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Report from a Nordic Expert meeting on Cost-Effective International Agreements on Air Pollution Control

21—22 January 1992

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REPORT FROM A NORDIC EXPERT MEETING ON COST-EFFECTIVE INTERNATIONAL AGREEMENTS ON AIR POLLUTION CONTROL.
21-22 JANUARY 1992.

1. A Nordic expert meeting was held 21 and 22 January 1992 to discuss various aspects related to making international agreements on air pollution more cost-effective. The discussions were focussed on regional air pollution problems, particularly on questions relevant to the coming negotiation on a "second generation" protocols under the "Convention on Long-Range Transboundary Air Pollution".

2. The meeting was organized by the Norwegian Ministry of Environment and the Norwegian Institute for Air Research (NILU) with economic support from the Senior Executives' Committee for Environmental Affairs (EK-M) of the Nordic Council of Ministers (NMR). The list of participants is included as Annex 1.

3. The meeting was chaired by Jan Thompson, Norway.

4. In his introduction, he recalled that the Nordic Ministers of Environment at their meeting in February 1991 had requested the EK-M to put Nordic co-operation on cost-effective international agreements on its agenda, and that this expert meeting was one response to this request. Mr. Thompson underlined the strong commitment from the Nordic countries that the sensitivity of the environment should be taken as the basis for reducing air pollution in Europe. Further, he noted that the scope and character of the challenges facing us makes it necessary to seek cost effective solutions. Solutions to the problems of regional air pollutants must be seen in conjunction with that of global problems. In the implementation of the Convention on Long-range Transboundary Air Pollution, three protocols have been concluded for control of sulphur, NO_x and VOC, respectively. These "first generation" protocols are fairly simple, specifying an equal percentage emission reduction

for all countries. Preparations for "second generation" protocols are in progress; elaboration of a new protocol on sulphur dioxide reductions will start in February 1992. This will be an important first attempt to make the critical loads approach operational in an international agreement. Mr. Thompson stressed that the scientific knowledge on the sulphur problem is more developed than for other European scale air pollution problems, and it is therefore of great importance that serious efforts are made to elaborate a sulphur protocol which can take into account both environmental needs and cost-effectiveness. Such a protocol might then serve as a model to the subsequent protocols on regional air pollution problems. He expressed the hope that the seminar would provide practical input to the negotiation process, which he expected to be difficult because the scientific issues are complex, the data base still incomplete and the fact that many countries are in a very difficult economic situation.

5. The discussion at the expert meeting was centered around three main issues:

   (1) An evaluation of problems associated with the implementation of the critical loads approach.

   (2) The scientific basis for including more than one air pollution component in a critical loads based protocol.

   (3) Use of economic instruments as a tool to ensure dynamic efficiency in implementing international agreements.

6. As a basis for the discussions, two invited papers were presented under each of these items. The concluding discussion focussed on identififaction of issues that need further studies or assessment before a possible introduction in the Geneva-negotiations.

7. Lars Björkbom presented his evaluation of international issues of relevance for the forthcoming negotiations ("International environmental diplomacy in a wider context" - Annex 2). In order to arrive at a situation of real negotiations on a sulphur protocol one has to be able to demonstrate the availability of financial resources that can be channeled to East and Central Europe. Such a demonstration is a prerequisite for motivating these countries to take measures against emissions of SO_2 (and other acidifying, eutrofying, oxidant producing and climate changing substances) as part of the process of their economic and political transition. To provide incentives to the governments in these countries as well as to governments in the West and to international financial institutions, which control directions of capital flows, a number of relevant arguments must be provided in addition to the need to control the acidification process in Europe by sulphur emission reductions. One must be able to convincingly demonstrate "by-profits" in a number of areas that will be deemed important enough to the relevant actors to redirect investment capital in sufficient quantities to the Central and Eastern European countries for emissions abatement. Such additional gains must be considered to be competitive in monetary terms in relation to other investments and preferably also be considered to be conducive to political gains in all quarters. Such investments would e.g. probably be considered to be more cost effective if they are used for control of climate change as well as of acidification, which is a realistic combination. The security dimension of facilitating a smooth transition process might be a persuasive political argument in the context.

8. A draft paper prepared by Kerstin Lövgren on "Economic Restructering and Environmental Improvement in Eastern Europe" was distributed, and is included as Annex 3.

9. Anton Eliassen presented results (Annex 4) from model calculations at EMEP/MSC-W showing:

   - Geographical distribution of the present exceedance of critical loads (1%, 5% and 50%) for sulphur.

   - Division of the exceedance into transboundary and indigeneous exceedance. Roughly half of the exceedance is transboundary.

   He also illustrated how one can determine the national sulphur emission reductions so that the present sulphur deposition is reduced down to the critical load at the least possible cost (optimal emission reductions), and underlined the importance of ensuring that any intermediate step in a new sulphur protocol leads towards these optimal emission reductions, and not towards less optimal and more costly ways of attaining the critical loads.

10. His presentation also included suggestions for how <u>intermediate target loads</u> might be set in order to ensure that one moves towards such optimal emission reductions at a realistic rate. This may be achieved by for example:

    a) Reduction of the present exceedance with the same percentage everywhere. (The percentage and time period to be determined.)

    In the ensuing discussion, the following additional proposals were made:

    b) An intermediate target load taken to be an agreed percentage exceedance of the critical load. (The percentage and time period to be determined.)

    c) An intermediate target load determined by a higher percentile of the critical loads distribution.

If the exceedance is a measure of the environmental condition, alternative a) will give the same relative improvement of the environmental condition everywhere, but still somewhat different national emission reduction requirements. Alternative b) will lead to the same relative exceedance of the critical load everywhere. Probably b) will give larger differences in reduction obligations from country to country than a). During the time period over which a), b) or c) is achieved, the critical loads are to be re-evaluated.

11. Anton Eliassen will present his paper also at the forthcoming meeting of the Working Group on Strategies.

12. Introductory papers on the scientific basis for including more than one air pollution component in a critical loads based protocol were presented by Peringe Grennfelt (effect-related issues - Annex 5) and Øystein Hov (atmospheric chemistry issues - Annex 6).

13. An acidification protocol would include the control of sulphur dioxide, nitrogen oxides and ammonia. For the acidification of soils and waters in Scandinavia, nitrogen deposition is unimportant except in the southernmost parts (Denmark, SW Sweden and to some extent southern Norway). For the rest of the Nordic countries, sulphur deposition is causing >95% of the acidification from atmospheric deposition. On the continent, deposition of ammonium and nitrate becomes more important and may in some areas cause 25-40% of the soil acidification. An acidification protocol may thus, for continental Europe, require control of sulphur and nitrogen deposition while acidification in Scandinavia is almost entirely a sulphur problem.

14. In terrestrial ecosystems nitrogen eutrophication effects occur earlier than nitrate leaching. The critical load for eutrophication will therefore be lower than the critical

load for the N contribution to acidification. Eutrophication effects are common on the continent and in the southern parts of Scandinavia, especially in areas close to intense farming. Some effects are observed in central and northern parts of the Nordic countries, e.g. in mountain streams. A eutrophication protocol requires control of ammonia and NO_x. It may, however, be difficult to formulate due to the large differences in transport scale between NO_x and ammonia. Ammonia is to a large extent a local/national problem, while NO_x has a transport distance similar to SO_2. In the most intense agricultural areas the ammonia emissions and deposition are so high that the deposition of sulphur dioxide will be enhanced due to the alkaline environment. Ammonia control will therefore decrease sulphur deposition in such areas and thus increase it at further distances downwind.

15. Photochemical oxidants are of interest on a regional scale due to episodic high ozone concentrations and on a hemispheric scale due to a long term increase in the tropospheric background concentrations. The epsiodes will give ozone concentrations above the critical level over central Europe up to mid Scandinavia. The critical level for the vegetation season are exceeded over all of Europe. The episodes require control of NO_x, VOC and CO emissions in central Europe while the background ozone mainly needs control of NO_x and CO over the whole northern hemisphere and of the global emissions of CH_4.

16. From the present understanding of atmospheric chemistry, the following conclusions were stressed:

    - A reduction in European SO_2-emissions will reduce sulphur deposition proportionally, but will have negligible effects on transformation and deposition rates of chemical compounds derived from emissions of NO_x, VOC, NH_3, CO or CH_4.

- A reduction in European NO_x-emissions will:

  - ● reduce NO_2- and nitrate-deposition approximately proportionally.
  - ● reduce ozone-formation in the troposphere.
  - ● lead to lower OH-concentrations (except in areas with large NO_x-emissions) which will lead to increased CH_4-, CO- and HCFC-levels in the atmosphere (increased greenhouse effect), and reduced transformation rate of NO_2 to nitrate.

- A reduction in European VOC-emissions will cause:

  - ● lower number of hours with high levels of ozone (episodes).
  - ● decreased concentrations of OH and H_2O_2 during episodes, but small effects on long term concentrations.

17. Finn Førsund presented a paper on "Sulphur trading in Europe" (Annex 7). His main conclusions were as follows:

- In the optimal solution of sulphur emissions, marginal control costs will in general not be equal between countries.

- The shadow prices on deposition constraints show the change in total control costs of tightening marginally one deposition constraint in turn.

- Bilateral pollution offset trade from a situation outside optimum to a trade price (exchange rate) between emissions equal to the ratio of marginal costs in full optimum will not realize this optimal solution, but changes will be in the direction of the optimal solution.

- Emission trading will in general reduce the total control costs, because trade is only agreed upon if the trade is profitable to both parties.

- The concern of third parties should be taken care of by not allowing any violation of deposition constraints while trading takes place.

18. Pekka Pirilä commented on trading of emissions and presented a paper on "Analysis and evaluation of emission reduction strategies in Finland using the EFOM-ENV model" (Annex 8). On emission trading he pointed out that:

    - The goal is to complement a simple agreement with trading to improve cost-effeciency.

    - It is necessary to create an international administrative body which can give permission to trade whenever two countries wish to trade and the results of the trading remain within "an accepted region". The latter should be determined from critical loads and transport coefficients. It may turn out that agreeing on an "accepted region" will be a very difficult problem.

19. The EFOM-ENV model has been used to analyze the costs of alternative strategies for reducing SO_2, NO_x and CO_2 from energy conversion and energy use in Finland. The results will also be presented at the next meeting of the Task Force on Integrated Assessment Modelling. The model is particularly useful in analysing simultaneous reductions for several air pollutants. A limitation with this type of models is, however, that they cannot take into account structural changes in national economy.

20. Conclusions and issues that should be considered for further work:

    (i) There was general agreement that the suggestion to base the first step of the new sulphur protocol on intermediate target loads for sulphur deposition determined either as a percentage reduction of the present exceedance or by an agreed exceedance of the critical loads ("gap closing approach"), deserve further attention and should be brought forward for discussions in the Working Group on Strategies. Integrated assessment models (e.g. IIASA's RAINS model) should be utilized to provide data on the consequences of these approaches.

(ii) From scientific considerations, a new sulphur protocol seems at present more appropriate than an acidification protocol. The next NO_x-protocol should preferably, however, take into account acidification, eutrophication, and formation of photochemical oxidants, and it may therefore be necessary to consider also emissions of ammonia, VOCs and CO at the same time. Cost-effectiveness aspects may strengthen or weaken these conclusions, depending on the degree of separability in the abatement cost functions for different pollutants.

(iii) European scale dispersion models for nitrogen deposition and photochemical oxidants are likely to become a very important tool for evaluation of future emission reduction strategies. Nordic research related to further development and application of such models should be strengthened to support the work being done within EMEP.

(iv) Work on quantifying the links between different pollutants should be strengthened. Reductions of nitrogen oxides will lead to many positive effects for the environment, and it is particularly important that these can be quantified. (A proposal to undertake this work during spring 1992 has been prepared.)

(v) If emission trading are to be further discussed as a possible element for future protocols, the concept and its practical consequences need further elaboration. It is of particular importance to address the institutional questions, determination of trading rates, etc. Such questions are likely to be dealt with by the newly established Task Force on Economic Aspects of Abatement Strategies, but input papers are needed to facilitate the work of the Task Force. Norway has commissioned IIASA to use the RAINS model to simulate trading, and in Sweden a research project on how national administrative structures find ways to implement international decisions is under evaluation.

ANNEX 1

LIST OF PARTICIPANTS

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NORDIC EXPERT MEETING ON COST-EFFECTIVE INTERNATIONAL AGREEMENTS ON AIR POLLUTION CONTROL
LILLESTRØM, 21. OG 22. JANUARY 1992

Denmark	Anette Schytz, Miljøstyrelsen
	Henrik Paaby, Danmarks Miljøundersøkelser
Finland	Markku Hietamäki, Ministry of the Environment
	Eija Lumme, Ministry of the Environment
	Pekka Pirilä, State Technical Research Centre
	Heikki Sourama, Ministry of Finance
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	Finn Førsund, University of Oslo
	Øystein Hov, University of Bergen
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	Mari A Sæther, Ministry of Environment
	Vebjørn Wiken, Ministry of Finance
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	Peringe Grennfelt, Swedish Environ. Research Inst.
	Ulla Weigelt, Ministry of Environment
Nordic Council of Ministers	Susanne Herfelt
Observers	Bernt Brun, Ministry of Finance, Norway
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	Øivind Lone, Ministry of Environment, Norway
Chairman	Jan Thompson, Ministry of Environment, Norway
Organizers	Harald Dovland, Norwegian Inst. for Air Research
	Magne H. Røed, Ministry of Environment, Norway

ANNEX 2

INTERNATIONAL ENVIRONMENTAL DIPLOMACY IN A WIDER CONTEXT

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1991-11-04

International environmental diplomacy in a wider context

Introduction

On the surface, the very short history of international environmental diplomacy can boast of important and impressive developmental results. This holds true, relatively speaking, on the global scene but perhaps, in particular, in the European (and North American) regional context.

The results, so far, of international environmental diplomacy have, however, been a number of rather simplistic international agreements. They have barely touched upon the underlying, very complex, reality and have certainly not finally solved any of the environmental issues that have been addressed. The major function and value of the agreements lies perhaps primarily in the fact that in their wake a number of networks have been established for international cooperation for the solution of common environmental problems. A further positive effect of the agreements has been that they have made the involved national governments and their experts more deeply aware of their mutual interdependence, when trying to address national environmental issues. The value of this should certainly not be underestimated. Before that awareness is transformed to a gut reaction by everyone involved, it will be difficult to establish the mental climate needed in the international area to successfully handle the underlying causes of non-sustainable development.

Many, the present author included, would no doubt have hoped for agreements that should have included more demanding obligations for the nations involved in relieving the pollution pressure on the environment in Europe. But I still think it is fair to assess these agreements as beeing conducive to a future improvement of the state of the natural environment in the European region and, perhaps, that of the globe as well.

Some have argued that these international agreements are just reflections of what would have been done as regards environmental measures by separate national governments, irrespective of whether there had been any international agreement or not. Although this argument contains a certain element of truth, I am not prepared to fully subscribe to this line of thinking.

Individual national governments, also the ones which deem themselves to be rulers of great powers, might find it difficult to disregard and resist concerted international pressure.

The point I will put forward in this paper is that such pressure, if it should be effective, can not be restricted only to arguments within the framework of environmental policy. The environmental argument, however forceful and convincing it might be, has rarely been sufficiently strong on its own merits to change national environmental policies that have negative impacts outside the national borders. You have to use a much wider set of arguments to bring "recalcitrant nations" to pay heed to the wishes of their neighbouring nations. Or, to put it slightly differently, non-cooperative national governments must be made to understand the need of assessing the costs of their "intransigence" on a particular environmental issue from the full range of their national interests. If this opinion is largely correct it should have important implications for the future conduct of international environmental diplomacy.

It is also clear that the time for "innocent" and simplistic international environmental agreements has passed. Let us approach the oncoming new situation by exemplifying from the wide sphere of ongoing or on the point of starting negotiations regarding "pollution" of the atmosphere. Under the Convention on Long-Range, Transboundary Air Pollution (LRTAP, covering Europe to the Urals and North America) preparations for a new set of agreements have started with the aim of reducing sulphur, nitrogen oxides and volatile organic compounds' (VOCs') emissions to a level where the depositions over land and waters are compatible with the carrying capacities of various sensitive ecosystems in the region. The ultimate goal is to come to grips with the very serious problems of acidification and eutrofication of the environment and the hazardous tropospheric ozon formation in Europe and North America.

At the same time, but in other organizations of a global structure, governments have started to formulate response strategies to global warming. These strategies aim, i.a., at diminishing emissions of carbondioxide and some other species of greenhouse gases (GHGs).

The mentioned negotiation areas have all at least three denominators in common:

- how to make Man's energy production and energy use less wasteful and less dependent on fossile fuels;

- a quest for cost effective solutions on an international (regional or global) scale;

- the need to accumulate enough political will in the "right" places for making international transfers of vast financial resources possible.

The formal background

The formal background is as follows:

The 1985 Protocol to the LRTAP on the reduction of sulphur emissions or their transboundary fluxes by at least 30 percent should be implemented by the parties to the protocol by the end of 1993. Negotiations on a second generation sulphur protocol have already started. The mandate issued by the executive body of the convention to the negociating group prescribes that a draft protocol should be based "on critical loads, best available technology, energy savings and other considerations, including market-based economic intruments".

The 1988 Protocol to the LRTAP concerning the control of emissions of nitrogen oxides or their transboundary fluxes stipulates in its article on basic obligations, that the parties shall, six months after the Protocol has entered into force (February 14, 1991), commence negotiations "on further steps to reduce national annual emissions of NOx or transboundary fluxes of such emissions, taking into account the best available scientific and technological developments, internationally accepted critical loads and other elements resulting from the work programme......"

In both cases, it is clear that at least most of the parties to the LRTAP would discard the flat rate approach - i.e. the same obligations for all parties - which characterized the first generation of SO_2- and NOx-protocols. Most parties would consider that a differentiated set of obligations for national reductions of emissions should be a cost effective abatement strategy to pursue for the European region.

In November 1991 a majority of the parties to the LRTAP will (have) sign(ed) a Protocol concerning the control of emissions of volatile organic compounds or their transboundary fluxes. This protocol already contains a differentiated approach. The parties can either opt for an obligation of a 30 per cent reduction or, if certain conditions are fullfilled, to freeze their VOC emissions, or in some few exceptional cases, apply their 30 per cent emission reductions only in certain parts of their respective areas of jurisdiction. The main reason for this rather odd legal construction is that it will (has) allow(ed) more parties to sign the protocol than would have been the case, had the parties chosen a flat rate reduction concept.

As is the case in the NOx protocol the parties to the VOC protocol have also obliged themselves to start negotiations, six months after the protocol has entered into force, on further steps to reduce annual emissions of the relevant compounds. Also here, they have i.a. foreseen a possible effects related approach, where scientifically determined critical levels and internationally accepted target levels probably would make it cost effective from a European point of view to concentrate reduction of emissions to certain parts of the region.

The corollary to the differentiated obligations approach pursued in the quest for cost effectiveness in the European regional context, which is foreseen in the three mentioned protocols to come, is of course some form of financial burden sharing among the parties.

The formal base for the global efforts to come to grips with the risks of climate warming is the Intergovernmental panel om climate change (IPCC). IPCC was formed on the initiative of the executive directors of UNEP and WMO in 1988. The panel's assessments of the risks and considerations of possible response strategies to them, induced the UN General Assembly in the autumn 1990 to mandate a global negotiating body, INC, set up for the purpose, to draft a Convention on climate change to be hopefully adopted by the governments of the world at the UN Conference on Environment and Development in Rio de Janeiro in June 1992. It is as yet uncertain how far the negotiations will reach until then. But, at least, two facets of a possible convention will probably be taken on board: measures that will aim at controlling and reducing carbondioxide emissions and measures that will ensure burden sharing between "the haves" (who are supposed to be the main villains in the drama of global warming) and the "have nots" (who will also have to take effective future action if the warming process should not get out of hand.)

Up to now, the four negotiating areas have been considered in isolation from each other. In spite of their, at least, three common denominators, refered to earlier, and the fact that the first three mentioned would-be Protocols are or will all be negotiated under the same Convention, the negotiating subjects and their negotiating groups are kept apart. Everyone, when considering the issues closely, would concede that the measures that have to be applied to achieve necessary reductions of emissions of the pollutants in many cases must probably refer to the same sources of emissions and the same type of human behavioral patterns. And the concept of cost effectiveness would only make sense, if the issues are considered in their mutual interdependance.

Cost effective international agreements

Let us consider for a while this concept of "cost effectiveness" or rather, "cost effective international environmental agreements". All countries, no doubt, seek to use cost effective methods when implementing national obligations under international environmental agreements. What is cost effective to one country is not neccessarily so to another country. Therefore, hitherto, in most agreements each country has retained its own right to choose the mix of measures needed to fulfill its obligation.

Cost effective international protocols under the LRTAP Convention must, however, be considered from an ECE - or European - regional perspective. To master this you have to be able to compare national cost curves in the region for various emission abatement measures. Such cost curves are totally unreliable in all formerly and still centrally planned national economies in Central and East Europe and, for the time being, at least, there is no way to compare them, meaningfully, with relevant cost curves in the market economies of the West.

Also, if this difficulty should be overcome, you have to find a "spokesman" for the ECE- or European regional perspective. Such a one is lacking. It must probably have to be a powerful supranational institution. The creation of such an institution, covering all Europe is, however, not to be foreseen over the next decade or so.

In the meantime, you might of course, find potential "spokesmen" for an ECE-optimum among governments of nations in the region whose national cost effective solutions happen to coincide with the regional optimization. But it is equally clear, that many national governments will find this regional optimization relatively unfavourable from their national cost perspectives. Such governments would be likely to oppose what would be considered as regionally favourable, if they would not be financially compensated by those, who were considered to be the "winners". The gains of the "winning" countries, if they would concede to pay such "compensation", would then diminish and, perhaps, be turned into losses.

There is then an obvious risk that agreements, which are theoretically calculated as being regionally cost effective solutions will not be considered cost effective from any national perspective.

From theory to reality

Translated to the presentday geopolitical reality of Europe, the above presented theoretical reasoning would come out roughly as follows:

A regionally cost effective air pollution abatement strategy for the 1990:ies, in order to solve the acidification, eutrofication and tropospheric ozon formation problems in the region, would most likely concentrate its efforts to measures to reduce sulphur and nitrogen oxides emissions from point sources in Central and Eastern Europe and in Mediterranean countries such as Spain, Greece and Turkey. Furthermore you would have to focus your measures to the transport sector in western and central Europe and to the hot spots of amonia emissions found wherever you have large concentrations of animals, both in eastern and western Europe.

A solidaric financial burden sharing to achieve this regionally most cost effective solution of the relevant environmental problems would most likely mean a substantial net transfer of capital and know how from the West- to Central- and Easteuropean countries. The resource flows needed, that we are considering here, are probably very substantial. Perhaps tens, even hundreds of billions US dollars.

Now, who would be the "winners" and who would be the "losers" by this cost effective approach to the regions' foremost environmental problems? Well, no doubt, it would be the net importers of transboundary fluxes of pollutants who would be the "winners". The Scandinavian countries would probably be the ones to reap the biggest harvests seen from the acidification effects perspective. They are the ones downwind from the emissions' hot spots. They are also the ones that have the very poorly buffered soils in the region. To them, you could probably add some odd parts of Germany and UK and perhaps most of the Netherlands. In a sense, of course, East and Central European countries should be the main environmental winners, but it is far from sure that they would accept that role in a short term economic perspective.

Seen from the eutrofication effects point of view, there would probably be a higher number of countries to be counted as winners. But, again, the need for a wide geographical spread of applied abatement measures might off-set large substantive gains by any of the would-be winners.

The picture would probably look roughly the same, if you consider the regionally cost effective approach to combatting tropospheric ozon formation, although there would probably be certain premiums to be fetched by relatively more densely populated and sun drenched countries in the region.

In almost all cases the Eastern and Central European countries, because of their geographic position and their industrial and energy-producing heritage would be central areas for abatement efforts.

Seen from the polluter pays principle, they should have to carry the brunt of the burden of the relevant abatement measures in their realms. It is today's brutal logic of past sins. In many cases the Western countries have started earlier to pay theirs. But the peoples and their democratically elected governments in the central and eastern and perhaps also in the southern parts of the region might accept no responsibility for past sins. And furthermore they might and will probably draw attention to the fact, that they have very little economic (and political and social) elbowroom to redeem their inherited environmental sins.

So, most likely, if major concerted abatement measures - in the name of regional cost effectiveness - should be concentrated to the economically weaker and politically relatively less stable parts of the European region, the representatives of most or all of these countries would refuse to enter into binding obligations under international environmental agreements to reduce relevant emissions, unless other, more well-to-do and postwar, historically more lucky nations of the region will pay a large share of the bill.

Now, to go back to the main question of this paper. Which of these latter mentioned "luckier" nations will be prepared to pay their "share" - in many cases probably very substantial ones - solely propelled by environmental arguments (coupled with a sense of international solidarity).

In some countries the acidification is no doubt considered to be a major threat to the long term reproductive capacity of their biological resource base. In some, risks of eutrofication of surface and marine waters are assessed as very serious future possibilities. And, in some others, health risks and decreased crop productivity, caused by tropospheric ozone concentrations, are issues of concern.

But, will these various assessments of environmental risks in different groups of European countries, some overlapping each other, be sufficiant to bring forward the political will to financial burden sharing, also if you could prove that such financial burden sharing would be the most cost effective way to solve the mentioned environmental problems on a European scale?

Frankly speeking, the answer is no and will probably remain no for the foreseeable future. Although much lip-service has been paid to environmental issues over the past decades, the general outcome of a choice between long term environmental objectives and short term economic, social and political needs have, so far, always given the latter mentioned objectives the upper hand in all, or most nations' internal affairs. The international dimension is certainly not likely to change that pattern.

The many of us, who think that the long term environmental concerns have to be taken seriously into account, have then, to try to enforce their environmental arguments with other arguments that might have a better potential to bring forward far-sighted political behaviour among the

European governments and their electorates.

In chase of an allied argument

The obvious arguments you should be looking for are those related to the need for European and even global security and political stability.

The final break down over the last two years of the political and economic systems in East and Central Europe, has very clearly changed the situation in Europe from the point of view of international security. This is not the place to try to assess, whether these changes will lead to enchanced or decreased stability in the region. Any seasoned political, economic, social and military analyst should, however, probably agree, that the power vacuum that has appeared in the wake of the decline and fall of the Soviet empire poses enormous demands upon the political and economic farsightedness, understanding and wisdom of the governments and peoples in the NATO, EC AND EFTA countries.

They must, through different measures, try to support the new and still very feable social fabrics and governments in the former Warsaw pact (Comecon) countries and the new republics which declare themselves autonomous inside the former realm of the Soviet Union. The West must help them to carry through the politically, economically and socially very complicated and dangerous transition from dictatorial regimes of command economies to decentralized market economies under democratic governance, which all parliaments and governments in the region have declared to be their societal goals.

Everyone would probably agree, that if this transition "fails", the future for these countries will indeed be dark and so will be the future political and military stability in the whole European region.

The Western response to the new situation has, so far, manifested itself in various support activities to ease the process of change. These activities include financial, technical and educational measures to underpin the capacity of the Central- and Easteuropean administrations, particularly in Poland, the Czech & Slovak Federal Republic and Hungary - to come to grips with the sad state of their natural environments, which are one of the legacies of the earlier political and economic systems.

The Western assistance is channelled through bilateral as well as multilateral arrangements, where the various banks for reconstruction and development (IBRD, EBRA, NEFCO etc) play central roles. The assistance is to a certain extent coordinated - so far with moderate success - by the G-24 countries (the Paris Club) and through the PHARE-Programme, by the European Economic Commission.

One of the areas, which have been given high priority in the development assistance programmes is support to facilitate measures in the energy sector to reduce emissions of sulphur and nitrogen oxides in the countries in the so called "Black triangle". (The responsibility for abatement measures in the German part of the triangle is, however and luckily, solely in German hands). So far, the financial flows from the countries in the area and from the West, that are directed to this purpose, are very modest in relation to the needs (with possible exception for the intra-German process). The USA have announced a possible "debt for nature swap" with Poland in this particular field. The preliminary Polish reaction to such a swap has been positive. Other projects of substantial formats are also in their planning stages.

As a matter of principle the West will probably demand abatement levels that are compatible with the levels prescribed in the EC directives for emissions from large combustion plants. If such levels are also imposed on existing power plants (which is what Germany demands for its five new Länder within a five year grace period), the financial needs will be of a size that will be very difficult to meet over the foreseable future.

There are no credible estimates done for the total costs for achieving emission reductions of sulphur and other acidifying substances to achieve critical loads of depositions in the European region.

A number of estimates have, no doubt, been based on national cost curves for the use of best available control technologies (BAT) which are economically feasible. These estimates are generally considered to be very poor. The calculations should hardly be considered as serious by the new governments in the feeble economies of Central- and Eastern Europe. Nor would they be considered as realistic and helpful to potential donors in the West. Both East, Center and West could probably only agree on the impossibility of resolving the European acidification problems exclusively with the help of BAT, because, costwise, it goes far beyond the critical loads of the economies not only in the East and Center, but also in the West.

A consensus seems to be evolving that BAT applications for emission controls must be combined with other measures, such as energy conservation, revised mixes of raw material use for energy production and changes in comsumption patterns and life styles in the East as well as in the West, which all escape traditional methods of cost calculations.

So, to summarise, we will not know the full price of getting rid of acidification, eutrofication and tropospheric ozon build-up in the European region.

The major way out

The overriding idea, which is becoming more evident to many analysts is, that abatement programs of that size and duration which is needed here, can only be carried out as an integrated part of an overall economic, social and political transition process in the old Comecon region. One of the pronounced objectives for this transition is to integrate these countries into the global economy. The process will entail deep-going changes in their industrial structures and their patterns of comsumption. Many of the major point sources of suphur, nitrogen and carbondioxide emissions will have to be shut down in the new competitive process. The changes will be further accelerated by stift emission requirements imposed on their competitors in the West, who will most likely see to it that similar environmental costs will be carried by the countries, which they consider to assist, primarily from the point of view of their own long term national security.

What I thus perceive here, is that the primary motives for embarking upon serious emission abatement programs in the European region that, in the long run, might lead to achievements of critical loads for acidifying and eutrofying air borne depositions, will be a quest from the people and governments of Eastern and Western Europe and the North America for a reasonably stable political future for Europe. The environmental argument will never be able to do it alone. The spokesmen for the environmental cause must thus first convince the uppholders of national and international security policies. And that is a long term process, which has hardly begun. To my understanding, the "security people" has not yet even learnt to spell the word environment and, still less, seriously considered the concept "environmental security".

I have consequently small hopes for quick, substantial results from ongoing and planned work within the LRTAP as long as negotiations are conducted in isolation from the wider political environment of European opportunities.

Although further arguments may be needed

Let me finally add the following. I have, above, alluded to the need of coordinating the negotiations on international measures to resolve the problems of acidification, eutrofication and tropospheric ozon concentration in the ECE region with the negotiations on measures to respond to climat change on a global scale. The central response measures in that context will probably be to decrease emissions of carbondioxide. Use of fossil energy sources must be curtailed, energy conservation must be a main vehicle. The major energy spenders per capita must be the ones who take the lead in the CO_2 emission abatement process. These countries are to be found in the LRTAP group of countries and in particular in central and eastern Europe (and in the USA).

Measures to achieve the objectives of controlling acidification, eutrofication and tropospheric ozon formation and climat change must be considered as a package. Such measures - be they of a technological or social restructural character - can not be expected to be implemented consecutively to achieve objective by objective. The economic and social costs would be impossible to politically motivate case by case. The environmental security dimension appears also much clearer if you see the threats and risks together, although we might perceive how a north/south dimension is added to the predominate east/west dimension in the LRTAP cases.

The technical, political as well as mental coordination process needed will, most likely, prove to be very complicated. But it is probably the venue which you will have to pass in order to achieve the results.

I introduced by stating, that the results, so far, of international environmental diplomacy were a set of rather simplistic international agreements. I hope that I have made it clear by my exemplifications from some of the important areas of international environmental negotiations, which lie ahead of us, that international environmental diplomacy now has to leave its "age of innocence" and must merge with the main stream of international diplomacy in its quest for international political stability. In the process the environmentalists might have to dirty their fingers in order to reach their objective.

ANNEX 3

ECONOMIC RESTRUCTURING AND ENVIRONMENTAL IMPROVEMENT IN EASTERN EUROPE

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SNV
V
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DRAFT
1992-01-15

Economic Restructuring and Environmental Improvement in Eastern Europe

Introduction

The environmental situation in Eastern Europe is serious. In heavily polluted areas the health of the population is affected by the pollution load, many large rivers and lakes can no longer supply drinking water, forests and other ecosystems have been damaged etc.

