International Institute for
Applied Systems Analysis
IIASA www.iiasa.ac.at

Cost Functions for Controlling SO2 Emissions in Europe

Amann, M. and Kornai, G.

IIASA Working Paper

WP-87-065

May 1987

Amann, M. and Kornai, G. (1987) Cost Functions for Controlling SO2 Emissions in Europe. IIASA Working Paper. WP-87-065 Copyright © 1987 by the author(s). http://pure.iiasa.ac.at/2987/

COST FUNCTIONS FOR CONTROLLING SO_2 EMISSIONS IN EUROPE

Markus Amann
Gabor Kornai

May 1987

WP-87-065

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

Preface

This paper marks an important step in the development of the Regional Acidification INformation and Simulation (RAINS) model. One of the major goals of the project since its beginning four years ago, has been to get RAINS used in policy analysis. To that end the model should include variables that are very crucial in the eyes of the decision makers. The cost of reducing air pollutant emissions certainly is such an important policy relevant variable.

The authors have successfully developed a uniform approach for establishing cost-of-control functions for emissions of sulfur dioxide in virtually all European countries. This uniformity is particularly important for comparing the cost-effectiveness of various scenarios for controlling acid deposition in Europe.

Currently the assumptions and the numbers in this paper are under review by experts in many of the European countries. I would like to thank the members of the Working Party for Air Pollution Problems of the Senior Advisers to ECE Governments on Environmental Problems and the Group of Experts on Cost and Benefit Analysis of the Executive Body for the Convention on Long-Range Transboundary Air Pollution for providing the fora for discussing the work contained in this paper.

The cost-of-control functions allow the evaluation of targetted deposition levels at a variety of locations in Europe. This will be the topic of a subsequent paper. In the near future we will also develop similar control function for the emissions of nitrogen oxides and will eventually combine the functions into one cost-of-control function for acidifying emissions.

Finally I would like to acknowledge contributions both financially and in kind made by the Federal Environmental Agency of the Federal Republic of Germany, the Department of Energy of the United States of America, the Air Pollution Group of the Nordic Council of Ministers and the Dutch Priority Programme on Acidification. Naturally the responsibility for the use and interpretation of the materials provided by these institutions remains solely with the authors of the paper.

Leen Hordijk
Leader, Acid Rain Project

Acknowledgment

The authors are grateful to B. Schärer (Umweltbundesamt, FRG), D. Streets (Argonne National Laboratory, USA), and B. Tangena and R. Swart (National Institute for Public Health and Environmental Hygiene, the Netherlands) who were involved in discussions about the cost of control submodel. We are also indebted to the many individuals who worked and have been working in the Acid Rain Project.

Table of Contents

COST FUNCTIONS FOR CONTROLLING SO_2 EMISSIONS IN EUROPE

Markus Amann and Gabor Kornai

1. INTRODUCTION

The RAINS (Regional Acidification Information and Simulation) model is a set of interactive computer based models developed at IIASA to assess long-term acidification in Europe on a regional scale. The available submodels are grouped into three compartments: the energy, emissions and cost of pollution control submodels, the atmospheric transport submodel, and the impact compartment covering submodels for effects on lakes, groundwater, forest soils and direct impact of SO_2 on forests. Special emphasis is put on flexible use of the computer model both by advanced interactive software and graphical representation of the model results (Alcamo *et al.*, 1987).

This paper gives a description of the cost of control submodel, which is linked with the energy pathways and emission calculations within the first compartment.

2. GOALS AND LIMITATIONS OF THE APPROACH

The cost submodel of RAINS should serve as framework for a consistent assessment of pollution control costs for all 27 European countries in order to enable

- a cost evaluation of different abatement strategies, based on different energy scenarios and

- a comparison of pollution control costs between countries.

The international comparability of the resulting cost data is the basis for the development of optimized European wide emission reduction strategies, where targeted sulfur deposition levels are achieved in a cost optimal way (Batterman *et al.*, 1986).

The requirement to assess abatement costs for all countries of Europe limits necessarily the level of detail, which can be maintained. Data availability and computational constraints require simplifications, which might appear too rough for studies focused on one country only. Therefore the results of the cost submodel should be considered much more as indicative than as absolute cost estimates: the main emphasis is put on international consistency and comparability.

Keeping in mind the broad scope of RAINS - to provide a tool for integrated assessment of acidification from pollutant's release to ecological impacts - only direct pollution control costs are considered by the cost submodel. All indirect costs of emission reduction (effects on energy prices, trade balance, employment, etc.) as well as the benefits are excluded from the evaluation.

3. PRINCIPLES OF COST CALCULATION

A basic assumption of the RAINS' cost submodel is the existence of 'free trade and exchange of technology', or - in other words - of a competitive market for desulfurization equipment, accessible for all countries throughout Europe. Based on this assumption one can specify country independent capital costs for all abatement technologies, which are determined only by the type of the equipment. The actual abatement costs (per ton of removed SO_2) of each abatement technology are defined by national circumstances. These costs differ considerably among countries even for the same technology mainly. due to sulfur content of fuels, capacity utilization and boiler sizes of installations.

The RAINS' cost submodel provides an algorithm, which takes into account the technology dependent cost parameters as well as the country specific situations of their application.

4. ABATEMENT OPTIONS

Basically seven options to reduce sulfur emissions from energy combustion exist: energy conservation, fuel substitution, use of low sulfur fuels, fuel desulfurization, combustion modification, 'conventional' flue gas desulfurization and advanced, high efficient flue gas cleaning methods (regenerative processes). This chapter will discuss these options in some detail.

Although RAINS is able to evaluate ecological impacts of **energy conservation** strategies and provides the user the possibility to input his own energy scenario, it seems not reasonable to relate all costs of such policies only to emission reduction benefits, as there are a lot of other economic benefits (effects to the trade balance, employment, etc.). Therefore the cost submodel excludes the cost assessment of energy conservation explicitly.

Fuel substitution for reasons of emission reduction comprises the exchange of sulfur containing fuels (coal, oil) by sulfur free fuels (natural gas, hydropower, nuclear energy). A precise evaluation of costs involved would be very tedious and would require more detailed energy models. As this would enlarge the size of RAINS too much, the cost submodel contains only a rough cost estimation procedure for such strategies, assuming that the differences between the fuel prices in each country could be interpreted as opportunity costs and reflect somehow the more complex underlying cost structure of the energy system (Inaba, 1985).

The fuel prices of OECD countries are taken from IEA statistics (OECD, 1986). In order to avoid problems of evaluating non-convertible currencies versus hard currencies, for CMEA countries the export prices of energy to Western Europe (as reported by OECD) are assumed to represent opportunity costs of fuel substitution for the national economies of those countries.

A special algorithm preserves the consistency of the energy balance, keeping track of different combustion efficiencies of fuels and satisfying the basic demand/supply balances. The potentials for fuel substitution are derived for each country separately based on differences of extreme, but still on an European level consistent, energy scenarios.

According to one of the main assumptions of the cost submodel this approach is able to assess cost differences between scenarios, but it does not provide absolute cost figures.

The **use of low sulfur fuels** in order to reduce sulfur emissions is only implemented for hard coal, where low sulfur coal is defined as coal with 1 percent sulfur content. Although in some countries coal with lower sulfur content is available, it cannot be expected that there are enough coal reserves of this type to establish a long-term trade of coal of this quality.

The costs related to this option are derived from analysis of the long-term price differences on the world coal market for low sulfur coal and are assumed to be equal for all countries. Because of the competitive market for low sulfur coal qualities, also the costs of physical coal cleaning have to decline to the market price differential for naturally occurring low sulfur coal, if this desulfurization method is to be applied.

Due to high transportation costs only a negligible international trade of brown coal and lignite exists in Europe. It is, therefore, unlikely that domestic resources of those fuels will be substituted by imports with eventually lower sulfur content.

The **desulfurization of oil products** affects different product qualities. The database of RAINS contains the consumption of light fraction products (gasoline, jet fuel), gasoil (diesel and light fuel oil) and heavy fraction products (heavy fuel oil). The light fraction products contain a negligible amount of sulfur. Gas oil can be desulfurized down to 0.3 percent, and at higher costs down to 0.15 percent. Heavy fuel oil will be available with 1 percent sulfur content either by use of naturally occurring low sulfur crude oils (e.g. from the North Sea) as refinery input or by desulfurization during the refinery process.

Because of the vivid trade with refined oil products in Europe, the cost submodel restricts the cost calculation of fuel desulfurization to the fuel price differences, but performs no bookkeeping of refinery capacities and desulfurization investments. The price increments for low sulfur oil qualities are valid for all countries. The cost data for fuel desulfurization are based on the experience of the Federal Environmental Agency in the Federal Republic of Germany.

Desulfurization during or after combustion, in contrast to the already discussed emission reduction options, requires direct investments at the plant site. Therefore the three methods within this category: combustion modification, flue gas desulfurization and high efficient regenerative processes are modeled in a different way.

An algorithm was developed to derive country specific unit costs of abatement (per ton of removed SO_2) for these technologies, taking into account investment efforts as well as fixed and variable operating costs. The investment costs are described by a function, involving the type of technology, the flue gas volume of the fuel and the boiler size as well as the additional expenses caused by retrofitting installations. In order to convert the one-time payments of the investment expenses to costs per removed ton of SO_2, the country specific real interest rate and the average lifetime of plants (depending on the sector) are used to annualize the costs by the present value method. The capacity utilization (operating hours per year) and the sulfur removal efficiency relate those annualized costs to the actual amount of removed sulfur. The operating expenses are divided into two categories: fixed costs, which are independent on the use of the technology (maintenance, taxes, administrational overhead, etc.) and variable costs, which are directly related to the operation (labour costs, additional energy demand, costs for sorbents and waste disposal, etc.). Together with the annualized investment costs they add up to unit costs per ton of removed SO_2. **Appendix A** gives an overview of the cost calculations for desulfurization options during or after combustion.

The technology related input data for the cost calculation routine are different for each of the three abatement methods mentioned above. These three basic processes represent several different technological solutions, which have - in each group - similar overall technical and economical characteristics. For methodological reasons for each group the most common process was used to derive those significant properties, but one can assume that these data represent also other competitive methods of the same group.

Desulfurization technologies with low investment efforts, but high operating costs (due to large amounts of produced waste material), which are applied mostly for medium efficiency removals, are represented within the **combustion modification** group by the limestone injection method. As advanced, but not yet fully commercially available process the fluidized bed combustion would also be covered by this abatement option.

The most common desulfurization technology throughout Europe is the **flue gas desulfurization**, represented by the wet limestone scrubbing process. Removal efficiencies of 90 percent are typical.

Advanced, very high efficient desulfurization processes are grouped into the **regenerative process methods**, which achieve efficiencies in the range of 98 percent, but require higher costs. As example for the cost calculation the already fully commercial Wellman-Lord method is taken. For the future, e.g. the integrated gasification - combined-cycle plants, which are presently under development in the USA would also fit into this technology group.

The cost data for these methods were estimated in cooperation with the Federal Environmental Agency of the Federal Republic of Germany, using the specific West German experience (Schärer *et al.*, 1987). Appendix B contains the data used for cost calculations.

5. PROCESS EMISSION'S REMOVAL

Compared to emissions caused by energy combustion, man-made sulfur emissions originating from industrial processes not related to energy consumption, are badly documented. For purposes of a consistent assessment of emission reduction potentials and costs, data are only available for few countries. These few published data do not allow to derive even rough estimates for other countries. In order to avoid inequalities between countries reporting process emissions and those, who do not do so, it is necessary to use some generic assumptions about potentials and costs of reducing those pollutants. In absence of any data, which could be generalized, three reduction levels at different (generic) costs are assumed for those countries, who specify process emissions.

Even if there would exist more precise data about the origin of the emissions, it would be extremely difficult to estimate reduction costs, as emission reduction of those processes is mostly connected with a change of the production technology. Such a change is neither necessarily induced by environmental interests, nor should the resulting changes of productivity and efficiency be ignored.

6. NATIONAL COST CURVE

The national abatement costs are defined for each country by the unit costs and the actual potential for sulfur removal, which is mainly connected with the energy consumption. In order to allow comparisons of abatement costs between countries, RAINS contains a procedure to derive the least cost combination of available abatement options for each emission reduction level from zero reduction up to the technically feasible limit.

For a selected energy pathway a compilation of those least cost solutions will result in the 'National Cost Curve'. The cost efficiency serves as common criterion to select a set of pollution control policies out of the infinite number of possible combinations within each country and enables therefore a consistent international comparison and evaluation of abatement efforts.

The cost submodel performs in the first step for all implemented reduction possibilities (see Table 2 of Appendix A) the calculation of the country specific unit abatement costs, as long as they are technical feasible, irrespective whether they are cost efficient or not. In the second phase of the model run, these sets of theoretical options are used to form cost efficient combinations. It should be mentioned, that this process does not take care of introduced environmental legislation of individual countries, as otherwise difficult evaluation problems between countries would arise. It is assumed that limitations to some abatement methods, for example due to waste disposal problems, are reflected by the related (country specific) cost factor (e.g. disposal costs), which prohibits a cost efficient application of this process in a country.

