The Finnish Environment

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Integrated Environmental Assessment Modelling
Final Report of the EU/LIFE Project

Coupling of CORINAIR Data to Cost-effective Emission Reduction Strategies Based on Critical Thresholds (LIFE97/ENV/FIN/336)
Integrated Environmental Assessment Modelling

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LIFE97/ENV/FIN/336

HELSINKI 2000
Foreword

The use of mathematical models has been found helpful to explore different alternatives for reducing harmful impacts of air pollutants. Integrated modelling tools have given support to decision-making, especially in combatting acidification. The recent negotiations under EU and UN/ECE/CLRTAP on further reductions of air pollutant emissions in Europe have required extensive background work both at national and international levels. The issue has become complex by involving several pollutants (sulphur, nitrogen oxides, ammonia, volatile organic compounds) and effects (acidification, eutrophication, vegetation and health effects from ground-level ozone) simultaneously. The EU/LIFE project on Coupling of CORINAIR data to cost-effective emission reduction strategies based on critical thresholds (LIFE97/ENV/FIN/336) was launched to support various activities in national integrated assessment modelling to pull together the various detailed aspects of the complicated multi-pollutant/multi-effect evaluation and to provide viewpoints on temporal and spatial details important for national assessment. The EU/LIFE project beneficiary and co-ordinating institute was the Finnish Environment Institute (FEI).

This report summarises the findings of the EU/LIFE project. The results were obtained from the work and co-operation of the project participants: the National Environmental Research Institute (NERI) in Denmark, the Finnish Environment Institute (FEI) in Finland, the Research Center for Energy, Environment and Technology (CIEMAT) in Spain, and Lund University (LU) in Sweden. In addition, valuable external assistance was provided to the project from three institutions: the Coordination Center for Effects (CCE) in the Netherlands, the Meteorological Synthesizing Centre - West of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP/MSC-W) in Norway, and the International Institute for Applied Systems Analysis (IIASA) in Austria.

We acknowledge all persons and institutions who have supported and contributed to the work of this EU/LIFE project. The funding from the Financial Instrument for the Environment (LIFE) of the Environment Directorate-General (earlier DG XI) of the European Union is gratefully acknowledged for the main financial support to the project.

We thank Maria Holmberg and Kristina Saarinen for comments on the manuscript and Sirkka Vuoristo for technical assistance in this report.
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Executive summary

Background

The assessment of the acid rain problem has currently incorporated several related effects (acidification, eutrophication and ground-level ozone) and pollutants (sulphur and nitrogen oxides, ammonia, volatile organic compounds), resulting in a very complex model and policy assessment, often referred to as the multi-pollutant/multi-effect approach. The development of effects-oriented cost-effective emission reduction strategies in Europe has been supported by integrated assessment models. The key aim of the EU/LIFE project was to provide support for the demonstration and enhancement of national integrated assessment modelling on these topical air pollution issues.

Policy development in air pollution abatement in Europe has been carried out in the EU (European Union) and the UN/ECE/CLRTAP (Convention on Long-range Transboundary Air Pollution under the auspices of United Nations Economic Commission for Europe). In 1999 the Commission of the European Union adopted the proposals for the National Emission Ceilings Directive (NECD) and for the Air Quality Daughter Directive on Ozone in Ambient Air. The adoption was based on the Acidification Strategy and the Ozone Strategy prepared during the last few years. The new 1999 Gothenburg Protocol, or the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone under UN/ECE/CLRTAP, was adopted in 1999 in Gothenburg, Sweden. The activities of the EU/LIFE project were closely connected with the background work of the two negotiation processes and further supported national assessment of the internationally proposed emission reduction requirements to reduce environmental effects.

The overall aim of the EU/LIFE project was to support, further develop and apply databases, methods and tools in national integrated assessment modelling. The EU/LIFE project was co-ordinated by the Finnish Environment Institute. The work was carried out during 1997–1999 by the international four-country consortium consisting of partners in Denmark, Finland, Spain and Sweden.

Main conclusions

Emission inventories, scenarios and abatement

- The potential use of the CORINAIR air pollutant emission database was demonstrated for carrying out national emission projections, to convert data for other modelling purposes and to assess the emissions resulting from various technical and legislative abatement measures.
- High resolution emission inventories were derived with new methodology using CORINAIR database and detailed geographic information on appropriate surrogate indicators in Spain. The spatially and temporally detailed emission estimates were combined with detailed meteorology for local ground-level ozone modelling.
- National energy projections and emission reduction strategies depicted through emission factor changes were derived to highlight the importance and possible range of the total emission reduction potential in Denmark due to different energy use futures and abatement measures.
- Emissions scenarios were created in Spain for 2020 for several activity classes in the CORINAIR database based on the forecasted energy consumption projection. The results gave directions to further future national work.
• Emission control technologies and related costs using Finnish national data were extensively compared with more aggregated international approaches to highlight the major differences in the convergent results. The combined \( \text{SO}_2 \) and \( \text{NO}_x \) cost curve indicated that most of the abatement measures for \( \text{SO}_2 \) are more cost-efficient than those for \( \text{NO}_x \) on the basis of their acidifying impact on ecosystems.

Deposition loads
• The variability of deposition levels calculated with different models were found comparable in Finland, although spatially more detailed deposition estimates will benefit national impact studies.
• The base cation deposition level was found significant in reducing the acidifying impact of sulphur and nitrogen compounds in Finland. The relative reduction in net acidifying deposition, which was calculated by subtracting base cation deposition from total sulphur and nitrogen deposition, was found smaller than that of total acidifying deposition in 1985–95.
• High resolution deposition studies in Spain suggested that wind speed and surface resistance can be more important than the atmospheric concentration in determining total deposition.

Environmental impacts
• The area of exceedances of critical loads, which describe the long-term tolerance of ecosystems against pollutant load, in the small calculation grid was found to be much higher than when calculated in large grid cells in Denmark. The difference was most pronounced for acidification. An analysis carried out at European level supported the findings of the national analysis.
• The number of measurement sites in a grid cell had a substantial effect on the uncertainty in the environmental impact calculations in Sweden. The uncertainty might not always be reduced, however, when the number of sites is increased from 60–80 sites. The critical load mapping on a high spatial resolution will result in a higher uncertainty due to less measurement sites per grid, but it may increase the informational quality.
• The Swedish study showed that results from single-site uncertainty and sensitivity studies can not be applied to the regional scale due to differences in informational quality. Furthermore, conclusions are dependent on the geographical area and the studied entity. Currently the uncertainties in deposition and soil chemical parameters contribute most to the uncertainty in calculated critical load exceedances in Sweden.
• One third of the Danish forest area is presently nitrogen saturated according to monitoring data. Scenario analyses with the dynamic SAFE soil acidification model at three sites in Denmark suggested that acidification is not the major problem at these sites, although the accumulation of nitrogen and eutrophication are slowly advancing.
• The dynamic soil acidification modelling study in Finland demonstrated, that soils can be acidifying in spite of the non-exceedance of the critical load calculated with the current standard criteria. Dynamic model simulations were shown to be useful in providing in-depth information on soil chemical status, rate of improvement and time lags before reaching harmful conditions for forest vitality.
• The temporal variation of ground-level ozone exposure was found important for the occurrence of environmental effects in Spain and especially emphasized for plants with high market value. Most damages occurred in early harvests when the economic value is largest.
• Environmental conditions (water stress) induced similar yield losses as the ozone exposure in experiments with tomato in Spain. In the fumigation experiments harmful effects were not detected for plants with a water deficit. The environmental conditions (water stress) and increased ozone levels recorded in eastern Spain were also found to favour infection by plant virus. The plant viruses are a big agricultural problem and the ozone exposure increases the sensitivity of the plants.
• The currently used yield loss relation to ground-level ozone exposure may be an overestimate according to Spanish results. As for the forest effects, the ranking of sensitivities to ozone depended on choosing visible injury or biomass reductions as indicators, because some species showed injury but no biomass reduction.

Integrated modelling
• The analysis on the sensitivity of calculated emission ceilings for sulphur and nitrogen in Denmark suggested that the national action plan to reduce CO₂ emissions resulted in lower optimised emission ceilings for the country. The influence on marginal costs of emission reductions was limited. The emission ceilings were strongly dependent on deposition targets in few grid cells in neighbouring countries.
• The results both from a compilation of variability and uncertainty estimates on three Finnish integrated models and from an integrated uncertainty analysis suggested that environmental effects, usually represented by critical loads, dominate the total uncertainty. The total uncertainty was predicted to diminish considerably in the future due to decreasing acidifying deposition levels.
• The incorporation of uncertainty in the assessment of critical load exceedances would lead to higher reduction requirements for acidifying emissions according to the Swedish analyses. The consequent shift from the threshold characteristics of the critical load concept into a risk concept would enable the definition and the use of an acceptable risk level for harmful effects.

Dissemination of results
• International projects cannot supply a long-term permanent basis for integrated modelling activities in countries, but they can provide a basis for capacity building and support for additional research and applications. The developed tools and achieved results from these projects should be made widely available with clear documentation. This is the basic component of the process to implement and further develop international air pollution abatement strategies to help policy-makers to make decisions and to help the public to guide policy-makers.
• The dissemination activities proved the importance of continued science-policy dialogue in the forthcoming amended organisational structures on air pollution of EU and UN/ECE/CLRTAP.
**Environmental benefits**

Harmonisation and documentation of available data
- Emission-related national data on current energy and activity levels and projections, conversions between different databases, control technologies and related costs were collected, compared, evaluated and harmonised. These activities facilitate future submission and checking of national and international data on country emissions and reduction potential.
- The data on environmental impacts were reassembled for new integrated assessment purposes. The compilations demonstrated the usability of existing data for new viewpoints and enhanced environmental impact studies.

New assessment methods and tools
- The work on national emission scenarios in Denmark demonstrated a promising method to estimate future emissions and reduction potential. The work on the emission scenarios, the derivation of national cost curves and the appropriate documentation in Finland laid a foundation on further evaluations on other pollutants.
- The work on connecting dynamic soil acidification processes and long-term environmental targets, represented by critical loads, demonstrated the feasibility of using different indicators for state and risk of environmental effects. The assessment of the uncertainty helps to identify chemical and other characteristics important for specific areas, which can be used in the confirmation of the critical load concept.
- Several integrated modelling approaches tailored for different purposes were demonstrated. The developed and tested resources are used in the continued detailed national assessments.

International context in national applications
- In all tasks a common approach was taken to use the results from the development of emission reduction strategies of EU and UN/ECE/CLRTAP. These emission scenarios were used throughout the integrated modelling work covering the emissions and their controls, concentration and deposition levels, environmental effects and uncertainty analyses.
- The effects from international agreements and actions, for example, the expected reductions in acidifying deposition, were linked to the local level. The developed methods for environmental effects assessment can be used as a scientific basis for strategies and guidelines for national and local actions.
- The data and methods, which were developed and demonstrated in the project, are available for various users. The findings enable stakeholders to relate international protocols to national actions and to solutions of other environmental problems.
Dissemination of results

- The dissemination of results was carried out extensively among international and national air pollution experts and decision-makers through workshops, conferences, meetings, reports, presentations and articles. The activities reached policy-makers, researchers and the wider audience interested in environmental issues.
- The participants of the project were involved in the national policy-making processes of the EU and UN/ECE/CLRTAP emission reduction negotiations. The EU/LIFE project enabled policy-relevant case studies and provided direct interaction between researchers and stakeholders in, for example, environmental administration and energy production companies.

