

IIASA

# options

International Institute for Applied Systems Analysis

Winter '93



*Inside*

**Acidification**  
*Modeling Transboundary Air Pollution*

REPRINT

## **T H E B O O K :**

### ***The RAINS Model of Acidification Science and Strategies in Europe***

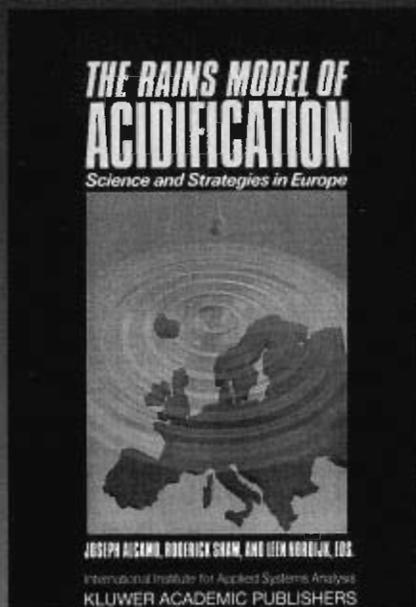
J. Alcamo, R. Shaw, and L. Hordijk, Editors

A clear and comprehensive description of the scientific basis of the RAINS Model, a review of major findings from early use of the model, and a systems perspective of the acidification problem in Europe.

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## **T H E M O D E L :**

A user-friendly computer model to assess acidification. Operational on IBM-compatible personal computers with MS-DOS operating system.

*Copies can be purchased from IIASA.*

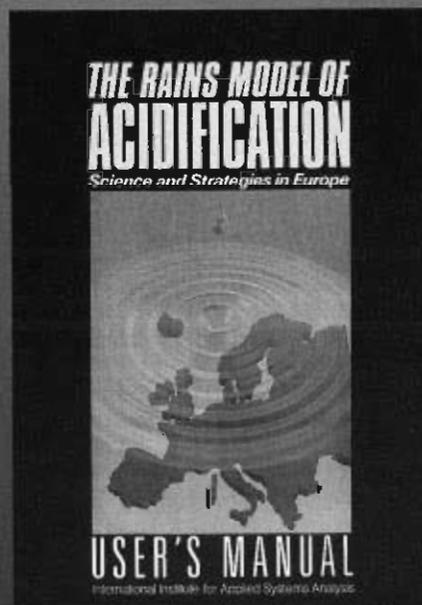
For more information please contact:  
Transboundary Air Pollution Project

A-2361 Laxenburg, Austria

Telephone: +43 2236 71521

Telefax: +43 2236 71313

E-mail [tap@iiasa.ac.at](mailto:tap@iiasa.ac.at).



# IIASA's PROJECT ON Transboundary Air Pollution

## EDITORIAL

Copyright © 1993 ISBN 0252 9572  
International Institute  
for Applied Systems Analysis  
A-2361 Laxenburg, Austria  
Telephone 43 2236 71521 0  
Telex 079137  
Telefax 43 2236 71313  
E-mail postmaster@iiasa.ac.at

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Managing Editor: Marc Clark  
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IIASA is an international, interdisciplinary research institution which draws on the scientific and financial resources of member organizations to address problems of global significance.

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We at IIASA are often asked about the usefulness of our work to decision makers. These questions are raised because of doubts that mathematical models of the sort characterizing IIASA's work are useful for people who grapple with messy policy options. How could simplified models capture the complexities and subtleties that confront politicians?

We don't delude ourselves that modeling can answer all policy questions. But we strongly believe that coherent, empirical models can be an important *aid* to decision-making. We can point to a number of IIASA models that have been used: none has been more successful than RAINS, the Regional Acidification Information and Simulation system, which is the main subject of this issue of *Options*.

RAINS is an outstanding example of IIASA's special strengths. It demonstrates the institute's ability to assemble a strong in-house research team, and at the same time to draw as needed on a wide network of specialists. Its use in important international negotiations underscores the importance of IIASA's international, nongovernmental status. The institute is seen to be neutral, free of direct governmental influence and national labels, which makes it an ideal base for impartial, scientific analysis of a politically sensitive issue like acid rain. This combination — a significant in-house research capacity, a powerful network, and clear impartiality — has helped the scientists behind RAINS to create a tool that is simple enough to help decision makers searching for ways to control air pollution cost-effectively, and scientifically sound enough to help scholars studying the impacts of airborne pollutants.

RAINS is continually growing and evolving. Currently it is being updated, expanded, and improved for use in Europe and in Asia. Financial support comes from IIASA and from a number of collaborating institutions, most notably the World Bank, the Netherlands Ministry of Housing, Physical Planning, and the Environment, and the German and Swedish Environmental Protection agencies. We are grateful to them for their support of this important work.

RAINS will undoubtedly affect the quality of the air that present and future generations of Europeans breathe. I hope that readers of the following pages get a sense of the high quality of the work and its very real impacts.

Peter E. de János  
Director

# Transboundary Air Pollution

Early in 1994, representatives of almost every country in Europe are expected to sign a comprehensive agreement to sharply reduce emissions of sulfur dioxide, the main cause of acid rain. This new SO<sub>2</sub> protocol will be a major step in the protection of the European environment. It will also mark a watershed in the application of science to international policy.

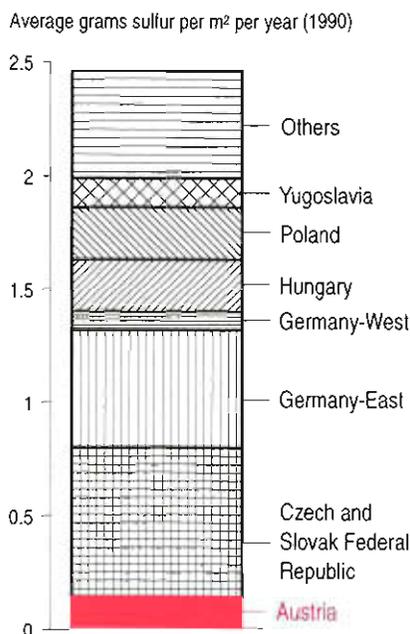
The negotiation of the protocol marks the first time that all parties to a major international treaty have accepted a computer simulation model — the Regional Acidification Information and Simulation model, RAINS, developed at IIASA — and made it an integral part of their negotiations. The negotiators accepted RAINS because it helped them to keep the talks on a sound scientific footing and, in the end, to negotiate a deal that gives the most environmental protection for the least money.

The RAINS model is the outcome of one of IIASA's most successful and innovative research efforts. Since 1983 dozens of scientists have worked at IIASA on RAINS and on related problems of regional and transboundary air pollution. The most important result has undoubtedly been the use of RAINS in the negotiation of protocols to limit air pollution in Europe, but project members have also explored other areas. Ongoing activities within the Transboundary Air Pollution project include:

- studies of the use of economic instruments to limit air pollution (page 14).
- development of the first consistent, comprehensive inventory of emissions of air pollutants in Central Europe (page 12).

- development of a RAINS-type model for use in Southeast Asia (page 10).
- continuing improvement of RAINS—Europe, dissemination of the model, and workshops to train users.
- an integrated assessment of strategies to reduce tropospheric (i.e., low-level) ozone (page 9).
- the synergisms and tradeoffs in controlling various air pollutants including CO<sub>2</sub> and other greenhouse gases, ozone, and acidifying pollutants.

Research is conducted by a 12-member team at IIASA in conjunction with a worldwide network of well over 100 scientists.



Sources of sulfur deposited in Austria, showing the importance of transboundary fluxes: fully 93 percent of the sulfur has its origin outside the country.

## A Description of the RAINS Model

RAINS is one of the first successful integrated assessment tools. It comprises a series of submodels that organize information in three categories: pollution generation and control, including costs; atmospheric transport and deposition; and environmental impacts, including submodels for lake and soil acidification (see figure opposite).

The model is essentially a scenario-generating device that helps users to visualize the impacts of future actions — or inaction — and to design strategies to achieve long-term environmental goals. With a few hours of training, scientists, bureaucrats, politicians, and other nontechnical users can put to RAINS any number of “what-if” questions: How much would it cost to convert Germany's coal-fired power plants to natural gas, and how would that change patterns of acid deposition? What is the cheapest way to halt acidification of forest soils in Bohemia? In all of Europe? RAINS gives answers to such questions, usually within minutes, using a personal computer.