However, there are some other underlying assumptions, influencing the construction of the cost curves. To evaluate the abatement costs for future years, one should also know the potential of new and old power plants, as the investment costs to retrofit old plants are much higher. The cost submodel is based on the generic assumption, that the power plants of the year 1985 are phased out in a linear way within their lifetime of 30 years. The resulting gap in electricity production – depending on the selected energy pathway – has to be filled with new installations.

For reasons of internal consistency it should be assured that desulfurization equipment, which has been constructed once, has to operate until the end of its calculated lifetime, otherwise the cost calculation, which is based on an annualization procedure, would fail. As result of this condition only those old power plants are allowed to be retrofitted with desulfurization equipment, which will be still in operation at the end of the time horizon of the cost of control submodel (in the year 2000). For those plants, which are to be closed down earlier, only the use of low sulfur fuels is applicable.

Appendix C contains the abatement cost curves for all 27 European countries. They are based on the official energy pathways as they were reported from individual governments to IEA and ECE and relate to the year 2000 (IEA coal information, ECE energy database). As they should reflect the original energy scenario, for the purpose of this paper, no fuel substitution is included although the cost submodel is able to handle also this option (as described above).

The curves show the least costs to reduce emissions for increasing reduction levels, starting from the amount of unabated emissions, which would result from the forecasted fuel consumption without any abatement measures. The level of the 30% reduction (compared to 1980 emissions), to which most countries agreed in the Convention on Long-Range Transboundary Air Pollution, is indicated by a star. The graphs contain the curves for the total annual abatement costs and marginal costs curves.

REFERENCES

Alcamo, J., Amann, M., Hettelingh, J.-P., Holmberg, M., Hordijk, L., Kämäri, J., Kauppi, L., Kauppi, P., Kornai, G. and Mäkelä, A. (1987). Acidification in Europe: a simulation model for evaluating control strategies. *Ambio* (forthcoming).

Batterman, S., Amann, M., Hettelingh, J.-P., Hordijk, L. and Kornai, G. (1986). Optimal SO_2 abatement policies in Europe: some examples. *IIASA Working Paper WP-86-42*, IIASA, Laxenburg, Austria.

ECE Energy Data Base (1987) (on tape), Geneva.

Inaba, S. (1985). *Costs of Meeting Stricter Environmental Standards for Stationary Sources of Emissions – The Electricity Sector*. International Energy Agency, Paris.

International Energy Agency, Coal Information 1986, OECD, Paris.

OECD (1986). *Energy Prices and Taxes, Second Quarter 1986*, No. 4, International Energy Agency, OECD, Paris.

Schärer, B., and Haug, N. (1987). The cost of flue gas desulfurization and dentrification in the Federal Republic of Germany. *Economic Bulletin for Europe*, **39** (1), Pergamon Press.

APPENDIX A: an overview of the cost calculations for desulfurization options during or after combustion.

Table 1: Parameters used for cost calculation.

	Country specific data
sc	sulfur content
hv	heat value
sr	sulfur retained in ash
bs	average boiler size
pf	capacity utilization
q	real interest rate
$c^e, c^l,$ c^s, c^d	prices for electricity, labour, sorbents and waste disposal
	Technology specific data
I	investment function
ci^f	intercept
ci^v	slope
v	relative flue gas volume
lt	lifetime of plant
x	sulfur removal efficiency
f_t	maintenance costs and administrational overheads
$\lambda^e, \lambda^l,$ λ^s, λ^d	specific demand for energy, labour, sorbents and waste disposal

Investment Function

$$I = (ci^f + \frac{ci^v}{bs}) \; v \; / \; bs$$

Annualized investments

$$I_{an} = I \, \frac{q^{lt} (q - 1)}{q^{lt} - 1}$$

Fixed operating costs:

$$OM_{fix} = I \, f_t$$

Variable operating costs:

$$OM_{var} = (\lambda^l \, c^l + \lambda^e \, c^e + (\frac{sc}{hv} (1 - sr)) \, x \, (\lambda^s \, c^s + \lambda^d \, c^d))$$

Unit Costs per PJ

$$c_{PJ} = \frac{I_{an} + OM_{var}}{pf} + OM_{var}$$

Unit Costs per ton SO_2 removed

$$c_{SO_2} = c_{PJ} \; / \; (\frac{sc}{hv} (1 - sr) \; x)$$

Table 2: Pollution control options (excluding fuel switching).

		Low sulfur	Combustion modification	Flue gas desulfuriz.	Regener. process
Conversion	Hard coal			x	
	Heavy fuel oil			x	x
Power plants	Brown coal,old		x	x	
	Brown coal,new		x	x	
	Hard coal,old	x	x	x	
	Hard coal,new	x	x	x	
	Heavy fuel oil,old	x		x	
	Heavy fuel oil,new	x		x	
Domestic	Hard coal	x			
	Coke,Briquettes	x			
	Gas oil	x			
	Heavy fuel oil	x			
Transport	Gas oil	x			
Industry	Hard coal	x	x	x	x
	Coke			x	x
	Gas oil	x			
	Heavy fuel oil	x		x	x

APPENDIX B: Data used for the cost calculation.

Technology Specific Cost Data

Table 3: Technology specific data

		Combustion Modification		Flue Gas Desulfurization		Regenerative Processes	
		new	retrofit	new	retrofit		
Investment Cost Function:							
Intercept	ci^f	52.0	67.6	167.0	217.0	275.0	
Slope	ci^v	22500.0	29250.0	20000.0	26000.0	22500.0	
Resulting Specific Investments for a 210 MW_{el} plant:		159.1	207.2	262.2	340.9	382.1	DM / kW_{el}
Operating Costs:							
Annual Maintenance Costs	f_t	4.0		4.0		4.0	% of total investments/year
Other Overheads	f_t	2.0		2.0		2.0	% of total investments/year
Labour Demand	λ^l	5.0		10.0		10.0	Manyear/100 MW
Additional Energy Demand	λ^e	1.0		1.0		5.0	%
Sorbents		Limestone		Limestone		NaOH	
Sorbents Demand	λ^s	4.68		1.56		0.06	t Sorbents/t S02 removed
By-Product		Waste material		Gypsium		Sulfur	
Amount of By-Product	λ^d	7.80		2.60		0.50	t Product/t S02 removed
Sulfur removal efficiency	x	50.0		90.0		98.0	%

The notation of the parameters refers to the equations on page 12.

Country Specific Parameters

Table 4: Average Boiler Size (*bs*)- Powerplants (in MW el)

	Brown Coal	Hard Coal	Heavy Fuel Oil		Brown Coal	Hard Coal	Heavy Fuel Oil
Albania	210	210	210	Luxembourg	210	210	210
Austria	139	220	128	Netherlands	210	328	193
Belgium	210	160	158	Norway	210	210	210
Bulgaria	210	210	210	Poland	210	210	210
CSSR	210	210	210	Portugal	210	300	150
Denmark	210	178	201	Romania	210	210	210
Finland	210	134	82	Spain	257	254	195
France	202	252	306	Sweden	210	502	203
FRG	235	206	190	Switzerland	210	210	150
GDR	210	210	210	Turkey	195	150	126
Greece	243	210	155	UK	210	245	291
Hungary	210	210	210	USSR	210	210	210
Ireland	210	300	106	Yugoslavia	99	370	149
Italy	153	335	227				

Note: In case a fuel is not used in a country as powerplant input, for computational reasons a default boiler size of 210 MW is used.

Table 5: Capacity Utilization (*pf*)- Powerplants (in hours per year)

	Brown Coal	Hard Coal	Heavy Fuel Oil		Brown Coal	Hard Coal	Heavy Fuel Oil
Albania	4000	4000	4000	Luxembourg	4000	3504	3504
Austria	3504	3504	3066	Netherlands	4000	3154	3942
Belgium	4000	3416	3679	Norway	4000	4000	964
Bulgaria	4818	4818	4380	Poland	4380	4468	4468
CSSR	4818	4818	3153	Portugal	4000	4117	4117
Denmark	4000	3592	526	Romania	4380	4380	4380
Finland	4000	2365	3854	Spain	4730	4468	4468
France	3767	3767	1489	Sweden	4000	4000	1314
FRG	6745	4205	1226	Switzerland	4000	4000	1401
GDR	4818	4818	2716	Turkey	4993	2978	2978
Greece	6132	4000	3504	UK	4000	4468	876
Hungary	4292	4292	4292	USSR	5168	5168	5168
Ireland	4000	3592	3416	Yugoslavia	4380	1927	1927
Italy	3679	4030	4030				

Note: In case a fuel is not used in a country as powerplant input, for computational reasons a default capacity utilization of 4000 hours per year is used.

Table 6: Electricity Prices, Labour Costs and Real Interest Rates

	Ele-Price [10**6 DM per PJ] c^e	Labour Costs [1000 DM/ Manyear] c^l	Real Interest Rate [%] q		Ele-Price [10**6 DM per PJ] c^e	Labour Costs [1000 DM/ Manyear] c^l	Real Interest Rate [%] q
Albania	88.0	5.3	4.0	Luxembourg	115.0	28.1	4.0
Austria	118.0	25.3	4.0	Netherlands	126.0	24.8	5.3
Belgium	126.0	23.1	7.0	Norway	41.0	39.8	8.0
Bulgaria	88.0	11.8	4.0	Poland	88.0	10.8	4.0
CSSR	88.0	14.8	4.0	Portugal	153.0	5.9	4.0
Denmark	115.0	32.5	5.7	Romania	88.0	8.8	4.0
Finland	121.0	32.5	7.0	Spain	135.0	12.8	8.0
France	112.0	26.8	7.1	Sweden	88.0	34.9	6.9
FRG	138.0	29.5	4.5	Switzerland	141.0	41.4	2.2
GDR	88.0	18.5	4.0	Turkey	88.0	3.2	8.0
Greece	88.0	9.8	4.0	UK	135.0	22.8	4.4
Hungary	88.0	13.1	4.0	USSR	88.0	13.2	4.0
Ireland	182.0	15.1	7.8	Yugoslavia	88.0	10.9	4.0
Italy	168.0	18.2	5.6				

Note: The data for electricity prices represent tarifs for industrial consumers (without taxes). The differences in labour costs between countries are assumed to be reflected by the GDP (NMP) per capita.

Table 7: Default values assumed for all countries:

Average Boiler Size	bs		
Industry		30	MW_{el}
Capacity Utilization	pf		
Industry		6000	hours/year
Costs of Sorbents Material	c^s		
Limestone		35	DM/t
NaOH		250	DM/t
Costs of By-Products	c^d		
Waste Disposal for Limestone Injection		70	DM/t
Gypsum		0	DM/t
Sulfur		-360	DM/t

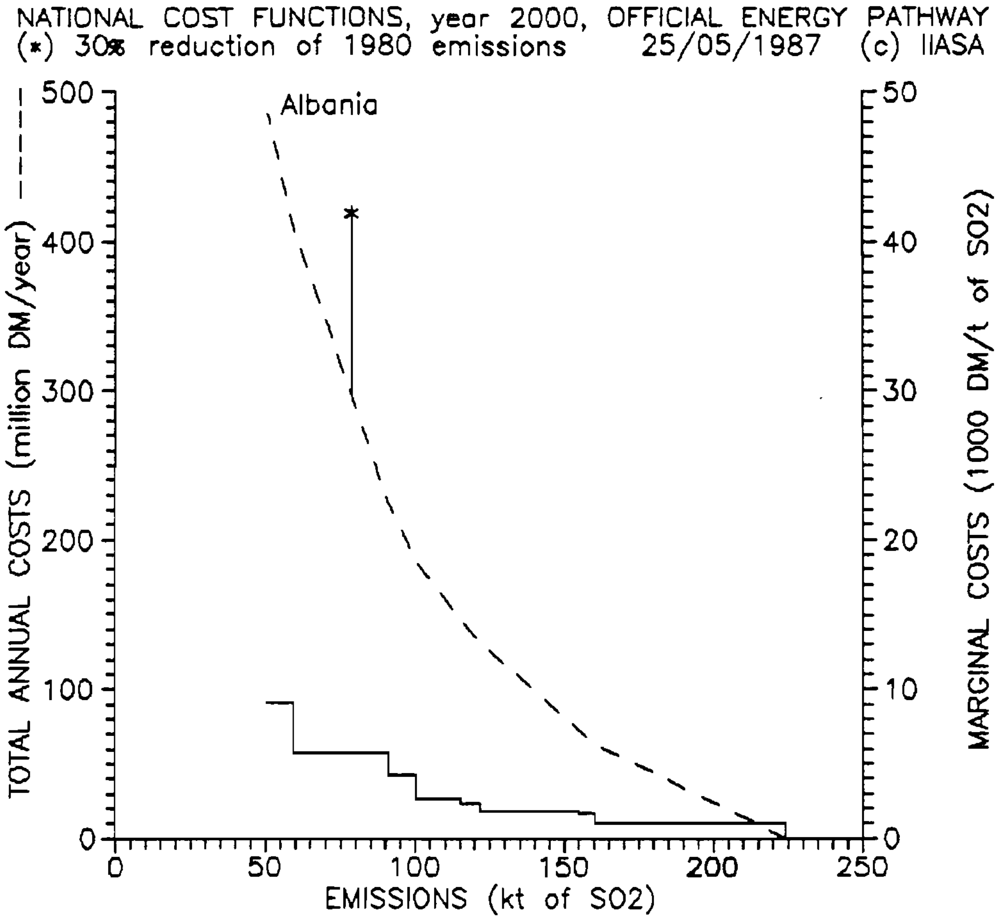
General Parameters valid for all Technologies