Enhanced networking for national integrated modelling

- The exchange of experience on national integrated model exercises among project partners contributed to a better understanding of the specific features and robustness of the modelling results by researchers and policy-makers.
- The project contributed to the networking of national integrated modelling groups at European level and to the discussion in the new organisational structure of the UN/ECE/CLRTAP and in the forthcoming amended organisational structures on air pollution of the EU prepared in the programme of Clean Air For Europe.
1.1 The extent of the air pollution problem

The detrimental effects caused by atmospheric pollution have been recognised as one of the major environmental problems in many countries. Local episodic pollution events pose a threat to human health, and regional long-term harmful effects on ecosystems have been of concern in several countries. The long-range transport of pollutants across country borders have made air pollution a truly international problem. The effects are difficult to mitigate with means other than emission controls at the source. The situation has resulted in intensive and extensive international co-operation in both scientific research and policy-making. Constructive negotiations have already led to several international agreements on issues such as ozone layer protection, acidification and climate change. The main elements of the air pollutant issue are shown in Fig. 1.

![Diagram of the main elements of the air pollutant issue](image)

Fig. 1. The main elements of the air pollutant issue.

Negotiations within the EU (European Union) and the UN/ECE/CLRTAP (Convention on Long-range Transboundary Air Pollution under the auspices of United Nations Economic Commission for Europe) have addressed several serious large-scale air pollution problems simultaneously: acidification, eutrophication and ground-level ozone. The reduction requirements to abate these problems are allotted to the emissions of sulphur and nitrogen oxides, ammonia and volatile organic compounds. The connections between emission sources, air pollutant compounds, receptors and environmental problems are presented in a schematic diagram in Fig. 2. Various feedback mechanisms, such as targeted emission reduction requirements, are not explicitly shown in the diagram. The assessment of all interrelations and uncertainties in an integrated assessment model (IAM) covering all these aspects becomes a challenging task. Due to the conceptual and technical complexity of these model systems, the robustness of the modelling results has usually been approached through sensitivity analyses, where the effects of the most important input parameters are examined.
As a first step, international agreements on reducing air pollutant emissions have often started from a flat percentage reductions. This approach demands that all signatories reduce national emissions by equal relative amounts, for example, 30%. Further reductions can be based on effectiveness, for example, best available emission reduction techniques or minimising environmental effects with funds available. In the effects-oriented approach, sensitive geographical areas are identified and mapped, and those emitters identified as contributing most to the pollutant loading of these areas should effect the most reductions. If reduction costs are taken into account, cost-effective solutions can be explored as a mathematical optimization problem. An effects-oriented approach may require strict and costly emission reductions if the environmental targets are very stringent. For example, the latest model studies roughly estimate the forthcoming total costs of annually reducing European emissions ($SO_2$, $NO_x$, $NH_3$, VOC) from the 1990 level by 2010, according to the current legislation and official reduction plans as implemented in the reference scenario (REF) of the RAINS (Regional Acidification INformation and Simulation) model of IIASA (International Institute for Applied Systems Analysis), to be about 67000 million €. These measures are still not enough, however, to completely protect ecosystems from acidification and ground-level ozone effects.

A high aggregation level for spatial, temporal and process descriptions are characteristic for IAMs, the level being determined by the purpose of the models. There is a trade-off between model complexity and regional or temporal applicability. IAMs can not always utilise most detailed estimates available on, for example, spatial heterogeneity or intra-annual variations of effects. This emphasises the need to confirm the performance of aggregated models and to identify ranges of applicability and acceptable levels of predictive accuracy. The assessment of one single pollutant or effect may be connected to other important pollutants or effects so tightly that it is beneficial to include all of them in the model system (see Fig. 2). This demands considerable efforts to produce a feasible approach necessitating a relatively high level of aggregation as a prerequisite for the integration of several pollutants and effects in the same assessment. Only
carefully designed and restricted aims lead to an operative integrated modelling system.

National modelling and other detailed studies are needed in spite of advanced continental integrated model systems. International integrated assessment models may use calculation parameters and data that may not be completely suitable for a country. The results of international integrated assessment models cannot, and do not have to, include such spatial, temporal or sectoral details as often desired by individual countries. To this end, national (integrated assessment) modelling is necessary to (i) provide detailed information on input data and calculation parameters to check against the data in international integrated assessment models, (ii) to explore in more detail the variation of proposed results within the country, and (iii) to convey findings and background information for national decision-makers. National integrated models have been used in Europe both as research tools and in support of policy-making, but they are few in number.

1.2 European emission reduction strategies

Acid rain has been regarded as a major threat to the environment during the last decades in Europe and North America. International legal instruments have been necessary to enable reductions in emissions of the most detrimental pollutants. This co-operation between governments led to the adoption of the Convention on Long-range Transboundary Air Pollution (CLRTAP) in 1979 under the auspices of the United Nations Economic Commission for Europe (UN/ECE). The signatories of the UN/ECE/CLRTAP also agreed to co-operate on research into the effects of major air pollutants and a large collaborative effort was set up and is operating under this scheme.

The development of effects-oriented, cost-effective emission reduction strategies in Europe has been supported by integrated assessment models (IAMs), and the first European effects-oriented emission reduction protocol supported by IAMs was signed under the UN/ECE/CLRTAP. In preparation for the 1994 Sulphur Protocol, or the Protocol to the 1979 Convention on Long-range Transboundary Air Pollution on Further Reductions on Sulphur Emissions, the environmental protection target was to reduce the current sulphur deposition levels over the long-term ecosystem tolerance, the critical load, by at least 60% all over Europe. Three IAMs were used in evaluating strategy alternatives for the 1994 Sulphur Protocol: RAINS (Regional Acidification INformation and Simulation), ASAM (Abatement Strategy Assessment Model) and CASM (Coordinated Abatement Strategy Model).

In the late 1990s, the UN/ECE/CLRTAP employed IAMs for analysing combined reductions of those emissions causing acidification, eutrophication and ground-level ozone. The incorporation of several pollutants (sulphur and nitrogen oxides, ammonia, volatile organic compounds) and effects resulted in a very complex model and policy assessment, often referred to as the multi-pollutant/multi-effect approach. The new 1999 Gothenburg Protocol, or the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, was adopted in 1999 in Gothenburg, Sweden. To date, this protocol has been signed by 27 countries. The protocol sets reduction targets for the year 2010 compared to 1990 levels for four air pollutants. Sulphur emissions in Europe should be cut by 63%, nitrogen oxides emissions by 41%, volatile organic compound emissions by 40% and ammonia emissions by 17%. The actual emission ceilings for each individual country depends on the impact that its emissions have on human health and on the vulnerability of the environment. Those countries whose emissions have the most
severe health or environmental impacts and where emissions controls are cheapest, are expected to have to reduce their emissions most.

The abatement measures and legislation that prevailed earlier in the European Union (EU) have been estimated as insufficient to thoroughly combat acidification and other impact problems such as ground-level ozone effects. Based on the conclusions of the Environment Council in 1997, the Commission of the European Union prepared an Acidification Strategy and an Ozone Strategy. The commitments included in both strategies are formulated such that they be implemented in Community legislation. In 1999, the Commission adopted proposals for a National Emission Ceilings Directive (NECD) and for an Air Quality Daughter Directive on Ozone in Ambient Air. These proposals have been transmitted to the Environment Council. The NECD has also been forwarded to the European Parliament for final adoption and enforcement in the European Union. The National Emission Ceilings Directive aims to reduce the ecosystem area of critical loads exceedances for acidification by at least 50% from 1990 levels in 2010. The goal for ground-level ozone is to reduce the excess exposure for vegetation and risks for health impacts using both the gap closure approach and maximum concentration peak cut-offs. To attain these targets, upper limits are set for the total emissions for four pollutants from each member state starting from the year 2010. The emissions will be partly reduced due to national legislation and community directives, for example the Sulphur in Liquid Fuels Directive, the Auto/Oil legislation, the Large Combustion Plant Directive (LCPD) and the Solvents Directive. It is largely left to the member states to decide which additional national measures are needed to comply with the emission ceilings. For most member states additional efforts will be required. Some of the emission ceilings are lower than the values agreed by the member states in the 1999 Gothenburg Protocol.
The overall aim of the EU/LIFE project Coupling of CORINAIR data to cost-effective emission reduction strategies based on critical thresholds (LIFE97/ENV/FIN/336) was to support, further develop and apply national integrated assessment modelling in the assessment of acidification, eutrophication and ground-level ozone. The integrated modelling activities captured emission inventories and projections, control technologies and related costs, atmospheric transport and resulting air concentrations and depositions, environmental impacts and assessment of modelling uncertainties. The innovative use of existing and modified tools supported national checking and assessment of the results from international modelling exercises. The detailed spatial and temporal estimates improved the interpretation of the attainment of environmental targets. The integration of information from several disciplines and stages of the air pollution issue at national level provided useful guidelines and experience for taking similar action in other countries.

The specific aims of the EU/LIFE project were:

• comparison of emission inventories, estimates on energy and activity projections, preparation of national emission scenarios
• assessment of emission control techniques and related costs
• comparison and use of observation data and atmospheric models to estimate current and predicted concentrations and depositions
• calculation of critical loads and their exceedances, that is, ecosystem sensitivity and risk for harmful effects, in different spatial resolutions
• assessment of temporal aspects in environmental impacts
• uncertainty analyses on both individual models and integrated model systems
• assessment of performance of emission reduction strategies
• estimation of the applicability of the project results in other regions or countries
• dissemination of results to stakeholders through project workshops, technical memoranda, articles and reports to research community and decision-makers, presentations in various conferences and workshops including policy-related meetings

An integrated assessment can provide an overview of an environmental problem and its connections to other issues, which otherwise might not arise from separate case studies. The EU/LIFE project intended to demonstrate and enhance the use of integrated modelling and assessment on a national level in the EU/LIFE project partner countries using the available data and modelling tools. The specific main results expected from the whole EU/LIFE project were:

• operative frameworks demonstrating the use of existing modelling and assessment methods, tools and data in a new, innovative way
• use of more detailed spatial and temporal resolution in studies to enhance the integrated assessment
• evaluation of the attainment of environmental targets in detail
• appropriate dissemination of results and knowledge to relevant stakeholders through workshops, presentations and reports
• improved co-operation and co-ordination of integrated assessment modelling activities within and between the EU/LIFE project partner institutes and countries, and to promote international networking
• reporting of policy-related results to relevant international bodies, especially European Union and UN/ECE/CLRTAP

The expected main environmental benefits from the EU/LIFE project were:
• development, documentation, demonstration and dissemination of data, methods and tools on national integrated assessment modelling
• assessment of emission control potential, costs and environmental effects using scenarios from the development of alternative air pollutant emission reduction strategies of the EU and UN/ECE/CLRTAP
• enhancement of the national and international dialogue between environmental researchers, integrated assessment modellers and policy-makers

The results and environmental benefits from the EU/LIFE project were related to the air pollution policy of the European Union in many aspects, particularly in:
• development of the Acidification and Ozone Strategies of EU/Environment Directorate-General (earlier DG XI), leading to the proposal of the National Emission Ceilings Directive (NECD)
• the existing and proposed Large Combustion Plant Directive (LCPD)
• Regulation on the protection of forests against atmospheric pollution
• European Environmental Agency (EEA) activities on emission inventories and projections and integrated environmental assessment
• applications of the CORINAIR air pollutant emission database
• ExternE project of EU/Research Directorate-General (earlier DG XII) JOULE programme on external cost assessment with connections to the Acidification Strategy of the EU
• the member state outlook in UN/ECE/CLRTAP (Convention on Long-range Transboundary Air Pollution) in the development of the new multi-pollutant/multi-effect strategy for a new emission reduction protocol
Fig. 3. The planned information flow and expected results in the EU/LIFE project.
The EU/LIFE project Coupling of CORINAIR data to cost-effective emission reduction strategies based on critical thresholds (LIFE97/ENV/FIN/336) was co-ordinated by the Finnish Environment Institute (FEI) in Helsinki, Finland. The duration of the EU/LIFE project and its national subprojects was from 1 October 1997 to 31 December 1999. A special allowance of three months up to 31 March 2000 was granted to the co-ordinating institute for finalisation of the project. The international four-country consortium consisting of partners in Denmark, Finland, Spain and Sweden was responsible for implementation of the project. The project was divided into four country-specific subprojects. Each one included the main tasks on management, dissemination, emissions and impacts, with the exception of the lacking in-depth emission assessment in Sweden. All tasks dealt with both profound expertise on the substance and its association to integrated modelling and assessment.

