BAT	60% over 1980	80% over 1980	BAT
Austria	2291	4265	172471	1421	2078	3281
Belgium	1284	4250	526792	1072	1826	4116
Denmark	825	3955	373945	827	1775	3220
Finland	1295	6875	107812	908	1511	2769
France	798	1805	196770	744	1031	3709
Germany, West	1866	3607	492098	1407	2007	4149
Germany, East	712	712	131641	634	679	1237
Greece	3973	8670	126672	1032	1514	1814
Ireland	1289	3390	116909	961	1409	2553
Italy	730	2338	576521	725	939	2097
Luxembourg	1664	8670	924529	1176	4024	18538
Netherlands	3973	5561	506214	1892	2528	4489
Norway	1805	31874	124299	975	2646	3130
Portugal	2188	5322	209831	1321	1725	3384
Spain	966	1720	325910	503	822	1924
Sweden	1805	8192	270209	1221	1811	3252
Switzerland	5817	n.f.	203006	1993	n.f.	5143
United Kingdom	729	2065	499674	724	1051	2131
EC/EFTA	712-	712-	107812-	887	1244	2563
	5817	31874	924529			

BAT: best available technology
n.f: not feasible

Differences in cost estimates among countries are due to differences in the volumes of energy use, the fuel types, boiler size, operating hours, and sulfur content of the fuels. In France, for example, marginal costs are relatively low, mainly because part of the reduction in SO_2 emissions in 1990 (compared to 1980) is already achieved through an increase in nuclear power plants. The reduction to be achieved by add-on technologies is than small and hence marginal and average costs are low.

Table 8 also shows the average costs, i.e., the total annual abatement costs divided by the total emissions removed. Again, large differences among countries occur. The average costs in the EC/EFTA region increase from 829 DM/ton SO_2 removed (60% reduction) to 1144 DM/ton (80% reduction over 1980) and even to 2355 DM/ton (BAT).

Table 9 shows results comparable to Table 8, but for the year 2000. Since energy use in 2000 differs from 1990, also emission control costs are different. For a 60% reduction in sulfur emissions in 2000 (compared to the 1980 level) marginal costs in the region vary between 712 and 5817 DM/ton SO_2. Marginal costs for an 80% reduction are slightly higher (712-31874 DM/ton SO_2). For some countries (FRG-E, for example) the marginal costs are the same for a 60% and a 80% reduction, because the application of some abatement measures (e.g FGD on brown coal fired power plants) could achieve both a 60 and an 80% reduction.

Summarizing, differences in the volume and structure of future energy consumption patterns, as well as differences in country specific circumstances (such as boiler size, operating hours, sulfur content of the fuel) lead to differences in average costs and, consequently, in marginal costs for reducing emissions by the same percentage over a given base year.

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