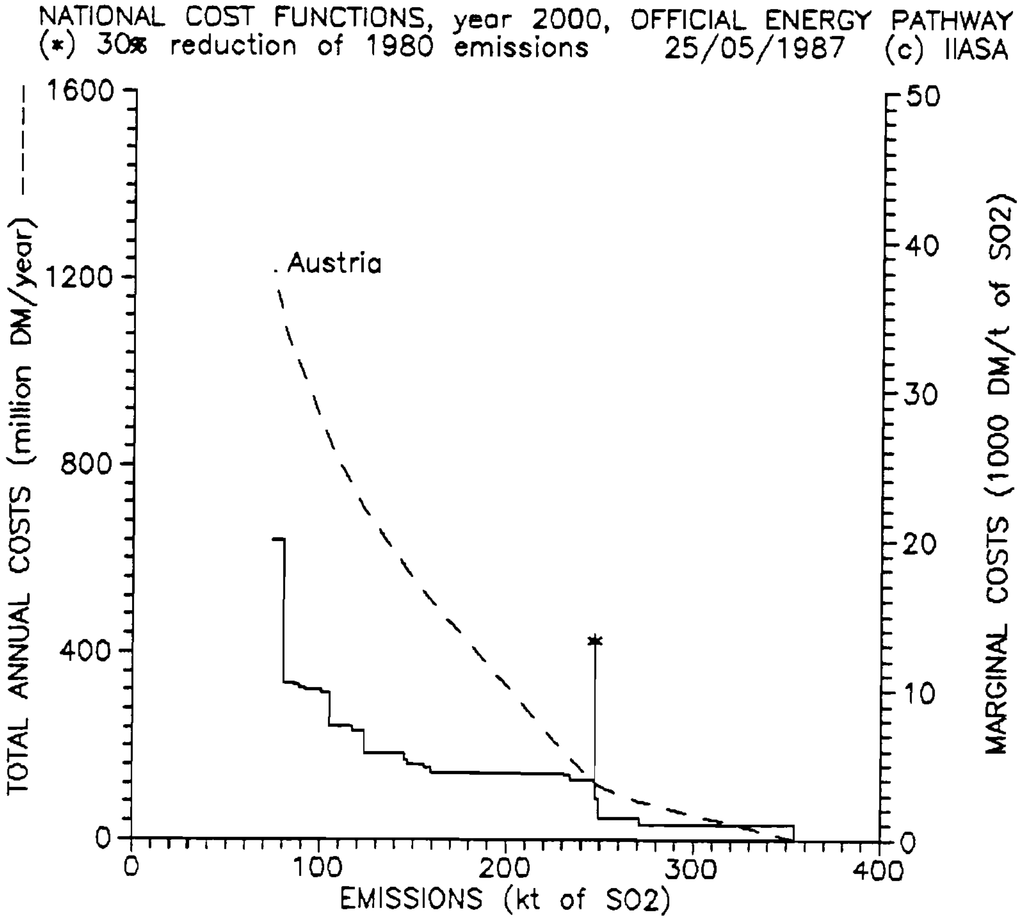
Table 8: General Parameter valid for all Technologies			
Lifetime of Pollution Control Equipment *lt* (in years)		Flue Gas Volume relative to Hard Coal Combustion *v*	
Conversion	20	Brown Coal	1.2
Powerplants	30	Hard Coal	1.0
Industry	20	Heavy Fuel Oil	0.9

Table 9: Process Emissions Control Costs:		
Reduction from 0 % to 30 % :	5000	DM/t SO2
Reduction from 30 % to 60 % :	10000	DM/t SO2
Reduction from 60 % to 80 % :	20000	DM/t SO2

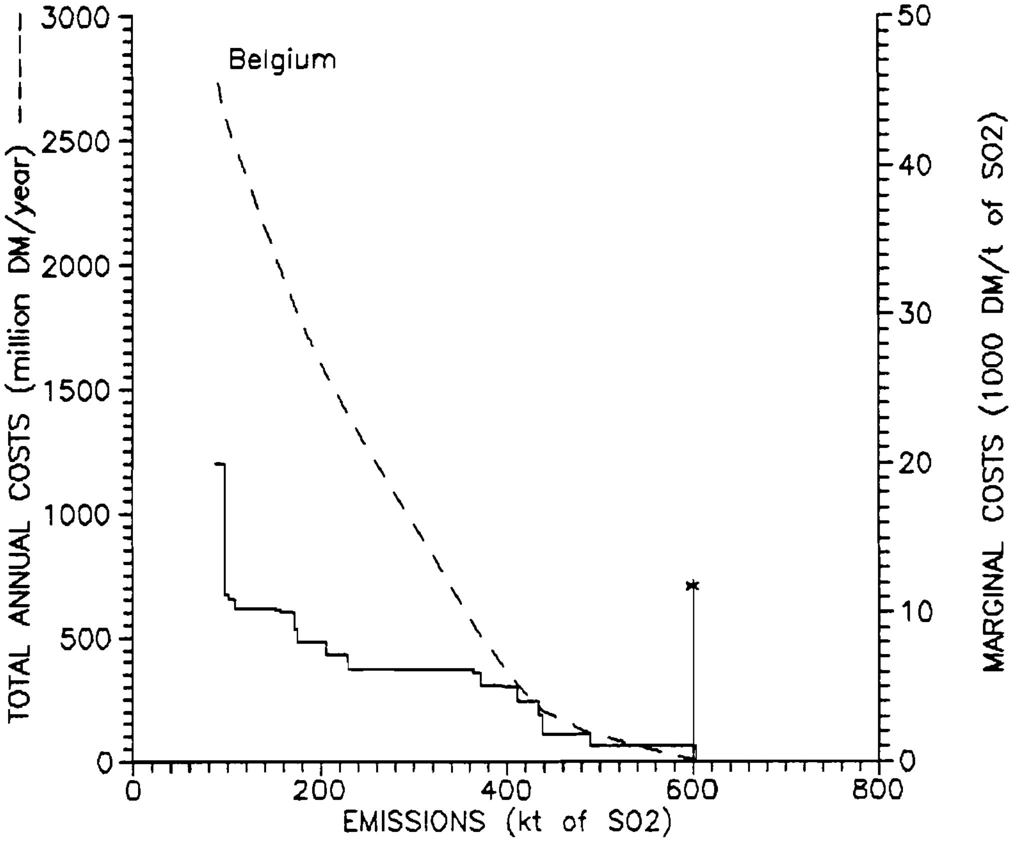
APPENDIX C:

The following cost curves are based on the official energy pathways, as they were reported from the individual governments to IEA and ECE and relate to the year 2000 (IEA Coal information, 1986; ECE Energy database, 1986). As they should reflect the original energy scenarios, for the purpose of this paper no fuel substitution is included, although the cost submodel is able to handle also this option (as described above). The curves show the least costs to reduce emissions for increasing reduction levels. Displayed are the curves of total annual and marginal costs, versus the remaining emissions for the year 2000.

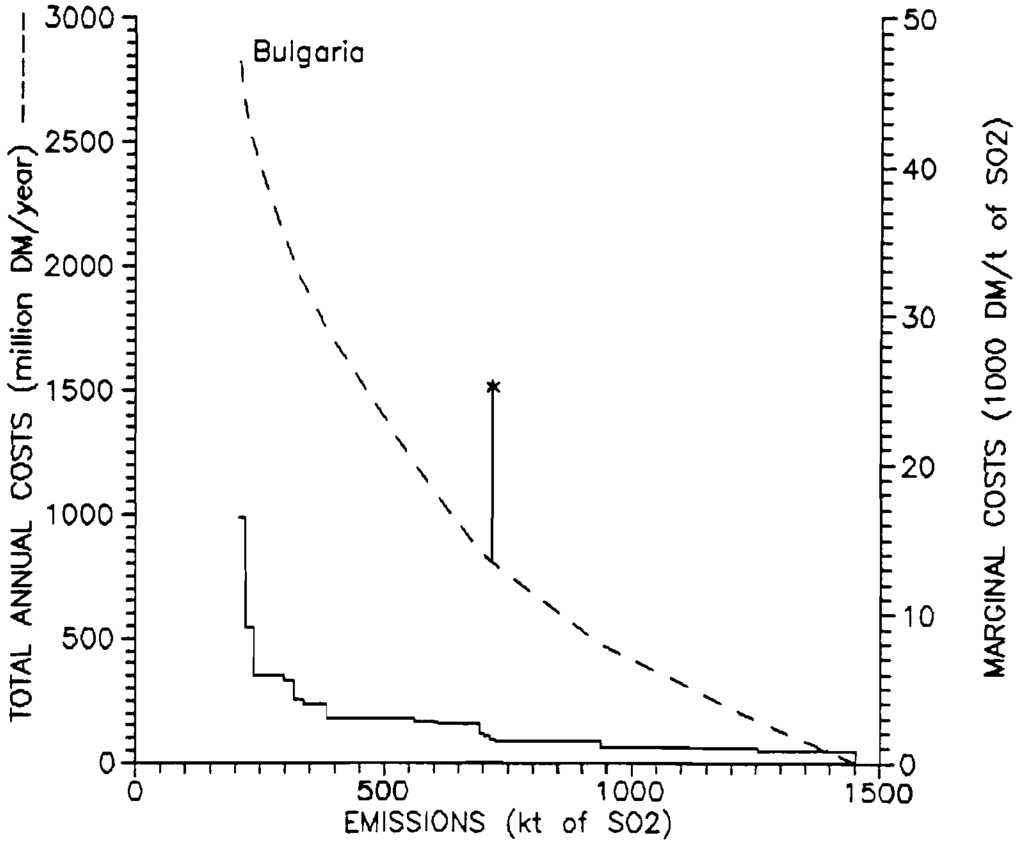

NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
Albania
TOTAL ANNUAL COSTS (million DM/year) - - -
0
100
200
300
400
500
MARGINAL COSTS (1000 DM/t of SO2)
0
10
20
30
40
50
EMISSIONS (kt of SO2)
0
50
100
150
200
250

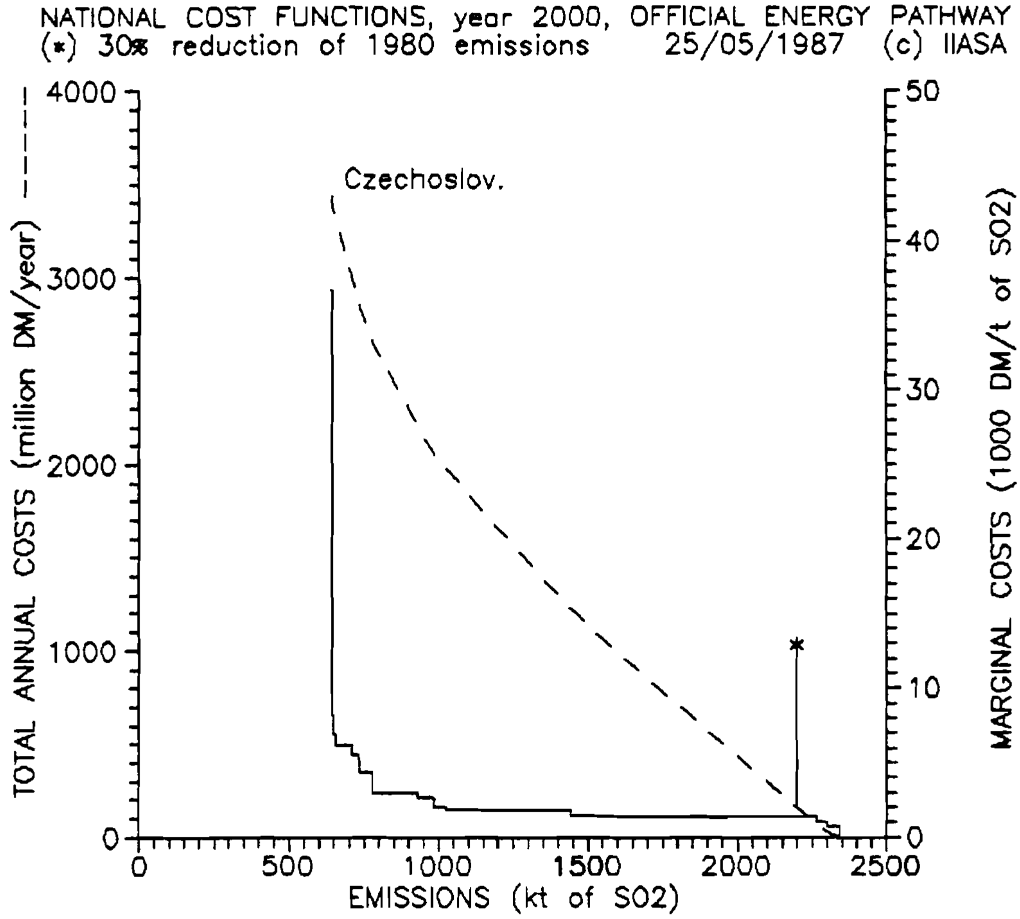

NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
Austria
TOTAL ANNUAL COSTS (million DM/year) - - -
0
400
800
1200
1600
MARGINAL COSTS (1000 DM/t of SO2)
0
10
20
30
40
50
EMISSIONS (kt of SO2)
0
100
200
300
400