The EU/LIFE project beneficiary and coordinator

FEI
NERI
CIEMAT
LU

Management team

External assistance

CCE
EMEP/MSC-W
IIASA

CCE = Coordination Center for Effects, the Netherlands
CIEMAT = Research Center for Energy, Environment and Technology, Spain
EMEP/MSC-W = Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe, Meteorological Synthesizing Centre – West, Norway
FEI = Finnish Environment Institute, Finland
IIASA = International Institute for Applied Systems Analysis
LU = Lund University, Sweden
NERI = National Environmental Research Institute, Denmark

Fig. 4. The official management scheme of the EU/LIFE project. During the project each partner made use of other national and international contacts, which are not shown in this figure.
The management of the EU/LIFE project was the responsibility of FEI, as well as the main dissemination activities. The implementation of each subproject was the responsibility of the participant institute in each partner country. The official project management scheme is presented in Fig. 4. The international management team of the project consisted of the project co-ordinator and the subproject leaders.

Implementation of the tasks, approximately following the scheme shown in Fig. 5, was carried out by the following four organisations:

- Finnish Environment Institute (FEI, Suomen ympäristökeskus), Impacts Research Division and Pollution Prevention Division, Helsinki, Finland; the EU/LIFE project beneficiary and co-ordinating institution; project co-ordinator Dr. M. Johansson on 1 October 1997–31 May 1999, on a leave of absence from FEI from 1 June 1999 at IIASA; official project co-ordinator Dr. M. Forsius from 1 June 1999
- National Environmental Research Institute (NERI, Danmarks Miljøundersøgelser), Department of Atmospheric Environment in Roskilde and Department of Terrestrial Ecology in Silkeborg, Denmark; subproject leader Dr. G. Geernaert
- Research Center for Energy, Environment and Technology (CIEMAT, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas), Madrid, Spain; subproject leader Dr. R. Guardans
- Lund University (LU), Department of Chemical Engineering II, Lund, Sweden; subproject leader Dr. A. Barkman on 1 October 1997–31 December 1998 and Dr. M. Alveteg from 1 January 1999

In addition to the partners, the project used external assistance through the Finnish subproject from the following organisations and fields of expertise:

- Coordination Center for Effects (CCE) of UN/ECE/CLRTAP (Convention on Long-range Transboundary Air Pollution under the auspices of United Nations Economic Commission for Europe) at RIVM (National Institute for Public Health and the Environment), Bilthoven, the Netherlands; European database on critical loads and thresholds; contact Dr. M. Posch
- Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe, Meteorological Synthesizing Centre - West (EMEP/MSC-W), Oslo, Norway; long-range atmospheric transport modelling of air pollutants; contact Dr. J. Bartnicki
- International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria; integrated assessment modelling; contact Dr. M. Amann

The EU/LIFE project management structure was rather straightforward, where the project co-ordinator discussed with subproject leaders to carry out necessary tasks and dissemination. However, co-ordination was in practice extremely complex due to the variety of disciplines the integrated assessment modelling covered and the efforts needed to introduce specific findings in an integrated framework. Direct case-specific co-operation between researchers in the participating institutes was encouraged and successful. The project provided a basis for capacity building and support for additional work on national integrated assessment modelling and further applications of databases and calculation methods. However, it clearly demonstrated that individual projects cannot supply a long-term permanent basis for integrated modelling activities in countries.

An additional difficulty in the implementation of the project was the turnover of experts carrying out the work in the participating institutes. The present mobility of individual researchers may hamper the fulfilment of goals, although the institutes are committed in completing the agreed tasks. Although the change
of some key experts was compensated for by the large knowledge capacity of the participating institutes, the transition periods further complicated the overall co-ordination of the project.

Project duration was 27 months, with an extra extension of three months for the co-ordinating institute for the economic and technical final reporting. When the preparation time needed in the participating institutes and the final reporting was taken into account, there were effectively one and a half years for productive technical work. This period enabled the original objectives of the project to enhance and demonstrate the further use of existing data and tools for national integrated modelling and assessment of international requirements. The time did not allow the development of completely new approaches or methods, but indications and directions for further work were presented.
The project was divided in four country-specific subprojects. Each one included emission and impact tasks in addition to management and dissemination. All tasks dealt with both in-depth expertise on the subject and its association to integrated modelling and assessment. The overall structure and list of actions is given here only in a brief format. The technical actions are described in more detail in the four final reports of the subprojects.

The common basis for all tasks in the project was to use the same data and methods in the applications as much as possible. The emission tasks employed the CORINAIR air pollutant emission database and software tools for inventory assessment and projection estimates. The deposition scenarios and impact studies used emissions reduction strategies proposed during the development of the National Emission Ceilings Directive (NECD) of the EU (European Union) and the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone of the UN/ECE/CLRTAP (Convention on Long-range Transboundary Air Pollution under the auspices of United Nations Economic Commission for Europe). The variability and uncertainty studies made use of these scenarios as well. The use of these common data and methods enabled the comparison of national results in the international framework and the further future exploitation of project results.

Fig. 6. Total annual CORINAIR emissions and official sulphur emission estimates of project partner countries (Denmark, Finland, Spain and Sweden) for the years 1990 and 1994. The data are from national CORINAIR inventories for 1990 and 1994 and EMEP/MSC-W (Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe, Meteorological Synthesizing Centre - West).
The different studies carried out within the tasks of the project and its subprojects are summarised in Table 1. The list displays the involvement of the participating institutes and assisting organisations in alphabetical order. The participation of several institutes in an individual study indicates co-operative efforts within the study. The main results of the project are described in detail in the four final reports of the subprojects.

Table 1. The studies carried out within the tasks of the project and its subprojects. The involvement of the participating institutes and assisting organisations is alphabetically indicated with the institute acronymes, which are listed below the table.

<table>
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<th>Study Area</th>
<th>Institutes</th>
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<td>Emissions</td>
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<td>National control technologies and costs</td>
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<td>Spatial and temporal resolution in emission disaggregation</td>
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<td>Database conversions for inventories and projections</td>
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<td>Deposition and concentration levels</td>
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<td>Base cation deposition evaluation</td>
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<td>Critical loads and exceedances</td>
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<td>Ground-level ozone impacts on health</td>
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<td>High spatial and temporal resolution aspects</td>
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<td>Integrated assessment</td>
<td>CIEMAT, FEI, IIASA, LU, NERI</td>
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CCE = Coordination Center for Effects at RIVM (National Institute for Public Health and the Environment), the Netherlands
CIEMAT = Research Center for Energy, Environment and Technology, Spain
EMEP/MSC-W = Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe, Meteorological Synthesizing Centre - West, Norway
FEI = Finnish Environment Institute, Finland
IIASA = International Institute for Applied Systems Analysis, Austria
LU = Lund University, Sweden
NERI = National Environmental Research Institute, Denmark
Conclusions and environmental benefits

5.1 Main conclusions

The results and conclusions are reported in detail in the four technical final reports of the EU/LIFE project. The main conclusions are grouped here in several themes.

Emission inventories

- The potential use of the CORINAIR database was demonstrated for carrying out national emission projection studies. The database provides a very detailed layout and annual inventories should be thoroughly and properly compiled. An appropriately assembled database could be used to assess the emissions resulting from various technical and legislative measures, for example, the controls on power plants through proposed Large Combustion Plants Directive of EU.

- High resolution emission inventories were derived for two regions in Spain from aggregated CORINAIR emission database (50 km×50 km grid) and detailed (5 km×5 km) geographic information on appropriate surrogate indicators. The methodology proved effective and the spatially and temporally detailed emission estimates combined with detailed meteorology provided a sound basis for accurate local ground-level ozone modeling in Spain.

- The conversion of activity data of the CORINAIR air pollutant emission database into the RAINS model sector/fuel classification was successfully demonstrated. This tool facilitates further data comparison and update from the national CORINAIR air pollutant emission database to the international RAINS model classification.

Emission scenarios

- The combination of two different energy projections (business as usual, action plan) and two extreme emission reduction strategies (1997 emission factors, maximum reduction emission factors) were used to derive four emission scenarios for Denmark. The national energy projections were successfully converted into the required database classification. The transfer of emission factors from the inventory to the projection database proved to be problematic for some of the CORINAIR categories. When the data for the assessment are properly compiled, combinations similar to the four scenarios presented can highlight the importance and possible range of the total emission reduction potential in a country due to different energy use futures and abatement measures.

- Spanish emissions in 2020 were preliminarily estimated for all CORINAIR pollutants (SO₂, NOₓ, NH₃, VOC, CH₄, CO, CO₂ and N₂O) for several SNAP activity classes of the CORINAIR 1990 methodology.
Fig. 7. Scenarios of Danish sulphur emissions in tonnes of SO$_2$ calculated with the CollectER programme. The four emission scenarios are combinations from two energy scenarios (business as usual, action plan) and two emission factor projections (1997 emission factors, maximum reduction emission factors). There is a discrepancy in the values between 1995 and 2000–2010, because projected emission factors were not available for power plants, which contribute largely to total sulphur emissions. Instead, emission factors from the 1997 CORINAIR inventory were applied. The changes in control technology leading to lower emission factors resulted first in largest emission reductions, but later the reductions in energy consumption became more important.

Emission abatement

- Based on the Finnish case study on emission control technologies and related costs, the special conditions in the country could be considered in detail in the national cost curves. The aggregation level of cost and emission estimates in international integrated modelling was regarded practical and the major differences to national results were highlighted. Sensitivity analysis for the national sulphur cost curve identified the interest rate, payback time, investment costs and annual plant operating hours to be most important factors affecting the total costs and the removal efficiency most influential for the control potential.
National estimates on reduction potentials in Finland, both on sulphur and nitrogen oxides, were well convergent on the estimates of the international RAINS model. The combined SO$_2$ and NO$_x$ cost curve indicated that most of the abatement measures for SO$_2$ are more cost-efficient than those for NO$_x$ on the basis of their acidifying impact on ecosystems. For the control of ammonia emissions, discrepancies between current national and RAINS estimates, both on costs and reduction potentials were found notable. The documentation highlighted the most important factors for such comparisons.

