Status Report

UN/ECE WORKSHOP ON EXPLORING EUROPEAN SULFUR ABATEMENT STRATEGIES

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Calculations of the atmospheric transfer of pollutants within this paper are based on the results of the EMEP/MSC-W project at the Meteorological Synthesizing Center - West (MSC-W) at the Norwegian Meteorological Institute, Oslo. The inventory of critical loads used was established by the Coordination Center for Effects (CCE) at the National Institute for Public Health and Environmental Protection (RIVM) in the Netherlands.

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Contents

1 Introduction

During the last decade international negotiations have focused on harmonizing the reductions of acid emissions in Europe. Agreements have been reached to reduce the emissions of sulfur and nitrogen oxides, as laid down in the 'Helsinki-' and 'Sofia' protocols within the framework of the UN/ECE Convention on Long-Range Transboundary Air Pollution. These protocols call for a uniform percentage emission reduction (or stabilization) by all signatory countries. However, no provisions were made for regional differences in environmental sensitivities, emission densities and the potential for, and costs of, emission reductions. As a result, it has become generally accepted that such 'flat-rate' strategies do not necessarily provide the most cost-effective instruments to reduce the ecosystem damage presently being experienced in Europe. Consequently, alternative strategies to derive better cost-effective solutions are currently being discussed.

This paper, prepared as a background document for the UN/ECE 'Workshop on Exploring European Sulfur Abatement Strategies' (24 – 26 June 1991, Laxenburg, Austria), provides an analysis of the major approaches presently being explored for further reducing SO_2 emissions in Europe. By using an integrated assessment model, the analysis reflects the current state of various model developments, taking into account the most recent information on energy strategies, emission projections, atmospheric long-range transport and sensitivities of ecosystems in Europe. The paper provides quantitative results from the the 'Regional Acidification Information and Simulation' (RAINS) model by analyzing various scenarios. Some more general qualitative conclusions and lessons are drawn from the model results. Further, the paper also attempts to illustrate the current limitations for scenario analysis caused by the limited availability and reliability of present data and models.

The paper explores the advantages and disadvantages of alternative approaches by analyzing and evaluating different aspects of the various abatement strategies, such as

- relative emission reductions (compared to the baseyear 1980),
- cost of abatement measures,
- the burden to national economies as implied by emission control expenditures (i.e. the fraction of GDP required for emission reductions),
- the consequences on acid deposition, and
- their environmental impacts in terms of critical loads achievement.

It should be noted however, that it is not the intention of this paper to perform any value judgments on the various strategies. Such preferences have to be established by negotiators. Undoubtedly, other considerations, which are not incorporated into this formalized analysis, will also influence the decisionmaking on the topic.

2 Scientific Tools Used for the Analysis

The authors of this paper have attempted to access the complexity of international emission reduction strategies by using the methods of systems analysis. Relevant findings of individual scientific disciplines are set in relation to each other to enable robust overall conclusions on the effectiveness of alternative strategies.

2.1 The RAINS model

The analysis for this paper has been performed by using the 'Regional Acidification Information and Simulation' (RAINS) model system developed at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. The RAINS model combines information about energy use and agricultural activities on emission parameters of SO_2 NO_x and NH_3 with emission control technologies and abatement costs. Together, these data determine national emission levels. By incorporating the results of the European Monitoring and Evaluation Programme (EMEP) model developed at the Meteorological Synthesizing Center-West (MSC-W) at the Norwegian Meteorological Institute, Oslo, the deposition of sulfur and nitrogen compounds are estimated. The environmental impacts of emission scenarios are evaluated by comparing them with maps of critical loads as established at the Coordination Center for Effects - West (CCE), and by dynamic simulations of regional impacts of acid deposition on forest soils, lakes and silvicultural ecosystems[1]. The scientific background of the RAINS model has been documented in Alcamo *et al.* (1990).

2.1.1 Projections of energy consumption and SO_2 emissions

The RAINS model computes SO_2 emissions based on statistics and projections of energy consumption, fuel characteristics and applied emission control measures. The data base contains data for 27 European countries.

The energy consumption forecasts used in this paper should reflect the national governmental energy policies for the year 2000. The projections have been retrieved from publications of international organizations (IEA/OECD, 1990; UN/ECE, 1990a) and were sent out for review in April 1991. Feedback, received from eight countries so far, has been incorporated in the data base. The most recent status of the data base is documented in Amann & Sorensen (1991).

2.1.2 Potential and costs of emission reductions

The national potentials and costs of emission reductions are estimated based on a detailed data base of the most common emission control techniques. For reductions of SO_2 emissions, the use of low-sulfur fuels, fuel desulfurization, combustion modification (e.g. lime stone injection

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[1] These features of the RAINS model have not been used in this paper.

processes and fluidized bed combustion) and flue gas desulfurization (e.g. wet limestone scrubbing processor) have been considered. Presently this means that the (economic) evaluation of emission control is limited to technological options; structural changes, such as fuel substitution and energy conservation, are excluded from this preliminary analysis, although they might provide cost effective emission reductions. Work is underway to improve the RAINS model in this respect.

The costs of applying the options referred to are estimated based on the international operating experience of pollution control equipment gained in Europe during recent years. Where necessary, they were adapted to country-specific conditions of application (local fuel qualities, boiler sizes, capacity utilization, etc.). A free exchange of technology is assumed throughout Europe. A detailed description of the methodology used for the cost evaluation can be found in Amann (1990).

For each country the specific cost estimates for pollution control equipment are related to the particular potential for emission reduction provided by the predicted pattern of energy consumption. By ranking the available pollution control options according to their cost effectiveness, 'national cost curves' can be established that describe the cost optimal combination of measures to achieve specified levels of national emission reductions. An international comparison of these cost curves shows that there are significant differences in the abatement costs which reflect the diverse structures of national energy systems (Amann & Sorensen, 1991).

2.1.3 The atmospheric transport of pollutants

The RAINS model applies results of the EMEP model to compute the atmospheric long-range transport of sulfur and nitrogen compounds (Iversen *et al.*, 1990). The EMEP model follows the trajectories of sulfur and nitrogen in the atmosphere over a period of several days and establishes thereby annual 'country-to-grid' transfer matrices of atmospheric long-range transport over Europe. At present the RAINS model incorporates these matrices for 1985, 1988, 1989 and 1990 as derived from the most recent version of the EMEP/MSC-W model. Calculations in this paper are based on the meteorologic average conditions for these four years.

2.1.4 Critical loads maps

The RAINS model has incorporated the recent version of the maps of critical loads for acidity and sulfur over Europe established at the Coordination Center for Effects (CCE) at the National Institute of Public Health and Environmental Protection (RIVM), Netherlands (Figure 1). Critical loads for an ecosystem are values of pollutants (sulfur, nitrogen, acidity) below which no damage will occur to an ecosystem according to current knowledge, see Hettelingh *et al.* (1991) for a more formal definition. This paper has used the map of critical loads for sulfur as the scenario assessments concentrate on sulfur abatement strategies. This map results from the cooperative national mapping activities undertaken in 1990 (UN/ECE, 1990b) and is described in detail in Hettelingh *et al.* (1991). For each cell of the EMEP grid system (150 x 150 km) the map contains the cumulative distribution of critical loads for sulfur for a mixture of forest soil combinations and surface waters.

At the moment, critical loads are determined predominantly using the steady state mass balance approach and, in some countries, the so-called level approach.

As mentioned before, throughout this paper, maps of critical loads for sulfur deposition are used. No conclusions are drawn on necessary reductions of nitrogen emissions to achieve critical loads of total acidity.

2.1.5 Scenario analysis and optimization mode

The RAINS model can be operated in the 'Scenario Analysis' mode: for specified energy and emission control scenarios, the regional effects on acid deposition and the environmental impacts can be evaluated. The internationally cost-optimal allocation of emission reductions for achieving specified deposition targets (e.g. target and critical loads) can be calculated using the 'Optimization' mode. This optimization takes into account (i) that some emission sources are more strongly linked to specified receptor areas via the atmosphere than others, and (ii) that some sources are cheaper to control than others.

2.2 Current limitations of integrated assessment models

Although integrated assessment models (such as the RAINS model) cover a variety of aspects of emission control strategies, their methodology, as well as shortcomings in availability and reliability of data, has limitations that should be kept in mind when interpreting results. The following describes a few of these limitations, which are common to most integrated assessment models.

2.2.1 Future economic development

One major limitation concerns the future economic development in different countries in Europe. For all integrated assessment models, the economic performance and the future structure of energy consumption is an exogenous input to model calculations. Therefore, any projections of energy consumption used in the models are either based on studies performed elsewhere, reflect targets specified in national policies, or are mere assumptions. In no case are they the outcome of the integrated assessment models, nor do these models consider any feedbacks of required emission reductions on the economy or on energy demand.

This limitation is of particular relevance for emission reduction strategies in Eastern Europe. The large uncertainties associated with the on-going economic transition processes in these countries result in a wide range of possible futures, and any selection of one particular forecast seems to be basically subjective. In view of the unexpected changes that have and are still taking place it seems questionable if further research could ever decrease this type of uncertainty.

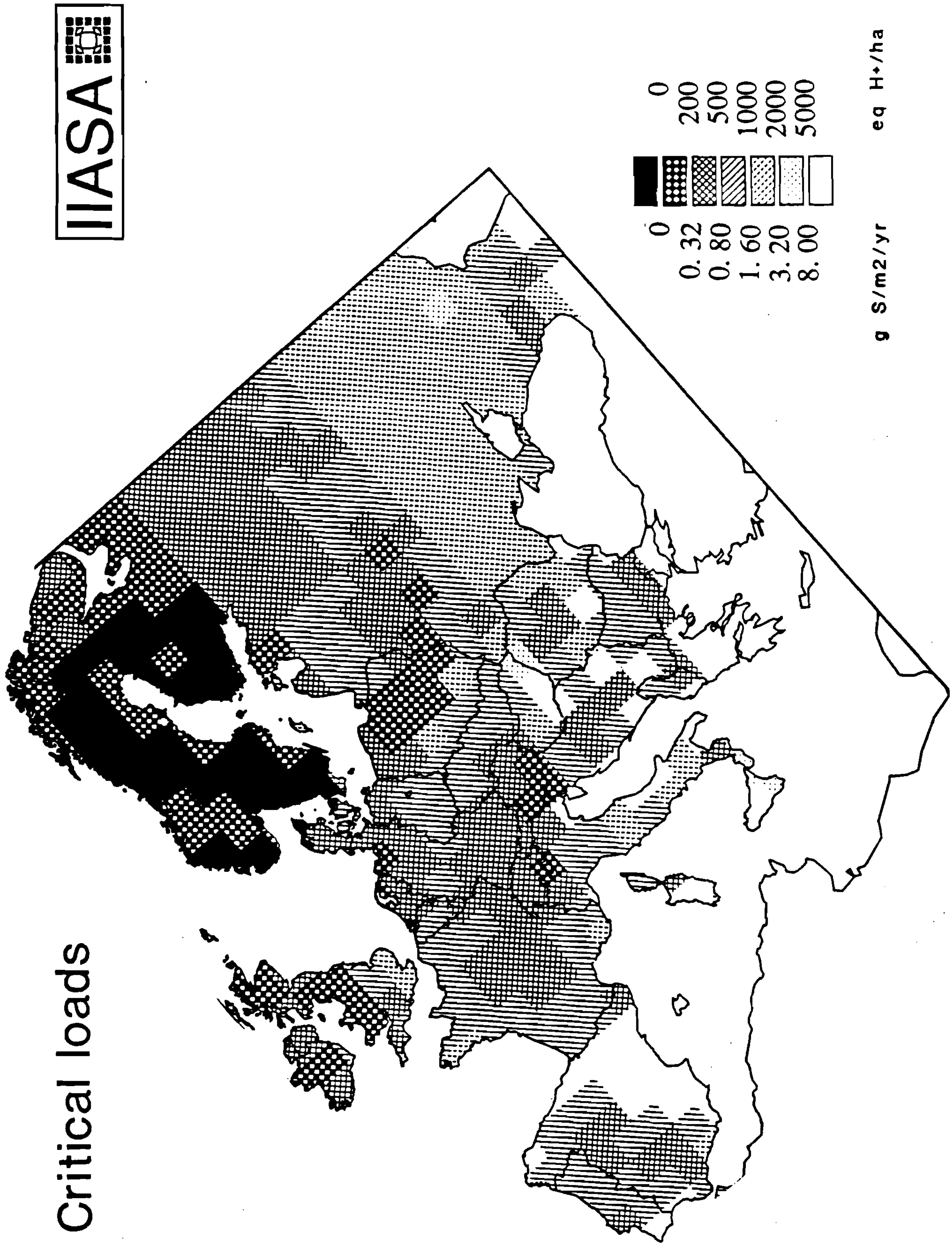

Figure 1: Map of the 5th percentile actual critical loads for sulfur. Source: CCE (Hettelingh *et al.*, 1991)

Unfortunately, the future structure of energy consumption does have a crucial impact on the design of efficient emission reduction strategies. It therefore, has to be kept in mind that any results obtained by using integrated assessment models will be based on a set of assumptions regarding future economic development and might be sensitive to modifications of these input data. However, integrated assessment models can be used to determine the sensitivities of alternative emission reduction approaches to economic development, and explore the scope for more robust strategies.