The model highlights problems for negotiators and points out ways to save money — potentially vast amounts of it. Sample calculations show how targeting cuts in emissions can accomplish the same reductions as across-the-board cuts, but at a fraction of the cost. Alternatively, given the same sum of money, it shows how to get the most environmental benefit.

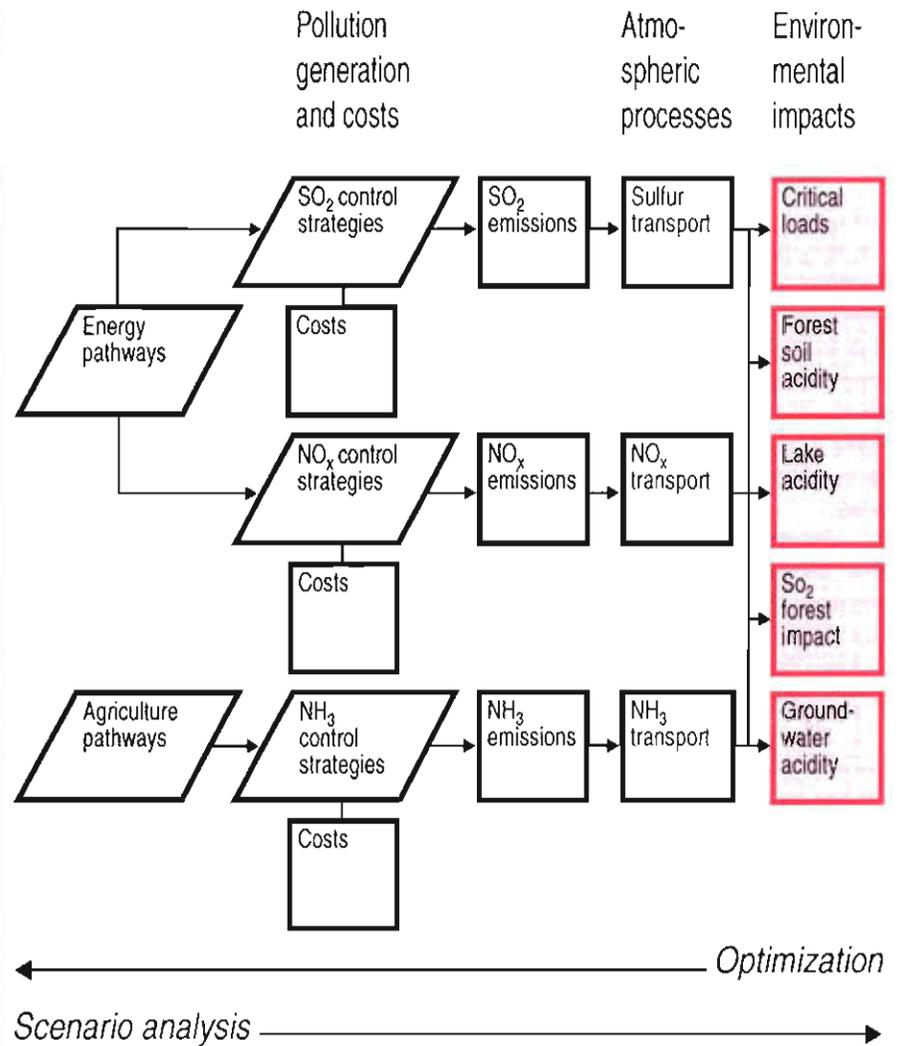
RAINS covers all of Europe as far east as the Urals, with a resolution of 150 by 150 kilometers. Databases and simulations extend back to 1960 and forward to 2040.

When RAINS was conceived in 1983 the project team adopted four guiding principles:

- *The model should be jointly designed by analysts, experts, and potential users.* The model was reviewed in detail by scientists at three meetings during the early stages of development; experienced bureaucrats and policy makers – the intended users – also attended the meetings and provided significant input. Development of RAINS was a truly international, multidisciplinary effort, involving economists, energy experts, engineers, meteorologists, soil scientists, forestry experts, limnologists, and other experts in some 20 countries. The model combines energy and emission data supplied by several international organizations, a meteorological model developed at the Norwegian Meteorological Institute, and ecological effects submodels using features developed in Finland, the Netherlands, and Germany.

- *The model should be of modular construction.* The first versions of RAINS contained information only on sulfur dioxide (SO<sub>2</sub> accounts for about 60 percent of acidifying emissions in Europe). Modules for nitrogen oxides (NO<sub>x</sub>, about 20 percent of emissions) were incorporated in 1989, and for ammonia (NH<sub>3</sub>, the remaining 20 percent) in 1992. Each submodel has been revised at least once. Databases are updated regularly.

- *Submodels should be simple yet based on more detailed data or models.* For example, relatively simple atmospheric transfer matrices are used to represent the complex relationship between emissions and depositions in Europe, but the matrices are based on complicated models of the transport of sulfur and nitrogen. The use of simple matrices makes it possible to perform calculations quickly on a personal computer.



RAINS' modular design allows for easy addition of new submodels; the nitrogen oxide chain (NO<sub>x</sub>), for example, was added in 1990, and ammonia (NH<sub>3</sub>) in 1992.

- *The model should have interactive inputs with flexible choices and clear graphic output.* Even the first versions of RAINS incorporated simple menus that helped users to explore the range of options. The latest version, RAINS 7.0, includes a new Windows-style interface.

More than 200 copies of RAINS and the user's manual have been sold to users in governments, universities, research institutions, non-governmental environmental organizations, and private companies. RAINS has served as a base for national acidification models in Finland, Hungary, and Ukraine, and

is currently used as a teaching aid in universities in several countries in Europe and in Canada.

It has also been a central element in well over 100 published scientific studies. At IIASA it was used in the first major effort to quantify the damage to European forests caused by acidification (*Options*, Sept '90). Efforts are currently under way to explore the regional environmental impacts of global energy scenarios being developed by IIASA's Environmentally Compatible Energy Strategies project.

But by far the greatest impact has been in the renegotiation of international protocols to control air pollution in Europe. ▶

## IIASA and the New Sulfur Protocol

British scientist R.A. Smith first noted the problem of acid rain in Europe in 1872, but it took another century before environmental acidification was widely recognized as a major problem. During that century the acidity of precipitation in Europe increased at least by a factor of 10. In the last 20 to 50 years, forest soils in large areas of the continent have become 5 to 10 times more acid.

Studies in the 1970s confirmed the long-distance, transboundary transport of air pollution. In November 1979 the Convention on Long-range Transboundary Air Pollution was signed by 35 countries, including all European countries, the Belarussian and Ukrainian republics of the former USSR, the USA, and Canada. The convention was negotiated through the UN Economic Commission for Europe, a Geneva-based body that was one of the few international organizations which brought together European countries from East and West. The UNECE convention was, and is, the framework for subsequent agreements to limit air pollution.