**Deposition loads**

- The variability of modelled depositions in Finland were compared using results from domestic and long-range atmospheric models. The deposition levels were found comparable. The deposition levels resulting from European emission reduction scenarios should be consistently reflected to critical load exceedances in Finland by both models, although spatially more detailed deposition estimates will benefit national impact assessment.
- The importance of the base cation deposition in reducing the acidifying impact of sulphur and nitrogen compounds was studied in Finland. The relative reduction in net acidifying deposition, which was calculated by subtracting base cation deposition from total sulphur and nitrogen deposition, was smaller than that of total acidifying deposition in Finland in 1985–95. The potential reductions of base cation deposition in the future should therefore be considered when assessing the net benefits of reducing acidifying emissions.
- High resolution deposition studies in Spain showed that wind speed and surface resistance can be more important than the atmospheric concentration in determining total deposition. National detailed deposition modelling should be encouraged to evaluate environmental impacts in higher spatial and temporal resolutions than currently employed in international assessment.

**Environmental impacts**

- The national assessment of critical load exceedances in Denmark including uncertainty and fine scale spatial variation showed a much higher area of critical load exceedance than calculations in large grid cells. The difference was most pronounced for acidification, where European scale calculations yielded less than 3% exceeded area in Denmark. For forests the estimated exceeded area increased from 0.2% for pine and 3.8% for oak to 30% for beech and 47% for pine. The differences arise, among other things, from ecosystem-specific high dry deposition velocities in forests and forest edges.
- An analysis on the sensitivity of critical load exceedances including uncertainty and fine scale spatial variation was carried out at European level using data on the critical load database and deposition of the RAINS model. This analysis suggested that (i) including uncertainty and spatial variation in exceedance calculations will in general give higher exceeded area for acidification, for example, the estimated area in the WGS31c scenario of UN/ECE/CLRTAP increased from 2% to 6–13% in Europe at different levels of uncertainty, (ii) European scale calculations on large grids (for
Comparison of reviewed national and RAINS SO$_2$ cost curves, Finland 1990

Fig. 8. Comparison of national and RAINS model SO$_2$ cost curves for Finland in 1990 starting from the 'no-control' situation. The text on the right hand side of the curves correspond to the national curve and on the left to the RAINS curve. The explanations for the first segment on the right hand side refer to both the national and the RAINS curve.

example, in the 150 km×150 km grid) cannot be employed in the validation of relationships between critical load exceedances and ecosystem status, (iii) the exceeded areas will be larger if known biases (for example, ecosystem-specific dry deposition velocities) were included in the assessment, and (iv) there are practical possibilities to include uncertainty and variation estimates also in integrated models.

• The number of measurement sites in a grid cell had a substantial effect on the uncertainty in the environmental impact calculations in Sweden, even when the representativeness was ignored. For grid cells with more than 60–80 sites the results indicated, however, that uncertainty might not always be reduced when the number of sites is increased. The critical load mapping on a high spatial resolution will result in a higher uncertainty due to less measurement sites per grid, but it may increase the informational quality. On the 50 km × 50 km resolution using 1994 deposition a few grid squares in Sweden were significantly non-exceeded while no 150 km × 150 km grid cells were significantly non-exceeded.

• The Swedish study showed that results from single-site uncertainty and sensitivity studies can not be applied to the regional scale due to differences in informational quality. Furthermore, conclusions are dependent on the geographical area and the studied entity, for example, whether critical
loads, their exceedances or weathering rates are examined. Currently, the uncertainties in deposition and soil chemical parameters contribute most to the uncertainty in calculated critical load exceedances in Sweden.

- One third of the Danish forest area is presently nitrogen saturated according to monitoring data. Scenario analyses with the dynamic SAFE soil acidification model at three sites in Denmark suggested that acidification is not the major problem at these sites, although the accumulation of nitrogen and eutrophication are constantly advancing slowly. The use of the current reduction plans deposition scenario in the simulation retarded the eutrophication compared to the business as usual scenario.

- The results from dynamic soil acidification modelling of a forested catchment in Finland demonstrated that the soils can be acidifying in spite of the non-exceedance of the critical load calculated with the current standard criteria. Although the threshold of relative aluminium concentration in soil solution would not be reached, the decrease of the soil base saturation may pose an increasing risk for forest vitality. Dynamic model simulations were shown to be useful in providing in-depth information on soil chemical status, rate of improvement and time lags before reaching harmful conditions for forest vitality.

- The temporal variation of ground-level ozone exposure was found important for the occurrence of environmental effects in Spain and especially emphasised for plants with high market value. The water modulation and phenological phase were found to be significant dynamic factors for irrigated horticultural crops in temperate regions, which were more sensitive than standard response functions for wheat indicated. Most damages occurred in early harvests when the economic value is largest.

- Environmental conditions can have a notable effect on plant sensitivity comparable to that of ozone exposure. Water stress induced similar yield losses as the ozone exposure in experiments with tomato in Spain. In the fumigation experiments harmful effects were not detected for plants with a water deficit. The environmental conditions (water stress) and increased ozone levels recorded in eastern Spain were also found to favour infection by plant virus. The plant viruses are a big agricultural problem and the ozone exposure increases the sensitivity of the plants.

- The case study in Spain on the yield loss of wheat suggested that the currently used yield loss relation to ozone exposure may be an overestimate. The inclusion of the water stress parameter in the calculation resulted in a significantly lower yield loss estimate. As for the forest effects, the ranking of sensitivity to ozone observed in experiments on shrubs and trees was different if based on development of visible injury or biomass reductions. Some species showed injury but no biomass reduction. The observed results agreed with the critical threshold value (AOT40 10ppm h) and sensitive species such as Holm oak (Quercus ilex ssp. ballota) and wild olive (Olea europaea ssp. sylvestris) showed significant biomass loss near that exposure level. These species were almost as sensitive as Fagus sylvatica and much more sensitive than Aleppo pine.

**Integrated modelling**

- The analysis on the sensitivity of calculated emission ceilings for sulphur and nitrogen in Demark suggested that the use of a national energy scenario based on the national action plan to reduce CO\textsubscript{2} emissions, which signified lower energy demand and unabated emissions, resulted in lower
Fig. 9. The potential effect of the proposed Large Combustion Plants Directive (LCPD) of EU was examined using point source data from Finnish CORINAIR and VAHTI air pollutant emission databases and the energy market scenario (EMS) of the Ministry of Trade and Industry. The figure shows the NO\textsubscript{x} emissions in Finland in 2010 from existing large combustion plants in three cases: (i) the base case with 1995 emission factors for existing boilers and current national limits set for new boilers, (ii) assuming the proposed LCPD limit to all boilers in 2010, and (iii) applying current national limits set for new boilers to all boilers in 2010.

- Optimised emission ceilings for the country. The influence of changes in Danish marginal costs was limited. The emission ceilings were strongly dependent on deposition targets in few grid cells in neighbouring countries.
- The results both from a compilation of variability and uncertainty estimates on three Finnish integrated models and from an integrated uncertainty analysis suggested that environmental effects, usually represented by critical loads, dominate the total uncertainty of the integrated assessment modelling on acidification in Finland. The total uncertainty was predicted to diminish considerably in the future due to decreasing acidifying deposition levels.
- The incorporation of uncertainty in the assessment of critical load exceedances would lead to higher reduction requirements for acidifying emissions according to the Swedish analyses. The consequent shift from the threshold characteristics of the critical load concept into a risk concept would enable the definition and use an acceptable risk level for harmful effects.

**Dissemination of results**

- The work during the project pointed out that international projects (such as the EU/LIFE project) and co-operation can provide a basis for capacity building and support for additional research and applications, but cannot supply a long-term permanent basis for integrated modelling activities in
countries. The national integrated assessment modelling should be further supported by national and international efforts. The developed tools and achieved results should be made widely available with clear documentation. This is the basic component of the process to implement and further develop international air pollution abatement strategies to help policy-makers to make decisions and to help the public to guide policy-makers.

- The workshop on national integrated assessment modelling of the EU/LIFE project proved that it is important to ensure continued science-policy dialogue through a body similar to the UN/ECE Task Force on Integrated Assessment Modelling in the forthcoming amended organisational structures on air pollution of the EU and the UN/ECE/CLRTAP. The efforts made in the project to improve the dissemination of modelling methods and results to both decision-makers and the public were received favourably and also indicated the need to improve the transfer of knowledge outside the traditional research community.

## 5.2 Environmental benefits

**Harmonisation and documentation of available data**

- Emission-related national data on current energy and activity levels and projections, conversions between different databases (for example, national energy scenarios to CORINAIR database, between CORINAIR database and RAINS model), control technologies and related costs were collected, compared, evaluated and harmonised. These activities facilitate future submission and checking of national and international data on country emissions and reduction potential.

- The data on environmental impacts were reassembled (for example, ground-level ozone impacts on vegetation in Spain and model uncertainty estimates in Finland) for new integrated assessment purposes. The compilations demonstrated the usability of existing data for new viewpoints and enhanced environmental impact studies.

**New assessment methods and tools**

- The work on national emission scenarios in Denmark based on CORINAIR air pollutant emission database demonstrated a promising method to estimate future emissions and reduction potential. The work on the emission scenarios, data aggregation, the derivation of national cost curves and the appropriate documentation in Finland laid a foundation for further evaluations on other pollutants. The careful comparison of national findings with international estimates secure that best possible national information is used in international modelling.

- The work on the connections between dynamic soil acidification processes and long-term environmental targets represented by steady-state critical loads demonstrated the feasibility of using different indicators for state and risk of environmental effects. The use of both dynamic and steady-state calculations enables a transparent way to confirm model predictions with observational data. By assessing the uncertainty in environmental effects it is possible to identify geographical, chemical and other characteristics important for specific areas. This information can be used in the confirmation of the critical load concept, which is becoming an increasingly important aspect in near-future integrated modelling work.
Fig. 10. a) The spatial distribution of sulphur emission changes in 1990–93 in Spain in the 50 km × 50 km grid based on CORINAIR air pollutant emission database. b) The modelled spatial distribution of hourly emissions of nitrogen oxides at one o’clock in the afternoon on a typical day in July 1992 in the greater Madrid area in Spain.

- Several integrated modelling approaches tailored for different purposes were demonstrated. The new data and methods derived and applied for emission controls, atmospheric transport and environmental effects led to a wider variety of tools for integrated modelling than earlier. These resources can be used in forthcoming assessments requiring, for example, higher spatial and temporal resolutions and more detailed activity sectors.
International context in national applications

- In all tasks a common approach was taken to use the results from the development of emission reduction strategies of the EU and the UN/ECE/CLRTAP. These emission scenarios were used throughout the integrated modelling work covering the emissions and their controls, depositions, environmental effects and uncertainty analyses. The approach related the work to international and national policy-making processes, for example, the effects from directives and other legislative measures.
- The effects from international agreements and actions, for example, the expected reductions in acidifying deposition, were linked to the local level. The developed methods for environmental effects assessment can be used as a scientific basis for strategies and guidelines for national and local actions, for example, in the proposed national action plan to abate ammonia emissions from agriculture in Denmark and in local mitigation strategies on forest liming in Sweden.
- The data and methods developed and demonstrated in the project are available for various users. For example, the results can be applied to emission reduction trading schemes and economic optimisation of regional compliance to climate change conventions. The findings thus enable various stakeholders to relate currently ongoing and agreed protocols on specific pollutants to related national actions and any connections to solving other environmental problems.

Dissemination of results

- The dissemination of results was carried out extensively among international and national air pollution experts and decision-makers through workshops, conferences, meetings, reports, presentations and articles. The activities for dissemination of results reached policy-makers, researchers and the wider audience interested in environmental issues.
- The participants of the project were involved in the national policy-making processes of the EU and UN/ECE/CLRTAP emission reduction negotiations. The EU/LIFE project enabled policy-relevant case studies and provided direct interaction between researchers and other stakeholders, for example, environmental administration and energy production companies.

