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Europe

How Science and Policy Combined to Combat Air Pollution Problems

by Leen Hordijk* and Markus Amann**

The British scientist Robert Angus Smith first noted the problem of acid rain in Europe in 1872, but it took another century before its environmental effects were widely recognised as a major problem. During that century the acidity of Europe's rain increased at least tenfold; and in the second half of the twentieth century, the soils of Europe's forests became five to ten times more acid.

By the 1980s the effects of acid rain were highly visible. Coniferous trees in Germany's Black Forest had lost needles and turned yellow, fish had disappeared from thousands of lakes in the northern hemisphere, and the gilded roof of the sixteenth-century Sigismund Chapel in Katowice, Poland, was so eroded it had to be replaced. People's health was also at risk – neutralising chemicals had to be added to the largest reservoir in the United States in Quabbin, Massachusetts, to protect the drinking water supply of millions of people living in this densely populated area, which includes the city of Boston.

Acid rain occurs when sulphur dioxide, nitrogen oxides and ammonia are emitted into the atmosphere from various sources such as power stations, vehicles and agriculture. The pollutants are absorbed by water droplets in clouds and subsequently fall to earth as rain, snow, mist, dry dust, hail or sleet. The resulting acid rain acidifies lakes, which kills fish. It dissolves nutrients in the soil, which then leach out, making the soil infertile and killing trees. And acid rain also attacks the stonework of buildings, costing a fortune to repair.

Yet why were many of the forests and lakes affected by acid rain in remote places, far from industrial activities? The problem is that the air pollutants are not static, but are blown by the wind across "artificial" international boundaries, meaning that any attempt to curb air pollution requires agreement among countries on the measures to be used. In Europe in the 1980s this meant forging an agreement across the iron curtain between countries in east and west Europe.

To this, add the scientific complexity of air pollution. As the sources of air pollution are numerous, ranging from agriculture through industry to transport, measures to tackle it must be equally numerous. There are a range of air pollutants which, individually and in combination, have multiple effects on the environment, including acidification and eutrophication. The latter process occurs when pollutants cause an excessive amount of nutrients (*e.g.*, nitrogen) to enter soils, lakes and rivers, threatening biodiversity, encouraging the overgrowth of algae and killing other organisms. Any attempt to tackle air pollution thus requires an excellent scientific understanding of both its causes and its effects.

And as if the scientific and international nature of acid rain were not complicated enough, there are large differences among countries in terms of the type and amount of air pollution generated, and these must be taken into account if any agreement to curb air pollution is to be effective. For example, in Europe, countries are not equal contributors to the acid rain problem. The London-Paris-Ruhr triangle has the highest concentration of industry, traffic and people in Europe, which are the main sources of air pollution. The Leipzig-Dresden-Halle triangle, then in East Germany, and the Donetsk basin in the former USSR and now in the Ukraine had even higher pollution. Nor are the effects of acid rain felt equally. The north of Europe is more sensitive to acidification than the south. Moreover, the prevailing wind is from the south-west and so sends more air pollutants to the north-east of Europe. Not surprisingly, developing an environmental policy that identifies the most cost-effective measures to reduce emissions across a large number of different countries is far from easy.

Yet, the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission for Europe (UNECE) has done precisely that. It is one of the oldest and most successful multilateral international treaties protecting the environment, with targets that have led its Parties to slash their emissions of air pollutants drastically. Indeed, over the past 20 years sulphur dioxide emissions in Europe have plunged by more than 60 per cent.

What was and is the secret of the Convention's success? The answer is the close collaboration that took place between scientists and policy makers who negotiated the international agreement. This may sound simple, but more often than not scientists and policy makers talk past each other, as each group has different agendas and operates under different constraints.

In much applied research, the scientists view their task as the proper marshalling of all the facts to identify the most rational course of action in support of the common good. In other words, in order to induce national governments to reduce emissions of air pollutants from their power plants, it should be sufficient to produce a cogent forecast of the cumulative destructive effects of these

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emissions on the environment of their own or nearby countries.

But this is seldom enough for the policy maker working in the real world. It is not the case that decision makers fail to heed the warnings of scientists, but that the costs and benefits of adopting any policy are not equally distributed – or place too large a burden on the economy. Therefore policy makers may agree on the net benefits of certain policies or actions but find it impossible to agree on how the costs of taking these actions should be shared among the people and interest groups affected.