In addition, the Eastern European countries contribute heavily to long-range transboundary pollution. Acidification and forest damage in Northern and Western Europe will be impossible to bring to a halt without participation from the Eastern European countries. The same is true for the eutrophication of the Baltic, to pick another example of great concern to the Scandinavian countries.

Eastern Europe, as well as all other major regions of the world, must also be involved in the efforts to cut emissions of greenhouse gases.

Chances of environmental improvement are very much dependent upon the process of economic development. Technical and economic cooperation between eastern and western countries might ease the transition to market based economies and facilitate emission reduction measures and other forms of environmental protection. Economic and environmental improvement should be supported jointly. If this is to be done, appropriate links must be esablished between, on one hand, negotiations and agreements under conventions on the environment (HELCOM, PARCOM, convention on long-range transboundary air pollution etc) and, on the other hand, discussions and agreements on technical and economic cooperation (within the PHARE-program, the EBRD etc).

The purpose of this paper is to provide some data on the environmental investments and costs involved in handling one important environmental problem - the reduction of sulphur emissions in Eastern Europe to acceptable levels. Some attention is also paid to carbon dioxide. It is shown that the magnitude of the environmental costs, as well as the future environmental impact, depends crucially on the path of economic development. It is hoped that this information will be useful in attempts to establish appropriate links between work under the conventions to protect the environment and work in the sphere of technical and economic cooperation. The information provided here will have to be supplemented by information related to e.g.

eutrophication of the sea, metals and persistant organic compounds.

Climate change, acidification and Eastern Europe

The emissions of carbon dioxide threaten to disrupt the climate of the earth. According to the IPCC, present day emissions will have to be cut back by as much as 60 percent to stabilise the carbon dioxide concentration in the atmosphere at today's level. As a first step, emissions would have to be stabilized in the industrial countries.

The formerly centrally planned economies in Eastern Europe (including the former Soviet Union) contribute some 25 percent of global carbon dioxide emissions. Emissions per unit of GDP are quite high, reflecting the emphasis on heavy industries as well as rather inefficient use of energy, including widespread use of low energy fossil fuels (brown coal).

Critical loads for sulphur are exceeded in large parts of Europe. The critical loads have been mapped, mostly based upon work carried out by national teams. A substantial number of countries have set target loads based upon the maps of critical loads that are now available.

The sulphur protocol under the Convention on Long-range Transboundary Air Pollution calls for a 30 percent reduction of sulphur emissions to be reached by 1993 based on 1980 emissions. Negotiations on a second generation sulphur protocol have started. The mandate issued by the executive body of the convention to the negotiating group states that a draft protocol should be based "on critical loads, best available technology, energy savings and other considerations, including market-based economic instruments".

Approximately 50 per cent of European sulphur emissions emanates from Eastern European countries. All the model assessments carried out in expert groups under the convention indicate that emissions must be reduced sharply in Eastern Europe if target loads for sulphur are to be attained.

IIASA study on energy sector development and pollution

Future emissions of carbon dioxide and sulphur - and the costs of reducing these emissions - depend very much on energy sector development. Amann-Hordijk-Klaassen-Schöpp and Sörensen have analyzed this in the report "Economic Restructuring in Eastern Europe and Acid Rain Abatement Strategies". Their analysis is restricted to Eastern Europe excluding the former Soviet Union. The main results from their analysis - based on the RAINS model - are summarized here.

Sulphur emission abatement in Europe has been modelled not only in RAINS but also in other models such as the Stockholm Environment Institute's Co-ordinated Abatement Strategy Model (CASM) and the Abatement Strategies Assessment Model (ASAM) developed at the Imperial College in London. Similar calculations could be made using these other models.

The energy scenarios officially reported to the UN-ECE date back to the era before the political changes in 1989. These scenarios reflect the expectations of the former governments pursuing centralized planning.

According to these official projections, total primary energy demand was expected to increase by almost 30 per cent between 1985 and 2000. The fastest growth rates were projected for final energy demand in the industrial and transportation sectors. Only a 14 per cent increase was envisaged for private households.

The high energy intensity of the Eastern European economies is largely due to the great use of energy in the industrial sector(Table 1). This reflects both the emphasis on energy intensive heavy industries and the bad performance of existing technical equipment. The energy consumption for transportation purposes - per unit of GDP - is ten per cent above the Western European average level. However, in eastern countries the major fraction of fuels was used for freight transport. In western countries private passenger traffic was more important.

Amann et al. have constructed an alternative energy pathway - the energy efficiency scenario - for Eastern Europe. Growth rates of GDP are assumed to follow the lines envisaged by the former governments but major economic restructuring processes are assumed to take place, transforming industrial infrastructures from their current orientation on energy-intensive heavy industry towards more advanced production processes and less energy-intensive activities. To explore the implications of energy efficiency on international emission reduction strategies, it is assumed that half the gap between eastern and western energy-intensity levels will have been closed by the year 2000. It is further assumed that the energy consumption of households and services - on a per capita basis - will reach the 1985 level of Western Europe. Fuel demand for transportation - per unit of GDP - is also assumed to adapt to the average value of western market economies.

For energy supply, it is assumed that the efficiency of thermal electricity generation will increase to 40 per cent.

If the assumptions above allow a decline of energy input, fuels with the highest carbon dioxide emissions are assumed to be phased out first.

The assumptions of the energy efficiency scenario result in a drastically changed pattern of energy demand for the year 2000. Total primary energy consumption is 25 per cent below the 1985 level, instead of 30 per cent above as implied by the energy scenarios reported by the former governments. Fuel demand drops by more than 30 per cent in the industrial sector. The priority on phasing out fuels with the highest carbon dioxide emissions first, results in a cut in brown coal consumption of almost 70 per cent.

According to the old official energy projections, carbon dioxide emissions increased by almost 20 per cent from 1985 to 2000. In the energy efficiency scenario, they decline by more than 20 percent compared to 1985.

If no additional abatement efforts were taken, the sulphur emissions of the energy efficiency scenario would be almost 30 per cent below the level of the official energy projections.

Emission reductions needed to attain target loads for sulphur deposition

Current sulphur reduction plans in Europe imply, roughly, a 30 per cent cut by the year 2000 as compared to 1980. A much larger cut - approximately 70 per cent - is needed to attain specified target loads. The analysis by Amann et al. indicates that the costs of attaining target loads would be very much lower in the case of the energy efficiency scenario for Eastern Europe, than in the case of the official energy scenarios reported before 1989. Total European costs are estimated at approximately 35 billion DM per year in the energy efficiency case and approximately 60 billion DM per year in the case of the official energy projections (table 2).

The largest abatement cost savings accrue to the Eastern European countries. Costs for these countries (excluding the former Soviet union) are roughly 10 billion DM in the energy efficiency case and roughly 22 billion DM in the case of the official energy projections. However, cost savings also accrue to several western countries, whose abatement requirements are relaxed as a consequence of larger emission reductions in Eastern Europe.

It should be recalled that the energy efficiency scenario of Amann et al. excludes the former Soviet Union. If energy efficiency scenarios were explored for the new republics, the effects on total European emissions and abatement costs would be even greater.

Discussion

More efficient use of energy is in line with market-orientation. In many centrally planned economies energy prices were kept artificially low - sometimes well below the costs of energy production. A change to cost-based prices will encourage a more rational use of energy. The energy intensive heavy industries will also be very much affected by increased competition. Restructuring - including the closure of plants - will no doubt be necessary. It must be remembered, however, that energy requirements do depend on the stage of development. Historically, more energy per unit of GDP have been needed in earlier phases of industrialization than in more mature ones. Even if energy intensities fall in eastern countries they cannot be expected to drop to western european levels in the near future.

There are large environmental benefits to be gained by more efficient use of energy, if energy supply is adapted to lower demand levels in an environmentally sound way. The most heavily emitting fuels and installations should be phased out first. The environmentally worst installations are likely to be old and poorly maintained, so environmental and economic improvement may well coincide.

The decrease of carbon dioxide emissions will result solely from energy efficiency improvements and from changes in energy supply. There are no practicable means of removing carbon dioxide from flue gases. Emission reductions depend wholly on changes in energy use and energy structure.

Fuels emitting much carbon dioxide, generally, also emit much sulphur. Consequently, energy system changes reducing carbon dioxide emissions will also reduce sulphur emissions. The sulphur abatement to be obtained from energy restructuring, however, will fall short of what is needed to halt acidification. If specified target loads for sulphur are to be attained, European sulphur emissions must be reduced by something like 70 per cent as compared to 1980. This is only possible if efficient abatement measures are applied in all power plants and other large emitters remaining in operation in Eastern Europe.

The energy efficiency scenario developed by Amann et al. shows the amount of abatement expenditure needed in Eastern Europe in the rather favourable case of GDP growing at about 1 per cent per annum and restructuring benefits being fully exploited. The annual sulphur abatement expenditure of roughly 7 billion DM for the eastern countries (excluding the former Soviet Union and East Germany) would thus seem to indicate the minimum direct abatement effort needed in these countries to solve the acidification problem satisfactorily. Abatement expenditures would have to be much larger if energy intensities remain high. If the energy pathway indicated by the former official energy scenarios were to be followed, the annual sulphur abatement expenditures of the eastern countries referred to would amount to roughly 17 billion DM. Abatement expenditures in western countries would also increase on an average basis.

The expenditure estimates quoted imply the use of flue gas desuphurisation (FGD) on all large power plants in operation at the assumed lower levels of energy demand. This level of abatement effort is required to attain specified target loads for sulphur deposition. However, even if an eastern-western burden sharing scheme is devised, quite some time will no doubt be needed to implement the necessary investments.

New power plants should of course be fitted with up-to-date cleaning equipment when they are built. For existing plants a two-stage procedure might have to be considered. Such a procedure could imply, for example, that sorbent injection or other fairly cheap measures are implemented rapidly for most existing plants, while FGD and similar more expensive techniques are introduced gradually. Viable large plants in heavily polluted areas should be the first to be fitted with FGD and similar techniques.

The abatement strategies for sulphur and carbon dioxide must be linked to the strategies chosen to combat the other environmental problems of the energy sector.

Improving energy efficiency is beneficial not only in terms of sulphur and carbon dioxide, but also in terms of i.a. nitrogen oxides, particulates and the disposal of solid combustion wastes. It will also make it easier to shut down unsafe nuclear power plants.

Simple and fairly cheap abatement measures that can be applied rapidly in existing plants are important, not only in relation to sulphur.For example, particulate emissions carry toxic metals and other toxic substances. These emissions should be controlled, as a matter of urgency in some areas, to reduce health effects. Such control would also bring down high dust and soot levels and provide a generally cleaner environment. The emissions of particulates can be controlled by fairly cheap methods. It would seem profitable to install particulate control equipment - as well as to undertake simple measures to reduce nitrogen oxides emissions, to improve the efficiency of electricity generation etc - at the same time as sorbent injection or other fairly simple measures to reduce sulphur emissions are put in place.

Catalytic cleaning of flue gases to reduce emissions of nitrogen oxides and other expensive techniques must be considered along the same lines as FGD and similar advanced sulphur removal techniques.

Table 1. Energy intensities in Eastern European countries in 1985.

	ENERGY INTENSITY IN EASTERN EUROPE, 1985		
	INDUSTRY (PJ/Mill.DM GDP)	DOMESTIC (TJ/cap/yr)	TRANSPORT (PJ/Mill.DM GDP)
ALB	2.56	12	1.50
BUL	2.52	22	1.98
ČSFR	5.15	48	1.24
GDR	3.95	70	0.95
HUN	2.71	37	1.26
POL	3.44	40	0.90
ROM	7.30	24	1.66
YUG	3.99	10	1.34
AVERAGE-EAST	4.50	34	1.20
AVERAGE-WEST	1.35	34	1.07

Source: Amann - Hordijk - Klaassen - Schöpp and Sörensen: Economic Restructuring in Eastern Europe and Acid Rain Abatement Strategies.

Table 2. SO_2 abatement costs in the year 2000.

	Abatement costs (million DM/year)			Costs as percent of GDP (%)		
	OEP	EEE	CRP	OEP	EEE	CRP
Albania	90	0	0	0.64	0.00	0.00
Austria	651	210	658	0.26	0.08	0.26
Belgium	1554	1216	152	0.44	0.34	0.04
Bulgaria	1293	0	1046	1.07	0.00	0.86
ČSFR	2541	1711	281	1.10	0.74	0.12
Denmark	743	747	88	0.28	0.29	0.03
Finland	934	297	181	0.37	0.12	0.07
France	2105	2111	0	0.09	0.09	0.00
Germany, West	6725	6749	3627	0.25	0.26	0.14
Germany, East	4515	2815	750	1.34	0.84	0.22
Greece	50	0	0	0.03	0.00	0.00
Hungary	892	475	198	0.64	0.34	0.14
Ireland	282	282	0	0.34	0.34	0.22
Italy	2979	2987	600	0.16	0.16	0.00
Luxembourg	29	16	4	0.19	0.11	0.03
Netherlands	892	893	539	0.16	0.16	0.09
Norway	166	92	77	0.07	0.04	0.03
Poland	5469	3514	1375	1.22	0.78	0.31
Portugal	134	0	53	0.12	0.00	0.10
Romania	3481	1158	0	1.70	0.56	0.00
Spain	988	424	195	0.13	0.06	0.03
Sweden	660	429	385	0.16	0.11	0.10
Switzerland	13	57	44	0.00	0.02	0.01
Turkey	0	0	0	0.00	0.00	0.00
UK	5685	5579	1453	0.30	0.30	0.08
USSR	14286	2399	4790	0.50	0.08	0.17
Yugoslavia	3650	0	0	1.98	0.00	0.00
Total	60807	34161	16496	0.35	0.19	0.09

Source: Amann - Hordijk - Klaassen - Schöpp and Sörensen: Economic Restructuring in Eastern Europe and Acid Rain Abatement Strategies.

ANNEX 4

ON IMPLEMENTATION OF THE CRITICAL LOADS APPROACH

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Anton Eliassen 21/1-92

Attaining Critical Loads for Sulphur

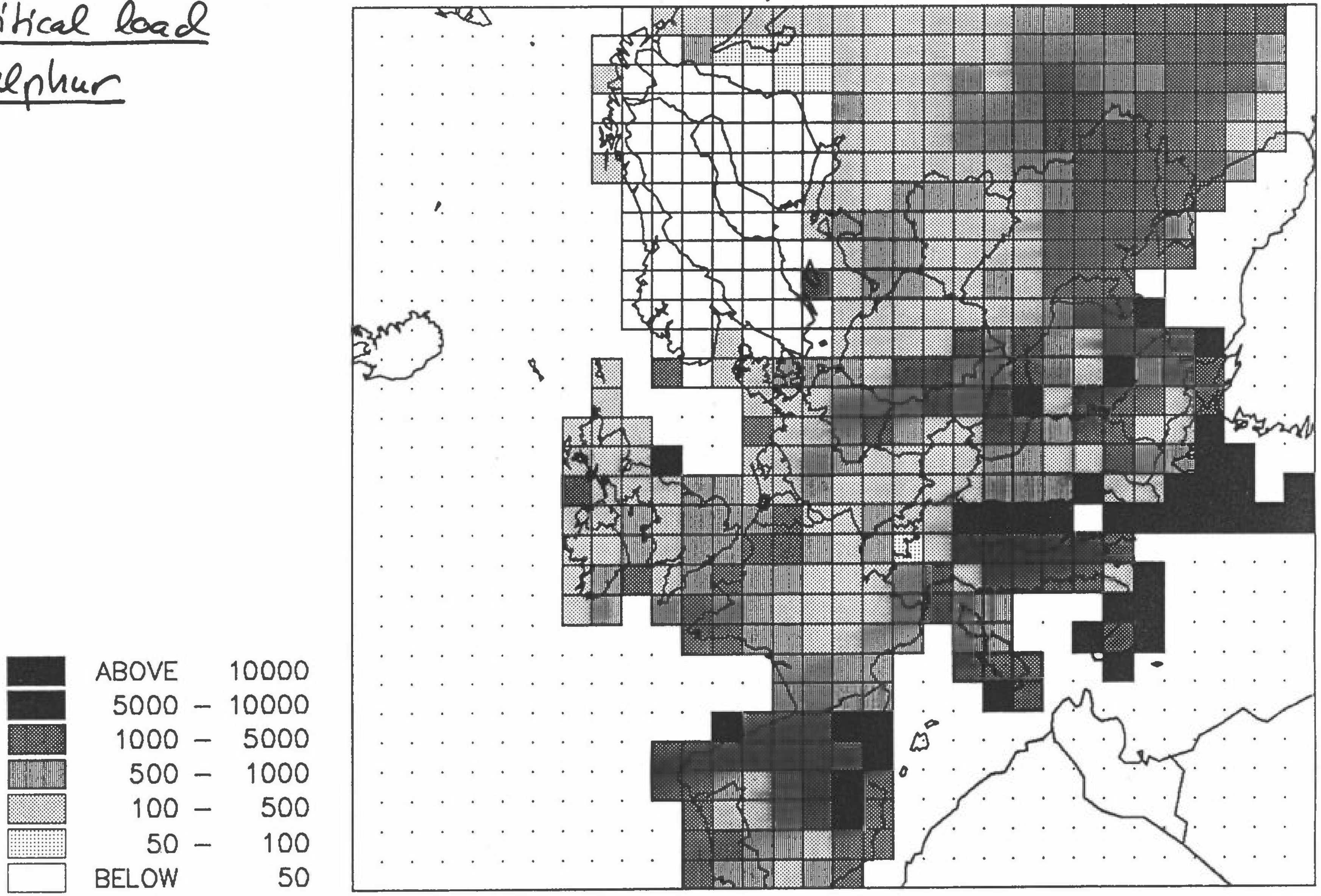
IIASA / RAINS model,	% red. rel. to 1980
Denmark	100
Finland	100
Germany, West	100
East	91
Netherlands	100
Norway	58
Sweden	100

These reductions will not be agreed upon.

Critical load

Sulphur

1 percentile

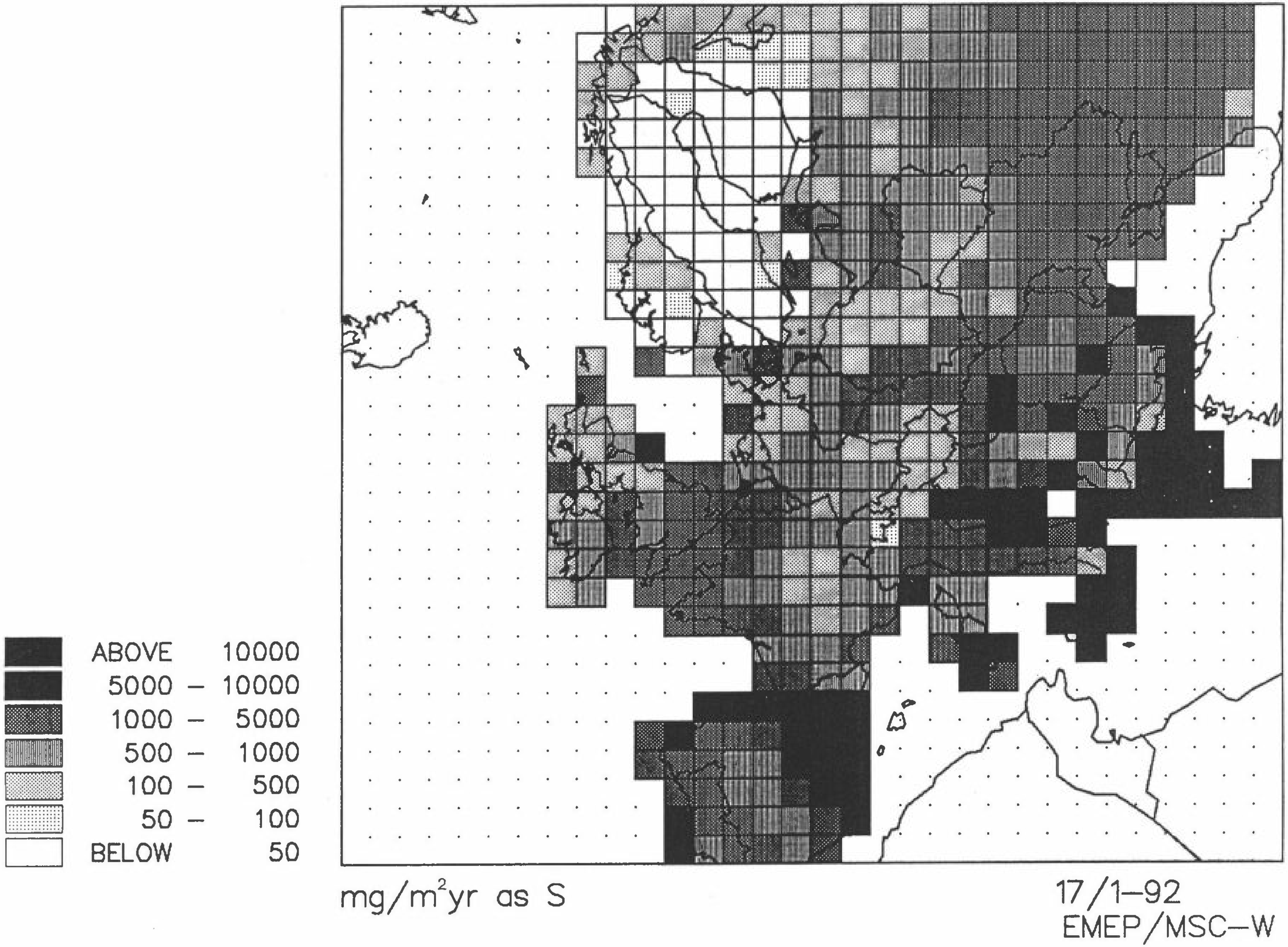


mg/m^{2}yr as S

17/1–92
EMEP/MSC–W

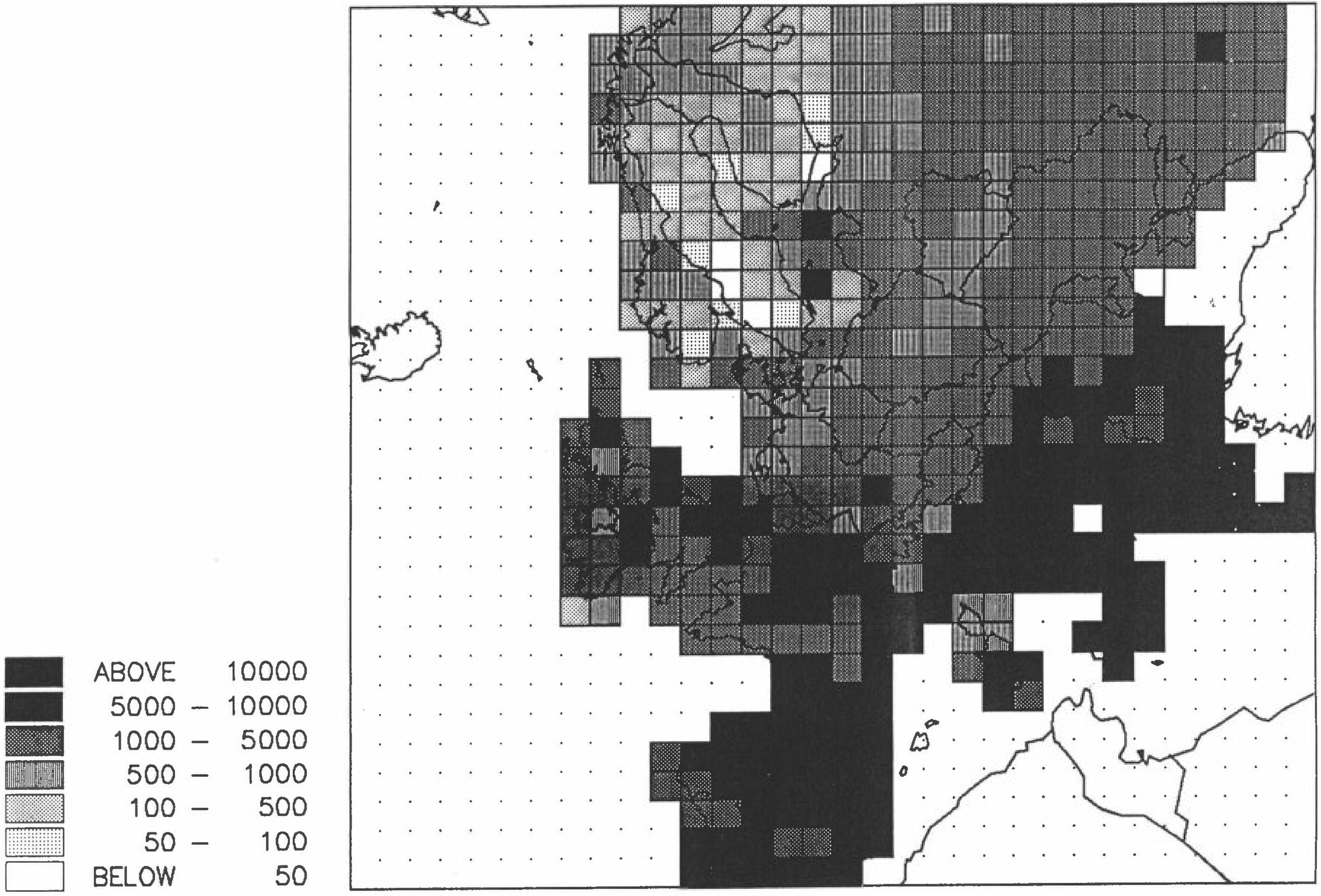
CRITICAL LOADS OF SULPHUR

5 percentile



CRITICAL LOADS OF SULPHUR

50 percentile



mg/m^{2}yr as S

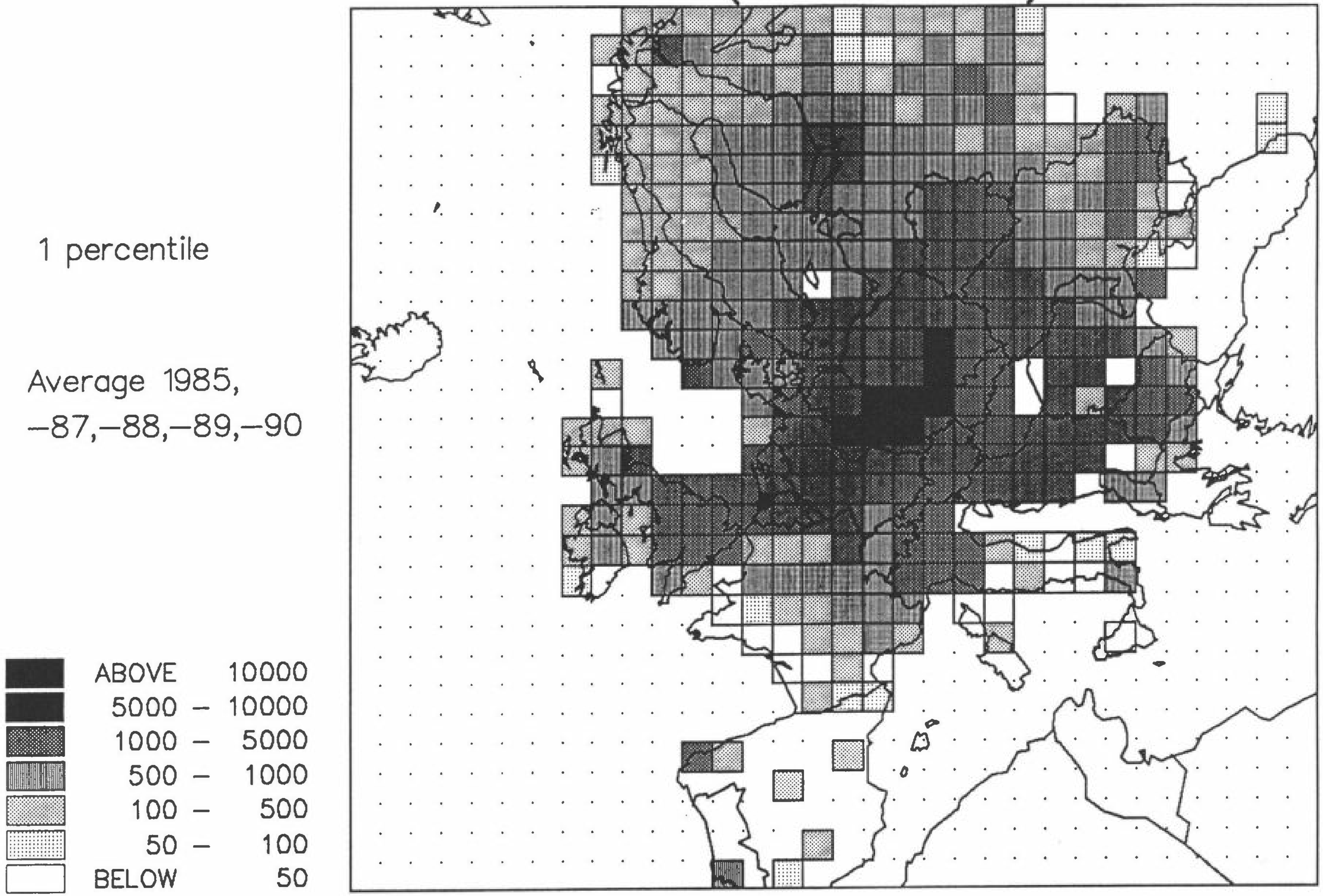
17/1–92
EMEP/MSC–W

EXCESS DEPOSITION OF SULPHUR

Total (all contributions)

1 percentile

Average 1985,
-87,-88,-89,-90

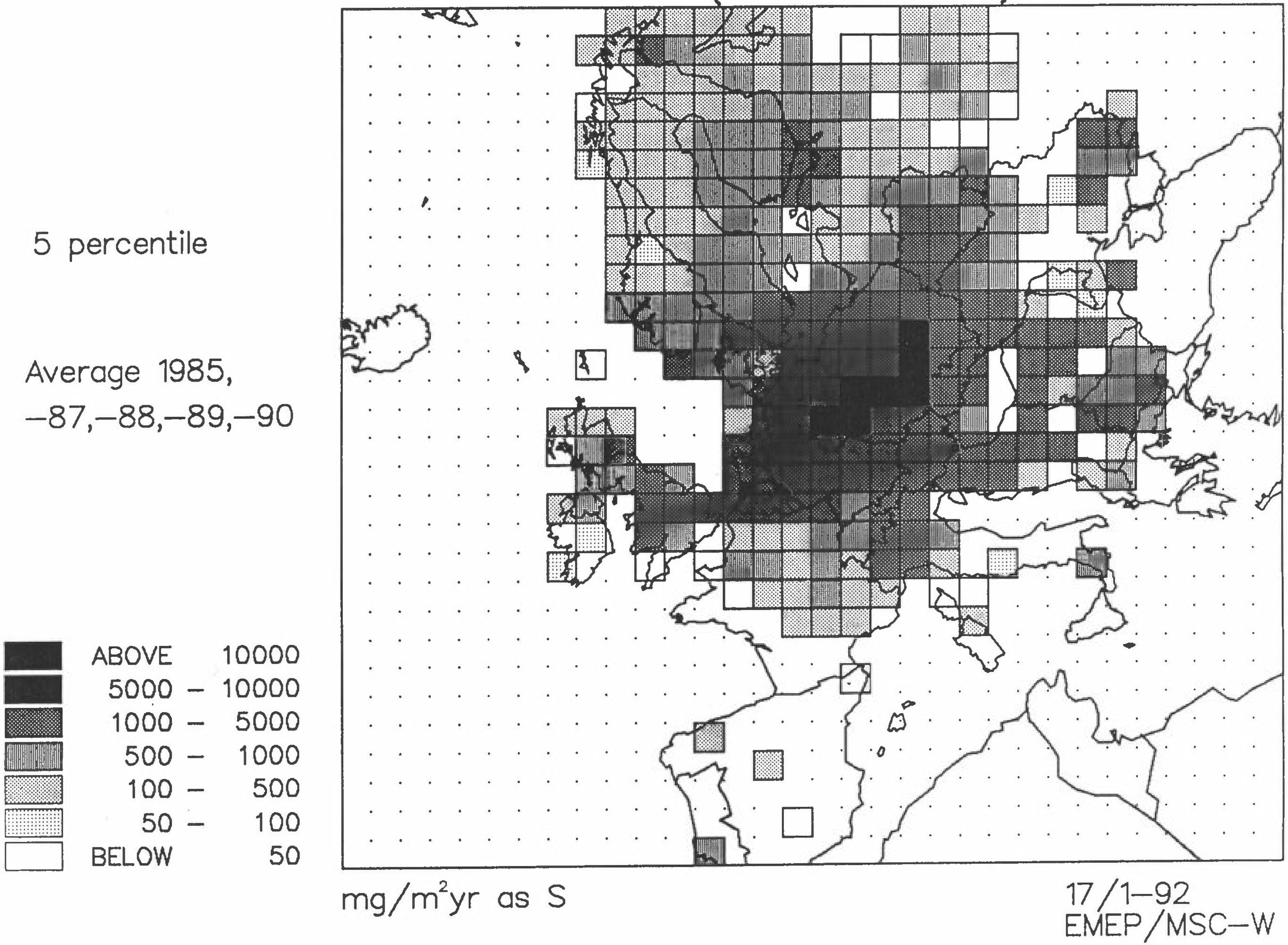


mg/m²yr as S

17/1-92
EMEP/MSC-W

EXCESS DEPOSITION OF SULPHUR

Total (all contributions)