Enhanced networking for national integrated modelling

- The exchange of experience on national integrated model exercises among project partners contributed to a better understanding of the specific features and robustness of the modelling results by both modelling groups and other users of the results, for example the policy-makers in environmental administration.
- The project contributed to the networking of national integrated modelling groups at European level. In addition to the interaction between project partners, other parties were involved through the project workshop in June 1999 and the workshop report. The meeting was also of use in the discussion on the new organisational structure of the UN/ECE/CLRTAP and the forthcoming amended organisational structures on air pollution of the EU prepared in the CAFÉ (Clean Air For Europe programme).
6 Dissemination

6.1 General

The dissemination activities were one of the key activities in the EU/LIFE project. As the co-ordinating institution, FEI had the main responsibility in disseminating the findings of the whole EU/LIFE project. The dissemination for the EU/LIFE project and its subprojects was carried out through the following activities:

- the preparation of technical memoranda annexed to the regular progress and interim reports of the EU/LIFE project for fast transfer of knowledge between partners
- publication of main results in institute report series for detailed technical documentation and in scientific journals for the research community
- holding project workshops for both internal and external dissemination of data, methods and main findings
- presentation of major results at conferences and other meetings, including communication with national and international decision-makers
- dissemination through popular articles
- summarising the results on the Internet homepage of the EU/LIFE project and making as many deliverables as possible available through the Internet in electronic form

The LIFE financial instrument of the Environment Directorate-General of EU was explicitly acknowledged in all of the following deliverables.

6.2 Final reports

The final reporting of the EU-LIFE project consisted of one joint final report and four country-specific subproject final reports. The joint final report was compiled by the co-ordinating institution, the Finnish Environment Institute. It contains a summary of the results and conclusions of the more detailed subproject final reports. The country-specific final reports of the subprojects describe the data, methods and results of the tasks in more detail.


Fig. 11. Modelled total acidifying deposition as sum of sulphur, nitrogen oxides and ammonia in Europe in 2010 assuming the WGS31c scenario of the UN/ECE/CLRTAP, which was the basis for the 1999 Gothenburg Protocol (Protocol to Abate Acidification, Eutrophication and Ground-level Ozone). Emission and atmospheric transport data are from UN/ECE/CLRTAP, IIASA, EMEP/MSC-W and FEI.


6.3 Technical reports and articles

**Official documents**

The EU/LIFE project and its activities related to and supporting integrated assessment modelling activities were documented in the UN/ECE document EB.AIR/WG.5/1998/3, which was the Chairman’s report on the 22nd meeting of UN/ECE Task Force on Integrated Assessment Modelling (TFIAM) held on 30 November–2 December 1998, in London, UK.

**Institute reports**

Institute report series provide an appropriate forum for disseminating results for a wide audience. Technical reports enable the inclusion of in-depth technical details on the data, methods and calculations from the studies.


Bak J, Fenhann J, and Winther M., in press. Analyse af modeller til fremkrivning af emissioner af VOC, SO2, NOX og NH3 (Analysis of models for the projection of emissions of VOC, SO2, NOX, and NH3), National Environmental Research Institute, Technical report. (In Danish with English abstract.)


**Scientific journal articles**

The basis for using project data and methods for integrated assessment and policy-making support is the publication of the results in scientific journals for open evaluation. The results gain a wide audience in the research community and contribute to an application of the findings in other countries and institutes.


Fig. 12. The modelled monthly maximum deposition values in the 5 km × 5 km grid and concentrations in the 150 km × 150 km grid in Spain in 1992. The results illustrate the importance of the complex dynamics of meteorological conditions on concentration and deposition levels.

Fig. 13. The trends in base cation deposition in three different areas in Finland: (i) in the south-eastern part including southern coastal areas, (ii) other southern areas and central Finland, and (iii) in northern Finland. Values averaged over five-year periods (1971–75, 1976–80, 1981–85, 1985–90 and 1991–95) were compared with each other. Data are from the Finnish national deposition observation network of FEI.

Alveteg M. and Barkman A., manuscript. Exceedance of critical loads for Swedish forest soils in a risk perspective. Will be submitted to *Water, Air and Soil Pollution*.

Alveteg M., Barkman A. and Sverdrup H., manuscript. Probable effects of the 1999 Gothenburg protocol on the exceedance for Swedish forest soils as predicted by the PROFILE model. Will be submitted to *Water, Air and Soil Pollution*.

Alveteg M. and Barkman A., manuscript. On the representativity of sites in the estimation of 95%-ile exceedances for Swedish forest soils. Will be submitted to *Water, Air and Soil Pollution*.


Johansson M., manuscript. Integrated assessment modelling on air pollution in four European countries. Will be submitted to *Water, Air, and Soil Pollution*.


Karvosenoja N. and Johansson M., manuscript. National cost curve analysis for SO$_2$ and NO$_x$ emission control. Will be submitted to *Environmental Science and Policy*.


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**Fig. 14.** The exceedances of critical loads of sulphur in project partner countries (Denmark, Finland, Spain and Sweden) in 1990 and 2010 assuming the reference scenario (REF), which includes effects of current and forthcoming national and international legislation and current reduction plans. The emission data are from UN/ECE/CLRTAP and IIASA, the modelled deposition data from EMEP/MSC-W and FEI and the critical load data from respective National Focal Centers and UN/ECE/Coordination Center for Effects (CCE).
Technical memorandum

Many of the results were reported as technical memoranda during the project. They were annexed to the progress and interim reports of the project, which delivered to project partners every half a year. In this manner, a quick and wide distribution of results was made available for partners and other interested parties. The contents of these memoranda were later reported through journal articles and in institute report series. In the following list TA denotes Technical Annex, PR Progress Report and IR Interim Report of the EU/LIFE project.


Ahonen J. 1999. Using the parametrization of a dynamic model to calculate the steady state critical loads for a forested catchment in Finland: comparison to the values of official national mapping. TA 6, PR 3 of LIFE97/ENV/FIN/336. 26 October 1999, Finnish Environment Institute, Helsinki, Finland, 6 pp.+1 figure.


Ahonen J. and Johansson M. 1998. About the differences and similarities in deposition estimations and their impact on critical loads and their exceedances in Finland. TA 8, PR 2 of LIFE97/ENV/FIN/336. 30 September 1998, Finnish Environment Institute, Helsinki, Finland, 3 pp.+figure s.


Fig. 15. The percentage of Danish ecosystems with exceedances of the critical loads for acidity (CL(A)) and eutrophication (CL(N)), or nutrient nitrogen, was calculated on the basis of average deposition values on an EMEP 150 km x 150 km grid (average) and with a new approach taking into account the local scale variation and uncertainties (variable).


Karvosenoja N. and Tohka A. 1999. Effect of national and EU emission limits on sulphur and nitrogen oxide emissions in large combustion plants (LCP) in Finland in 2010. TA 1, PR 3 of LIFE97/ENV/FIN/336. 26 October 1999, Finnish Environment Institute, Helsinki, Finland, 5 pp.+1 appendix.


6.4 Popular presentations

The dissemination of results from national and international efforts on air pollution prevention is an ever-interesting subject for the public. Even the complex multi-pollutant/multi-effect approach, which deals with several air pollutants and environmental effects at the same time, can be explained in general terms. The dissemination of modelling methods and results to both decision-makers and public was encouraged during the project.


Johansson M., manuscript. Kansalliset kokonaismallit ilmansaasteiden arvionnissa (National integrated models in the assessment of air pollution). Will be submitted to Ympäristö (Environment). (In Finnish.)


6.5 Project workshops

The internal project workshop on emission tasks was held on 27–28 April 1998 at the National Environmental Research Institute (NERI) in Roskilde, Denmark. The aim of the workshop was to discuss the exchange of data and methods, the detailed work plan, the cost curve data and methodology, the possibilities to apply CORINAIR air pollutant emission data and the conversion between CORINAIR database and the RAINS model of IIASA.

The internal project workshop covering all themes of the EU/LIFE project was held on 11–13 January 1999 at the Research Center for Energy, Environment and Technology (CIEMAT) in Madrid, Spain. The aim was to present results from various tasks and to discuss the final phase of the project, deliverables and timetables.
The international workshop on National Integrated Assessment Modelling (NIAM) was held on 7–8 June 1999 at the Italian National Board for New Technologies, Energy and Environment (ENEA, Ente per le Nuove Tecnologie, l’Energia e l’Ambiente) in Rome, Italy. It was held back-to-back with the 24th meeting of UN/ECE Task Force on Integrated Assessment Modelling (TFIAM). The aim of the workshop was to provide an informal forum to discuss experiences related to both national and international modelling and assessment work on emission reduction strategies in Europe. The presentations covered the four main themes: (i) results from the EU/LIFE project, (ii) national integrated assessment modelling activities, (iii) national policy experiences, and (iv) international policy assessment. Altogether 43 participants from 14 countries and 29 institutes, both policy-makers and researchers, participated the workshop.

Fig. 16. a) Schematic view of the forest/soil system and the nutrient cycle in the SAFE and PROFILE soil acidification models. Results on b) the soil layer specific base saturation and c) the Bc-Al-ratio in Gårdsjön catchment in Sweden based on the SAFE soil acidification model simulations with the WGS3 1 c emission scenario of UN/ECE/CLRTAP, which was used as the basis for the 1999 Gothenburg Protocol. The chemical threshold criterion, above which harmful effects in the tree rooting zone should not occur, is the molar ratio 1.0 of base cation concentration to aluminum concentration in soil solution (the Bc-Al-ratio).
6.6 Presentations in meetings

The presentations given at scientific conferences, workshops and other meetings covered both the whole EU/LIFE project theme and the specific issues of the integrated modelling approach. The audience varied from international experts on air pollution research to experts in related disciplines and national decision-makers. In addition to the official meetings reported here, project researchers participated and presented subproject results in several national meetings related to the discussion on international emission reduction strategies of the EU and the UN/ECE/CLRTAP.

Conferences


Ahonen J. 1998. SMART2 model application to a forested catchment in Finland: Effects of emission reduction scenarios. 23rd General Assembly of the European Geophysical Society, 20–26 April 1998, Nice, France. (Poster and oral presentation.)


Barkman A. 1998. Uncertainty analysis of critical loads as environmental protection targets. 9th UN/ECE Coordination Center for Effects (CCE) workshop on mapping critical loads and levels, 11–14 May 1998, Kristiansand, Norway. (Oral presentation.)


**Fig. 17.** The impacts of ground-level ozone in Spain are displayed considering the temporal and spatial variability. 

a) The effect of the harvesting scheme is based on three years of experiments in open top chambers, where tomato plants were exposed to (i) filtered air, which did not contain ozone (AF), (ii) non-filtered ambient air (NF) and (iii) non-filtered ambient air with 40 ppb ozone added (FU). Early harvest are significantly larger and also more damaged by ozone, because young plants are more sensitive than old plants.

b) The spatial dimension of ozone impact is illustrated by comparing the area occupied by different crops and their economic value. Irrigated crops clearly represent a much smaller area but a much larger economic value than non-irrigated crops. There is also evidence that damage calculated with current models may be overestimated for non-irrigated crops and underestimated for irrigated crops.

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Johansson M. 1999. Integrated approach to deposition scenarios and potential ecosystem recovery in the EU/LIFE project. Workshop on Reversibility of Acidification, European Science Foundation (ESF), 10–13 May 1999, Sitges, Spain. (Oral presentation.)