2.2.2 Cost evaluation

Considerable uncertainties are also connected with the international evaluation of emission control costs. Although wide international experience on the performance of emission control equipment is available, the basic question of how this data could be accurately extrapolated to specific situations in other countries remains. Observed data to verify cost estimates will only be available after the equipment has been implemented. On the other hand, within the scope of integrated assessment models, interest is mainly focused on how to allocate additional measures, for which naturally no verified data are available at the time of the model run.

Consequently, the cost estimates should not be interpreted as predictions of the actual abatement costs for a specific plant. The aim of the approach is to provide a consistent framework to *compare* abatement costs

- among different countries in Europe,
- and for alternative emission reduction strategies.

2.2.3 Options for emission reductions

As mentioned above, the current version of the RAINS model considers only technological means for emission reductions. For reasons of methodological simplification, changes in the energy structure (such as energy conservation and fuel substitution) are excluded from the analysis, although they can provide cost-effective potentials for emission reductions (Amann *et al.*, 1991). Therefore, all conclusions on the technical feasibility of emission reduction strategies drawn in this paper do not take such structural changes into account.

2.2.4 Calculations of the atmospheric transport

The RAINS model incorporates results of the EMEP-MSC/W model. This latter model focuses primarily on the transboundary long-range transport of air pollutants and computes deposition fields with a spatial resolution of 150 x 150 km over Europe. Consequently, the results of this model can not be used to analyze local air pollution problems in areas with high emission densities.

Furthermore, the EMEP results are basically implemented in RAINS in the form of 'country-to-grid' transfer matrices. Thereby, it is implicitly assumed that the spatial relative distribution of emissions within a country will not dramatically change in the future. Although this is definitely a strong assumption, analysis undertaken at IIASA indicates that the error in computed deposition values introduced by this simplification lies within the general range of model uncertainties when considering long-range transport (Alcamo, 1987). Undoubtedly, this simplification does not allow to derive conclusions of atmospheric dispersion within countries, but this is beyond the scope of the EMEP model anyhow.

Whereas this restriction does not have very serious consequences for transboundary transport among smaller countries, reduction requirements computed with the model for the largest countries (in particular for the Soviet Union) have to be interpreted cautiously. The EMEP model has recently been improved to disaggregate emission regions in the USSR, but organizational problems did not allow implementing the necessary changes to the RAINS model in time for this paper. However, it is expected that these changes will be ready before the end of 1991.

2.2.5 Critical loads

Due to the short time span available to perform the mapping exercise, the map of critical loads provided by the Coordination Center on Effects (CCE) has to be considered as a preliminary version, especially since the Coordination Center has not yet received submissions from all European countries. Critical loads for ecosystems in those countries that did not submit critical loads data were computed using the Steady State Mass Balance method incorporating European data (see Hettelingh *et al.*, 1991). Additional national submissions might change this map in the future.

The critical loads values as provided by the CCE represent 'actual critical loads' for a specified soil or lake type (Hettelingh *et al.*, 1991, page 10.). Actual critical loads are based on ecosystem characteristics predominantly. Characteristics that may affect acidity levels (e.g., base cation deposition uptake) but which are not inherent to particular ecosystems are not included in the computation of critical loads. However, in computing the exceedance of critical loads by deposition (as defined in UN/ECE EB.AIR/R53) the latter should be modified for effects of base cation deposition ('decreasing' acidity deposition values) and base cation uptake ('increasing' acidity deposition values). (See Hettelingh *et al.*, 1991.) Since reliable regional information on these mechanisms is still under review, the data provided by the CCE has to be considered as preliminary.

3 The Potential for Further Emission Reductions

Before analyzing the details of alternative emission reduction strategies, the available freedom for negotiations will be explored by the introduction of two extreme cases.

3.1 Scenario A: Current Reduction Plans for the year 2000

Table 1 lists SO_2 emissions as they are expected to be in the year 2000 after implementation of the currently committed reductions. Whenever possible, the emission levels are extracted from recent UN/ECE information (UN/ECE, 1991). In those cases where no values are reported in this document for the year 2000, data is interpolated from other years. If no data are provided at all, the RAINS estimates, based on the energy data base and on national information on emission control strategies, are used.

With this scenario, total European SO_2 emissions are expected to decline in the year 2000 by 29 percent compared to the year 1980. According to the RAINS estimate, abatement costs amount to 16.5 billion DM/year, which is roughly 0.09 percent of the European GDP predicted for the year 2000. Of the European ecosystems, 22 percent face deposition levels above critical loads (Figure 2).

Although the current sulfur protocol calls for a uniform 30 percent reduction of SO_2 emissions for all signatories, major differences among countries can be observed. Emission reductions are highest in Western European countries (up to 80 percent), whereas most Eastern European countries abide to the 30 percent commitment. Some Southern European countries have not signed the protocol and are expected to further increase their emissions (Table 1, Column 2).

The significant reductions of SO_2 emissions in Western Europe requires approximately 50 percent of total European abatement costs, whereas the other 50 percent will be necessary to implement the lower commitments in Eastern and Southern European countries. If, however, the burden put on national economies is taken as a criterion, all Eastern European countries rank among the top ten countries (Column 4). The discrepancy of low emission reductions requiring a high share of the GDP can be nicely demonstrated e.g. for the case of Poland, where the 30 percent reduction will take up 0.31 percent of the Polish GDP forecasted for the year 2000. In comparison, the 77 percent reduction of SO_2 emissions from the Netherlands only requires 0.09 percent of the Dutch GDP.

Environmental damage (ecosystems with deposition above critical loads) show peaks in Central and Northern Europe (Column 6): According to the model, 82 percent of the Dutch ecosystems would experience a sulfur deposition above critical loads, whereas lower exceedances are to be expected in Southern European countries.

SCENARIO A: CURRENT REDUCTION PLANS, 2000

	Emissions		Abatement Cost			Deposition
Country	kt SO_2	Reduction compared to 1980 (%)	10^6 DM/ year	% of GDP	DM/ capita/ year	% of ecosystems above CL
Albania	167	-65[4]	0	0.00	0	0
Austria	78	80	658	0.26	86	19
Belgium	427[1]	48	152	0.04	15	78
Bulgaria	520	50	1046	0.86	115	1
ČSFR	2169[1]	30	281	0.12	17	81
Denmark	178	60	88	0.03	17	24
Finland	266	54	181	0.07	36	34
France	1334[1]	60	0	0.00	0	22
Germany, West	860	73	3627	0.14	60	62
Germany, East	1500[2]	65	750	0.22	46	77
Greece	919[2]	-130[4]	0	0.00	0	0
Hungary	1094	33	198	0.14	19	31
Ireland	234	-5[4]	0	0.00	0	14
Italy	2255[2]	41	600	0.03	10	14
Luxembourg	10[1]	58	4	0.03	11	75
Netherlands	106	77	539	0.09	34	82
Norway	68[1]	52	77	0.03	18	37
Poland	2900	29	1375	0.31	34	74
Portugal	304	-14[4]	53	0.05	5	8
Romania	3261[2]	-81[4]	0	0.00	0	55
Spain	2889[2]	11	195	0.03	5	5
Sweden	182	65	385	0.10	45	58
Switzerland	60	52	44	0.01	7	13
Turkey	3253[2]	-278[4]	0	0.00	0	0
UK	2446	50	1453	0.08	25	51
USSR[3]	8220	36	4790	0.17	27	10
Yugoslavia	2393[2]	-84[4]	0	0.00	0	21
Total	38093	29	16496	0.09	22	22

Notes: [1] Extrapolated from UN-ECE (1991)
[2] RAINS estimate
[3] European part of USSR within EMEP
[4] Increase

Table 1: Scenario A: Current Reduction Plans for SO_2 emissions for the year 2000.

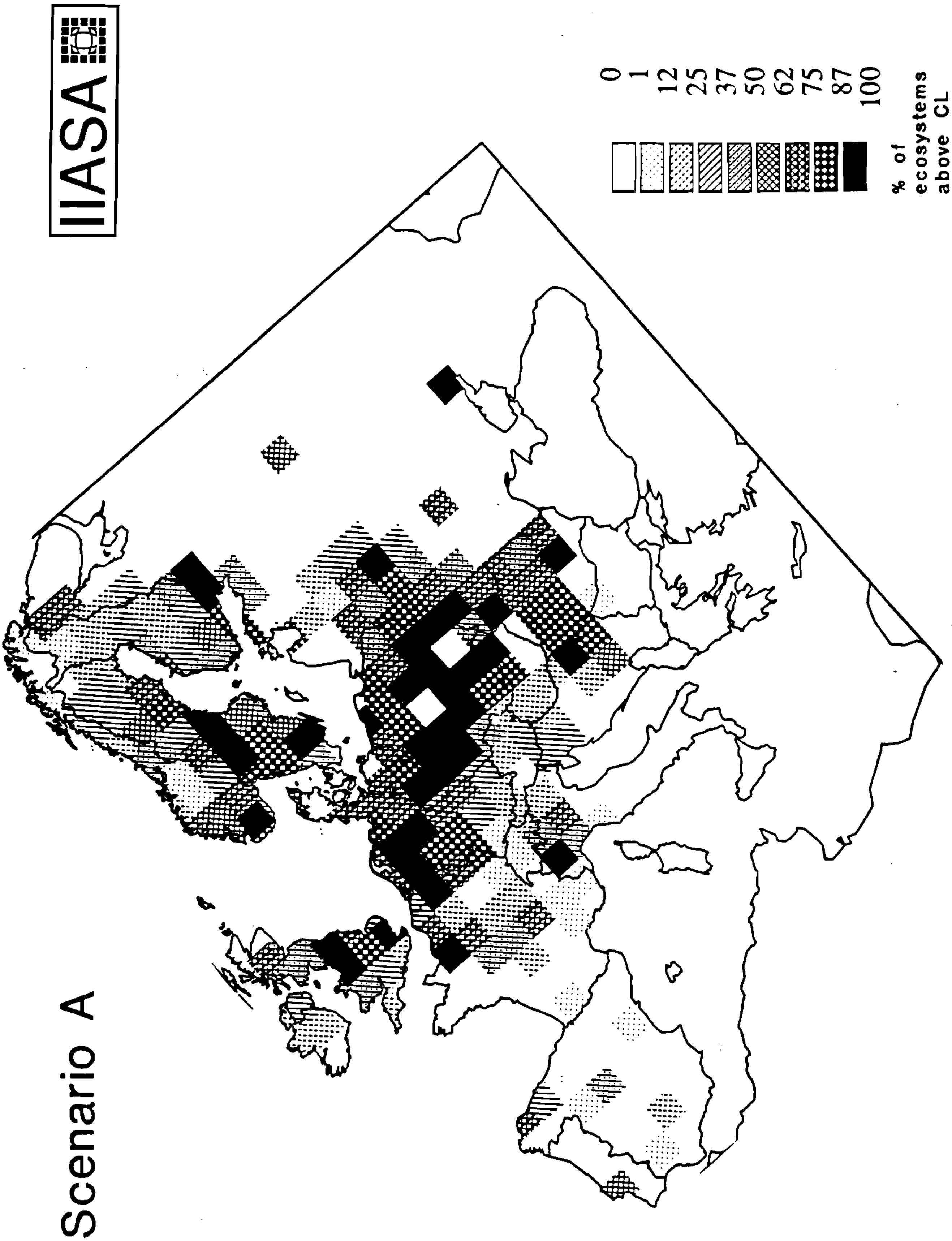

Figure 2: Regional distributions of ecosystems with sulfur deposition above critical loads of sulfur after implementation of the currently committed emission reductions in the year 2000 (Scenario A). Data sources: IIASA, CCE, MSC-W

SCENARIO A: CURRENT REDUCTION PLANS, 2000

Rank	Relative emission reduction	%	Abatement costs	% of GDP	Exceedance of CL	% of ecosystems
1	AUS	80	BUL	0.86	NL	82
2	FRG-W	73	POL	0.31	ČSFR	81
3	SWE	65	AUS	0.26	BEL	78
4	FRG-E	65	FRG-E	0.22	FRG-E	77
5	DEN	60	USSR	0.17	LUX	75
6	FRA	60	HUN	0.14	POL	74
7	LUX	58	FRG-W	0.14	FRG-W	62
8	FIN	54	ČSFR	0.12	SWE	58
9	CH	52	NL	0.09	ROM	55
10	NOR	52	UK	0.08	UK	51
	EUROPE	29	EUROPE	0.09	EUROPE	22

Table 2: List of the top-ten countries of relative emission reductions, abatement costs and area with deposition above critical loads for Scenario A.

3.2 Scenario B: Maximum technically feasible emission reductions in the year 2000

For comparison, a second example case outlines the lowest emission and deposition levels achievable by full implementation of currently available emission control technologies (Table 3). Based on the results of the RAINS model this estimate assumes the validity of projections of energy consumption for the year 2000. Changes in energy consumption structure, resulting in lower emission levels, such as energy conservation and fuel substitution, are excluded from this example case. As a consequence of this strategy, the total European SO_2 emissions would decline by 83 percent compared to 1980; the cost would amount to 86.3 billion DM/year (0.49 percent of total European GDP in the year 2000).