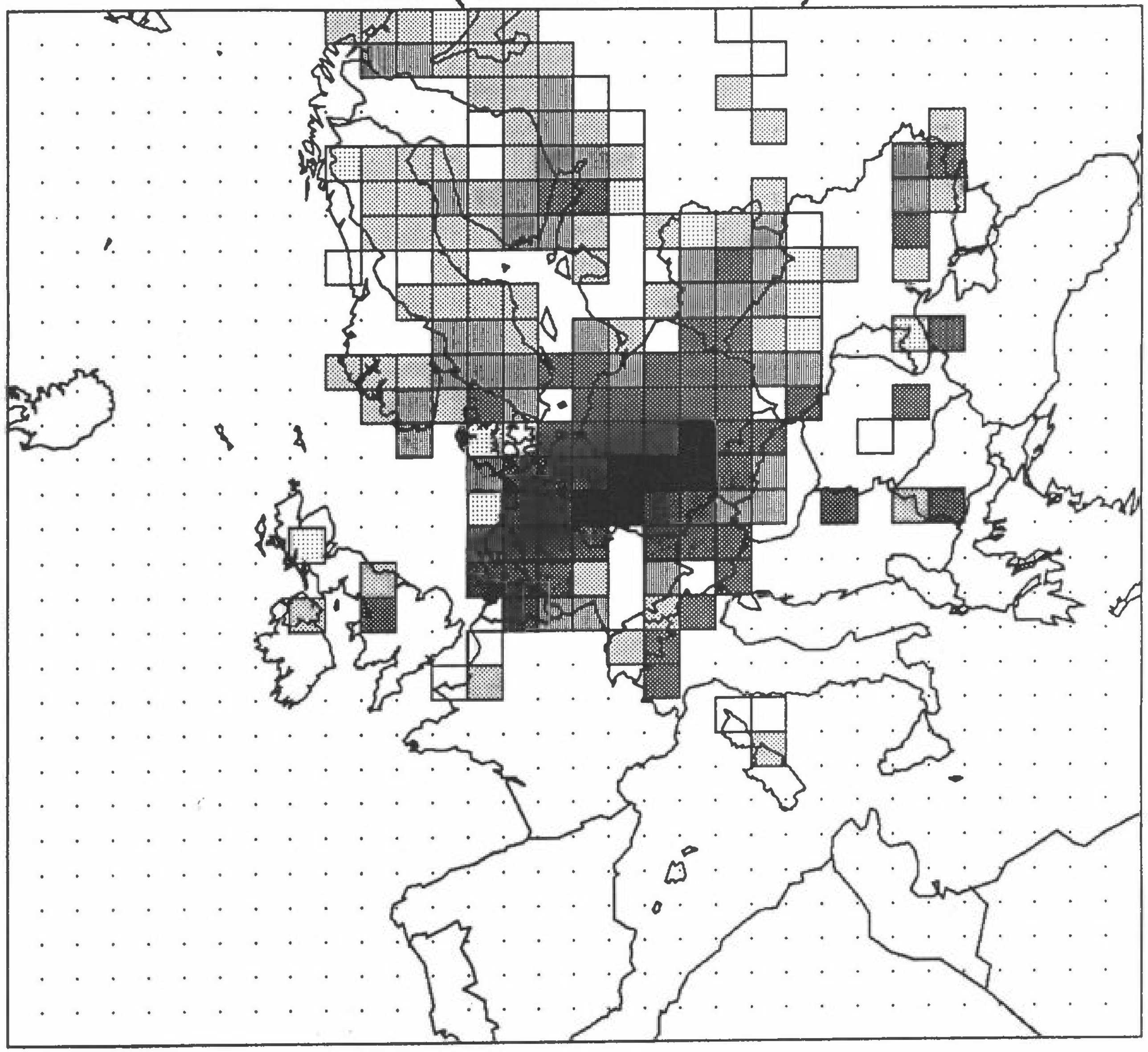


EXCESS DEPOSITION OF SULPHUR

Total (all contributions)

50 percentile

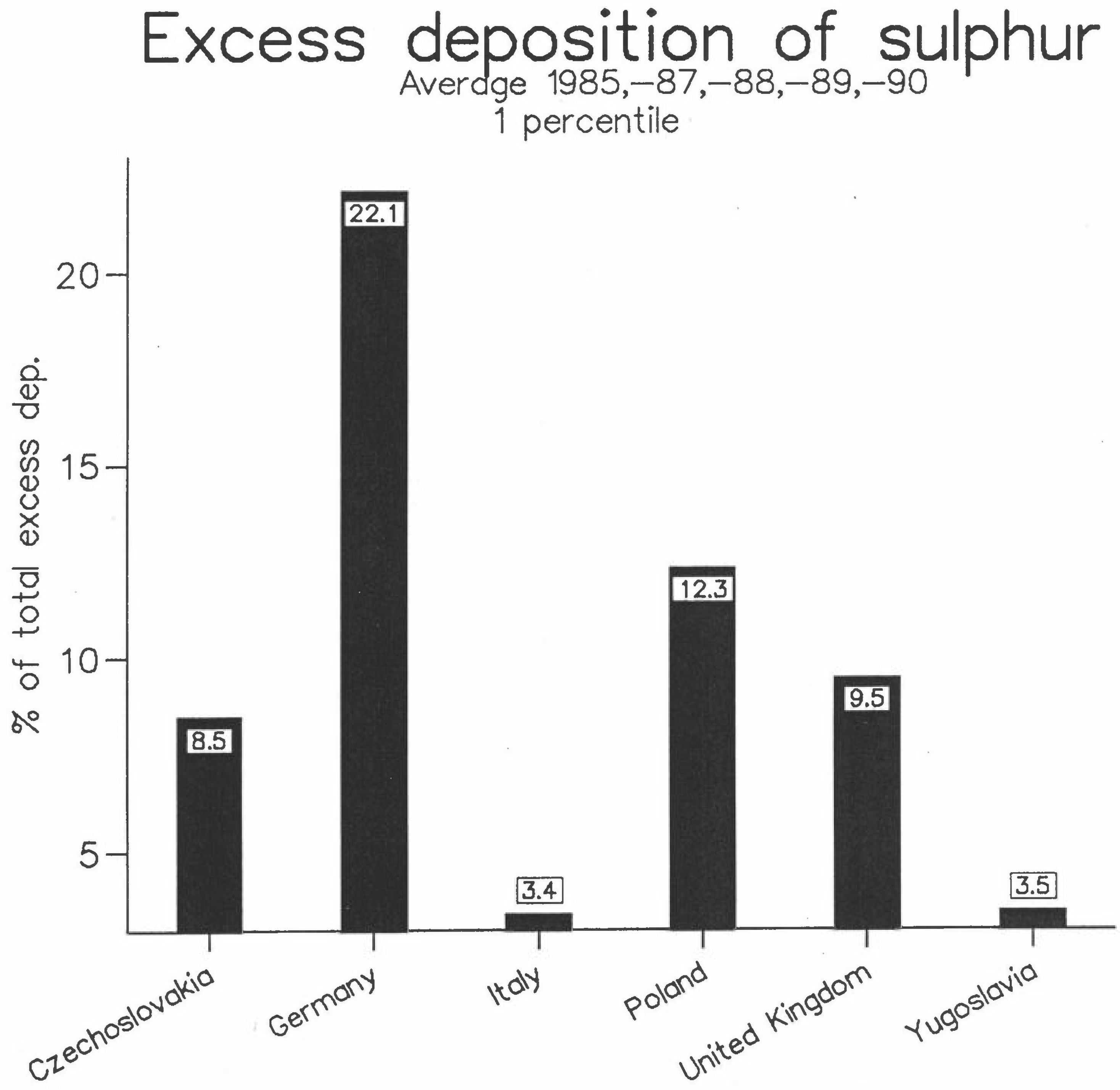
Average 1985,
-87,-88,-89,-90



■ ABOVE 10000
■ 5000 – 10000
▩ 1000 – 5000
▨ 500 – 1000
▦ 100 – 500
░ 50 – 100
□ BELOW 50

mg/m²yr as S

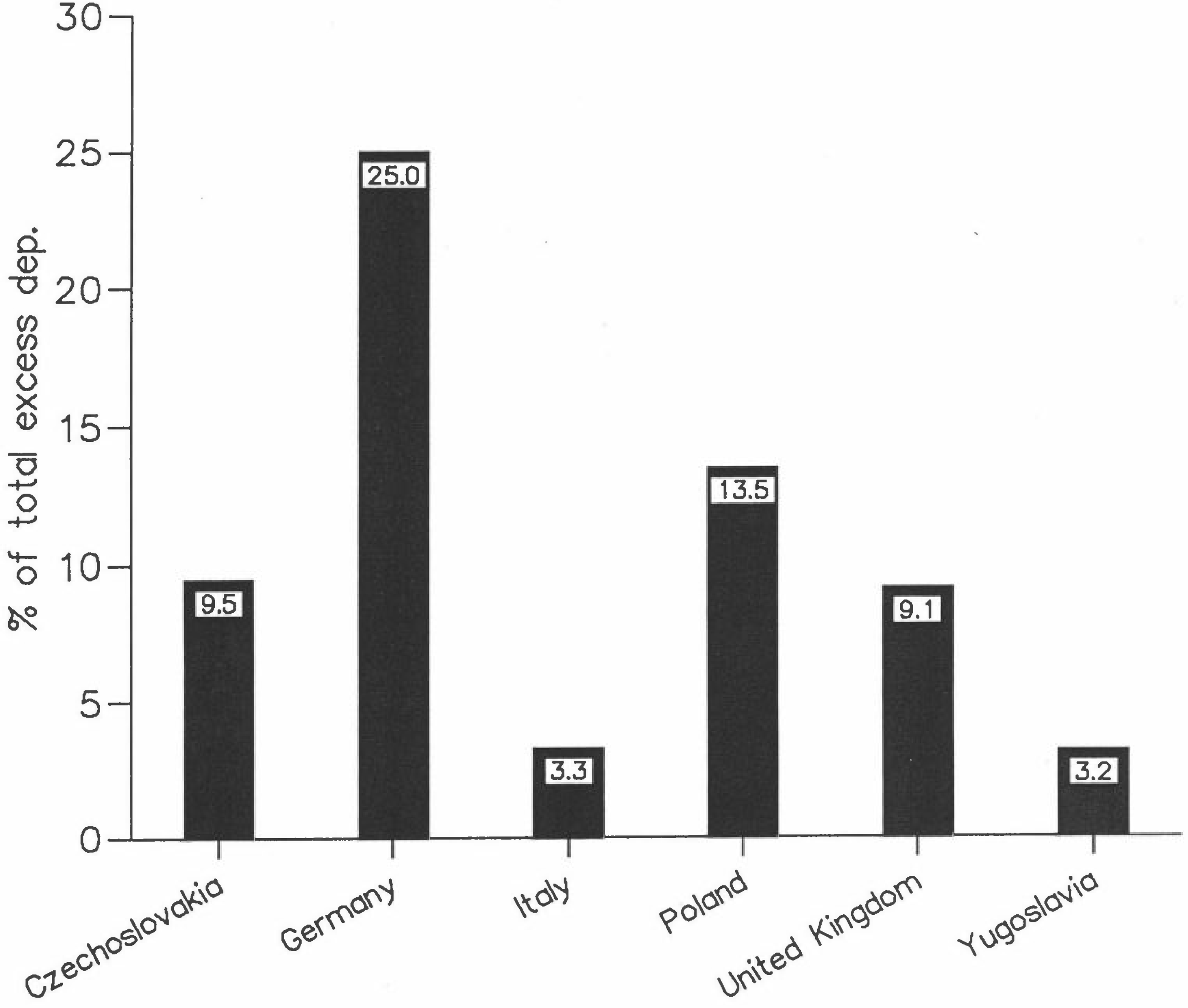
17/1-92
EMEP/MSC-W



Excess deposition of sulphur

Averdge 1985,–87,–88,–89,–90

1 percentile



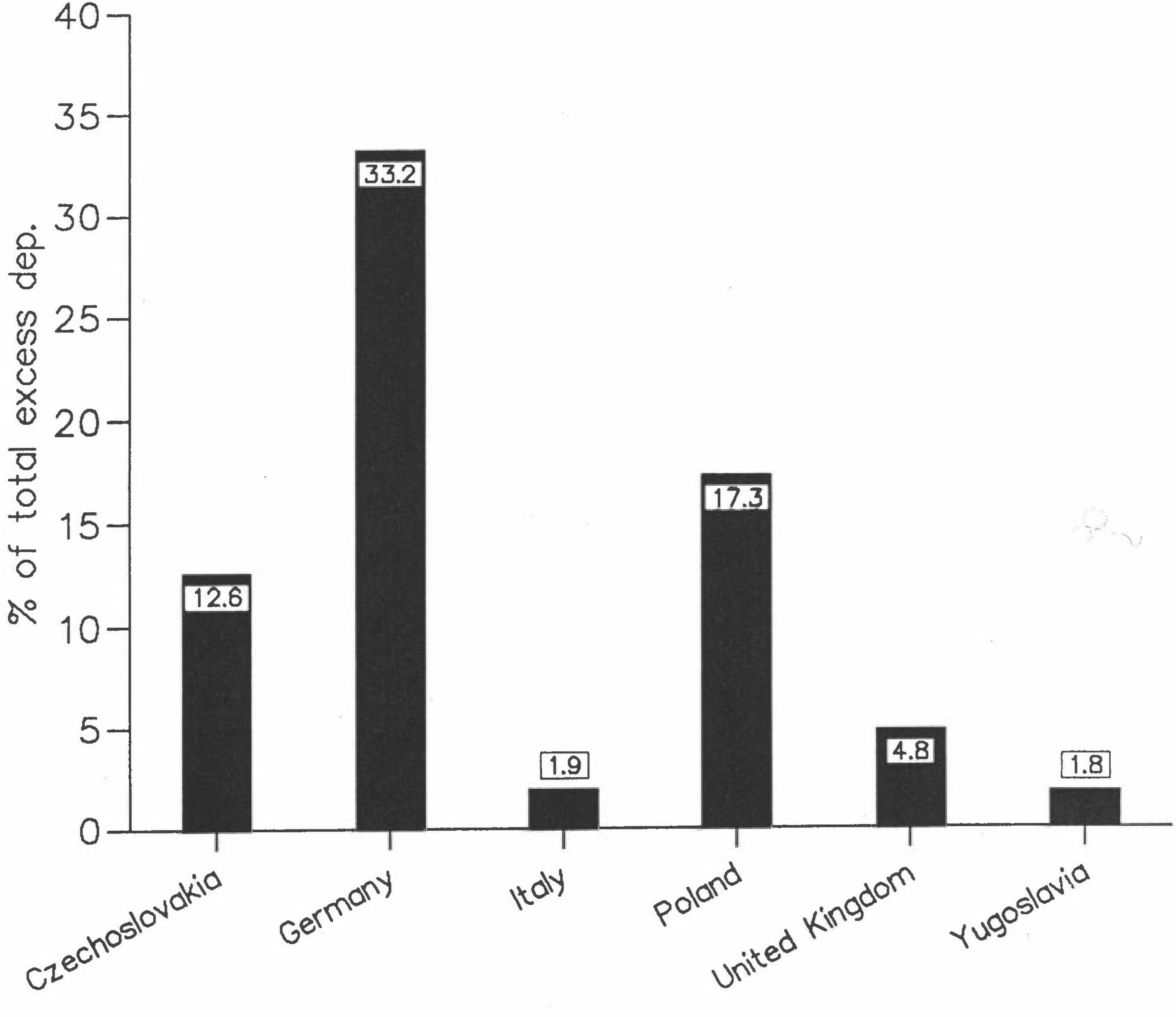
Excess deposition of sulphur

Averdge 1985,–87,–88,–89,–90

5 percentile

Excess deposition of sulphur

Averdge 1985,–87,–88,–89,–90
50 percentile



DISTRIBUTION OF EXCESS DEPOSITION OF SULPHUR
(Excess = Deposition - Critical Load)

1 percentile

Average of 1985, -87, -88, -89 and -90, % of total exceedance

Country	Transb.exc.	Indig.exc.	Tot.exc.
Albania	0.02	0.05	0.07
Austria	0.15	0.17	0.31
Belgium	1.04	0.29	1.33
Bulgaria	0.68	0.94	1.62
Czechoslovakia	5.59	2.91	8.49
Denmark	0.60	0.22	0.81
Finland	0.33	0.63	0.96
France	1.75	1.15	2.91
German Dem. Rep.	11.29	5.84	17.13
Germany, Fed. Rep.	3.09	1.93	5.02
Greece	0.10	0.04	0.14
Hungary	2.23	0.82	3.06
Iceland	0.00	0.00	0.00
Ireland	0.15	0.11	0.27
Italy	1.48	1.94	3.42
Luxembourg	0.04	0.00	0.04
Netherlands	0.55	0.32	0.87
Norway	0.08	0.11	0.19
Poland	5.82	6.52	12.34
Portugal	0.03	0.14	0.17
Romania	1.25	1.54	2.79
Spain	0.36	1.00	1.36
Sweden	0.29	0.43	0.72
Switzerland	0.09	0.06	0.16
Turkey	0.03	0.00	0.03
USSR (Tot. European)	2.12	11.38	13.50
United Kingdom	3.44	6.06	9.50
Yugoslavia	1.44	2.03	3.47
Re.landb. (N.Africa)	0.03	0.00	0.03
The Baltic Sea	0.14	0.08	0.23
The North Sea	0.32	0.11	0.43
Remaining Atlantic	0.11	0.02	0.13
The Mediteranian	0.00	0.00	0.00
The Black Sea	0.00	0.00	0.00
Nat.emis. from ocean	0.57	0.30	0.87
Total attrib. contr.	45.20	47.17	92.36
Inattribut. contr.	7.64	0.00	7.64
Total	52.83	47.17	100.00

Transb.exc./Emis. = (4678.4033kt/ 21436.58kt) = 0.2182

Indig.exc./Emis. = (4176.3442kt/ 21436.58kt) = 0.1948

Total exc./Emis. = (8854.7432kt/ 21436.58kt) = 0.4131

DISTRIBUTION OF EXCESS DEPOSITION OF SULPHUR
(Excess = Deposition - Critical Load)

5 percentile

Average 1985, -87, -88, -89 and -90, % of total exceedance

Country	Transb.exc.	Indig.exc.	Tot.exc.
Albania	0.02	0.03	0.05
Austria	0.15	0.20	0.35
Belgium	1.10	0.30	1.40
Bulgaria	0.66	0.96	1.62
Czechoslovakia	6.10	3.39	9.49
Denmark	0.66	0.23	0.90
Finland	0.33	0.77	1.10
France	1.82	1.00	2.82
German Dem. Rep.	12.42	7.08	19.51
Germany, Fed. Rep.	3.36	2.17	5.52
Greece	0.10	0.03	0.12
Hungary	2.22	0.69	2.91
Iceland	0.00	0.00	0.00
Ireland	0.14	0.04	0.18
Italy	1.49	1.81	3.31
Luxembourg	0.04	0.00	0.04
Netherlands	0.59	0.36	0.95
Norway	0.09	0.12	0.21
Poland	5.71	7.80	13.51
Portugal	0.02	0.17	0.19
Romania	1.02	1.53	2.55
Spain	0.32	0.11	0.43
Sweden	0.31	0.51	0.82
Switzerland	0.10	0.07	0.16
Turkey	0.02	0.00	0.03
USSR (Tot. European)	2.31	8.47	10.78
United Kingdom	3.65	5.49	9.14
Yugoslavia	1.38	1.79	3.18
Re.landb. (N.Africa)	0.02	0.00	0.02
The Baltic Sea	0.15	0.09	0.24
The North Sea	0.31	0.09	0.40
Remaining Atlantic	0.10	0.01	0.11
The Mediteranian	0.00	0.00	0.00
The Black Sea	0.00	0.00	0.00
Nat.emis. from ocean	0.57	0.29	0.85
Total attrib. contr.	47.29	45.61	92.90
Inattribut. contr.	7.10	0.00	7.10
Total exceedance	54.39	45.61	100.00

Transb.exc./Emis. = (3933.1919kt/ 21436.58kt) = 0.1835

Indig.exc./Emis. = (3298.6465kt/ 21436.58kt) = 0.1539

Total exc./Emis. = (7231.8359kt/ 21436.58kt) = 0.3374

DISTRIBUTION OF EXCESS DEPOSITION OF SULPHUR
(Excess = Deposition - Critical Load)

50 percentile

Average 1985, -87, -88, -89 and -90, % of total exceedance

Country	Transb.exc.	Indig.exc.	Tot.exc.
Albania	0.01	0.00	0.01
Austria	0.13	0.16	0.28
Belgium	1.15	0.35	1.50
Bulgaria	0.21	0.33	0.54
Czechoslovakia	7.28	5.33	12.60
Denmark	0.71	0.14	0.85
Finland	0.31	0.68	0.99
France	1.64	0.29	1.93
German Dem. Rep.	15.21	11.72	26.93
Germany, Fed. Rep.	3.80	2.47	6.27
Greece	0.03	0.00	0.03
Hungary	1.69	0.63	2.32
Iceland	0.00	0.00	0.00
Ireland	0.09	0.00	0.09
Italy	0.94	0.99	1.93
Luxembourg	0.04	0.00	0.04
Netherlands	0.65	0.48	1.12
Norway	0.08	0.09	0.18
Poland	5.54	11.75	17.29
Portugal	0.01	0.00	0.01
Romania	0.68	0.43	1.11
Spain	0.18	0.00	0.18
Sweden	0.25	0.53	0.78
Switzerland	0.06	0.03	0.08
Turkey	0.01	0.00	0.01
USSR (Tot. European)	1.83	7.76	9.58
United Kingdom	3.68	1.14	4.83
Yugoslavia	1.00	0.77	1.78
Re.landb. (N.Africa)	0.01	0.00	0.01
The Baltic Sea	0.15	0.08	0.23
The North Sea	0.30	0.08	0.37
Remaining Atlantic	0.06	0.00	0.06
The Mediteranian	0.00	0.00	0.00
The Black Sea	0.00	0.00	0.00
Nat.emis. from ocean	0.43	0.19	0.62
Total attrib. contr.	48.16	46.41	94.57
Inattribut. contr.	5.43	0.00	5.43
Total exceedance	53.59	46.41	100.00

Transb.exc./Emis. = (2185.1287kt/ 21436.58kt) = 0.1019

Indig.exc./Emis. = (1892.3954kt/ 21436.58kt) = 0.0883

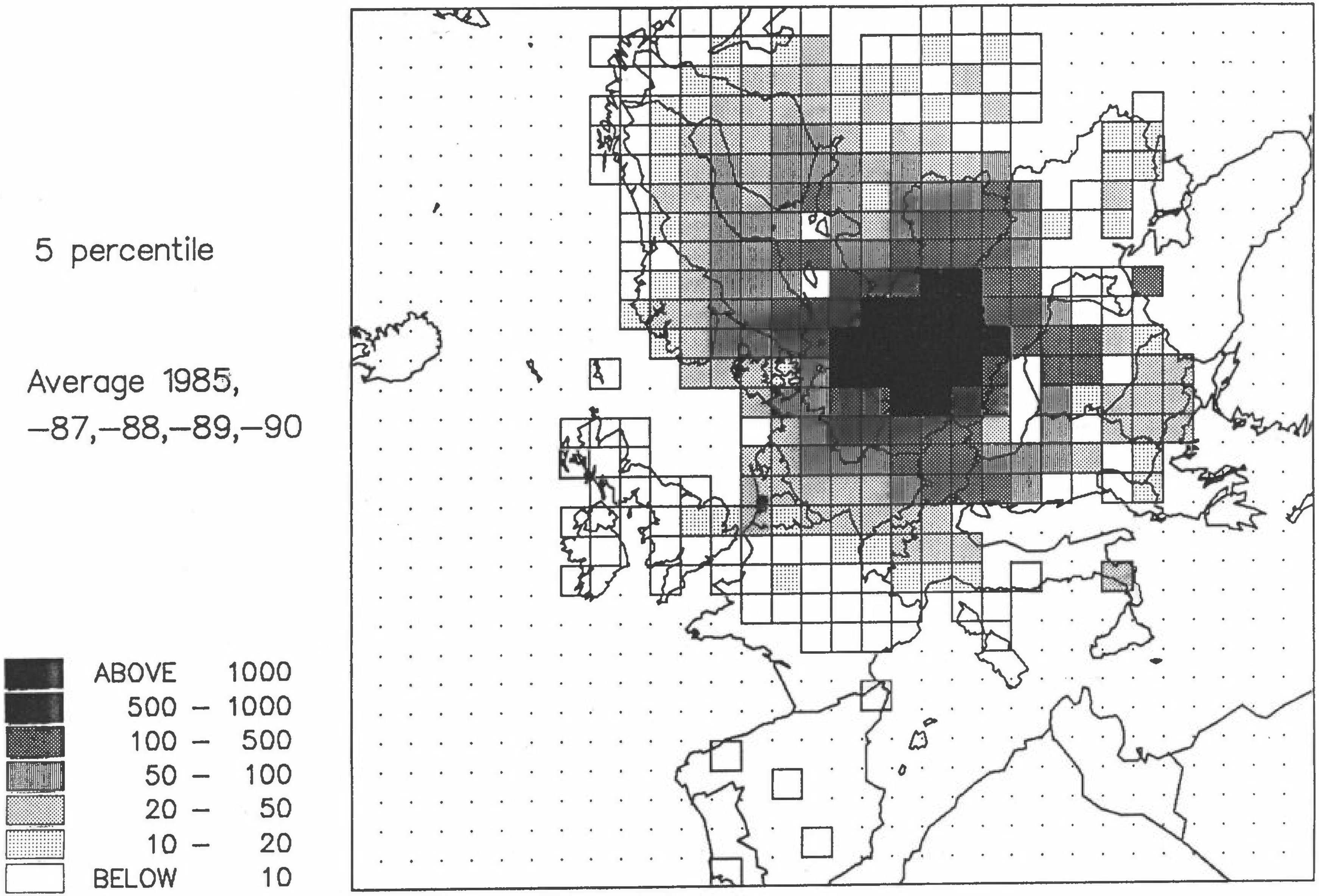
Total exc./Emis. = (4077.5229kt/ 21436.58kt) = 0.1902

EXCESS DEPOSITION OF SULPHUR

Contribution from Poland

5 percentile

Average 1985,
−87,−88,−89,−90



mg/m^{2}yr as S

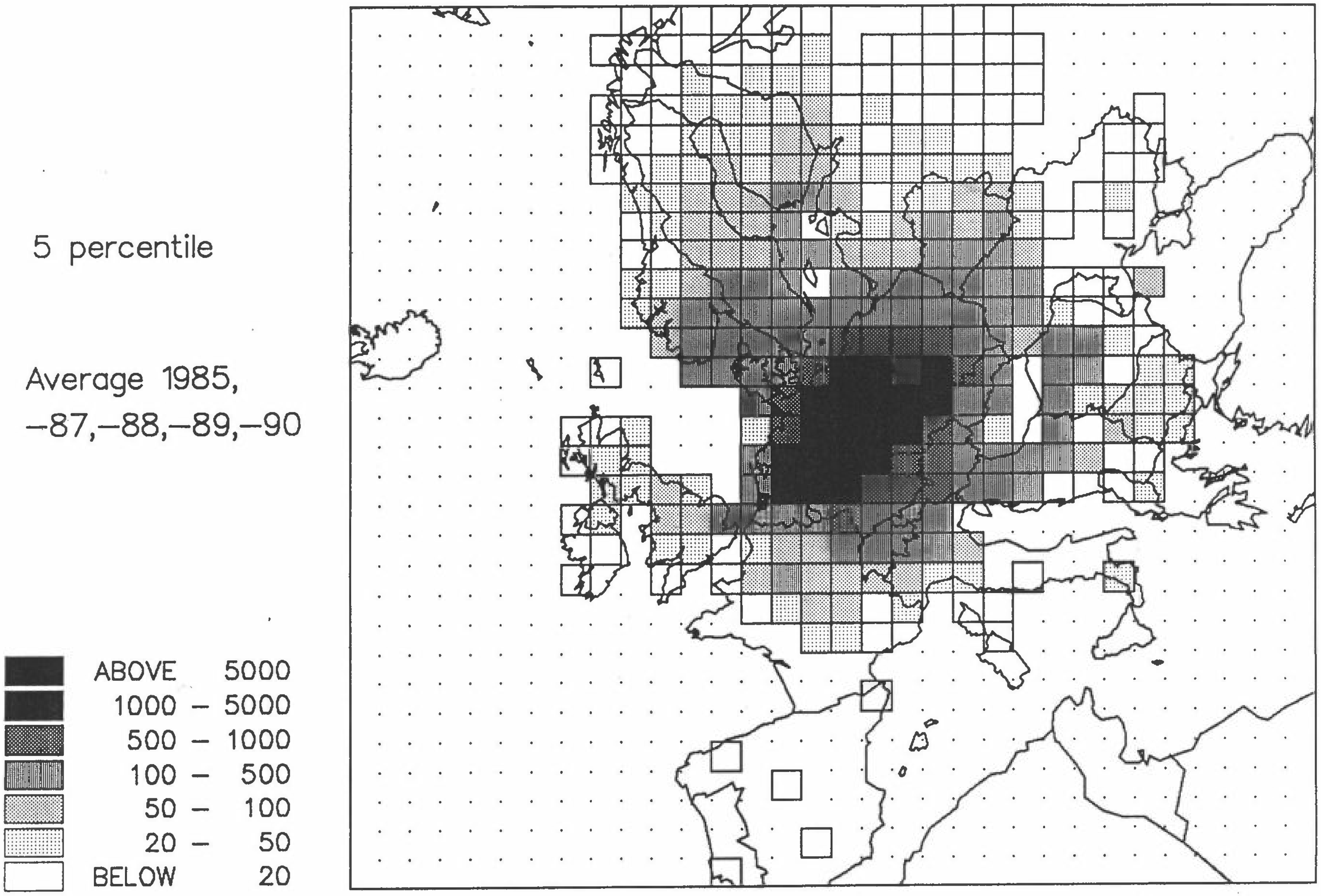
17/1–92
EMEP/MSC–W

EXCESS DEPOSITION OF SULPHUR

Contribution from Germany

5 percentile

Average 1985,
-87,-88,-89,-90

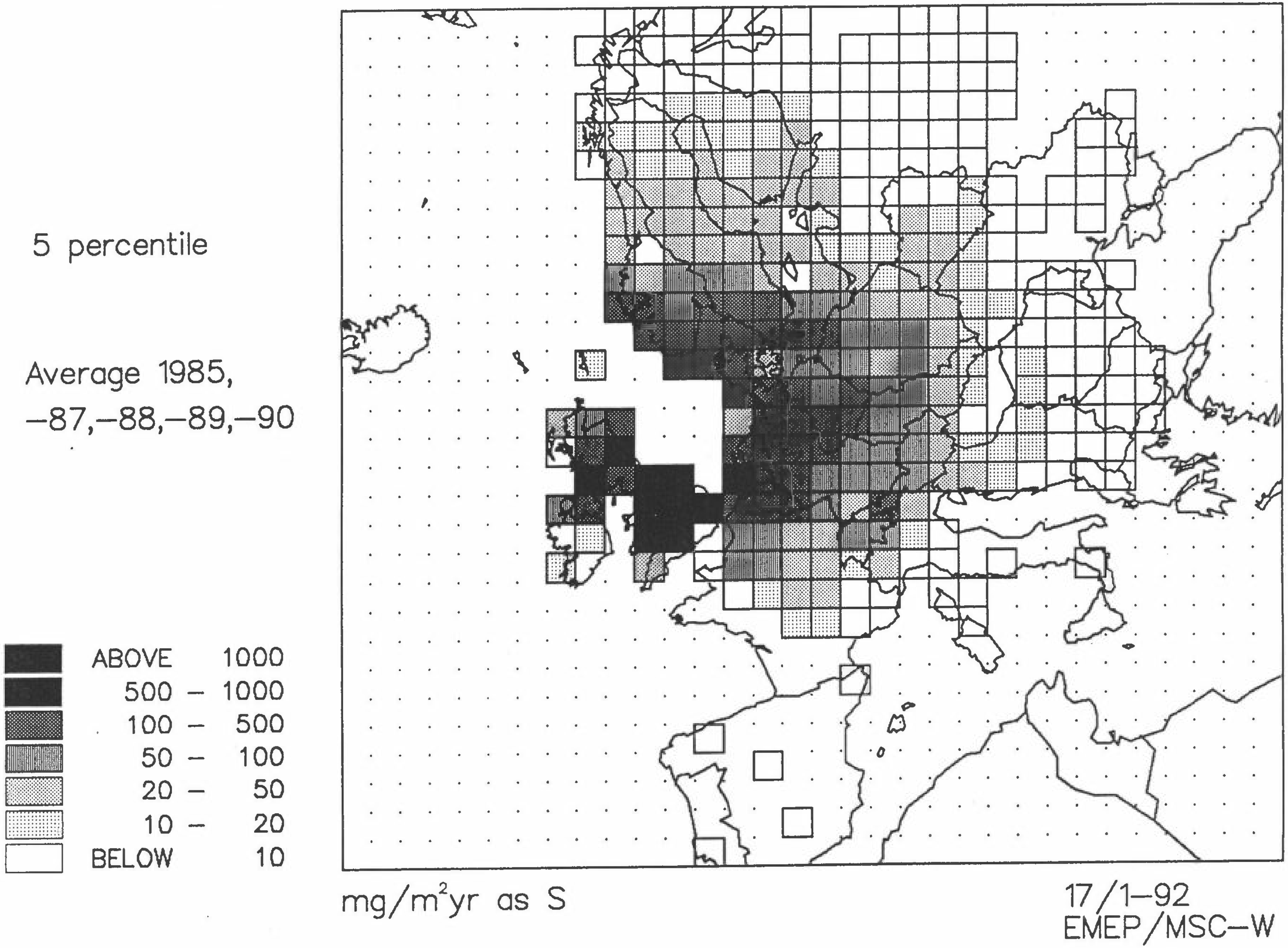


mg/m^{2}yr as S

17/1-92
EMEP/MSC-W

EXCESS DEPOSITION OF SULPHUR

Contribution from the United Kingdom



1/11-92

5 percentile:

Transboundary exceedance : 18.4 % of emissions

Indigeneous exceedance : 15.4 % of emissions

Total exceedance : 33.7 % of emissions

Total exceedance

1% -tile	41.3 % of emissions
5%-tile	33.7% of emissions
50%-tile	19.0 % of emissions

Deposition as a function of emissions

i = receptor area $\quad i = 1, 2, \cdots n.$

j = emission area $\quad j = 1, 2, \cdots m.$

d_i deposition

$$d_i = \sum_{j=1}^{m} f_{ij} Q_j$$

f_{ij} = transport function

deposition in receptor i from emitter j

f_{ij} is assumed known from model calculations

$$d_i = \sum_{j=1}^{m} f_{ij} Q_j \qquad i = 1, 2, \cdots n$$

Given $Q_j \longrightarrow d_i$

<u>Given $d_i \longrightarrow Q_j$ (?)</u>

a) $n = m$ number of receptors = number of emittors

We are OK in principle, i.e.

