REPORT

Feasibility study
- a Swedish Integrated Assessment Model

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B1674
April 2006

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Report Summary

Project title

Feasibility study - a Swedish Integrated Assessment Model

Project sponsor

ASTA

Author

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Title and subtitle of the report

Feasibility study - a Swedish Integrated Assessment Model

Summary

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Keyword

Integrated assessment model, non-technical measures, air pollution

Bibliographic data

IVL Report B1674

The report can be ordered via

Homepage: www.ivl.se, e-mail: publicationservice@ivl.se, fax+46 (0)8-598 563 90, or via IVL, P.O. Box 21060, SE-100 31 Stockholm Sweden

Acknowledgement

This study has been financed by the ASTA-programme (International and National Abatement Strategies for Transboundary Air Pollution) to which the authors are very grateful. We also want to thank the IIASA team, especially Mr Wagner for valuable information about the GAINS model. Mr Pigniatelli, at ENEA in Italy, has also been of irreplaceable help, providing us with information about the Italian RAINS model. Finally, we want to gratefully acknowledge all the people we have been in contact with, whom has answered all our questions and provided us with supplementary information.

Catarina Sternhufvud Stefan Åström

Summary

Integrated assessment models, such as RAINS and GAINS play an important role in the strategies to abate air pollution in Europe, both within the CLRTAP and the EU. In addition to the regional IAM, many countries have also realised the usefulness of national integrated assessment models, for instance, Italy and the Netherlands. The additional benefits of models with higher resolution are that the countries can perform their own estimates on the outcome of different emission abatement solutions on a more detailed scale. The models will also facilitate for the countries to verify the results from the European RAINS and GAINS models. Another purpose is that a national model can be useful in the international negotiations. All these arguments are also valid for Sweden.

The purpose of this feasibility study is to find out the interests in and requirements for the development of a Swedish Integrated Assessment Model (IAM) based on the Regional Air Pollution Information and Simulation model (RAINS) or the Greenhouse Gas and Air Pollution Interactions and Synergies model (GAINS). This study should also make clear the possibilities and constraints of a national model as well as discuss different applications of such a model.

In developing a Swedish IAM a decision has to be made whether to extend the existing RAINS model or the GAINS model. Both models will make possible performance of national estimations of abatement potential, abatement impact and cost. But in addition to this, a GAINS Sweden will also include GHG and it does already include some non-technical measures. Another advantage is that this will be the first attempt in Europe to create a national GAINS. GAINS Sweden should be possible to extend further than GAINS Europe with regard to abatement measures cost calculations and impact estimations, and will therefore serve as a demonstration example for the international community on what modelling opportunities that exist within the RAINS/GAINS framework.

RAINS and GAINS are composite by a couple of modules. This study has focused on possible improvements of each of the modules, which are the emission and cost module, the source-receptor module and the effect module.

There are several possibilities to improve the emission and cost module in GAINS, at least from a principle point of view, for instance inclusion of structural and behavioural measures, dynamic effects, and regionalised costs. Many of these improvements require however a lot of information and the added value of changes in the modules have to be compared with the work required as well as the difficulties to find adequate data.

In the source receptor module it is possible to use atmospheric models, which are based on higher geographical resolution than what is currently the case in GAINS-Europe, both for emissions and deposition. This higher resolution enables a more detailed description of effects on human health and ecosystems. There are quite a few models available, which could be used in a Swedish IAM.

Higher resolution will also increase the possibilities to a more detailed effect module. Another improvement of this module would be to include dynamic modelling, which have four main benefits:

- Time of ecosystem recovery resulted by reduced acid deposition;

- The effects on biodiversity from air pollution;
- The potential of simulating effects of climate change;
- The introduction of changes in land use, as either an abatement measure or as an autonomous change in the model.

During the study quite a few stakeholders have been contacted to find out their need of a Swedish IAM and which improvement compared to the regional GAINS they find most important. Six main areas mentioned were:

- Inclusion of Greenhouse gases in order to obtain more cost-efficient solutions;
- Inclusion of additional non-technical measures;
- Alternative scenarios;
- Possibilities to evaluate the Swedish environmental quality objectives;
- Higher resolution and possibility to estimate the health effects in urban areas;
- Sustainable use of the forest and the connection to biofuels.

The inclusion of structural and behavioural changes will most probably show that there are ways to reach the environmental targets in a more cost-efficient way and also show that targets lower than MTFR (maximum technical feasible reduction) are possible to reach. The inclusions of higher resolution will enable a more detailed description of effects on human health and ecosystems.

Contents

Abbreviation

AMS	Atmospheric Modelling system
ASTA	International and National Abatement Strategies for Transboundary Air Pollution
CAFE	Clean Air For Europe
CBA	Cost Benefit Analysis
CLRTAP	Convention on Long-Range Transboundary Air Pollution
DEHM	Danish Eulerian Hemispheric Model
DMU	the Danish National Environmental Research Institute
EMEP	European Monitoring and Evaluation Programme for Transboundary Long-Range Transported Air Pollutants
ENEA	Italian Agency for New Technology, Energy and Environment
EPA	Environmental Protection Agency
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies
GHG	Greenhouse Gases
IAM	Integrated Assessment Modelling
IIASA	International Institute for Applied Systems Analysis
KSLA	the Royal Academy of Forest and Agricultural Enterprise
MATCH	Model of Acidification of Groundwater in Catchments
MERLIN	Multi-pollutant, Multifactor, Assessment of European Air Pollution Control Strategies: an Integrated Approach
MINNI	Integrated National Model in support to the International Negotiation on Air Pollution
MNP	the Netherlands Environmental Assessment Agency
MSC-west	Meteorological Synthesizing Centre – West
MTFR	Maximum Technical Feasible Reduction
NTM	Non-Technical Measures
RAINS	Regional Air Pollution Information and Simulation
SLU	the Swedish University of Agricultural Sciences
SMHI	Swedish Meteorological and Hydrological Institute
SRM	Source-Receptor Matrices
STEM	Swedish Energy Agency
TM	Technical Measures

1 Introduction

1.1 Purpose of the study

The purpose of this feasibility study is to find out the interests in and requirements for the development of a Swedish Integrated Assessment Model (IAM) based on the Regional Air Pollution Information and Simulation model (RAINS) or the Greenhouse Gas and Air Pollution Interactions and Synergies model (GAINS). This study should also make clear the possibilities and constraints of a national model. It will also discuss different applications of such a model.

1.2 Method

A review of the regional (RAINS, GAINS and Merlin - Multi-pollutant, Multieffect, Assessment of European Air Pollution Control Strategies: an Integrated Approach) and national IAM:s used for air pollution assessments have been carried out. The focus on national models has been on the Italian RAINS model and the RAINS-NL in the Netherlands, which both have been created in the recent years.

The review was used as base for a number of interviews in order to find out the interests in and needs for a Swedish IAM. Our work has also included an inventory of available data to run the model. A contact with the International Institute for Applied Systems Analysis (IIASA), who is responsible for RAINS and GAINS, has also been taking place.

Finally, three participants of the project workgroup visited the Italian Agency for New Technology, Energy and Environment (ENEA) and received valuable information about RAINS-Italy.