Despite these significant emission reductions, not all ecosystems could be preserved from sulfur deposition above critical loads. This applies in particular to the Netherlands and Scandinavia, where substantial parts of the ecosystems would face exceedances of their critical loads (Figure 3). However, over the whole of Europe 97 percent of the ecosystems could achieve critical loads deposition levels through such a drastic emission reduction strategy.

SCENARIO B: MAXIMUM TECHNICALLY FEASIBLE REDUCTIONS

	Emissions		Abatement Cost			Deposition
Country	kt SO_2	Reduction compared to 1980 (%)	10^6DM/ year	% of GDP	DM/ capita/ year	% of ecosystems above CL
Albania	41	59	225	1.61	59	0
Austria	62	84	926	0.37	122	0
Belgium	65	92	1874	0.53	191	3
Bulgaria	236	77	2331	1.93	257	0
ČSFR	708	77	2892	1.25	179	5
Denmark	21	95	717	0.27	139	7
Finland	42	93	1430	0.57	282	1
France	213	94	4040	0.17	69	0
Germany, West	369	89	8534	0.32	140	3
Germany, East	355	92	2755	0.82	170	13
Greece	88	78	1346	0.93	132	0
Hungary	580	64	1084	0.77	103	0
Ireland	50	77	383	0.47	94	1
Italy	231	94	5785	0.31	101	0
Luxembourg	1	96	191	1.27	507	0
Netherlands	43	91	972	0.17	61	12
Norway	33	77	311	0.13	72	22
Poland	749	82	5694	1.27	141	0
Portugal	26	90	1010	0.91	95	0
Romania	313	83	3601	1.76	148	0
Spain	261	92	4332	0.58	107	0
Sweden	94	82	1165	0.29	136	33
Switzerland	43	66	204	0.06	30	0
Turkey	1341	-56[2]	4771	1.10	71	0
UK	496	90	6940	0.37	119	8
USSR[1]	2452	81	18415	0.64	102	0
Yugoslavia	321	75	4326	2.35	174	0
Total	9234	83	86254	0.49	114	3

Notes: [1] European part of USSR within EMEP

[2] Increase

Table 3: Scenario B: Maximum technically feasible emission reductions in the year 2000 based on official energy projections.

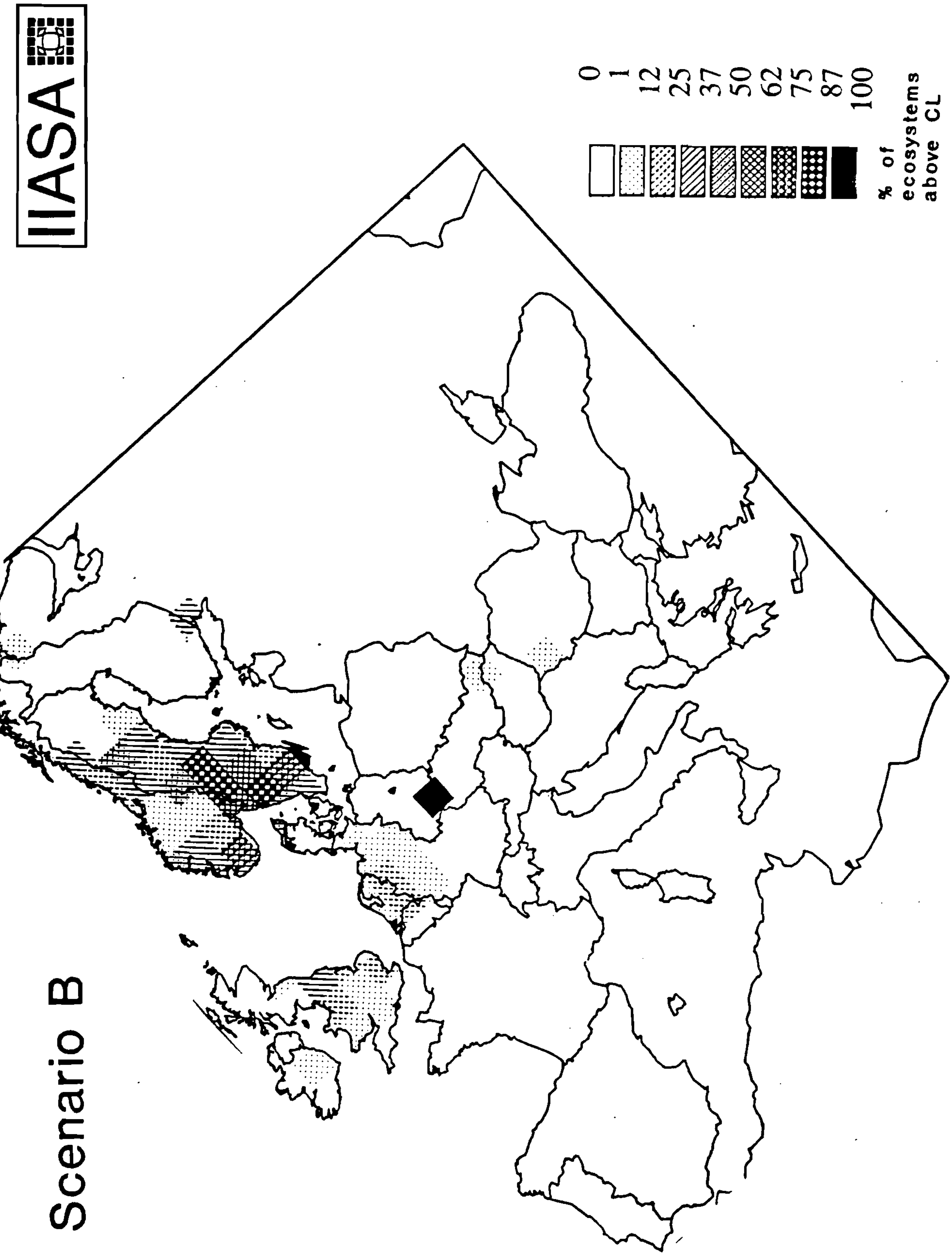

Figure 3: Regional distributions of ecosystems with sulfur deposition above critical loads of sulfur after implementation of all currently available emission control technologies in the year 2000 (Scenario B). Data sources: IIASA, CCE, MSC-W.

4 Receptor Oriented Strategies

4.1 Scenario C: Achievement of critical loads

Scenario B demonstrates that a realization of projected energy consumption would not allow the achievement of critical loads everywhere in Europe, even if all currently available emission control technologies were applied. This is due to the fact that technical control options usually do not have 100 percent removal efficiency, and control technologies are not available for all emission sources (e.g. in the household sector).

Scenario C explores the theoretically necessary emission reductions (independent of their feasibility) that would be necessary to achieve critical loads over all of Europe.

For this purpose, the RAINS optimization module is used. Since no technical limitations should hinder the achievement of critical loads in this example, the cost estimates of the RAINS model, (which incorporate limitations of abatement technologies), are neglected. Instead, a simple generic 'cost'-curve for all countries is applied which allows for a complete reduction of SO_2 emissions to the zero-emission level. The weights of these curves are based on the principle that – with increasing reduction percentages – emission reductions become increasingly expensive. Thereby, optimization allows for a gradual approach to the zero emission level, although no costs can be assigned to it.

If the map of critical loads, as documented in Hettelingh *et al.* (1991) is taken as a deposition target, the actual critical loads of five-percentile of the ecosystems in large areas of Finland, Norway and Sweden allows for a sulfur deposition of virtually zero grams, reflecting the high sensitivity of lakes in these regions (Figure 1). On the other hand, the EMEP model accounts for a certain fraction of sulfur deposition from natural and non-European sources, which, according to the EMEP model calculations, is significantly higher than zero. Consequently, if these findings are correct, critical loads for these sensitive ecosystems are not achievable even with a complete reduction of all anthropogenic SO_2 emissions in Europe. The implications of this on European emission reduction strategies are beyond the scope of this paper.

However, if these sensitive ecosystems in the three Nordic countries could be ignored, the remaining critical loads for forest soils in this region could turn out to be higher than the estimated deposition of non-anthropogenic sulfur, in particular, if base cation deposition is taken into account. In this case, the optimization problem becomes feasible.

As a result, SO_2 emissions would have to be reduced throughout Europe by 68 percent (Table 4), although major regional differences occur. Whereas the high base cation deposition and the low sensitivity of ecosystems in Southern Europe would even allow for an increase of emissions in South East Europe (Albania, Greece, Turkey), countries in Central and Northern Europe, e.g., West Germany, the Netherlands, Denmark and Sweden would have to entirely eliminate all their SO_2 emissions. As explained, no cost figure can be provided for this scenario.

SCENARIO C: ACHIEVEMENT OF CRITICAL LOADS

	Emissions		Abatement Cost			Deposition
Country	kt SO_2	Reduction compared to 1980 (%)	10^6DM/ year	% of GDP	DM/ capita/ year	% of ecosystems above CL
Albania	168	-66[2]	-	-	-	0
Austria	256	34	-	-	-	0
Belgium	179	78	-	-	-	0
Bulgaria	1038	0	-	-	-	0
ČSFR	300	90	-	-	-	0
Denmark	0	100	-	-	-	0
Finland	0	100	-	-	-	1
France	634	81	-	-	-	0
Germany, West	0	100	-	-	-	0
Germany, East	382	91	-	-	-	0
Greece	920	-130[2]	-	-	-	0
Hungary	464	72	-	-	-	0
Ireland	73	67	-	-	-	0
Italy	1114	71	-	-	-	0
Luxembourg	6	75	-	-	-	0
Netherlands	0	100	-	-	-	0
Norway	60	58	-	-	-	22
Poland	846	79	-	-	-	0
Portugal	148	44	-	-	-	0
Romania	316	82	-	-	-	0
Spain	2020	38	-	-	-	0
Sweden	0	100	-	-	-	30
Switzerland	25	80	-	-	-	0
Turkey	3260	-279[2]	-	-	-	0
UK	98	98	-	-	-	0
USSR[1]	3900	70	-	-	-	0
Yugoslavia	846	35	-	-	-	0
Total	17053	68	-	-	-	2

Notes: [1] European part of USSR within EMEP

[2] Increase

Table 4: Scenario C: Achievement of critical loads, no technical constraints for emission reductions are assumed.

Although this scenario has only academic value, it can be concluded that complete achievement of critical loads throughout Europe also also as a long-term policy target, will remain an ambitious task.

On the other hand, if the objective is to come as close as technically feasible, to the critical loads values, a strategy similar to Scenario B (maximum technically feasible emission reductions) would be required at least in Central and Northern Europe.

4.2 National target loads

The difficulties involved in directly using critical loads as long-term policy targets are an incentive to specify (interim) target loads as intermediate objectives for further emission reduction strategies (UN/ECE, EB.AIR/R.53, 1990). Presently, official target loads are available from ten European countries (Table 5, Figure 4). A number of countries explicitly sate that these target loads should be seen as interim target loads only and stress the preliminary status. For Austria interim target loads equal 5 percent percentile of the critical loads. The target load for Denmark is 0.5 g S/m2/year. Target loads for Finland are grid specific. North of EMEP grid 16 the target load is lowest (0.2 g S/m2/year). Inofficial target loads for France are equal to the 5 percent percentile of the critical loads. The target load for the Netherlands is 2400 eq. acid/ha. per year of which 1600 eq. may be contributed in the form of nitrogen. If the latter contribution equals the maximum, the contribution of sulfur may not exceed 800 eq./ha/year. This corresponds to 1.28 g S/ha/year. For Norway a target load of 0.5 g S/m2/year was used. This conforms to the 'Nordic action plan against air pollution' (UN/ECE 1990c, pp9). Sweden has a separate target load for Nörrland. The (interim) target loads for Switzerland equal the five percent value of the critical loads. The targets for the USSR are specified for each of the grids. Target loads for the United Kingdom are given as frequency distributions for each grid. For the analysis the lowest value for each grid was used. Where countries have specified different values for the same grid the lowest value was used.

Where target loads were apparently based on critical loads, the target loads were corrected to account for base cation deposition. This is similar to the corrections made for calculation of the exceedance of critical loads. (Hettelingh *et al.* 1991, pp17). In formula:

$$\mathrm{TL(s)}_{COR} = \mathrm{TL(s)}_{O} + \mathrm{sf}\,(\mathrm{BC}_{U} - \mathrm{BC}_{D})$$

Where:

$\mathrm{TL(s)}_{COR}$ = corrected target load for sulfur
$\mathrm{TL(s)}_{O}$ = original target load for sulfur
sf = sulfur fraction
BC_{U} = base cation uptake
BC_{D} = base cation deposition

Data for the corrections are based on submissions from the Coordination Centre for Effects.

This chapter explores the use of these target loads in devising a European abatement strategy. Section 4.2.1 shows the results of an optimization if these target loads for the ten countries are used.

