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ACID RAIN ABATEMENT STRATEGIES IN EUROPE

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ABSTRACT

The paper describes briefly the RAINS (Regional Acidification Information and Simulation) model and presents three alternative abatement strategies for acidification in Europe. These alternatives are: a percentage reduction of emissions per country, reductions based on indicators and targetted emission reductions.

INTRODUCTION

International deliberations on reductions of effects of acid deposition are dominated by the flat-rate-of-reduction paradigm. This is demonstrated by the protocol signed by 21 countries in July 1985 in Helsinki. Article 2 of this protocol reads: "The parties shall reduce their national annual sulphur emissions or their transboundary fluxes by at least 30 percent as soon as possible and at the latest by 1993 using 1980 levels as the basis for calculation of reductions". Based on 1980 emissions the total reduction resulting from the European signatories would amount to roughly 7,500 kilotonnes sulfur, this is 25% of the emissions in Europe.

Although from a political point of view 30% reduction of SO_2 emissions in 21 countries can be considered as a good step forward in abating effects of acidification, one may wonder how effective and how efficient this flat rate policy is. It could well be that another distribution of 7,500 kilotonnes reduction of emissions would be more effective. The problem, however, is to define effectiveness. Ideally one should measure effectiveness in terms of reduced effects of acid deposition on effect categories like lakes, soils, forests, crops, materials, etc. To that end it would be necessary to identify:

1. the dose effect relationships for the effect categories;
2. the location of the lakes, soils, etc., exposed to acid deposition (the stock at risk);
3. the deposition levels; and
4. the link between deposition levels and emissions.

This information is only partially available on the regional scale of Europe. Nevertheless policies to abate acidification are being developed and carried out.

In an attempt to assist these policies, the International Institute for Applied Systems Analysis (IIASA) has started an Acid Rain Project which developed a set of linked computer models describing the bond between human activities and pollution effects.

In this paper we will briefly introduce this model, known as the RAINS (Regional Acidification INformation and Simulation) model. Detailed description of RAINS can be found in Alcamo et al. [ref. 1] and Hordijk [ref. 2]. Furthermore we will show some results of using RAINS. These results are meant to be examples of abatement strategies and do not intend to be policy advices nor do they reflect the view of IIASA or the National Member Organizations that support it.

THE RAINS MODEL

Figure 1 describes the current status of the RAINS model. Starting from the left hand side of the figure the RAINS data bank contains a number of different energy pathways for Europe. These energy pathways have been derived from publications by the Economic Commission for Europe [ref. 3] and the International Energy Agency [ref. 4] for each of 27 larger European countries. The energy use per country is broken down into 8 categories of fuel: hard coal, brown coal, derived coal, light oil, heavy oil, derived oil, gas and others (hydro, nuclear, biomass). The emission producing sectors are conversion (refineries), power plants, industry, domestic, transport and other. The emissions of SO_2 per fuel

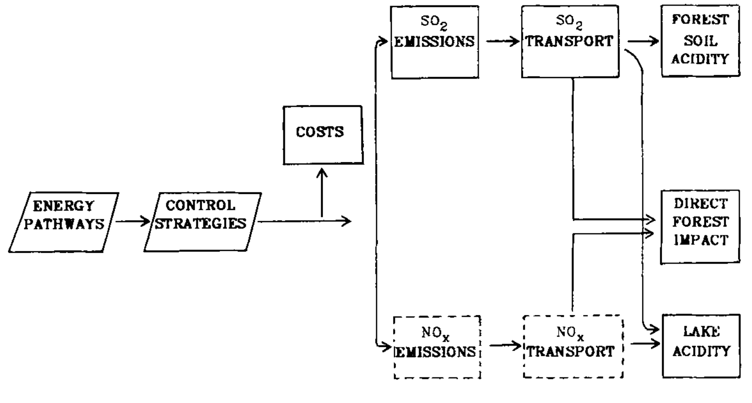

Fig. 1. Current structure of the RAINS model and its submodels. Boxes with dashed lines indicate that the submodel has not yet been implemented.

and per sector have been calculated using sulfur content and heat values of the fuels. These numbers were collected from many different data sources, both international (UN, OECD) and national. The number of energy pathways in RAINS will be extended to include a pathway in which maximal natural gas use is assumed and a pathway reflecting increased efforts in energy conservation throughout Europe. In this way a wide range of possible energy futures will be covered by the RAINS data bank.

