THE REGIONAL AIR POLLUTION INFORMATION AND SIMULATION (RAINS) MODEL

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Keywords: Integrated assessment models, air pollution, optimization, RAINS model

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Summary

Integrated assessment models, such as the RAINS model, provide a powerful tool for analyzing the full chain of emissions from their origin to their environmental effects and

for exploring the interaction of various pollutants contributing to a variety of environmental problems. Optimization utilities support the search for cost-effective strategies aimed at achieving given environmental targets at least cost.

The Regional Air Pollution INformation and Simulation (RAINS) model, developed at the International Institute for Applied Systems Analysis, establishes a consistent framework for the analysis of emission reduction strategies, focusing on acidification, eutrophication, and tropospheric ozone.

RAINS comprises modules for emission generation (with databases on current and future economic activities, energy consumption levels, fuel characteristics, and so on), for emission control options and costs, for atmospheric dispersion of pollutants, and for environmental sensitivities (i.e. databases on critical loads).

To create a consistent and comprehensive picture of the options for simultaneously addressing the three environmental problems (acidification, eutrophication, and tropospheric ozone), the model considers emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), and volatile organic compounds (VOC).

1. Introduction

There is substantial concern about the environmental impacts of air pollution on the local, regional, and global scales. It has been shown that observed levels of various air pollutants can threaten human health, vegetation, and wildlife, and cause damage to materials. To limit the negative effects of air pollution, measures to reduce emissions from a variety of sources have been initiated.

Once emitted, many air pollutants remain in the atmosphere for some time before they are finally deposited on the ground. During this time, they are transported with the air mass over long distances, often crossing national boundaries.

As a consequence, at a given site the concentration of pollutants and their deposition on the ground is influenced by a large number of emission sources, frequently from many different countries. Thus, action to efficiently abate air pollution problems has to be coordinated internationally.

Most of the current international agreements determine required abatement measures solely in relation to technical and economic characteristics of the sources of emissions, such as available abatement technologies, costs, historic emission levels, and so on. No relation is established to the actual environmental impact of emissions.

For achieving overall cost-effectiveness of strategies, however, the justification of potential measures in relation to their environmental benefits must also be taken into account.

Integrated assessment models, such as the RAINS model, provide a powerful tool for analyzing the full chain of emissions from their origin to their environmental effects and to explore the interaction of various pollutants contributing to a variety of environmental problems. Optimization utilities support the search for cost-effective strategies aimed at achieving given environmental targets at least costs.

2. Model Description

The Regional Air Pollution INformation and Simulation (RAINS)-model developed at the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria) establishes a consistent framework for the analysis of emission reduction strategies, focusing on acidification, eutrophication, and tropospheric ozone.

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The European implementation of the RAINS model incorporates databases on energy consumption for 38 regions in Europe. Emissions of SO_2, NO_x, NH_3, and VOC for 1990 are estimated based on information collected by the CORINAIR'90 inventory of the European Environmental Agency and on national information.

Options and costs for controlling emissions of the various substances are represented in the model by considering the characteristic technical and economic features of the most important emission reduction options and technologies.

Atmospheric dispersion processes over Europe for sulfur and nitrogen compounds are modeled based on results of the European EMEP model developed at the Norwegian Meteorological Institute. For tropospheric ozone, source-receptor relationships between the precursor emissions and the regional ozone concentrations are derived from the EMEP photo-oxidants model.

The RAINS model incorporates databases on critical loads and critical levels compiled at the Coordination Center for Effects (CCE) at the National Institute for Public Health and Environmental Protection (RIVM) in The Netherlands.

The RAINS model can be operated in the "scenario analysis" mode, i.e. following the pathways of the emissions from their sources through to their environmental impact. In this case the model provides estimates of regional costs and environmental benefits of alternative emission control strategies.

Alternatively, a (linear programming) optimization mode is available to identify cost-optimal allocations of emissions reductions to achieve specified environmental targets.