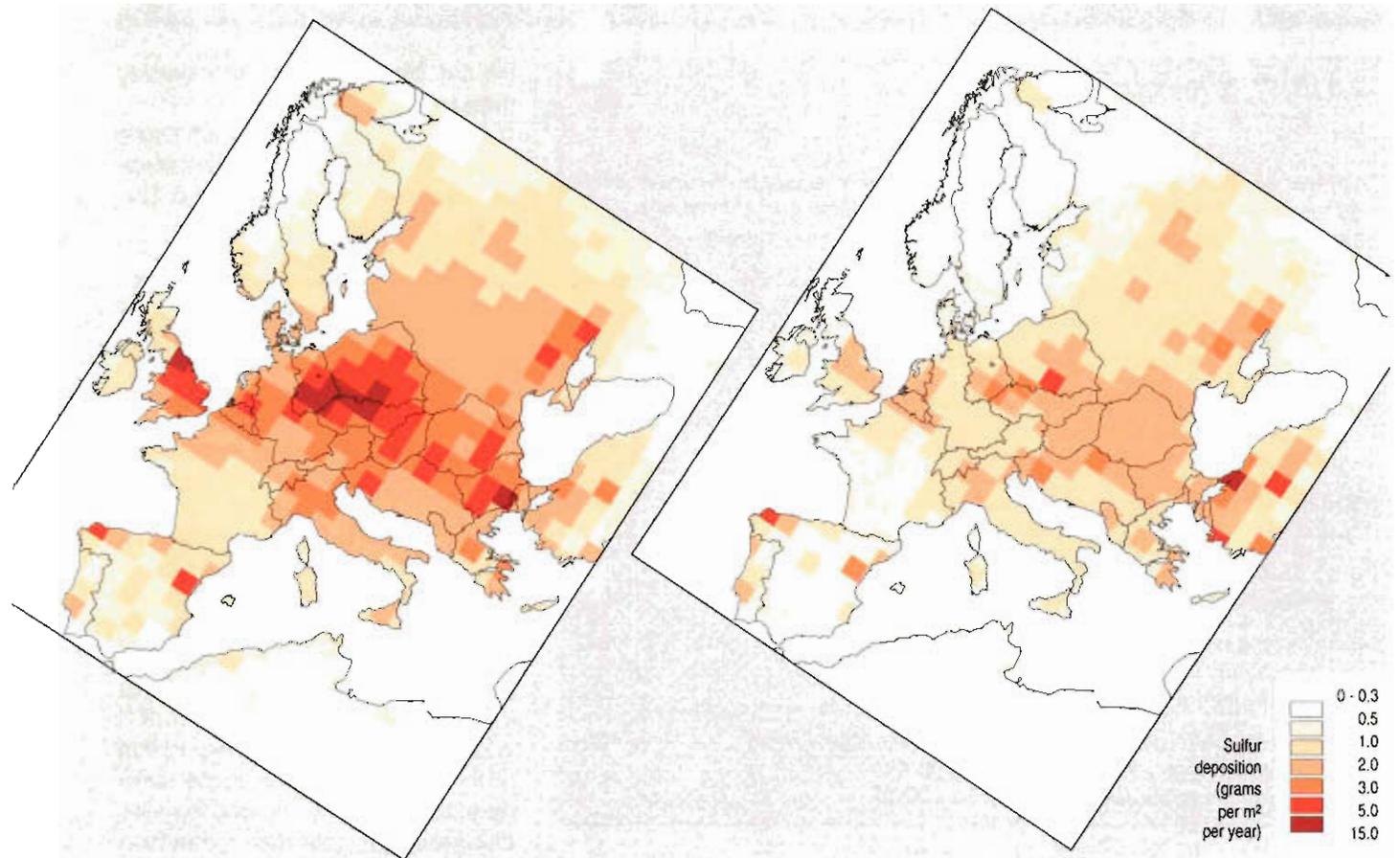
In July 1985 a protocol to the convention was signed by 20 countries. All signatories agreed to reduce their annual sulfur emissions or "exports" by at least 30 percent by 1993, relative to 1980. This protocol has been under renegotiation since 1990, and it is in these talks that IIASA's RAINS model has found its niche.

An agreement on a uniform 30 percent cut, while better than nothing, is crude and inefficient. It ignores the fact that some ecosystems are very sensitive to acidification while others are not; if the goal is to protect the environment, it makes little sense to cut emissions if they fall in places where they do no harm. Moreover, across-the-board cuts don't take into account the fact that some emissions can

Country or region	Emission Target		Abatement Costs			Protection
	Kilotons SO <sub>2</sub>	Percent change from 1980	Million DMs per year	Percent of GDP	Dms per capita per year	Percent of ecosystems
Albania	132	+31	0	0.00	0	100
Austria	78	-80	514	0.25	68	90
Baltic Region <sup>1)</sup>	89	-86	642	0.79	72	99
Belarus	457	-38	69	0.07	7	100
Belgium	190	-77	749	0.28	76	75
Bulgaria	520	-50	252	0.32	28	85
Former CSFR	853	-72	1234	0.61	79	80
Denmark	58	-87	656	0.47	128	93
Finland	116	-80	864	0.65	174	95
France	675	-80	442	0.03	8	99
Germany, West	520	-84	3863	0.29	77	67
Germany, East	230	-95	2247	0.29	77	67
Greece	595	+49	213	0.18	21	100
Hungary	521	-68	279	0.28	26	99
Ireland	132	-41	101	0.17	29	96
Italy	1042	-73	1327	0.09	23	92
Luxembourg	10	-58	7	0.06	19	87
Moldova	231	-30	90	0.23	21	100
Netherlands	106	-77	719	0.19	48	38
Norway	34	-76	293	0.27	69	77
Poland	1397	-66	2178	0.91	58	71
Portugal	294	+11	68	0.05	7	100
Romania	1065	-41	809	0.73	35	100
Russia <sup>2)</sup>	3725	-38	1334	0.53	14	100
Kola-Karelia	271	-58	313	0.53	14	100
St. Petersburg	105	-79	186	0.53	14	100
Spain	1485	-55	515	0.07	13	98
Sweden	88	-83	742	0.32	87	91
Switzerland	60	-52	16	0.01	2	85
Turkey	2887	+236	0	0.00	0	100
Ukraine	1696	-56	2065	0.44	40	100
United Kingdom	1011	-79	2439	0.17	42	91
Former Yugoslavia	1016	-22	766	0.39	32	93
Baltic Sea	74	+1	0	.	.	.
North Sea	174	+1	0	.	.	.
Atlantic Ocean	317	0	0	.	.	.
<b>EUROPE</b>	<b>22254</b>	<b>-59</b>	<b>25990</b>	<b>0.21</b>	<b>93</b>	<b>93</b>

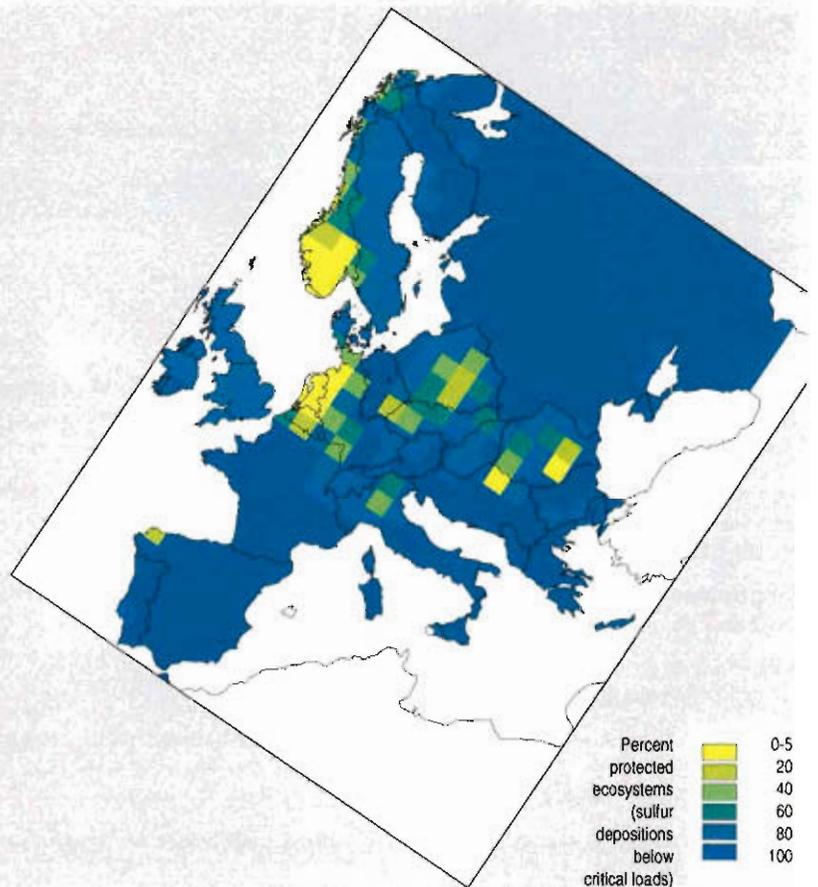
<sup>1)</sup> Estonia, Latvia, Lithuania, and Kaliningrad.