1.3 Limitations

Due to the limitation in the budget as well as the time constraint it has not been possible to study all the different models in detail. We have chosen to focus on RAINS and GAINS instead of Merlin, as they are the ones used in the international air pollution strategies and more information is available about these models.

1.4 The structure of the report

The study starts with a background chapter where the international initiatives to reduce air pollution are discussed as well as short presentations of a few IAM. Chapter 3 discusses international experience of national IAM, focusing on the work in Italy and the Netherlands. In chapter 4 the need of a Swedish IAM is discussed and in chapter 5 possibilities and difficulties with a GAINS Sweden is analysed. Finally, the discussion and conclusions can be found in chapter 6.

2 Background

2.1 International initiatives to reduce air pollution

The UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) is an international instrument, established in 1979. The Convention aims to control the regional air pollution problems in Europe by establishing a broad framework for co-operative actions. CLRTAP sets up a process for negotiating concrete measures to control specific pollutants through legally binding protocols, most recently the so-called Gothenburg Protocol directed towards sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia in one joint strategy (Munthe et al., 2002; Sliggers & Kakebeeke, 2004).

In parallel with CLRTAP the European Union has in 2001 launched a programme to abate air pollution, the so-called Clean Air For Europe (CAFE). The aim of CAFE is to develop a long-term, strategic and integrated policy advice to protect against significant negative effects of air pollution on human health and the environment. This programme is the basis for the development of the Thematic Strategy on Air Pollution, which was adopted by the Commission in 2005 and of the Council in March 2006 (http://europa.eu.int/comm/environment/air/cafe).

Air pollution strategies developed within the framework of CLRTAP and CAFE are partly based on Integrated Assessment Modelling. The most used models are the RAINS model and more recently the GAINS model, but Merlin also plays an important role.

2.2 RAINS

The RAINS model, developed by IIASA, is constructed with a multi-pollutant, multi-effect approach. Air pollution effects on acidification, eutrophication, vegetation damage and human health and abatement costs are among the available results (Klaassen et al., 2004). The RAINS model uses scenarios for agricultural activities and energy use following projections on economic activities in order to calculate financial costs and environmental effects of emission abatement. The PRIMES model carries out the energy projections, which are used as exogenous variables. RAINS can estimate the cost for reaching specified emission levels or environmental targets by using country-specific cost calculations for air pollution abatement (Amann et al., 2004).

The RAINS model has different components. The first component focuses on energy use and emissions of pollutants, the second on possible emission controls and their costs, the third on the geographic dispersion, and the fourth on the environmental effects. In addition to these modules there is an optimization tool that can be used to identify combinations of emission controls meeting user-supplied air quality targets to the least costs, see Figure 1.

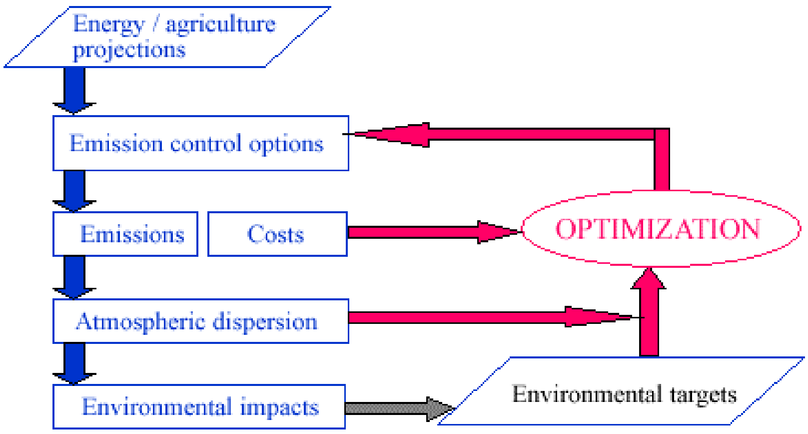

Figure 1. The information flow between the different components in RAINS (Amann et al, 2004)

2.3 GAINS

The GAINS model is an extension of the RAINS model, and includes Greenhouse gases (GHG), see Figure 2. Though, there are some important differences between the models. For instance, the GAINS model uses change in energy demand via fuel efficiency improvements and fuel shifts as potential abatement measures, while the RAINS model only uses energy demand projections as an exogenous parameter. Another important difference is that GAINS minimises the costs for abating all pollutants simultaneously, while RAINS minimises the costs for abating the pollutants separately (Klaassen et al., 2004; Klaassen et al., 2005).

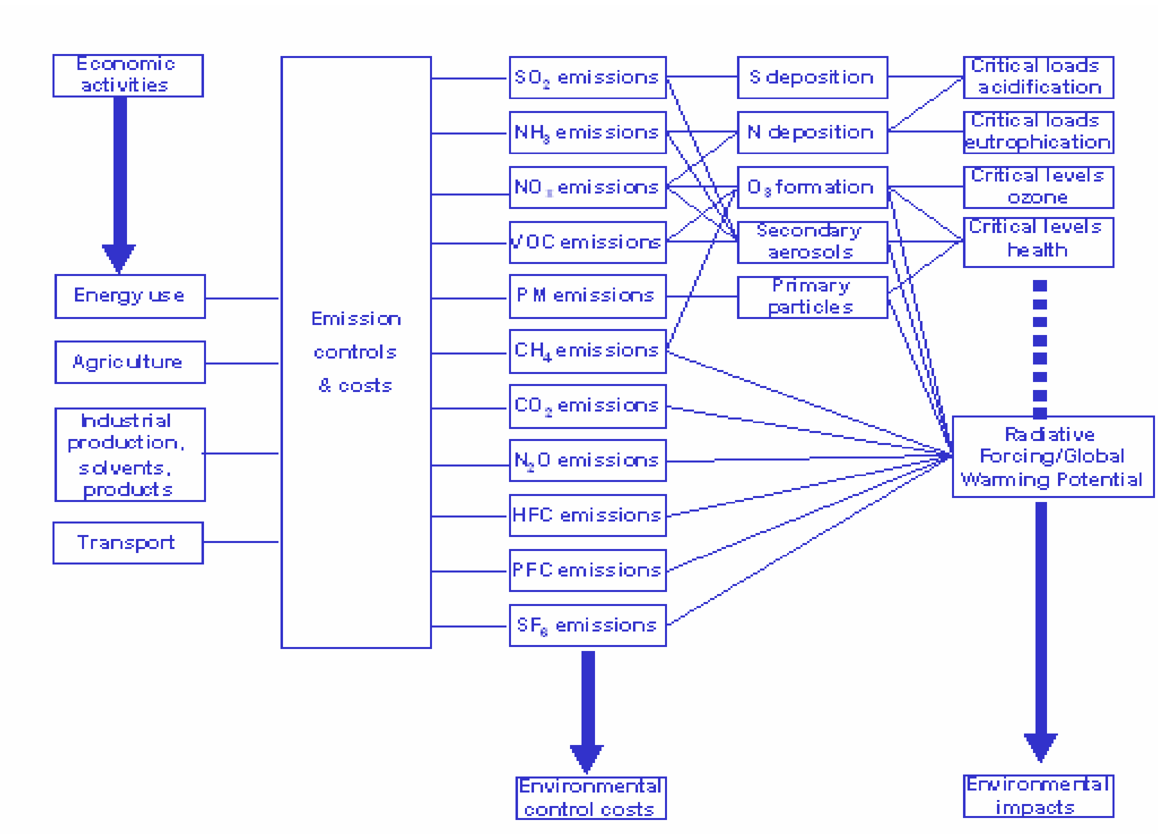

Figure 2 Diagram of the RAINS model including greenhouse gases (http://www.iiasa.ac.at/rains/gains/model%20description.html)

2.4 MERLIN

MERLIN is a model developed simultaneously with the RAINS model. MERLIN includes macro-economic effects and cost-benefit assessment in the optimization, which are not included in RAINS. This means that economic evaluation of the benefits of reducing the environmental impact of air pollutants is included in the search for optimal emission controls. MERLIN also uses a different approach to emission abatement, which enables inclusion of some non-technical abatement measures (NTM) in the emission abatement calculations (UCL, 2004).