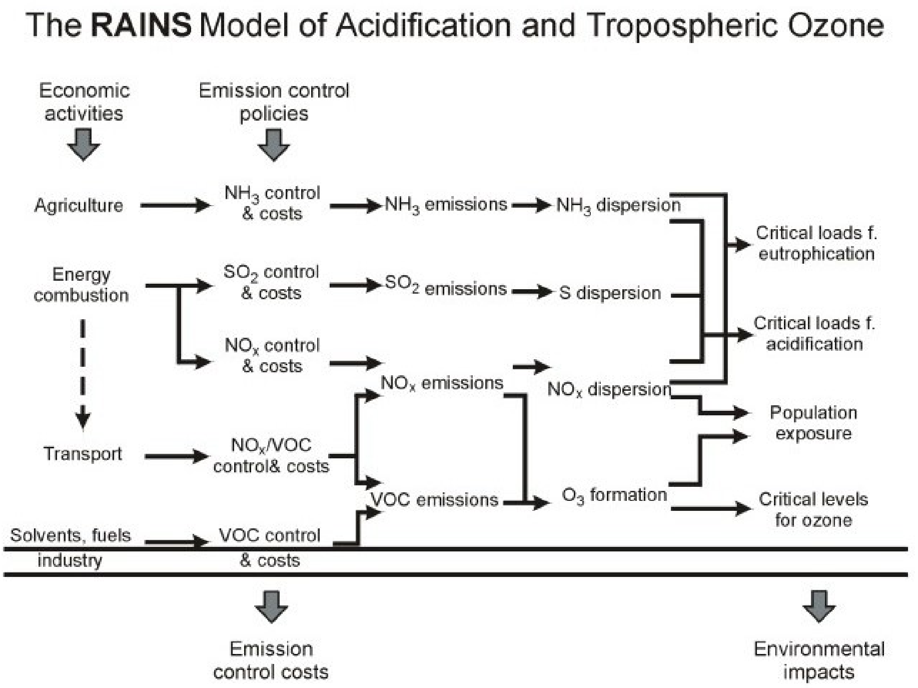

Figure 1. Schematic flowchart of the RAINS model framework

2.1. Scenarios of Anthropogenic Activities

Inputs to the RAINS model include projections of future levels of anthropogenic activities up to the year 2010.

The model stores national energy balances for selected future years, distinguishing fuel production, conversion, and consumption for 22 fuel types in 6 economic sectors. These energy balances are complemented by additional information relevant for emission projections, such as boiler types (e.g., dry-bottom vs. wet-bottom boilers), size distribution of plants, age structures, fleet composition of the vehicle stock, and so on.

Agricultural activities are a major source of ammonia emissions, which in turn make a contribution to the acidification problem. Next to specific measures directed at limiting the emissions from livestock farming,

The future development of the animal stock, which is an important determinant of future ammonia emissions, is described by national livestock numbers distinguishing eight animal categories.

The forecast of the future development of VOC emission-generating activities is linked to other information on general economic development. About half of the anthropogenic emissions of VOC originate from combustion and distribution of fossil fuels. Therefore, the information on projected levels of fuel consumption contained in the RAINS energy database is used to estimate future emissions of VOC from the relevant sources, i.e. traffic, stationary combustion, extraction and distribution of fuels. The development of the other VOC-emitting sectors is linked to projections of GDP values for various industrial sectors and to population forecasts.

2.2. Emission Estimates

The RAINS model estimates current and future levels of SO_2, NO_x, VOC, and NH_3 emissions based on information provided by the economic (energy/agricultural) scenario and on emission factors derived from the CORINAIR'90 emission inventory database and guidebook. Emission estimates are performed on a disaggregated level, which is determined by the available details of the energy and agricultural projections and the CORINAIR'90 emission inventory.

Considering the intended purposes of integrated assessment, the major criteria for aggregation are:

- Contribution to total emissions (compared to total European emissions and to emissions for a particular country). It was decided to aim for individual source categories in a share from 0.5% to 2% of total anthropogenic emissions;
- Possibility to define uniform activity rates and emission factors;
- Possibility to construct forecasts of future activity levels. Since the emphasis of the cost estimates is on future years, it is crucial that reasonable projections of the activity rates be constructed or derived;
- Availability and applicability of similar control technologies;
- Availability of relevant data. As far as possible, emission related data should be compatible with the CORINAIR'90 emission inventory.

The sectoral disaggregation selected for the RAINS model is presented in Tables 1−4.