Since one might expect that emission reductions needed to achieve target loads might be too high for some countries, Section 4.2.2 shows the effects of one country not adhering to the optimal solution.

The final section (4.2.3) explores the influence of modified target loads on the international allocation of emission reductions.

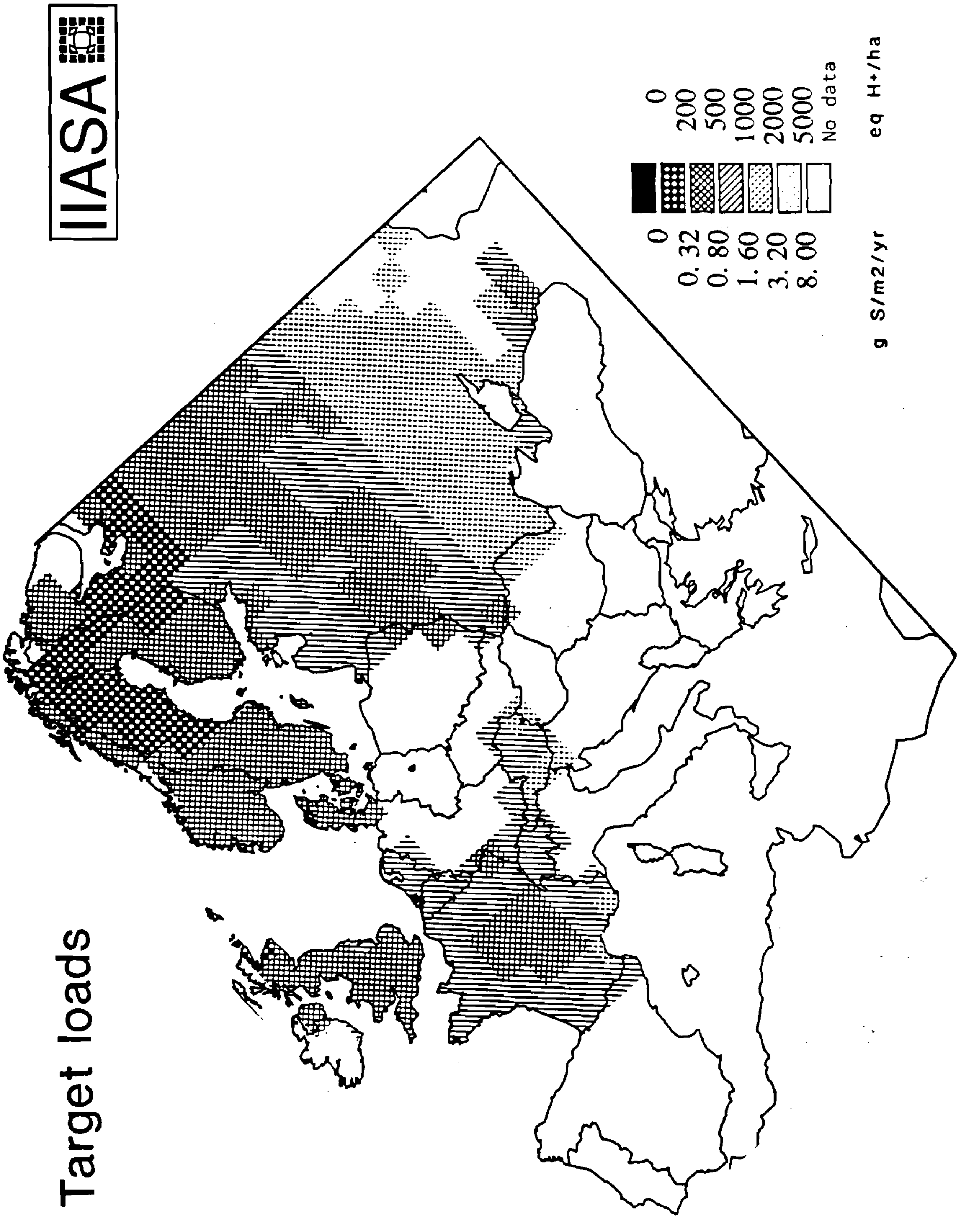

Figure 4: Map of (preliminary) target loads for sulfur deposition in Europe.
Source: Country submissions to CCE.
Note: Target loads for France and Norway have not yet been authorized at the appropriate administrative level.

NATIONAL TARGET LOADS			
Country	EMEP Grids	Target load g $S/m^2/yr$	Remarks
Austria		1.22 - 1.74	grid specific values: 5-percentile of the actual critical loads, corrected by base cation balance
Denmark	all	0.5	corrected by base cation balance
Finland	north of EMEP 16 19/26 19/27 others	0.2 0.4 0.4 0.5	
France[1]		0.52 - 2.38	grid specific values: 5-percentile of the actual critical loads, corrected by base cation balance
Netherlands	all	1.28	total acidity 2400 eq H^+/ha of which $N_{max} = 1600$ eq H^+/ha Hence $800 < S < 2400$ eq H^+/ha
Norway[1]	all	0.5	
Sweden	north of EMEP 24 others	0.3 0.5	Nörrland 0.3 $g/S/m^2$,
Switzerland		1.02 - 1.3	grid specific values: 5-percentile of actual critical loads, corrected by base cation balance
UK		0.32 - 6.4	grid specific values
USSR		0.3 - 2.0	grid specific values corrected by base cation balance

Note: [1] Target loads for France and Norway are not authorized at the appropriate level of administration.

Table 5: National target loads used for Scenario D

4.2.1 Scenario D1: Target loads for ten countries

For reference, the RAINS model is used to determine the cost-optimal allocation of emission reductions to achieve sulfur deposition lower or equal to the target loads of the ten countries listed in Table 5. For methodological reasons, all existing commitments on emission reductions are ignored in this example and no target loads are assumed for the remaining European countries.

According to the optimization, (Table 6) a 69 percent decline of the European SO_2 emissions would be necessary to achieve the target loads of these ten countries. By achieving these target loads, only four percent of the European ecosystems will face a sulfur deposition above the critical loads.

Over the whole of Europe, costs of 51.6 billion DM/year (0.29 percent of the European GDP) occur. Due to stringent target loads, drastic emission reductions are required in North West Europe (Belgium, the Netherlands, Germany, France, Scandinavia, UK, etc.). Less efforts are necessary in Central Europe (Austria, Switzerland) and, because of the lack of target loads in this particular area, very little is allocated for measures in South East Europe.

Only 45 percent of total expenditures would be allocated for measures within countries that have specified target loads. The major part of the resources would be required for reductions in those countries that have no defined target loads for their own territory. In many cases, emission reductions are higher for countries who have not specified target loads, for example the ČSFR (75 percent), Poland (82 percent), than for those that have e.g., Austria (61 percent), Switzerland (52 percent).

This disparity applies not only to emission reductions and absolute abatement costs, but also to the burden placed on national economies (Table 7). Within the group of the five countries with the highest percentage of GDP utilized for emission reduction, none have specified national target loads. All Eastern European countries rank within the highest ten.

This result clearly illustrates that optimization identifies only the allocation of emission reduction measures needed in order to achieve the European cost minimum. The question of who should pay for the reductions is not answered by the optimization procedure of the RAINS model. A fair solution to these problems requires additional considerations, *inter alia* an analysis of the distribution of environmental benefits from the emission reductions. As shown in this example, costs and benefits do not necessarily coincide spatially.

SCENARIO D1: TARGET LOADS WITHOUT RESTRICTIONS

	Emissions		Abatement Cost			Deposition
Country	kt SO_2	Reduction compared to 1980 (%)	10^6DM/ year	% of GDP	DM/ capita/ year	% of ecosystems above CL
Albania	168	-66[2]	0	0.00	0	0
Austria	153	61	382	0.15	50	0
Belgium	68	92	1554	0.44	158	5
Bulgaria	1157	-12[2]	332	0.27	37	6
ČSFR	766	75	1966	0.85	122	9
Denmark	21	95	743	0.28	144	8
Finland	47	92	1268	0.51	250	5
France	225	93	3195	0.13	55	0
Germany, West	379	88	6725	0.25	111	4
Germany, East	360	92	2412	0.72	149	14
Greece	919	-130[2]	0	0.00	0	1
Hungary	642	61	486	0.35	46	7
Ireland	51	77	345	0.42	84	1
Italy	1061	72	1832	0.10	32	2
Luxembourg	2	92	193	1.29	512	0
Netherlands	44	91	891	0.16	56	17
Norway	42	70	166	0.07	38	24
Poland	752	82	5469	1.22	135	2
Portugal	232	13	134	0.12	13	7
Romania	493	73	2277	1.11	94	11
Spain	475	85	2227	0.30	55	0
Sweden	100	81	890	0.22	104	36
Switzerland	61	52	40	0.01	6	3
Turkey	3074	-257[2]	128	0.03	2	0
UK	508	90	5860	0.31	100	8
USSR[1]	3077	76	11605	0.40	64	0
Yugoslavia	1982	-52[2]	474	0.26	19	10
Total	16859	69	51594	0.29	68	4

Notes: [1] European part of USSR within EMEP
[2] Increase

Table 6: Scenario D1: Target loads for ten countries, no restrictions assumed.

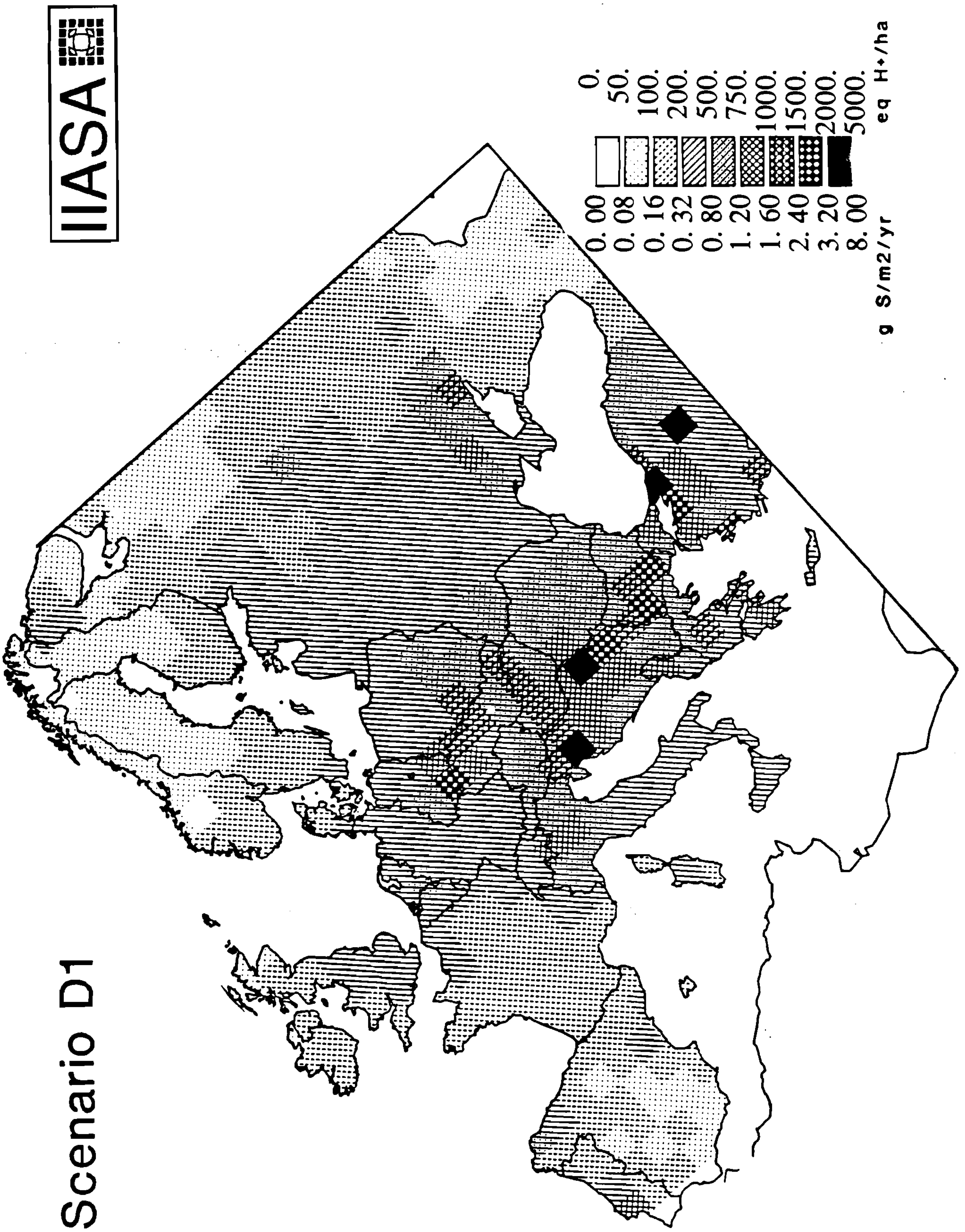

Figure 5: Map of sulfur deposition in Europe for the Scenario D1 (Target loads). Sources: IIASA, MSC-W.