The MERLIN model works in a framework somewhat similar to the RAINS model, but with the additional feature of a recursive optimization tool that allows for modification of the input data on which the activity and emission calculations are based. This is performed in the OMEGA optimization tool and is illustrated in Figure 3.

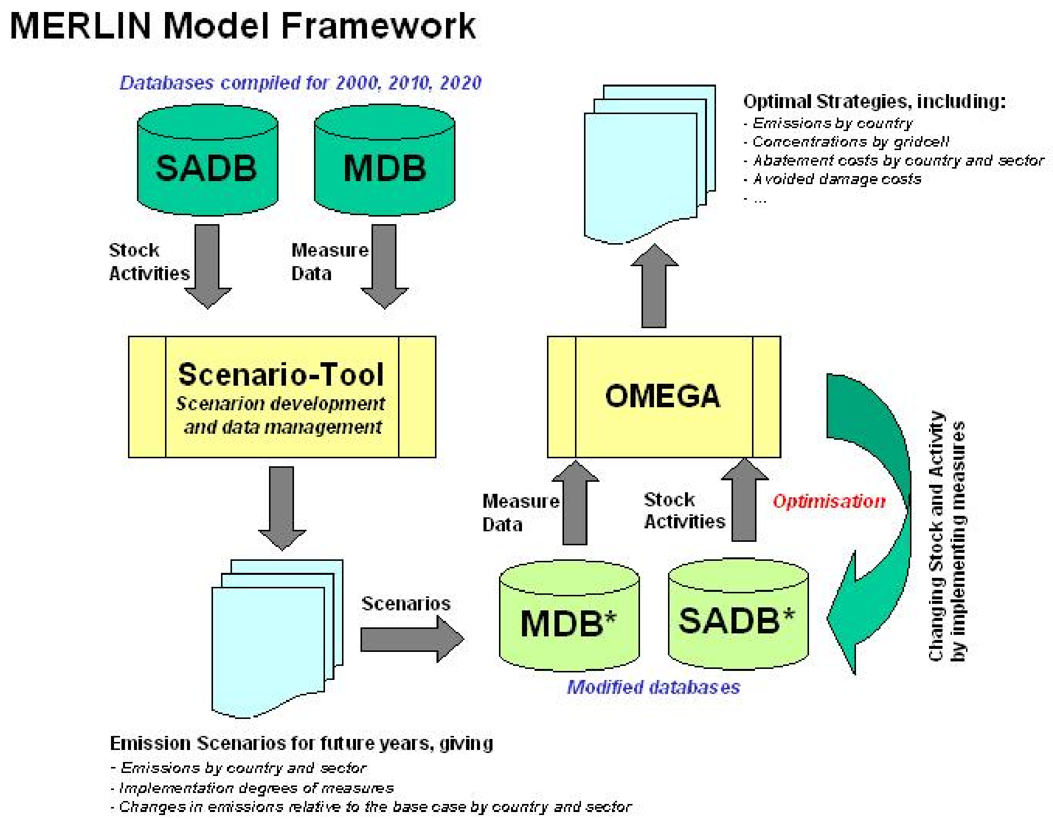

Figure 3 The MERLIN model framework (http://www.merlin-project.info/)

2.5 A Swedish Integrated Assessment Model

Sweden has played an important role in the European air pollution strategies and has also been involved in the development of the RAINS model. The research programme International and National Abatement Strategies for Transboundary Air Pollution (ASTA) has for instance provided important scientific material in this field. Though, unlike many other European countries, Sweden has not developed its own national Integrated Assessment Model.

During 2006 a new scientific programme, financed by the Swedish Environmental Protection Agency (EPA), will start. The need of such a model has been stressed in the programme call and the first phase of a Swedish IAM can hopefully take place within this programme.

3 National Integrated Assessment Models

RAINS, GAINS and MERLIN are often found to be too aggregated, both in terms of geographical resolution and in terms of the inclusion of particular source categories, to be used for modelling at a national scale. Therefore, some countries, such as Italy, Finland, UK and the Netherlands have created there own national integrated assessment models. The models are more or less developed together with IIASA. More recently, both Spain and Poland have showed an interest in creating there own models as well.

This chapter focus on the models developed in Italy and the Netherlands.

3.1 The Italian RAINS model

The Italian Agency for New Technology, Energy and the Environment, ENEA, has in close collaboration with IIASA developed a national IAM, the so-called RAINS-Italy. The project is part of the Italian MINNI project (Integrated National Model in support to the International Negotiation on Air Pollution) and was initialised in 2002 and expected to last three years (Pignatelli et al. (to be published); pers. comm. Pignatelli, 2006-03-06).

The purpose of an Italian IAM is twofold. Firstly, Italy wants to be able to verify the results from RAINS Europe. Secondly, RAINS-Italy will be used as a policy tool for Italy in order to use national specific data and to enable Italy to perform its own estimations on the outcome of different emission abatement solutions in Italy. IIASA also has an interest in the project as the results from RAINS-Italy can bee seen as a sensitivity analysis of the results of RAINS Europe.

The project consists mainly of the development of two linked models, one atmospheric dispersion model generating source-receptor matrices and an integrated assessment model of the same structure as RAINS-Europe. The atmospheric dispersion model (AMS; Atmospheric Modelling System) is a combination of three existing products and used to estimate the dispersion of pollutants. The use of similar framework as the RAINS-Europe facilitates communication between the involved parties.

The models inherit all the features of RAINS Europe, but have two significant differences. Firstly, a higher spatial resolution of 20*20 km^2 is used to capture more local effects than if a 50*50 km^2 had been used. Secondly, in the model 20 administrative regions, 4 metropolitan areas, national sea traffic and 14 large power sources, are individually considered as source data for emissions.

3.1.1 Atmospheric Modelling System

The AMS is an Eulerian model, which is a common atmospheric model. The AMS model calculates area-to-grid transfer matrices for the considered pollutants. The matrices are calculated for each region and emission scenario in order to get the grid cell concentrations from each region. These calculations are carried out for each region separately by setting the emissions from all other regions to zero for the identification of each vector, and thereafter performing the same calculation for each region. In the AMS, winter and summer conditions for certain areas are taken into account when developing the atmospheric transfer matrices, but these estimates are averaged when introducing the transfer matrices into RAINS-Italy. In the RAINS-Italy, no climate change effects on atmospheric conditions are considered and this is largely due to the timeframe of the model (up to 2030). The way the source-receptor matrices are calculated may generate problems since the model is not able to fully take into account non-linearities in the atmospheric system.