RAINS Sector	
Primary	**Secondary**
Power plants and district heating plants	New boilers
	Existing boilers, dry bottom
	Existing boilers, wet bottom
Fuel production and conversion (other than power plants)	Combustion
	Losses
Domestic	Residential, commercial, institutional, agriculture
Industry	Combustion in boilers, gas turbines, and stationary engines
	Other combustion
	Process emissions
Non-energy use of fuels	Use of fuels for non-energy purposes (feedstocks, lubricants, asphalt)
Other emissions	Other sources: air traffic LTO cycles, waste treatment and disposal, agriculture

Table 1. RAINS sectors of the SO_2/NO_x modules for stationary sources

RAINS Sector	
Primary	**Secondary**
Road transport	Heavy duty vehicles (trucks, buses, and other)
	Light-duty vehicles, four-stroke (cars, vans, motorcycles)
	Light-duty vehicles, two-stroke (cars, motorcycles)
	Gasoline evaporation
Off-road	Other mobile sources and machinery with two-stroke engines
	Other mobile sources and machinery with four-stroke engines
Maritime activities	Medium vessels
	Large vessels

Table 2. Sectors in the RAINS module for mobile sources

RAINS sector	
Primary	**Secondary**
Livestock	Dairy cows
	Other cattle
	Pigs
	Laying hens
	Other poultry
	Sheep and goats
	Fur animals
	Horses
Fertilizer use	Agricultural cultures with fertilizers (except animal manure)
Fertilizer production	Production processes in inorganic chem. industry
Other industrial	Production processes—nitric acid
Waste treatment and disposal	Waste treatment and disposal
Other	Various activities including stationary combustion, mobile sources and industrial processes

Table 3. Main activity groups distinguished in the RAINS NH_3 module

RAINS Sector	
Primary	**Secondary**
Solvent Use	Dry cleaning
	Metal degreasing
	Treatment of vehicles
	Domestic solvent use (excluding paint)
	Architectural painting
	Domestic use of paints
	Manufacture of automobiles

	Other industrial use of paints
	Products incorporating solvents
	Products not incorporating solvents Pharmaceutical industry
	Printing industry
	Application of glues, adhesives in industry
	Preservation of wood
	Other industrial use of solvents
Chemical Industry	Inorganic chemical industry
	Production processes in organic chemistry
	Storage and handling of chemical products
Refineries	Refineries—process
	Refineries—storage
Fuel Extraction and Distribution	Gaseous fuels
	Liquid fuels
Gasoline Distribution	Service stations
	Transport and depots
Stationary Combustion	Public power, co-generation, district heat
	Industrial combustion
	Commercial and residential combustion
Miscellaneous	Stubble and other agricultural waste burning
	Cultures with and without fertilizers
	Food and drink industry
	Other industrial sources
	Waste treatment and disposal

Table 4. Sectors in the RAINS VOC module for stationary sources

2.3. Emission Control Options and Costs

Although there is a large variety of options to control emissions, an integrated assessment model focusing on the continental scale has to restrict itself to a manageable number of typical abatement options to estimate future emission control potentials and costs. Consequently, the RAINS model identifies for all emission source categories considered in the model a limited list of characteristic emission control options. For each of these measures, the model extrapolates the current operating experience to future years, taking into account the most important country—and situation-specific circumstances modifying the applicability and costs of the techniques.

RAINS estimates the specific costs of reductions for all emission control options, taking into account investment-related and operating costs. Investments are annualized over the technical lifetime of the pollution control equipment, using a discount factor of 4%. The technical performance, and investments, maintenance, and material consumption, are considered to be technology-specific and thereby, for a given technology, equal for all countries. Fuel characteristics, boiler sizes, capacity utilization, labor and material costs (and stable sizes and applicability rates of abatement options for ammonia) are important country-specific factors influencing the actual costs of emission reduction under given conditions.

The databases on emission control costs have been constructed based on the actual operating experience of various emission control options documented by a number of national and international organizations. Country-specific information has been extracted from relevant national and international statistics.

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Biographical Sketch

Markus Amann obtained his Degree in Electrical Engineering at the Technical University of Vienna, Austria, in 1984, and a Ph.D. in Economics from the University of Karlsruhe, Germany, in 1991.

He was a Research Scholar at the International Institute for Applied Systems Analysis (IIASA) from 1985–1991, and since 1991 he has been the Leader of the Transboundary Air Pollution Project.