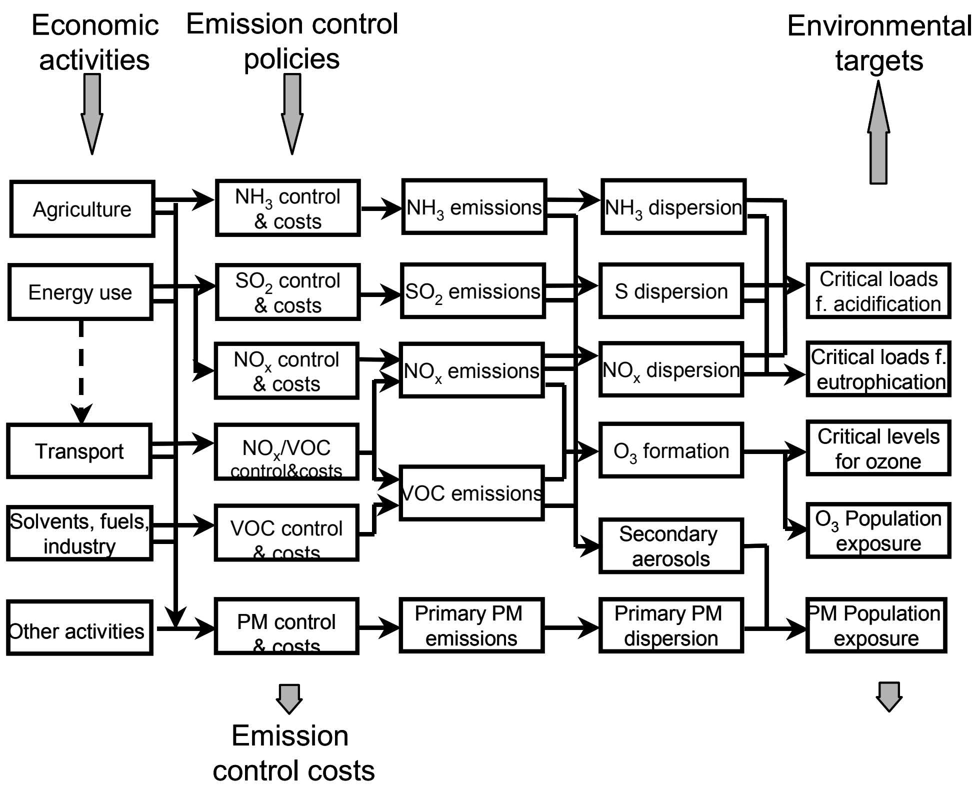
Behind the success of the Convention lies the willingness of scientists and policy makers to jointly analyse the implications of implementing different policies to curb air pollution. And to identify points of resistance from certain groups and countries so that policies can be devised that mitigate their opposition.

Especially important in helping to build a crucial bridge between the science and the policy in this area has been a scientific tool, developed by the International Institute for Applied Systems Analysis (IIASA), known as the Regional Acidification INformation and Simulation (RAINS) model. RAINS was the first computer model to be at the centre of major international environmental negotiations.

The Scientific Tool

RAINS, one of the first successful integrated assessment tools, comprises a series of submodels and databases that organise information in three broad categories: pollution generation and control options, including costs; atmospheric transport and deposition; and impacts on the environment (see Figure 1).

Figure 1. Structure of the RAINS model in 2006



In essence, RAINS is a scenario-generating device that helps users to understand the impacts of future actions – or inaction – and to design strategies to achieve long-term environmental goals at the lowest possible cost. With a few hours of training, scientists, bureaucrats, politicians and other non-technical users can pose any number of "What if…?" questions to RAINS. How much would it cost to reduce ozone levels to a given standard for all of Europe? For the worst affected areas only? What is the cheapest way to stop acidification of forest soils in Bohemia? What would be the impact of a new emissions standard for, say, power plants on eutrophication? On acidification? On ozone formation? RAINS gives answers to such questions, usually within minutes.

The European version of RAINS covers 43 countries stretching as far east as the Urals. A version of the model has been developed to cover 23 countries in Asia including China, India, Indonesia, Japan and the Philippines. Databases and simulations for the versions extend from 1990–2030.

IIASA began to develop RAINS in 1983 with the vision to produce a scientific tool that would help national governments in Europe not only to understand air pollution but to collaborate and agree on strategies to reduce emissions. Many years of hard work followed; this continues today.

