Service contract for Review of the RAINS Integrated Assessment Model - Reference ENV.C1/SER/2003/0079

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1 Introduction

This report presents the main conclusions and recommendations of a review, from a scientific perspective, of the IIASA RAINS model to be used in the CAFE thematic strategy in 2005 and for further applications in European air pollution control. The conclusions address a number of specific questions posed by the European Commission. Recommendations, related to improving the modelling framework, are not exclusively directed towards IIASA, they are also to some extent directed to other relevant stakeholder bodies - such as CAFE, and the UNECE LRTAP Convention bodies (EMEP and the Working Group on Strategies and Review) - with an interest in scientific basis of Integrated Assessment Modelling.

The review has been conducted via a contract between DG Environment (CAFE) and Swedish Environmental Research Institute with the support of AEA Technology. Task 1 of the Contract (Co-ordination and reporting) – together with information on the composition of the review team - is detailed in Appendix A. For brevity supporting text and argumentation is added as endnotes to the body of the Report[1].

The RAINS model was initially examined on the basis of documentation submitted to the review and via a visit to IIASA by the Review Team in February 2004. These initial findings were subject to further analysis at a second meeting of the Team in May 2004. A description of the model was prepared by IIASA and presented at the February meeting (http://www.iiasa.ac.at/rains/review/). The review took place during the development of the model for the CAFE application and the Review Conclusions reflect the status of the model at the time of the review.

2 Background

In its general approach, the RAINS Model reflects its historical development. For this reason it embodies a number of assumptions and decisions that have been taken for technical, practical and political reasons - many of them having a significant influence on the nature of the model output.

The IIASA RAINS model has evolved over a period of more than 20 years, as a result of attempts by the International community to base policy decisions on scientific knowledge. The present model - and the way it is used - is a product of the various research and policy initiatives taken during this period. One of its main purposes during the last 10-15 years has been to assist policy development on transboundary air pollution in Europe. The model has been used to assist the negotiations of the second sulphur protocol and the Gothenburg Protocol under the Convention on Long-range Transboundary Air Pollution (CLRTAP) and for the EC Directive on National Emissions Ceilings addressing acidification, eutrophication and tropospheric ozone. It has also been used in connection with the development of sector specific EC directives on sulphur in marine fuels and VOCs.

Following the use of the RAINS model in the formulation of Gothenburg Protocol and the EC NEC Directive, the Clean Air For Europe (CAFE) initiative has extended the priorities and proposed scope of integrated air policies to include health effects from particles. This enlargement, together with overall improvements in the existing modules of the RAINS model, constitutes a challenge for the CAFE process in

general, and the RAINS team in particular. Since a majority of the people in Europe lives in urban areas, the challenge has been to develop an integrated assessment tool that concurrently can handle regional and local air pollution impacts.

The key feature of the RAINS model is that it can link projected socio-economic development with potential air pollution effects to human health and environment and that it is capable of identifying least cost strategies with differentiated control requirements for different countries and emission sources based on the impacts of different pollutants. It is, so far, the only tool currently available capable to give policy advice on this level of complexity and integration.

The sophistication of the Model requires of its users a deep insight and understanding of a variety of environmental problems, their causes, and the possible measures and costs to counteract them. The complexity, in particular, makes it difficult for a single outside expert to review and understand all the compartments of the model, and information from other sources is used in the policy development context. Whether this complexity really produces scientifically credible, relevant and useful results for the development of policy advice is the basis for this review[2].

The RAINS model development is mainly project-driven, i.e. it has throughout its entire history been dependent on short and medium term contracts, mainly from external funding. Given the structure and financial support of IIASA, there has always been a risk of a termination of the project. The personnel have also been employed on short-term contracts, forming an uncertain situation both for the employees but also for the customers of the model.[3] CAFE and LRTAP, provided they find continuing value in the role played by the Model, should consider working with IIASA to ensure its longer-term future.

3 Assessment of model design (Task 2 of the Review)

The review was asked to answer the following two questions:

- *To what extent does the structure of each module provide a scientifically credible representation of the reality*
- *What are the limitations of the model structure and the implied system boundaries and to what extent may these restrict the validity of the conclusions and policy advice.*

The second of the two questions raises the more generic issues and is answered first.

