WORKING PAPER

A SCHEME FOR SHARING THE COSTS OF REDUCING SULFUR EMISSIONS IN EUROPE

Lars Bergman
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January 1990
WP-90-005

IIASA
International Institute
for Applied Systems Analysis

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Preface

The Regional Acidification INformation and Simulation (RAINS) model developed by the Transboundary Air Pollution Project is being used to develop cost-effective emission reduction strategies to reduce acidic deposition in Europe. The model is proving to be especially useful in the work of the United Nations Economic Commission for Europe in developing new emission reduction protocols under its Convention on Long-Range Transboundary Air Pollution. Cost-effective emission reduction strategies usually involve non-uniform emission reductions among countries, and non-uniform expenditures. This Working Paper proposes a scheme for sharing the costs of emission reductions among countries to improve the general state of the European environment.

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Acknowledgements

We wish to thank Markus Amann and Rod Shaw of the Transboundary Air Pollution Project at IIASA for providing valuable advice and comments. The financial support from the Foundation IIASA Netherlands as well as the University Simulating Fund (USF) and the Institute for Environmental Studies of the Amsterdam Free University are gratefully acknowledged.

Abstract

A particular scheme for sharing the costs of controlling sulfur emissions in Europe which is beneficial for all countries and ensures cost-efficiency is examined. The contribution of each country to the scheme depends on its gain from cooperation. An example indicates that these gains can be considerable for each country. However, in reporting cost functions, in specifying deposition targets, or both, it is possible to deceive. Some countries might even gain more from cooperation by leaving specific countries outside the cooperation. Even with deceiving it might still be beneficial for countries to cooperate. Moreover, both cost functions and deposition targets could be checked.

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Lars Bergman, Herman Cesar and Ger Klaassen

1. Introduction

It is becoming a common knowledge that a cooperative European programme to reduce sulfur emissions might lead to considerable cost advantages over isolated, national strategies. Shaw (1989) for example shows that the funds required for a 50% uniform reduction in emissions could be applied in a more efficient way to reduce sulfur deposition to 3–4 g/m^2 instead of 5–8 g/m^2. Such a cost-effective, targeted abatement strategy, however, implies an uneven distribution of pollution control efforts and associated costs since the most cost-effective measures will be concentrated in a limited number of countries. Consequently, countries which have to carry the cost burden are likely to oppose to the abatement strategy. To implement cost-effective strategies inter-country transfers of funds within Europe are therefore probably indispensable. A scheme for these transfers has to be designed such that it is beneficial for all countries to participate.

Countries such as Sweden and the Netherlands are presently discussing the possibilities of paying countries to reduce their emissions instead of taking more stringent, and hence more expensive, abatement measures domestically. The Electricity Producers in the Netherlands, in their latest annual report (SEP, 1989), suggested making investments in abatement measures in other countries, especially in Poland. Comparable proposals were discussed in the Swedish Parliament. Several principles can be applied to share the costs of reducing sulfur emissions in Europe (Klaassen and Jansen, 1989). It is difficult however to find a scheme that provides sufficient incentives for each country to participate (Māler, 1989).

This paper focuses on a particular scheme for sharing the costs of reducing sulfur emissions in Europe: a scheme which is beneficial for all countries. In addition, the incentives for countries to deceive, as well as the possibilities to counteract deceiving are examined.

The remainder of this paper is as follows. Section 2 introduces the scheme. Section 3 gives an overview of the model used to calculate the minimum costs to reach deposition targets. Illustrative results of the cost-sharing scheme are included in section 4. Section 5 examines the possibilities for countries to deceive when cooperating and the possibilities of a fund to counterbalance this. Conclusions are the subject of section 6.

2. The Scheme

A. Mode of operation

The scheme for international cost-sharing outlined in the following aims at establishing a mode of operation of a supranational institution, a "European Environmental Protection Fund", and at the exchange of information between individual countries and the "Fund". The purpose of the scheme is to give each individual country in Europe the incentives to support a joint program for sulfur emission reduction and to ensure that the joint program is designed to attain cost-efficiency. Cost-efficiency implies that target deposition levels are attained at minimum costs with respect to the allocation of abatement measures across countries.