<u>$d_i \longrightarrow Q_j$</u>

$n < m$

?

$n > m$

<u>Costs of control</u>

Control costs

Initial situation : $d_i = \sum_{j=1}^{m} f_{ij} Q_j$

After control $d_i' = \sum_{j=1}^{m} f_{ij} Q_j'$

Emission reduction $\Delta_j = Q_j - Q_j'$

Costs at emitter $j = C_j(Q_j, \Delta_j)$

$$\boxed{\text{Total costs} \quad \bar{C} = \sum_{j=1}^{m} C_j(Q_j, \Delta_j)}$$

"Integrated Assessment Models"

Find the set of Δ_j that will

Minimize $\overline{C} = \sum_{i=1}^{m} c_j(Q_j, \Delta_j)$

in such a way that

$$d_i' \geq \sum_{j=1}^{m} f_{ij} Q_j'$$

$\leq \rightarrow = \;?$

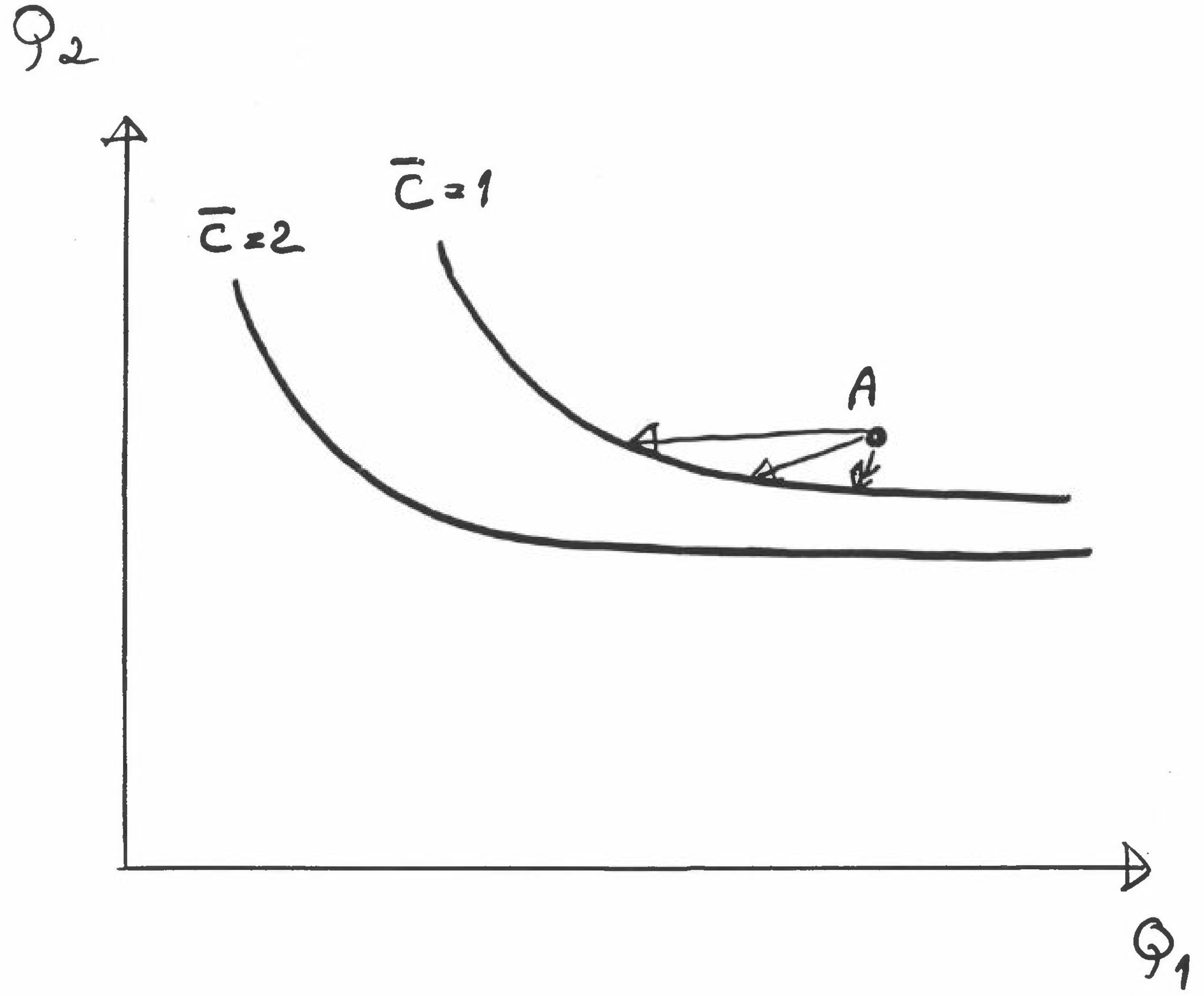
Costs will be of least importance for the solution if $n = m$

$n = m$

$n < m$ — $n = 30$ countries target depositions, $m = 1000$ emission grid squares

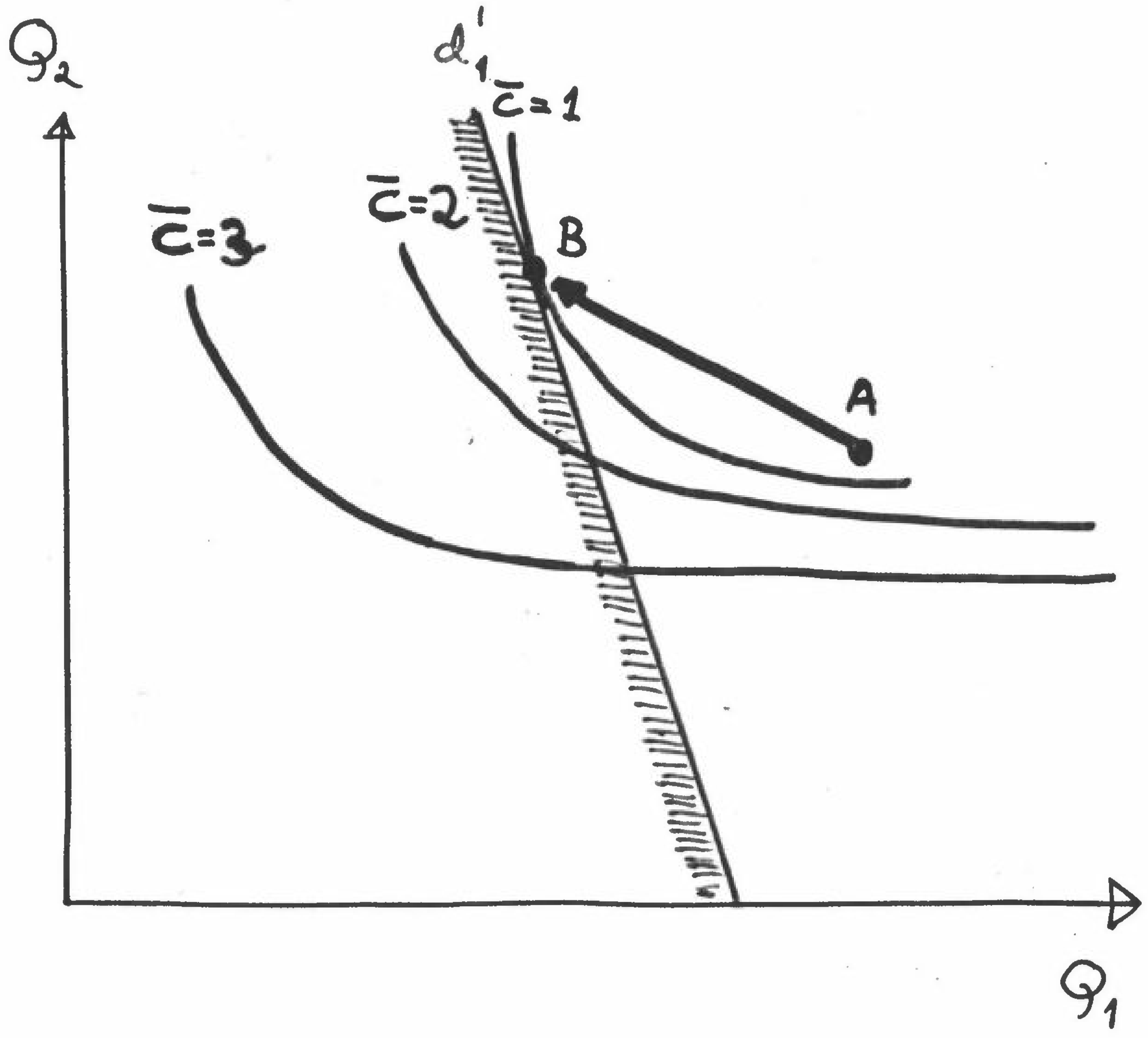
⊛ $n > m$ — $n = 9000$ receptor grid squares — $m = 30$ emitter countries

Solution of Integrated Assessment Model:



- * two emitters Q_1, Q_2
- * four times cheaper to reduce Q_1 than Q_2
- * A: Here we are now

Solution of integrated assessment model:



* two emitters Q_1, Q_2

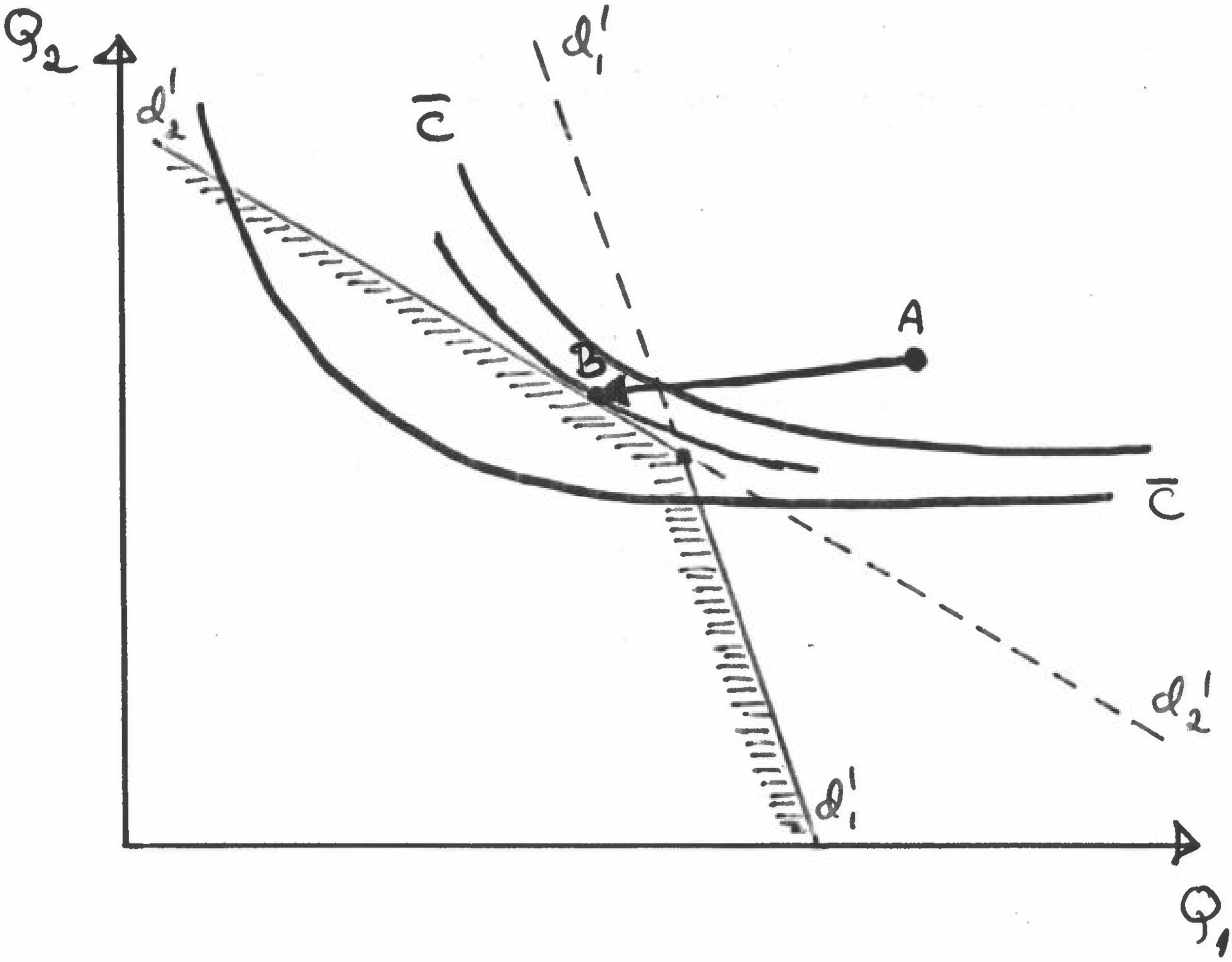
* four times cheaper to reduce Q_1 than Q_2

* critical (or target) load given at one receptor: d_1'

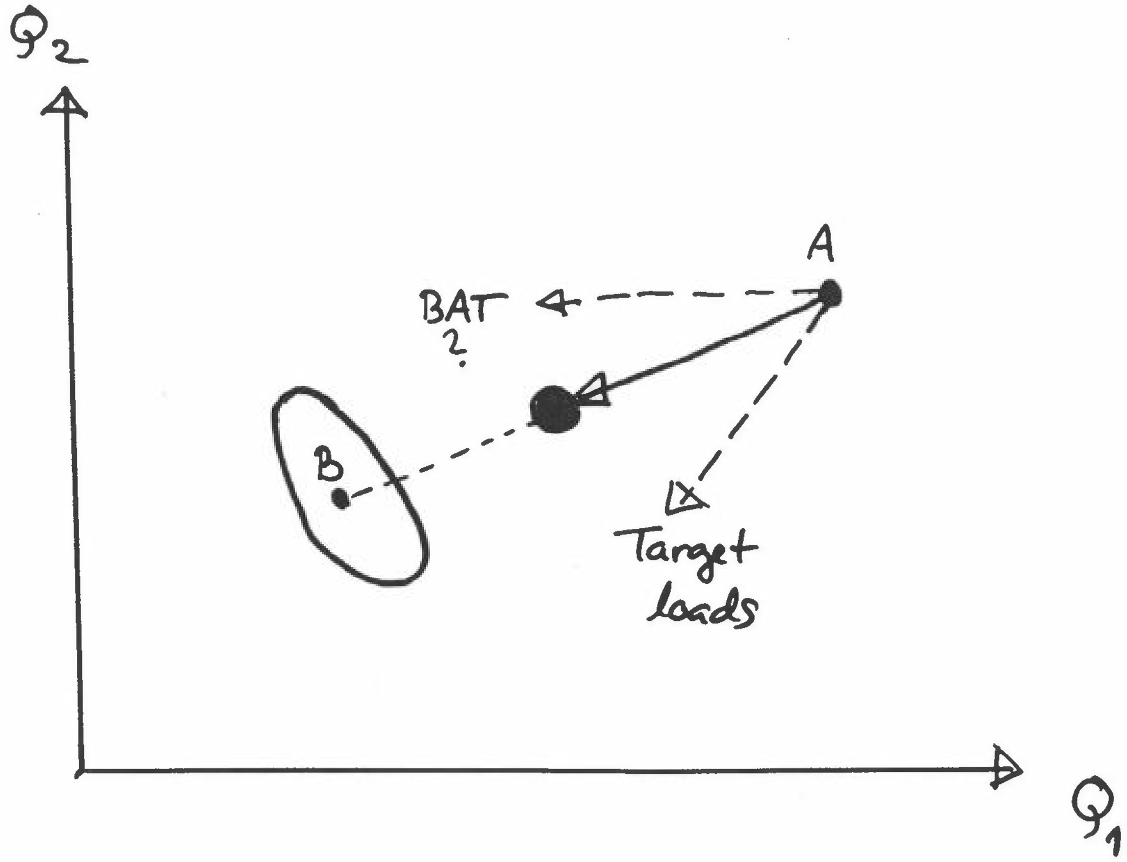
A : Here we are now

B : Optimal solution

Solution of an integrated assessment model:



* As previous figure, but with two critical (or target) loads: d_1' and d_2'



A : Starting point

B : Optimal solution, critical loads attained

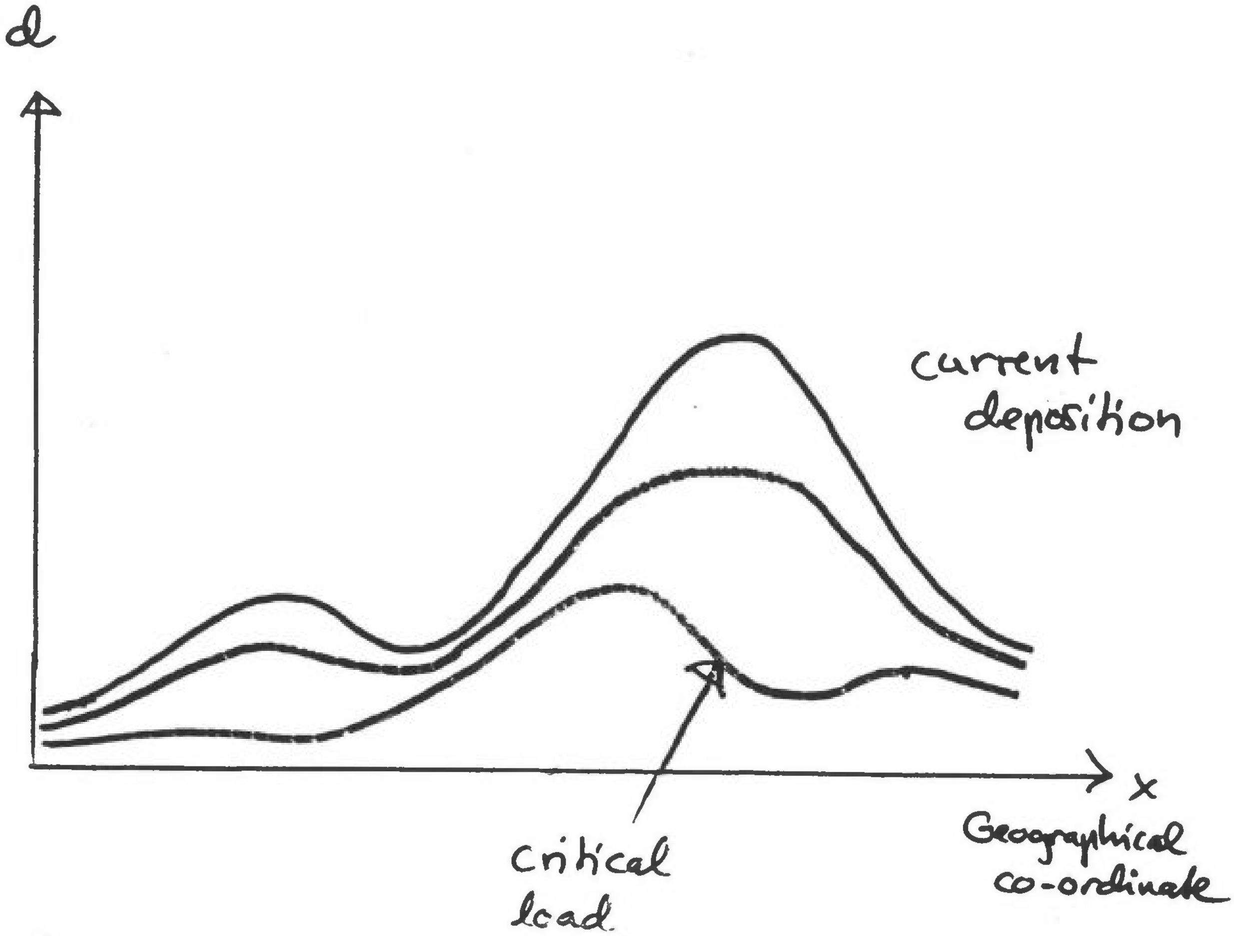
Uncertainty (cost functions, meteorology) :

Any point within ○ is a valid optimal solution

● OK result of negociations "as a first step"

X % of optimal Δ's to attain c.l. 2

Another possibility for proceeding towards optimal solution:

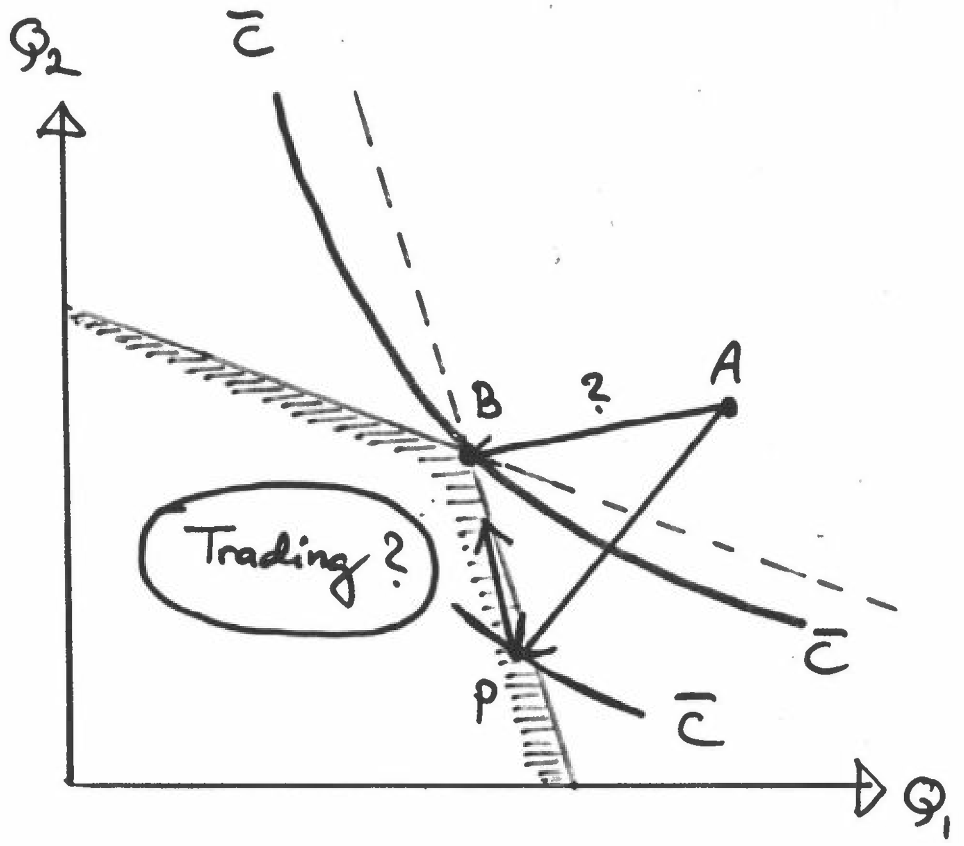


—— new agreed target load: reduces gap between current deposition and critical load by the same % at all points

* Every area will get the same relative improvement towards an acceptable situation

* Will bring us towards B

Emission trading



A: Here we are now

B: Optimal solution from IAM (can change with time

P: Possible non-optimal sulphur protocol

Trading can force emissions towards optimal solution (if proper system can be designed) ?

ANNEX 5

WHAT SCIENTIFIC EVIDENCE DO WE HAVE FOR THE TREATMENT OF SO_x , NO_x , NH_x AND VOC IN THE SAME PROTOCOL.

THE RELATION BETWEEN DIFFERENT EFFECTS

Peringe Grennfelt
Swedish Environmental Research Institute

What scientific evidence do we have for the treatment of SO_x, NO_x , NH_x and VOC in the same protocol. The relation between different effects.

NMR seminar at NILU 21-22 January 1992.

Peringe Grennfelt

Introduction

Regional (continental) air pollution problems are at present focused on acidification, eutrophication and direct effects from regional ozone. The relationship between source categories, emissions, effects and receptor systems are illustrated in figure 1. As seen from the figure nitrogen oxides plays a crucial role for the development of all mentioned effects.

In this summary interactions between different compounds are discussed with respect to exposure/deposition and effects. The only receptor system covered is forest ecosystems and forest soils. The reason is that forests represent a key receptor for regional air pollution and that pollution induced changes in forest soils may cause effects in groundwater, lakes, streams and even in the marine environment.

Acidification of forest soils

Acidification of forest soils may be illustrated by figure 2. The upper part of the figure illustrates a situation, where the soil has a high base saturation, i.e. the cations on the soil particles consists to a large extent of base ions (calcium, magnesium and potassium). The incoming acid - in this case sulphuric acid - is neutralized by ion exchange, where hydrogen ions replaces the base cations. If this process is larger than the production of new cations from weathering, the soil will loose base saturation. The soil will be acidified.

In the lower part of the figure the soil has lost its base saturation to an extent, where the passing acid will not be fully neutralized by leaching base cations from the soil particles. Instead some of the acid will be neutralized by aluminium ions and some of the hydrogen ions will pass the soil. The soil has become acid and acidity is also exported to groundwater and to streams and lakes. The acidity of the exported solution may be defined as the amount of OH necessary to neutralize the solution. Such a definition means that the aluminium ion will also act as an acid.

Acidification by sulphur is driven by the sulphate ion, which in many acid sensitive soils is transported through the soil profile without any losses.

The role of nitrogen for acidification and eutrophication of forest systems

For nitrogen the picture is more complicated. Most forest ecosystems are naturally lacking in nitrogen and nitrogen will in its first step act as a nutrient. Later nitrogen deposition will cause ecosystem changes and finally at high nitrogen loads for a long time nitrate leaching will occur. This process is illustrated in figure 3. In most of the nordic countries the nitrogen load has not reached a situation of extensive nitrogen leaching, while on the continent nitrogen leaching is common. The fate of nitrogen in forst systems is illustrated in figure 4.

How will nitrogen contribute to different effects? In order to understand we need to describe and quantify the different pathways of nitrogen. Nitrogen deposition may in forest systems essentially have three main fates: a) uptake in stems and barch, which at harvesting is taken away from the forest system, b) accumulation in the forest, either in the living biomass or as organic compounds in the soil, and c) be leached from the soil, most often as nitrate, (Figure 5). In this presentation we have excluded processes such as denitrification and absorption of ammonium to soil particles.

The different pathways may contribute to regional effects in the following way:

- The accumulation of nitrogen in biomass and in the organic pool is contributing to eutrophication and other nutrient-oriented effects.

- The uptake of nitrogen in the stemwood will contribute to the acidification since the uptake of nitrogen is also associated with an uptake of alkaline ions, which will contribute to losses of base saturation in the soil. The ratio between alkaline uptake and nitrogen uptake in stems and barch is often 1-1,5.

- The leaching of nitrate is associated with leaching of a cation and contributes to acidification in the same way as sulfate outflow from the forest soil.

The accumulation of nitrogen in the forest soil will change the availability of nitrogen in relation to other nutrients and to organic carbon which will decrease the capacity of the soil to retain nitrogen. This may lead to increased nitrate leaching. The accumulation of nitrogen in soils is a natural process in northern forests soils and this process has been going on since the last glaciation. If we consider the accumulation as a linear process the yearly accumulation of nitrogen has typically been 1-3 kg/ha, yr. The deposition of nitrogen is in central Europe and Scandinavia far above this value.

Most forest soils have a capacity to accumulate large amount of nitrogen. At the lake Gårdsjön area for example the nitrate leaching is still below 1 kg N/ha,yr, although the forest soil is very acid and that the systems yearly receive 15-20 kg N/ha,yr. The accumulation will lead to a higher nitrogen status of the soil, higher production and also to ecosystem changes before nitrate leaching will occur. Thus, we may conclude that ecosystem changes due to nitrogen deposition is an earlier effect in forest ecosystems than acidification due to nitrate leaching.

The importance of nitrate for the acidification in different parts of Europe may be illustrated from Table 1.

Region	Nitrogen keq/ha,yr	Sulphur keq/ha,yr	N fraction %
N and C Scandinavia	0	0,3	0
S Scandinavia	0,1	1,5	<5
C Europe	0,3-1	2-4	10-30
Netherlands	1-2	2-3	30-50

From the table it is obvious that nitrogen plays an important role for the acidification in central Europe, while in Scandinavia it is of minor importance. The situation may, however, change and an increased nitrate leaching is expected in southern Scandinavia. We can, however, conclude that sulphur is at present the only compound of importance for the acidification in Scandinavia with exceptions for minor areas in the southern Scandinavia. In central Europe nitrate leaching (caused by deposition of NO_x as well as of NH_x) may contribute with 10-50% to the acidification. That leaching is related to deposition is shown from figure 6, where nitrate leaching from catchments in Europe are plotted against the input by wet deposition. From the figur one may conclude that nitrate leaching seems not to occur until wet deposition of nitrogen (nitrate and ammonia) exceeds 5-7 kg/ha,yr.

Total deposition (wet and dry) is, in many cases, twice as high as the wet deposition.

In the discussion of nitrogen we have not so far made any distinction between different forms for the input of nitrogen. In most cases it is not necessary to take these processes into account as long as overall processes of the soil are considered. The chemical form may, however, be of importance for some certain effects but also for the internal processes within the soil profile. There are effects that are uniquely associated with ammonium, e. g. high ammonium deposition may lead to ratios of K/NH_4 and Mg/NH_4 in the soil, that are unfavourable for plants.