3.1 Model structure and system boundaries

- *What are the limitations of the model structure and the implied system boundaries and to what extent may these restrict the validity of the conclusions and policy advice?*

General

Conclusions

- The RAINS model has a modular structure that gives it an appropriate degree of flexibility to address air pollution policies at the European level. The modules address economic activities[a] and emission control policies in relation to environmental and health targets. Its limitations are determined by the

[a] N.B Uncertainties relating to economic activities are discussed in Section 5.

availability and quality of the underlying compartment models and data, and the amount of resources fed into the system. The interaction and support from countries and other organisations is crucial for the applicability of the model and the validity of its results. [4]

Rationale
The version of the RAINS model intended for use in the CAFE strategy has been subject to a number of additions and changes in relation to the versions used for the Gothenburg Protocol and the NEC Directive. These changes have greatly increased the scientific credibility of the model. [5]

Geographical scale and resolution
Conclusions

- The 50 km grid scale in the RAINS model makes it possible to take into account the finer scales in emissions and effects. The resolution, however, is not enough to fully assess urban air pollution problems and local ecosystem impacts.

- The country-to-grid approach enables the application of the RAINS model to the assessment of scenarios and the development of control strategies at a national level.[6]

- The increased hemispheric background concentrations of ozone contribute to ozone exposure in Europe to such an extent that it may be advantageous to extend the modelling of control emissions to scales larger than the European Continent.

- Marine emissions make a significant contribution to air pollution deposition and exposure in Europe but they are not included in RAINS in a way that it is possible to address them properly in policy development.

- Emissions and policy actions in non-EU countries may influence the air quality in Europe. RAINS and EMEP should therefore include as far as possible accurate emission data and expected emission and policy development for these countries.

Rationale
The Model was originally developed to support regional (transboundary) air pollution policies - this remains a key issue. The approach, however, may cause problems when assessing emissions and effects that occur on a smaller scale than that considered in the EMEP model. The improvements of the model going from 150 km grid size to 50 km grid size have been important and taken some of the smaller scale issues into account, but the scale is still too large for the assessment of urban scale problems. The RAINS team has taken important initiatives, in particular through CityDelta, to better estimate the urban air pollution component, but there are still problems in establishing reliable source-receptor data on these scales. There is also a problem of estimating sub-grid processes and effects related to ecosystems. To some extent these problems can be handled by statistical approaches but for ammonia in particular there is a need for a finer resolution.

For some pollutants, air quality in Europe is severely affected by pollutants emitted outside the EMEP domain. This may lead to sub-optimal solutions, and in a long term, there is a need to include the hemispheric scale. This is particularly important for ozone, for which the increased (and probably still increasing) background concentrations may be as important for some effects as ozone produced within Europe.

RAINS does not fully include marine emissions and control within the EMEP domain. These emissions have become increasingly important during the last 10-15 years. In parallel with land based emission reductions in EU, emissions from shipping have grown substantially and they now make a significant contribution to atmospheric concentrations and deposition over large areas of the Europe. An exclusion of these emissions may limit the value of the output from the model.

Several stakeholders have suggested that emissions and control measures should be applied with a finer resolution than country specific national boundaries. For large countries a regional approach may be more appropriate from a scientific point of view, since the outcome of a strategy may be quite different depending on where in a country control measures are implemented. The present approach, however, is advantageous for many countries since it gives countries a larger degree of freedom in their implementation of control measures.

In the present version of the RAINS model, the representation and resolution of effects is dependent on the grid size used. Decreasing the grid size will give the appearance of larger exceedances and increasing it will appear to give less exceedances. Therefore there is a need to improve the transparency and understanding of how effects are expressed and how effect measures are influenced by geographical scales etc.

Geographical scales other than grid cells, such as countries (national boundaries) or even the whole of Europe, have been suggested as effect targets for optimisation calculations, e.g. in an optimisation to achieve the maximum benefit for Europe. Such approaches may reach an overall benefit at less cost with relaxation of control in the most damaged (sensitive) grids. The choice of approach is a policy choice and should be presented in a transparent way to the different bodies under CAFE and LRTAP.