<sup>2)</sup> Russian Federation within the EMEP area, Kola-Karelia, St. Petersburg, and Kaliningrad regions excluded.



### Sulfur Emissions and Environmental Protection

The figures above show annual depositions of sulfur in Europe in 1990 (left) and assuming a 60 percent cut in depositions exceeding critical loads. The lower figure shows the percentage of ecosystems in each grid square that are protected – meaning sulfur depositions below critical loads – in this scenario (93 percent of the total, compared to 70 percent in 1990). The chart details what the 60-percent scenario would imply for countries and regions in Europe. The scenario was one of several produced by IIASA, using the RAINS model, at the request of parties negotiating a new protocol to control emissions of SO<sub>2</sub>. The negotiators have accepted it as the basis of the new protocol, which should be signed in 1994. Protocols to limit emissions of nitrogen oxides and ammonia are expected to follow. Depositions of sulfur account for about 60 percent of Europe's acidification; nitrogen oxides and ammonia each account for about 20 percent.



Data sources: RAINS-IIASA, EMEP-MSC/W, RIVM-CCE

## FEATURE

## RAINS Versions

This list shows the step-by-step evolution of RAINS over a 10-year period. Intermediate versions (RAINS 5.2, 5.3, etc.) had updated databases. More than 200 copies of RAINS have been sold to users in research, government, and private industry.

1.0 Initial model concept, implemented on mainframe computers (VAX/UNIX).	1984
2.0 Consolidated mainframe version for a major review meeting.	1986
3.0 First version for PC/DOS. Limited to emissions and transport of sulfur, environmental impact analysis for lakes, forest soils, and vegetation.	1987
4.0 Extension with modules for cost and for optimization of emissions reductions. First distributed version.	1988
5.0 Inclusion of emissions, control costs, and atmospheric transport of nitrogen oxides.	1990
6.0 Ammonia emissions included, introduction of the critical loads concept, new GEOMAN software to process geographical data.	1992
7.0 Model structure generalized to be applicable to any region, inclusion of large point sources, WINDOWS-like user's interface, implementation for Southeast Asia.	1994

## Selected Publications

A list of more than 90 publications is available from the Transboundary Air Pollution project.

**The RAINS Model of Acidification: Science and Strategies in Europe.** J. Alcamo, R.W. Shaw, and L. Hordijk editors. Kluwer Academic Publishers 1990. Hardback US \$117.50, Paper \$35.00.

**Emissions of Air Pollutants in the Region of the Central European Initiative – 1988.** Z. Klimont, M. Amann, J. Cofala, F. Gyarfas, G. Klaassen, W. Schöpp. IIASA SR-93-3, 1993. US \$20.

**Economic Restructuring in Eastern Europe and Acid Rain Abatement Strategies.** M. Amann, L. Hordijk, G. Klaassen, W. Schöpp, L. Sørensen. *Energy Policy*, Dec. 1992, pp. 1186-1197.

**Low Energy, Low Emissions: SO<sub>2</sub>, NO<sub>x</sub>, and CO<sub>2</sub> in Western Europe.** J. Alcamo and B. de Vries. *International Environmental Affairs*, Vol. 4, No. 3, 1992, pp. 155-184.

**Use of the RAINS Model in Acid Rain Negotiations in Europe.** L. Hordijk. *Environmental Science & Technology*, Vol. 25, No. 4, 1991.

**Modeling of Critical Loads for Acid Deposition in Austria.** W. Schöpp. IIASA SR-91-4, 1991. US \$7.

**Ammonia Emissions in Europe: Emission Coefficients and Abatement Costs.** Proceedings of a workshop held 4-6 February, 1991, at IIASA. G. Klaassen editor. IIASA CP-92-4, 1992. US \$20.

**Optimized Reductions of Nitrogen Emissions in Europe.** M. Amann and G. Klaassen. IIASA SR-92-7, 1992. US \$10.

**Trading of Emission Reduction Commitments for Sulfur Dioxide in Europe.** G. Klaassen and M. Amann. IIASA SR-92-3, 1992. US \$10.

be cut more cheaply and quickly than others.

RAINS was designed with these issues in mind. In 1989 a task force of the Executive Body of the UN-ECE convention noted:

An integrated assessment model that can assist in cost-effectiveness analysis is now available. . . . [The task force] recommends that the RAINS model be used by the Parties to the Convention, the Executive Body, and the various subsidiary bodies.

This was a historic resolution. To the best of our knowledge, it marked the first time that all parties to a major international negotiation have accepted a computer model and agreed to use it as a key tool in negotiations. The nearest parallel was in the 1970s during negotiation of the Law of the Sea; some large negotiating teams allowed smaller delegations to use their simulation models, but this was done informally. RAINS, by contrast would become a key part of the negotiation of the new sulfur protocol.

RAINS project members worked closely with members of the UN-ECE convention Working Group on Strategies, which acted as the negotiating body. Early in the talks IIASA generated sample scenarios to illustrate the use of RAINS to assess various options, related costs, and environmental impacts.

In June 1991 an important training session (sponsored by the Netherland Ministry of the Environment) was held at IIASA, when the leaders of almost all of the national negotiating teams spent three days practicing with RAINS and studying its potential use. Following the workshop IIASA staff routinely got phone calls from negotiating parties and members of the convention Executive Body asking how to do or interpret something with RAINS.

Meanwhile, IIASA staff members have had regular meetings in Geneva with other scientists in the UN-ECE Task Force on Integrated Assessment Modelling to discuss

new findings about acidification and to compare models and simulation techniques.

Over time the negotiating parties have accepted the concept of critical loads as a key to a successful agreement. Critical load is a quantitative estimate of an ecosystem's vulnerability to damage from pollution. In the case of RAINS, it refers to the amount of acid deposition that a region can tolerate annually without long-term damage. Vulnerability to acidity depends on local conditions, especially soil chemistry; soils derived from limestone, for example, can absorb and neutralize acids, while granitic soils can tolerate very little acid deposition. Other important factors are soil thickness, precipitation, and deposition of dust and other acid-neutralizing materials.

In the summer of 1992 the negotiating parties asked IIASA to use RAINS to analyze a range of scenarios that would optimize cuts in sulfur emissions, based on critical loads. In the end, they settled on a scenario that would leave only 7 percent of the ecosystems receiving sulfur depositions above their critical loads (currently about 30 percent are above). The results of this analysis, showing what it implies for sulfur emissions for each country or region, estimates of the costs to reduce emissions to these levels, and the percentage of ecosystems that would be protected are shown in the table and maps on pages 6-7.

At the time of writing, the national negotiating teams were proposing how close they could come to the emission targets set for them by RAINS. Some countries will probably agree to reduce less than their target; a few countries will probably pledge to exceed them. A final agreement is expected in 1994.

The coming years will see negotiation of new UN-ECE protocols for emissions of nitrogen. IIASA's RAINS team is prepared to play a similar role in these talks.

*Markus Amann*

## The Next Step *Tropospheric Ozone*

International agreements will probably lead to a gradual decline of acid deposition on natural ecosystems in Europe and North America. But concern is growing about another air pollutant: ozone.

Background concentrations of ozone in Europe today are at least twice as high as a century ago. Ozone in the lower parts of the atmosphere (tropospheric ozone, as opposed to stratospheric, or high-altitude, ozone) has been implicated as a contributor to forest dieback, damage to agricultural crops, and human health problems.

In 1994 and beyond, IIASA's Transboundary Air Pollution project will focus on the integrated assessment of ozone generation, much as it focused earlier on sulfur and other acidifying pollutants. The goal is to develop and add to RAINS an effective tool for the comprehensive analysis of strategies to reduce environmental impacts from both photo-oxidants and acidification.

Tropospheric ozone is a secondary pollutant, formed from emissions of nitrogen oxides, non-methane volatile organic compounds (NM-VOC), and carbon monoxide (CO). A reduction of ozone formation can be achieved only by a balanced cut in all three pollutants.

Ozone formation also depends on many other, to a certain extent local, factors, such as solar radiation and temperature. Reductions of one pollutant leading to lower ozone concentration in one part of Europe might turn out to be ineffective in other parts and, under certain conditions, might even increase concentrations.