Unlike universities which group researchers according to academic discipline, IIASA's researchers are organised into programmes that meld different academic disciplines to research real world problems. This approach frequently results in both innovative and practical research. To develop RAINS, chemists specialising in air pollution worked with ecologists who studied the environmental impacts of acid rain, and together they worked with economists to find cost-effective measures to reduce air pollution.

Moreover, the researchers came from many different countries and thus did not represent any national self-interest. This international cooperation in developing the model ensured that when countries began to use the model's results in the international negotiations, the results were free from the type of suspicion that would have arisen if, say, only Russian or Swedish researchers had produced the model. IIASA's independent position as an international institute funded by scientific organisations in both the East and the West ensured its science was free from such mistrust.

The first version of the model focused on the air pollutant sulphur dioxide (SO_2) because of the prime role of sulphur in the formation of acid rain. RAINS helped policy makers to make decisions in two main ways. Decision makers could view the implications for sulphur emissions of their current environmental decisions for up to 40 years into the future. Alternatively, they could specify the emissions level that they wished to achieve in, say, 2030 and ask the RAINS model to determine a cost-effective approach to achieving it. During these approaches, the model queried its massive air–pollution-related database and produced concise information that could be understood by the policy maker.

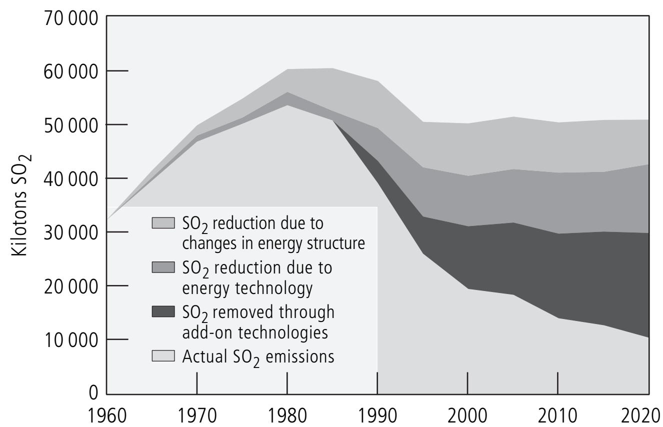
Science and Policy Combined

In 1994 the IIASA RAINS model underpinned the agreement of 33 European governments to reduce damaging SO_2 emissions, when the Second Sulphur Protocol to the Convention on Long-range Transboundary Air Pollution was signed in Oslo. Also known as the Oslo Protocol, it contributed to the sharp decrease in SO_2 emissions during the 1990s (see Figure 2).

RAINS played a key role in reaching such a successful environmental agreement by providing a workable interface between two completely different worlds: science and policy.

To give an example: before the Oslo Protocol, negotiators were set on reducing their annual sulphur emissions by a uniform 60 per cent per country to build on the 1985 agreement of a 30 per cent flat rate cut. While better than nothing, this uniform approach is crude and inefficient. RAINS provided the decision makers with the expertise to make a far more efficient agreement that resulted in a cost saving of several billion euros per year over the original plan to cut emissions in each country equally.

Figure 2. The prevention of sulphur dioxide (SO_2) emissions in Europe 1960–2020: Actual levels compared to hypothetical levels, taking into account energy consumption growth



An equal reduction of emissions for each country 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 occur where they do no harm. Moreover, across-the-board cuts do not take into account that some emissions can be cut more cheaply and quickly than others, that some countries have already implemented stricter controls than others, and that in some countries the cost are lower than in others.

In essence, RAINS helped a process of mutual education between the scientists and the policy makers. Slowly, negotiators came to accept the need to target cuts in emissions; and sample calculations showed them how targeted cuts could protect the environment more effectively than across-the-board cuts, and at a fraction of the cost.

While scientists educated the negotiators, scientists were also sensitised to political realities. A uniform cut in emissions has its virtues. It appears fair. Targeted cuts, by definition, are unequal; if they oblige some industries or countries to cut more and pay more than others, they can distort competition. For the negotiators and their political masters, this was a long bridge to cross. But the potential benefits were simply too great to ignore.