It is assumed that each country has adopted a plan for emission control and that these plans are common knowledge for all relevant countries. Thus, unless additional commitments are made, each country expects the emission vector

$$\bar{E} = (\bar{E}_1, \bar{E}_2, \ldots\ldots \bar{E}_n) \tag{1}$$

for the n countries in the relevant group of countries. (Appendix A contains the full list of symbols used.) However, it is also assumed that the deposition levels resulting from $\bar{E}$ are regarded as unacceptable or at least not low enough by all n countries. Thus there is a serious interest in additional emission control. With this background the scheme can be described in a series of steps:

1. Each country estimates a cost function

$$C_i = C_i\,(E_i);\; dC_i/dE_i < 0 \tag{2}$$

for emission reduction in the home country. C_i is the total cost and E_i is the total emission in country i. There are no particular quality requirements with respect to the estimated cost functions, but once the country has submitted it to the Fund it has to accept the policy recommendations that the Fund might make on the basis of, among other things, the submitted cost function.

2. On the basis of the submitted cost functions and committed emissions reductions for all countries the Fund calculates deposition control functions

$$\hat{C}_i = \hat{C}_i\,(Q_i, \bar{E}, a, b){:}\frac{d\hat{C}_i}{d\hat{Q}_i} < 0 \tag{3}$$

for each country. Q is the deposition in country i, b is a vector of cost functions parameters while a is the vector of parameters of the atmospheric transportation matrix, for instance, the so-called European Monitoring and Evaluation Programme (EMEP) matrix. In principle C_i^* is finite for $Q_i = 0$, but low Q_i values are likely to imply emission reductions implemented outside country i but paid by country i. It should be emphasized that $\hat{C}_i$ includes the cost of control measures in other countries, paid by country i, in order to reduce depositions in country i. The cost function $\hat{C}_i$ is interesting as it indicates the cost for country i in attaining additional deposition reductions by independent action.

3. The Fund reports the cost function (3) to country i. On the basis of that function, and its willingness to pay for deposition reduction, country i determines a target deposition level Q_i^*. That level may or may not be equal to the estimated "critical load" for country i and it may or may not be the result of an analysis of marginal damage costs and the marginal costs of deposition reduction implied by (3). The cost to country i for the target deposition reduction is

$$\bar{C}_i = \hat{C}_i\ (Q_i^*;\bar{E},\ a,\ b)$$

4. On the basis of this information the Fund identifies a vector e = (e1, e2,.....en) of cost efficient, additional emission reductions by solving the problem

$$C^* = \min_{e_i} \sum_i \{C_i\ (\bar{E}_i - e_i) - C_i\ (\bar{E}_i)\} \tag{4}$$

subject to:

$$\sum_j a_{ij}\ (\bar{E}_i - e_i) = Q_i^*;\ \text{for } every\ i$$

where a_{ij} are the coefficients of the EMEP matrix and the summation over i includes all countries willing to collaborate in a joint emission control effort. The equality constraint reflects the need to avoid free riding.

5. The Fund requires all countries in the group of collaborating countries to reduce (or perhaps increase) their emissions by e_i^*. Moreover, in order to finance this additional emissions control the fund reimburses country i by

$$C_i\ (\bar{E}_i - e_i^*) - C_i(\bar{E}_i)$$

That is for the extra cost estimated on the basis of the cost function submitted by country i itself.

6. Finally, each country contributes to the Fund by paying $\alpha. \ \bar{C}_i$ where

$$\alpha = C^* / \sum_i \bar{C}_i \leq 1 \tag{5}$$

Clearly $\sum_i \alpha \ \bar{C}_i = C^*$, that is, the Fund is breaking even, i and $\alpha \ \bar{C}_i \leq \bar{C}$. That is, each country benefits from the scheme. Thus, given that country i is actually willing to pay $\bar{C}_i$ in order to attain its deposition target, the benefit of being a member of the Fund is equal to $(1 - \alpha) \ \bar{C}_i$. In section 4 estimates of "benefits" defined in this way are presented. It should be added that, in the light of the reduced costs of attaining the initially stated deposition target, country i may want to revise its deposition target. In that case the procedure is repeated.

B. Some observations

A few observations can immediately be made. First, membership to the Fund is implicitly assumed to be voluntary; any country that wishes to become a member is accepted. In practice the gain to the individual country depends on which countries participate. Thus from the point of view of the individual country there is an "optimal" group of members of the Fund. We have not analyzed this issue in depth, but a few illustrative, numerical results are included in section 5.