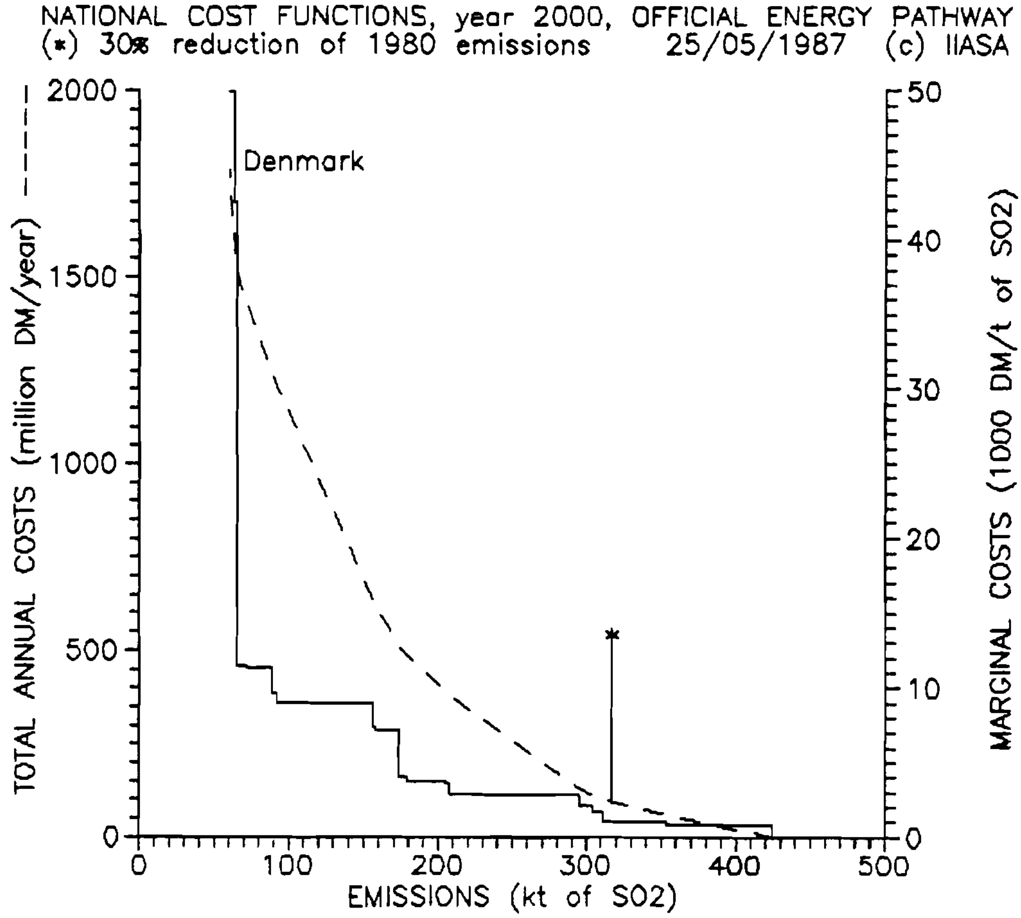
NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

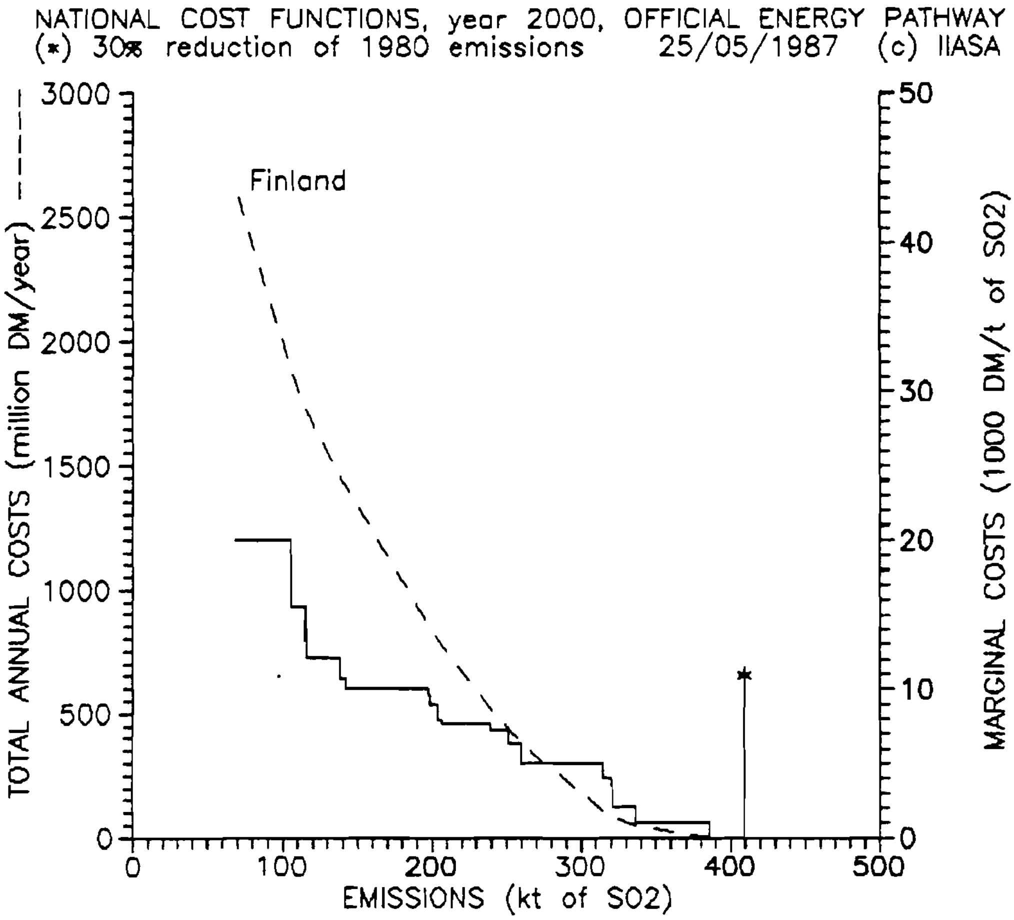


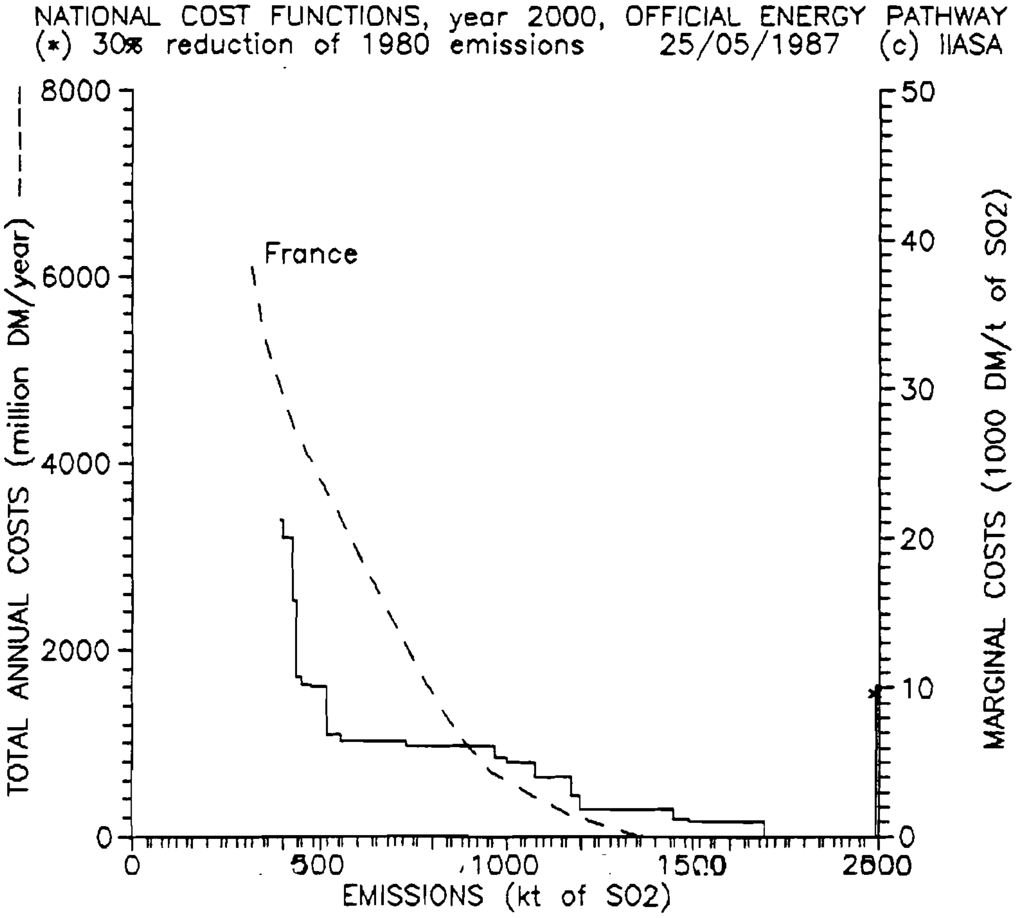
NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

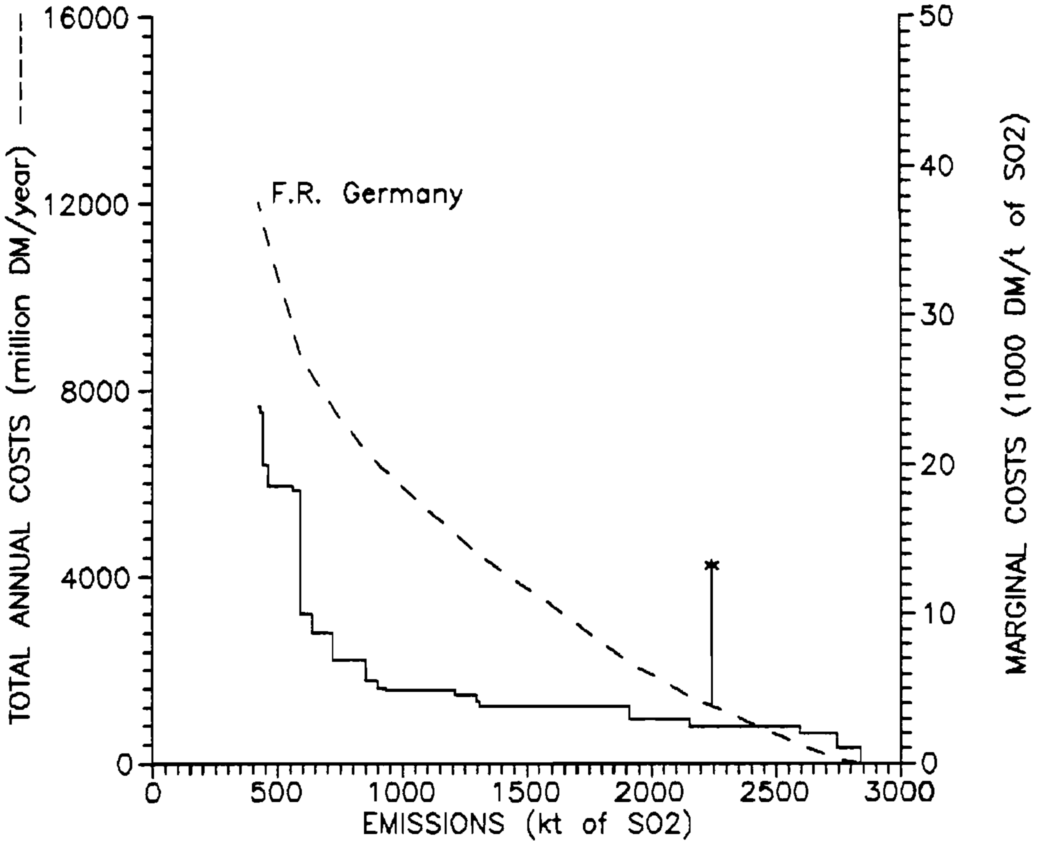



NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
TOTAL ANNUAL COSTS (million DM/year) - - - -
MARGINAL COSTS (1000 DM/t of SO2)
Czechoslov.
*
0
1000
2000
3000
4000
0
10
20
30
40
50
0
500
1000
1500
2000
2500
EMISSIONS (kt of SO2)