The model user has many ways to influence model runs. This begins with the choice of an energy pathway. Since we consider the energy future to be one of the largest uncertainties, we have left the choice of a particular energy future to the user. The next submodel of RAINS, which calculates SO_2 emissions, can also be influenced by the user. The menu of RAINS presents options for abatement strategies: switch to low sulfur fuels, physical or chemical fuel cleaning, desulfurization units on power plants and combustion modified power plants (e.g. fluidized bed combustion). The user can select a combination of strategies for any country or combination of countries and also select the year of implementation and the efficiency of the strategies. The costs of the control policy constructed by the user will then be presented.

The SO_2 emissions are input to the atmospheric transport submodel. Currently RAINS uses transfer matrices derived from the atmospheric transport model developed at the Meteorological Synthesizing Center-West of the Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) in Oslo. This model has been described inter alia in Eliassen and Saltbones [ref. 5] and WMO [ref. 6]. The transfer matrices are used to calculate deposition of sulfur in grid squares of 150 x 150 km all over Europe. A user of RAINS may obtain output in the form of European maps showing selected isolines of deposition or coloured maps showing total deposition patterns.

Output of the atmospheric transport submodel is used in the forest soil and lake acidity submodels. Soil acidification has been described as a decrease in the acid neutralizing capacity of the soil [ref. 7]. Such a decrease may coincide with a decrease in soil pH. The reaction of the soil to the incoming acid stress depends on its buffering properties. In the submodel these buffering properties are described using two variables, one for the gross potential (buffer capacity) and the other for the rate of the reaction (buffer rate). Buffering is assured to be governed by several reactions: carbonate, silicate weathering, cation exchange and aluminum buffering. The data bank for the forest soil submodel contains the spatial distribution of 88 soil types in grids of 1^{o} longitude by 0.5^{o} latitude. Model output is provided in maps and graphs for soil pH, Al^{3+} concentration, Ca^{2+}/Al^{3+} ratios and base saturation levels. The forest soil submodel has been described in detail in Kauppi et al. [ref.8], Kämäri et al. [ref.9] and Posch et al. [ref.13].

The lake acidification submodel consists of several modules for meteorology, hydrology, soil chemistry and water quality of lakes. The meteorologic module regulates the input flows of water and deposition to the soil and directly to the lake. The hydrologic and soil chemistry modules together determine the flow of ions leaching from the terrestrial catchment to the lake. New equilibrium concentrations in the lake water are then computed in the lake module. Currently the lake acidity submodel has been implemented for Finland and Sweden. Model output is in the form of maps of these countries showing spring or summer pH classes of lake areas. Documentation of the submodel is provided in Kämäri et al. [refs. 10, 11 and 12].

Present work in the RAINS model includes the further development of the cost and direct forest impact submodels, construction of sensitivity maps for groundwater acidification, development of a NO_x emissions submodel and extensive sensitivity and uncertainty analysis [refs. 13 and 14].

ABATEMENT OPTIONS IN EUROPE

Three Scenarios

In this section we will present a number of deposition maps representing different abatement policies in Europe. First we will describe these abatement policies.

As was stated in the Introduction 21 countries have pledged a 30% cut in SO_2 emissions. On top of that, several countries have announced higher reduction percentages. Table 1 column (1) presents an overview of those countries and their commitments. Together we have named these commitments Current Reduction Plans. The percentages shown in Table 1 have been derived from several official and unofficial sources.

The SO_2 emissions in 1980 have been calculated in the RAINS model and are shown in Table 2. The same table also shows the effects of the Current Reduction Plans (Column (1)).

As a next step in reducing SO_2 emissions we have looked at three indicators for emission intensity in each country. These indicators are: emissions per inhabitant, emissions per PJ, emissions per m^2. The indicators have been calculated for the year 1995, i.e. the year for which we assume that the Current Reduction Plans have been implemented. Next the median values for the three indicators are found and additional emission reductions are calculated such that values of three indicators are below the original medians for all European countries. Finally the average of the three reduction percentages was calculated and applied to the 1980 emissions of SO_2 in all European countries. We assumed that this scenario, Reductions Based on Indicators, will be implemented such that in the year 2000 the calculated reductions have been reached. Columns (2) of Table 1 and Table 2 present reduction percentages and emission totals, respectively.