Scenario D1: TARGET LOADS without restrictions

Rank	Relative emission reduction	%	Abatement costs	% of GDP	Exceedance of CL	% of ecosystems
1	DEN	95	LUX	1.29	SWE	36
2	FRA	93	POL	1.22	NOR	24
3	FRG-E	92	ROM	1.11	NL	17
4	BEL	92	ČSFR	0.85	FRG-E	14
5	LUX	92	FRG-E	0.72	ROM	11
6	NL	91	FIN	0.51	YU	10
7	UK	90	BEL	0.44	ČSFR	9
8	FRG-W	88	IRE	0.42	DEN	8
9	SPA	85	USSR	0.09	UK	8
10	POL	82	HUN	0.35	POR	7
	EUROPE	69	EUROPE	0.29	EUROPE	4

Table 7: List of the top-ten countries of relative emission reductions, abatement costs and area with deposition above critical loads for Scenario D1

4.2.2 Scenario D2: Target loads as in D1, but not all countries participate in the abatement schedule

As demonstrated, an optimized target load scenario might require significant measures in countries which have not set exposure limits for their domestic ecosystems. Since optimized solutions might also place extreme burdens on such countries, an example is analyzed in which one country does not fully participate in implementing the internationally optimized strategy.

As an illustration a theoretic case is analyzed in which the ČSFR, with a 75 percent reduction required in Scenario D1 for 0.85 percent of the GDP, would not comply with this 'optimized' schedule, but would only reduce its SO_2 emissions by a maximum of 50 percent; the ČSFR has not yet specified national target loads. If all countries keep their target loads constant, additional emission reductions would have to be implemented to compensate for the higher emissions from the ČSFR. Not surprisingly, a revised optimization, taking into account the external constraint on the ČSFR emissions, results in a rescheduling of reduction requirements (Table 8), and overall costs would be 18 percent higher. Three groups of countries can be distinguished:

- *Central Europe.* These countries have to significantly increase their abatement efforts to maintain target loads in Central Europe, for example, Austria 79 percent instead of 61 percent, Switzerland 60 percent instead of 52 percent, Italy 85 percent instead of 72 percent.

- *North-West Europe.* Due to their low target loads, countries in this region, already reduced (under Scenario D1) their emissions close to the maximum technically feasible level. The remaining reductions are extremely expensive and are therefore not utilized for compensation of the increased ČSFR contribution.

- *South-East Europe.* Due to the high marginal costs in Central and Northern Europe the necessary compensation has to be achieved by utilizing cheap reduction potentials at those distant sources not activitated in Scenario D1. As displayed in Table 8, Albania, Bulgaria, Greece, Turkey and Yugoslavia have to substantially decrease their emissions for Scandinavia to obtain deposition below target loads.

Although this rearrangement of these abatement efforts does not change the list of the 'top-ten' countries for relative emission reductions (Table 9), the reductions required from the Southern European countries put heavy burdens on their economies. Again, the question could be asked if these increased burdens, which only become necessary to satisfy target loads in Scandinavia, would be accepted by these countries, or if additional countries would be inclined to drop out of the cooperative solution. On the other hand, the additional measures in South-East Europe result also in a better protection of the ecosystems in this region, although with reduced abatement efforts in the ČSFR, 35 percent instead of nine percent of the ecosystems will face sulfur deposition above critical loads.

SCENARIO D2: TARGET LOADS, ČSFR ≤ 50 %

	Emissions		Abatement Cost			Deposition
Country	kt SO_2	Reduction compared to 1980 (%)	10^6DM/ year	% of GDP	DM/ capita/ year	% of ecosystems above CL
Albania	54	47	119	0.85	31	0
Austria	80	79	651	0.26	86	0
Belgium	68	92	1701	0.48	173	4
Bulgaria	350	66	1293	1.07	143	0
ČSFR	1550	50	853	0.37	53	35
Denmark	21	95	743	0.28	144	8
Finland	47	92	1271	0.51	250	5
France	225	93	3195	0.13	55	0
Germany, West	369	89	8667	0.33	143	4
Germany, East	360	92	2412	0.72	149	15
Greece	197	51	701	0.49	69	0
Hungary	607	63	635	0.45	60	3
Ireland	51	77	346	0.42	85	1
Italy	565	85	2979	0.16	52	0
Luxembourg	2	92	193	1.29	512	0
Netherlands	44	91	990	0.17	63	15
Norway	35	75	227	0.10	52	24
Poland	752	82	5469	1.22	135	7
Portugal	39	85	632	0.57	60	0
Romania	493	73	2277	1.11	94	4
Spain	407	87	2624	0.35	65	0
Sweden	100	81	890	0.22	104	36
Switzerland	50	60	85	0.02	13	0
Turkey	1971	-129	1257	0.29	19	0
UK	500	90	6441	0.34	110	8
USSR	3077	76	11605	0.40	64	0
Yugoslavia	468	64	2924	1.59	117	1
Total	12482	77	61180	0.35	81	4

Notes: [1] European part of USSR within EMEP

[2] Increase

Table 8: Scenario D2: Target loads for 10 countries, 50 % maximum reduction in ČSFR.

SCENARIO D2: TARGET LOADS, ČSFR $\leq$ 50 %

	Relative emission reduction		Abatement costs		Exceedance of CL	
Rank		%		% of GDP		% of ecosystems
1	DEN	95	YU	1.59	SWE	36
2	FRA	93	LUX	1.29	ČSFR	35
3	FRG-E	92	POL	1.22	NOR	24
4	FIN	92	ROM	1.11	FRG-E	15
5	BEL	92	BUL	1.07	NL	15
6	LUX	92	ALB	0.85	DEN	8
7	NL	91	FRG-E	0.72	UK	8
8	UK	90	POR	0.57	POL	7
9	FRG-W	88	FIN	0.51	FIN	5
10	SPA	87	GRE	0.49	BEL	4
	EUROPE	77	EUROPE	0.35	EUROPE	4

Table 9: List of the top-ten countries of relative emission reductions, abatement costs and area with deposition above critical loads for Scenario D2 (Target loads, Reduction in ČSFR $\leq$ 50 %).

4.2.3 Scenario D3: Modified target loads

This section analyzes the influence of modified target loads on emission reduction requirements. In Scenario D1, target loads were only considered for ten countries in Europe, with no restrictions on sulfur deposition assumed for the remaining countries. As illustrated in that scenario, the strong transboundary transport of pollutants requires emission reductions in the majority of European countries, even if they have no specified target loads for their domestic ecosystems. At the same time, deposition not only improves at locations where target loads are specified, but also in countries where it is not. Consequently, additional countries could specify target loads for their area higher or equal to the deposition of Scenario D1 (Figure 5) without imposing further emission reductions. These new target loads would be achieved automatically by the requirements of the ten original countries. This mechanism could become important if possible cost sharing schemes are based on initial selections of target loads.

If countries specify target loads lower than the deposition resulting from Scenario D1, additional emission reductions in a number of countries will be required,

However, the set of target loads used throughout this paper, which are close to the lowest achievable deposition, do not easily allow for substantially lower target loads in the Center and North-West of Europe. Consequently, no major additional emission reductions can be expected in this area.

Therefore, in order to investigate the sensitivity of optimized emission reduction strategies to modified target loads, an example is explored in which Scandinavian target loads are relaxed instead of tightened. For reasons of simplicity, it is assumed that Denmark and Finland increase their target loads by 10 percent to 0.55 g/S/m^2/year.

The optimization for these modified target loads results in an overall reduction of European SO_2 emissions by 62 percent compared to 69 percent in Scenario D1. Abatement costs would be 17 percent lower. Most strikingly, no changes in emission reductions occur in Denmark and Finland, but requirements for other countries are relaxed considerably (Table 10).

Subsequently, it can be stated that the optimization procedure requires the basic assumptions that

- all countries are willing to implement the optimized solution, and
- target loads are not modified after the allocation of emission reductions.

. Any deviation from the selected target loads as well as from the optimal reduction requirements, once they have been allocated might cause a significant rearrangement of the obligations for other countries. How far such versatility would hinder the formulation of international commitments for emission reductions has to be thoroughly discussed.

SCENARIO D3: TARGET LOADS, Higher loads in Denmark and Finland

	Emissions		Abatement Cost			Deposition
Country	kt SO_2	Reduction compared to 1980 (%)	10^6DM/ year	% of GDP	DM/ capita/ year	% of ecosystems above CL
Albania	168	-66 %	0	0.00 %	0	0
Austria	232	40 %	188	0.07 %	25	0
Belgium	129	84 %	965	0.27 %	98	11
Bulgaria	1555	-50 %	0	0.00 %	0	16
ČSFR	966	69 %	1390	0.60 %	86	23
Denmark	21	95 %	743	0.28 %	144	9
Finland	44	92 %	1325	0.53 %	261	6
France	605	82 %	985	0.04 %	17	1
Germany, West	379	88 %	6725	0.25 %	111	8
Germany, East	384	91 %	2109	0.63 %	130	15
Greece	919	-130 %	0	0.00 %	0	2
Hungary	642	61 %	486	0.35 %	46	6
Ireland	58	74 %	281	0.34 %	69	1
Italy	954	75 %	2080	0.11 %	36	2
Luxembourg	7	71 %	13	0.09 %	34	2
Netherlands	44	91 %	891	0.16 %	56	39
Norway	62	56 %	92	0.04 %	21	26
Poland	843	79 %	4673	1.04 %	116	10
Portugal	363	-36 %	0	0.00 %	0	8
Romania	634	65 %	2158	1.05 %	89	11
Spain	2272	30 %	353	0.05 %	9	4
Sweden	164	68 %	427	0.11 %	50	40
Switzerland	61	52 %	40	0.01 %	6	3
Turkey	3254	-278 %	0	0.00 %	0	0
UK	524	89 %	5652	0.30 %	97	10
USSR	3424	73 %	10718	0.37 %	60	0
Yugoslavia	1810	-39 %	748	0.41 %	30	11
Total	20518	62 %	43042	0.24 %	57	6

Notes: [1] European part of USSR within EMEP

[2] Increase

Table 10: Scenario D3: Higher target loads in Denmark and Finland assumed.

5 Source Oriented Strategies

As an alternative approach, source-oriented strategies will be analyzed in this section. The common property of such strategies is that they quantify emission reductions only on the basis of the structural characteristics of the emission sources; environmental consequences, such as the achievement of critical or target loads, do not direct influence the prescribed levels of emission reductions.

In Section 5.1 a strategy asking for a 60 percent flat rate reduction of SO_2 emissions is analyzed. Since this approach does not explicitly make provisions for future growth in energy consumption, an alternative example explores the features of a strategy prescribing certain minimum emission standards for large sources (Section 5.2). Taking into account recent discussions on the potential of economic incentive instruments to determine (optimal) national emission levels, Section 5.3 analyzes the effects of introducing a uniform emission tax of 2500 DM/t SO_2 throughout Europe. This strategy is contrasted with a burden sharing approach, in which all countries would be required to use 0.2 percent of their GDP (the average costs of the 60 percent flat rate strategy) for reducing their domestic SO_2 emissions (Section 5.4).

5.1 Scenario E1: A 60 percent flat rate reduction of SO_2 emissions

As an extension of the current sulfur protocol, a case is analyzed in which the general reduction requirements are increased from the current 30 percent to 60 percent for all countries. For reasons of simplicity it is assumed in this example that all countries adhere exactly to this 60 percent rule, possibly revising their national legislation to less stringent emission standards. Due to the expected economic growth and increased energy consumption in Turkey, a 60 percent reduction is not considered to be achievable there in the year 2000; instead implementation of the maximum technically feasible reduction is assumed.

The results in Table 12 show that the problem associated with a flat rate policy also applies to a number of other growing economies: to comply with the 60 percent rule, a considerable share of the GDP would have to be used in Southern Europe. Whereas the burdens vary between 0 percent and 0.86 percent for implementation of the Current Reduction Plans (Scenario A), in the 60 percent flat rate scenario the variation ranges from 0 percent to 1.61 percent. Furthermore, the heavy burdens shift from East and Central European countries to those in the South-East, where currently very little action is being taken. However, due to their relatively low emission levels and low sensitivities of the ecosystems, environmental damage would be rather low in this region. On the other hand, the achievement of critical loads in North-West Europe, compared to Scenario A, does not improve significantly; because no substantial reductions are required on top of the current planning. The largest environmental improvements, in terms of critical loads achievement, occur in Central and East European countries: Austria, ČSFR, Hungary, Poland, etc., due to tighter obligations for the major emitters in this area (Figure 6).