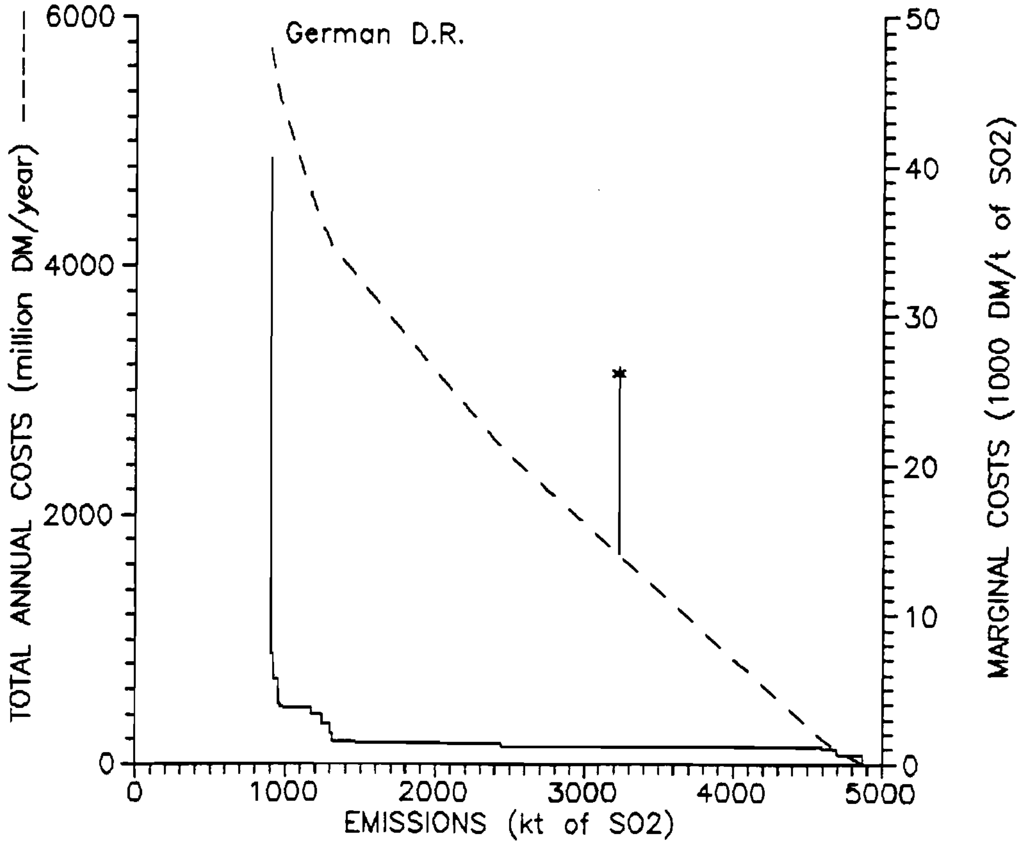

NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
TOTAL ANNUAL COSTS (million DM/year) - - - -
MARGINAL COSTS (1000 DM/t of SO2)
Denmark
*
0
500
1000
1500
2000
0
10
20
30
40
50
0
100
200
300
400
500
EMISSIONS (kt of SO2)


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
TOTAL ANNUAL COSTS (million DM/year) - - -
3000
2500
2000
1500
1000
500
0
MARGINAL COSTS (1000 DM/t of SO2)
50
40
30
20
10
0
Finland
0
100
200
300
400
500
EMISSIONS (kt of SO2)


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
TOTAL ANNUAL COSTS (million DM/year) - - -
8000
6000
4000
2000
0
MARGINAL COSTS (1000 DM/t of SO2)
50
40
30
20
10
0
France
0
500
1000
1500
2000
EMISSIONS (kt of SO2)

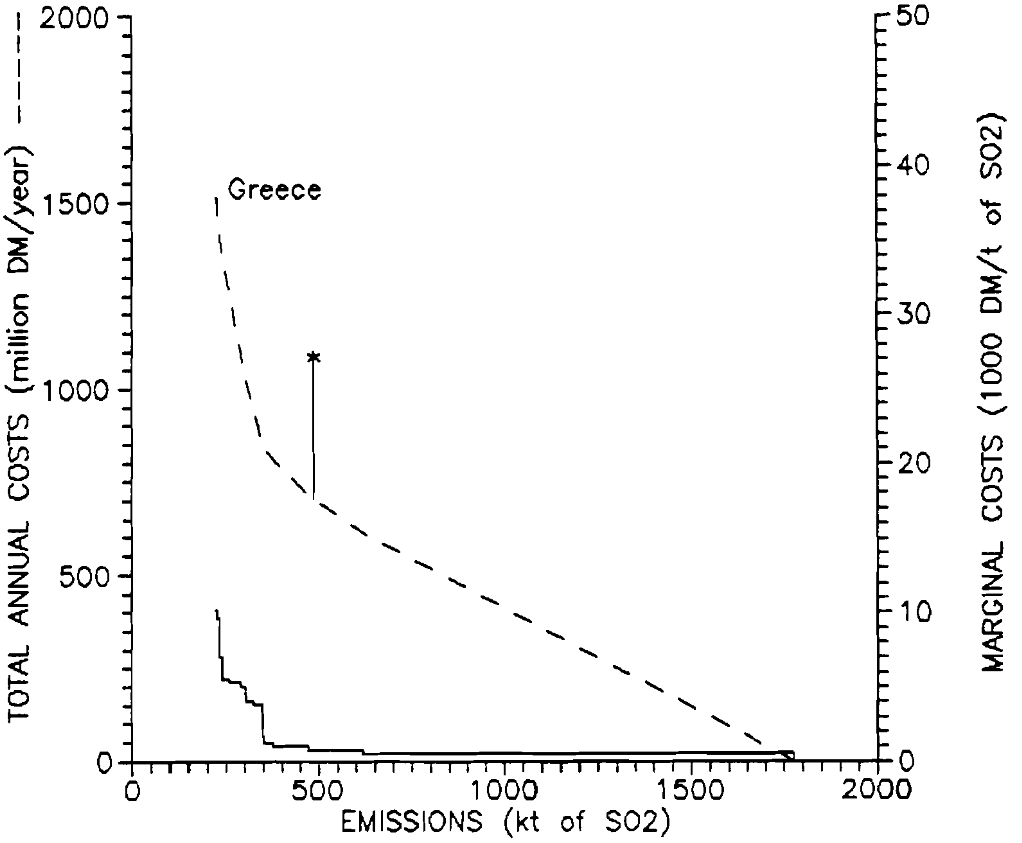


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

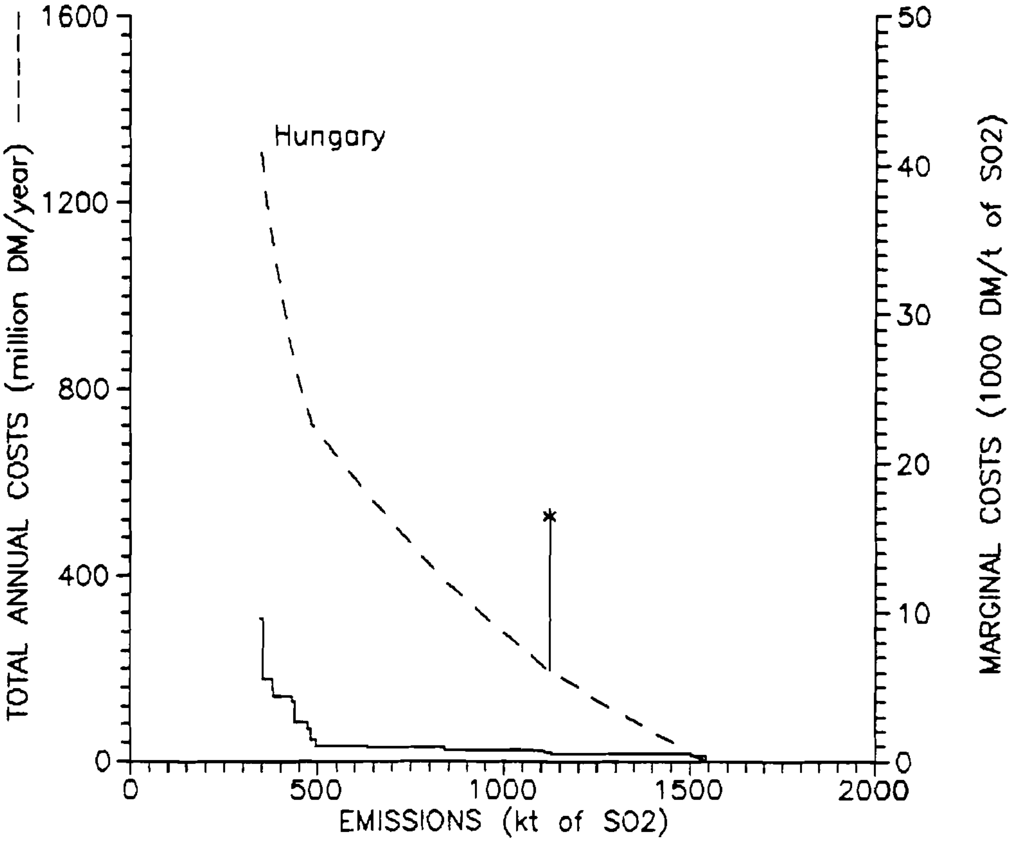


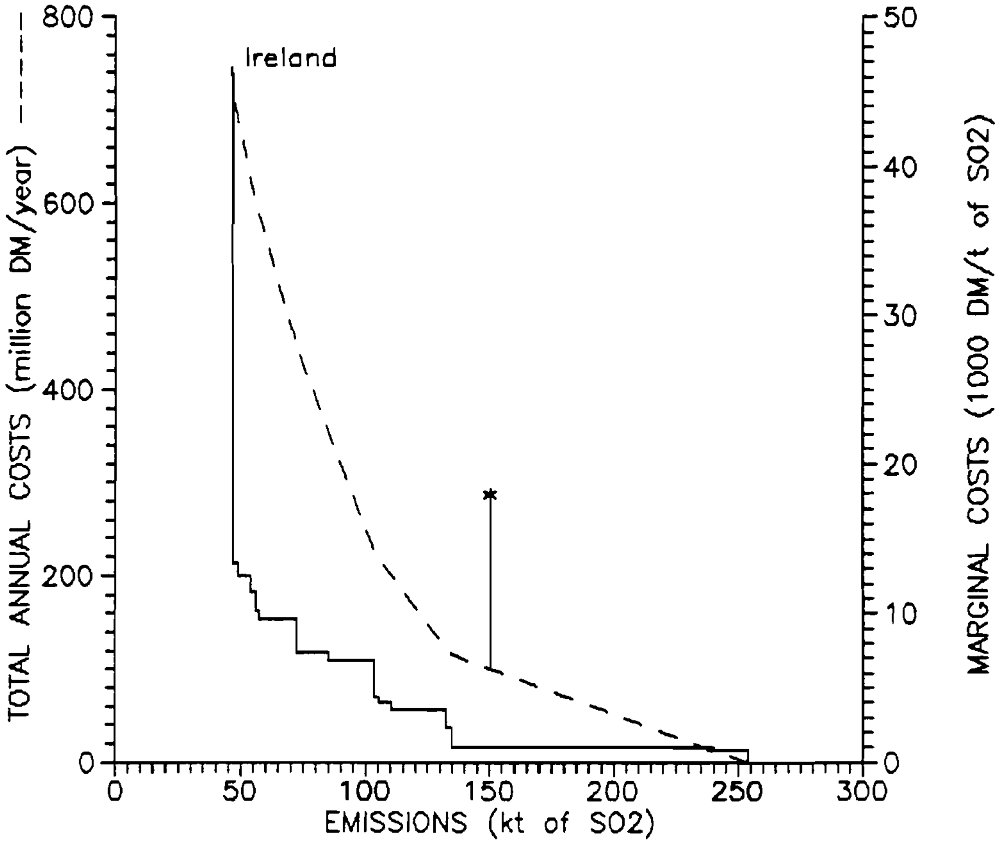
NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