TABLE 1

Percentage reduction of SO_2 emission in European countries based on 1980 emissions, for three scenarios.

Country	(1)	(2)	(3)
Albania	-	5	-
Austria	50	50	50
Belgium	50	60	50
Bulgaria	30	42	14
Czechoslovakia	30	71	50
Denmark	50	50	12
Finland	50	50	4
France	50	50	40
Fed. Rep. of Germany	60	40	50
German Dem. Rep.	30	77	40
Greece	-	23	5
Hungary	30	64	50
Ireland	-	8	17
Italy	30	40	49
Luxembourg	30	45	50
Netherlands	60	60	50
Norway	50	50	2
Poland	-	39	46
Portugal	-	4	3
Romania	-	9	33
Spain	-	44	8
Sweden	65	65	7
Switzerland	30	30	47
Turkey	-	11	2
United Kingdom	-	37	50
USSR (European part)	30	31	43
Yugoslavia	-	30	50
European average	25	44	40

(1) Current Reduction Plans

(2) Reductions Based on Indicators

(3) Targetted Emissions Reductions

Another alternative reduction scheme based on targetted deposition levels has been implemented. Since no agreed set of target areas exists in Europe we have taken the ten areas where according to our calculations the deposition in 1980 was the highest. We used a four year (1979-1982) average of EMEP transfer matrices to calculate these depositions. The ten areas are presented in Table 3 and figure 2 presents the spatial distribution of these points and a three dimensional deposition map for 1980.*) Using an algorithm developed and applied by

*) The mapping has been developed by Maximilian Posch and Jean-Paul Hettelingh at IIASA.

TABLE 2

Reduced levels of SO_2 emissions in European countries for three scenarios (kilotonnes S per year).

Country	1980	(1)	(2)	(3)
Albania	39	39	37	39
Austria	159	80	80	80
Belgium	432	216	173	216
Bulgaria	508	355	294	436
Czechoslovakia	1832	1282	531	916
Denmark	226	113	113	199
Finland	294	147	188	282
France	1657	829	829	994
Fed. Rep. of Germany	1602	641	641	801
German Dem. Rep.	2415	1691	556	1449
Greece	345	345	266	328
Hungary	813	569	293	406
Ireland	119	119	109	99
Italy	1898	1328	1139	968
Luxembourg	20	14	11	10
Netherlands	243	97	97	122
Norway	72	36	36	80
Poland	1741	1741	1062	940
Portugal	130	130	124	126
Romania	757	757	689	507
Spain	1879	1879	1052	1729
Sweden	243	85	85	226
Switzerland	67	47	47	36
Turkey	497	497	442	487
United Kingdom	2342	2342	1475	1171
USSR (European part)	8588	6012	5926	4895
Yugoslavia	837	837	586	419
Europe	29755	22225	16879	17949

(1) Current Reduction Plans

(2) Reductions Based on Indicators

(3) Targetted Emission Reductions

Shaw and Young [refs. 15 and 16] we derived emission reductions such that deposition throughout Europe will be 4.0 g $S/m^2/yr$ maximum. The maximum allowed emission reduction for all European countries was taken to be 50%. With this constraint it was impossible to reach the target level in the Donetz and Erzgebirge areas. Reduction percentages and emission levels for this scenario (Targetted Emission Reductions) are shown in columns (3) of table 1 and table 2, respectively.

TABLE 3

Ten areas in Europe with the highest calculated deposition levels in 1980.

Area	Approximate longitude/latitude	Country
Donetz	39/47.5	USSR
Erzgebirge	13/51	GDR/CSSR
Katowice	19/50	Poland
Bilo Gora	17/46	Yugoslavia
Lombardy	9/46	Italy
Börzsöny Hills	19.5/48	Hungary
Rhineland	7/51	FRG
West Yorkshire	-2/53*)	United Kingdom
Belgrade	21/45	Yugoslavia
Moscow	39/56	USSR

*) -2 indicates two degrees west of Greenwich

Resulting deposition patterns

The emission reductions calculated above lead to different deposition patterns The RAINS model provides several output modes to show these deposition patterns. Unfortunately it is not possible to reproduce the most illustrative of these modes: a colour map of Europe showing deposition in intervals 0-1, 1-2, 2-4, etc. g $S/m^2/yr$. Two other options of RAINS have been used below.