SCENARIO E1: 60 % FLAT RATE

Country	Emissions kt SO_2	Reduction compared to 1980 (%)	Abatement Cost 10^6DM/ year	% of GDP	DM/ capita/ year	Deposition % of ecosystems above CL
Albania	40	60	225	1.61	59	0
Austria	155	60	381	0.15	50	7
Belgium	331	60	301	0.09	31	79
Bulgaria	413	60	1178	0.97	130	0
ČSFR	1240	60	1116	0.48	69	49
Denmark	179	60	85	0.03	16	23
Finland	233	60	265	0.11	52	24
France	1335	60	0	0.00	0	17
Germany, West	1284	60	2672	0.10	44	62
Germany, East	1705	60	580	0.17	36	74
Greece	160	60	806	0.56	79	0
Hungary	652	60	464	0.33	44	8
Ireland	88	60	203	0.25	50	4
Italy	1520	60	1168	0.06	20	9
Luxembourg	9	60	5	0.03	13	75
Netherlands	186	60	294	0.05	19	82
Norway	56	60	107	0.04	25	33
Poland	1640	60	3027	0.67	75	45
Portugal	106	60	396	0.36	37	0
Romania	720	60	2058	1.00	85	10
Spain	1300	60	1128	0.15	28	1
Sweden	205	60	334	0.08	39	52
Switzerland	50	60	85	0.02	13	6
Turkey	1341[3]	-59[2]	4771	1.10	71	0
UK	1939	60	2174	0.12	37	45
USSR[1]	5120	60	7765	0.27	43	3
Yugoslavia	520	60	2807	1.53	113	1
Total	22527	58	34395	0.20	46	14

Note: [1] European part of USSR within EMEP

[2] Increase

[3] Maximum technically feasible reductions

Table 11: Scenario E1: 60 % flat rate reduction of SO_2 emissions.

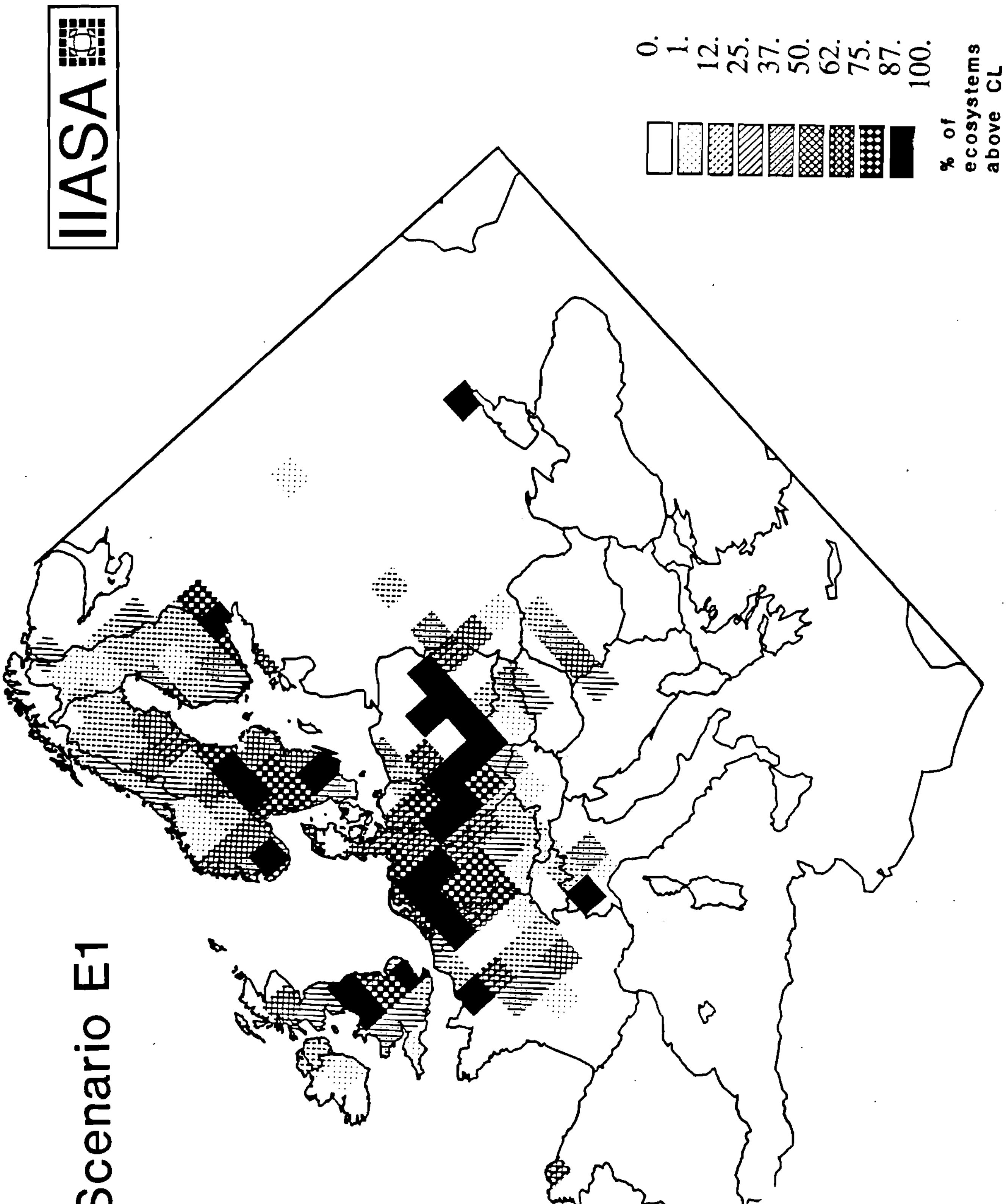

Figure 6: Regional distributions of ecosystems with sulfur deposition above critical loads for sulfur for SCENARIO E1 (60 % flat rate reduction). Data sources: IIASA, CCE, MSC-W.

Scenario E1: 60 % FLAT RATE

	Relative emission reduction		Abatement costs		Exceedance of CL	
Rank		%		% of GDP		% of ecosystems
1	all countries	60 %	ALB	1.61	NL	82
2			YU	1.53	BEL	79
3			TUR	1.10	LUX	75
4			ROM	1.00	FRG-E	74
5			BUL	0.97	FRG-W	62
6			POL	0.67	SWE	62
7			GRE	0.56	ČSFR	49
8			ČSFR	0.48	UK	45
9			POR	0.36	POL	45
10			HUN	0.33	FIN	24
	EUROPE	60	EUROPE	0.20	EUROPE	14

Table 12: List of the top-ten countries of relative emission reductions, abatement costs and area with deposition above critical loads for Scenario E1 (60 % flat rate reduction).

5.2 Scenario E2: Minimum technical emission standards

As demonstrated, flat rate strategies do not take into account structural changes and economic growth, resulting in high burdens on countries starting with a comparably low level of emissions. Other source-oriented approaches are able to provide flexibility for growing economies. As an example a strategy is discussed that extrapolates the major requirements of the EEC Directive on Large Combustion Plants to all European countries cooperating within the UN/ECE framework. For certain emitters the directive specifies minimum technical standards for emissions. In particular, common standards are defined for new plants, and country-specific emission caps are set for emissions from existing boilers.

For simplification, the example assumes the following regulations:

- use of heavy fuel oil with a maximum sulfur content of 1 percent;
- desulfurization of all new coal power stations and refineries with an average removal efficiency of 95 percent;
- the old power plant stock in operation in the year 2000 has to be retrofitted with flue gas desulfurization;
- large industrial boilers fired with solid fuels have to be desulfurized, for simplification it is assumed that desulfurization will be applied to 50 percent of the emissions from industrial energy combustion,
- desulfurization of flue gases from refineries,
- and a 30 percent decline in industrial process emissions.

The RAINS data base has been used to derive the consequences on national emission levels. As a result, overall European SO_2 emissions decline by 61 percent. Since the high emission densities in Europe are mainly caused by large combustion plants, priority for reduction is automatically focused on countries with a high share of power plants and industrial emissions. This applies to some Western European countries such as the UK, FRG-W, France, Spain etc., but also to the large emitters in Central and Eastern Europe (FRG-E, ČSFR, Poland). Countries with an expected growth in energy consumption have comparably lower reduction requirements, e.g., Albania, Turkey, Greece.

As a result, total European costs amount to 32.8 billion DM/yr (0.23 percent of GDP). Despite the high emission reductions in Western Europe the related cost burdens in these countries are in general around the average level (some 0.2 percent of GDP). For measures necessary in Eastern and Central Europe the burden is typically four times higher.

As a consequence of such a regulation, 89 percent of the European ecosystems would have sulfur deposition below critical loads. However, since in many cases the assumed measures are elements of the current EEC Directive on Large Combustion Plants, no major additional emission reductions are required for many EEC countries compared to the Current Reduction Plans (Scenario A). Consequently, environmental improvements in North-West Europe are limited, although the increased removal of emissions from the UK has certain positive effects on a number of countries in this region. Significant improvements in critical loads achievement occurs in Central Europe, for example, in the ČSFR only 23 percent of the ecosystems would have deposition above critical loads (instead of 81 with CRP), in Poland 29 percent instead of 74 percent, and in FRG-E 34 percent instead of 77 percent (Table 14).

SCENARIO E2: MINIMUM EMISSION STANDARDS

	Emissions		Abatement Cost			Deposition
Country	kt SO_2	Reduction compared to 1980 (%)	10^6DM/ year	% of GDP	DM/ capita/ year	% of ecosystems above CL
Albania	78	23	82	0.59	22	0
Austria	170	56	418	0.17	55	0
Belgium	285	66	675	0.19	69	62
Bulgaria	647	37	962	0.80	106	0
ČSFR	840	73	1773	0.77	110	23
Denmark	68	85	412	0.16	80	16
Finland	204	65	711	0.28	140	25
France	829	75	671	0.03	12	4
Germany, West	885	72	3630	0.14	60	41
Germany, East	555	87	1596	0.48	98	34
Greece	242	40	679	0.47	67	0
Hungary	715	56	423	0.30	40	7
Ireland	116	48	193	0.24	47	4
Italy	1172	69	2768	0.15	48	4
Luxembourg	11	54	4	0.03	11	25
Netherlands	119	74	501	0.09	32	73
Norway	110	23	26	0.01	6	32
Poland	1096	73	4139	0.92	103	29
Portugal	175	34	305	0.27	29	4
Romania	811	55	2059	1.00	85	11
Spain	921	72	1780	0.24	44	1
Sweden	298	42	201	0.05	23	53
Switzerland	74	41	16	0.00	2	4
Turkey	1797	-109[2]	2035	0.47	30	0
UK	1081	78	3621	0.19	62	26
USSR	6968	46	7793	0.27	43	3
Yugoslavia	585	55	2722	1.48	109	1
Total	20852	61	40195	0.23	53	11

Note: [1] European part of USSR within EMEP

[2] Increase

Table 13: SCENARIO E2: Minimum emission standards.

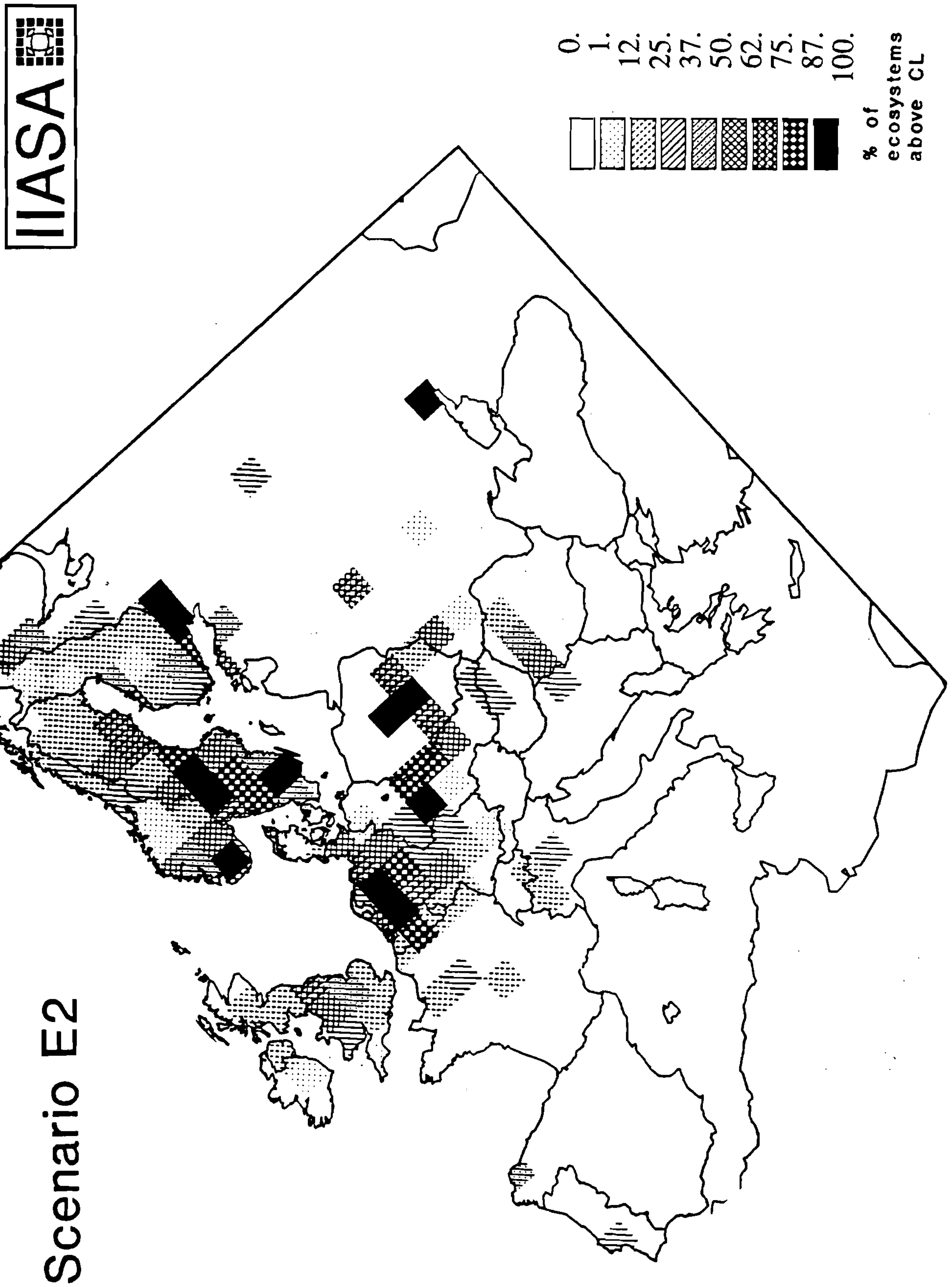

Figure 7: Regional distributions of ecosystems with sulfur deposition above critical loads for sulfur for Scenario E2 (Minimum emission standards). Data sources: IIASA, CCE, MSC-W.