Codeposition of ammonia and sulphur dioxide

In areas in Europe with very high emissions of ammonia, e. g. The Netherlands, there are results indicating an increased deposition due to interactions between ammonia and sulphur dioxide. The mechanism as well as the quantitative importance of this process is not yet very well investigated. One consequence of the process is, however, that control of ammonia emissions in agricultural areas may decrease sulphur deposition and extend the transport distance of sulphur.

What do we need to include in effect-oriented protocols?

An acidification protocol will include the control of sulphur dioxide, nitrogen oxides and ammonia. For the acidification of soils and waters in Scandinavia nitrogen deposition is unimportant except in the southern most parts, (Denmark, SW Sweden and to some extent southern Norway). For the rest of Scandinavia, sulphur deposition is causing >95% of the acidification from atmospheric deposition. On the continent, deposition of ammonium and nitrate becomes more important and may in some areas cause 25-40% of the soil acidification. (Figure 7)

An acidification protocol may thus, on the continent, require control of sulphur and nitrogen deposition while it, in Scandinavia, is almost entirely a sulphur problem.

In terrestrial ecosystems nitrogen eutrophication effects occur earlier than nitrate leaching. The critical load for eutrophication will therefore be lower than the critical load for the N contribution to acidification. Eutrophication effects are common on the continent and in the southern parts of Scandinavia, especially in areas close to intense farming. Minor effects are observed in central and northern Scandinavia, e.g. in mountain streams. A eutrophication protocol requires control of NH_3 and NO_x. A combined NH_3/NO_x protocol may, however, be difficult to formulate due to the large differences in transport between NO_x and NH_3. Ammonia is to a large extent a local/national problem, while NO_x has a transport distance similar to SO_2. (Figure 7)

In the most intense agricultural areas the ammonia emissions and deposition are so high that the deposition of sulphur dioxide will be enhanced due to the alkaline environment. Ammonia control will therefore decrease sulphur deposition in that area but increase it at further distances.

Photochemical oxidants are of interest on a regional scale due to episodic high ozone concentrations and on a hemispheric scale due to a long term increase in the tropospheric background concentrations. The episodes will give ozone concentrations above the critical level over central Europe up to mid Scandiavia. The critical levels for the vegetation season are exceeded over all of Europe. The episodes require control of NO_x, VOC and CO emissions in central Europe while the background ozone mainly needs control of NO_x and CO over the whole northern hemisphere and of the global emissions of CH_4.(Figure 8)

Final comments

It has not within the scope of this presentation been able to discuss within which areas different effects may be the most important for the control of emissions. Such an evaluation may, at least in semiquantitative terms, be able to make. It is also of importance to consider how a strategy for one effect will affect other effects. The most important compound in this evaluation is of course NO_x since it will contribute to all effects. One may e.g. expect that control of nitrogen oxides is not of importance for nitrogen effects in forest ecosystsems in northern Scandinavia, but the control might be of importance for the avoidance of long term ozone effects on vegetation.

Figure 1 Regional air pollution problems. Relations between dominant sources, emitted compounds and effects at different receptors.

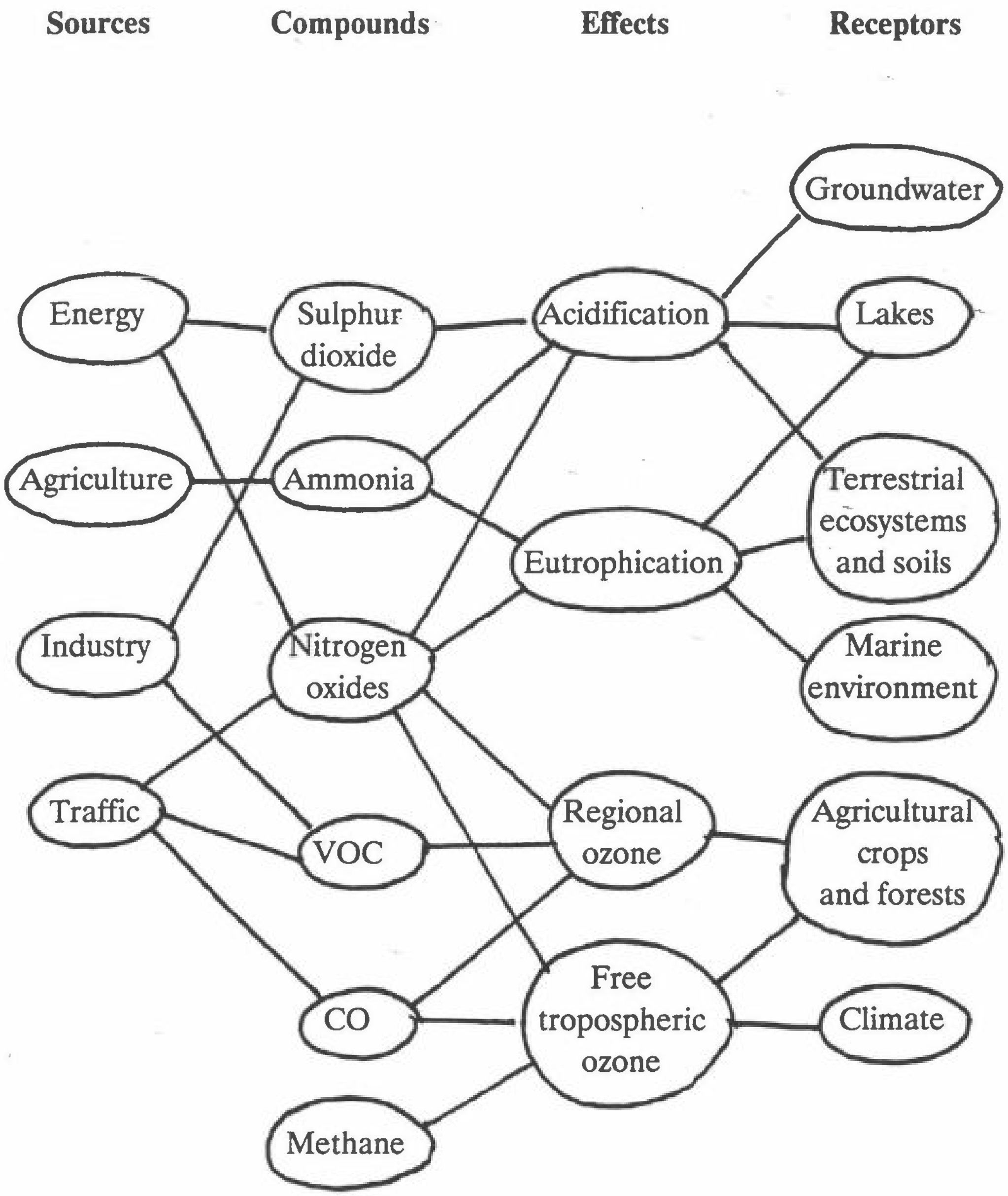


Figure 2 Simplified scheme of the mechanisms for soil acidification with sulphuric acid

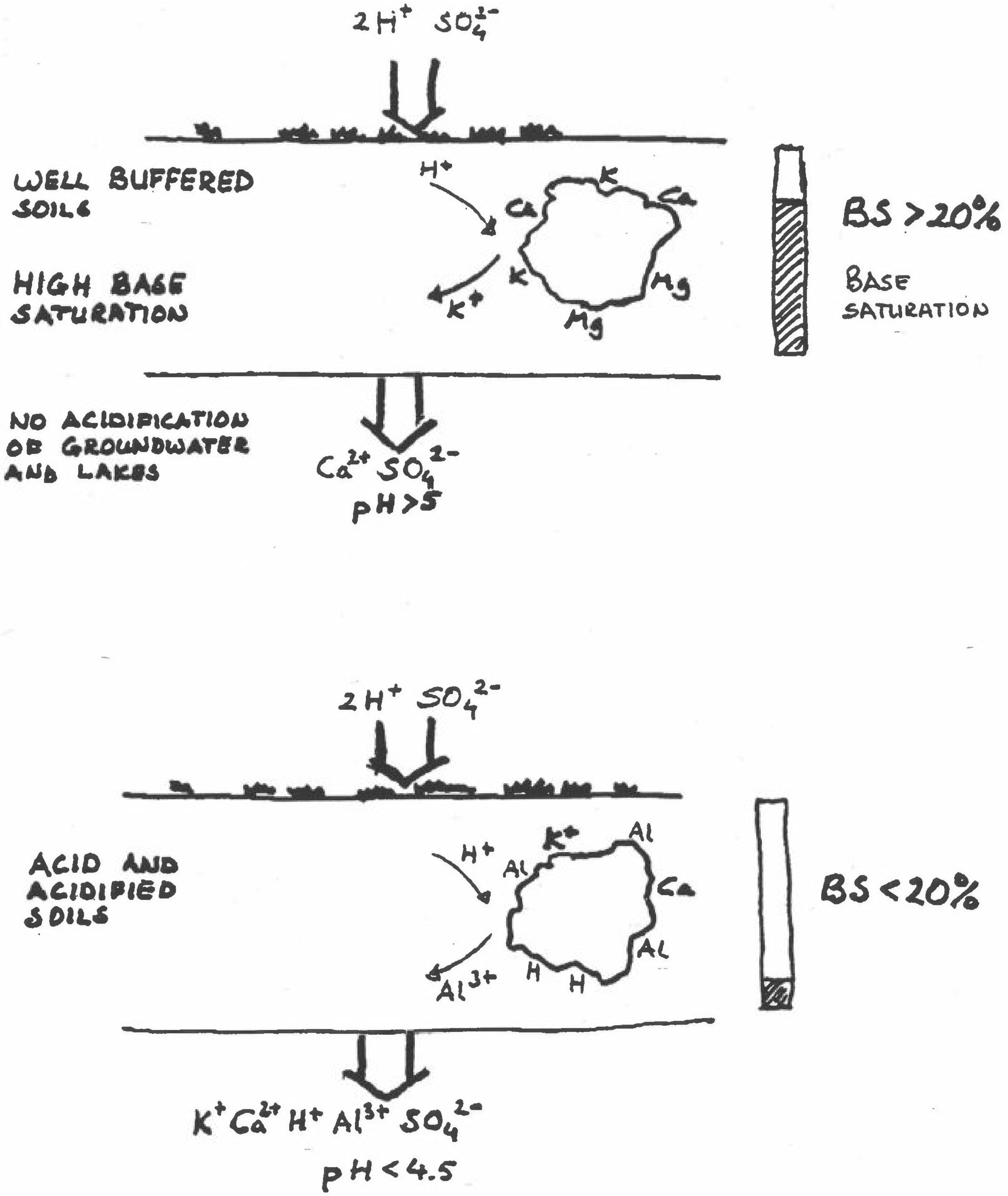


Figure 3 The development of nitrogen effects on forest ecosystems

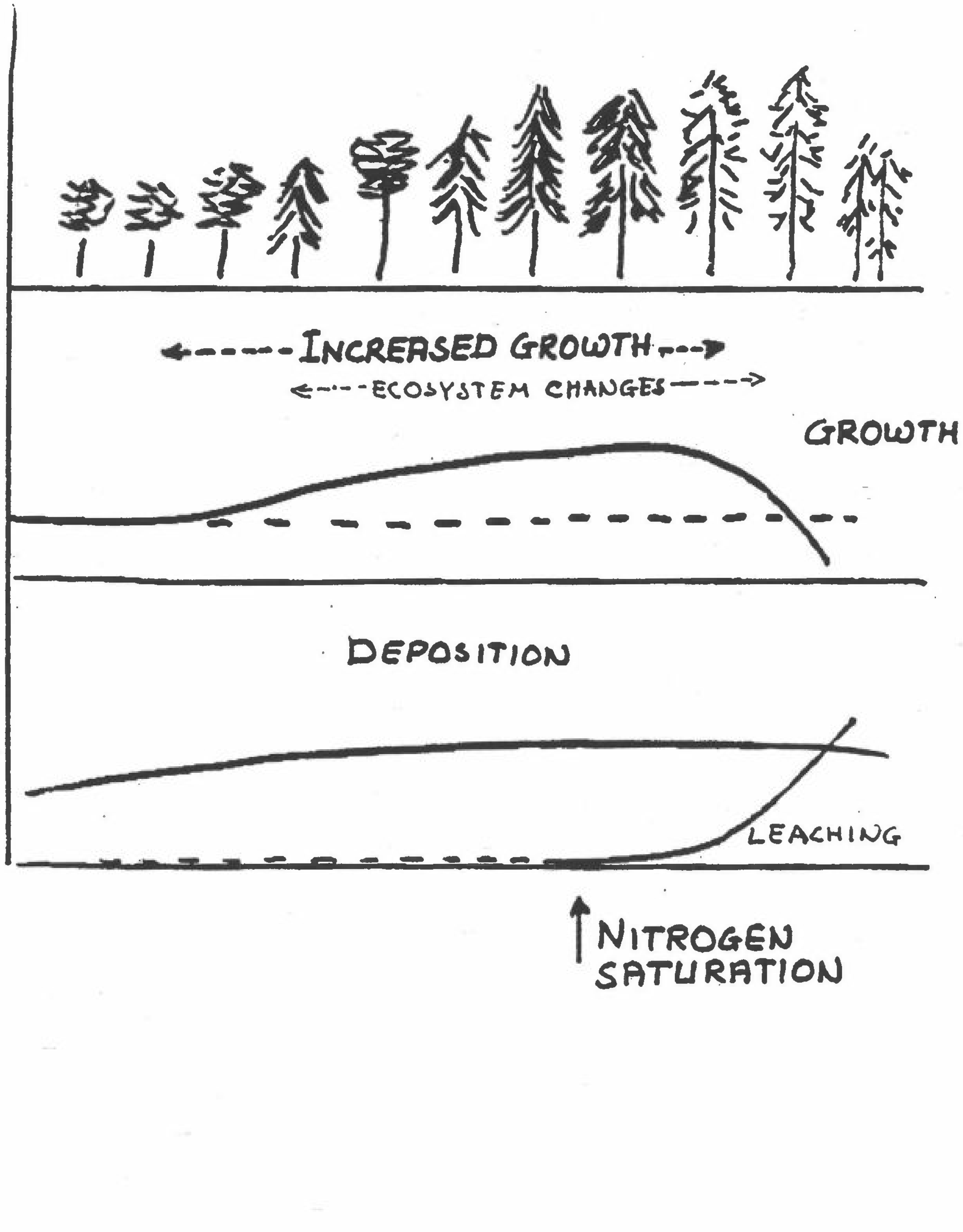


Figure 4 The fate of nitrogen in forest ecosystems on Scandinavia and central Europe. Nitrate leaching in Scandinavia <1 kg/ha, yr and in central Europe mostly larger than 5kg/ha, yr.

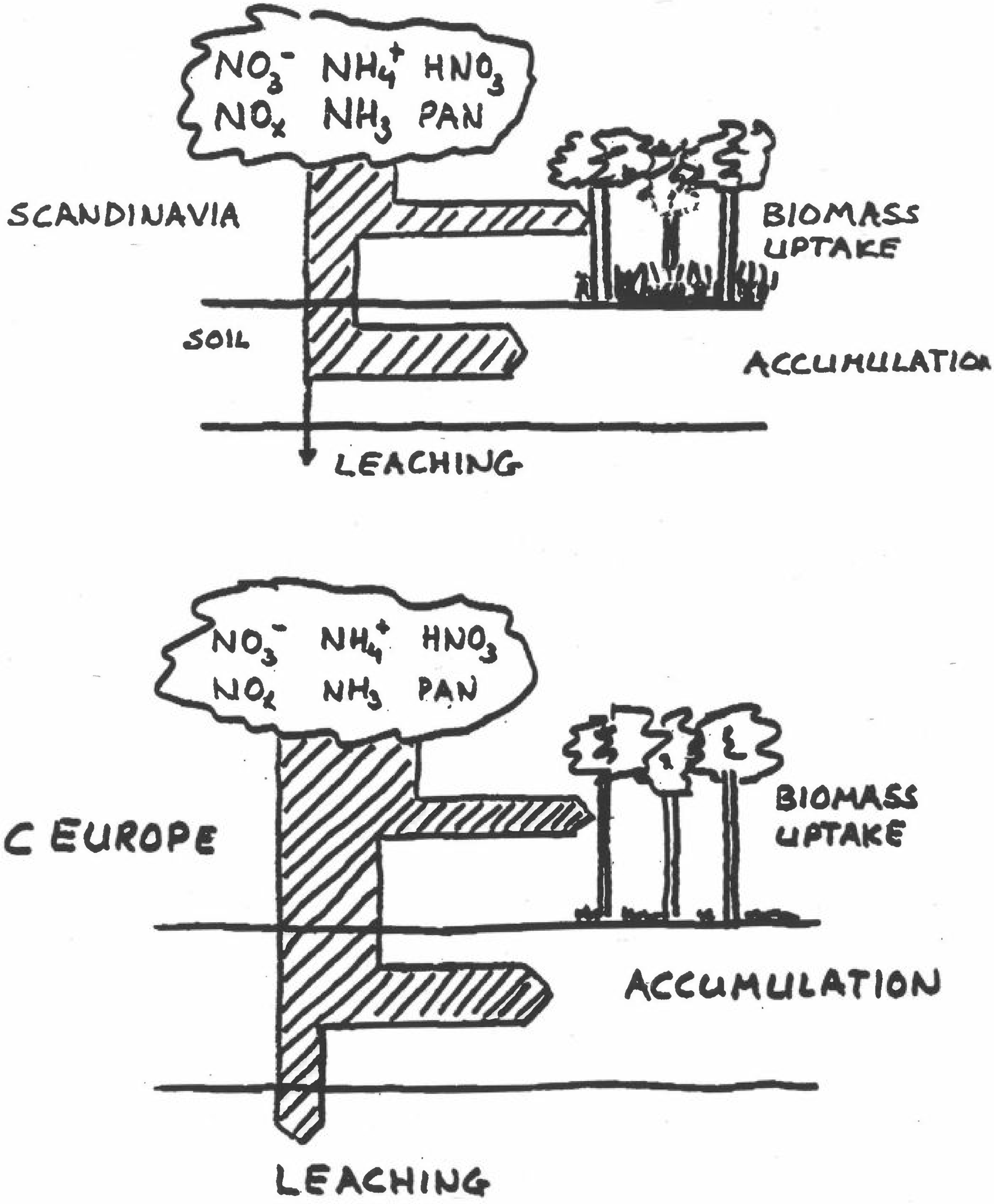


Figure 5 Main pathways for S and N deposition in forest ecosystems.

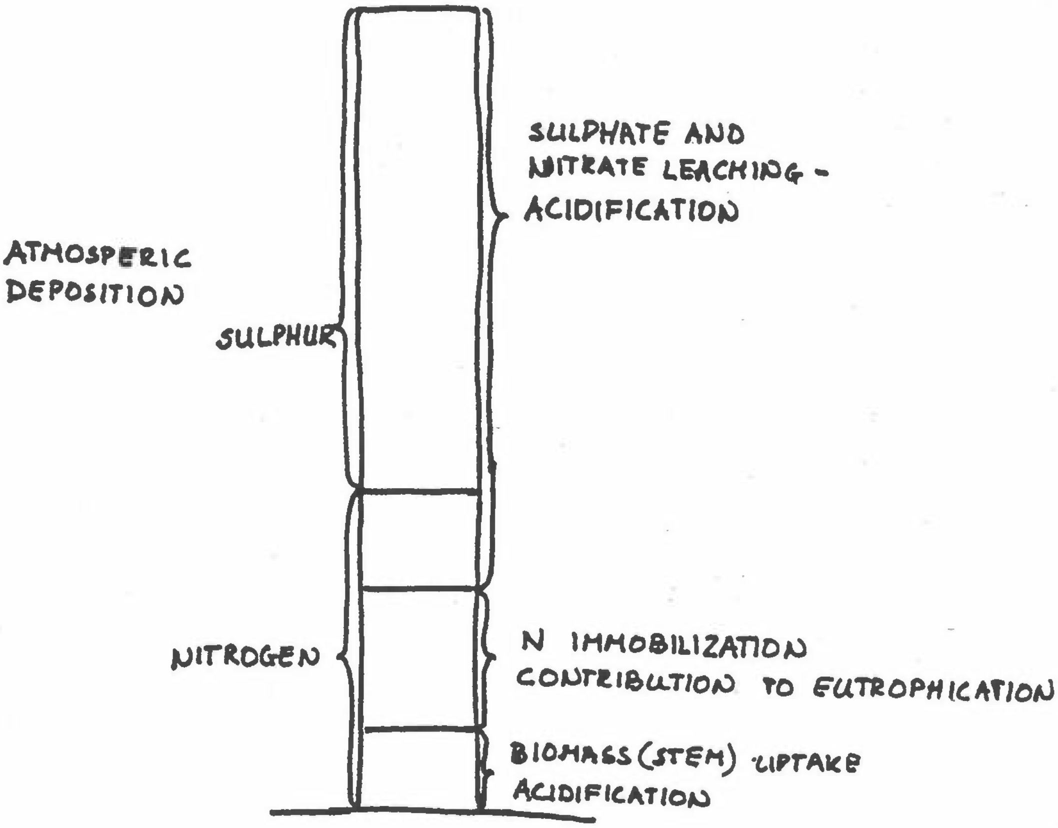


Figure 6 Nitrate leaching versus wet deposition of nitrogen at forested catchments in Europe. Extended data from Grennfelt and Hultberg 1986. The two arrows illustrate two catchments in Germany which within a few years time increased their leaching.

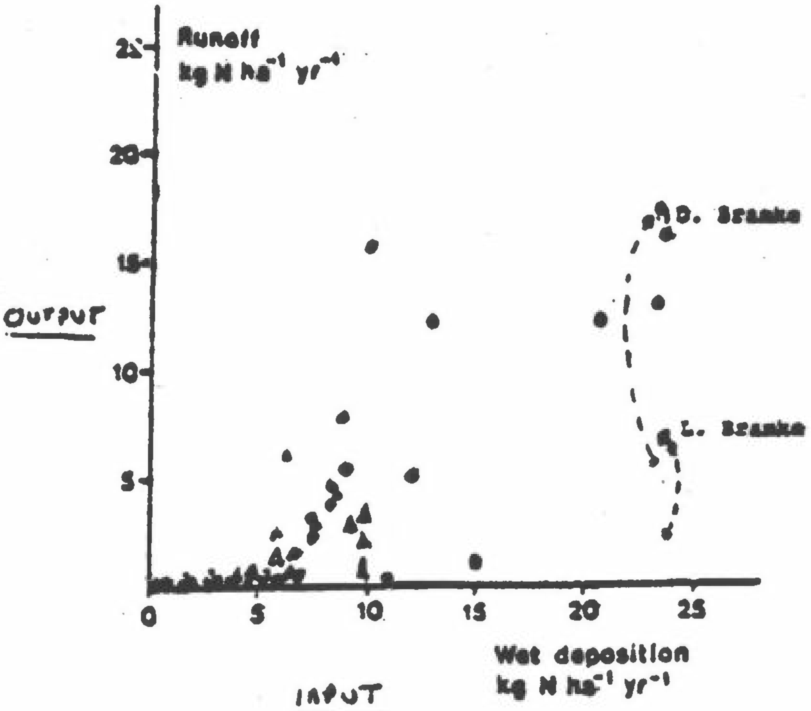
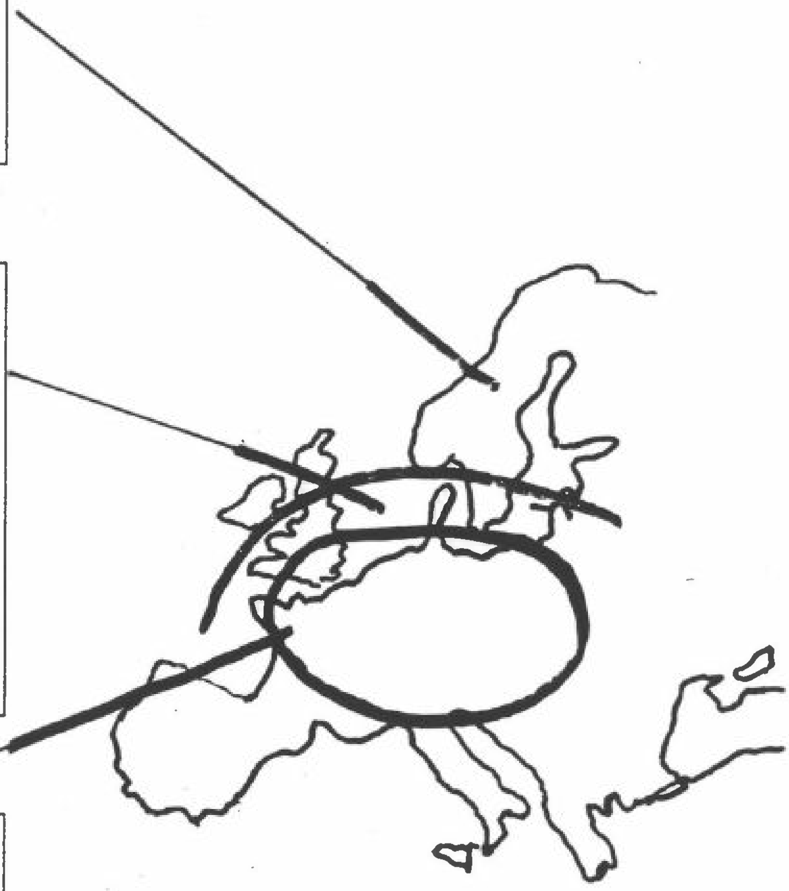


Figure 7 A schematic description of the main acidification and eutrophication problems in different regions in central and northern Europe and their relation to the critical loads.



ACIDIFICATION

Lake acidification. Acidification episodes during snowmelt. Sulphur, the only compound of importance. Present load <3 x critical load.

EUTROPHICATION

No regional eutrophication effects.
Mountain streams?
Present load ≳ critical load

ACIDIFICATION

Soil and lake acidification.
Sulphur is the dominant compound.
Nitrogen of minor importance except in agricultural areas.
Present load 3-5 x critical load.

EUTROPHICATION

Eutrophication effects especially in agricultural areas. No or small N leaching PL 2-3 x CL.

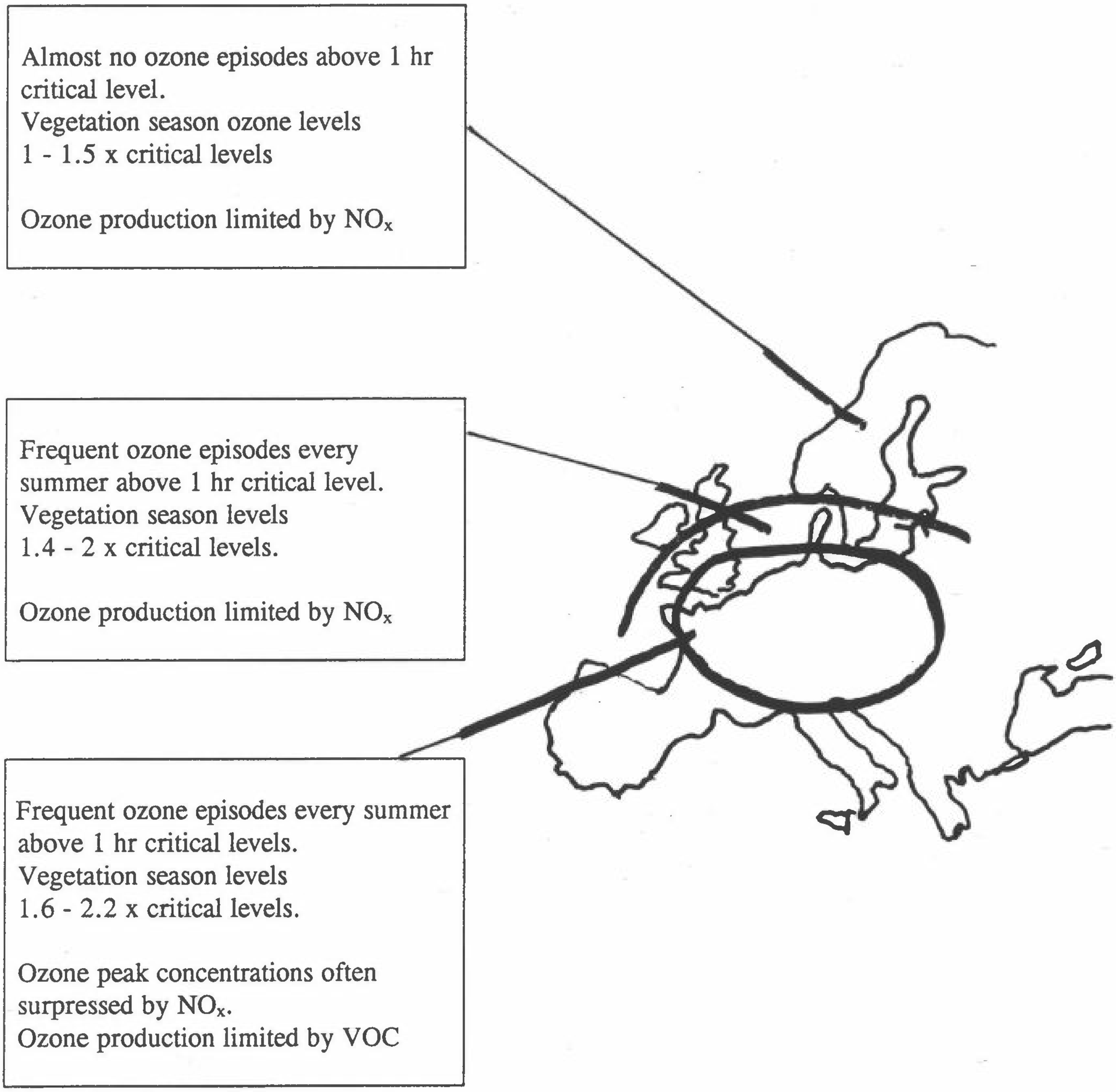
ACIDIFICATION

Soil acidification.
Sulphur and nitrogen of importance.
Present load 3-5 x critical load.

EUTROPHICATION

Severe ecosystems changes in agricultural areas.
Present load 3-5 x critical load.
In agricultural areas: Present load >5 x critical load.

Figure 8 A schematic description of the ozone levels and their relation to critical levels and which precursor that limits the ozone production in different regions in central and northern Europe.



Almost no ozone episodes above 1 hr critical level.
Vegetation season ozone levels
1 - 1.5 x critical levels

Ozone production limited by NO_x

Frequent ozone episodes every summer above 1 hr critical level.
Vegetation season levels
1.4 - 2 x critical levels.

Ozone production limited by NO_x

Frequent ozone episodes every summer above 1 hr critical levels.
Vegetation season levels
1.6 - 2.2 x critical levels.

Ozone peak concentrations often surpressed by NO_x.
Ozone production limited by VOC

ANNEX 6

ATMOSPHERIC CHEMISTRY: CONSEQUENCES OF A COMBINED NO_x, SO_2 AND VOC EMISSION REDUCTION

Øystein Hov
University of Bergen

Notes, paper presented at "Nordisk ekspertmøte om kostnadseffektive internasjonale miljøavtaler, NILU, Lillestrøm 21-22.1.1992"

ATMOSPHERIC CHEMISTRY: CONSEQUENCES OF A COMBINED NO_x, SO_2 AND VOC EMISSION REDUCTION

Øystein Hov, Geofysisk institutt, Universitetet i Bergen,
Allégaten 70, N-5007 Bergen

1. Control strategies need to address the time scale defined by the environmental effects:

Critical load, sulphur:

The highest load that will not lead in the long-term (within 50 years) to harmful effects on biological systems (2-3kgS/ha•a).

Critical load, nitrogen:

Critical loads for nitrogen are set to prevent forest ecosystems from becoming nitrogen saturated in the long-term (25-50 years) (5-20kgN/ha•a in forestry).

Effect threshold ozone:

Peak hourly concentrations (often set to 100 ppb), average concentration over the growing season (often set to 40 ppb).