Figure 3 shows the 3 $g/m^2/yr$ isolines in the year 2000 for two scenarios: Current Reduction Plans and Reductions Based on Indicators. It can be concluded that the area covered by deposition greater than 3 grammes $S/m^2/yr$ isolines will be substantially lower in the case of the second scenario. In table 4 we present an overview of comparisons of the three scenarios.

It can be concluded that the Current Reduction Plans scenario already reduces peaks in deposition substantially. The other two scenarios which require larger emission reductions throughout Europe reduce the peaks even more. In these scenarios depositions greater than 5 g $S/m^2/yr$ have virtually disappeared. At the same time the area where the deposition is greater than 2 g $S/m^2/yr$ decreased by approximately the same percentage as the emission reduction. The major differences between the second and third scenarios are the following. The reduction required in the third scenario is limited to 50% based on 1980 figures whereas the Reduction Based on Indicators scenario points to very high reduction percentages in some Eastern European countries. As a result of this, the deposition pattern of the second scenario looks more flat than the one for the third scenario. The latter scenario shows deposition peaks in the Donetz and Katowice areas only. Figure 4 shows the resulting deposition map for the third scenario.

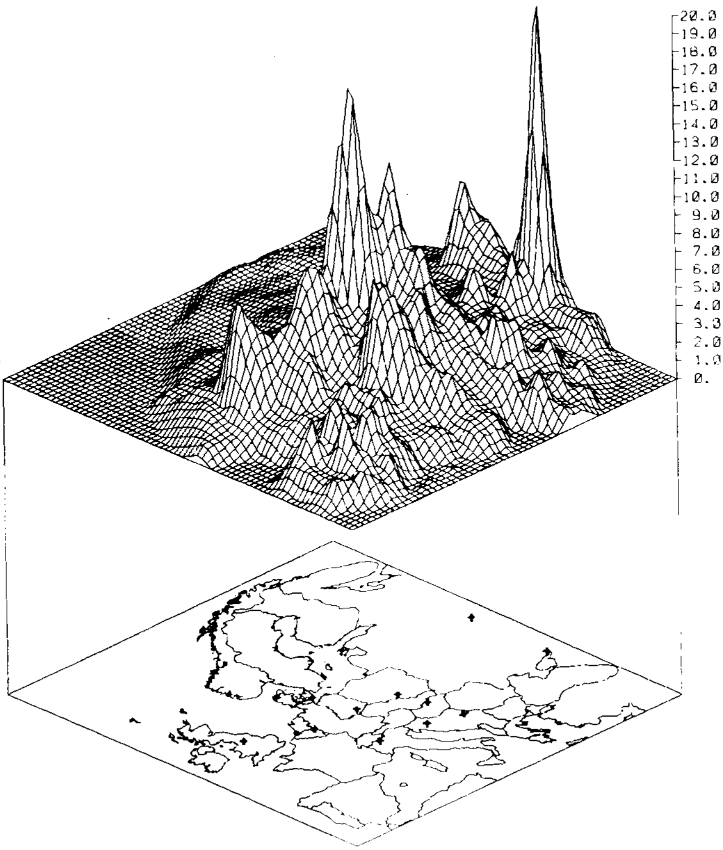

Figure 2. Calculated deposition (gram $S/m^2/yr$) in Europe. The ten highest deposition areas are indicated on the map.

CONCLUSION

The RAINS model can be used to evaluate different schemes for SO_2 emission reductions throughout Europe. We have focused on deposition patterns since this is the most advanced part of the RAINS model. Elsewhere we will present the effects of the scenarios presented on indicators for forest soil and lake acidification.

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TABLE 4.

A comparison of three scenarios with the 1980 situation.