An integrated assessment of ozone reduction strategies will have to combine information on the sources of NO<sub>x</sub>, NM-VOC, and CO emissions; the technical po-

tential for and the associated costs of emission reductions for these three pollutants; and an understanding of the chemical and physical processes in the atmosphere influencing ozone formation. Finally, an assessment of the regional sensitivity of ecosystems to high ozone concentrations and the potential impacts on human health will be necessary.

IIASA, in collaboration with the Free University, Amsterdam, is working on a RAINS database of information on past, current, and future NM-VOC emissions. The database will be finished in 1994, along with a module that explores options and costs of controlling NM-VOC emissions. Design and testing of the atmospheric part of the model will get under way, and the statistical relationship between peak level ozone concentrations and background concentrations will be studied.

The development of the ozone formation model is a major new activity within the project. In cooperation with the European Monitoring and Evaluation Programme at the Norwegian Institute for Meteorology — one of the main collaborators in the development of RAINS — a framework will be developed to allow a simplified representation of the impacts of reductions of various pollutants on ozone levels during vegetation growing seasons; recent research suggests that ozone has its greatest impact on vegetation at this time.

These elements will be combined in one consistent framework. In a further step IIASA will apply its expertise in nonlinear optimization techniques to develop strategies for balanced cuts of NO<sub>x</sub> and NM-VOC emissions, maximizing the environmental benefits in light of the potential tradeoffs.

*Markus Amann*

## FEATURE

## Modeling Acid Rain in Southeast Asia

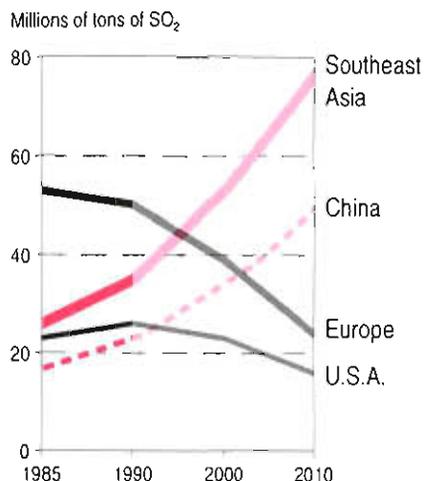
Until recently acidification of the environment was regarded as a big problem only in Europe and North America. But it is now clear that Southeast Asia is on the verge of an acidification problem as widespread and severe as anything seen in Europe or North America.

Spectacular economic growth in the region has led to sharp increases in consumption of energy and consequently in emissions of sulfur dioxide and other pollutants. Energy consumption has been doubling every 12 years. Local air pollution problems are already severe: 12 of the 15 most polluted cities in the world (i.e., highest levels of particulate matter) are in Asia. If nothing is done, widespread problems of acidification are only a matter of time.

In 1992 a group of scientists, including ex-IIASA researchers who are key members of the RAINS network, suggested to the World Bank that it supports development of a variant of RAINS for use in Southeast Asia. The original model was conceived only after Europeans saw the environmental damage done by acid rain and began signing agreements to limit transboundary pollution. In Asia air pollution is a more recent problem, damage from it is not yet widespread, and there are no international agreements to limit it. RAINS-Europe took eight years to develop; the idea behind RAINS-Asia is to prepare a comparable tool before the damage is evident.

IIASA will play a central role in the RAINS-Asia team, with responsibility for development of the model, for integration of inputs from other team members, and finally for calculation of possible strategies to control acidification in the region. IIASA's objectives are:

- to create a tool to investigate acidification in Southeast Asia;



*Sulfur dioxide emissions are expected to drop steadily in Europe and North America and to climb rapidly in Asia.*

- to analyze future emission and deposition levels;
- to explore sets of preventive measures.

The map opposite shows the region under study, with preliminary calculations of critical loads (the maximum long-term levels of exposure that can be tolerated without damage to the environment).

The RAINS-Asia model will be a variant of RAINS 7.0, the latest version. The European and Asian versions of the model will share the same software, but use different databases. The most important modifications and extensions are:

### The RAINS-Asia Team

*Below are some of the key institutions collaborating on the RAINS-Asia project. Many other institutions in Asia serve as local focal centers responsible for data collection and verification and, in the future, for the dissemination of project results.*

#### Energy and Emissions

**Resource Management Associates**, Madison, Wisconsin, USA, is responsible for energy demand forecasts. The **Argonne National Laboratory**, Argonne, Illinois, USA, participates in verification and comparison of emission inventories for the base year, 1990. The **Asian Institute of Technology**, Bangkok, Thailand, and the **Tata Energy Research Institute**, Delhi, India, are involved in the collection of energy and socioeconomic data needed for energy demand forecasting.

#### Atmospheric Transport

The **Indian Institute of Technology**, Delhi, coordinates the regional monitoring organization and assists in model development. The **University of Iowa**, Iowa City, USA, is responsible for calculations of atmospheric transport of pollutants and for development of pollution transfer matrices.

#### Impacts

The **National Institute for Public Health and Environmental Protection**, Bilthoven, the Netherlands, and the **Stockholm Environment Institute**, York, UK, and **Lund University**, Sweden, map critical loads for acidification. The **Center for Eco-environmental Sciences**, Beijing, is involved in data collection and model verification.

#### Integration and Coordination

**IIASA**, Laxenburg, Austria, is responsible for model development, integration of inputs from team members, and for strategy calculations. The **Agricultural University**, Wageningen, the Netherlands, is responsible for general project coordination.

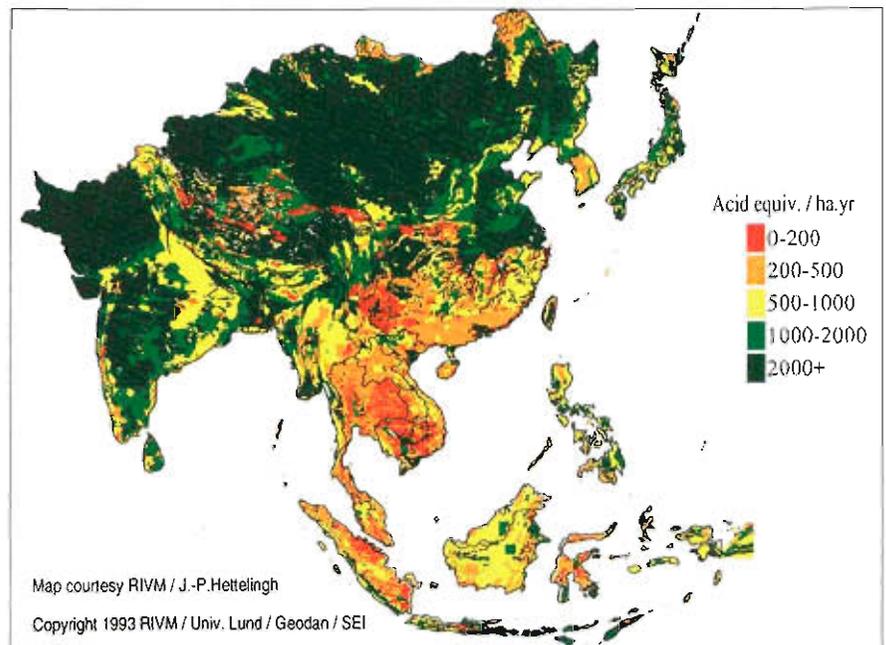
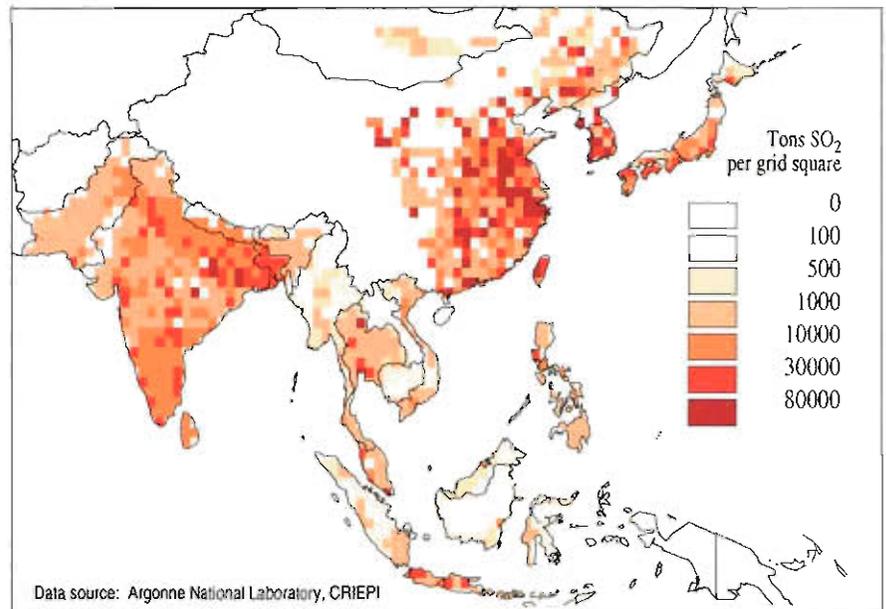
#### Funding

The project is financed by the **World Bank**. The contribution of Asian experts is financed by the **Asian Development Bank**.