Relations to climate change policies

Conclusion

- Climate change policies may significantly influence the outcome of any European air pollution strategy.

Rationale

There is a need to extend the Model to include climate change policies. To a large extent, these policies will influence the outcome of future air pollution strategies; a European wide GHG trading system may significantly influence the fulfilment of the NEC directive. The ongoing work to extend the model to include the greenhouse gases, as shown in the recently published report *The Extension of the RAINS Model to Greenhouse Gases* (IIASA, 2004), is welcomed and may deepen our understanding of the interrelations of air pollution and GHG strategies.

Scope of policy options
Conclusions

- The use of multi-effect cost-effectiveness analysis, as implemented in the RAINS model, is a reliable and scientifically defendable tool for policy advice for the CAFE strategy.

- The space for national control measures under a national ceilings policy is decreasing due to EU legislation.

Rationale
RAINS uses effects-based cost-effectiveness rather than cost-benefit analysis. As implemented in RAINS, the former approach seeks solutions that minimize the cost of control necessary to attain specified environmental targets, taking into account differentiated environmental sensitivities, atmospheric source-receptor relationships, and marginal abatement costs. In contrast, the latter approach seeks solutions that maximise net benefits (benefits minus costs) measured in the same metric (typically money). This approach assumes that one can quantify and assign economic values to all costs and benefits associated with a control strategy and must address differences in economic valuation of these effects across Europe. While RAINS could be modified to support such cost-benefit analyses, the principle advantage of the current RAINS approach is its pragmatic avoidance of the subjectivity inherent in valuing benefits in economic terms - creating thereby a level platform for international negotiations.

We believe that it is inadvisable to modify RAINS to incorporate a cost-benefit analysis approach. However, other cost-benefit analysis tools or analyses could be used, in conjunction with RAINS, to gain insights for CAFÉ, especially in the process of target setting.

EU has taken a leading role in air pollution legislation within almost all sectors, with the exception of agriculture. Legislation within the transport and energy sectors has become very strict in comparison with un-controlled emissions. The degrees of freedom for national decisions will through this legislation become more and more limited, which may influence the use of the RAINS model for calculating national emission reductions, particularly so if only technical measures are included.

Environmental and health effects
Conclusions

- Major environmental and health effects from emissions of sulphur dioxide, nitrogen oxides, VOC, ammonia and fine particles are all included in RAINS (with the exception of health effects from nitrogen dioxide).

- Some effects that are not or only partly included in RAINS might, if included, influence the strategy. The scientific knowledge of these effects, with the possible exception of marine eutrophication, is not yet at a level that they could be included in the RAINS model.

Rationale
The model is suited to the assessment of a limited set of environmental and health effects. A number of other possible endpoints are omitted for various reasons, most

often due to lack of reliable dose-response data or established source-receptor relationships. These effects include morbidity effects from particles and ozone, health effects from nitrogen dioxide, effects to children from air pollution in general, effects to materials, and marine eutrophication. Some of these effects, if included at the same target level as assumed to be used in RAINS, will most probably increase the predicted optimal level of control in comparison to the current list of effects addressed in the Model.

Recommendations (Model structure and system boundaries)

- The RAINS team should develop the model to include marine emissions in adjacent (EMEP) sea areas. There are enough data on emissions, emission trends, control options and their costs to include these emissions in RAINS. Some additional work is also necessary by EMEP in order to establish reliable source-receptor matrices for these emissions. (Short term)

- The RAINS model should be developed to include hemispheric pollution problems. (Long term)

- The model should include local air pollution problems in a more sophisticated way, e.g. through nesting approaches. (Long term)

- The geographical resolution should be further elaborated in order to understand how the geographical resolution influences the outcome of RAINS calculations. (Short term)

- RAINS should not be modified to incorporate a cost-benefit analysis approach. Other cost-benefit analysis tools or analyses could, however, be used, in conjunction with RAINS, to gain insights for CAFE, especially in the process of target setting.