Secondly, in practice the equality constraints in Equation (4) may be impossible to satisfy. The reason is that there is only one control variable, the emission level, for each country but several receptor points. Thus $(\bar{E} - e)$ is an n-dimensional vector while Q is an m-dimensional vector with m > n. In other words there are more goals than means, and (4) has to be rewritten

$$C^* = \frac{\min}{e_i} \sum_i \{C_i \ (\bar{E}_i - e_i) - C_i \ (\bar{E}_i)\} \tag{4'}$$

subject to:

$$\sum_j a_{ij} \ (\bar{E}_j - e_j) \leq Q_i^*; \text{ for } every \ i$$

In addition, there should perhaps be a non-negativity constraint on e_i; countries may feel that cooperation, in order to reduce depositions, should not lead to increased emissions in any one of the cooperating countries.

With these modifications of the scheme, however, there is a possibility of free riding. By stating a higher target deposition level than a country desires and is willing to pay for, a country can attain the desired deposition level at a lower cost. The numerical results will illustrate this possibility for a few cases (section 5).

Thirdly, countries may have incentives not to report the true cost functions. To see this, consider the following benefit function for country i

$$B_i = (\bar{C}_i - \alpha K_i \bar{C}_i) + (K_i C_i^* - C_i^*); \; V_i \tag{6}$$

where B_i are the benefits in country i and C_i^* the cost of additional emission reduction in country i in the coordinated cost minimizing plan over and above the initial emission reduction plans. The parameter K_i is controlled by country i and has the following role. When country i reports its cost function to the Fund it reports the true cost function times K_i, especially in $K_i C_i$. Truthful revelation of the cost function thus implies $K_i = 1$.

With the inclusion of K_i the contribution to the Fund is $\alpha K_i C_i$, while the reimbursement from the Fund is $K_i C_i^*$. As the true cost function in the optimal program is C_i^*, country i can gain from excessive reimbursement by cheating about its cost function. On the other hand $K_i > 1$ means that the contribution to the Fund will be higher than it would be otherwise. In other words the benefits, B_i, can be seen as a function of K_i.

A necessary condition for maximization of B_i with respect to K_i is, after some manipulations and under the simplifying assumption that both C_i and α are independent of K_i,

$$\frac{dB_i}{dK_i} = C_i^* - \alpha \bar{C}_i(1 + \frac{\delta\alpha}{\delta K_i} \cdot \frac{k_i}{\alpha}) + (K_i - 1)\frac{\delta C_i^*}{\delta K_i} = 0 \tag{7}$$

With $\delta C_i^*/\delta K_i \leq 0$

It is obvious that truthful revelation of the cost function, especially in $K_i = 1$, is only a special case. However, it is also clear that the degree of cheating depends on how sensitive the optimal plan is with respect to the cost level in country i. If country i should carry out more or less the same measures at any cost level, then $\delta C_i^*/\delta K_i$ is small in absolute value, and the optimal K_i deviates significantly from unity. If, on the other hand, a small cost increase in country i would shift a significant share of abatement measures from country i to some other country, there is not much room for cheating with the cost function.

Finally, even if countries have no possibilities to cheat with the cost functions alone, there can be situations in which a combination of untrue revelation of both the cost function and deposition goals may be beneficial to these countries. The reason is that a country that is the main polluter of some neighboring countries will be paid by "The Fund" to abate its pollution, especially when the costs are low. This holds even when the revealed target deposition in this country is very low. By announcing too low abatement costs and too high deposition goals, it can avoid payments to the Fund. By contrast the country will be paid by the Fund to reduce emissions. Its only costs are then the true costs of abatement minus the announced costs of abatement. This amount may be much smaller than the costs this country would have had to contribute to the fund had it rightly announced its target deposition and cost function.

3. The Model Used – RAINS

RAINS (Regional Acidification INformation and Simulation) is an integrated model of acidification in Europe. It describes the set of relations that links the generation of pollutants through deposition with their adverse impacts on natural resources such as forests, groundwater and lakes. The emphasis is on the transboundary aspects of air pollution (Alcamo *et al.*, 1987). The model is developed by the International Institute of Applied Systems Analysis (IIASA) and is designed as a tool for evaluating control strategies. Currently the model is mainly sulfur-based, but nitrogen is being incorporated and ammonia emissions are to be included in the near future.

The model consists of a number of submodules (*Figure 1*): Energy pathways, SO_2 control strategies, Costs, SO_2 emissions, SO_2 transport, Lake acidity, Forest soil acidity and Direct forest impacts. In this paper the first five submodules were used.