- RAINS 7.0 calculates emissions and develops abatement strategies not only for aggregated economic sectors, but also treats separately the most important sources (mainly electricity generating stations) in each region.
- Links between emissions and deposition have been improved through the use of grid-to-grid emission transfer matrices for large point sources instead of country-to-grid matrices.
- Specification of fuels and sectors is more detailed.
- Input information has been organized into relational databases in dBase format, which allows for easier handling of data.
- The model has been reprogrammed in the object-oriented language C++. It also includes a Windows-style user interface. RAINS 7.0 can be used with different operating systems (DOS, WINDOWS, UNIX).

Work began on RAINS-Asia early in 1993. Phase I of the project, which includes the development of the prototype model and preliminary strategy calculations, should be completed by March 1994. The principal goal of Phase II will be to develop a module to analyze the impact of abatement strategies on air quality in big cities. Modules for nitrogen oxides and for optimization of emissions reductions might be added later.

Preliminary calculations of critical loads and current depositions with the prototype model suggest that critical loads for acidity are already being exceeded in much of Japan, China, and Indochina. If current trends continue for 30 years, emissions of sulfur dioxide could grow four-fold. Business-as-usual projections to the year 2020 indicate that depositions in large areas of Asia would be many times critical loads, causing rapid degradation of the environment.



*Preliminary calculations of SO<sub>2</sub> emissions in Southeast Asia in 1990 (top) and of critical loads; regional SO<sub>2</sub> emissions are expected to triple in the next 20 years.*

Even if the best available control technology were used it would cut emissions by only 70 percent, leaving them higher than in the base year, 1990. These preliminary calculations suggest that, if the countries in Southeast Asia are to prevent long-term environmental damage, they must begin thinking now about ways to conserve energy and to change the course of their structural development.

As stated above, these calculations are only preliminary; further work must be done to improve the model and data sets. But they underscore the need for a tool like RAINS to help Asian policy makers assess the environmental impacts of uncontrolled growth and to identify pathways to sound, sustainable development.

*Janusz Cofala*

## FEATURE

## An Emission Inventory for Central Europe

Until the political upheavals of 1989 and 1990, governments in Central Europe often treated environmental data as confidential information. Now it is possible to get information, but the quality and reliability of statistical material are in many cases still questionable, and the international consistency, and consequently the comparability, of the environmental data of this region has still to be established.

In 1993 IIASA, with support from the Italian Ministry of the Environment, published the first comprehensive, consistent inventory of

emissions of air pollutants for Austria, Croatia, the Czech Republic, Hungary, Italy, Poland, Slovakia, and Slovenia, the members of the Central European Initiative (CEI). *Emissions of Air Pollutants in the Region of the Central European Initiative - 1988* contains data and analysis of emissions of sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), particulate matter, and carbon dioxide (CO<sub>2</sub>) in 1988, the last year before the collapse of socialism in Central Europe.

Earlier estimates of emissions in Central Europe were based

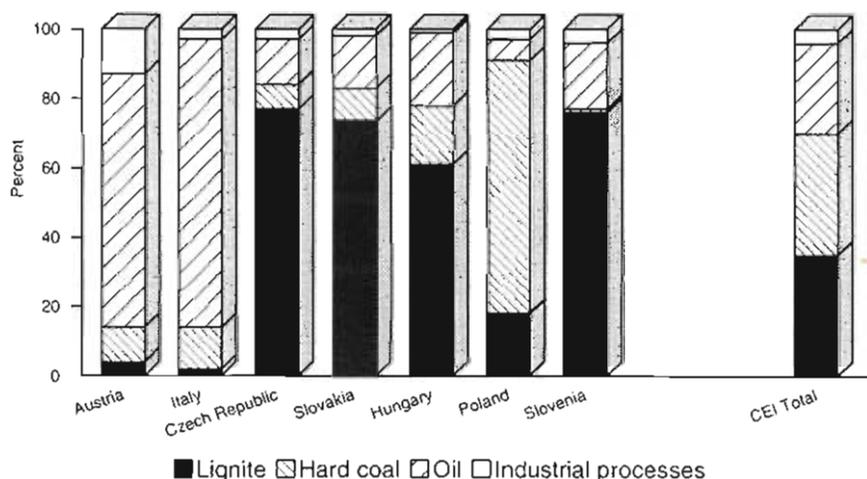
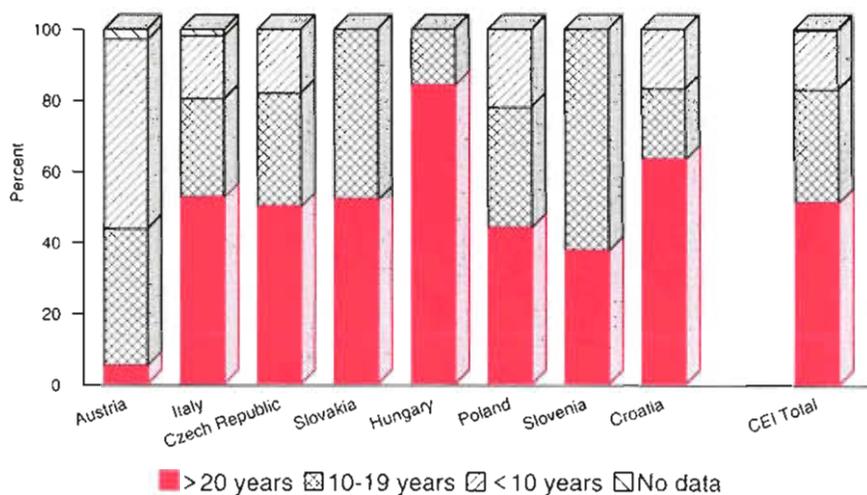
mainly on Western European experience and literature studies, and did not make use of existing national inventorying systems or expert knowledge available at many environmental institutes and agencies. The IIASA study involved national experts from each of the CEI countries in collecting data and in verifying the final report.

The resulting CEI'88 inventory is being used by researchers in Britain, Germany, the Netherlands, and Poland, among other places, in various studies of air quality, acidification, and ozone formation (the PHOXA and GENEMIS projects).