Scenario E2: MINIMUM EMISSION STANDARDS

Rank	Relative emission reduction	%	Abatement costs	% of GDP	Exceedance of CL	% of ecosystems
1	FRG-E	87	YU	1.48	NL	73
2	DEN	85	ROM	1.00	BEL	62
3	UK	78	POL	0.92	SWE	53
4	FIN	65	BUL	0.80	FRG-W	41
5	NL	74	ČSFR	0.77	FRG-E	34
6	POL	73	ALB	0.59	NOR	32
7	ČSFR	73	FRG-E	0.48	POL	29
8	SPA	72	GRE	0.47	UK	29
9	FRG-W	72	TUR	0.47	LUX	25
10	ITA	69	HUN	0.30	FIN	25
	EUROPE	61	EUROPE	0.23	EUROPE	11

Table 14: List of the top-ten countries of relative emission reductions, abatement costs and area with deposition above critical loads for Scenario E2 (Minimum emission standards).

5.3 Scenario E3: Emission charge of 2500 DM/t SO_2

As an alternative approach, cost-effective strategies might be defined by prescribing reduction measures with marginal costs lower than a certain level. At least in theory, the selection of appropriate measures could be automatically achieved by introducing a tax on the remaining emissions. Thereby, all reductions with marginal costs below the tax level would result in cost-savings for the emitter. Such emission charges have recently been introduced in some countries in Europe (e.g. in Sweden, 30 Swedish Crowns/kg sulfur = 4300 DM/t of SO_2).

The example described here assumes a uniform tax for all countries of 2500 DM/t of SO_2 emitted. The cost curves implemented in the RAINS model show sharp increase of marginal costs beyond this level for all countries (Amann & Sorensen, 1991).

As a result, total European emissions would decline by 72 percent. Similar to Scenario E2, the highest reductions occur in those countries with high shares of emissions from large combustion plants (FRG-E, Spain, UK, Italy, etc.) and where marginal costs of reduction are low.

Since this concept has the cost-effectiveness principle incorporated (all measures with marginal costs below the charge are implemented), total costs are only slightly higher than in Scenario E2 (minimum emission standards), but significantly more SO_2 is being reduced. With this approach the highest burdens are placed on countries in Eastern and Southern Europe (Table 16). In these countries, up to 1.5 percent of the GDP would be required, whereas in the Netherlands, Norway and Switzerland for example only between 0.01 and 0.04 percent of GDP would need to be diverted.

Although the emission charges in this example do not take into account differences in environmental sensitivities, the increased sulfur removal has positive impacts on ecosystems. In Europe, 93 percent of the ecosystems would have sulfur deposition below critical loads. Although most exceedances still would occur in the North-Western part of Europe, considerable improvements are achieved by reducing emissions from the strong emitters in this region. The largest improvements, however, also in comparison to the other scenarios introduced up to now, take place in Central and Eastern Europe, where in many countries less than 15 percent of the ecosystems would exceed the critical loads (ČSFR, Poland, Hungary, etc.).

SCENARIO E3: EMISSION CHARGE 2500 DM/t SO_2

	Emissions		Abatement Cost			Deposition
Country	kt SO_2	Reduction compared to 1980 (%)	10^6DM/ year	% of GDP	DM/ capita/ year	% of ecosystems above CL
Albania	58	43	109	0.78	29	0
Austria	205	47	249	0.10	33	0
Belgium	324	61	318	0.09	32	61
Bulgaria	323	60	1344	1.11	148	0
ČSFR	855	72	1680	0.73	104	16
Denmark	171	62	103	0.04	20	16
Finland	262	55	191	0.08	38	19
France	629	81	903	0.04	16	3
Germany, West	829	74	3700	0.14	61	39
Germany, East	504	88	1686	0.50	104	25
Greece	179	55	755	0.52	74	0
Hungary	633	61	511	0.37	49	3
Ireland	66	70	256	0.31	63	2
Italy	615	84	2786	0.15	49	1
Luxembourg	10	58	4	0.03	11	15
Netherlands	259	44	76	0.01	5	76
Norway	62	56	91	0.04	21	28
Poland	947	77	4330	0.96	107	13
Portugal	97	64	416	0.37	39	0
Romania	494	73	2314	1.13	95	4
Spain	490	85	2195	0.29	54	0
Sweden	167	68	420	0.10	49	44
Switzerland	60	52	44	0.01	7	0
Turkey	1915	23	1381	0.32	21	0
UK	790	84	3892	0.21	67	17
USSR[1]	3370	74	10381	0.36	58	0
Yugoslavia	507	61	2835	1.54	114	1
Total	14821	72	42970	0.24	57	7

Note: [1] European part of USSR within EMEP

Table 15: Scenario E3: Reductions up to marginal costs of 2500 DM/t SO_2

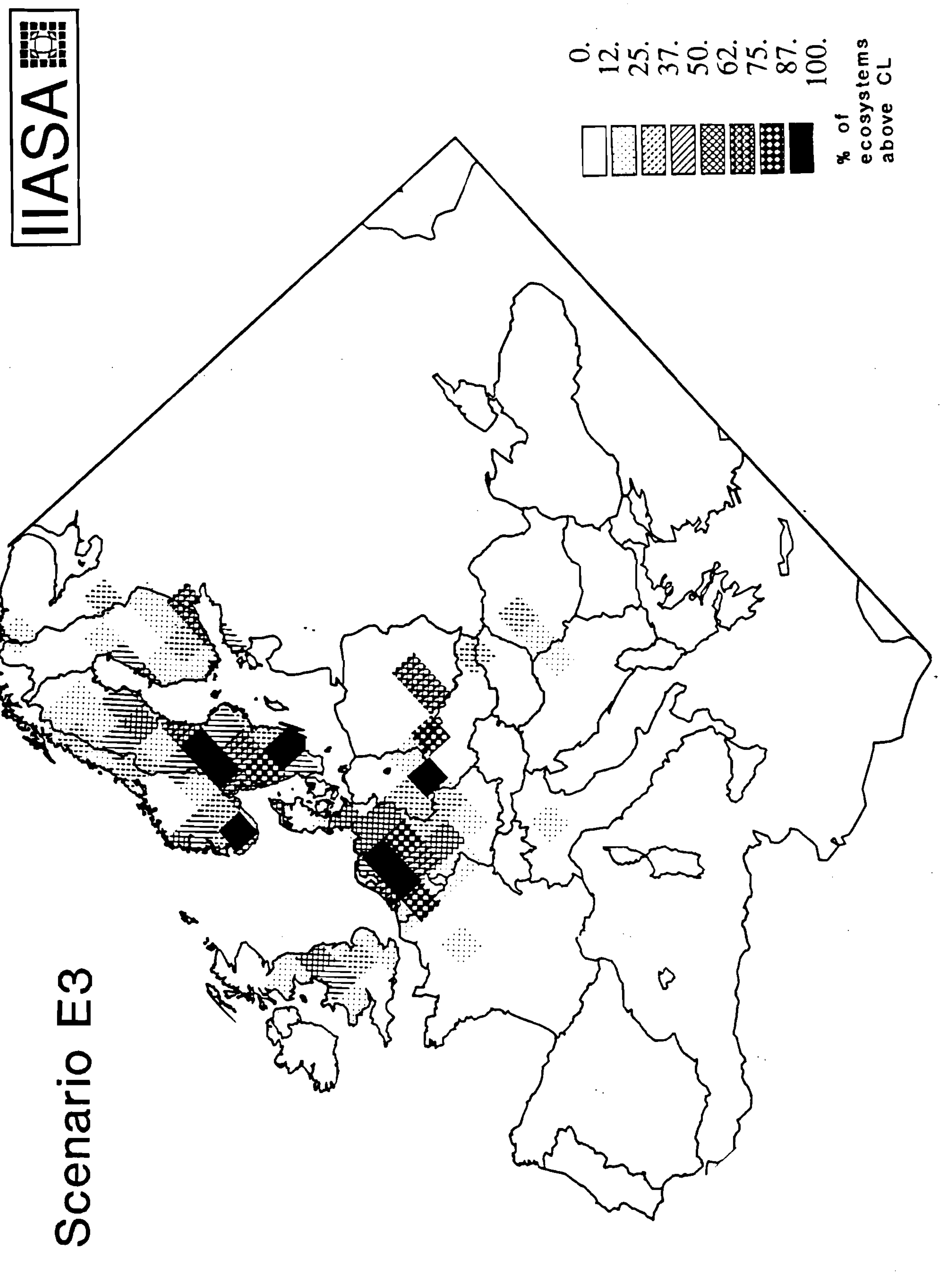

Figure 8: Regional distributions of ecosystems with sulfur deposition above critical loads for sulfur for reductions up to 2500 DM/t SO_2. Data sources: IIASA, CCE, MSC-W

SCENARIO E3: EMISSION CHARGE 2500 DM/t SO_2

Rank	Relative emission reduction	%	Abatement costs	% of GDP	Exceedance of CL	% of ecosystems
1	FRG-E	88	YU	1.54	NL	76
2	SPA	85	ROM	1.13	BEL	61
3	UK	84	BUL	1.11	SWE	44
4	ITA	84	POL	0.96	FRG-W	39
5	FRA	81	ALB	0.78	NOR	28
6	POL	77	ČSFR	0.73	FRG-E	25
7	USSR	74	GRE	0.52	FIN	19
8	FRG-W	73	FRG-E	0.50	UK	17
9	ROM	73	HUN	0.37	ČSFR	16
10	ČSFR	72	TUR	0.32	DEN	16
	EUROPE	72	EUROPE	0.24	EUROPE	7

Table 16: List of the top-ten countries of relative emission reductions, abatement costs and area with deposition above critical loads for Scenario E3 (Reductions with marginal costs lower than 2500 DM/t SO_2).

5.4 Scenario E4: Emission reductions for 0.2 percent of GDP

The concept of emission charges, as introduced in Scenario E4, incorporates mechanisms for achieving cost-effectiveness, at least on a national level. However, as demonstrated above, cost-effectiveness does not automatically result in an equal distribution of burdens to national economies. In order to illustrate this difference a scenario is introduced in which all countries are obliged to reduce their emissions for an equivalent of 0.2 percent of their GDP. In this example the 0.2 level has been derived from the overall costs of Scenario E1 (60 percent flat rate) and is similar to the costs of the emission charge scenario (E3).

Table 17 presents the national emission levels if the 0.2 percent of GDP were optimally spent in each country. Most strikingly, some countries would not be able to spend 0.2 percent of their GDP for reductions of SO_2 emissions in any cost-effective way. For example, in France, the Netherlands, Norway and Switzerland even the implementation of the maximum technically feasible reduction would not use up all of the 0.2 percent. In these cases, the maximum feasible reductions have been assumed, but no redistribution of the remaining resources to other countries has been allowed.

For these funds, total European emissions would decline only by 47 percent because cost-effectiveness is not adhered to. Very expensive measures close to the maximum technically feasible are required from some countries. Not surprisingly, the highest reductions are allocated to countries of Northern and Western Europe with high GDP, e.g., Denmark 93 percent reduction, whereas only moderate measures could be implemented in Eastern and Southern countries, e.g., increasing emissions in Albania, Bulgaria, Romania etc., 20 percent decline in Poland, and 36 percent in the ČSFR.

Furthermore, the concentration of emission reductions in Western Europe, with few measures in Eastern European countries, results also in a relatively poor achievement of critical loads throughout Europe. At similar costs of other strategies, 15 percent of the ecosystems have deposition above critical loads compared to, for example, 14 percent of the 60 percent flat rate, and 11 percent of the emission charge scenario. The bad environmental performance of this strategy is mainly caused by the high exceedances in Eastern European countries: ČSFR 73 percent, Poland 72 percent, and FRG-E 63 percent.