In the Energy Pathway and SO_2 emissions submodels, different energy projections can be implemented. The submodel accounts for five emission-producing sectors: conversion (e.g., refineries), power plants, domestic, industry and transportation. Eight fuel types are distinguished: brown coal, hard coal, derived coal (e.g., coke, brown coal briquettes), light oil (e.g., gasoline), medium distillate (gas oil), heavy oil, gas and other fuels. The latter two are assumed to produce no sulfur emissions. Moreover, process emissions are taken into account when calculating the total emissions.

In the Pollution Control and Cost submodels, four types of emission reduction are considered: energy conservation, fuel substitution, use of low sulfur fuels and desulfurisation. For the latter type the following technologies are considered: combustion modification, flue gas desulfurisation and regenerative processes. For the option "energy conservation", no costs are assessed. For the remaining options, costs are based on country and technology-specific parameters (Amann and Kornai, 1987). The resulting national abatement cost functions incorporate the most important cost influencing factors of the European countries in an internationally comparable way. The cost functions are piecewise linear reflecting that, in order to increase emissions further, another technique with higher marginal abatement costs has to be applied.

The transport submodel predicts concentration and sulfur deposition for 150×150 km grids over Europe from the emission patterns of SO_2. In doing so, it uses source-receptor linkages generated by the long-range atmospheric transport model developed by the Norwegian Meteorological Institute under the European Monitoring and Evaluation Program (EMEP) of the ECE Convention on Transboundary Air Pollution. Each country consists of at least several grids so that regional differentiation of deposition loads within a country is possible.

As shown in *Figure 1*, the model can be operated in two ways:

- The Scenario Analysis mode:

  Given a specified pattern of energy use and control strategies, the environmental consequences are assessed.
- The Optimization mode:

  Given environmental targets, specified in terms of sulfur deposition or desired emissions, the optimum (i.e., cost efficient) geographical distribution of sulfur emission reduction are calculated.

In the Scenario Analysis mode the submodels described above will be used to calculate emission and deposition. Furthermore, the optimization mode is used to estimate potential cost savings of more cost-effective policy measures.

4. The Cost Sharing Scheme – An Example

In this section, the proposed scheme will be illustrated using a specific set of cost functions and target deposition levels. The contributions of the countries to the Fund as well as reimbursements of the Fund to the countries will be calculated for this set.

The cost functions used are the standard, piecewise linear functions given in the RAINS model for the official energy pathway in the year 2000[1]. It is assumed that the initial emissions are those following from current reduction plans as incorporated in RAINS. This means that the costs calculated for the scheme are the extra costs to attain target deposition levels over and above the costs of the current reduction plans. The optimization mode of the RAINS model is used for all minimum cost calculations. Target deposition levels are quite arbitrarily chosen and summarized in *Table 1.* Note that these are peak grid levels, the average national sulfur deposition might be much lower.

In order to calculate the payment scheme for this specific example, four calculations have to be carried out. First, the costs to country i ($\bar{C}_i$) for unilaterally attaining its target deposition levels (Q^*_i) have to be computed. These are minimum costs of abating air pollution to such an extent that the deposition targets for this country are reached. This means that abatement measures can both be taken in the country itself and elsewhere, depending on the costs. The results are summarized in *Table 2.* Note that for some countries, such as Ireland and Bulgaria, deposition goals will be met by the current reduction plans without any further costs.

Secondly, the minimum costs (C^*) of jointly attaining target deposition levels (Q^*) in all countries contributing to the fund have to be calculated. For each

1 The fuel burnt in new and existing plants was however based on more detailed information (Cesar and Klaassen, 1989).

country these are the costs of the abatement techniques that it should install to reach the overall deposition goals. In the scheme, these costs would be reimbursed to the countries by the Fund (*Table 2*). Note that these costs are much lower than the sum of the costs of unilaterally attained reductions ($\bar{C}_i$), illustrating the gains from cooperation.

Thirdly, the contribution of each country to the fund is calculated. In order for the fund to break even, only a fraction α of the cost $\bar{C}_i$ needs to be paid by the countries to the fund. The sum of $\bar{C}_i$ equals the quotient of C^* and the sum of $\bar{C}_i$ being about 0.36. Hence, the contribution of country i is $\alpha \bar{C}_i$ and the benefits of each individual country from the scheme is $(1 - \alpha)\bar{C}_i$ (*Table 2*).

Finally, the net payments to the fund are calculated as the difference between the contribution to the Fund and the reimbursement by the Fund to each country (*Table 2*). Note that the sum of the net payments is zero which indicates that the fund is breaking even.