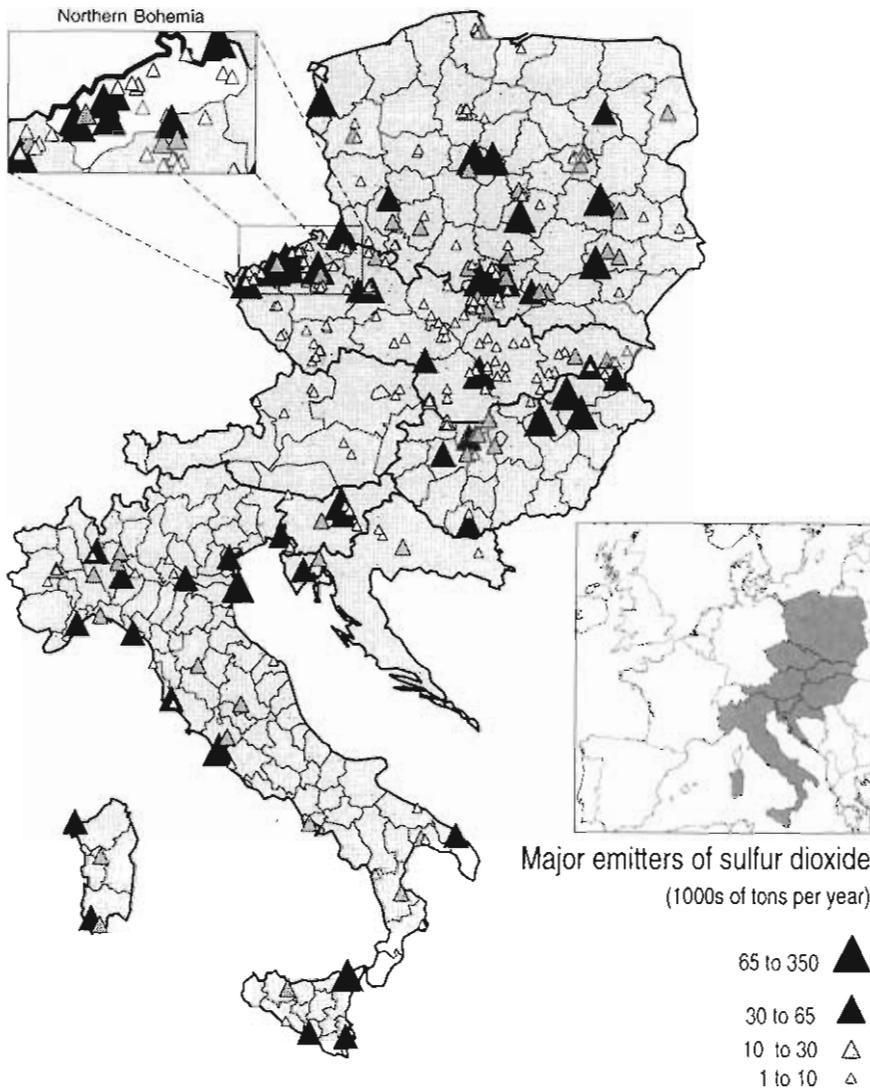
The inventory is based on CORINAIR, the data-reporting methodology adopted as the standard for all European countries to fulfill their obligations within the Convention on Long-range Transboundary Air Pollution (page 6). CORINAIR is part of the European Community's CORINE (Coordination of Information on the Environment) Programme, which unifies formats for information on land use, air pollution, waste, water pollution, etc.

The CEI'88 inventory distinguishes between emissions from large point sources and smaller, dispersed sources, (traffic, small industry, households, etc.). It includes information on technical characteristics of the large point sources. By identifying the largest pollution sources in each region and outlining their key features, the inventory can help the design of cost-effective strategies to reduce emissions. The study defines large point sources as:

- power plants of more than 50 megawatts (thermal input),
- oil refineries,
- plants which produce sulfuric acid or nitric acid,
- plants which discharge more than 1000 tons of SO<sub>2</sub> or NO<sub>x</sub> or particulate matter per year.



The upper figure shows emissions of sulfur dioxide in 1988 from public power stations by age of boilers; the lower one shows SO<sub>2</sub> emissions by fuels and from industrial processes (steel making, oil refining, etc.; data for Croatia unavailable).



Slovenia, coal use created more than 75 percent of SO<sub>2</sub> emissions; in Poland, 90 percent. By contrast, in Austria and Italy, where solid fuels were largely imported, SO<sub>2</sub> emissions from coal were less than 20 percent of national totals.

## Large Point Sources

In the member countries of the CEI, about 60 percent of SO<sub>2</sub> and 30 percent of NO<sub>x</sub> is emitted by large point sources. The CEI'88 emission inventory includes detailed techno-economic information on the main sources of air pollution in the region. Currently the database identifies 402 large sources. The locations and the emission levels of large point sources of SO<sub>2</sub> are shown in the map.

Of the 402 sources, 204 were public power plants. The generation of electricity in those plants caused almost half (46 percent) of all SO<sub>2</sub> emissions of the region. In six of the seven countries of the CEI, they accounted for more than 60 percent of national emissions. The exception was Austria, where a rigorous desulfurization program applied to large boilers lowered the contribution to about 25 percent.

Power plants are major candidates for reducing SO<sub>2</sub> emissions. An effective emission reduction strategy should focus, not on environmental aspects alone, but also on the broader economic context, in particular the energy efficiency of national economies, the age and technical performance of the equipment, and changes in energy demand caused by structural changes in the economy.

The upper bar chart displays SO<sub>2</sub> emissions in public power stations according to the age of the boilers, i.e., differentiated according to the commissioning year of the source. Over half of the SO<sub>2</sub> emissions from public power plants in the region were from plants older than 20 years. The exception was again Austria, where power stations

Data on the other category in the inventory – area sources – are essential for analysis of the environmental impacts of air pollution. Data are stored as national totals and for 187 administrative units within the CEI countries. For each country emissions are aggregated into major economic sectors.

## National and Regional Emissions

Total emissions of SO<sub>2</sub> and NO<sub>x</sub> in the CEI in 1988 were 10.3 and 5.0 million tons respectively, or 25 percent of all European emissions. The highest emission of SO<sub>2</sub> (more than 100 tons per km<sup>2</sup>) were in Northern Bohemia (Czech Republic) and Upper Silesia (Poland); by contrast, they were below 2 tons

per km<sup>2</sup> in some regions of Austria.

The CEI'88 inventory reveals radically different patterns in emissions of pollutants in different regions; this has important implications for the design of pollution control strategies. For example, it shows that the market economies of Austria and Italy contributed 10 to 20 percent of all CEI emissions of particulate matter and SO<sub>2</sub>, but about 40 percent of the NO<sub>x</sub> and CO<sub>2</sub>. This was due mainly to higher volumes of traffic.

The CEI'88 inventory allows in-depth structural analysis of national emissions. The lower bar chart on page 12 shows the importance of coal in the energy systems of Central Europe. The overwhelming majority of SO<sub>2</sub> emissions in the CEI region (70 percent) originated from combustion of locally produced coal. In the Czech and Slovak Republics, Hungary, and

## CONFERENCE

## Economic Instruments for Pollution Control

18 – 20 October 1993

*New market-based economic instruments**– emission charges, tradeable permits, and so on –*

*are potentially powerful tools in the fight against air pollution. What these instruments have in common is that they distribute decision-making about pollution control; in essence, they create artificial markets in which hundreds of individuals and organizations are encouraged to look for cheaper and simpler ways to cut pollution. At this conference 108 leading scholars and practitioners compared current theory and models on economic instruments with practical experience.*

older than 20 years, using sulfur-containing fuels, operated only in peak mode and contributed only 5 percent to the country's SO<sub>2</sub> emission. In Hungary, on the other hand, more than 80 percent of the SO<sub>2</sub> was produced in boilers older than 20 years.

In general, boilers have a lifetime of 20 to 40 years. Consequently it does not seem promising to retrofit plants older than 20 years with desulfurization equipment. Rather, it would be preferable to replace the entire plant by new installations with a higher energy efficiency.

The formerly centrally planned economies of Eastern Europe were notorious for their high energy intensities and high emissions of pollutants. The largest emitter in the CEI, the power plant in Belchatow, Poland, emitted 342 kilotons of SO<sub>2</sub> in 1988 – almost three times as much as all Austrian sources together (116 kt SO<sub>2</sub>). This is not exceptional: nine other plants identified in the inventory had emissions surpassing all of Austria. In total, the 25 largest of the 402 point sources in the inventory were responsible for 30 percent of all SO<sub>2</sub> emissions in the CEI in 1988.

Efforts are under way at IIASA to produce an updated inventory for 1990 emissions; databases in the RAINS model will be updated to include this information. Comparisons with CEI'88 should also reveal the effects of economic restructuring and recession in the formerly socialist countries. The new inventory will also be fully compatible with the EC's CORINAIR'90 system (CEI'88 used a simplified format).

The inventories will comprise the first set of reliable, comprehensive, comparative data on the subject. They will provide important information for in-depth analysis of air pollution, not only for Central Europe, but for the whole of Europe; information that is essential for the design of cost-effective strategies to reduce air pollution.