Other meetings


Syri S. 1999. Estimating local variations of ozone in urban areas. 10th UN/ECE Coordination Center for Effects (CCE) workshop on mapping critical loads and levels, 15–18 June 1999, Prague, Czech Republic. (Oral presentation.)

Fig. 18. The exceedance levels of critical loads of acidification for forest soils in Sweden in 2010 assuming the depositions from the WGS31c scenario of UN/ECE/CLRTAP, which was used as the basis for the 1999 Gothenburg Protocol, in a) the 150 km × 150 km and b) 50 km × 50 km grid. The values in the legend indicate the number of EMEP 150 km × 150 km grid cells belonging to the specified category and the number in parenthesis refers to the number of cells in the EMEP 50 km × 50 km grid.
6.7 Dissemination in the Internet

The EU/LIFE project and subprojects are described on the Internet homepage in the computer server of the co-ordinating institute. The information additionally includes the project and subproject main results, the list of deliverables from the project, some of which are available electronically in pdf-format and links to other projects and institutions on national integrated assessment modelling. The Internet address is http://www.vyh.fi/eng/research/euproj/lifeiea/life2.htm.

![Uncertainties](image)

**Fig. 19.** The total uncertainty of an integrated model system on acidification, expressed as coefficient of variation in %. The total uncertainty was assumed to be dependent on the uncertainties of the four different system modules considered. ‘E+T+I+C’ denotes the inclusion of uncertainties from emissions (E), atmospheric transport (T), within-grid deposition variability due to deposition gradients and in-grid emission sources (I) and critical loads as indicators of harmful impacts (C). Case ‘C’ denotes the effect of critical loads uncertainty only. The analysis employed data on the uncertainty of individual modules available for Finland. The results suggested that the total uncertainty of the model system was mainly arising from the impact module.
The total budgeted and eligible costs and estimated final costs of the project are presented in Table 2. The total budget of the EU/LIFE project was 924 235 euro, with maximum LIFE funded assistance 452 823 euro (48.99%). The more detailed description on cost breakdown can be found in the separate Financial Report of the project.

Table 2. Summary of total budgeted and eligible costs and estimated final costs of the project in 1997–2000 in €.

<table>
<thead>
<tr>
<th>Item</th>
<th>Total budgeted costs, €</th>
<th>Eligible costs, €</th>
<th>Final project costs, €</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel</td>
<td>730 000</td>
<td>730 000</td>
<td>774 000</td>
</tr>
<tr>
<td>Travel</td>
<td>42 000</td>
<td>42 000</td>
<td>43 000</td>
</tr>
<tr>
<td>Outside assistance</td>
<td>70 000</td>
<td>70 000</td>
<td>54 000</td>
</tr>
<tr>
<td>Durables</td>
<td>34 000</td>
<td>15 000</td>
<td>23 000</td>
</tr>
<tr>
<td>Consumables</td>
<td>35 000</td>
<td>35 000</td>
<td>17 000</td>
</tr>
<tr>
<td>Other costs</td>
<td>13 000</td>
<td>13 000</td>
<td>9 000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>924 000</td>
<td>905 000</td>
<td>920 000</td>
</tr>
</tbody>
</table>
List of acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOT</td>
<td>Accumulated Over the Threshold</td>
</tr>
<tr>
<td>CASPER</td>
<td>Calculation Scheme for Predicting Emissions into Air, software for emission projections using CORINAIR data</td>
</tr>
<tr>
<td>CCE</td>
<td>Coordination Center for Effects (of UN/ECE), the National Institute for Public Health and the Environment (RIVM), Bilthoven, the Netherlands</td>
</tr>
<tr>
<td>CIEMAT</td>
<td>Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (Research Center for Energy, Environment and Technology), Madrid, Spain</td>
</tr>
<tr>
<td>CLRTAP</td>
<td>Convention on Long-range Transboundary Air Pollution under the auspices of UN/ECE</td>
</tr>
<tr>
<td>CORINAIR</td>
<td>A software tool to establish a consistent inventory of air pollutant emissions in EU and Europe by the European Topic Center on Air Emissions of the European Environment Agency</td>
</tr>
<tr>
<td>EMEP/MSC-W</td>
<td>Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe, Meteorological Synthesizing Center - West</td>
</tr>
<tr>
<td>EMS</td>
<td>Energy Market Scenario of the Ministry of Trade and Industry in Finland</td>
</tr>
<tr>
<td>ENEA</td>
<td>Ente per le Nuove Tecnologie, l’Energia e l’Ambiente (Italian National Agency for New Technology, Energy and the Environment), Rome, Italy</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FEI</td>
<td>Finnish Environment Institute (Suomen ympäristökeskus, SYKE), Helsinki, Finland</td>
</tr>
<tr>
<td>IAM</td>
<td>Integrated Assessment Model</td>
</tr>
<tr>
<td>IIASA</td>
<td>International Institute for Applied Systems Analysis, Laxenburg, Austria</td>
</tr>
<tr>
<td>LCP(D)</td>
<td>Large Combustion Plant (Directive of the EU)</td>
</tr>
<tr>
<td>LIFE</td>
<td>L’Instrument Financier pour l’Environnement de Environment Directorate-General of the EU</td>
</tr>
<tr>
<td>LU</td>
<td>Lund University, Lund, Sweden</td>
</tr>
<tr>
<td>NECD</td>
<td>National Emission Ceilings Directive of the EU</td>
</tr>
<tr>
<td>NERI</td>
<td>National Environment Research Institute (Danmarks Miljøundersøgelser), Roskilde and Silkeborg, Denmark</td>
</tr>
<tr>
<td>NIAM</td>
<td>The EU/LIFE project workshop on National Integrated Assessment Modelling on 7–8 June 1999 at ENEA in Rome, Italy</td>
</tr>
<tr>
<td>PROFILE</td>
<td>Model for calculating weathering rates and critical loads (Lund University, Sweden)</td>
</tr>
<tr>
<td>RAINS</td>
<td>Regional Acidification INformation and Simulation model of IIASA</td>
</tr>
<tr>
<td>REF</td>
<td>REFerence emission scenario of the RAINS model of IIASA addressing the lower country emission value from CRP (Current Reduction Plans (on air pollutant emissions, officially announced by the countries through UN/ECE/CLRTAP)) and CLE (Current Legislation: emission scenario of the RAINS model on the effects of national and European Union legislation on reducing emissions)</td>
</tr>
<tr>
<td>SAFE</td>
<td>The dynamic counterpart of the PROFILE model</td>
</tr>
<tr>
<td>SMART</td>
<td>Simulation Model for Acidification’s Regional Trends</td>
</tr>
<tr>
<td>SNAP</td>
<td>Selected Nomenclature for Air Pollution, the emission source category split for the CORINAIR air pollutant emission database</td>
</tr>
</tbody>
</table>
TFIAM  Task Force on Integrated Assessment Modelling, under UN/ECE/CLRTAP/Executive Body/Working Group on Strategies

UN/ECE  United Nations Economic Commission for Europe

VAHTI  Database on air emission permits of the Finnish environmental administration

WGS31c  The scenario for total annual country emissions in 2010, which served as the basis for the new UN/ECE/CLRTAP 1999 Gothenburg Protocol (Protocol to Abate Acidification, Eutrophication and Ground-level Ozone)

VOC  Volatile Organic Compound
Annex A. Summary of the final report of the Danish subproject

The aim of the emission task of the Danish subproject has been to develop and implement a transparent technique for using the CORINAIR emission inventory database to calculate future emissions of SO$_2$, NO$_x$, NMVOC and NH$_3$. This has been achieved by studying current CORINAIR data and historical emission trends, by developing a method for conversion of national energy scenarios to CORINAIR classifications and by comparing the emissions projected with the CollectER software to results from other emission projection tools.

The Danish Energy Agency has created several scenarios for the projection of the national gross energy consumption. Two of these scenarios were investigated in combination with two emission factor scenarios. Projections of emissions from non-energy related sources were collected from relevant experts.

Four different scenarios were investigated using CollectER, the resulting emissions compared to the recently agreed emission ceilings for 2010 as well as to 2010 emissions calculated with RAINS.

The method of using the new CORINAIR emission inventory tool CollectER for compiling emission projections has several advantages, including simplicity and easy access for the national reference centres who can acquire the software directly from the European Environment Agency (EEA).

In the projections made with CollectER, the basic data consist of energy scenarios and CORINAIR emission factors from 1997 as well as emission factors projected by national experts. Of the emission factors only the 1997 emission factors are described using the CORINAIR classification (SNAP). A conversion of the energy scenarios and the projected emission factors to SNAP was therefore carried out.

For the CollectER scenario with the largest reductions in energy consumption and the highest impact of emission reduction technologies, the emission of NH$_3$ lies 4% above the agreed ceiling. However for the same scenario emissions of SO$_2$ and NMVOC are 75% and 46% higher respectively than the agreed ceilings. Emissions of NO$_x$ coincide with the agreed ceiling. The CollectER scenario with the maximum reductions is rather hypothetical especially with respect to the projected energy consumption.

The emissions calculated with the RAINS maximum reduction scenario are very much lower than the corresponding emissions from CollectER. In the case of SO$_2$, the 2010 emission calculated with RAINS is only 19% of the 2010 emission calculated with CollectER.

There is a shortage of national data for emission projections. The result is that national emission projections have to be partly based on historical data, which in turn can give an overestimation of the projected emissions. This is the case for the SO$_2$ projections compiled with CollectER. The problem is the very high emission factors for emissions from power plants. These emission factors have not been projected in the projections carried out by national experts.

The major conclusion is, that it is possible and simple to use CollectER to estimate future emissions using national scenarios. The important thing to be aware of is the quality and consistency of the data sets used.

The impact task of the Danish subproject has been focussed on the further development of critical loads and exceedances as a tool for assessing the risk of environmental damage.

An important element is the handling of uncertainty and variation in these calculations and the choice of spatial and temporal scale used for exceedance calculations. Danish national impact assessment has traditional been based on critical loads calculated for individual ecosystem types on a 1 km×1 km grid. National deposition modelling has been performed on a 20 km×20 km and 30 km×30 km resolution for SO$_2$ and NO$_x$ and on 5 km×5 km resolution for NH$_3$. The resolution of national calculations is relatively high compared to European...
calculations on the EMEP 150 km×150 km grid and reflects thereby better the spatial distribution of emission sources. The resolution is, however, still low compared to the local variation in deposition caused by e.g. differences in surface roughness for different vegetation types, local sources of ammonia etc. In Denmark and other areas of Europe with an intensive agricultural production and small ecosystems the local variation in ammonia deposition is very big and largely determining the area affected by eutrophication and, to a smaller extend acidification. In such areas, deposition values calculated as an average for a grid, can substantially underestimate the deposition to ecosystems with high surface roughness, especially forest edges, and coniferous forest.

A new approach for calculating areas with critical load exceedance on national and regional scale has been developed in the project. In this calculation both critical loads and deposition values are perceived as average numbers calculated for individual areas. When calculating exceedances both the estimated uncertainty on the calculated average and the estimated variation within the area is included as distribution functions, and the resulting calculated exceedance is therefore also a distribution function for each area. This approach allows for the inclusion of e.g. forest edge effects in national and regional assessment.

A national Danish assessment of critical load exceedances including uncertainty and fine scale spatial variation shows much higher exceeded area than calculations using average values for large grids. The difference is most pronounced for acidification where calculations on the EMEP 150 km×150 km grid in Denmark give less than 3% exceeded area for forests. The area with exceedances in the national calculation for the same scenario is between 30% for beech and 47% for pine.