Over time decision makers accepted the concept of "critical loads" as a key aid to negotiation. A critical load is a quantitative estimate of an ecosystem's vulnerability to pollution. For the purposes of the sulphur negotiation, it was defined as the amount of acid deposition that an ecosystem can tolerate annually without long-term damage. Vulnerability to acidity depends on local conditions, especially soil chemistry; soils derived from limestone, for example, readily absorb and neutralise acids, while granitic soils do not. Other important factors are soil thickness, precipitation, and deposition of dust and other acid-neutralising materials.

In 1992 negotiators asked IIASA to analyse a range of scenarios for sulphur emissions, using the RAINS model. Under one scenario, only seven per cent of ecosystems would receive sulphur depositions above their critical loads (compared to 30 per cent in 1990). With minor alterations, this scenario, and all that it implied for each country, became the basis of the Second Sulphur Protocol, signed in 1994. Never before had international negotiators allowed a computer tool so closely to guide discussions and influence their outcome.

Toward Comprehensive Air Pollution Control

By 1999 international negotiators from 35 countries had signed an even more ambitious agreement to sharply limit air pollution in Europe. Known as the Gothenburg Protocol, it addressed a complex range of related air pollutants and problems simultaneously. Without the RAINS model this far more efficient approach (compared to artificially isolating air pollutants in separate agreements) would not have been possible.

It was during renegotiation of the Oslo Protocol in the early 1990s that negotiators learned a great deal about the complexity of air pollution chains and the power of integrated assessment tools to help them find more effective, less costly solutions. The inefficiency of single-pollutant agreements became obvious when they began to consider the next agreement up for renegotiation, the Nitrogen Oxides Protocol.

The paths of nitrogen oxide (NO_x) through the environment, and its impact, are much more complex than those of sulphur. In the presence of sunlight, NO_x combines with volatile organic compounds (VOCs) and carbon monoxide to form ozone – hence the need to negotiate controls of NO_x and VOCs simultaneously.

Like sulphur dioxide, NO_x is also an important source of environmental acidification (responsible for about 20 per cent in Europe, compared to 60 per cent for sulphur and 20 per cent for ammonia). But unlike sulphur, nitrogen is also a basic plant nutrient. It can be taken up by plants, often to excess, creating the problem of over-fertilisation or eutrophication. Nitrogen from ammonia (NH_3) can have the same impact.

Clearly, a comprehensive approach to acidification and eutrophication means that ammonia had to be included in the negotiations. Hence negotiations to improve the Nitrogen Oxides Protocol expanded to an international agreement of measures to control the four pollutants (SO_2, NH_3, NO_x and VOCs) responsible for three major environmental problems: acidification, eutrophication and ozone formation. This was the Convention's Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, the first-ever multi-pollutant and multi-effect Protocol.

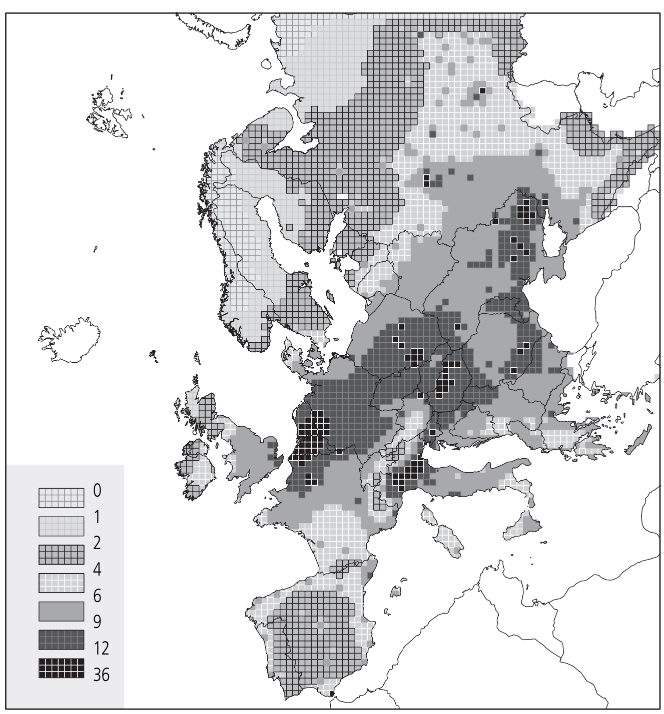
Health and Climate Change

Both the Oslo and Gothenburg Protocols have greatly reduced problems of acid rain and ozone pollution. But these agreements overlooked another pollution problem: the damage to human health caused by fine airborne particles which, according to estimates, reduce average life expectancy of European citizens by more than nine months.