Zbigniew Klimont

The focus of the first of four plenary sessions, opened by Tom Tietenberg of Colby College, Maine, was on *theory and models* for national applications. Agreement was reached that there is no single optimal policy instrument. The proper design depends crucially on the nature of the problem.

A good starting point for many problems, including acidification, would be ambient concentration (or deposition) limits. A system of tradeable emissions permits based on ambient concentrations could, in theory, be substantially more cost-effective than conventional command-and-control approaches. The practical implementation of such systems, however, would be much more difficult than a simple trading of emission rights, without detailed consideration of the resulting ambient air quality, as is currently used in the USA.

If the spatial complexity of the atmospheric dispersion of pollutants is not taken into account in designing such trading systems, economic incentive approaches are not necessarily cheaper than command-and-control measures, such as regulatory standards for emissions or fuels.

The session on *practical experience* reviewed the use of various

economic instruments on a national scale. Hans Opschoor, from the Free University, Amsterdam, suggested that many product charges and deposit refund systems were introduced in OECD countries mainly to raise revenues: any changes in polluter behavior have been an unintentional bonus. From an analytical viewpoint, in most cases their actual impact on pollution is unclear.

However, a discussion of the Swedish experience with taxes on emissions of sulfur and nitrogen oxides confirmed that well-designed tax systems (addressing the right level of marginal costs of pollution abatement) will result in sharp reductions in emissions.

Proponents of technology-based emission standards often argue that these sorts of policy instruments are driving forces for technological innovation. There is little empirical evidence that economic instruments have a similar function, but conference participants noted that SO<sub>2</sub> scrubbing in the USA became more efficient as a result of the sulfur emissions permit trading program.

Perhaps the most important conclusion of the conference was that economic incentives appear to operate best in national settings in

combination with, or in support of, other instruments such as direct regulations.

In the discussion of *international* use of various economic instruments it was generally agreed that various tools could provide a means of exchange beneficial for both parties. Much of the discussion focused on joint implementation, largely in the context of the Convention on Climate Change and its goal of reducing greenhouse gas emissions. Without underestimating the practical difficulties in establishing such systems, joint implementation was considered an option to increase the general acceptance of an agreement.

David Pearce, chairman of the UN-ECE Task Force on Economic Aspects of Abatement Strategies, guided the session on the *international use of economic instruments to limit sulfur emissions*. Since sulfur is dispersed non-uniformly in the atmosphere, environmental impacts depend on the location of control measures. To take this into account, emission trading systems

could weight the individual emission reductions with 'exchange rates' rather than trading on a one-to-one basis as suggested for 'global' pollutants. In theory, the potential cost savings are significant. But while there might be a net benefit to the continent as a whole, some countries could find themselves with less environmental protection.

Furthermore, the combination of national emission caps with technology-based emission standards, as suggested for the next sulfur protocol in Europe, leaves little room to improve cost-effectiveness through emission trading.

Some participants suggested that a tax on the export of sulfur emissions was a near-optimal solution, but others doubted whether it would create the correct incentives; they also saw problems in distributing the tax revenue.

A selection of papers from the conference will be published in a special issue of *Environmental and Resource Economics*, and other papers in an edited volume.

Ger Klaassen

## Acid Rain—Transboundary Air Pollution staff, 1983-93

Current staff members are marked \*

Joseph Alcamo (USA)  
 Markus Amann (Austria)\*  
*Project Leader since 1991*  
 Marina Baldi (Italy)\*  
 Arturo Barragan (Norway)  
 Jerzy Bartnicki (Poland)  
 Stuart Batterman (USA)  
 Imrich Bertok (Slovakia)\*  
 Janusz Cofala (Poland)\*  
 Lourdes Cornelio (Philippines)  
 Peter Dörfner (Hungary)\*  
 Marc Doubson (Russia)\*  
 Robert Gardner (USA)  
 Margret Gottsleben (Germany)\*  
 Brigitte Gromus (Austria)  
 Frantisek Gyartas (Slovakia)\*  
 Jean-Paul Hettelingh (Netherlands)  
 Chris Heyes (UK)\*  
 Maria Holmberg (Finland)  
 Leen Hordijk (Netherlands)  
*Project Leader, 1984-1987*  
 Vicky Hsiung (UK)  
 Juha Kämäri (Finland)  
 Lea Kauppi (Finland)  
 Pekka Kauppi (Finland)  
 Monir Khondker (Bangladesh)  
 Ger Klaassen (Netherlands)\*  
 Zbigniew Klimont (Poland)\*  
 Gabor Kornai (Hungary)  
 Leonid Kropp (USSR)  
 Ralph Lehmann (Germany)  
 Barbara Lübker (Germany)  
 Anniki Mäkelä (Finland)  
 Andries Nentjes (Netherlands)  
 Krzysztof Olendrzynski (Poland)  
 Xander Olsthoorn (Netherlands)  
 Sergei Pitovranov (USSR)  
 Sergei Popov (USSR)  
 Maximilian Posch (Austria)  
 Peter Raffelsberger (Austria)  
 Eliodoro Runca (Italy)  
*Project Leader, 1983*  
 Wolfgang Schöpp (Austria)\*  
 Roderick Shaw (Canada)  
*Project Leader, 1987-1990*  
 Lene Sørensen (Denmark)  
 Frank Springmann (Germany)  
 Michael Sutton (USA)  
 Edward Taffel (USA)  
 Harry Valentine (USA)  
 Achim Wittmüß (Germany)  
 Laura Wright (USA)  
 Mioko Yamada (Japan)





◆ Capital Cities of NMO Countries

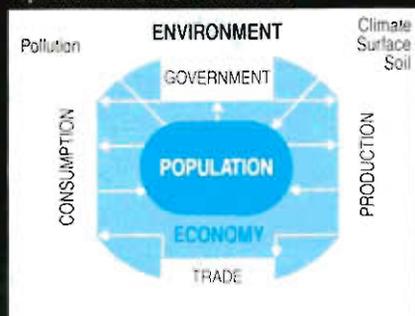
# IIASA

International Institute  
for Applied Systems Analysis

## IIASA's ROLE

The International Institute for Applied Systems Analysis is an international, nongovernmental research institution sponsored by scientific organizations from 15 countries. IIASA's objective is to bring together scientists from various countries and disciplines to conduct research in a setting that is non-political and scientifically rigorous. It aims to provide policy-oriented research results that deal with issues transcending national boundaries. Resident scientists at IIASA coordinate research projects, working in collaboration with worldwide networks of researchers, policymakers, and research organizations.

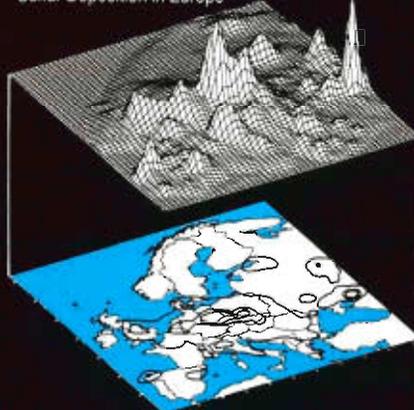
### Population / Environment Interactions



## RESEARCH

Recent projects include studies on global climate change, computer modelling of global vegetation, heavy metal pollution, acid rain, forest decline, economic transitions from central planning to open markets, the social and economic implications of population change,

Sulfur Deposition in Europe



processes of international negotiations, and the theory and methods of systems analysis. IIASA applies the tools and techniques of systems analysis to these and other issues of global importance.

Energy and the Environment



## MEMBERSHIP

IIASA was founded in 1972 on the initiative of the USA and the USSR, and now also includes 11 European countries, Canada, and Japan. IIASA has member organizations in: Austria, Bulgaria, Canada, the Czech and Slovak Republics, Finland, Germany, Italy, Japan, the Netherlands, Poland, the Russian Federation, Sweden, Ukraine, and the United States of America.

## FURTHER INFORMATION

The Office of Communications,  
IIASA, A-2361 Laxenburg, Austria.  
Telephone +43 2236 71521  
Telefax +43 2236 71313  
E-mail postmaster@iiasa.ac.at