Boundary conditions for the AMS are obtained from the EMEP model. These are provided in a 50*50 km^2 resolution but are scaled down to fit the AMS model. At the moment only emissions for year 2000 are used for the grid cell concentration calculations, estimations for other years will be performed later.

The creation of the Atmospheric Transfer Matrices was according to Pigniatelli (pers. comm. 2006-04-19) the most difficult and time-consuming part in the project. The reason is that it required great calculus potential and an accurate post processing of data to make the matrices suitable for RAINS as well as comparable with monitored data.

3.1.2 RAINS-Italy

RAINS-Italy considers the same pollutants as RAINS-Europe, but it also includes emissions from national sea traffic (from national port to national port). The model is also prepared to include secondary organic aerosols in the future.

The information on pollutant activities on a regional scale provided in RAINS-Italy corresponds to the governing regions in Italy. For the base year 2000, these data concerns both general activities in the region as well as the applicability potential of available abatement measures in RAINS-Europe. The applicability of the abatement measures is initially estimated as proxy-variables by the RAINS-Italy team but will be more detailed described after consultations with the considered regions. Since the Ministry of Industry only provides polluting activities on a national level, distribution factors between regions are required in order to capture regional prognosis. Therefore, the RAINS-Italy assumes identical economic growth for all regions in Italy.

The MARKAL model is used a tool for the development of scenarios. The MARKAL calculations replace the calculations performed with the PRIMES model for RAINS-Europe. Furthermore, RAINS-Europe uses TREMOVE for their calculations regarding the transport sector, while RAINS-Italy uses MARKAL calculations in combination with other data on transport activities in order to establish scenarios for the transport sector. The Italian group has experienced that the effects of the scenarios used are significant and the assumptions made in MARKAL (or PRIMES) are of great importance for the outcome.

In the current RAINS-Italy, the abatement measures available for the construction of control strategies are identical with those identified in RAINS-Europe. The inclusion of non-technical measures has to been done by the alternation of the energy scenarios and without any estimation of costs for the implementation of these scenarios. The alteration of energy scenarios requires recalculations by the MARKAL model. There is also no cost optimisation feature in the RAINS-Italy model. One reason for this is the low political interest in the Italian regions. Though, there are plans to construct regional abatement cost curves.

3.1.3 Technical details

In the development of RAINS-Italy the contribution from IIASA has been essential. They supply RAINS-Italy with the framework by constructing the adjustment of the 20 considered regions and four major cities in Italy. IIASA also supplies other types of background materials derived from RAINS-Europe. But apart from the important inputs from IIASA, RAINS-Italy works independent of RAINS-Europe from a local server into which IIASA can make adjustments on demand.

The cost of the total project has been estimated to 1.268 million Euros. Mr Pignatelli (pers. comm. 2006-03-06) estimated that ENEA has spent 24 man months times 3 years with the AMS project and about 18 man months each year with RAINS Italy. In addition to this, ENEA had a contract with IIASA (170 000 Euro) and a contract with a company called ARIANET, who was involved in the AMS model (budget unknown, but less than IIASA). The AMS model is commercial and can be bought by anyone. ENEA has also bought data from EMEP.

A longer visit to IIASA is, according to Mr Pignatelli, essential in the beginning of the project. He was also interested in creating a network between the countries attempting to evaluate their own national IAM.

3.2 RAINS-NL

In the Netherlands a specific version of the RAINS model with Dutch extensions has been developed - the so-called RAINS-NL. The Netherlands Environmental Assessment Agency in collaboration with IIASA carried out the project, which started in 2003. The aim of the project was to extend the RAINS Europe to support Dutch policy makers in European negotiations (Aben et al. 2005; pers. comm Aben, 2006-04-14).

3.2.1 Extensions of the modules

The RAINS-NL has extended all the modules in RAINS Europe to better suit the conditions in the Netherlands. In the Emission and Cost modules the activities and economic sectors used in RAINS Europe have been changed to better comply with the actor-oriented division that is used in Dutch policy making. In most cases the RAINS sector/activity has been aggregated in one Dutch sector, but in a few cases they have been divided into several sectors.

The same compounds are calculated in the RAINS-NL dispersion model as for RAINS Europe. In addition the model includes NO_2 concentration, as the NO_2 concentrations are a large problem in the Netherlands. An empirical relation between NO_X and NO_2 is used to estimate the NO_2 concentrations. In the dispersion module it is not only possible to run the scenarios created in the model, but also externally generated emission scenarios, as long as they comply with the sectoral structure in the transfer matrices.

The source-receptor module in RAINS-NL is based on the Dutch OPS dispersion model, which gives concentration and deposition data in5*5 km^2 grid cells. l. The use of the 5*5 km^2 grid cells was a reasonable compromise between the response time of the model and the preferred resolution, which was 1*1 km^2 in order to describe the impacts on human health and ecosystems in detail. No attempt has been made to divide the country into different regions, as the Netherlands is a small country with comparatively homogenous conditions regarding topography and land use.

In the impact module, the RAINS-NL uses a database for ecosystems based on a 250*250 m^2 grid cell system, which is used to calculate the average exceedence in the 5*5km^2 cells. To estimate the health effects in each grid the population is split into five-year age-classes.

3.2.2 Technical details

In this project IIASA has been responsible for the adaptation of the RAINS-NL, while MNP has taken care of the specific Dutch data production as well as testing the results. Aben (pers. comm. 2006-04-14) estimates the work carried out by MNP to approximately 3 man years.

The project started in May 2003 and was expected to last for one year. Due to high working load at IIASA, caused by the CAFE program, the project was delayed and the final version of the model was delivered in December 2005.

4 The need of a Swedish Integrated Assessment Model

The objective of creating a Swedish IAM is to support the policy makers in the design and assessment of air pollution policies at local, national and international level. Different organisations have different needs and requirements. By clearly understand these stakeholder requirements, the correct decisions can be taken when evaluating the model. This will also facilitate an allocation of the budget between different tasks. The aim is to make the model useful to as many stakeholders as possible.

4.1 Stakeholders' opinions

In the contact with possible stakeholders six requirements on a Swedish IAM have been mentioned more frequently:

Inclusion of Greenhouse gases in order to obtain more cost-efficient solutions
There are many synergies between traditional air pollutants and greenhouse gases both with respect to control measures and environmental effects. Therefore, it will be more cost-efficient to have a common approach and a model that optimise on all the pollutants at the same time. This argument has especially been mentioned by the Swedish EPA and the Swedish NGO Secretariat on Acid Rain. It will also be valuable for the stakeholders in the energy sector, such as the Swedish Energy Agency, as this sector need to find cost-efficient solutions to reduce the greenhouse gases.

Inclusion of additional non-technical measures
There is a need of further development of cost and effect calculations on other types of abatement measures than the ones currently included in GAINS. By finding a solution to the inclusion of a wider set of non-technical measures this can be transferred and used in the regional integrated assessment models, which is an important issue for the Swedish EPA as it might affect the target setting on a European scale. Another important issue connected to the cost estimates is the possibility to compare the European data used in RAINS/GAINS with national data. This is not only important to the Swedish EPA, but also to the different sectors in Sweden

Alternative scenarios
In a national model it will be possible to create own scenarios. The inclusion of alternative scenarios will facilitate for Sweden to find out which policies that are of most importance for the air quality in Europe. This is an important question for the Swedish EPA and could also be useful for the National Institute for Economical Research and the Swedish Energy Agency.