3.2 The representation of reality in the modules

- *To what extent does the structure of each module provide a scientifically credible representation of reality?*

Conclusions

- In general, RAINS represents reality in a scientifically credible way. Some endpoints/effects are not included – and so can't be modelled - due to problems in quantifying exposure, i.e. effect relationships (morbidity, health effects to children etc.) are missing. Specific conclusions with respect to the scientific understanding of environmental and health effects and the adequacy in their representation in the individual RAINS modules and their compartment models are presented under section 7.

- The RAINS team has a good overview of the development of the science in the areas of importance for the Model, including environmental and health effects, the generation of source – receptor matrices, scenario development including emission estimates, abatement technologies and their costs. They have also taken important initiatives to ensure that scientific research in adjacent areas are

connected and that research scientists understand the needs of integrated assessment models.

Recommendations (The representation of reality in the modules)

- Recommendations for the Model's individual environment and health modules and their compartment models modules are presented in section 7.

4 Uncertainties (Task 3 of the Review)

The review has addressed the following issues:

- *Have the most policy-relevant uncertainties (related to variability of the system inexactness of input data and lack of knowledge) been adequately addressed?*
- *Is there an alternative formulation conceivable that could provide better policy-relevant insights into uncertainties?*
- *In view of the uncertainties, are the model results robust enough for policy advice or are there alternative ways conceivable for attaining more robust conclusions?*
- *Is there a risk that the RAINS model gives policy advice that systematically underestimates or overestimates the policy measures need to protect the environment? What are the major reasons for a bias, if any?*

4.1 Addressing uncertainties

- *Have the most policy-relevant uncertainties (related to variability of the system inexactness of input data and lack of knowledge) been adequately addressed?*

Conclusions

- Policy relevant uncertainties have been identified and addressed in earlier work where they are associated with (statistical) uncertainties in underlying data.

- Uncertainties due to biases in model formulation, lack of scientific understanding, and inability to predict future behaviour, have only been addressed to a limited degree in earlier assessments. But they may be as important as uncertainties in input data and model parameters that are handled with traditional statistical methods. (Sections 4.4 and 7)

- Interannual variability in air pollution dispersion patterns may introduce uncertainty and result in policy solutions that are less robust than might otherwise be thought..

- Climate change may influence air pollution distribution and effects over Europe. The EMEP model and the effect modules have not assessed such changes.[7]

- Limited knowledge of future economic activity is likely to be one of the largest sources of potential error/misstatement in the RAINS output (see Section 5).

Rationale

Several aspects relevant for uncertainties were highlighted and tested in connection with the preparation of the Gothenburg Protocol. (See for example UN ECE EB.AIR/WG.5/1999.4) These tests were, even if motivated from a policy point of

view, only covering a limited number of aspects. Later statistical uncertainties due to underlying data have been tested with error propagation methods.

The interannual variation in European air pollution impact may be large in particular for secondary pollutants such as ozone, which is, in addition to general transport patterns also strongly dependent on temperature and sunshine. The five-year adjusted mean used for the Gothenburg Protocol was reasonable as way control for the interannual variations. At present, there is a risk that there will not be data from more than two years available for the RAINS calculations and this may decrease the reliability of the model output.

European climate has changed during the last decades and it is expected that climate may undergo more changes in the future due to the global warming. These factors are not considered in the model calculations. In an analyses of the reliability of the model output, this issue needs at least to be highlighted as an area for further long-term research.

Discussion of economic issues is given in Section 5.

Recommendations

- The nature of uncertainties in RAINS should be addressed in a more structured way, both quantitatively and qualitatively, thereby avoiding misunderstandings and misleading conclusions. (Short term)

- Interannual variations need to be further considered and the source-receptor matrixes should if possible be extended to at least five years. (Short term)

- Climate-change needs to be addressed in future air pollution policies. Long term)

4.2 Alternative formulations of uncertainties

- *Is there an alternative formulation conceivable that could provide better policy-relevant insights into uncertainties?*

Conclusions

- Currently the RAINS model has primarily addressed statistical uncertainties. From a scientific perspective uncertainties exist in a number of categories including:
  a) Uncertainties due to lack of scientific understanding,
  b) Uncertainties due to assumptions, simplifications etc. in the handling of data and the design of the RAINS compartment models that may cause biases in the modelled outcome,
  c) Uncertainties due to statistical variance in input data collection etc.
  d) Uncertainties related to socio-economic and technological development[b].