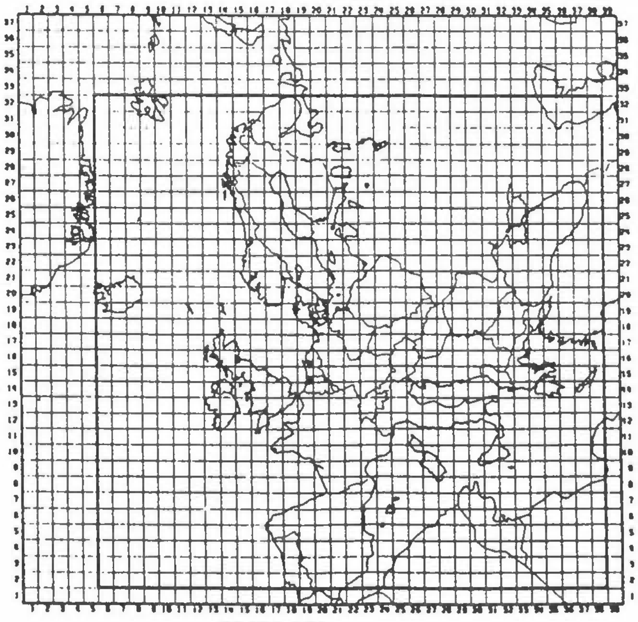
Control strategies should:

- Reduce long-term deposition (within 25-50 years) deposition of sulphur and nitrogen.
- Photooxidant levels should be reduced in episodes and averaged over growing seasons.

2. Control strategies must address the spatial scale of the environmental impact

The calculated deposition within the subdomain of the EMEP model area shown in the Figure, of the anthropogenic emissions of NO_x and SO_2, is shown in the Table below. NO_y denotes the sum of all compounds derived from NO_x. The numbers in paranthesis are the fraction of the emissions which is deposited (based on Iversen et al., 1991).

Year	NO_x emission (MtN/yr)	SO_2 emission (MtS/yr)	NO_y deposition in Europe (MtN/yr)	S deposition in Europe (MtS/yr)
1985	6.7	24.0	3.6 (0.54)	15.7 (0.65)
1986	6.7	24.1	not calculated	
1987	7.0	23.4	3.9 (0.56)	15.4 (0.66)
1988	7.0	22.3	3.6 (0.51)	13.9 (0.62)
1989	7.1	21.4	3.7 (0.52)	13.7 (0.64)
1990	7.1	22.0	3.8 (0.54)	14.0 (0.64)



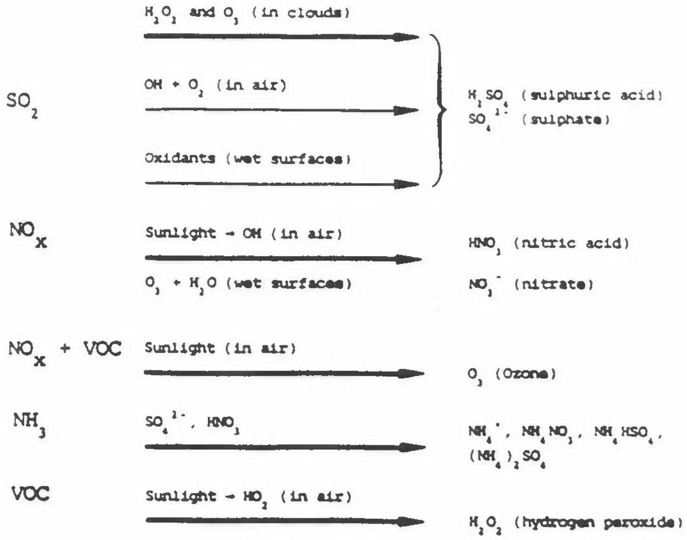
THE EMEP-GRID

The Table shows that 51-56% of the European anthropogenic NO_x and 62-66% of the SO_2 emissions are deposited within the region. The variability from year to year reflects meteorological changes.

The acid deposition problem has a continental character and should be dealt with on that spatial scale (Eurasia or North America). The greenhouse gases are global and need a global control strategy.

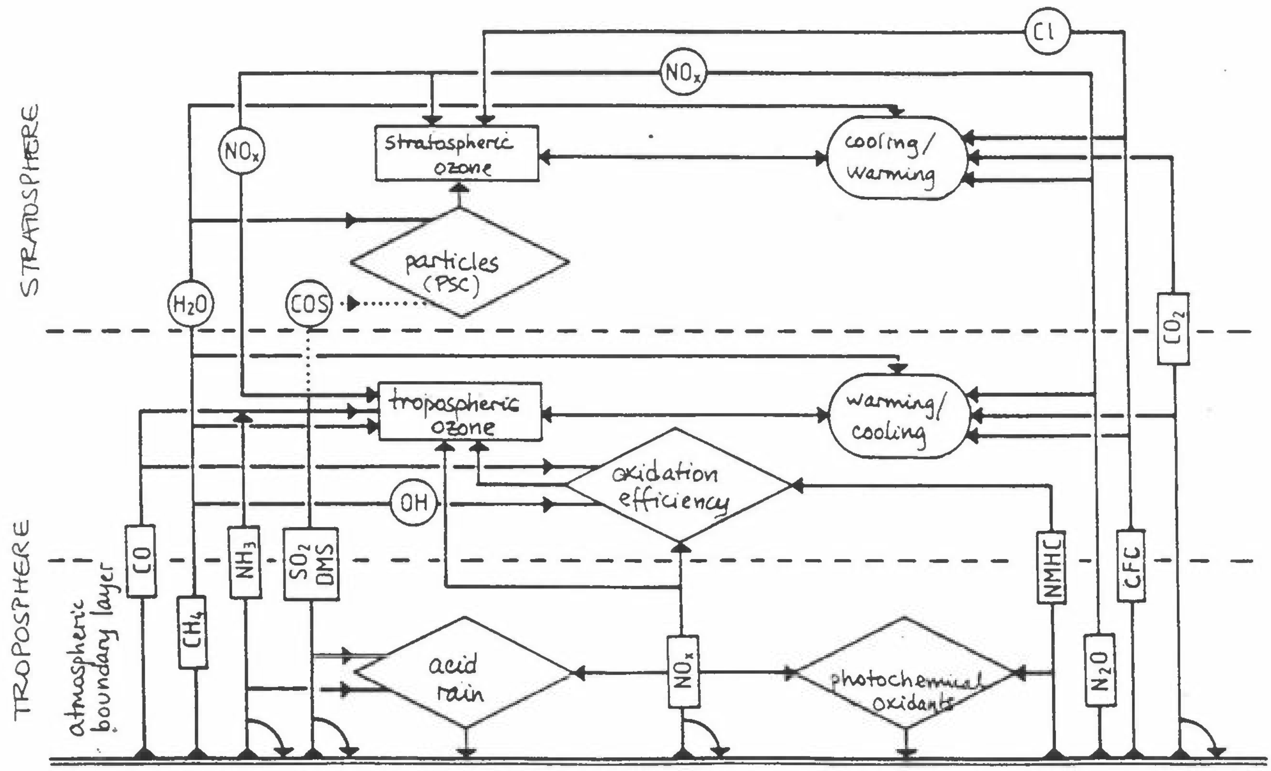
3. How will a combined NO_x + SO_2, NO_x + VOC, NO_x + SO_2 + VOC emission reduction influence protocol work? What additional effect would a climate protocol have (CH_4, CO_2)?

In the Figure below is shown how SO_2 is transformed to sulphate in the atmosphere, NO_x to nitrate and VOC to ozone and other secondary pollutants. The question of interest in a combined protocol is how changes in the emission of one compound may influence the transformation rate and thereby the deposition pattern and concentration pattern of chemical species derived from the emission of other groups of compounds.



In the Figure below, an outline is given of how emissions (vertical lines) of greenhouse gases (CO_2, CFCs, N_2O, CH_4), acid deposition precursors (SO_2, NO_x, NH_3) and photooxidant precursors (NMHC, NO_x, CO) interact in their influence on stratospheric ozone, warming/cooling of the troposphere and the stratosphere, tropospheric ozone, the tropospheric oxidation efficiency, acid rain and photochemical oxidant formation in the atmospheric boundary layer.

This Figure gives an indication of the central role of NO_x emissions, influencing acid deposition, photooxidant formation, oxidation efficiency, tropospheric ozone and thereby also the greenhouse effect.



In the Table below, the strength of the relationship between a change in the precursor emissions of acid compounds and ozone, and the concentration of the compounds responsible for the transformation of SO_2 and NO_x to sulphate and nitrate, is shown. Also the sign of the relationship is shown (+ means that when the precursor emission increases, the concentration of the intermediate increases, - means that when the precursor emission increases, the concentration of the intermediate decreases).

Intermediate ⇒ Precursor ↓	O_3 episodic	O_3 long term	OH long term	H_2O_2 long term
CH_4	weak	strong(+)	strong(-)	strong(+)
CO	weak	weak	strong(-)	strong(+)
VOC (NMHC)	strong(+)	weak	weak	weak
NO_x	strong(+)	strong(+)	strong(+)	medium(-)
SO_2	none	none	none	medium?(-)
NH_3	none	none	none	none

These relationships can be quantified through model calculations. These calculations need to cover a significant part of the northern hemisphere atmosphere to say something about long term changes (years), while a smaller domain is sufficient for episodic or seasonal changes. In the following some examples are given from a global model calculation.

In these calculations a meridional distribution from pole to pole is obtained from the global emissions (with a latitudinal dependence), meteorological circulation, chemical transformation and removal processes.

Global emissions estimate in Mt/a (Hough and Johnson, 1990):

	1	2	3	4	5	6	7	8	9	10	11
NO*	21	-	-	-	5	-	-	8	-	8	42
CO	650	-	75	-	-	-	-	800	50	-	1575
CH_4	130	80	-	-	35	110	130	70	40	-	595
NMHC	90	-	90	-	-	-	-	35	6	-	221
isop	-	-	450	-	-	-	-	-	-	-	450
terp	-	-	-	550	-	-	-	-	-	-	550

CO_2 26000 $MtCO_2/a$
*) as N

1: Industrial society, 2: Ruminants, 3: Vegetation (not terpenes), 4: Vegetation (terpenes), 5: Soils, 6: Natural wetlands, 7: Paddy fields, 8: Biomass burning, 9: Oceans, 10: Lightning, 11: Sum.

Anthropogenic fraction of global emissions:

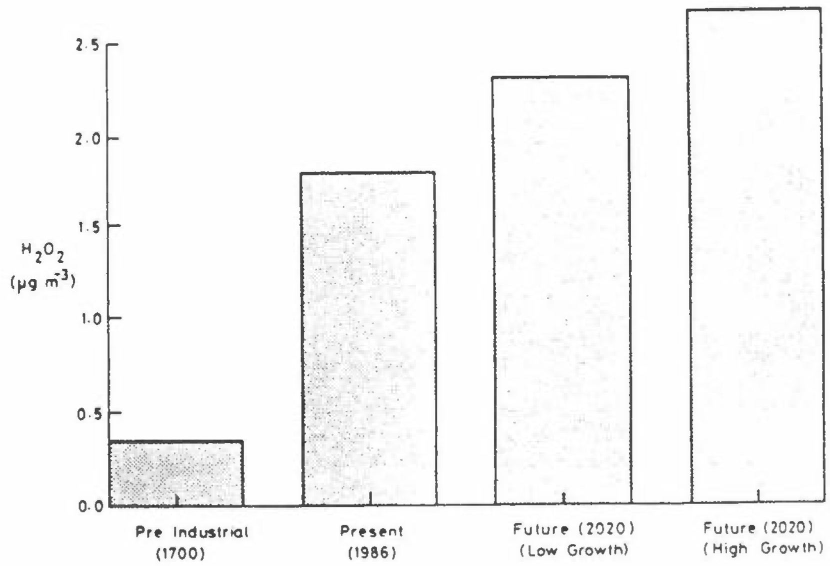
NO	50% (or more)
CO	92%
CH_4	70%
NMHC	55%

European emission estimates, Mt/a (1985):
(Including European part of USSR)

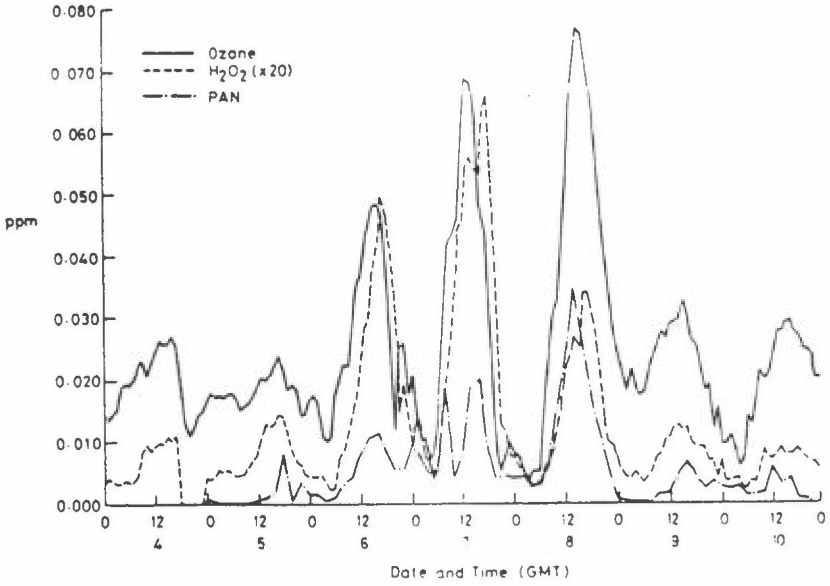
NMHC	22.4 (industrial society)
isoprene	2.8
terpenes	15.4
NO_x (as N)	6.5 (industrial society)
SO_2 (as S)	22.2 (industrial society)

On the next pages is shown how the concentration of H_2O_2 is predicted to change at the latitude of Europe over the coming years due to changes in methane, NO_x and NMHC emissions. Also shown is the measured development of H_2O_2, ozone and peroxyacetylnitrate (PAN) during a photochemical episode at

Harwell, a rural area in central south England, 4-10 August 1988 (Dollard and Davies, 1991). Also shown is a Table with the globally averaged results of how changes in precursor emissions will influence ozone, PAN, H_2O_2 and OH (Hough and Johnson, 1990).



Modelled H_2O_2 concentrations for a grid cell with its southern boundary at 48.6°N. Scenarios after Hough & Derwent (1990).



O_3, PAN and H_2O_2 concentrations in air during the period 4–10 Aug. 1988.

Scenario	O_3 production Mt/a	PAN budget Mt	H_2O_2 budget Mt	OH budget t
Reference	5095	3.625	5.555	213.6
-20% NO_x industrial society	-140	-0.130	0.035	- 3.4
-20% NO_x biomass burning	-105	-0.01	-0.01	- 3.4
-20% NO_x lightning	-220	-0.75	0.05	- 3.4
-20% CO industrial society	- 45	-0.020	-0.130	2.2
-20% CO biomass burning	- 50	-0.025	-0.185	3.6
-20% NMHC industrial society	- 35	-0.030	-0.045	1.2
-20% NMHC biomass burning	- 5	-0.050	-0.020	0.8
-20% NMHC vegetation	- 5	-0.135	-0.055	2.6
-20% isoprene	30	-0.110	-0.120	7.6
-20% terpenes	- 15	0.020	-0.020	1.0
-20% CH_4 all sources	-145	-0.050	-0.420	10.8
-40% NO_x, -40% CO, -20% NMHC, -20% CH_4, industrial society	-455	-0.695	-0.33	0.4
-60% NO_x, -40% CO, -40% NMHC, -30% CH_4, industrial society	-670	-1.205	-0.390	- 1.6

4. Conclusions

In the Table below is shown how the transformation of SO_2 to sulphate and NO_x to nitrate may change as the precursor emissions (left column) change.

Intermediate ⇒ Precursor ↓	O_3 episodic	O_3 long term	OH long term	H_2O_2 long term
CH_4	weak	strong(+) SO_4^{2-} and NO_3^- increase	strong(-) NO_3^- and SO_4^{2-} decrease	strong(+) SO_4^{2-} increase
CO	weak	weak	strong(-) NO_3^- and SO_4^{2-} decrease	strong(+) SO_4^{2-} increase
VOC (NMHC)	strong(+)	weak	weak	weak
NO_x	strong(+)	strong(+) SO_4^{2-} and NO_3^- increase	strong(+) SO_4^{2-} and NO_3^- increase	medium(-) SO_4^{2-} decrease
SO_2	none	none	none	medium?(-) SO_4^{2-} decrease
NH_3	none	none	none	none

Increased rate of transformation of $SO_2 \rightarrow SO_4^{2-}$ or $NO_2 \rightarrow NO_3^-$ but a constant emission level of NO_x and SO_2 will give rise to more long range transport of sulphur and nitrogen and consequently enhanced (mainly wet) deposition far from the sources (eg. Southern Scandinavia).

Decrease in NO_x emissions will:

- decrease NO_x and nitrate deposition (proportional to emission reduction)
- decrease episodic and long term ozone increase; this is also a function of the source height of NO_x where high altitude sources (commercial aircraft) are particularly efficient ozone producers in a height region where ozone has a maximum greenhouse effect
- decrease OH ⇒ increase in CH_4 and in other greenhouse

gases where OH reaction is rate determining step (i.i. CFC substitutes) (positive radiative forcing)

- decrease nitrate radical formation, reducing nighttime transformation of e.g. NO_2 to nitrate, DMS to MSA and possibly hydrocarbons to PAN and other organic nitrates
- increase H_2O_2 (which may enhance sulphate transformation and transport distance of S)

Decrease in NMHC emissions will:

- reduce episodic ozone

Decrease in SO_2 emissions will:

- increase H_2O_2

Increase in greenhouse gases will have:

- indirect effect on photolysis rates and wet deposition through changes in clouds and precipitation patterns
- indirect effect on the chemical processes through their temperature dependence

ANNEX 7

SULPHUR TRADING IN EUROPE

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Januar 1992

Sulphur trading in Europe

by

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1. Introduction

The atmospheric transportation of sulphur emissions across Europe is well documented. An important feature of sulphur as pollutant is that the damage varies according to the receptors in question, e.g. depending on the buffer capacity of lakes, precipitation, type of vegetation, etc. When considering possibilities of reducing emissions of sulphur countries differ due to different economic structure, different emitting activities and different purification technologies due to age of equipment and/or different local environmental regulation.

In order to derive a cost effective solution one must either have agreement as to physical depositions at receptors, or have established accepted damage functions for them. In addition, there must be agreement on the pattern of transportation between sources and receptors.

The RAINS model developed at IIASA is based on an accepted linearised transportation matrix of sulphur emissions between countries as sources, and regional receptors. The model allows physical constraints on depositions to be formulated.

Any collective action to reduce the total emission of sulphur in Europe must decide on volumes of cut-back for individual countries. When considering the implementation of a cost effectiv solution the problem of how to share the burden of purification costs must be solved. Both due to this problem and due to the fact that there are real uncertainties in the physical data of the model both as regards transportation of pollutants and purification cost functions, other solutions than "first best" are realistic to consider. A new challenge then emerge: is it possible to introduce regulation instruments that will lead countries to improve the initial allocation of emissions in their own self interest, both in the short run and in the long run?

To open up possibilities to trade emission permits is one suggestion of a self improving incentive system. We shall explore the background for such a proposal and investigate consequences.

2. The model framework

The basic model for analysing cost effective means of reducing sulphur depositions consists of two relationships:

- The efficient purification cost functions for each source.
- The transport coefficient matrix showing the amount of one unit of emission from one source reaching all receptors in question as depositions for all sources in turn.

The purification cost function is written:

$$c_i(r_i) = c_i(e_i^0 - e_i) \ ,i = 1,..,n \tag{1}$$

r_i = amount purified at source no. i, i = 1,..,n.

e_i^0 = initial emission

e_i = remaining emission (after purification, $0 \le e_i \le e_i^0$)

Note the standard assumption of keeping initial emissions constant. The implications are that both level of output and technology are fixed. In a more general setting the level of output of the emitting source is variable and hence the initial emission. This implies that the cost function (1) will shift in general, and the nature of the purification function has to be specified in more detail.

The simplifying assumption about atmospheric transportation of pollutants is that there is a fixed proportion of emission at a source reaching each receptor in question. The fixed unit transportation coefficients may be seen as average values according to weather patterns, prevailing winds, etc. over a time period, e.g. one year. The transport matrix covering n sources and m receptors is:

$$\begin{pmatrix} a_{11} & .... & a_{1m} \\ .. & .... & .. \\ a_{nl} & .... & a_{nm} \end{pmatrix} \tag{2}$$

a_{ij} = transport from source i to receptor j per unit emitted from source i.

Number of sources = n, number of receptors = m.

Total deposition, D_j, in receptor no. j per unit of time is:

$$D_j = \sum_{i=1}^{n} a_{ij} e_i \ , \ j = 1,..,m \tag{3}$$

The background deposition from other (natural) sources than the ones specified with purification possibilities is disregarded.

We are talking about sources and receptors. Countries can be identified by the appropriate subsets of source indices and receptor indices. In the RAINS model sources are aggregated to one source per country while there may be several receptors within each country (on the level of squares of area 150 km times 150 km.).

3. The cost effective solution

A cost effective solution is achieved when a given goal of (reduced) levels of depositions at receptors is obtained at least total cost summing over source purification costs:

$$\begin{aligned} &Min \sum_{i=1}^{n} c_i(e_i^0 - e_i) \\ &given \\ &\sum_{i=1}^{n} a_{ij} e_i \le D_j^* \ , \ j = 1,..,m \end{aligned} \tag{4}$$

D_j^* = deposition target at receptor j.

The necessary condition for interior solution is:

$$MC_i - \sum_{j=1}^{m} a_{ij}\lambda_j = 0 \ , \ i = 1,..,n \tag{5}$$

λ_j = shadow price on the deposition target D_j^*.

MC_i = marginal purification cost of source i.

In this type of models corner solutions, i.e. solutions with strict inequalities in the constraints in (4), will often occur[1]. The shadow price, λ_j, of the constraint will then be zero. Note that another aspect of the corner solution may be that at one source the degree of purification shall be 100 %, while at an other source the degree of purification shall be zero[2].

It is very important to note that condition (5) tells us that marginal costs shall not be equal for all sources. In general the marginal costs at each source is equal to the total impact of its transported emissions as expressed by the transportation unit coefficients weigthed by the shadow prices on the receptor deposition constraints. This sum should not be confused with the total damage that a unit of emission from source i generates. The shadow prices relate to the changes in total purification costs of a marginal tightening of each deposition constraint in turn. The relationship between marginal purification cots at source i and source s at the optimal solution is:

---

[1] If n = m and one demands deposition constraints to hold with equality, the solution may, under certain mathematical assumptions, be unique, i.e. a solution is obtained independent of the cost function. However, relaxing the demand of equality may in our model lead to a solution implying less costs and less deposition at one or more receptors.

[2] In the former case the marginal purification cost is less than the total impact of emissions for the whole range (0, e^0) of emission, and in the latter case the marginal purification cost is greater over the entire range. These two cases are not abnormalities, but ~~will~~ be part of a standard solution.
may

$$\frac{MC_i}{MC_s} = \frac{\sum_{j=1}^{m} a_{ij}\lambda_j}{\sum_{j=1}^{m} a_{sj}\lambda_j} \tag{6}$$

This ratio will be called the "exchange rate" below.

The optimal solution (5) is illustrated in figure 1 with two sources. Source (country) 1 has the highest value of deposition "costs" termed d_1 and d_2 in the figure.

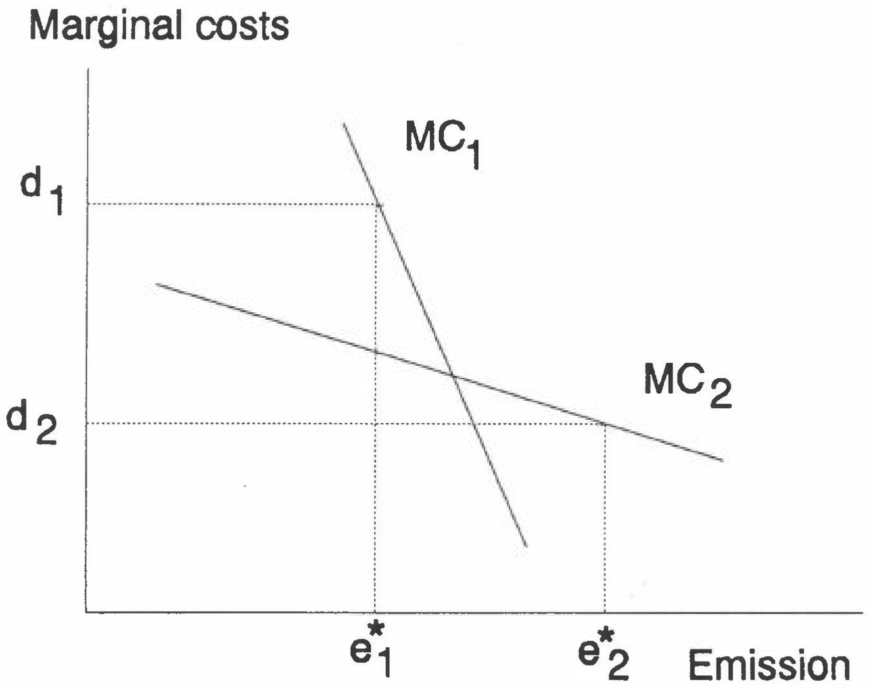

Figure 1. Optimal emission levels

The marginal deposition costs in optimum of each source vary according to variation in the transportation coefficients.

In order to get a better understanding of the optimal solution the optimised total purification function can be introduced. Inserting the optimal solutions for emissions, e_i^*, in the objective function of (4) an isocost curve is defined:

$$\sum_{i=1}^{n} c_i(e_i^0 - e_i^*) = constant \tag{7}$$

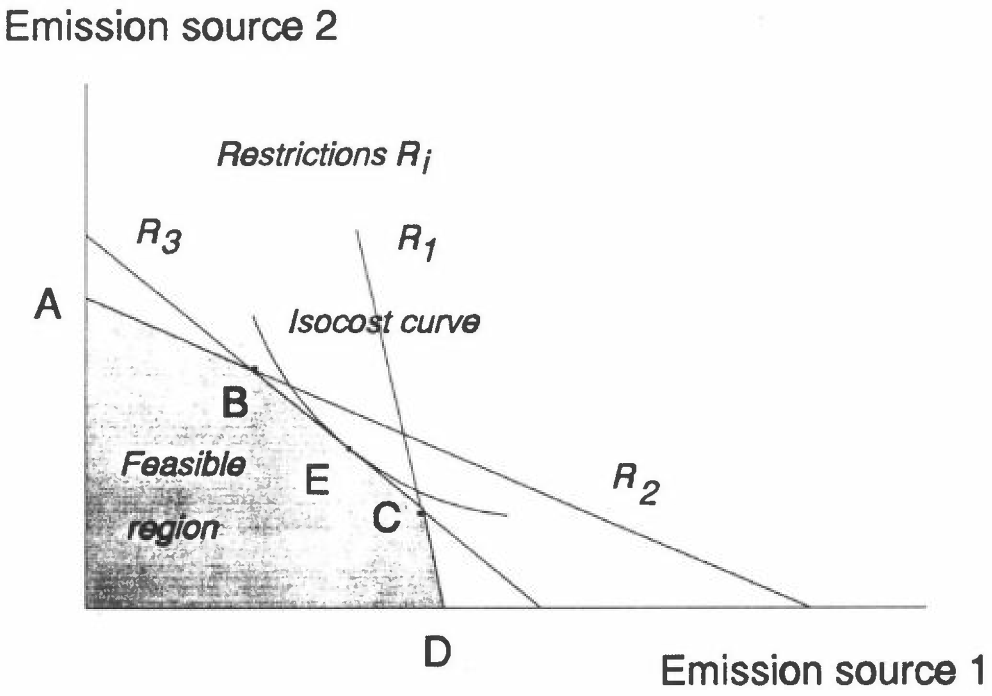

Figure 2. The cost efficient solution

In the case of two sources isocost curves can be introduced in a diagram depicting emissions from the two sources along the axes. The isocost curve in figure 2 shows the relationship between the two emissions for a constant level of total purification costs. Deposition constraints can also be introduced in such a diagram as staight lines since the unit transportation coefficients are constants. Three receptors with the deposition restrictions R_1, R_2 and R_3 are shown. The slopes of the lines reflect the value of the transportation coefficients in question.

The cost efficient solution is found at point E on the line segment BC. In this solution it is only the deposition target for receptor 3 that is binding. The shadow prices $\lambda_1$and λ_2 are accordingly equal to zero.

From the constraint set in (4) equality in the deposition constraint for receptor 3 implies:

$$\begin{aligned} a_{13}e_1 + a_{23}e_2 &= D_3^* \\ e_2 &= \frac{D_3^*}{a_{23}} - \frac{a_{13}}{a_{23}}e_1 \end{aligned} \tag{8}$$

The slope at E is the "exchange rate" - a_{13} / a_{23}. Differentiating the optimised total cost function in (7) yields:

$$\begin{aligned} -MC_1 de_1 + MC_2 \cdot -de_2 &= 0 \\ -\frac{de_2}{de_1} = \frac{MC_1}{MC_2} &= \frac{a_{13}}{a_{23}} = r \end{aligned} \tag{9}$$

r = exchange rate.

4. Problems of trade

There are two general ways of organising trades in permits. One way is to issue permits to deposit at each receptor, the total volume reflecting the deposition constraint, as given in equation (4). Another approach more in line with existing sulphur agreement is to issue each country with a certain number of permits adding up to total emission volumes per country. As to the former it is shown in the literature that if optimal market prices are introduced, and all countries (sources) are price takers, then the optimal cost effective solution can be sustained by such prices. But this is not so helpful if one does not know these prices. It is very difficult to design trade regimes such that the players by themselves will approach the optimal solution. Consider all the markets each country has to operate on, and consider further all revisions of prices due to differing pattern of emissions and depositions as trade takes place. A country has to obtain permits for all downwind markets, or decide on wether to by or sell if initial permits are issued in all regional markets, and when permit prices change its permit demand in each of the regional markets has to be recalculated.

When issuing emission permits on a country basis the resulting deposition pattern may well be inoptimal and may also violate deposition targets. Introducing trade in permits, e.g. a pollution offset system, does not restore the consideration of different regional deposition constraints. One idea is then to introduce "exchange rates" for pollution offsetting trades reflecting the different impact of emissions.

5. Pollution offset trade

First an initial emission situation has to be defined. Proportional reductions have been seen as the only fair solution in past agreements. It is now well understood that such a shceme is hardly cost effective, but we will still use it as basis for our discussion. If we take deposition targets seriously an initial emission reduction can be defined as the least proportional reduction not violating the constraints:

$$Max\ \gamma\ \ such\ that\ \sum_{i=1}^{n} a_{ij}(1-\gamma)e_i^0 \leq D_j^*\ for\ all\ j=1,..,m \tag{10}$$

Referring to figure 2 such a rule ensures that we start at a point on the feasible region ABCD. The situation is shown in figure 3.

The agreement on uniform proportional reduction moves us to point F on the feasible region. This is not cost effective, as can be seen by comparing the isocost curve intersecting at F and the least cost curve tangent to the feasible region at E.

Opening up for pollution offset trade from point F may improve the cost effectiveness. But instead of trading on a one to one basis as regards pollution offset the potential impact of the deposition patterns will be taken into consideration by imposing "trade prices" equal to the exchange rates defined in eq.(6) when considering pairwise offsets. Let us assume that countries find the new emission agreement at F a burden and all try to lessen the costs by trading. Country 2 offers country 1 to decrease its emission by r units in order to itself to increase emissions with one unit as long as the payment it has to offer is less than what it saves by purifying less.