Airborne particulates come mostly from the exhausts of cars, trucks, heating and power plants. Some of them are directly emitted. In addition, the so-called secondary particles are formed from pollutant gases, including sulphur dioxide and nitrogen oxides. They cause respiratory and cardiovascular diseases and have been linked to increased rates of mortality.

The European Commission's Thematic Strategy on Air Pollution for Europe, which was agreed in 2005, was also based on work by IIASA scientists using the RAINS model. The strategy sets out the air-quality objectives for 2020 and maximises the synergies and minimises the costs from controlling a range of air pollutants. According to RAINS projections, the envisaged decline in particulate matter by 2020 will bring about an average gain in statistical life expectancy of three months for people living in Europe (see Figure 3).

Figure 3. RAINS estimates of loss in statistical life expectancy attributable to exposure to fine particulate matter from emissions from human sources for the year 2000 (months)



Air pollution and greenhouse gases are often generated by the same sources and interact in the atmosphere through complex chemical reactions. Therefore, policies to reduce emissions of both air pollutants and greenhouse gases at the same time are the most cost-effective approach to improving air quality and addressing climate change. IIASA's scientists have extended the RAINS model to identify the most economic approaches to further improving local and regional air quality while controlling emissions of various greenhouse gases. This new model is known as the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model and is available for Europe and being developed for Asia.

Lessons Learned

The key position that IIASA's RAINS model plays in the international agreement requires all those countries and stakeholders involved to trust and understand the model and the science. To achieve such a high level of trust, IIASA's scientists ensure transparency of the model and the input data. All input data is scrutinised through extensive bilateral review sessions and information is made freely available online.

The availability of the model online has encouraged the use of RAINS by experts for national purposes. As a result of training workshops and continued reports to policy makers in an atmosphere where there is willingness to understand mutual viewpoints, policy makers have a far greater appreciation of the relationship between costs and environmental improvements, so vital to defining a generally agreed level of emission reductions.

The achievements of the Convention encourage decision makers to strive for even more ambitious reductions of combinations of air pollutants which, in turn, poses important challenges to the users and developers of the model. First, the integration of more and more aspects makes the model increasingly complex. For negotiators, this complexity raises a host of problems. It takes more effort and commitment from national experts to understand the model in detail and to validate all input data. And it forces model developers to identify the critical issues and interactions and present them in understandable and manageable ways.

Furthermore, negotiators are faced with a staggering number and variety of cross-linkages. Almost everything becomes a trade-off with something else. Many trade-offs can be framed as scientific or technical questions, as in the balancing of emissions between sulphur and nitrogen. In such cases RAINS can help. But in other cases, the trade-offs are moral and social, and hence political. Which is more important, protecting forests from acid rain or limiting human exposure to harmful ozone? Should we put all our efforts into helping the worst affected areas, or should we try to spread benefits evenly? How do we balance the interests of agriculture versus transport versus electricity production? These questions require political judgment and cannot be answered by a formal scientific model.

When negotiators choose to put RAINS at the centre of their negotiations, they open the door to such complexity. However, integrated assessment also helps them to separate scientific questions from purely political ones. Combining and linking the relevant scientific and technical information in one package minimises the chances that negotiators will get bogged down in scientific minutiae. It helps them to set overarching goals for environmental protection, then focus on the search for practical, fair solutions. In a sense, RAINS contains and bounds the science, and leaves the politics to the politicians. The results should benefit everybody.

The Future

A great deal has been achieved to clean Europe's air since Leen Hordijk became leader of IIASA's Acid Rain Project in the 1980s, but still more needs to be done. Science is showing us that air pollution is a global phenomenon. In Europe, background concentrations of ozone and particulate matter across the northern hemisphere have a critical influence on the achievability and costs of air quality targets.

In Asia, huge economic growth is contributing to air pollution. Many Asian countries have begun to use advanced technical measures to reduce emission and improve local air quality. As we have seen with RAINS, it is now possible to design more refined emission control strategies that simultaneously address multiple air quality problems, balancing emission controls over different economic sectors so that societies can improve the air quality at least cost.

IIASA is delighted that its scientists are now working with researchers in China and India to build a scientific model (GAINS-Asia) to give decision makers a valuable scientific tool to continue cleaning up the world's air.

More information:

RAINS model: www.iiasa.ac.at/rains

GAINS-Asia model: www.iiasa.ac.at/rains/gains_asia

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