SCENARIO E4: EMISSION REDUCTIONS up to 0.2 percent of GDP

	Emissions		Abatement Cost			Deposition
Country	kt SO_2	Reduction compared to 1980 (%)	10^6DM/ year	% of GDP	DM/ capita/ year	% of ecosystems above CL
Albania	135	-34[2]	28	0.20	7	0
Austria	119	69	500	0.20	66	7
Belgium	201	76	691	0.20	70	16
Bulgaria	1267	-23[2]	237	0.20	26	13
ČSFR	1979	36	452	0.20	28	73
Denmark	32	93	513	0.20	100	15
Finland	180	69	491	0.20	97	27
France	213[3]	94[3]	4040[3]	0.17	69	0
Germany, West	534	83	5167	0.20	85	36
Germany, East	1611	62	658	0.20	41	63
Greece	617	-54[2]	282	0.20	28	2
Hungary	933	43	274	0.20	26	20
Ireland	107	52	161	0.20	39	4
Italy	400	89	3640	0.20	64	1
Luxembourg	5	79	36	0.20	95	2
Netherlands	43[3]	91[3]	972[3]	0.17[3]	61	62
Norway	33[3]	77[3]	311[3]	0.13[3]	72	31
Poland	3280	20	878	0.20	22	72
Portugal	193	27	217	0.20	20	4
Romania	2728	-52[2]	402	0.20	17	48
Spain	1017	69	1472	0.20	36	1
Sweden	108	79	791	0.20	92	50
Switzerland	43[3]	66[3]	204[3]	0.06[3]	30	0
Turkey	2275	-165[2]	851	0.20	13	0
UK	1008	79	3557	0.20	61	25
USSR[1]	7282	43	5611	0.20	31	7
Yugoslavia	2065	-59[2]	361	0.20	14	15
Total	28408	47	32797	0.19	43	15

Notes: [1] European part of USSR within EMEP

[2] Increase

[3] Maximum technically feasible reductions

Table 17: Scenario E4: Emission reductions for 0.2 % of GDP.

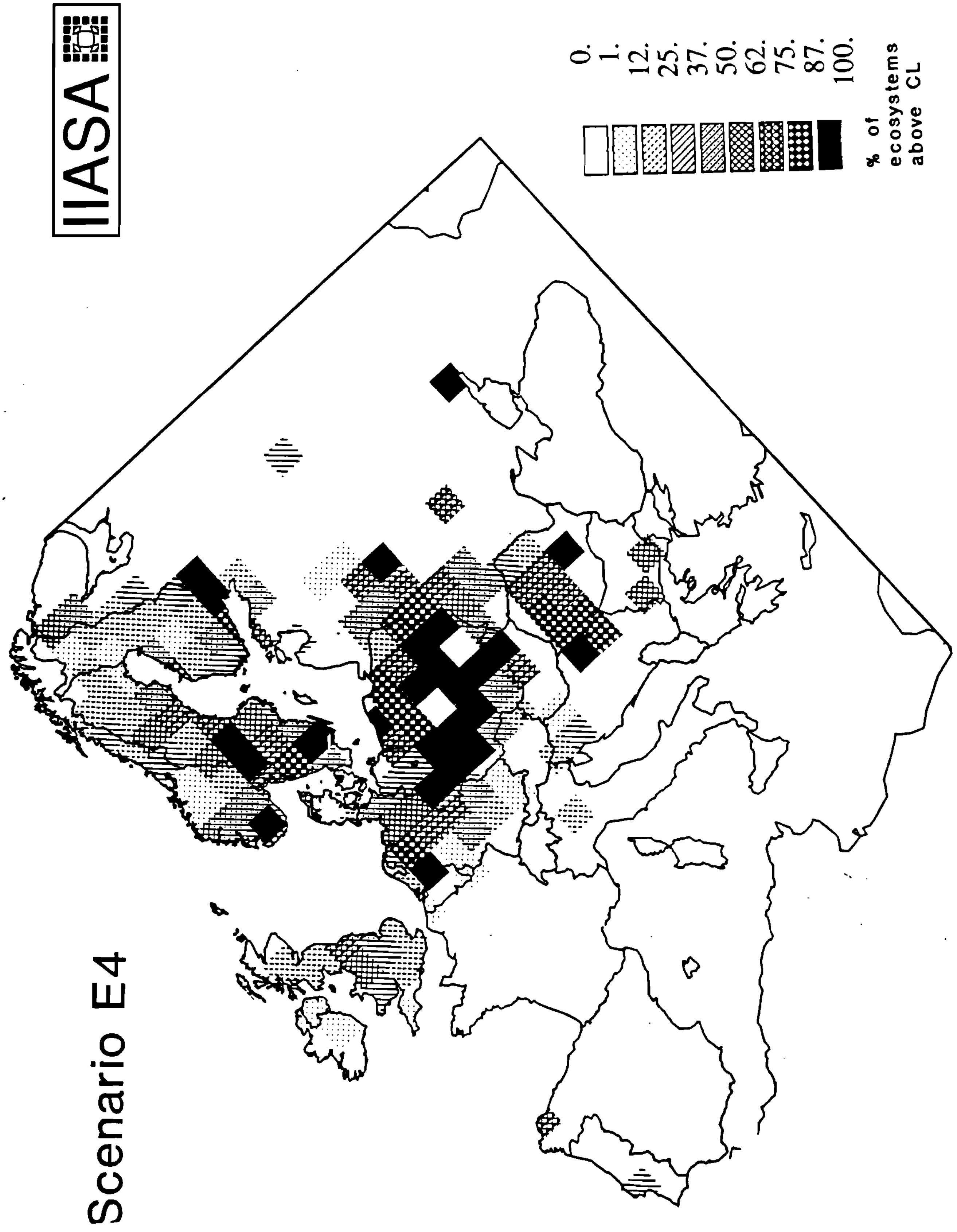

Figure 9: Regional distributions of ecosystems with sulfur deposition above critical loads for Scenario E4 (Emission reductions with cost up to 0.2 % of GDP). Data sources: IIASA, CCE, MSC-W

SCENARIO E4: EMISSION REDUCTIONS up to 0.2 % of GDP						
Rank	Relative emission reduction	%	Abatement costs	% of GDP	Exceedance of CL	% of ecosystems
1	FRA	94	all countries 0.2 %		ČSFR	73
2	DEN	93			POL	72
3	NL	91			FRG-E	63
4	ITA	89			NL	62
5	FRG-W	83			SWE	50
6	LUX	79			ROM	48
7	SWE	79			FRG-W	36
8	UK	79			NOR	31
9	NOR	77			FIN	27
10	BEL	76			BEL	16
	EUROPE	47	EUROPE	0.19	EUROPE	15

Table 18: List of the top-ten countries of relative emission reductions, abatement costs and area with deposition above critical loads for Scenario E4 (Emissions reductions for 0.2 % of GDP).

6 Cross-scenario Comparisons

This section provides tables with inter-scenario comparisons of reduction requirements, abatement costs (as percentage of GDP) and the exceedance of critical loads for the example cases introduced. The advantages and disadvantages of the various scenarios have to be identified on a country-by-country basis. The large number of countries involved in the analysis and the variety of aspects considered makes it difficult to draw any general conclusions about individual strategies.

One conclusion, however, does emerge: Transboundary air pollution in Europe is a highly interconnected problem; any efficient solution requires the cooperation of all European countries and cannot be achieved in isolation by only a few countries.

7 Conclusions

Since this paper has been prepared as a background document for the UN/ECE Workshop on 'Exploring European Sulfur Strategies' no further conclusions will be drawn at this time in order not to prejudice the international negotiation processes.

Relative Emission Reductions (% of 1980)

	Scenario					
Country	A	D1	E1	E2	E3	E4
Albania	-65	-66	60	23	43	-34
Austria	80	61	60	56	47	69
Belgium	48	92	60	66	61	76
Bulgaria	50	-12	60	37	69	-23
ČSFR	30	75	60	73	72	36
Denmark	60	95	60	85	62	93
Finland	54	92	60	65	55	69
France	60	93	60	75	81	94
Germany, West	73	88	60	72	74	83
Germany, East	65	92	60	87	88	62
Greece	-130	-130	60	40	55	-54
Hungary	33	61	60	56	61	43
Ireland	-5	77	60	48	70	52
Italy	41	72	60	69	84	89
Luxembourg	58	92	63	54	58	79
Netherlands	77	91	60	74	44	91
Norway	52	70	61	23	56	77
Poland	29	82	60	73	77	20
Portugal	-14	13	60	34	64	27
Romania	-81	73	60	55	73	-52
Spain	11	85	60	72	85	69
Sweden	65	81	60	42	68	79
Switzerland	52	52	60	41	52	66
Turkey	-278	-257	-56	-109	-123	-165
UK	50	90	60	78	84	79
USSR	36	76	60	46	74	43
Yugoslavia	-84	-52	60	55	61	-59
Total	29	69	58	61	72	47

Notes: Negative numbers indicate an increase in emissions

Scenario A: Current Reduction Plans
Scenario D1: Target loads without restriction
Scenario E1: 60 % flat rate reduction
Scenario E2: Minimum emission standards
Scenario E3: Emission charge 2500 DM/t SO_2
Scenario E4: 0.2 % of GDP for all countries

Table 19: Comparison of reduction percentages for the scenarios introduced above.

Abatement Cost as % of GDP

	Scenario					
Country	A	D1	E1	E2	E3	E4
Albania	0.00	0.00	1.61	0.59	0.78	0.20
Austria	0.26	0.15	0.15	0.17	0.10	0.20
Belgium	0.04	0.44	0.09	0.19	0.09	0.20
Bulgaria	0.86	0.27	0.97	0.80	1.11	0.20
ČSFR	0.12	0.85	0.48	0.77	0.73	0.20
Denmark	0.03	0.28	0.03	0.16	0.04	0.20
Finland	0.07	0.51	0.11	0.28	0.08	0.20
France	0.00	0.13	0.00	0.03	0.04	0.17
Germany, West	0.14	0.25	0.10	0.14	0.14	0.20
Germany, East	0.22	0.72	0.17	0.48	0.50	0.20
Greece	0.00	0.00	0.56	0.47	0.52	0.20
Hungary	0.14	0.35	0.33	0.30	0.37	0.20
Ireland	0.00	0.42	0.25	0.24	0.31	0.20
Italy	0.03	0.10	0.06	0.15	0.15	0.20
Luxembourg	0.03	1.29	0.03	0.03	0.03	0.24
Netherlands	0.09	0.16	0.05	0.09	0.01	0.17
Norway	0.03	0.07	0.04	0.01	0.04	0.13
Poland	0.31	1.22	0.67	0.92	0.96	0.20
Portugal	0.05	0.12	0.36	0.27	0.37	0.20
Romania	0.00	1.11	1.00	1.00	1.13	0.20
Spain	0.03	0.30	0.15	0.24	0.29	0.20
Sweden	0.10	0.22	0.08	0.05	0.10	0.20
Switzerland	0.01	0.01	0.02	0.00	0.01	0.06
Turkey	0.00	0.03	1.10	0.47	0.32	0.20
UK	0.08	0.31	0.12	0.19	0.21	0.19
USSR	0.17	0.40	0.27	0.27	0.36	0.20
Yugoslavia	0.00	0.26	1.53	1.48	1.54	0.20
Total	0.09	0.29	0.20	0.23	0.24	0.19

Scenario A: Current Reduction Plans
Scenario D1: Target loads without restriction
Scenario E1: 60 % flat rate reduction
Scenario E2: Minimum emission standards
Scenario E3: Emission charge 2500 DM/t SO_2
Scenario E4: 0.2 % of GDP for all countries

Table 20: Comparison of abatement cost (as percentage of GDP) for the scenarios introduced above.

Ecosystems Above Critical Loads (in %)

	Scenario					
Country	A	D1	E1	E2	E3	E4
Albania	0	0	0	0	0	0
Austria	19	0	7	0	0	7
Belgium	78	5	79	62	61	16
Bulgaria	1	6	0	0	0	13
ČSFR	81	9	49	23	16	73
Denmark	24	8	23	16	16	15
Finland	34	5	24	25	19	27
France	22	0	17	4	3	0
Germany, West	62	4	62	41	39	36
Germany, East	77	14	74	34	25	63
Greece	0	1	0	0	0	2
Hungary	31	7	8	7	3	20
Ireland	14	1	4	4	2	4
Italy	14	2	9	4	1	1
Luxembourg	75	0	75	25	15	2
Netherlands	82	17	82	73	76	62
Norway	37	24	33	32	28	31
Poland	74	2	45	29	13	72
Portugal	8	7	0	4	0	4
Romania	55	11	10	11	4	48
Spain	5	0	1	1	0	1
Sweden	58	36	52	53	44	50
Switzerland	13	3	6	4	0	0
Turkey	0	0	0	0	0	0
UK	51	8	45	26	17	25
USSR	10	0	3	3	0	7
Yugoslavia	21	10	1	1	1	15
Total	22	4	14	11	7	15

Scenario A: Current Reduction Plans
Scenario D1: Target loads without restriction
Scenario E1: 60 % flat rate reduction
Scenario E2: Minimum emission standards
Scenario E3: Emission charge 2500 DM/t SO_2
Scenario E4: 0.2 % of GDP for all countries

Table 21: Comparison of ecosystems above critical loads for the scenarios introduced above.

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