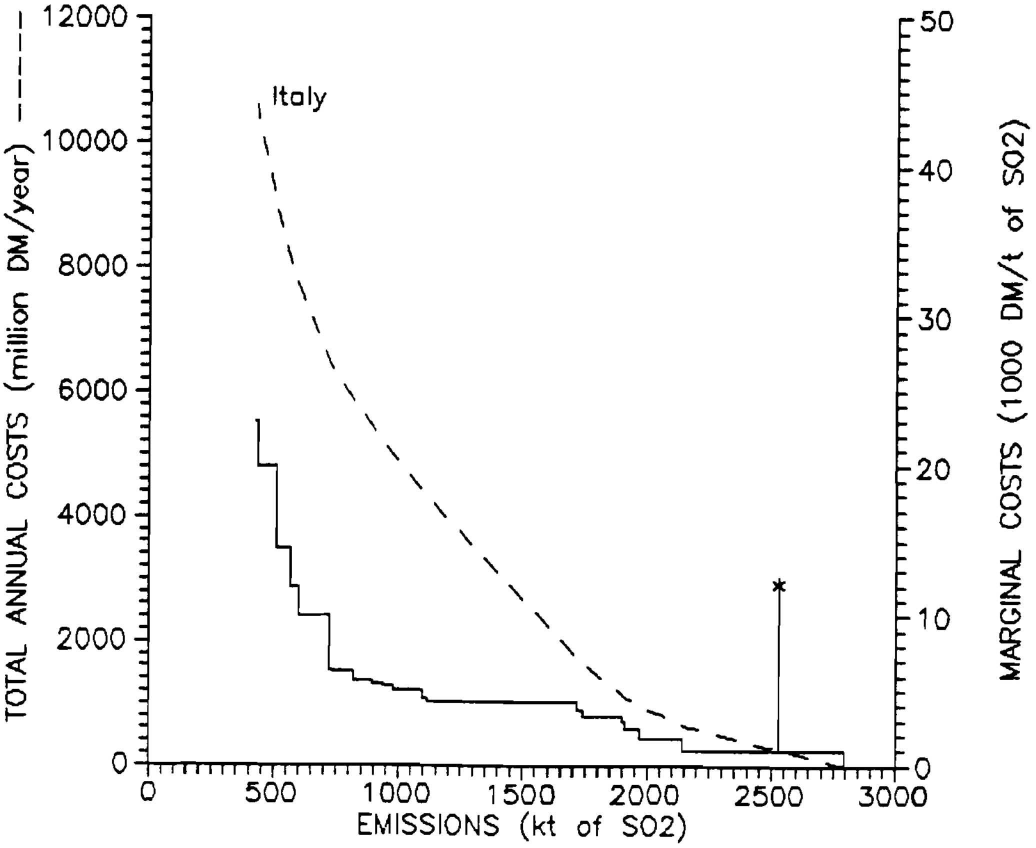


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA



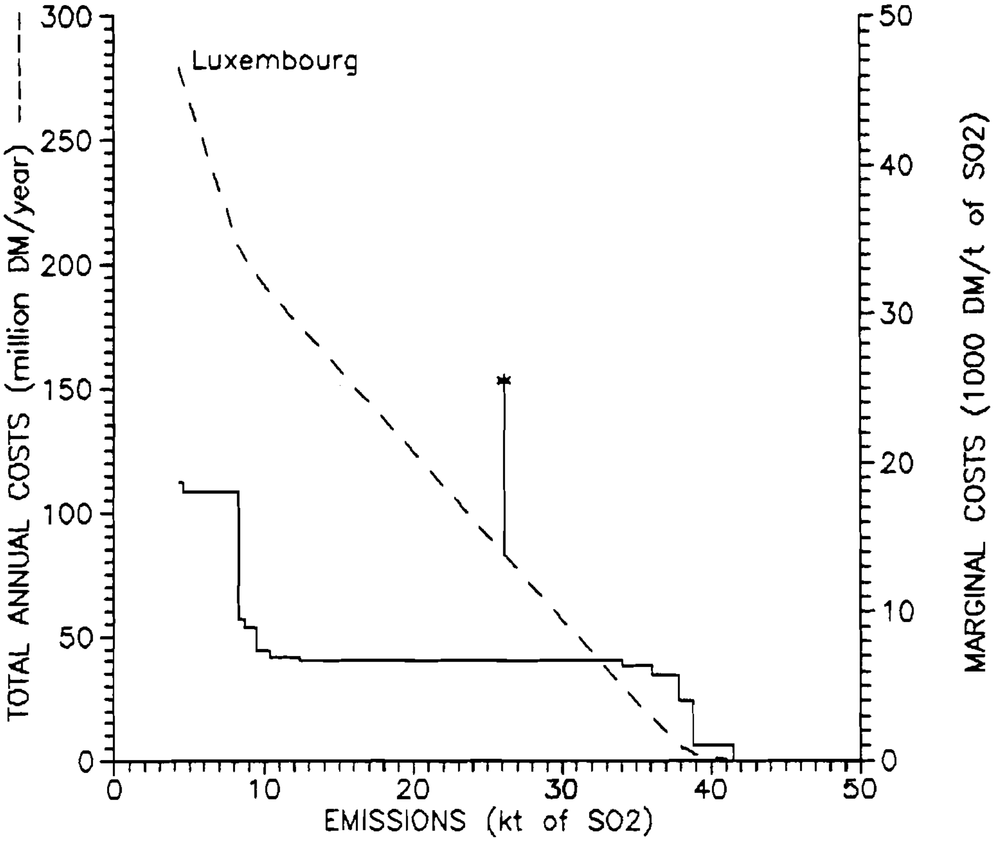


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

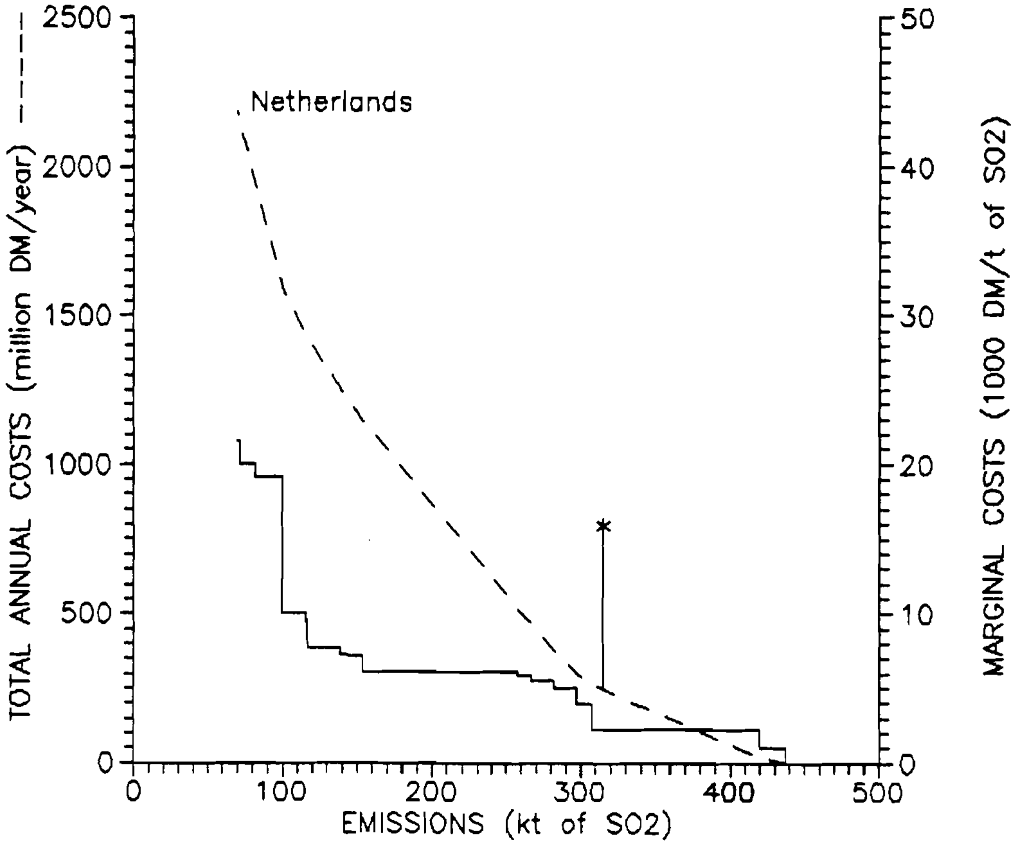


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

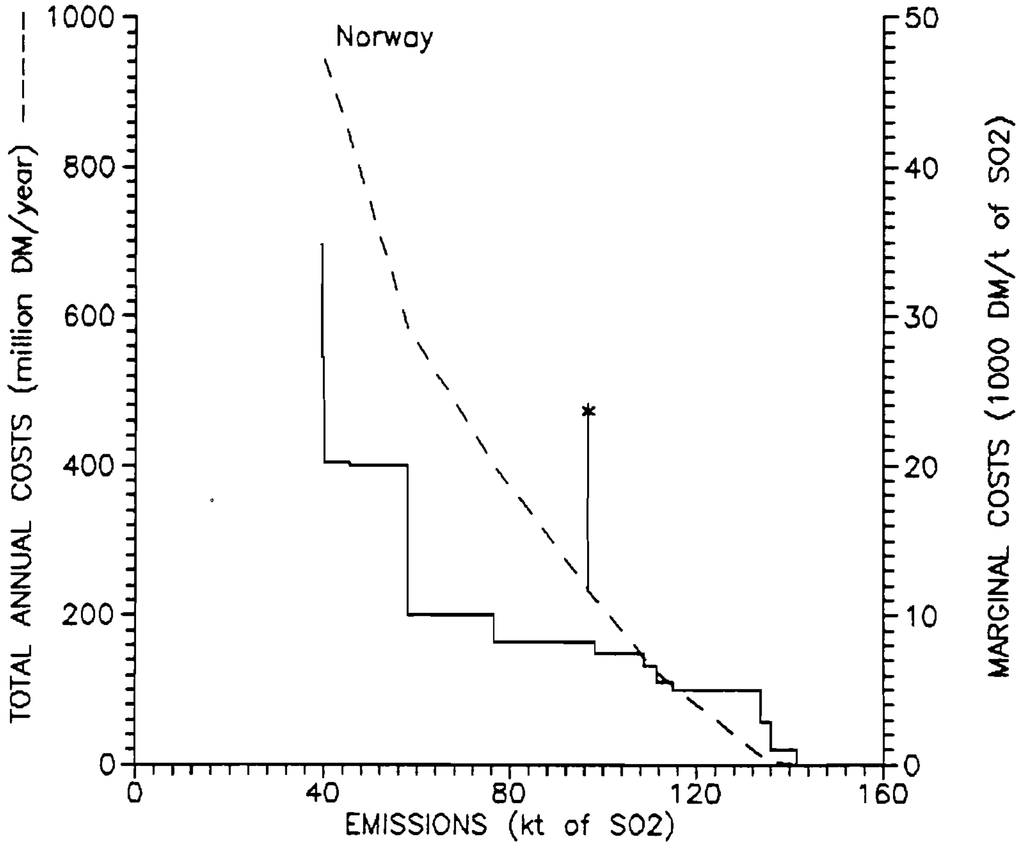
NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA



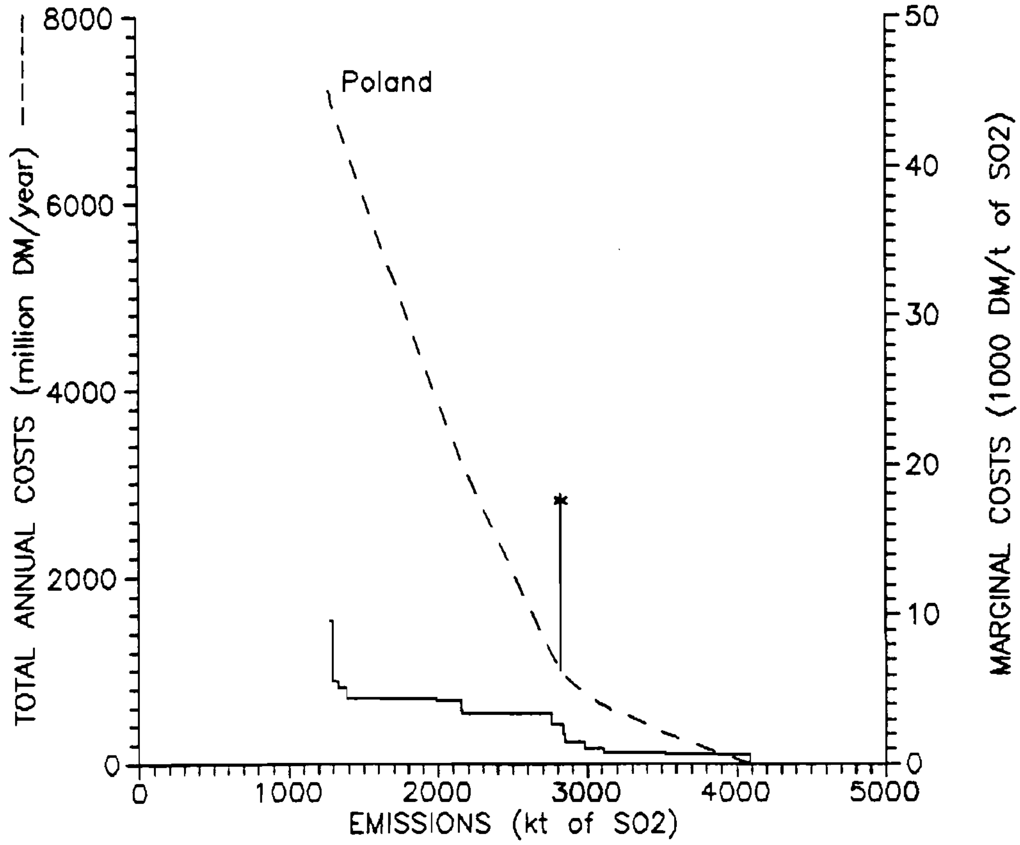
NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