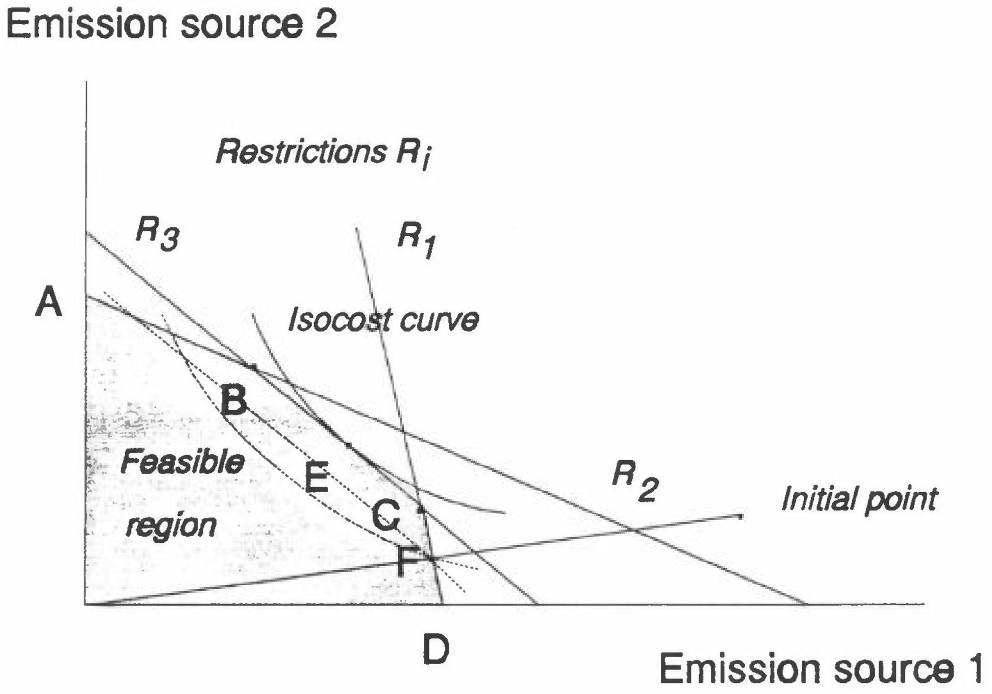

Figure 3. Trade at fixed exchange rate

Expressing the solution (5) or the definition of the exchange rate (6) in the following way:

$$MC_1 = r \cdot MC_2 \tag{11}$$

where r is the ratio of marginal costs in the optimal solution, the following condition for profitable trades emerge:

> If $MC_1 > rMC_2$, then country 1 profits by paying country 2 to purify more and itself to increase its emissions.

If $MC_1 < rMC_2$, then country 2 profits by paying country 1 to purify more and itself to increase its emissions.

Using the optimal exchange rate, r, for all trades means that in figure 3 we are moving along a trade line through F with a slope equal in absolute value to the excange rate. If country 1 is to increase its purification we move into the interior of the feasible region, but clearly the optimal point E cannot be reached. Is it possible to move in the opposite way, i.e. for country 1 to profitably increase emissions? Since the downward sloping iso cost curve is intersecting the trade line from below through F this means that the slope of the iso cost curve must be greater (i.e. not fall so steeply) implying that $MC_1 < rMC_2$, i.e. the profitable trade must be found by moving to the interior of the feasible deposition constraint region ABCD.

At which point on the trade line will profitable trades be exhausted? In general the following condition is satisfied when profitable trades are exhausted between country 1 and 2 (or more general countries i and s):

$$\int_{e_1^*}^{e_1^0} MC_1(e_1)de_1 = \int_{e_2^0}^{e_2^*} MC_2(e_2)de_2 \qquad \textbf{(12)}$$

e_i^* = emission after trade from country i, i = 1,2.

The increase in purification costs for country 1 by purifying the extra amount $e_1^0 - e_1^*$ must be equal to the decrease in purification costs for country 2 by increasing emissions by $e_2^* - e_2^0$, provided no one strikes a better deal than the other (i.e. no profit from exploiting bargaining strength).

The trade is done with the fixed exchange rate, r, defining the trade line:

$$\begin{aligned} e_2^{*} - e_2^{0} &= r(e_1^{0} - e_1^{*}) \\ e_2^{*} &= (e_2^{0} + re_1^{0}) - re_1^{*} \end{aligned} \qquad \textbf{(13)}$$

The condition for the marginal trade is found by differentiating the total condition (12) taking into consideration the trading rule by for instance inserting the solution (13) for e_2^* in the upper integration limit in (12). The rule (11) reemerges, but it does not represent point E due to eq.(13) which now has to be satisfied.

The reason the trade within the pollution offset regime does not realise the optimal solution is that the exchange rate should only apply in optimum, while the trading rule imposes the optimal rate for all intramarginal trades.

ANNEX 8

ANALYSIS AND EVALUATION OF EMISSION REDUCTION STRATEGIES IN FINLAND USING THE EFOM-ENV MODEL

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Analysis and evaluation of emission reduction strategies in Finland using the EFOM-ENV model

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January 20, 1992

Abstract

Alternative strategies for reducing emissions of SO_2, NO_x and CO_2 from energy conversion and energy use are compared with respect to reduction levels and economic costs using the model EFOM-ENV. The work is based on an approach applied earlier to the member countries of the European Communities, but significant enhancements have been made to the model in order to improve the description of Finnish energy system.

1 Introduction

Systems analytical models have been widely used in the economic comparison of alternative energy supply strategies. More recently models have also been applied to the calculation of environmental consequences of emissions from energy production and industrial processes. The value of the models has increased significantly in parallel with the number of criteria to be taken into account in the decision making process.

The EFOM-ENV model is one of the first models to include a relatively detailed simultaneous description of both economic and environmental aspects of national energy systems. It has been used to analyze the energy systems of all member states of the European Communities as well as Turkey. In addition to the case of Finland, discussed in this paper, further applications are in progress or planned for additional non-EC countries, e.g. for Hungary and for the Baltic countries.

In the Nordic countries, there is considerable experience in the use of EFOM-ENV in Denmark and now also in Finland. A comparable model MARKAL has been used extensively in Sweden and also in other Nordic countries. MARKAL has been used as the principal model in international collaboration organized through OECD/IEA while EFOM-ENV is the main tool of anlysis for the CEC. The models are similar enough to make collaboration between groups using either model relatively straightforward.

The reduction measures, which can be assessed with the EFOM-ENV model are based on

- fuel switching and improvement of fuel quality,
- emission reduction techniques,
- technology substitution, i.e. use of less-emitting techniques,
- energy conservation and efficiency improvements.

The strategies, which are applied to Finland, are analyzed with respect to possible shifts of the national energy supply and industrial structures, national emission control cost functions and preference structures for emission reduction measures. The strategies are based on the present situation in Finland and scenarios published by the Ministry of Trade and Industry of Finland for the future end-user demand of energy and energy intensive products. The selection of technologies available for emission control is based on earlier work for European countries, but takes also into account factors specific to Finland.

2 Energy and Environment in Finland

2.1 Energy system

When compared with typical Central European countries, the Finnish energy system and environmental policies differ in several important ways which must be taken into account in a comparative analysis of emission reduction strategies. Many of these factors are shared with other Nordic countries, in particular with Sweden.

Considering the use of energy the most significant characteristic features are:

- the importance of energy intensive industry, in particular forest industry, for the Finnish economy; the share of industrial use is 56% of the final consumption of electricity and 40% of other final energy consumption;

- the increased energy consumption in space heating due to the relatively cold climate;

- long traditions in efficient use of energy based on the important role of energy in economy.

On the energy supply side the Finnish energy system is characterized by the following (figures based on year 1989):

- most important domestic sources of primary energy are hydro power (11% of primary energy calculated as coal equivalent), industrial waste products (black liquor, waste wood, etc.) (13%), peat (3%) and firewood (3%), total share of domestic sources is 30% of primary energy;

- the shares of the imported fuels are oil (31% of primary energy), coal (11%), gas (6%), and nuclear fuel (15%, calculated as coal equivalent from the produced electricity), in addition electricity is imported in an amount equivalent to 6% of primary energy;

- the significance of coproduction of heat and power is large both in space heating and in steam generation for industry; 13% of electricity is produced in district heating plants and 12% through industrial cogeneration;

2.2 Environmental situation

Most of the SO_2-emissions are due to the energy production from fossil fuels in power plants and industrial boilers. The process emissions from industry have also been significant, typically about one quarter of total emissions. The emissions peaked in the seventies and have dropped by more than 50% from 1980 to 1990. The reduction is almost totally due to the changes in fuel supply (nuclear energy replacing coal in electricity production, gas replacing oil and reductions in the sulphur content of coal and oil). Improvements in industrial processes have lead to reductions in process emissions.

The transportation sector is the dominant source of NO_x-emissions although the share of stationary energy production is somewhat larger than in many other countries. The emissions have been steadily increasing and further increase is expected in absence of regulation.

3 The EFOM-ENV model

3.1 General Structure

The energy-emission model EFOM-ENV is a linear dynamic optimization model. The model is based upon a techno-economic approach, i.e. it aims at the determination of an optimal mix of technologies for the energy system. It is driven by an exogenous demand for useful or final energy. The whole energy chain, starting from the primary energy supply, passing through the intermediate sectors (e.g. electricity generation) and ending in the demand sectors (industry, households, transportation, etc.) is represented by linear equations.

The model has a modular structure formed by the subsystems shown in Figure 1. The primary energy subsystems include extraction, preparation or refining (in the case of oil), transportation, as well as the import and export of primary energy sources. Including the energy consumption activities in the subsystems is one advantage of the EFOM model compared to many similar models, since it allows explicit consideration of measures, such as energy conservation, industrial process substitution, or the application of emission control technologies at end use level.

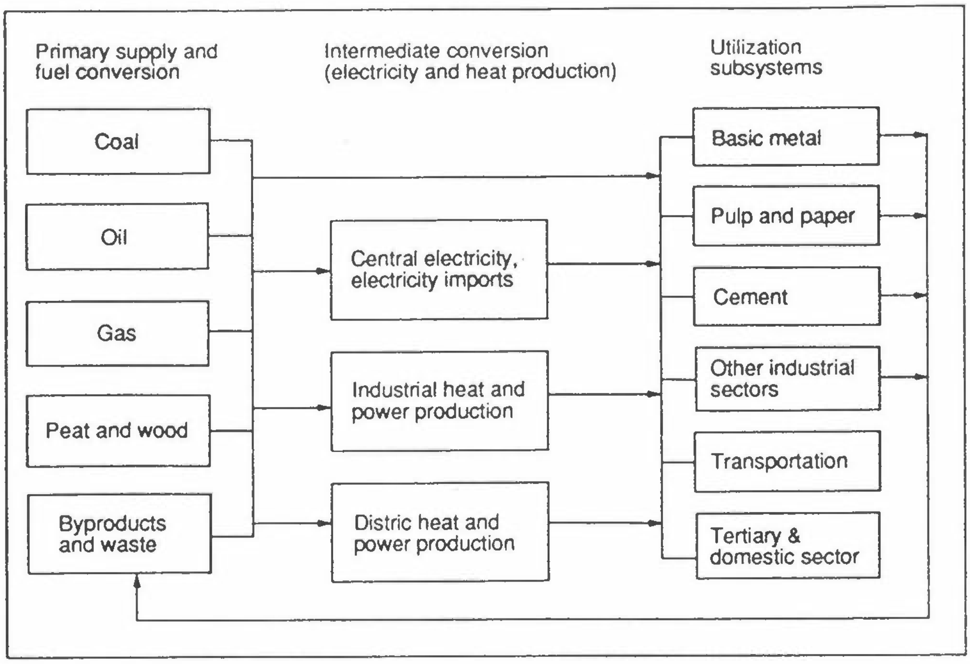

Figure 1. Subsystems in the energy-emission model EFOM-ENV.

The modular structure provides the opportunity to carry out global or sectoral optimization, e.g. flow and capacity planning in the central electricity subsystem. Each module or subsystem of the model contains a set of alternative energy conversion technologies. This includes on the one hand the existing technological basis of the energy supply system of the country under consideration, represented by the country-specific technological and economic parameters and data. On the other hand, possible future high-efficient, low-emission technologies, e.g. fluidized bed combustion or combined cycle processes with integrated coal gasification for electricity production, which could possibly be used by the end of this century, are also included. The technologies are represented and described by investment and operating cost, installed capacity, conversion efficiency, availability, by-products, etc.

A quasi-dynamic approach is applied in the model: That means that the development of the energy system over a period of time (presently 1990 - 2025) is taken into account, rather than considering the situation in one point of time only. In the present analysis three periods of 5 years and two periods of 10 years are used.

The consideration of the age structure of the existing equipment is of special relevance for the development of emission control strategies, because it determines the possibilities for technological substitutions in the energy system taking into account the long lifetimes of equipment in the energy sector.

The objective of the linear programme is the minimization of the cumulated annual costs (present value) over the total planning period for the entire energy supply system (including environmental options). The result of the model application is the optimal resource and technology mix to meet the exogenously determined energy demand, taking into account environmental requirements.

The originally energy orientated model (Van der Voort et al. 1984) has been extended by environmental modules to represent the impact of the energy supply system of a country or region on air pollution, the administrative emission reduction regulations as well as the future technical options for the reduction of emissions (Rentz et al. 1990). The specific impact of an energy conversion process on air pollution is expressed by an emission factor for each pollutant, which gives the emissions of the process per unit of energy flow.

For each energy conversion technology a set of alternative emission control technologies is provided in the model, where applicable. These include for SO_2-reduction the dry limestone injection process and the wet limestone process, and for NO_x-reduction combustion modification measures and the selected catalytic reduction process (SCR). An environmental module of this type is shown in Figure 2. Channelling the energy flow of the respective energy conversion process through the environmental module results in a reduction of emissions. Cost and investment, existing capacities, availability, energy consumption and other characteristics of the emission control technologies are described by a set of parameters, in the same way as in the case of energy conversion technologies. By including additional constraints in the model affecting the emission flows, different environmental policies or administrative measures, for example emission standards (e.g. 200 mg NO_x/m^3), fuel specifications (e.g. 0.3% sulphur content of gasoil), or flexible limit approaches (so-called 'bubble policy'), can be represented.

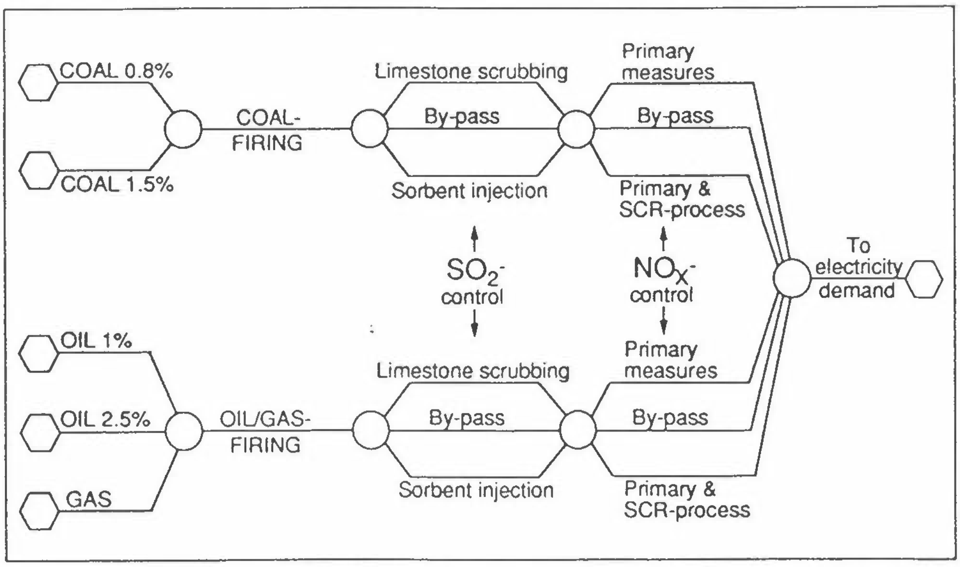

Figure 2. Environmental module for coal-fired and oil/gas-fired condensing power plants in EFOM-ENV.

3.2 Development of Cost-efficient Emission Control Strategies

The EFOM-ENV model may be used to find cost-efficient emission control strategies, which makes it possible to achieve a pre-defined emission level at lowest cost. Each of these strategies is characterized by a mix of technological measures, including fuel switching, technology substitution and application of emission abatement technologies.

Emission control strategies are determined as follows: Different emission control policies, comprising for example administrative emission standards or global emission reduction targets, are represented by emission control scenarios. For each of these scenarios the model is applied, resulting in a optimal mix of energy conversion and emission control technologies. The results of the emission control scenarios are compared with the results of the reference scenario, where no emission reduction is required. In this way, emission control costs are defined as the increase of the total energy system costs of the emission control scenario relative to the reference scenario. Since the result of the reference scenario represents an optimized energy supply strategy in the planning period, this method implies that emission control costs and measures are defined in relation to an optimized energy pathway, which may be quite different to a prognosis or official scenario.

3.3 Model Adaptations for Finland

Country-specific aspects can be integrated into the model by extending appropriate energy conversion subsystems and by switching off or simplifying other subsystems. These modifications must be applied also to the corresponding environmental modules.

In the case of Finland, the most significant additions to the model describe the technologies for the utilization of peat and the energy flows related to pulp and paper industry (energy use, cogeneration and production of industrial waste fuels: black liquor and waste wood). Peat-firing plants have been included both in the central electricity and district heating heat and power generation subsystems. Moreover peat can also be used for heating in the tertiary-domestic subsystem. Waste liquor is used in the industrial heat and power generation only, but waste wood can be used in district heating as well. An additional fuel of importance is fire wood in the domestic heating sector, which has lead to some additions in the tertiary-domestic submodel.

The important role of combined heat and power both in district heat and industrial heat production requires more detailed consideration than the same sectors in most other countries. The large amount of small district heating plants without electricity generation has made it necessary to include several types of such plants to the model. Pure steam boilers in the industrial generation have also required improvements to the original model structure. On the other hand there are some subsectors in the model, such as fuel conversion in the coal subsystem, which can be handled by much simpler models than in other countries.

4 Some Scenario Results for Finland

4.1 The Environmental Scenarios

In the sceanarios described below, the final energy consumption is set to agree with scenarios published by the Ministry of Trade and Industry of Finland in 1990. The most recent scenarios used by the Ministry differ somewhat from those used here. The analysis is based on the following scenarios:

- **reference scenario** with no emission control requirements
- **80%/30% scenario**, where SO_2 and NO_x emissions are reduced by 80 % and 30 %, respectively, from 1980 to 2000 and kept constant thereafter
- **80%/30%/25% scenario,** where in addition of the previous, CO_2-emissions are kept constant to 2000 and reduced thereafter gradually to 75% by year 2025.
- **intermediate CO_2 scenario** is intermediate between the two previous scenarios.
- **acid emission reduction scenarios** are used to find the most cost effective ways to reduce acidifying emissions. Limits are set to the combined acidifying potential of SO_2 and NO_x emissions. The required reductions from 1980 to 2000 are 50%, 68% and 75% (note: 80%/30% leads to 68% reductions).

4.2 Results

Some central results of the analysis are presented in the figures at the end of this report.

5 Conclusions

The EFOM-ENV model has proven to be a useful tool in analysing alternative strategies for emission control. The value of the model is particularly large in the analysis of simultaneous limitations to several emissions. The model suits best to the study of total emissions of a country or other region of comparably sized energy system.

Taking into account geographic distribution of emission sources and depositions cannot be easily incorporated in the EFOM-ENV -model as a model comprosing several regions tends to grow too large to be practical. A project combining the use of EFOM-ENV with the geographically oriented RAINS model of IIASA is currently in progress and our group in Finland is participating in this work. The more detailled model HAKOMA, developed in Finland from RAINS for national studies can also be combined with EFOM-ENV, but there are no definitive plans for such work.

The EFOM-ENV model has been extensively used as a tool for international comparisons within CEC. A similar work within Nordic countries as a collaboration of groups using either EFOM-ENV or MARKAL model could turn out to be quite useful in determining the most cost effective ways of reducing emissions in this area.

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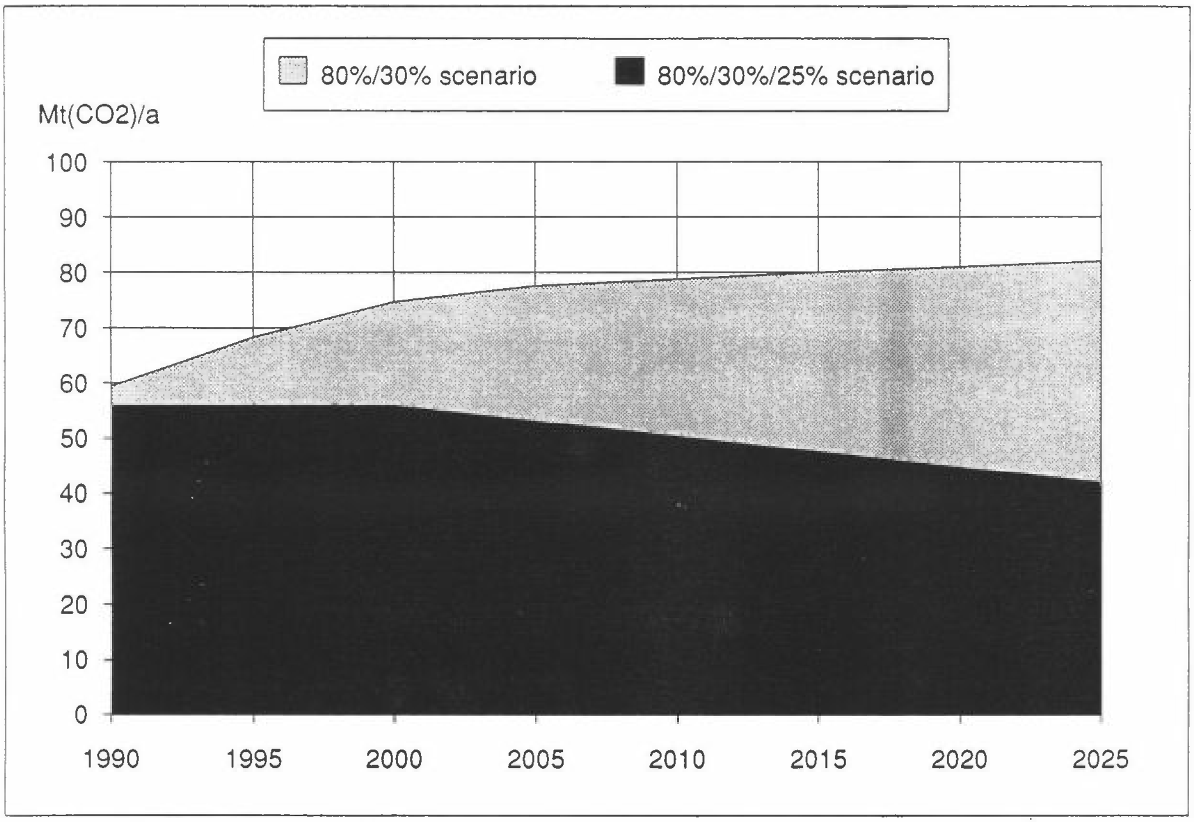
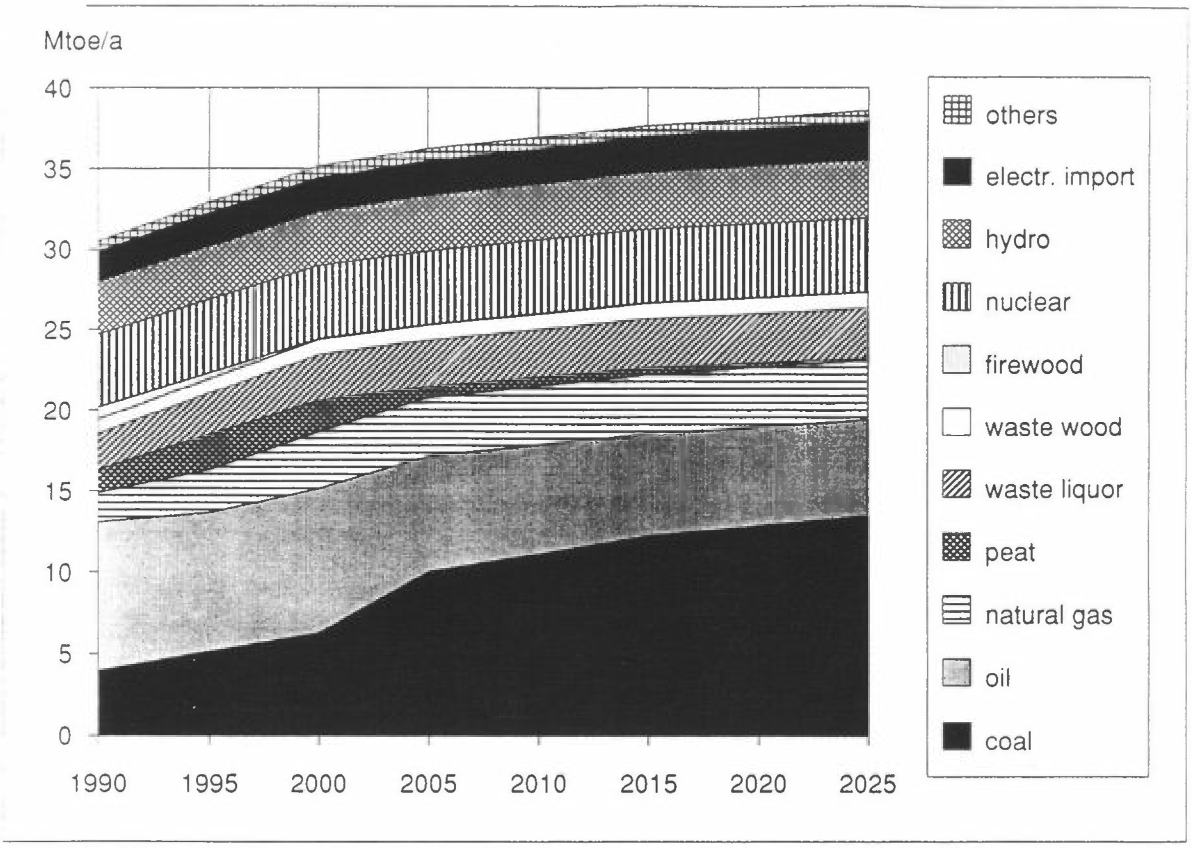
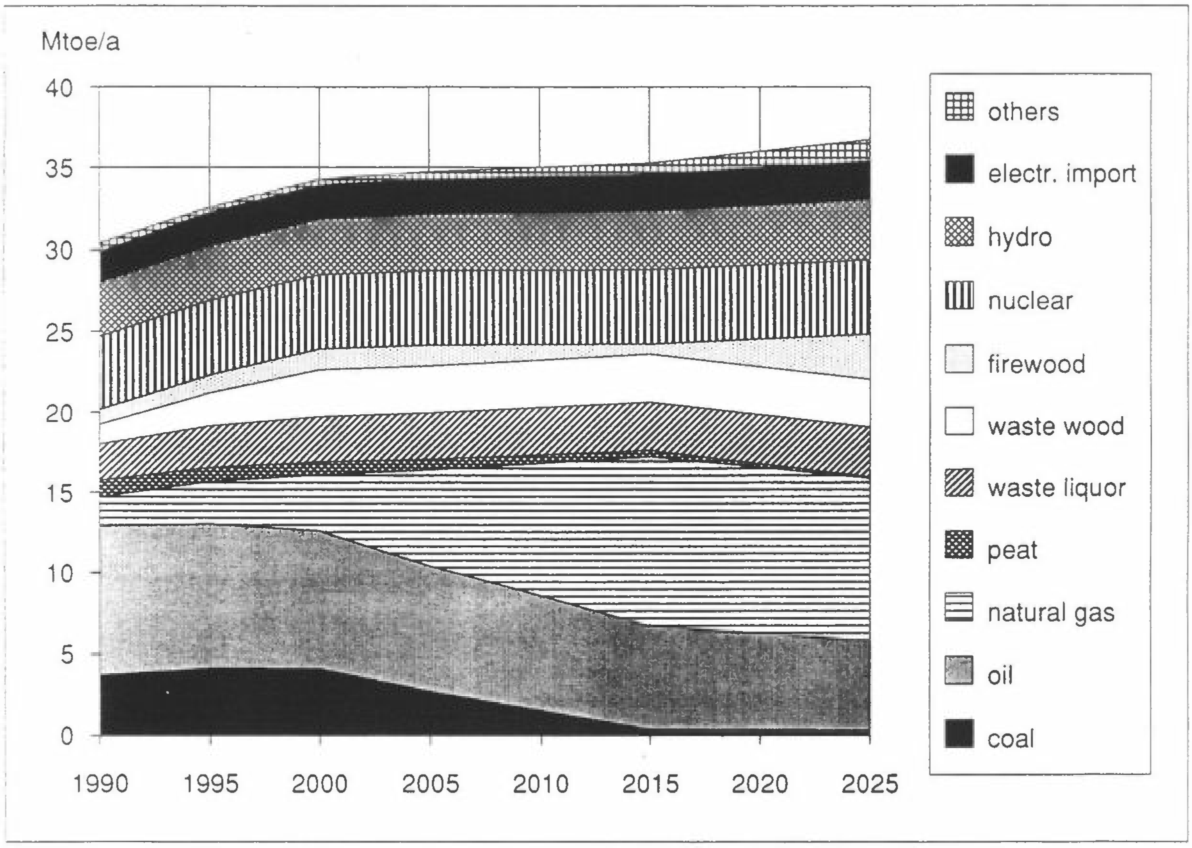


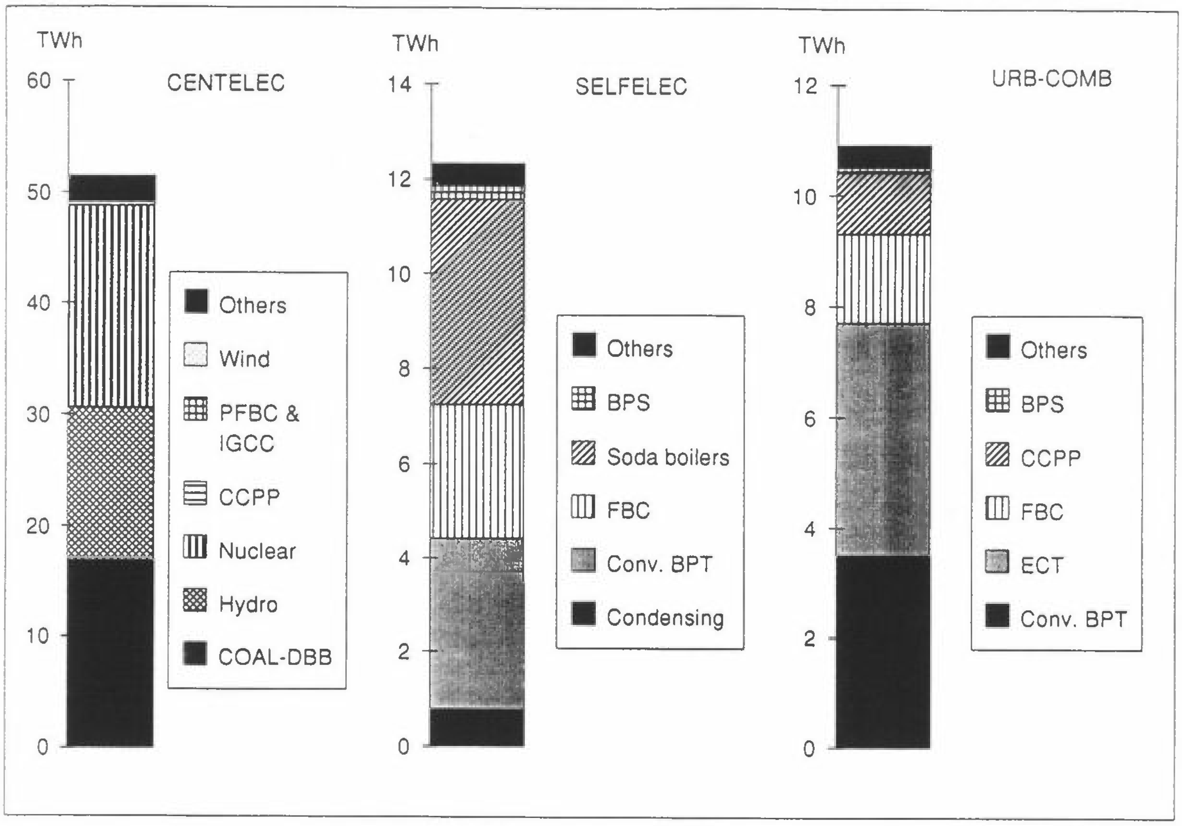
Development of CO2 emissions in the 80%/30% and in the 80%/30%/25% reduction scenario.