The same methodology has been used on European scale based on the critical load database and deposition data used in the RAINS model. It was demonstrated that including uncertainty and spatial variation in exceedance calculations gives higher exceeded area for the critical load of acidity. The estimated area with exceedance calculated for the basic scenario for the 1999 Gothenburg Protocol increases from ca. 2% to 6–13% dependant on the levels of uncertainty. It was further concluded, that the presently used resolution for setting environmental targets on European scale is probably too fine, but it will probably be possible to include uncertainty and variation also in European scale integrated assessment modelling.

One third of the Danish forest area is presently expected to be nitrogen saturated based on observed nitrate concentrations in soil water. Scenario analyses has been performed with the SAFE soil acidification model at tree intensively monitored sites where model calibration has been performed. These sites are not presently nitrogen saturated and the criteria for soil acidification are only violated periodically. Current reduction plans will improve the situation for acidification and delay nitrogen accumulation, so it will take decades before problems are expected.

A sensitivity analysis for the influence of Danish data on calculated Danish emission ceilings has been made based on the B1 scenario developed by IIASA for the European Commission during the preparation of the Acidification Strategy of EU. The analysis shows that the use of a energy scenario based on the national action plan to reduce CO₂ emissions results in lower Danish emission ceilings. The influence of changes in Danish marginal costs is limited.

A sensitivity analysis for the influence of uncertainty on deposition targets on Danish emission ceilings shows that Danish emission ceilings in this particular scenario are closely connected to deposition targets for a small number of grids. A uncertainty range of 20–30% for the deposition target in a single Swedish grid will give a cost range between 61 and 332 million EURO per year for Danish abatement costs.
Annex B. Summary of the final report of the Finnish subproject

The aims of the Finnish subproject were to co-ordinate the whole project, to further enhance the use of modelling tools in integrated assessment of acidification and eutrophication and to improve input data both internationally and in Finland, to evaluate modelling uncertainties and to continuously disseminate results to decision-makers to support the evaluation of ongoing European negotiations on emission reduction requirements. The Finnish subproject covered a wide range of integrated assessment data assessment and modelling activities:

- emission inventory data (national VAHTI and international CORINAIR air pollutant emission database)
- projections of activities and emissions (national energy projections, the CASPER emission projection tool built on CORINAIR database)
- data conversions between data systems (from national energy projections to the RAINS model of IIASA, from CORINAIR to the RAINS model using Finnish and Danish CORINAIR data from 1995) and special applications (potential effects on emissions of the Large Combustions Plants Directive of EU)
- derivation of cost curves for \( \text{SO}_2 \) and \( \text{NO}_x \) with national data and comparison with international estimates
- assessment of the variability of modelled acidifying deposition
- calculation of base cation deposition level using data from different sources, its temporal variation and effect on long-term protection targets (critical loads)
- environmental impact assessment based on critical loads and dynamic soil acidification models using different proposed emission reduction scenarios of EU and UN/ECE/CLRTAP
- the enhancement of methods to estimate local ground-level ozone impacts
- demonstration of different integrated model systems in evaluating the effects from emission reduction scenarios of EU and UN/ECE/CLRTAP
- assessment of the variability and uncertainty in integrated models

The work in the Finnish subproject of the EU/LIFE project resulted in the following major conclusions:

- In the national cost curves the special conditions in the country could be considered in detail in the national cost curves and the major differences in relation to the international model results were highlighted. The aggregation level of cost and emission estimates in international integrated modelling was regarded practical. National estimates on reduction potentials, both on sulphur and nitrogen oxides, were well convergent on the estimates of the international RAINS model.
- The national cost curve study emphasised the importance of taking into account the potential restrictions in the applicability of abatement technologies. The applicability of end-of-pipe technologies plays an especially significant role in the sectors with diverse characteristics, for example, plant sizes.
- The conversion of activity data of the CORINAIR air pollutant emission database into the RAINS model sector/fuel classification was successfully demonstrated. This means facilitates further data comparison and update from national CORINAIR database to the international RAINS model.
- The CORINAIR database could be used for carrying out various national emission projection studies in a consistent way with other countries. The database provides a very detailed layout and annual inventories should be thoroughly and properly compiled. An appropriately assembled data-
base could be used to assess the emissions resulting from various technical and legislative measures, for example the controls on power plants through proposed LCP-directive of EU.

- The long-term environmental targets, the critical loads of acidity and eutrophication, would still be partly exceeded in Finland in 2010 with the WGS31c scenario of the UN/ECE/CLRTAP according to the deposition scenario analyses. The need for continuous assessment of environmental effects still exists.

- The deposition values calculated with national and a European wide long-range transport model were found comparable, the deviation was deemed acceptable and no systematic differences between the mean values were found.

- The diminishing base cation deposition cuts down the benefits of reducing acidifying deposition consisting of sulphur and nitrogen compounds. The relative reduction in net acidifying deposition, which is calculated by subtracting base cation deposition from total sulphur and nitrogen deposition, were smaller than that of total acidifying deposition in Finland.

- The results from dynamic soil acidification modelling at a forested catchment demonstrated, that in spite of the non-exceedance of the site-specific critical load the soils can still be acidifying. The decreasing of soil base saturation may pose an increasing risk for forest vitality, although the criterion for harmful aluminium concentration in soil solution would not be reached. Dynamic model simulations were useful in providing information on actual soil chemical state and time lags before reaching harmful conditions or recovery periods.

- In the assessment of local effects of ground-level ozone, the NO$_x$ concentrations in urban areas were found to be a significant factor, which alters the ground-level ozone concentrations in comparison to those in the surrounding areas. The potentially hazardous levels of urban ozone concentrations can be estimated in more detail, if spatially and temporally detailed information about urban NO$_x$ levels and nearby rural ozone levels is available.

- The results both from a compilation of variability and uncertainty estimates on three Finnish integrated models and from an integrated uncertainty analysis suggested that environmental effects dominate the total uncertainty of the integrated assessment modelling on acidification in Finland. The uncertainties in the module for environmental effects were predicted to diminish considerably in the future, together with decreasing acidifying deposition levels.

- International projects (such as the EU/LIFE project) and co-operation provide a basis for capacity building and support for additional research and applications, but cannot supply a long-term permanent basis for integrated modelling activities in countries.

- The dissemination of results was carried out extensively among national and international air pollution experts and decision-makers. At national level, the activities reached various stakeholders involved in air pollutant emission reductions, especially the Finnish National Workgroup on Acidification at the Ministry of the Environment, which was functioning as a focal point for assessing the progress of international negotiations within EU and UN/ECE/CLRTAP on air pollutant emission reductions and had representatives from several administrative, private and research institutions. The dissemination of results also reached a wider audience interested in environmental issues through popular articles and Internet homepages of the project.
Annex C. Summary of the final report of the Spanish subproject

The subproject has focused on three tasks: to develop tools to improve knowledge on the spatial and temporal details of emissions of air pollutants in Spain, to exploit existing experimental information on plant response to air pollutants in temperate ecosystems and to integrate these findings in a modelling framework that can assess with more accuracy the impact of air pollutants to temperate ecosystems. The results obtained during the execution of this project have significantly improved the models of the impact of alternative emission control strategies on ecosystems and crops in the Iberian Peninsula.

Emission task

The emission task has carried out a spatial (50 km x 50 km) and sectorial (11 activity sectors) analysis of current CORINAIR emissions of SO₂, NOₓ, NMVOC, CH₄, CO, CO₂, N₂O, NH₃ for Spain and past trends. It has also computed projections up to 2020 of Spanish emissions of these pollutants from the energy sector based on the socio-economical scenarios developed by official sources. A methodology has been developed to disaggregate in space (5 km x 5 km) and time the CORINAIR provincial annual emissions in order to obtain high time and spatial resolution emission inventories this has been applied to two regions of Spain, a Mediterranean coastal area and the center of the Iberian Peninsula. In addition, simulations using these inventories, a photochemical model and ground level ozone measurements have been used to test this methodology with satisfactory results that confirm the disaggregation method is reasonable.

Impact task

The work under this task has focused primarily on the assessment of ozone impacts on both Mediterranean crops and natural vegetation. This pollutant is considered as a major concern throughout Europe and different actions have been carried out both at the United Nations and the European Union level to establish concentration thresholds that should not be surpassed to prevent damages on plant receptors. The work has improved the understanding and modelling of ozone impacts on Mediterranean crops and natural vegetation, contributing better estimates of plant response to ozone concentrations for use in national assessment models of alternative abatement strategies.

The activities performed by this group throughout the project development were organized as follows:
- To gather information on ozone exposure-plant response relationships which are suitable for Mediterranean conditions.
- To build empirical models of the environmental modulation of ozone phytotoxicity.
- To provide data on the ozone impacts on selected crop species and their stomatal conductance.
- To rank the sensitivity of different crop and natural plant species so actual impacts could be derived from ozone exposure maps.

The data base from several experiments performed in the past by CIEMAT’s section on Ecotoxicology of Air Pollution regarding ozone effects on watermelons (1988-1990) and tomatoes (1993-1996) were reassessed. Ozone effects were most apparent in the early harvests (29-58% losses), when the production and eco-
nomical value of fruits is highest. Watermelon plants appeared to be very sensitive to ozone, since ambient ozone induced yield losses ranging 19-39%, this losses were well correlated with ozone exposure throughout the growing season.

Tomato plants were also very sensitive to ozone, although this was highly dependent on the cultivar that was used. Ambient ozone levels induced significative yield losses among 20 to 42% in one cultivar depending on harvest and year but no significative yield losses where detected in an other. The results indicate that there is an enhanced sensitivity of tomato plants to virus following their early exposure to O₃ however it became apparent that this effect was stronger in summer than in spring suggesting that other environmental factors might be also involved in modulating plant response to virus.

A eleven-year (1985-1996) data base involving wheat phenology and yield records at the cereal experimental station “El Encín” (Madrid, Spain) was assessed. Estimates using the current regression of damage by ozone for non irrigated crops might overestimate the damage by 15% to 80% compared with estimates that consider water stress.

The sensitivity of different Mediterranean woody plants to ozone has been assessed based on experimental results. Holm oak (Quercus ilex ssp. ballota) and wild olive (Olea europaea ssp. sylvestris) are the most sensitive tree species to ozone since AOT40 values slightly higher than 10 ppm.h for 10 months of exposure determined important reductions in their stem and height growth respectively. These species appear to be almost as sensitive as Fagus sylvatica, and much more sensitive than Aleppo pine.The ranking of the sensitivity of these species is very different if it is based on the development of visible injury or on biomass reductions.

A model of stomatal conductance based on work by other authors has been developed. Functions for Mediterranean receptors have been reviewed based on the experimental data sets gathered by our group. The introduction of the seasonal variability of sensitivity for Mediterranean tree species will improve the calculation of ozone uptake by those species.

Integration
This project, and the simultaneous participation in the 1979 Convention on Long-range and Transboundary Transport of Air Pollution under the United Nations, (Working Group on Effects, Working Group on Strategies, Implementation Committee) of members of our team has been very effective in enhancing international cooperation on the development of tools and background data needed for Integrated Assessment Models at a regional and national scale. The results obtained provide a very good basis for the further application of detailed high resolution studies to assess the potential benefits of national and international emission abatement strategies.
Annex D. Summary of the final report of the Swedish subproject

The aim of this subproject was to assess the sensitivity and uncertainty in assessments of critical loads of acidity to forest ecosystems and the corresponding exceedances of critical loads. The results can be used to estimate the risk of adverse effects on forest ecosystems and to establish cost-effective measures to reduce uncertainty in critical loads assessments.