Alternative formulations would be required for the management of uncertainties in the categories a, b and d, where the uncertainty probability functions cannot be established or are not continuously distributed.

[b] Including uncertainty regarding the implementation rate of new technologies.

The Model, in its current version, has not equally addressed all four types of uncertainties. These might be addressed in policy context through an assessment of the uncertainty in the environmental and health targets and the division of control measures between countries and sectors.

Rationale
The level of scientific understanding varies between problems considered and modules. This issue is further discussed in connection with Task 2 of the Review (see Section 3) and also in Section 7.

Assumptions and simplifications made in the development and application of the compartment models, and in supporting data, may bias the outcome in the Model. Potential biases are to some extent analysed and discussed in section 4.4 and 7 but it is too demanding a task to fully analyse them within this review. Our view is that it is the responsibility of supporting bodies - in particular EMEP, WGE and WHO - to review their own data and report the result; the RAINS team could then make a better overall estimate of the biases and its consequences for the model output.

Statistical uncertainty analyses have been performed by error propagation methods. Such analyses are still important but they may be of limited value if not considered in relation to other uncertainties. A number of input data sets 'age' and their inherent uncertainty thus deteriorates with time.

Uncertainties in socio-economic development are, to a large extent, impractical to estimate; these are further discussed in Section 7.

Recommendations
- The RAINS team should develop an uncertainty management system, by which the uncertainties of different types can be handled and analysed with respect to their influence on policy.

- Supporting bodies and in particular EMEP, WGE and WHO, should review/assess the biases in their RAINS related work and report them. IIASA should then combine this information, with their own analysis of biases, within the RAINS model to make an overall estimate of the biases and its consequences for the model output.

- IIASA should continue their systematic work of estimate the statistical uncertainty in data sets, ensuring that uncertainty from ageing data sets is reduced to a minimum. The uncertainty analyses should be made in relation to the end use of model results (comparing scenarios, setting priorities between countries).

4.3 Robustness
- *In view of the uncertainties, are the model results robust enough for policy advice or are there alternative ways conceivable for attaining more robust conclusions?*

Conclusions

- In its present form RAINS can be used to assess statistical uncertainty for a large number of given policy options.
- The Model is not suitable for common and repeated use by all stakeholders. It is a research tool in a continuous state of development - it requires a knowledgeable user. It is not at present possible for a stakeholder to change key model parameters from preset values to test the significance of optional values. Taken together, these factors limit the possibility of the independent testing of the model under different conditions of use that gives user confidence.

- In the RAINS model version used for the Gothenburg Protocol and the NEC Directive a number of steps were taken in order to increase the reliability and robustness of the output of the model. These steps were directed towards areas where the effect of known uncertainty was felt to be most important. When assessing the robustness of the RAINS model, for the CAFE strategy, it is important to bear in mind that the complexity of the model has increased. This has occurred at a point when time for the consideration and development of different policy options has reduced; the opportunity for participation by countries in the process of Model development has probably also reduced.

- For optimisation calculations the robustness of the model output is largely dependent on how targets are set, the introduction of compensation mechanisms being an example. Therefore it is important to make these choices with a high degree of transparency and openly also present how different approaches influence the robustness.

Rationale
Robustness is not a well-defined concept. In this context it encompasses a number of aspects related to the possibility of an alternative model (or mode of RAINS usage) achieving a similar (equivalent) solution for a particular policy option (target emission reductions, costs, environmental and health benefit etc.). It implies that known uncertainties and biases should not unduly influence the outcome of the model calculations. It also relates to stakeholder confidence, and acceptance, of RAINS as a reliable tool for policy advice. Since the present version of RAINS has not been available for any tests and investigations on its robustness, it has been difficult to fully address the issues raised and our conclusions should be viewed more as observations than definitive findings.