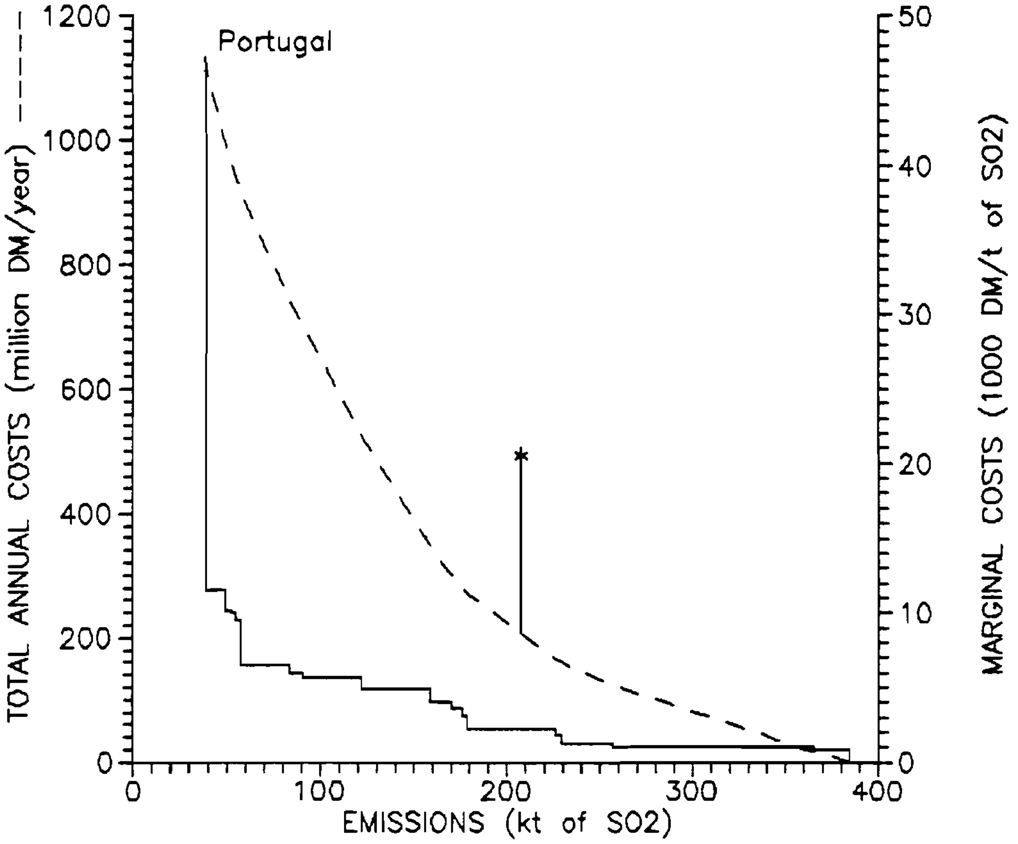


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

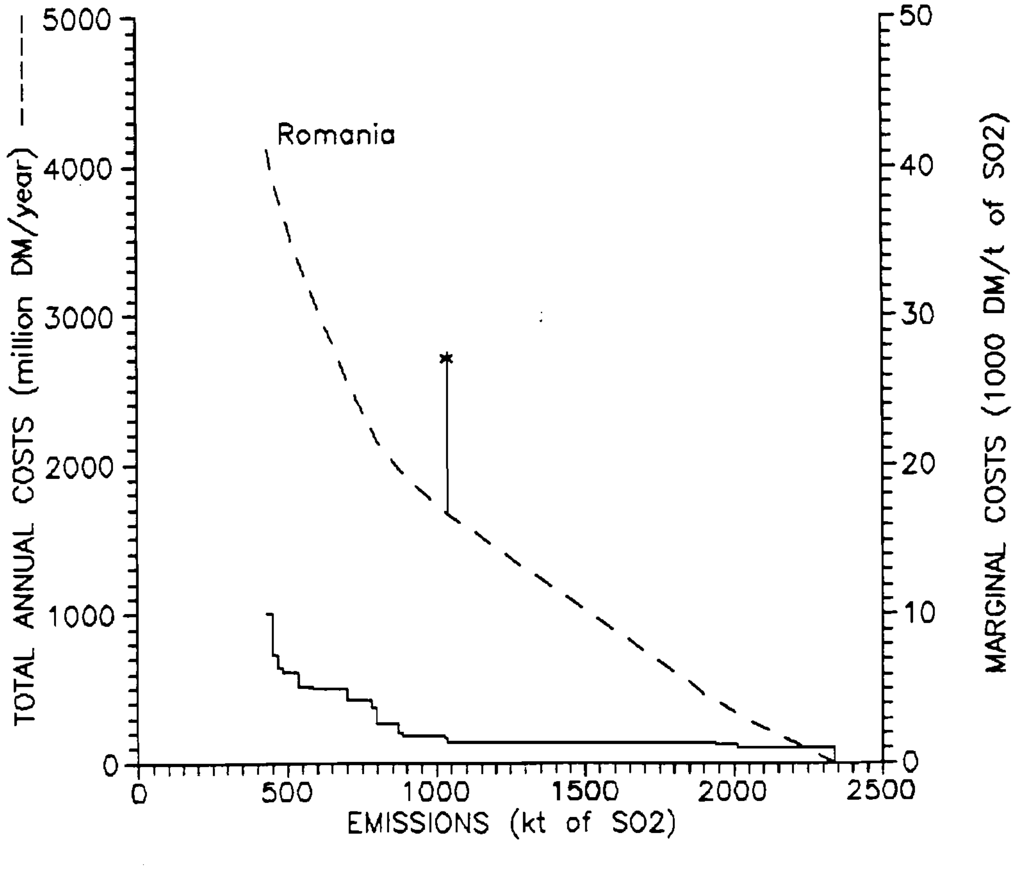


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA

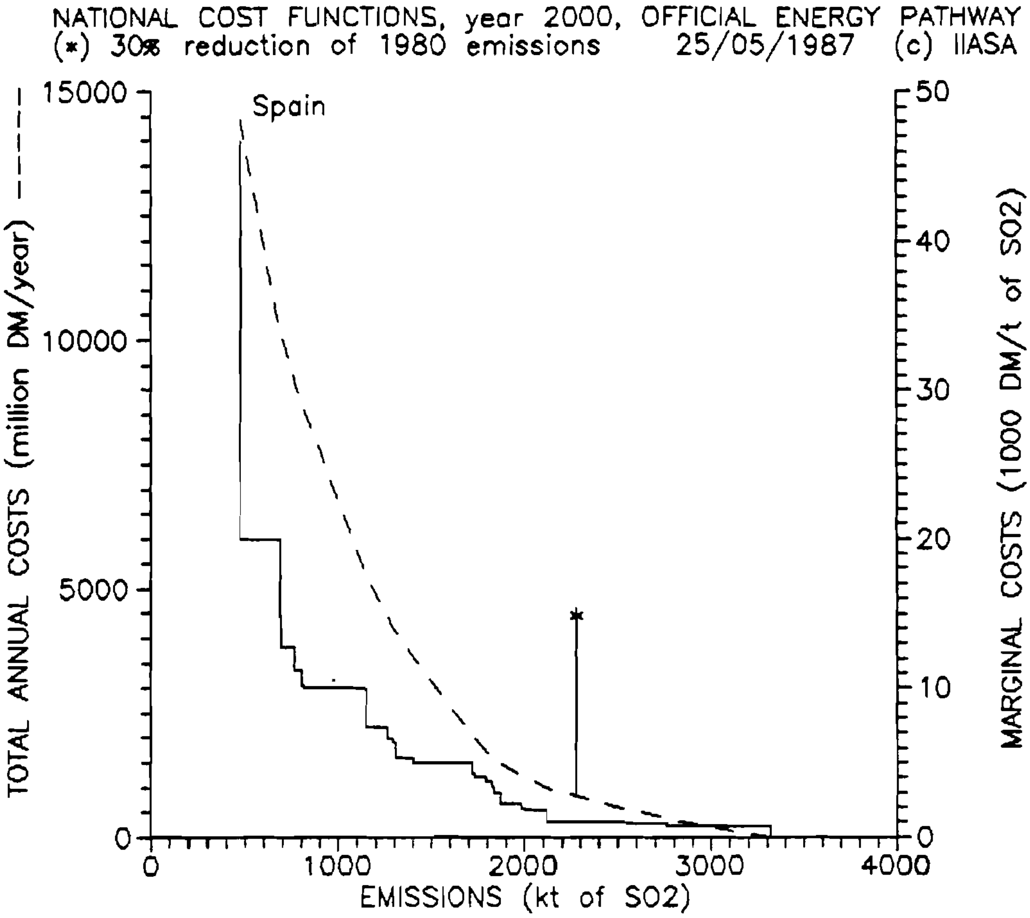


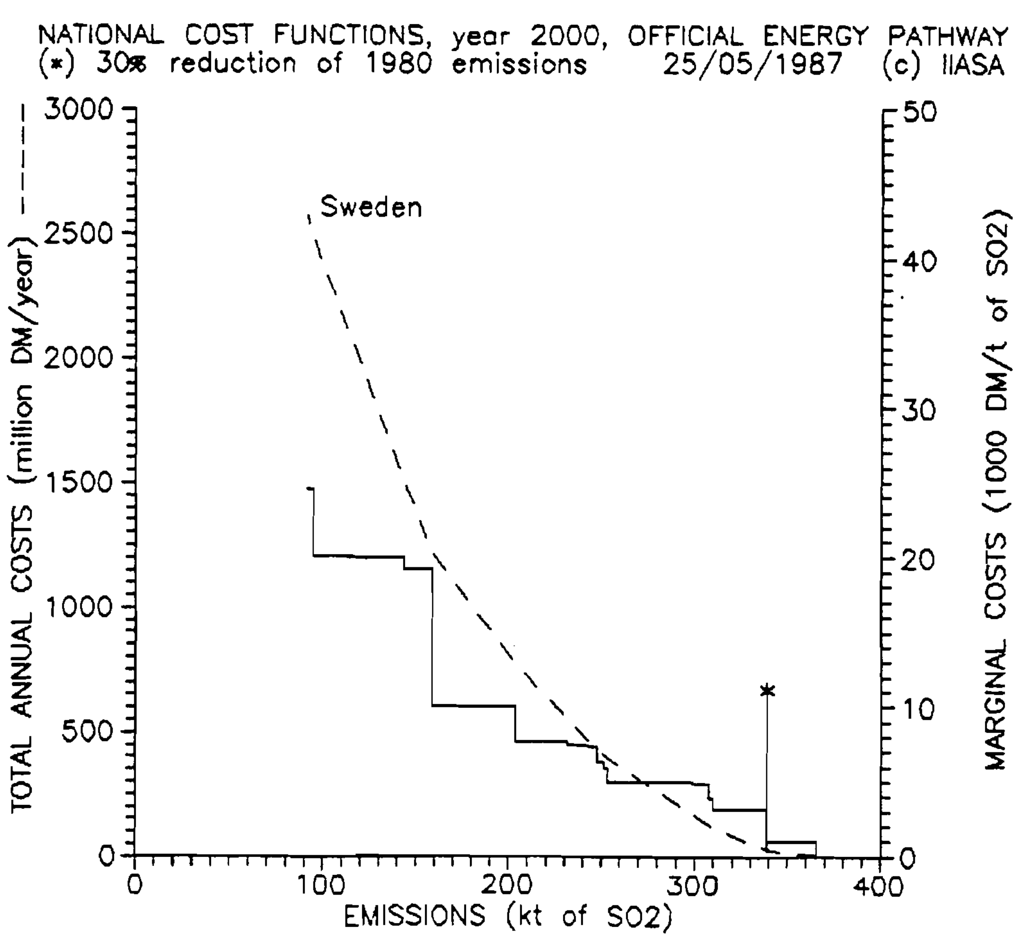


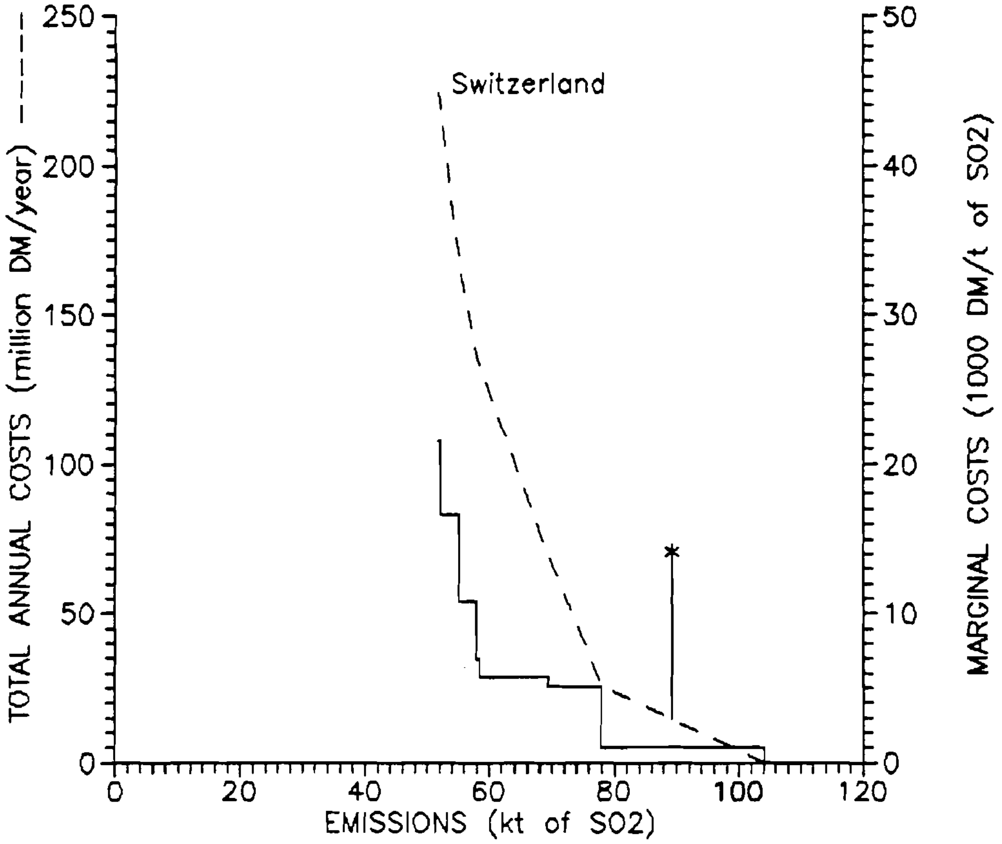
NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA



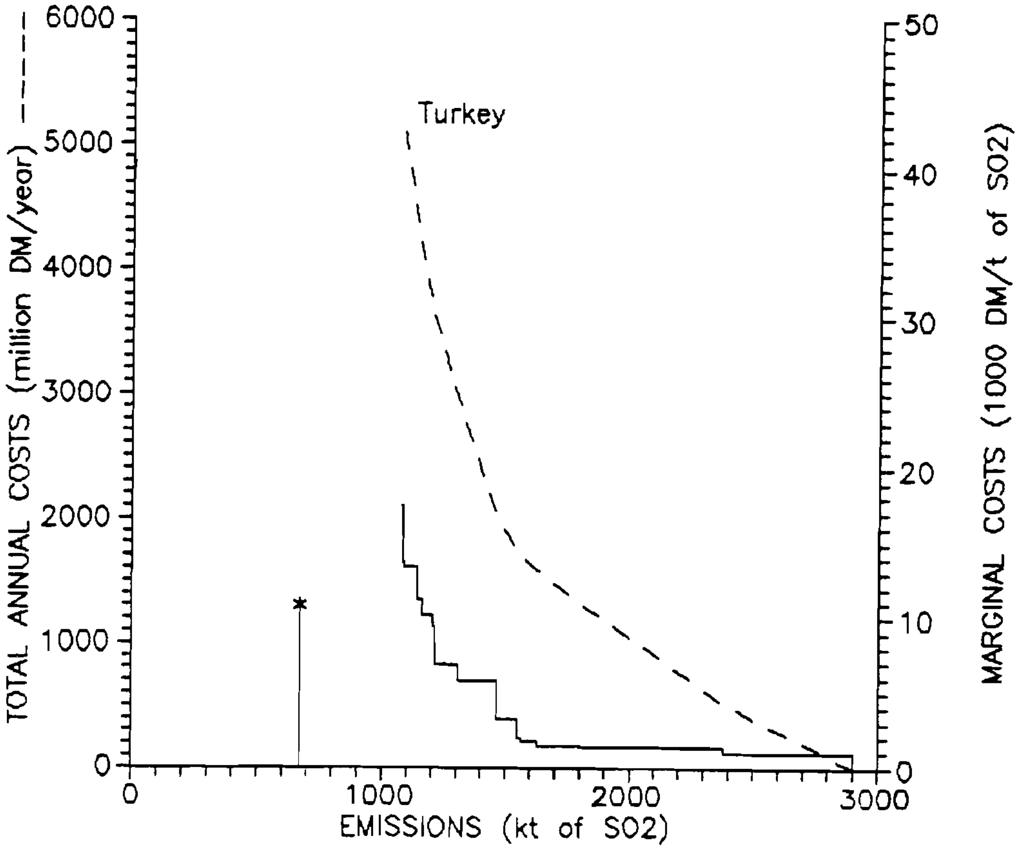
NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
Spain
TOTAL ANNUAL COSTS (million DM/year) - - - -
15000
10000
5000
0
MARGINAL COSTS (1000 DM/t of SO2)
50
40
30
20
10
0
0
1000
2000
3000
4000
EMISSIONS (kt of SO2)
*

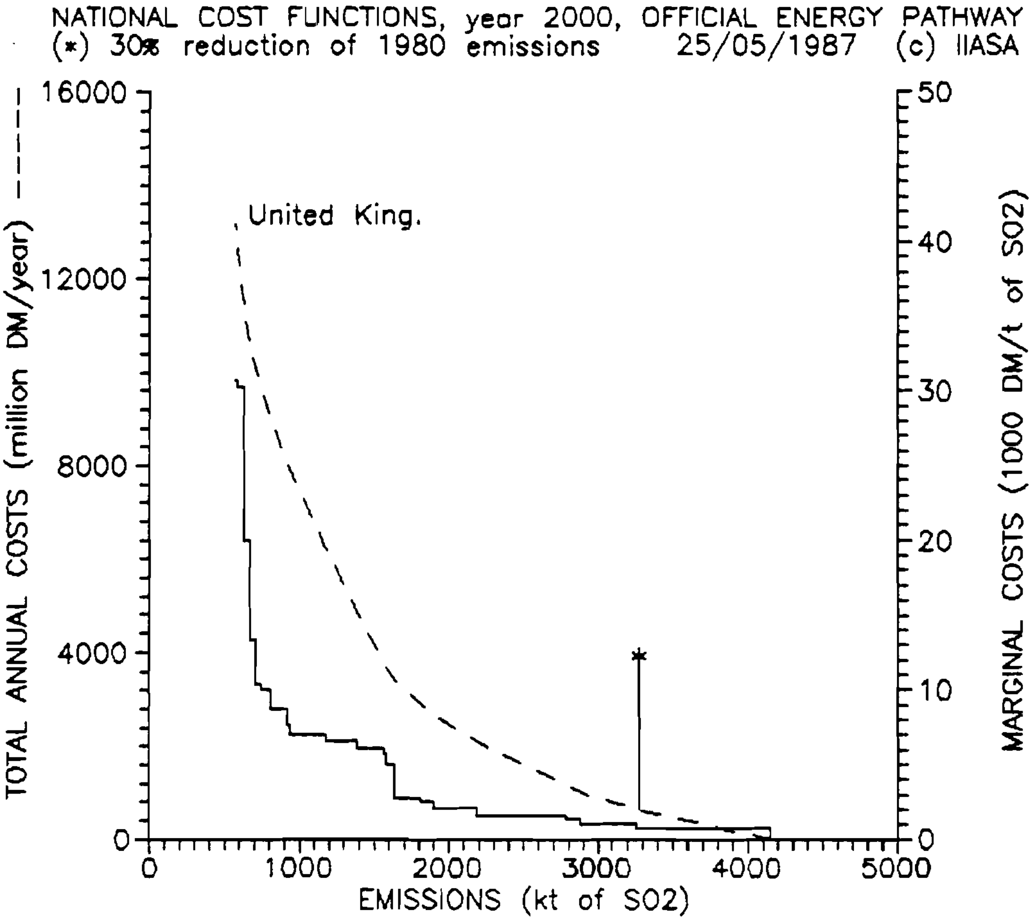

NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
Sweden
TOTAL ANNUAL COSTS (million DM/year) - - - -
3000
2500