Once this calculation is carried out by the Fund, a country might want to revise its deposition target. In order for a country to balance costs and benefits of such a revision, it should know the marginal costs of changes in its deposition target. For Austria, this is shown in *Table 3*. A change in deposition goals from 2.0 g S/m^2 to 1.5 g S/m^2 increases annual costs from 2000 million DM to 3378 million DM. Similarly, loosening of deposition targets to 2.5 g S/m^2 decreases costs from 563 million DM to 807 million DM. Similarly, other countries might want to revise the deposition targets as well. In that case the process can be repeated until no country wants to make any further changes.

This example shows that given the deposition targets and cost functions, the cost sharing scheme can be calculated quite easily. However, the problem is to what extent the countries will reveal their cost functions and deposition goals truly.

5. Incentive Compatibility

A. Deposition levels

The first possibility to deceive originates from the cost effective way to jointly attain the target deposition levels. This means that some countries might reach low peak depositions because of measures taken to decrease deposition in neighboring countries. This might even be true if their own deposition goals are high.

This creates the possibility for these countries to behave as a free rider since denying to the Fund their desire to decrease current deposition levels will lower their costs, while their lower deposition levels will be attained anyhow because of the measures taken for other countries. In our specific example (described in the previous section), 10 countries were able to gain by not truly revealing their deposition targets: the Scandinavian countries (Finland, Norway, Sweden), some Western European countries (France, Luxembourg, the Netherlands and Switzerland) as well as Hungary, Rumania and Yugoslavia. Though this may be different for any other example, it seems that the chance on changes in the composition of the group as well as the number of its participants is quite low. An elevation of the deposition goals for Czechoslovakia, the GDR and Poland to 6 g/m^2, for example, leaving other things unchanged will only lead to the exclusion of Sweden from the group of possible "cheaters".

The gain from over reaching differs per country and per situation. *Table 4* summarizes these gains for Sweden and for the Netherlands in our specific case. In Sweden, the peak grid deposition will always drop to 0.95 g S/m^2 for every target deposition in Sweden above this number. This means that Sweden's contribution to the Fund (1044 million DM) can drop to zero if their announced target depositions are high enough. A similar situation occurs for the Netherlands, which is able to gain even 1929 million DM annually by deceiving.

B. Cost functions

As was mentioned in the previous section, countries may also be able to deceive with their cost functions. This possibility was also simulated with the RAINS model. Given the target deposition levels and the cost functions, it was assumed that USSR would overestimate its costs. USSR was chosen because its dC^*/dk is zero for reasonable values of k, and its $\bar{C}_i$ is close to C_i^*.

In the extreme case with $\bar{C}_i$ and C_i^* being equal, an overestimation of the true costs with 100*(k - 1)% would lead to net payments from the fund being k times as large (assuming α to remain constant). This was checked in our example with k = 1.1 for USSR. The results are presented in *Table 5.* The numbers show that even though the contribution of USSR to the Fund increases, the additional reimbursement implies an overall gain of about 10%. It should be noted that the results for USSR are rather specific due to the fact that, given the selected deposition targets, USSR always has to take a specific number of domestic abatement measures to meet its own domestic targets. This explains the small difference between the costs of unilateral and cooperative action.

More generally, the scope for deceiving can be analyzed as follows. Recall that the net payment to the Fund is $(\alpha\bar{C}_i, - C_i^*)$. As a result of deceiving ($k_i \neq 1$) all three factors α, $\bar{C}_i$, and C_i^* change. First of all, unilateral costs ($\bar{C}_i$) will change with $y\ (k_i - 1)\ \bar{C}_i$. y will be smaller or equal than one because optimization implies that an increase in costs in country i with $(k_i - 1)$ will generally imply that it is cheaper to pay other countries. Hence $\bar{C}_i$ is likely to rise with less than $(k_i - 1)$. Secondly, optimal costs of cooperation ($\bar{C}_i^*$) change as well with $z.\ (k_i - 1)C_i^*$. z is smaller or equal to one. Since cooperation allows for more cost-effective solutions than unilateral action, z is likely to be smaller than y. Thirdly, α (the ratio of optimal cost for country i and the sum of the costs of unilateral action) will change. α is defined as $C_i^*/\Sigma\ \bar{C}_i$. Because cooperation generally offers more scope for cost-effective solutions the change in C_i^*, resulting from a change in country i's reported cost function, is likely to be smaller than the change in $\Sigma\bar{C}_i$. Consequently the change in α ($\delta\alpha$) will be smaller than 1. This leads to the following conclusion. Deceiving with the cost function is beneficial if it reduces net payments of country to the Fund. That is $\delta(\alpha\bar{C}_i - C_i^*) < 0$. This can be rewritten as: $\delta\alpha\ y/k - 1),\bar{C}_i - z(k-1)C_i^* < 0$. Or, alternatively, as $\delta\alpha y/z < C_i^*/\bar{C}_i$. Recall that, generally, $\delta\alpha < 1$, $y/z > 1$ and $c^*/\bar{C}_i < 1$. Thus, deceiving is beneficial only if the change in α is sufficiently large. The bigger the difference between C_i^* and $\bar{C}_i$, the higher $C_i^*/\bar{C}_i$, the smaller is the chance that the $\delta\alpha$, determining the contribution to the fund, is sufficiently large to reduce net payments. Stated otherwise if C_i^* is close to $\bar{C}_i$, that is for countries such as USSR, Spain, Greece and the United Kingdom (*Table 2*), cheating is more likely to be beneficial.