		Scenario		
	1980	(1)	(2)	(3)
Emissions (ktonnes S/yr)	29,755	22,225	16,879	17,949
% Reduction based on 1980	-	25	44	40
Area covered by deposition				
> 2 g $S/m^2/yr$	55	43	30	33
> 4 g $S/m^2/yr$	21	10	2	4
> 5 g $S/m^2/yr$	12	5	1	2
> 9 g $S/m^2/yr$	2	1	0	0

(1) Current Reduction Plans

(2) Reductions Based on Indicators

(3) Targetted Emission Reductions

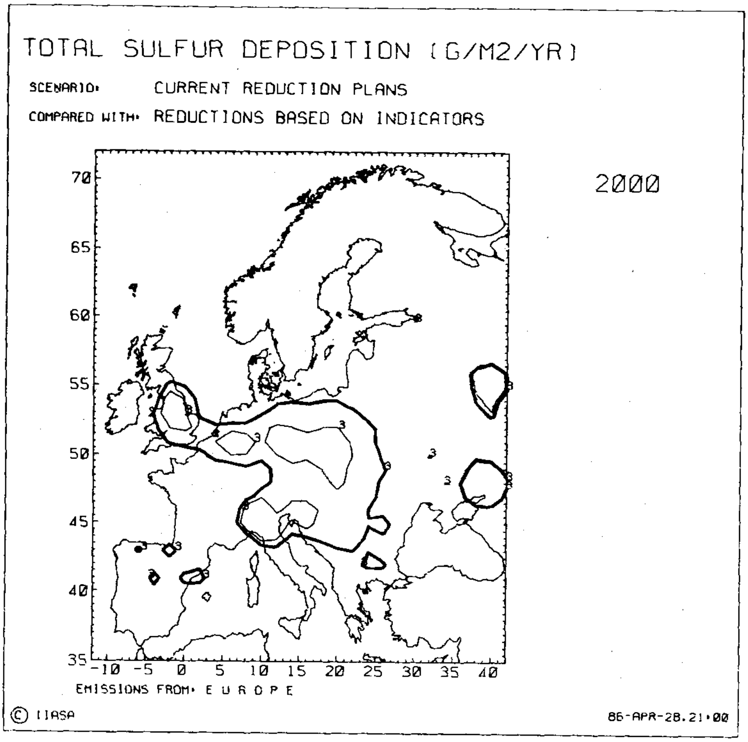

Figure 3. Calculated isolines of 3 g $S/m^2/yr$ for two scenarios in 2000.

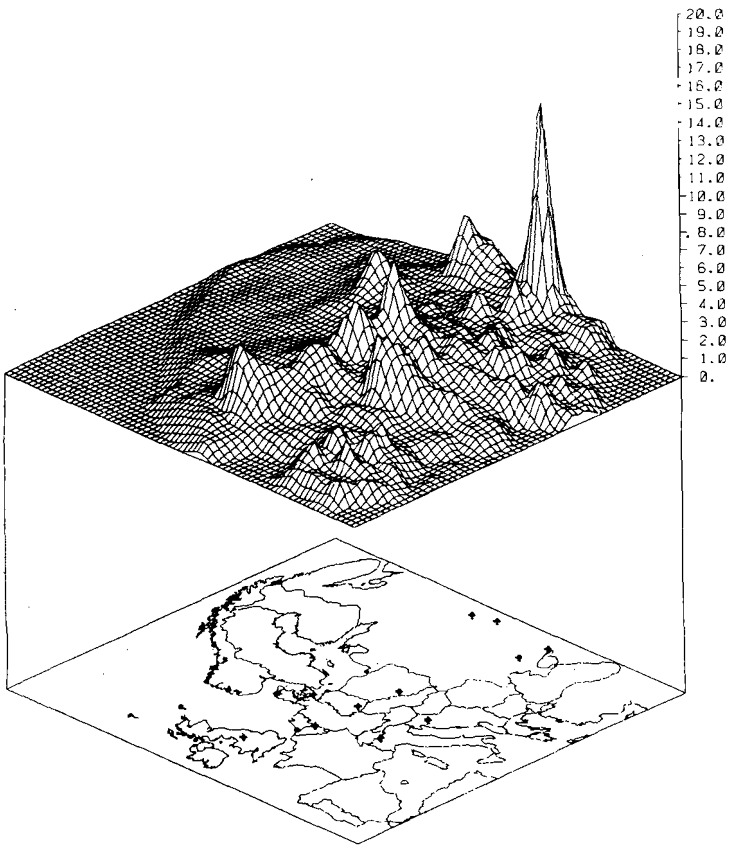

Figure 4. Calculated deposition (grammes $S/m^2/yr$) for Europe in 2000, for the Reduction Based on Indicators scenario.

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