2000
1500
1000
500
0
MARGINAL COSTS (1000 DM/t of SO2)
50
40
30
20
10
0
0
100
200
300
400
EMISSIONS (kt of SO2)
*

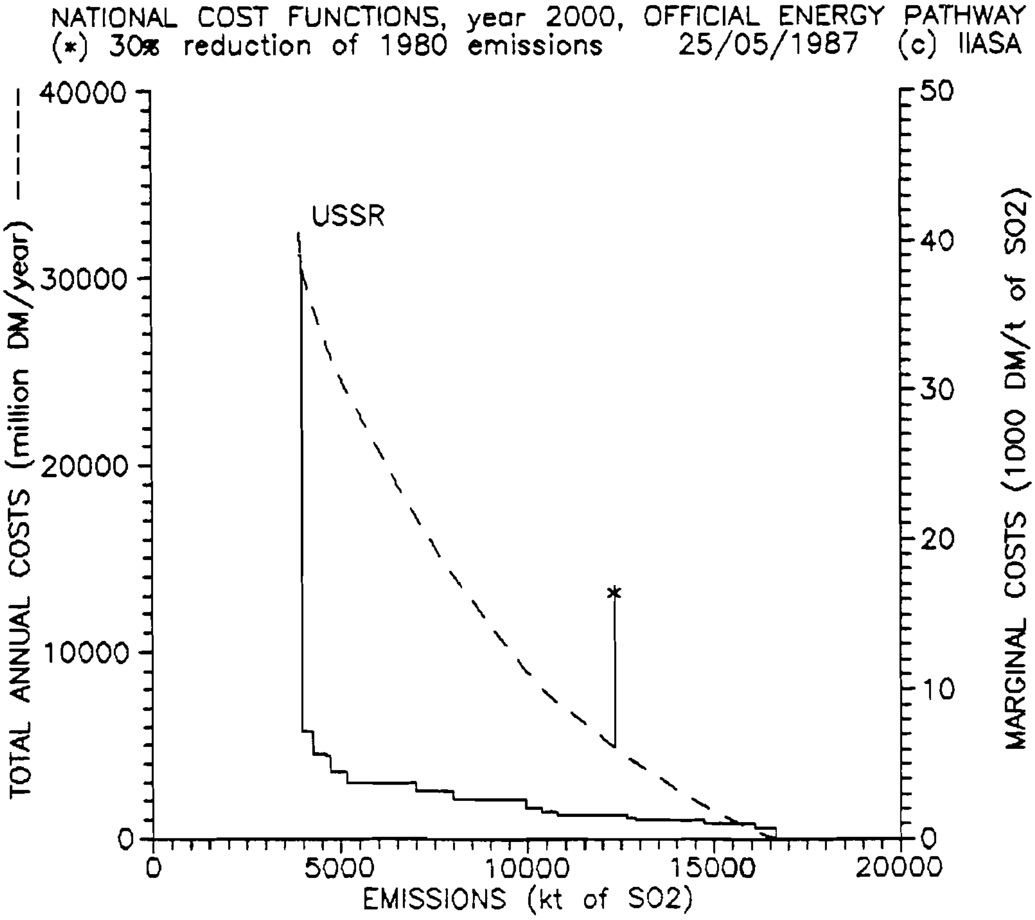


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA



NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
United King.
TOTAL ANNUAL COSTS (million DM/year) - - - -
0
4000
8000
12000
16000
MARGINAL COSTS (1000 DM/t of SO2)
0
10
20
30
40
50
EMISSIONS (kt of SO2)
0
1000
2000
3000
4000
5000
*


NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA
USSR
TOTAL ANNUAL COSTS (million DM/year) - - - -
0
10000
20000
30000
40000
MARGINAL COSTS (1000 DM/t of SO2)
0
10
20
30
40
50
EMISSIONS (kt of SO2)
0
5000
10000
15000
20000
*

NATIONAL COST FUNCTIONS, year 2000, OFFICIAL ENERGY PATHWAY
(*) 30% reduction of 1980 emissions 25/05/1987 (c) IIASA