C. Optimal group size

The problem of finding the optimal group size was already mentioned in section 2. Some numerical results of leaving one specific country out of the Fund are presented here. A Fund excluding Spain would not change peak deposition levels in the countries of the Fund. However, α would decrease with some 7% (*Table 6*). This means that the contribution of the remaining countries is 7% lower while deposition levels remain unchanged. Obviously, these countries are interested in leaving Spain out of the Fund.

The same is true to some extent if USSR or UK are left out of the Fund in which case α decreases by some 5% and 1% respectively. However, peak deposition in other countries will change in these cases. For instance, leaving USSR out will harm Finland to quite an extent.

D. Circumventing deceiving

Whether in practice the possibilities for deceiving will be a serious threat to the establishment and operation of the Fund is difficult to assess but a number of considerations can be mentioned. Firstly, even if some countries overreach, it might still be beneficial for other countries to participate since the costs of attaining target levels on their own might be higher. Moreover, attainment of desired deposition levels might not be feasible at all without cooperation. In that case the desire to reach the target deposition levels is to be balanced with the risk of deceiving.

Secondly, whether countries try to deceive with their deposition targets can be checked in several ways. Submitted deposition targets can be compared with official policy documents in order to reveal discrepancies. Furthermore, deposition targets can be compared with deposition levels resulting from present policies. Clearly, the desired targets should not be higher than the ones achieved with the present policies.

Thirdly, cost functions can be checked as well. Groups of experts could check whether the submitted cost-functions seem reasonable in view of available technical studies and empirical data. In addition, the cost function could be compared with the real costs for a number of relevant cases such as the application of flue-gas desulfurization in power plants. This, for example, could be done by a team of independent accountants. The accounting reports could be used to correct cost functions and to adjust countries initial payments and receipts from the Fund.

6. Conclusions

As pointed out there are some fundamental problems in connection with the coordination of abatement strategies in different countries. The possibilities for deceiving in "our" scheme only reflect this general problem.

In spite of the weaknesses "our" scheme demonstrates a mode of operation for a "Fund". In addition, it is shown that a simple cost-sharing scheme can significantly reduce the ex-ante costs of additional emission control for an individual country and can assist in speeding up the process of emission reduction.

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List of Symbols

a	= parameters of the transportation model
a_{ij}	= coefficients of the transportation model
α	= ratio of the optimized costs of co-operation and the costs of unilateral action
b	= vector of cost functions
β_i	= benefits of co-operating compared to unilateral action
C_i	= cost function of country i
$\hat{C}_i$	= cost of deposition control function in country i
C_i^*	= optimal costs of cooperation
$\bar{C}_i$	= costs for unilaterally attaining target deposition levels
E_i	= total emission of country i
$\bar{E}$	= vector of planned emission reduction
e	= vector of cost efficient (additional) emission reductions
k_i	= coefficient indicating deviation of revealed from true abatement costs in country i
Q_i	= deposition in country i
Q_1^*	= target deposition level of country i
y	= coefficient of change in unilateral costs
z	= coefficient of change in costs of cooperation

Table 1. Peak grid target depositions in European countries.

Denmark, Finland, Norway, Sweden	1 g S/m^2
EEC-countries, Austria, Switzerland	2 g S/m^2
Centrally planned economies, Albania, Turkey, Yugoslavia	4 g S/m^2

Note: A specific grid in Denmark was put to 2 g S/m^2 and one grid in Poland was not included, in order to keep the costs for these two countries reasonable and to make the problem feasible.