One of the more important factors in assessing robustness relates to the sensitivity to uncertainties in those input parameters determining the cost per reduced unit (emissions, abatement efficiency, costs). If there are small differences in costs between different policy options close to the optimisation target, small differences in these parameters may unduly influence the outcome. Another important factor influencing the optimisation and robustness is how the cost of emission controls is allocated between co-emitted compounds.

4.4 Systematic biases in the outcome of the model

- *Is there a risk that the RAINS model gives policy advice that systematically underestimates or overestimates the policy measures needed to protect the environment? What are the major reasons for a bias, if any?*

Conclusions

- A number of biases are identified which, overall, are likely to overestimate the protection levels to health and environment offered by a particular policy option.

- Some of the most obvious biases observed in connection with the development of the Gothenburg Protocol and the NEC Directive have been taken into account in the new version of the RAINS model.

- There is a risk that the model will give a bias in relation to the requirements in different regions in Europe and between different sectors.

- The direction of potential bias will depend on the 'endpoint' of concern – see Section 7.

Rationale

Assumptions, simplifications, and the omission of some endpoints are all potential contributors to bias. It is difficult to quantify the individual biases since if they had been known they would, in all probability, already be compensated for in RAINS. An analysis made by the Review Team indicates that most of them will contribute to less protection of environment and health than predicted by RAINS – see Section 7.

Some of the biases identified in connection with the development of the Gothenburg have been taken into account. The review team however identified a number of biases that still may be important for the outcome:

- Underestimation of deposition of S and N to sensitive ecosystems. The deposition calculations are still unable to fully take into account the variations in the deposition and to give an acceptable estimate of the deposition to complex terrain. Some of the most sensitive ecosystems are also found in such areas. (Underestimation of needs)
- An overestimation of the role of N in critical loads for acidification. Most results indicate that the immobilisation term in the critical loads should be higher. (Overestimation of needs)
- It has been assumed that the critical loads concept should be developed to include recovery of anthropogenically-acidified ecosystems. Such an approach will lead to more demanding control requirements.
- Resent scientific research indicate that eutrophication effects occur at lower deposition than in present estimates of critical loads (underestimation of needs)
- Health effects to the people younger than 30 years are not included, which means that large (and sensitive groups) of the population is not included in the estimates (underestimation of control needs).
- Changing concentration patterns of ozone over Europe. Background is increasing and the peak concentrations are decreasing. The changing pattern may lead to less protection than estimated by model. (underestimation of control needs)
- The AOT concept will lead to a bias in the control needs in effects between dry (Mediterranean) and wet (Central and North) areas in Europe at least for agricultural crops. This bias seems to be less important for forests.

- The inclusion of thresholds for the estimate of ozone effects to human health. (Underestimation of control needs)
- The exclusion of morbidity leads to a general underestimation of effects to human health. (Underestimation of control needs)

Recommendations
Recommendations on the management of bias in the RAINS compartment models is given in Section 7.

5 Abatement technologies and Costs (Task 4 of the Review)

- *To what extent does the fact that the RAINS model deals with only technical (end-of-pipe) measures bias the result? What would be gained if non-technical measures would be included in RAINS in terms of accuracy of (i) environmental results and (ii) economic assessment?*

- *How are the costs assessed and verified by IIASA? Is there a systematic difference between the ex-ante cost assessment used in RAINS and ex-post assessments of the real costs? If yes, for what reasons? What could have been the influence of those possible differences on the results of the Gothenburg Protocol and the NEC Directive?*

Effect of dealing predominantly on end-of-pipe measures
Conclusions

- The fact that the RAINS model deals only with technical measures does introduce a bias in the results in that it over-emphasizes costly (end-of pipe) solutions and overlooks less expensive options implied or inherent in structural changes and economy reactions to market stimuli.

- The inclusion of non-technological measures would result in a more accurate estimation of the cost of policy. By including non-technical measures, environmental benefits may be realised more quickly. But at the same time, it should be noted that non-technical measures might also be found incompatible with other (technological) measures implied by EU Directives (such as e.g. LCP(1988) and IPPC).