Possibilities to evaluate the Swedish environmental quality objectives
A construction of the Swedish IAM in a way that makes it possible to evaluate Sweden's possibilities to fulfil its obligations to the Swedish environmental quality objectives would be useful. It would also be valuable if the model could be used to carry out analysis of emission abatement strategies and its environmental impact.

The Swedish EPA sees that the results can be used to assess control needs and policy outcomes in relation to the environmental objectives primarily to *Clean Air*, *Natural Acidification Only* and *Zero Eutrophication*. It can also give significant input for assessments with respect to *Sustainable Forests*, *A Balanced Marine Environment* and *Reduced Climate Impact*. In more detail the model can be used to:

- Estimate the impact of further emission reductions in Sweden related to environmental objectives;
- Estimate if the environmental objectives will be sufficiently met, and if not, where further measures should be taken;
- Economic and environmental consequences following a proposed measure related to the environmental objectives (this is a mandatory requirement in the work with environmental objectives today);

<u>Higher resolution and possibility to estimate the health effects in urban areas</u>
For national purposes a higher resolution is desirable to enable good estimates of the health effects in urban areas. This information will be useful, not least, to the municipalities to make clear the effect on the urban air quality when different scenarios and measures are used and also in their ambitions to follow the Environmental Quality Standards. Health effects are connected with very high costs and also one of the most prioritised areas on both national and international scale.

<u>Sustainable use of forest and the connection to increased use of biomass for energy purposes</u>
An integrated assessment model will have the possibility to evaluate nutrient status, production and biodiversity development in relation to atmospheric deposition and emission control scenarios. Such models can be of interest for the assessments of needs for adding neutralising agents (including returning of wood ash) in order to compensate for soil acidification due to forest growth and atmospheric deposition. The model will also be able to further assess combined effects from forestry and atmospheric deposition such as changes in forest growth due to atmospheric N deposition and risks for nitrate leaching in connection with cutting activities. In such assessments there may be a need for higher resolution than normally obtained in the European models. The main stakeholders within this area are the Swedish Energy Agency and Swedish Forest Agency. KSLA (The Royal Academy of Forest and Agricultural Enterprise) has also pointed out the needs to have models that can illustrate questions related to the connection between land and water use, the natural environment and socio-economic consequences.

4.2 Summary of the need for a Swedish IAM

Most of the correspondences with stakeholders have been on the subject of a potential Swedish GAINS model. The knowledge about RAINS and GAINS is not very high, but the knowledge regarding other IAM is even lower. For instance, in the occasions when MERLIN has been mentioned there has been no or very low knowledge regarding that model.

To summarise, there are three important aspects that should be regarded in the discussion on a Swedish IAM:
1. The RAINS model is the model that is most accepted and used as a decision support tool for policy makers in the European air quality work.
2. The national knowledge is higher for RAINS than it appears to be for other types of IAM.

3. Other nations have chosen to implement a national version of RAINS, and if Sweden would choose to initialise a Swedish IAM based on RAINS / GAINS, the knowledge sharing and information dissemination would be easier than if another type of IAM would be used.

A GAINS Sweden will make it possible to perform national estimations of abatement potential, abatement impact and cost. But in addition to this, GAINS Sweden should be a complementary tool for the further development of IAM:s used as a policy decision tool in the international negotiations on air quality. GAINS Sweden should be possible to extend further than GAINS Europe with regard to abatement measures cost calculations and impact estimations. Thereby serving as a demonstration example for the international community on what modelling opportunities that exist within the RAINS framework.

Many of the stakeholders are more interested in the results from the model than using the model themselves. The most important areas according to the stakeholders are:

- Inclusion of Greenhouse gases in order to obtain more cost-efficient solutions;
- Inclusion of additional non-technical measures;
- Alternative scenarios;
- Possibilities to evaluate the Swedish environmental quality objectives;
- Higher resolution and possibility to estimate the health effects in urban areas;
- Sustainable use of the forest and the connection to biofuels.

5 Outline of a GAINS Sweden model

The European GAINS model consists of different modules, as discussed in the background chapter. A GAINS Sweden will use and work in a similar way as GAINS but the aim is to step by step change the different modules and make them more adjusted to Swedish circumstances. Figure 4 shows an outline of a Swedish GAINS model based on the European model. The figures also show the possibility to eventually add an optimisation module as well as using the final results to carry out cost benefit analysis (CBA).

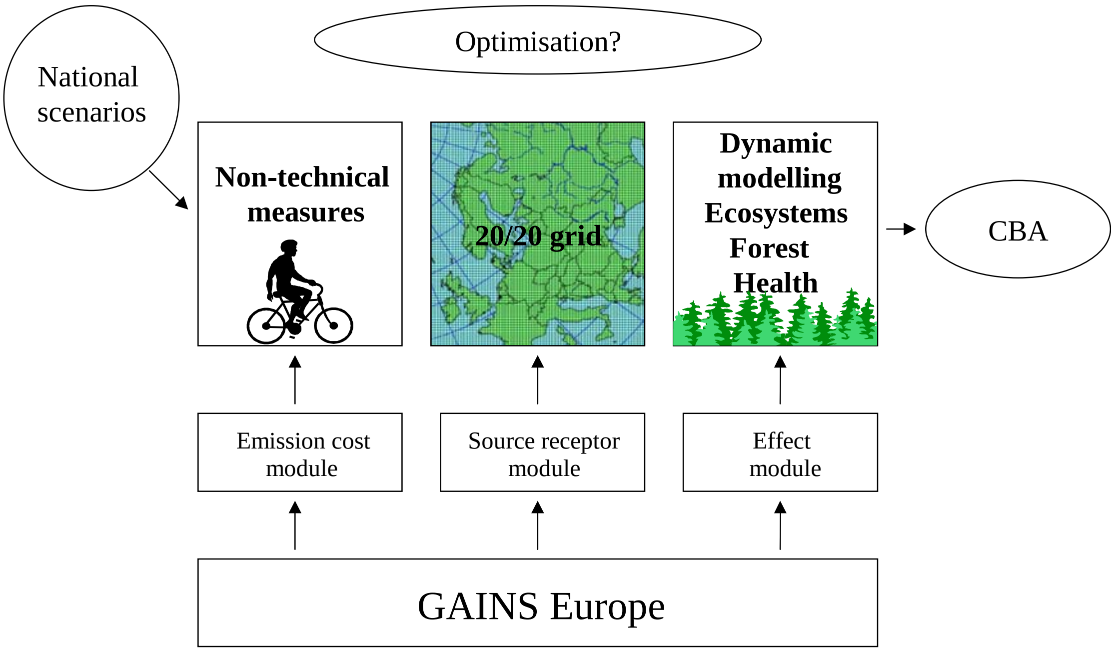

Figure 4 Possible differences between GAINS Europe and GAINS Sweden.

5.1 Emission and Cost Module

The emission and cost module in RAINS and GAINS includes emission estimates based on economic, energy and agricultural projections in the different countries. The amount of emissions is also influenced by the use of different control measures. In RAINS these measures are mainly limited to end-of-pipe solutions, while GAINS also include some non-technical measures, such as energy efficiency and fuel switch.