Table 2. Calculation of the cost sharing scheme (in mio DM).

Country	Min. costs to unilaterally attaining Q ($\bar{C}_i$)	Min. costs for jointly attaining Q (C_i^*)	Contribution of country i to the fund ($\alpha\bar{C}_i$)	"Benefits" from scheme to country i [$(1-\alpha)\bar{C}_i$]	Net payments of country i to the fund ($\alpha\bar{C}_i - C_i^*$)
ALB	0	0	0	0	0
AUS	3,849	0	1,370	2,479	1,370
BEL	5,421	1,245	1,929	3,492	684
BUL	0	0	0	0	0
CSSR	5,121	1,506	1,822	3,299	316
DEN	2,933	32	1,044	1,889	1,012
FIN	4,707	0	1,675	3,032	1,675
FRA	1,359	269	484	875	215
FRG	7,099	1,103	2,526	4,573	1,423
GDR	3,872	1,695	1,378	2,494	-317
GRE	558	532	199	359	-333
HUN	1,450	0	516	934	516
IRE	0	0	0	0	0
ITA	5,164	2,399	1,838	3,326	-561
LUX	883	0	314	569	314
NET	5,420	300	1,929	3,491	1,629
NOR	1,074	0	382	692	382
POL	4,463	885	1,588	2,875	703
POR	22	1	8	14	7
ROM	284	0	101	183	101
SPA	3,700	3,360	1,317	2,383	-2,043
SWE	2,933	0	1,044	1,889	1,044
SWI	2,946	0	1,048	1,898	1,048
TUR	0	0	0	0	0
UK	2,793	2,678	994	1,799	-1,684
USSR	9,589	9,273	3,412	6,177	-5,861
YUG	1,450	2,153	516	934	-1,637
SUM	77,090	27,431	27,431	49,659	0

($\alpha = 27{,}431/77{,}090 = 0.356$)

Table 3. Comparison of costs and deposition levels for Austria at different deposition levels (in mio DM).

Target deposition (g S/m^2)	Resulting deposition (g S/m^2)	Min. costs to unilaterally attaining Q ($\bar{C}_i$)	Min. costs for jointly attaining Q (C_i^*)	Contribution of country i to the fund ($\alpha\bar{C}_i$)	Net payments of country i to the fund ($\alpha C_i - C_i^*$)
Austria					
1.50	1.50	9,801	63	3,378	3,315
2.00	2.00	3,849	0	1,370	1,370
2.50	2.50	2,266	0	807	807

Table 4. Comparison of costs and deposition levels for Sweden and the Netherlands at different deposition levels (in mio DM).

Target Depos. (g S/m^2)	Resulting deposition (g S/m^2)	Min. costs to unilaterally attaining Q ($\bar{C}_i$)	Min. costs for jointly attaining Q (C_i^*)	Contribution of country i to the fund ($\alpha\bar{C}_i$	Net payments of country i to the fund ($\alpha C_i - C_i^*$)
Sweden					
1.00	0.95	2,933	0	1,044	1,044
1.25	0.95	778	0	285	285
1.50	0.95	0	0	0	0
Netherlands					
2.00	2.00	5,420	300	1,929	1,629
2.50	2.00	2,473	300	914	614
3.00	2.00	1,212	300	455	155
3.50	2.00	362	300	137	–163
4.00	2.00	0	300	0	–300

Table 5. Comparison of costs with 10% overestimation of costs for USSR.

Country	Min. costs to unilaterally attaining Q $(\bar{C}_i)$	Min. costs for jointly attaining Q (C_i^*)	Contribution of country i to the fund $(\alpha\bar{C}_i)$	"Benefits" from scheme to country i $(1-\alpha)\bar{C}_i)$	Net payments of country i to the fund $(\alpha\bar{C}_i - C_i^*)$
USSR					
k = 1	9,589	9,273	3,412	6,177	–5,861
k = 1.1	10,578	10,292	3,833	6,745	–6,469

Table 6. Calculation of the advantages of leaving Spain out of the fund.