- Given the current context, the approach taken by RAINS has offered the best reflection of (the overall) requirements imposed by the EC and other international policy bodies.

Issues related to cost data verification
Conclusions

- The costs are assessed in 'top down' procedures using cost coefficients for a spectrum of abatement measures: they are verified by dialogue with national experts.

- Ex-ante costs do seem to be systematically over-estimated.

- Costs are generally over-estimated because they ignore non-technological measures that can reduce the overall economic burden of environmental improvements.

- It is difficult to predict whether such a bias would lead to differences between GP and NEC Directive because a systematic over-statement of abatements costs does not imply that the overstatement is the same for all countries in percentage terms. (The GP and the NEC cover different geographical areas).

Rationale (for both sets of conclusions)
Cost of abatement data is drawn from the widest pool of expertise and information that we are aware of. Costs are assessed by IIASA research staff drawing on the open literature; contact with national governments, industrial trade association, and researchers; and as a result of information supplied to them by third parties. The RAINS data set is tested and verified in the process of discussion with interested parties and countries.

The abatement strategies evaluated using the RAINS model derive from a view of the current emissions and the driving forces (see below) that will determine future emission trends and the types of control techniques that are available to control them – now and in the future. RAINS uses a top-down approach acknowledging some national differences. Capital costs are assumed to be uniform for same type of equipment. It is not yet clear whether there are any differences between ex-ante and ex-post expectations and systematic studies are still to be undertaken. Some of this has been done at the national level but is not European wide[8]. Ex-post assessments consistently show that ex ante costs are overestimated due to methodology being restricted to technological measures. On the basis of the little information available, there would appear to be a bias in that aggregated cost projections appear to be high - possibly by a factor of 2 - but that the differences are not uniform between countries. Bias may be introduced by using a uniform discount rate for capital, the EC uniform discount rate of 4% may not be suitable for modelling the countries with economies in transition for example.

The approach taken by RAINS is a good reflection of (the overall) requirements set by the EC and other international policy bodies. The algorithms and calculation approach (cost curves and associated aspects of the optimisation process) are technically defensible under their conditions of use and were appropriate for the purposes of modelling the impact of measures available for the NEC Directive and the Gothenburg Protocol. The cost curve approach while not fully representative of 'true' conditions is considered by most stakeholders to have been a suitable representation, especially in the long run when governments are less constrained by the physical characteristics of the capital they have to deal with. In a shorter time horizon - say, until 2010 - retrofits will play a dominant role and local circumstances rather than uniform approaches are likely to determine much of the costs to be born. Nevertheless, IIASA's operational practices have largely brought the potential bias from incomplete or uncertain data on costs down to a tolerable level. Similarly the mechanism of bilateral discussions with member states and maintaining a high profile in scientific meetings goes a good way to addressing the need to assess and verify the

available cost data, but there is scope for greater industrial participation in cost data compilation.

Historically, the model has been developed with an emphasis on technical (end-of-pipe) measures and, consequently, an inability to assess directly the multi-pollutant reduction effects of alternative options. While this may have created a conservative bias in the past[9] it is not believed to have been significant in the policy context of the NEC Directive and Gothenburg Protocol. It may, however, become more important as policy makers assess alternative multi-pollutant and PM reduction policies. It is, interestingly, an example of a bias introduced by the pragmatic formulation of the model to meet policy makers needs which, in turn, influences future policy making options.

There is evolutionary development potential in RAINS that will preserve its utility for future policy development use. A recent, experimental, version of RAINS – designed for greenhouse gas management – uses a more computer-intensive approach to better reflect multi pollutant/multi effect relationships. It is also possible to include a range of non-technical measures including carbon trading and pollution taxes[10]. This approach is yet to be proven but represents a promising opportunity for the future and is a good example of the ability of the RAINS team to evolve. A number of initiatives are in hand to develop cost of control data suitable for use in RAINS in the near future[11].