The cost estimates in RAINS are pollutant-specific resulting in pollutant-specific cost curves for each country. This concept requires that there are (in principal) no synergy effects between the abatement of different types of pollutants. GAINS introduce emissions and abatement measures for GHG in addition to the pollutants traditionally modelled in RAINS. This requires a different methodological approach to the cost calculations since GHG abatement measures might very well affect emissions of other pollutants. In GAINS the pollutant-specific cost curves are replaced by technology-specific cost calculations, taking into account all the affected pollutants from any abatement technique (Klaassen et al., 2004).

5.1.1 Possible extensions of the emission and cost module

Structural and behaviour changes
The cost module in the current version of the RAINS model only includes end-of-pipe solutions, which might result in underestimation of the removal potential and overestimation of the related costs (Sternhufvud & Grennfelt, 2001). Some of these aspects are better treated in the extension of the RAINS model, GAINS. Nevertheless, there is still potential for further introduction of structural and behaviour changes into GAINS.

There are large difficulties with the inclusion of non-technical measures such as behaviour and structural changes in integrated assessment models due to problems in estimating the efficiency and costs of such measures. The abatement cost for technical measures are often included as yearly costs based on investment costs, fixed and variable operating costs. For non-technical measures the control costs may take different forms. They can be direct costs such as in the case of substitution of fuels, but it might also include welfare loss and non-monetary costs for the people affected by the measures. Examples of such costs might be additional time spent or experienced reduction in welfare due to inconveniences caused by lower indoor temperature, waste sorting or using a bicycle instead of driving. The discussion on what type of costs that should be considered is of interest since many non-technical measures can have a substantial impact on non-monetary costs for the private consumer. By ignoring such costs, non-technical measures might appear more favourable than would be the case if the welfare lost was included (Sternhufvud et al., 2006).

Measures included in the scenarios
Each scenario, which includes technical measures already implemented, according to current legislation, has a cost. Though, the costs of non-technical measures included in the scenarios in GAINS are not included. Examples of such measures are efficiency improvements that result in a negative cost for implementation (Wagner, pers. comm. 2006-03-10). Another example is the above mentioned structural changes. By implementing these measures into the scenarios without reflecting their costs, there is a risk that the cost for restructuring or the benefits from efficiency improvements will not be taken into account in air quality policy development.

Administrative costs
A matter of concern regarding the introduction of new types of abatement measures such as NTM into IAM cost calculations is whether the background assumptions in the cost calculations can remain unchanged or not. Non-technical measures often need to be accompanied by policy instruments to be realised and the administration costs for these instruments might be substantial in comparison to the control cost usually discussed. These costs are currently disregarded in the RAINS cost calculations (Amann et al., 2004). If these costs were to be considered in cost calculations, it might require a different formulation of the cost calculations.

Region specific emission sources and abatement costs
In RAINS-Italy, there are 20 regions that are considered for the abatement cost calculations (Zanini et al., no date). The higher geographical resolution on cost calculation enables the model to identify where implementation of abatement measures would be most efficient. Furthermore, this region-specific distribution of emission sources and abatement costs is necessary for Italy since the regions

have a certain degree of autonomy granted by the Italian government (www.wikipedia.org, pers. comm. Pignatelli, 2006-03-06). For Swedish conditions, higher geographical resolution on emission sources and cost calculations would enable more cost-efficient measures to be identified. Matters of concern would be to identify the costs for the measures on a regional scale. There is also a potential risk that higher resolution on the geographical scale for emission sources makes it more difficult to project social and economic activities, compared to projections on a national level (pers. comm. Pignatelli, 2006-03-06). Other aspects with respect to regionalisation are the possibility to assess environmental objectives on a regional basis. A third aspect of particular concern at present is the emissions from sea traffic in the Baltic and the North Seas. Aspects related to local air pollution and health effects are handled below.

Dynamic effects

The RAINS model integrates, as described earlier, the polluting activities in many countries and the costs for abating this pollution, with the following environmental impacts. Although the model is very large with large amounts of input data, there is a need to keep the model as simple as possible so it can be possible to perform many scenario calculations and to perform optimisations. This will require low levels of detail in some areas. In the RAINS and GAINS cost calculations for example, no specific attention is dedicated to the economic effects following the implementation of a measure. In economic theory, the implementation of a costly measure might affect the demand for the commodity in question. These types of effects are not considered in the models, and one main argument for this is the data requirements for the introduction of such a measure.

Another effect is the dynamic effect following the timing of measure implementation. The implementation of a measure in year X might affect the activity levels in the following year, an issue that is not considered in RAINS/GAINS at the moment (Wagner, pers. comm., 2006-03-10). The introduction of these dynamic effects in the cost calculations will allow for a more correct picture of the emission abatement option, but it would require extensive adjustments of the cost calculation approach and an even more extensive demand for data than the current version.

5.1.2 Possibilities, constraints and data availability

There are quite a few ways to improve the methodology for cost estimates. All possible concepts for improvements mentioned above can however not be included in GAINS Sweden as this would require a lot of information. In addition, there is no comprehensive database of possible measures to be undertaken in Sweden to abate air pollution available. A database has however been developed which includes a well functioning structure, some measures and an optimisation module (Ribbenhed et al., 2005). There are also plans to update the REKO database in the near future to include both technical and non-technical measures and their costs with relevance for Sweden (Engleryd, pers. comm. 2006-02-09). An updated REKO database would facilitate the creation of the cost module in GAINS Sweden.

The cost module developed in a potential Swedish IAM should preferably use the technology-specific cost calculations used in the GAINS model, as this method is already used in the Swedish REKO-project (Ribbenhed et al., 2005) and since this method is well suited to allow for the introduction of GHG-emission abatement. The inclusion of structural and behavioural NTM will most probably affect the outcome of the total cost calculations more than regional distribution of measures and the inclusion of dynamic aspects. One reason is that the regions in Sweden in general do not differ that much when it comes to salaries, economic growth etc.

5.2 Source receptor module - atmospheric modelling

The use of atmospheric modelling is an important part of IAM since with these it is possible to calculate ambient air concentrations and deposition levels that are related to environmental quality objectives. The changes in emission levels, due to implementation of abatement measures, result in changes in air concentration and deposition levels. Since these parameters are dependent on the emission levels as well as the meteorological and geographical conditions, atmospheric models are required to be able to describe the dispersion.

Easily available atmospheric models that can be of interest for a Swedish IAM are the EMEP model and the MATCH model. Both have earlier been used for regional scale dispersion and transport calculations. Recently they have also been developed to estimate concentrations and deposition on local scales. In some European countries there are already models implemented for local application of the RAINS concept. However, the use of these local models requires data input from a regional model such as EMEP or MATCH.

5.2.1 Regional / local models

EMEP

The RAINS/GAINS model at IIASA uses the EMEP model, developed by the UNECE European Monitoring and Evaluation Programme for Transboundary Long-Range Transported Air Pollutants (EMEP) and its Meteorological Synthesizing Centre - West (MSC-West) in order to get data on deposition and concentration of air pollutants following any given scenario. The resolution for the grid cells are 50*50 km^2 and the model gives *regional background data* for all components of interest.