Country	Min. costs to unilaterally attaining Q ($\bar{C}_i$)	Min. costs for jointly attaining Q (C_i^*)	Contribution of country i to the fund ($\alpha\bar{C}_i$)	"Benefits" from scheme to country i [$(1-\alpha)\bar{C}_i$]	Net payments of country i to the fund ($\alpha\bar{C}_i - C_i^*$)
Spain in					
Spain	3,700	3,360	1,317	2,383	−2,043
Rest	73,390	24,071	26,114	47,276	2,043
Sum	77,090	27,431	27,431	49,659	0
Spain out					
Spain	0	0	0	0	0
Rest	73,390	24,289	24,289	49,101	0
Sum	73,390	24,289	24,289	49,101	0

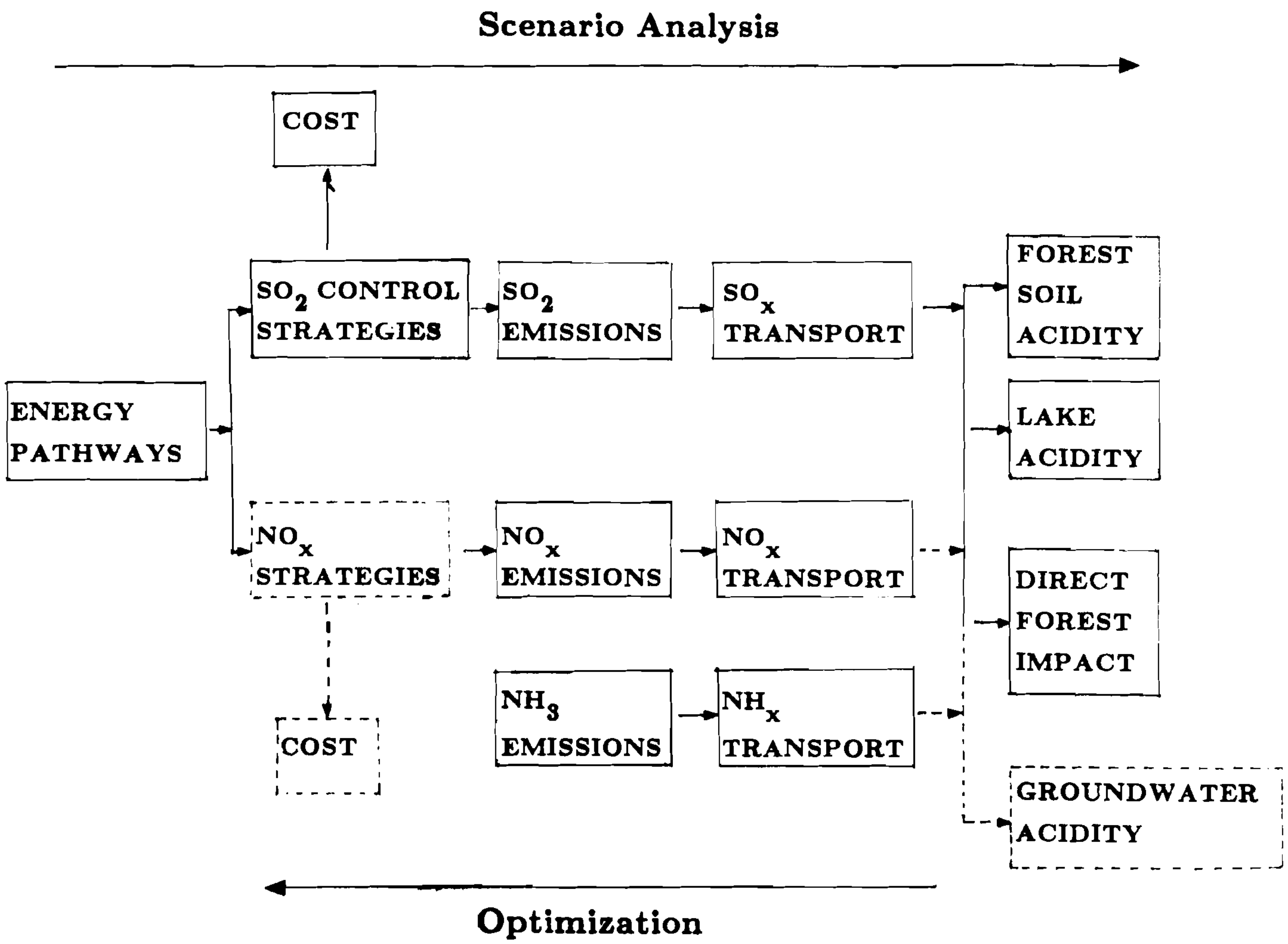

Figure 1. Schematic flowchart for the RAINS model.