Method
The uncertainty in the Swedish national assessment of critical loads and exceedance for forest soils were investigated through a regional Monte Carlo analysis of the PROFILE model using the Swedish critical loads database and national estimates of atmospheric deposition 1994, 1997 and estimated deposition 2010 based on the protocol to abate acidification, eutrophication and ground-level ozone signed in Gothenburg, Sweden in 1999. By taking the uncertainty in all sites of a grid cell into account simultaneously, modified 5 percentile critical loads and 95 percentile exceedances were calculated. The results were aggregated on the 150 km×150 km (EMEP150) and the 50 km×50 km (EMEP50) grid resolutions used by the Co-operative Programme for the Monitoring and Evaluation of the Long Range Transmissions of Air Pollutants in Europe (EMEP).

A sensitivity analysis using 1994 deposition was performed in order to determine possible ways to decrease the uncertainty in the Swedish critical loads assessment. The input parameters were divided into five categories: Atmospheric deposition (Dep), Stand characteristics (Std), Mineralogy (Min), Physical soil properties (Phy) and Chemical solution parameters (Che). The uncertainty in input parameters were removed for one category at a time and the resulting output uncertainty was compared to the output uncertainty when uncertainty in all input parameters were considered. The results were analysed on site level as well as on the EMEP150 grid resolution studying the output uncertainty of calculated critical loads, exceedances and weathering rates.

Temporal aspects were investigated by applying the dynamic soil chemistry model SAFE to the Gårdsjön catchment using emission scenarios based on the 1999 Gothenburg protocol.

Results
In an uncertainty analysis a cumulative distribution function (CDF) of critical load and exceedance is calculated for each site. Because the CDFs of different sites tend to overlap, a protection limit should not be linked to a site-specific calculation. To determine a protection limit, e.g. the 95%-ile exceedance, the uncertainty in all sites of the grid square should be taken into account simultaneously. The resulting percentiles, here called modified percentiles, will be different from the percentiles given by an ordinary critical loads assessment. The median of the modified percentiles generally imply lower deposition targets and have more narrow confidence intervals than site-specific calculations.

In an ordinary critical loads assessment the results are usually divided into arbitrary classes when producing maps. An uncertainty analysis, however, makes it possible to divide the results into statistically separable classes of critical loads and exceedances and to map the risk of exceedance of critical loads. Increasing the resolution also increases the uncertainty by reducing the number of sites per grid cell but may reveal non-exceeded areas that could not be identified in lower resolution.
In addition to using best estimates under uncertainty or separable classes the probability of exceedance can be used for mapping purposes. The results indicate that the 1999 Gothenburg protocol will lead to improvements, but areas with a high probability of exceedance are likely to remain.

The uncertainty in calculated exceedance is of course dependent on the number of measurement sites in each grid cell. The results, however, indicate that increasing the number of measurement points above 80 sites does not necessarily reduce the uncertainty. Other sources of uncertainty thus appear to dominate in grid cells with more than 80 sites.

The relative importance of uncertainty in the input categories depended on geographical location as well as on the studied output parameter. For exceedance calculations, chemical parameters were the most important in the north of Sweden while atmospheric deposition was the most important category in southern Sweden.

Conclusions

The developed method to incorporate uncertainty in critical loads and exceedance calculations can be used to identify areas with different level of risk for harmful effects. The developed method is flexible and applicable to different ecosystem receptors.

By assessing the uncertainty in exceedance estimates it is possible to identify areas that are significantly different. This can be used in the validation of the critical loads concept and thus increase its reliability as well as the prospects for evaluating the effects of realized emission reductions.

The uncertainty in calculated critical loads and exceedances can be reduced if they are determined through an uncertainty analysis. The critical loads and exceedances determined by this method will generally result in lower deposition targets. A worrying result from the uncertainty analysis is that only a very small part of Sweden is likely to receive a deposition in year 2010 that is significantly below the critical load for forest ecosystems. This result stresses the need for further emission reductions and continued research on acidification. The sensitivity analysis clearly shows that measures to reduce the uncertainty that are cost effective in one region may not be cost effective in neighbouring regions. Which measures are cost-effective is also dependent on whether it is the uncertainty in critical loads or exceedances that should be reduced. It is thus difficult to give general suggestions applicable to locations outside the studied area.

Currently the uncertainty in deposition and soil chemical parameters give the largest contribution to the uncertainty in the calculated exceedances of critical loads in Sweden. We therefore recommend response strategies to focus on reducing uncertainties in 1) The critical Bc/Al ratio in conjunction with the gibbsite solubility coefficient for the critical loads and exceedances on site level and on EMEP150 resolution in low deposition areas; 2) Atmospheric deposition, nutrient uptake and nutrient cycling in high deposition areas for critical loads and exceedances on EMEP150 resolution.

Although the 1999 Gothenburg protocol will lead to recovery for some sites, the recovery process for these sites will take a long time. While the soil recovery is in progress and the soil storage of Bc is increasing, the conditions in surface water chemistry may continue to deteriorate. Acidification is thus likely to continue to be a problem for several decades. Further emission reductions will be needed if the forest ecosystems are to recover from acidification within the 21st century.
Abstract

The research on acidification-related air pollution problems has currently incorporated several related effects (acidification, eutrophication and ground-level ozone) and pollutants (sulphur and nitrogen oxides, ammonia, volatile organic compounds), resulting in a very complex model and policy assessment, often referred to as the multi-pollutant/multi-effect approach. The development of effects-oriented cost-effective emission reduction strategies in Europe within EU (European Union) and UN/ECE/CLRTAP (Convention on Long-range Transboundary Air Pollution under the auspices of United Nations Economic Commission for Europe) has been supported by integrated assessment models.

The key aim of the EU/LIFE project was to provide support for the demonstration and enhancement of national integrated assessment modelling on these topical air pollution issues. The tasks were closely connected to the background work of the international emission reduction strategy development and supported more detailed national policy assessment. The work comprised of estimates on air pollutant emissions of sulphur, nitrogen and volatile organic compounds, potential and costs for emission controls, data and methods for energy, activity and emission projections, conversions between different air pollutant databases, the atmospheric transport and deposition of acidifying, eutrophying and neutralising depositions, effects of ground-level ozone exposure on vegetation and health, assessment of harmful environmental impacts with critical loads and their exceedances and dynamic soil acidification simulations, issues on variability and uncertainty and the national dialogue between scientific research and decision-making in air pollution prevention.

The results provided a quantified overview on methods, data and uncertainty of national integrated models and approaches. The findings were disseminated extensively among national and international air pollution experts and decision-makers and also public interested in environmental issues.

Keywords integrated, assessment, modelling, emissions, deposition, environmental effects
Tiivistelmä

Ilmansaasteiden happamoitumiseen liittyvien haitallisten vaikutusten tutkimus on kytkenyt toisiinsa useiden ilmansaasteongelmien (happamoituminen, rehevöityminen, alilmakehän otsonivaikutukset) sekä niitä aiheuttavien päästöjen (rikki, typenoksidit, ammoniakki, haihtuvat orgaaniset yhdisteet) yhtäaikaisen tarkastelemiseen. Tämä on johtanut monimutkaiseen mallintamiseen ja päätöksenteokseen, jota usein kutsutaan monisaastuke/rnonivaikutus-lähestymistavaksi. Yhdennetty arviointimallistaminen on tukeneet vaikutuslähtökohtaisen päästövähennystrategioiden kehittämistä Euroopassa Yhdistyneiden kansakuntien Euroopan talouskomission alaisen kuokokulkeumasopimuksen (UN/ECE/CLRTAP) sekä Euroopan unionin (EU) piireissä.


Tulokset antoivat kokonaiskuvan osallistujamaissa käytössä olevista ilmansaasteiden yhdennettyä arviointimallintamista yllämainitujen ilmansaasteongelmien osalta. Tehtävät liittyivät kiinteästi kansainvälisten päästövähennyksen vaikutusten mallintamiseen ja päätöksenteon vuoropuheluun. Tämä on johtanut monimutkaiseen mallintamiseen ja päätöksenteokseen, jota usein kutsutaan monisaastuke/rnonivaikutus-lähestymistavaksi. Yhdennetty arviointimallistaminen on tukeneet vaikutuslähtökohtaisen päästövähennystrategioiden kehittämistä Euroopassa Yhdistyneiden kansakuntien Euroopan talouskomission alaisen kuokokulkeumasopimuksen (UN/ECE/CLRTAP) sekä Euroopan unionin (EU) piireissä.
Sammandrag

Forskningen av försurningens skadliga effekter gällande luftförorening har sammanfört granskningen av flera luftföroreningssproblem (försurning, eutrofiering, ozonbesvär i nedre atmosfären) samt de utsläpp som förorsakar problemen (svavel, kväveoxider, ammoniak, flytliga organiska föreningar). Detta har lett till komplicerade modeller och ett beslutsfattande, som i internationella sammanhang ofta kallas för "multi-pollutant/multi-effekt approach". 

Integrerade utvärderingsmodeller har stött strategiutvecklingen av den effektbaserade ekonomiska utsläppsreduktionen i Europa under Luftvårdskonventionen (UN/ECE/CLRTAP) och Europeiska Unionen (EU).

Huvudmålet för detta EU/LIFE projekt var att stöda, presentera och utveckla de nationella integrerade utvärderingsmodellerna gällande ovan nämnda luftföroreningssproblem. Uppgiften var fast knuten till bakgrundarbetet för de internationella förhandlingarna om emissionsreduktion, samt stödde noggrannare utvärdering av nationellt beslutsfattande. Arbetet omfattade utvärdering av utsläppen för kväve, svavel och flytliga organiska föreningar, utredning av möjligheter för emissionsreduktion och beräkning av kostnader, data och melodier för utvärdering av energiöverförkommelserna, utsläpp och aktiviteter, omräkning mellan databaser gällande olika utsläpp, transport och deposition av försurning, eutrofiering och neutraliserande ämnen, effekterna på vegetation och hälsa av oxon i nedre atmosfären, beräkning av kritisk belastning och utvärdering av skadliga miljöeffekter, dynamisk modellering, utvärdering av variation och interverkan mellan forskare och beslutsfattare.

Resultaten gav en helhetsbild över integrerad utvärdering av luftföroreningar som används i de deltagande länderna. Resultaten har publicerats effektivt och är tillgängliga för nationella och internationella experter inom luftvård, beslutsfattare samt övriga intresserade av miljöfrågor.
Integrated Environmental Assessment Modelling
Final Report of the EU/LIFE Project

Models are used to support decision-making in assessing the impacts of acidification, eutrophication and ground-level ozone. This report summarises the final results of the international EU/LIFE-funded project "Coupling of CORINAIR data to cost-effective emission reduction strategies based on critical thresholds" (LIFE97/ENV/FIN/336), which supported national integrated assessment modelling activities in the four-country consortium co-ordinated by the Finnish Environment Institute. The work carried out in Denmark, Finland, Spain and Sweden covered air pollutant emissions of sulphur, nitrogen and volatile organic compounds, potential and costs for emission controls, the atmospheric transport and deposition of acidifying, eutrophying and neutralizing depositions, harmful impacts through critical loads and dynamic soil acidification simulation, issues on variability and uncertainty and the national dialogue between scientific research and decision-making in air pollution prevention. The results provide a quantified overview on methods, data and uncertainty of integrated model systems used to support assessment of air pollutant emission reduction strategies.