Due to the increased interest in estimating the human exposure of air pollution and the influence of local emissions on concentrations of particles and ozone, there has been an interest in linking the local influence on air pollution to the regional models. A certain project, CityDelta, partly supported by the European Commission has undertaken comparative studies in a number of European cities. None of these models have however so far been able to estimate the local influence with enough accuracy to be used in integrated assessments. Instead simple relationships including population densities and wind parameters have been as good as the more advanced models.

The EMEP model has recently also been developed in a *local scale*. Initial tests have been performed for some cities, and the local EMEP model is now under implementation in Sweden (probably Göteborg). The grid cell resolution is about 2*2 km^2, which would enable a good description of effects on human health and ecosystem if developed for entire Sweden. A future plan is to develop an Internet based user-friendly version of the EMEP model in all scales, to be used free of charge.

URBAN model

Within the Swedish SNAP-programme, IVL has developed the URBAN model, which is an 'empirical statistical calculation method for air quality assessments', using modelled meteorological parameters as input data to describe the local meteorological conditions (Forsberg et al. 2005; Sjöberg et al. 2004). This model describes the urban background air concentrations (so far only for NO_2 and PM_{10}) and exposure levels fairly well, but will not be suitable for more complex scenario analyses. Deposition calculations are not included.

The Swedish MATCH model

The Swedish MATCH model developed by SMHI is an Eulerian model with 50*50 km^2 resolution. The main pollutants considered are nitrogen, sulphur and ozone (Lagner pers. comm. 2006-03-20; http://www.smhi.se/sgn0102/n0205/nvv/1999/chemdata.htm). The MATCH model has also been developed for the *local scale* down to 1*1 km^2, the so-called MATCH-urban.

5.2.2 Models for national assessments

Netherlands Operational Priority Substances (OPS) model
The OPS model is a Lagrangian atmospheric transport and deposition model, linking emission sources divided in 5*5 km^2 grid cells with receptor areas of the size 5*5 km^2 in the Netherlands. The pollutants considered in the RAINS-NL are identical to the pollutants considered in RAINS - Europe. The resolution of the Source-Receptor Matrices (SRM) is considered as sufficiently high for a fairly detailed description of effects on ecosystems and human health (Aben et al. 2005).

The Italian 'Atmospheric Modelling System' (AMS) model
In the RAINS-Italy project, an Eulerian atmospheric model (AMS) has been developed with a grid cell receptor resolution of 20*20 km^2 and that concerns the source regions equivalent to the counties and 4 largest cities in Italy. This model can also be used on a 4*4 km^2 grid cell resolution. The grid is covering the entire Italy and some regions of the bordering countries, and the boundary conditions (air pollutants entering model domain) are given by EMEP. The pollutants considered are the same as in RAINS Europe (Pignatelli et al., no date; Pignatelli pers. comm. 2006-03-06).

The 'Danish Eularian Hemispheric Model' (DEHM)
The Danish National Environmental Research Institute (DMU) has developed an Eulerian model with a three receptor resolutions ranging from 150*150 km^2 down to 17*17 km^2 grid cells. This model can consider a number of different pollutants but is in its current version focused on nitrogen and sulphur (http://www.copernicus.org/EGU/acp/acpd/3/3525/acpd-3-3525.pdf).

5.2.3 Possibilities, constraints and data availability

As can be seen, there are a number of atmospheric models able to handle emissions and deposition with a better resolution than what is currently used in RAINS - Europe. This resolution enables a more detailed description of effects on human health and ecosystems. For the atmospheric modelling module in the current RAINS/GAINS Europe there are a couple of potential improvements

- Increased resolution on the receptor grid cells;
- Increased resolution on source regions;

To be able to fulfil the purposes of a Swedish GAINS a fine resolution is required for urban areas (about 1*1 or 2*2 km^2 grid cells). The reason is that the emission levels vary quite frequently in the urban areas and a high resolution will make possible a good estimate of the health effect connected to the emissions. The methods to achieve appropriate input data to the suggested resolution are already available. However, this will require substantial time for data collection, computational modelling and calculation processes.

In a model used for the development of policies relevant for 2020 and beyond, it is probably necessary to include the possible influence from climate change. Such changes may affect emissions atmospheric behaviour and effects of pollutants.

5.3 Effect module

In an integrated assessment model it is necessary to estimate the impact on human health and the environment. Such estimates are based on dose response functions. The current version of the RAINS model can illustrate impacts on the natural environment from air pollution concerning acidification, eutrophication and vegetation damages from ozone. The health impact of fine particles and ground-level ozone are also estimated.

5.3.1 Dynamic ecosystems models available

In the present assessments of acidification and eutrophication, steady-state models are commonly used. However, the static models are not able to take into account the recovery of the ecosystems. In order to include the recovery aspects, dynamic models have been developed to suit integrated assessment requirements and they are in principle possible to use. The main problem for implementing them in present models is lack of field data. Two dynamic ecosystem models have been assessed and investigated for Swedish conditions:

Model of Acidification of Groundwater in Catchments (MAGIC)
MAGIC (Cosby et al., 1985a, b) is used for dynamic modelling of effects from acid deposition on soil and fresh water on a catchment scale. It is a process-oriented model of intermediate complexity that simulates short- and long-term geochemical and biological processes. Two types of geochemical reactions are incorporated into MAGIC. The first consists of equilibrium (short-term) reactions between the soil and the soil solution as well as rapid biological processes. The second type consists of input-output reactions (long-term) describing fluxes of acids, bases, and neutral salts into and out of the soil layers and watershed. This model is currently suggested as being used for the future Swedish reporting of CLacid in surface waters for Sweden. Its strength is the limited need of data in comparison to other models, but this might result in less detailed estimates.

Model of biogeochemical processes in forest ecosystems (ForSAFE)
ForSAFE is a multilayer dynamic model, which simultaneously simulates changes of soil chemistry, growth of biomass and variations in soil organic matter (Wallman et al., 2005; Belyazid, 2006). It was developed from the soil acidification models PROFILE (Svedrup & Warfvinge, 1993) and SAFE (Alveteg, 1998) in combination with models of biomass growth and decomposition. There is currently an additional module in the ForSAFE model, the VEG module, which simulates the composition of the ground vegetation based on abiotic and biotic factors (Belyazid, 2006). ForSAFE and ForSAFE-VEG can be used to illustrate the effects on soil chemistry, tree growth, and eutrophication of aquatic ecosystems and ground vegetation composition from varying sulphur and nitrogen deposition. The mechanistic approach relating abiotic factors to ground vegetation composition is a major strength of the ForSAFE-VEG model. The usefulness of the model can, however, be restricted by the rather high demands on data, in areas where data is sparse.

5.3.2 Possibilities, constraints and data availability - dynamic ecosystems models

Both MAGIC and ForSAFEs are dynamic in their construction, which enables them to take into account the results from changes in acid deposition over time. However, the models are not considered as suited to be included directly in to the GAINS Europe framework as there is no space for time series, it would also decrease the flexibility of GAINS. The main purposes of these models are to provide data on critical load etc. These models are also considered as best suited for development together with a Swedish GAINS (Akselsson & Westling, pers. comm. 2006-03-22).