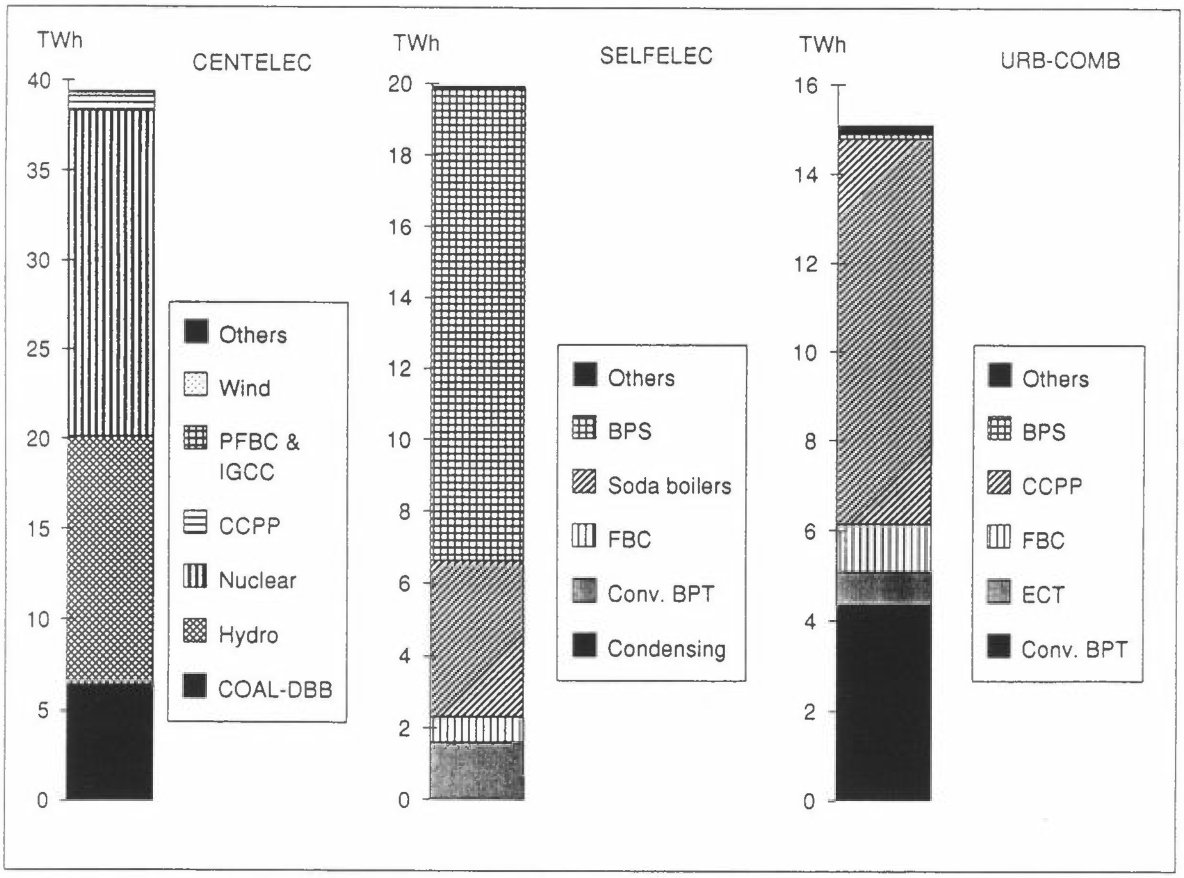
Primary energy consumption in the 80%/30% emission reduction scenario.



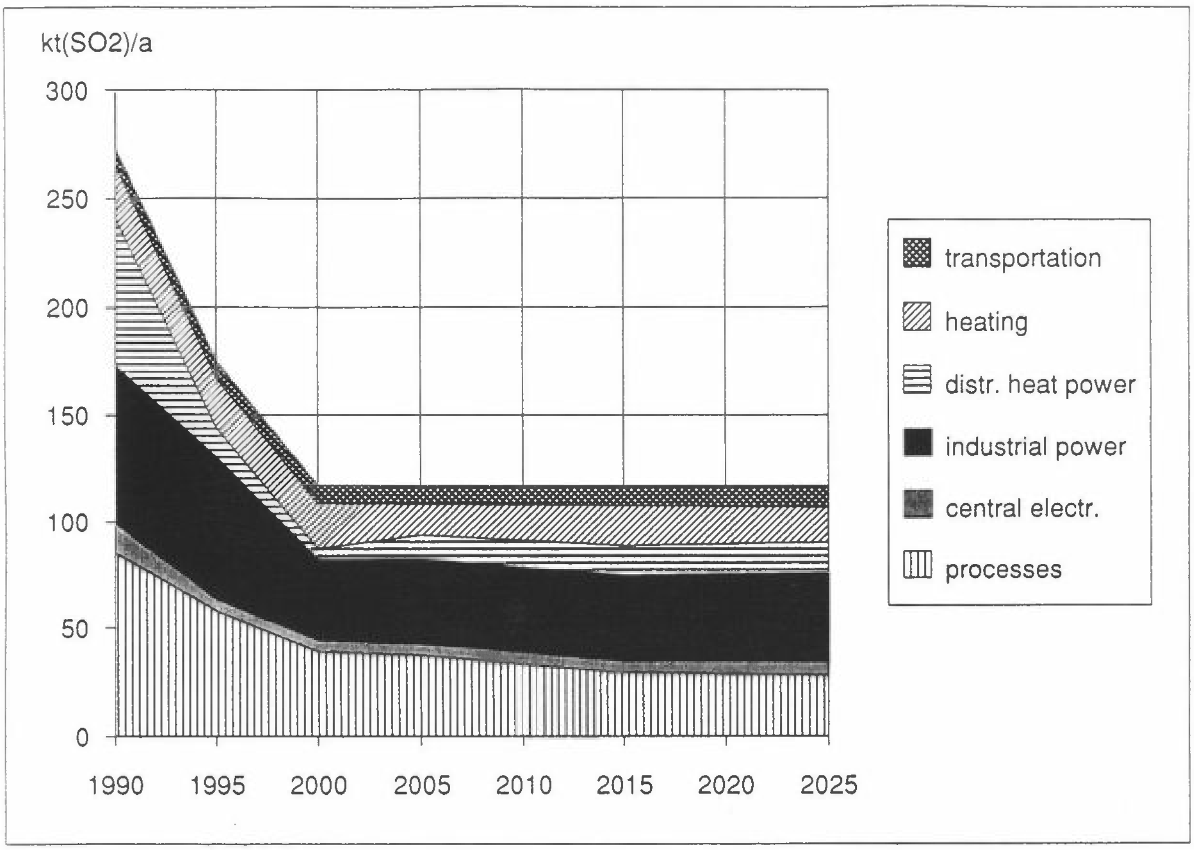
Primary energy consumption in the 80%/30%/25% emission reduction scenario.



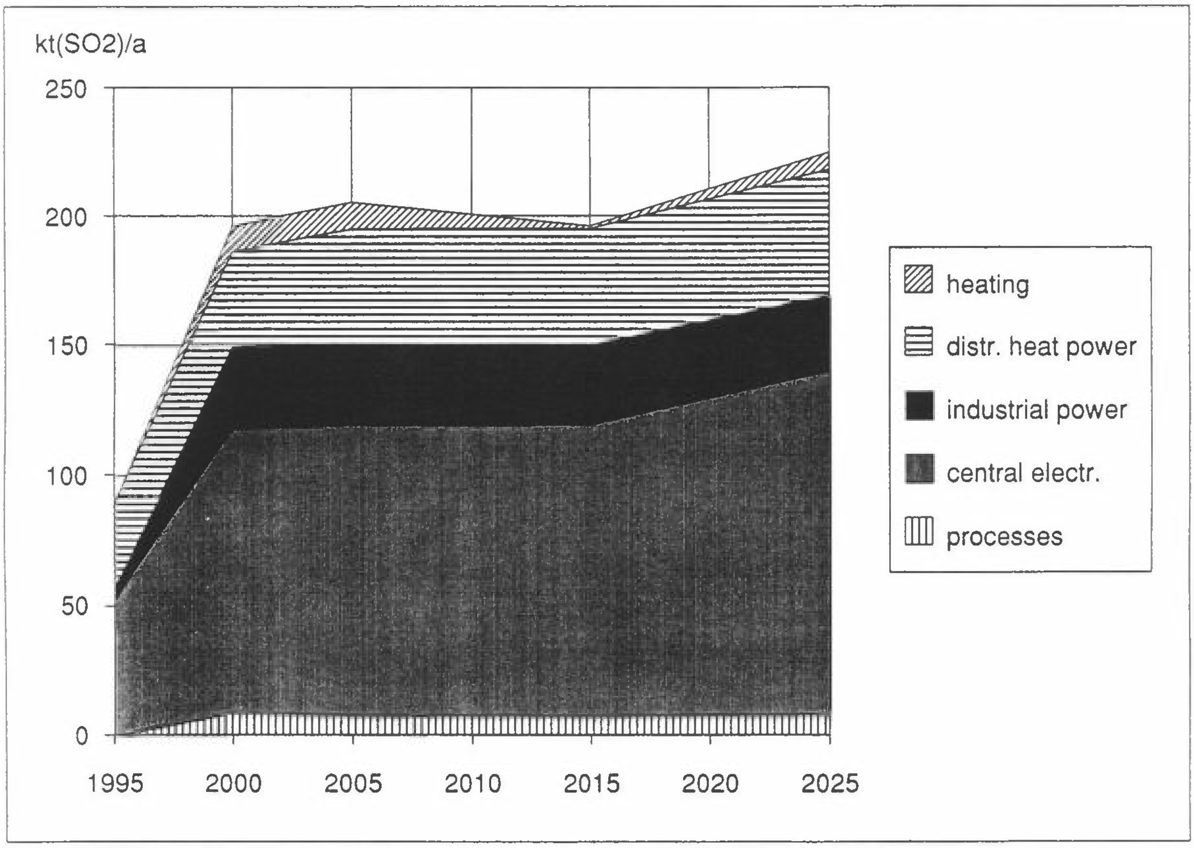
Optimal structure of electricity production in the 80%/30% scenario in 2005.



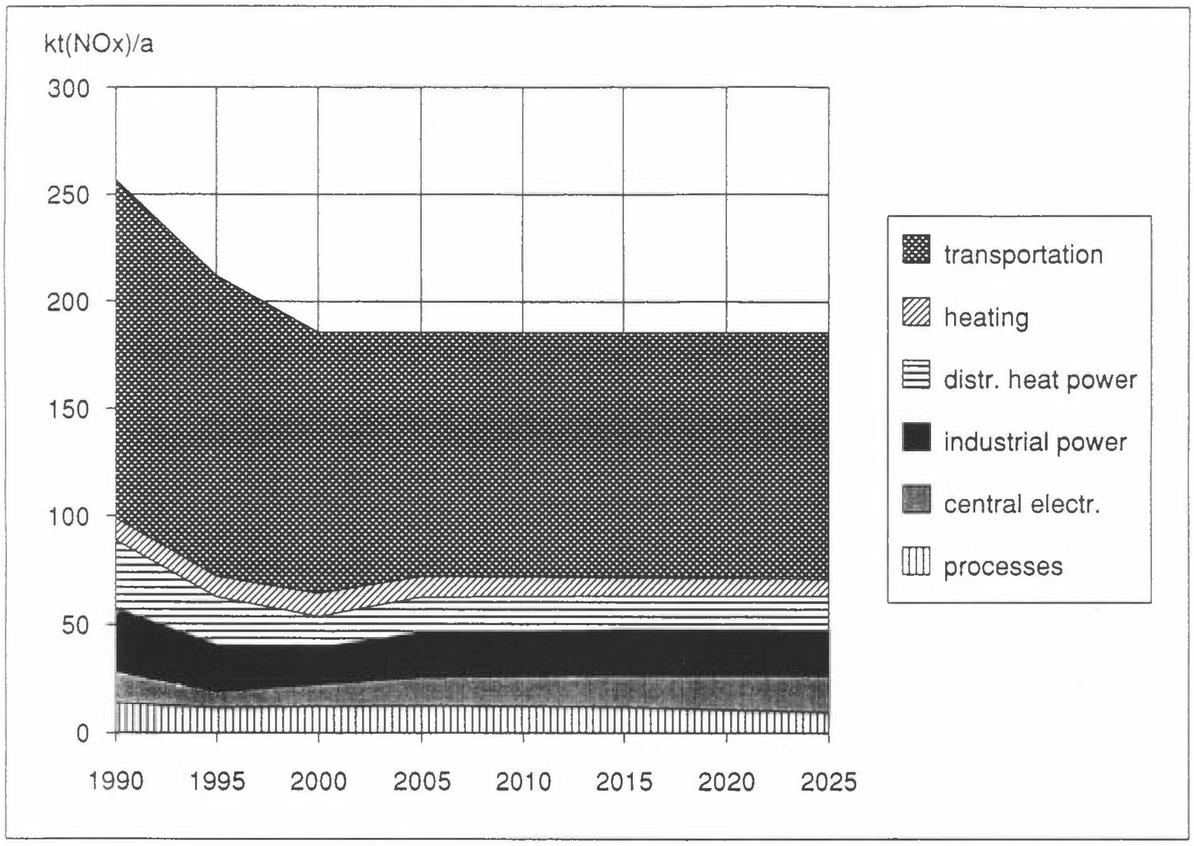
Optimal structure of electricity production in the 80%/30%/25% scenario in 2005.



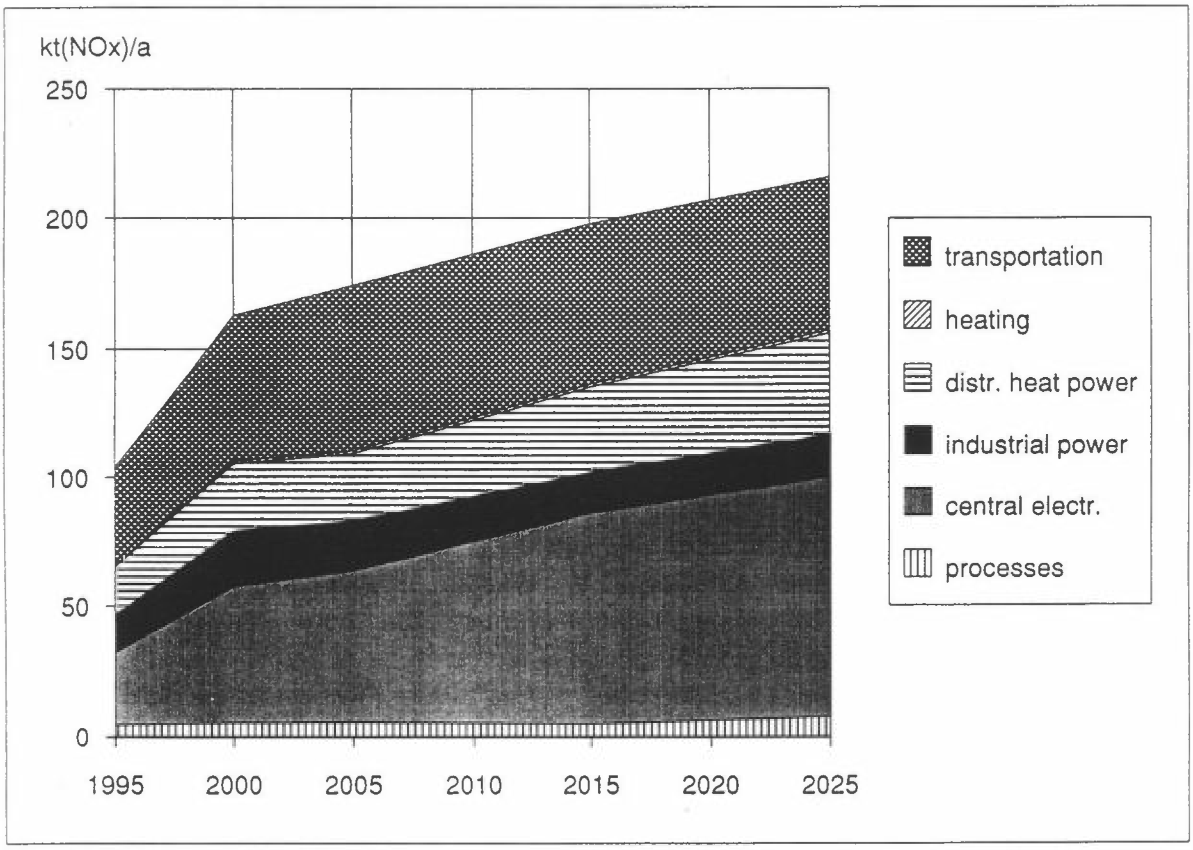
Development of SO2 emissions in the 80%/30% reduction scenario.
Breakdown by subsystem.



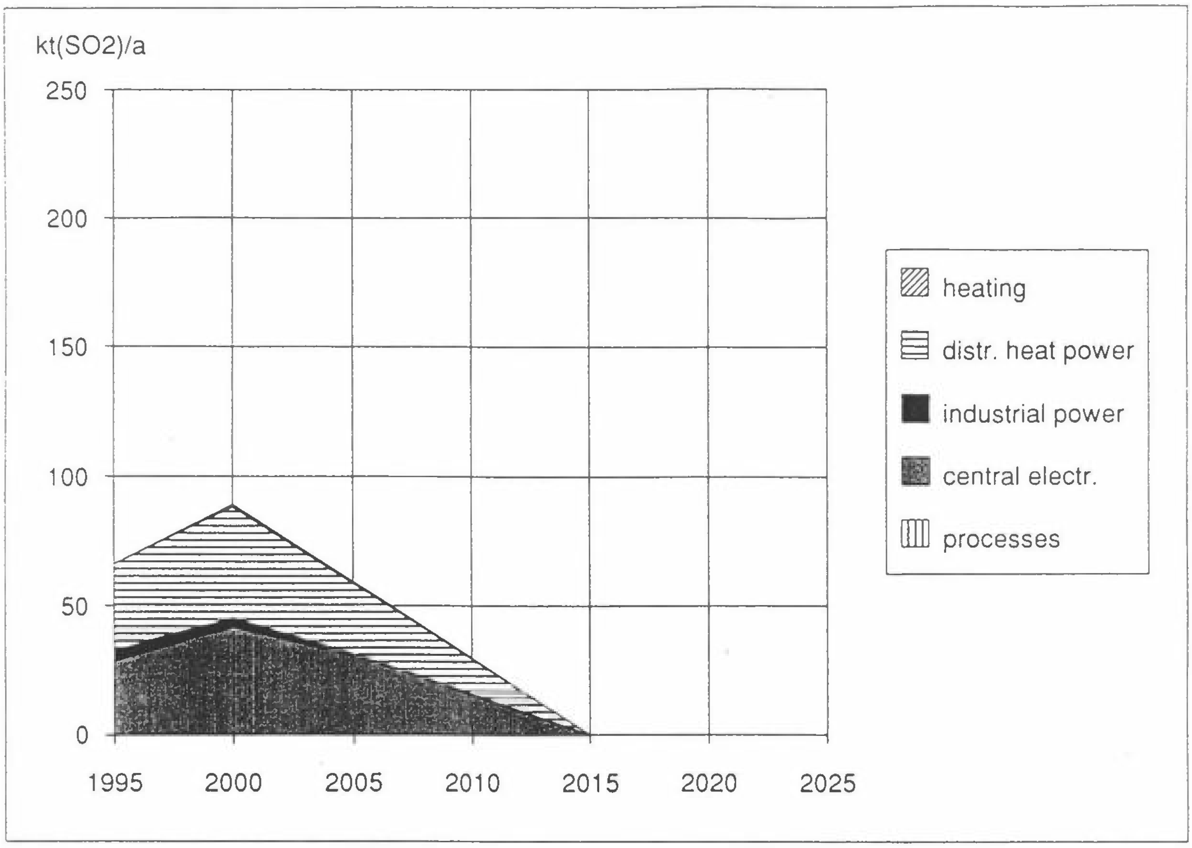
Development of SO2 reductions in the 80%/30% scenario.
Breakdown by subsystem.



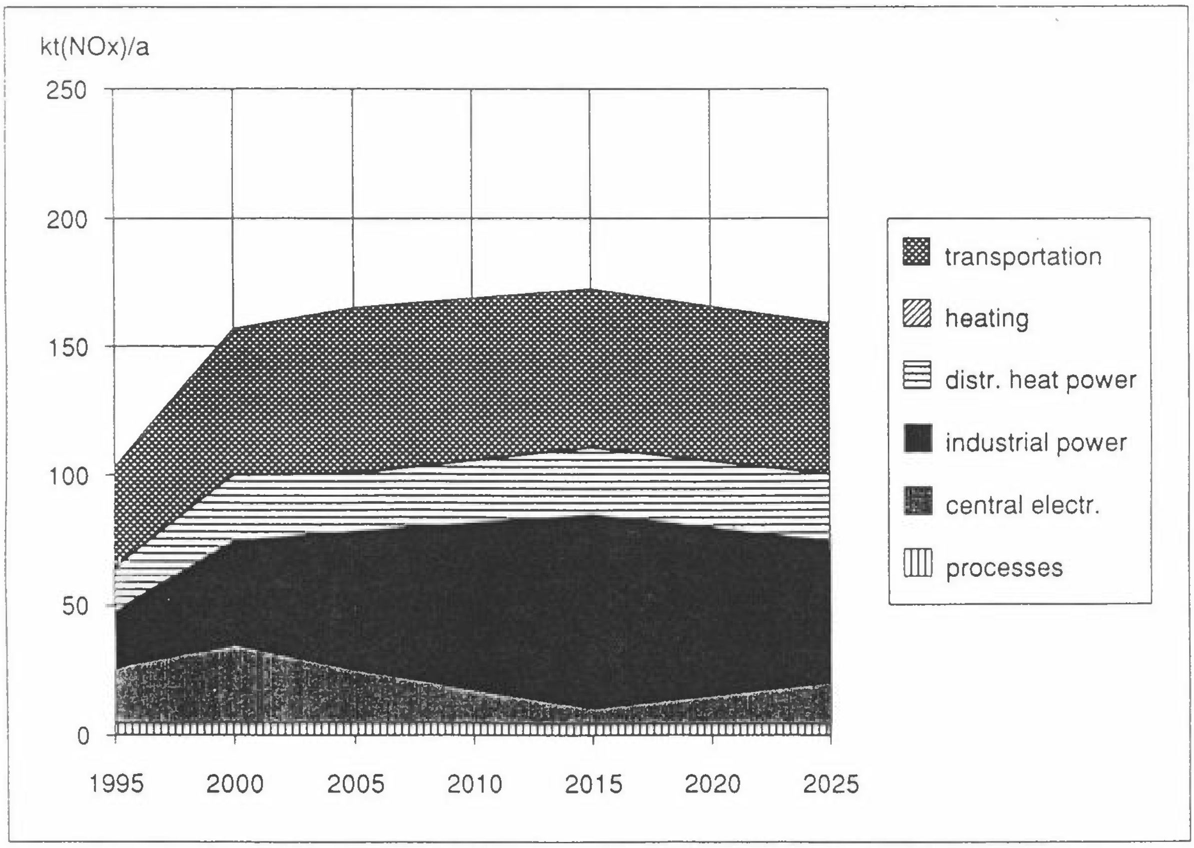
Development of NOx emissions in the 80%/30% reduction scenario.
Breakdown by subsystem.



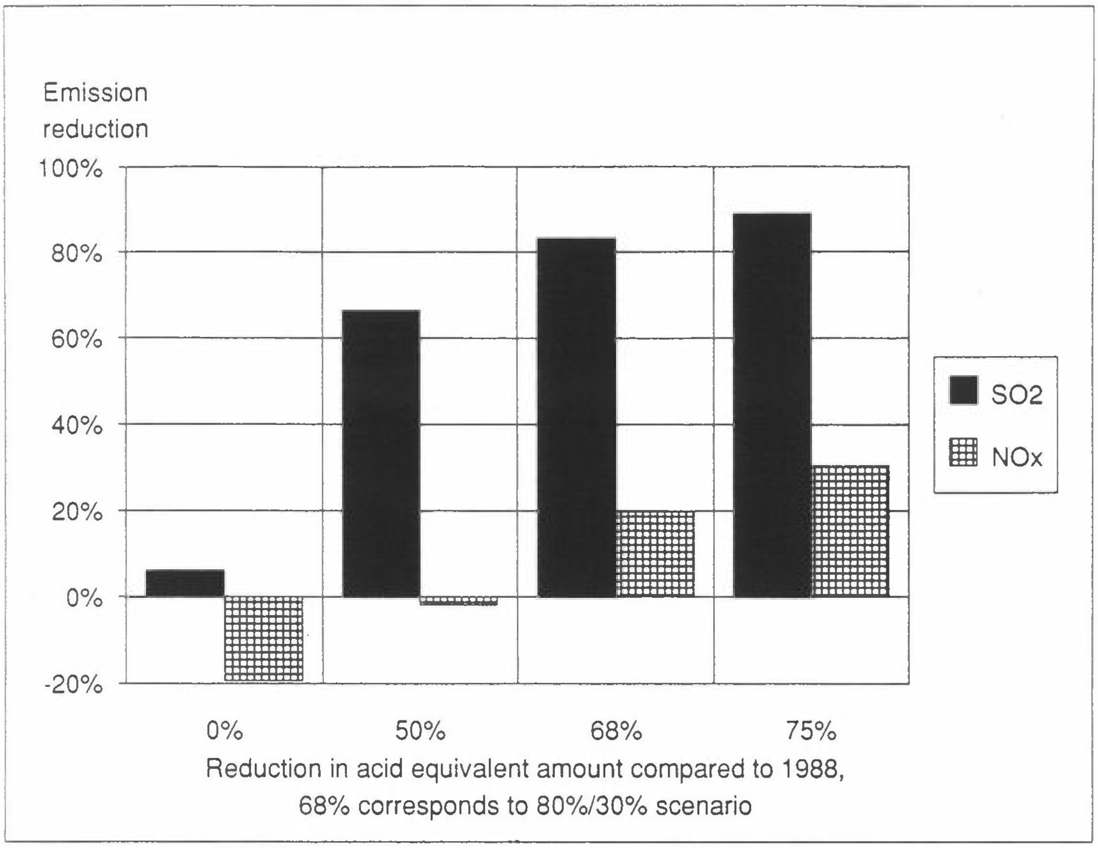
Development of NOx reductions in the 80%/30% reduction scenario.
Breakdown by subsystem.



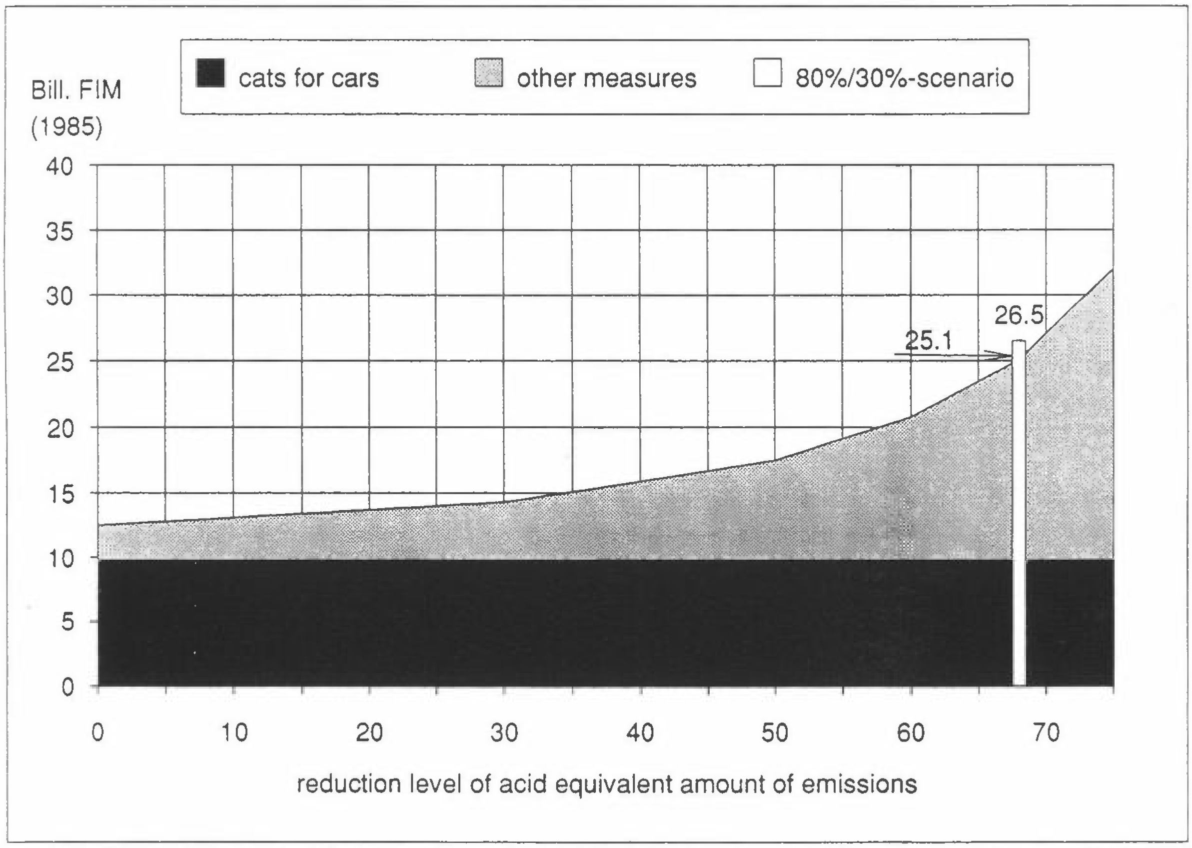
Development of SO2 reductions in the 80%/30%/25% scenario.
Breakdown by subsystem.



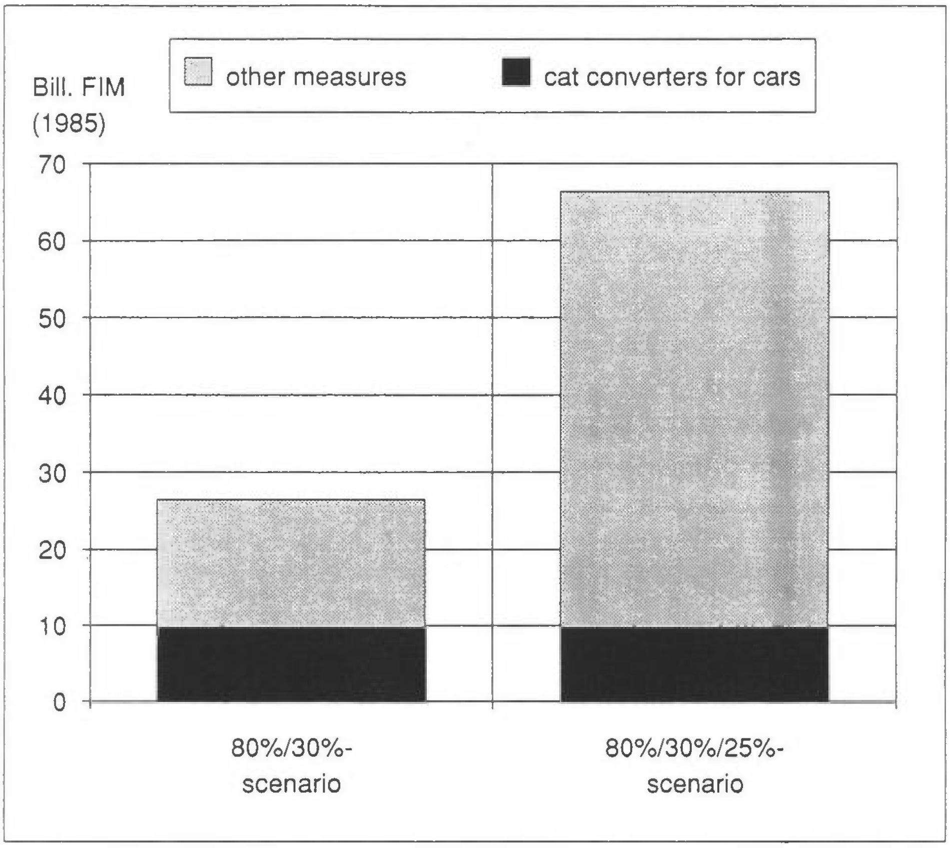
Development of NOx reductions in the 80%/30%/25% scenario.
Breakdown by subsystem.



Optimal reductions in SO2 and NOx emissions for 2015 as obtained by reduction targets for acid equivalent amounts.



Discounted cumulative costs (1988- 2025) for reducing acid equivalent amount of emissions as a function of reduction level compared to 1988.



Discounted cumulative costs 1988 - 2025 of emission reductions in the 80%/30% and in the 80%/30%/25% scenario.

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International agreements	Environmental protection	

REFERAT

TITLE Report from a Nordic Expert Meeting on Cost-Effective International Agreements on Air Pollution Control. 21-22 January 1992.

ABSTRACT

A Nordic meeting on cost-effective international agreements on air pollution control, after discussing papers presented on scientific and economic issues, concluded that for Europe a new sulphur protocol seems more appropriate than an acidification protocol. For the next NO_x protocol, however, efforts should be made to take into account both acidification, eutrophication and formation of photochemical oxidants. The meeting also stressed that if various economic instruments, e.g. emission trading, are to be further discussed, the concepts need further elaboration.

* Kategorier:	Åpen - kan bestilles fra NILU	A
	Må bestilles gjennom oppdragsgiver	B
	Kan ikke utleveres	C