There are four benefits with dynamic modelling, which could be valuable in a GAINS Sweden (Akselsson & Westling, pers. comm. 2006-03-22):

- Time of ecosystem recovery resulted by reduced acid deposition. The time dimension on environmental effects can be illustrated by using the results from dynamic models. For example, the recovery time for an acidified ecosystem will vary dependent on the future levels of acid deposition, an effect that can be illustrated by using models such as MAGIC for surface water, and ForSAFE for soils.

- The effects on biodiversity from air pollution. The ForSAFEveg model could be adjusted to illustrate changes in ground vegetation following acid and nitrogen deposition. There is an ongoing development of environmental criteria reflecting deviations from pre-industrial conditions, therefore effects on biodiversity could be interesting as an additional environmental quality criterion for a Swedish GAINS as well. For biodiversity calculations on Swedish conditions, additional data would be required for the Swedish conditions.

- -The potential of simulating effects of climate change. Changing temperatures and hydrology due to climate change directly affects tree growth, decomposition and ground vegetation composition, and thus changes the overall conditions of the forest ecosystems. The integrated approach of ForSAFE-VEG makes it possible to simulate effects on acidification, eutrophication, and tree growth and ground vegetation composition for different climate scenarios. MAGIC can be used to simulate effects of climate change on runoff water quality.

- The introduction of changes in land use, as either an abatement measure or as an autonomous change in the model. Changes in land use can be interesting both as a local version of abatement measure as well as a reflection of autonomous changes over time and it's consequence on sensitivity towards soil and water acidification. The forSAFE model would require some adjustments, but can in principal illustrate the effect on changes in land use. A parallel project could be the development of local abatement measures and their consequential costs, illustrating different types of land use management and how adjusted land use could abate damages from air pollution.

These potential improvements to the ecosystem modules in the current GAINS are all considered as achievable using the models mentioned. The background data available in Sweden is very extensive, therefore there is little need for further data collection. The exception would be the ForSAFE biodiversity calculations for Sweden, which are under development and where more data would be required in order to capture Swedish conditions (Akselsson & Westling pers. comm., 2006-03-22).

5.3.3 Available models - human health

For the estimate of human health effects from ozone and particulates, the RAINS/GAINS models use dose-response relationships developed in collaboration with WHO. These relationships include a linear dose-effect function with a threshold. These functions are easy to introduce in a Swedish model but there are also possibilities to use other parameterisations both for exposure and effects dependent on new scientific findings.

5.4 Uncertainties

Uncertainties have been identified as an important factor to assess for achieving a high credibility of the model output. Uncertainties in integrated assessment models have recently been considered in more general terms in connection with a review of the RAINS integrated assessment model (Grennfelt et al 2004). In the report they point to the importance to consider biases as a factor causing larger uncertainties in the model output than conventional (statistical) uncertainties. In a Swedish development, attention should be given to the assumptions, simplifications and other factors that may cause biases in the model.

5.5 Collaboration with IIASA and other institutes

Development of GAINS Sweden will require a close collaboration with IIASA and other countries that have already or are about to develop national IAM. The implementation of the Swedish initiative will be partly inspired by the existing experiences such as the ongoing Dutch and Italian projects for national IAM. Collaboration in this direction has already been initiated and a partnership is desired and called upon to share experiences and knowledge between different national projects within a European framework. For the implementation of a Swedish IAM competence, it is preferred to adopt a local national copy of RAINS, as has been realised in the RAINS-Italy project, rather than utilising a copy based in the IIASA server as opted in the corresponding Dutch project. Having a local copy of the model in Sweden will facilitate the discussion among the national stakeholders, but will still relate directly to IIASA. The close collaboration with IIASA will also be required in order to gain acquaintance and practical experience with the GAINS model, with the objective to participate actively in the future development of the model. The collaboration with IIASA will provide practical access to the GAINS model as a means to test new measures and policies and possibly implement structural changes, which may be needed for scenario analysis on a national level. The experiences from this collaboration may result in findings that could be relevant for application on a European level, and the collaboration with IIASA could then be an ideal channel to extend these findings to other European partners or to the European negotiations.

5.6 Need of resources

The development of GAINS Sweden will require a lot of resources. The choice of geographical resolution, regionalisation, adjustment of the cost module etc. will dramatically affect the final cost and it is at this state not possible to give a good estimate of the total cost required. The Italian project had a budget of almost 1 300 000 Euro, which included the work carried out by IIASA. RAINS-NL estimated the time spent by MNP alone to about 3 man-years, to this should the work carried out by IIASA be added. It is important to remember that neither the Italian nor the Dutch have changed the cost module in any way, the main alterations have been to include more detailed data. The cost of the improvement of the cost module itself can also vary a lot as there are quite a few possibilities suggested in this report.

In addition to economical resources, the development of GAINS Sweden is also dependent on personal resources. The project will, beside the IIASA team, require people with experience in integrated assessment modelling, economics, atmospheric modelling, effect modelling etc.

6 Discussion and conclusions

Integrated assessment models, such as RAINS and GAINS play an important role in the strategies to abate air pollution in Europe, both within the CLRTAP and the EU. In addition to the regional IAM, many countries have also realised the usefulness of national integrated assessment models, for instance, Italy and the Netherlands. The additional benefits of models with higher resolution are that the countries can perform their own estimates on the outcome of different emission abatement solutions on a more detailed scale. The models will also facilitate for the countries to verify the results from the European RAINS and GAINS models. Another purpose is that a national model can be useful in the international negotiations.

All the arguments mentioned above are also valid for Sweden, which has been verified in our discussions with possible stakeholders. Therefore, we conclude that there is a need of a Swedish integrated assessment model, such as the suggested GAINS Sweden.

There are many different ways how such a model could be developed. Italy and the Netherlands have both decided to extend the existing RAINS Europe, but have chosen to do it differently. For the implementation of a Swedish IAM competence, it is preferred to adopt a local national copy of RAINS or GAINS, as has been realised in the RAINS-Italy project, rather than utilising a copy based in the IIASA server as opted in the corresponding Dutch project. It is also suggested to extend the GAINS model instead of the RAINS model as GAINS includes green house gases and also estimate the cost slightly different, which would be favourable if additional non-technical measures, such as behavioural and structural changes, are to be included.

There are many possibilities to improve the regional GAINS model when it is used at a national scale. The reason is that more detailed data is available, which makes it possible not only to improve the methodology in the cost and effect modules, but also to find adequate data. According to the need of the stakeholders it seems like the most important issues are the inclusion of additional non-technical measures as well as higher resolution. The inclusion of structural and behavioural changes will most probably show that there are ways to reach the environmental targets in a more cost-efficient way and also show that targets lower than MTFR (maximum technical feasible reduction) are possible to reach. The inclusion of higher resolution will enable a more detailed description of effects on human health and ecosystems.

With a rather ambitious approach, a national IAM could be used to facilitate the introduction of new methods and other potential improvements into a European IAM such as RAINS / GAINS. It is reasonable to assume that it will be easier for a national model to try different methodological approaches and other improvements, mostly since the amount of stakeholders involved is smaller than in the RAINS Europe. Given this advantage, the progress of IAM could be advanced more rapidly by letting (encouraging) national IAM (to) perform first evaluations of different methodological approaches (improvements) before they are introduced and tried in a European scale IAM. In brief, national IAM could be used as test models before introduction of improvements into a European IAM such as RAINS.

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