5.1.1 Note on Driving Forces and Emissions[c]

The RAINS model relies on data from external bodies: countries, semi-official bodies, and others. These data sets can have a very limited overlap and so a large degree of operational flexibility is required to reconcile them. On the whole the RAINS team have operational procedures designed to check that emission data are as free from omission, error and material misstatement as currently possible[12]. These procedures place emphasis on dialogue with countries to reconcile aggregated results, understand the causes of differences, and bring about data convergence. As a result it is unlikely that the current emission estimates account for significant unidentified bias in the RAINS output.

Estimates of future activity levels are problematic. IIASA is reliant on the PRIMES and TREMOVE 'systems' and the accuracy of these inputs to RAINS is, to a large extent, outside the IIASA/RAINS sphere of influence. The largest errors/misstatements probably reside in the scenario related data from these external bodies. While it is sensible for IIASA to import some of the RAINS components (e.g. in the form of accepting scenarios from PRIMES and TREMOVE) such externally created scenarios may have a decisive impact on projected emissions and abatement cost curves. This impact is especially important since it leaves national governments and their experts – who might verify those cost curves - with even greater uncertainty in the Model's robustness. As a consequence limited knowledge of activity is likely to be the largest source of potential error/misstatement in the RAINS output.

[c] Apart from the assessment of costs, the Review Team were requested not to cover in detail the quality of the input data. It has been necessary, however, to examine those other aspects of the input data that are likely to have a significant impact on the effectiveness of the RAINS modelling and which, as a consequence, may introduce bias or misunderstanding – the source, suitability, completeness, and inexactness etc.

The emission calculation algorithm is not that used by countries to calculate and report national emissions, it is a variant on it that allows for the introduction of certain types of abatement techniques[13]. The algorithm while, not ideally suited to non-technical abatement options, is technically defensible under their current conditions of use[14]. The IIASA team are aware of the potential for bias and include in their country bilateral discussions.

The bias likely to result from taking national emissions as reported by countries but taking natural emissions from EMEP, each with their own – differing – process of data validation, is not known.

Recommendations
Abatement and Costs

- IIASA should maintain its dialogue with experts from Member States to identify abatement options and collect cost of abatement measures to ensure that all the potential abatement measures have been identified and that the most representative cost information is being used in RAINS.

- IIASA should analyse which aspects of the calculation are the most significant sources of bias (by sector and pollutant) leading to the greatest deviation between the ex-ante and ex-post cost assessments.

- The RAINS model should be extended to include non-technical measures as and when allowed by evolving EC policy.
- The EC should use its influence to encourage greater member state and industrial cooperation in the provision of abatement equipment cost data to IIASA. There is likely to be a great deal of abatement cost information, at a company level, resulting from IPPC driven requirements. This information is of relatively little value to RAINS as the model requires aggregated national data.

Supplementary recommendations related to Emissions and Driving Forces that will improve the RAINS modelling process:
- The RAINS team should continue its work of:
  - Driving data convergence with particular attention to ensuring good correspondence with energy, transport, and agriculture economic forecasting models,
  - Improving the emission, abatement, and implementation factors used.
  - Incorporating data sets related to non-technical abatement measures and takes advantage of information on emerging technologies provided by IPTS and Egtei.

- CAFE should ensure that:
  - PRIMES and other models providing input into RAINS be subject to a similar degree of scrutiny to that give to RAINS,
  - Target setting is undertaken independently of IIASA. Otherwise, the EC and MS are delegating inherently governmental functions.
  - National governments are encouraged to provide national inventory reports that provide documentation of the methodology used to develop the emissions data provided by national governments.

6 Communication with stakeholders, policy-makers and public (Task 6 of the Review)

- How does IIASA verify the quality of input data that is used in the RAINS model? Is the quality of the input data obtained from national sources and from other models sufficiently guaranteed? In what way does IIASA give feedback to providers of input to maximise the robustness of the RAINS results?

- In what way are users and stakeholders involved in the modelling process, and is this sufficient to ensure transparency and acceptability of the results for policy advice?

- Are the presentations of the results clear? If not, can the communication and dissemination of the results be improved?

- Is the model structure transparent? (E.g. are the assumptions clearly exposed and motivated, and is their influence on the model-results analysed?)

Verification of quality and feedback to providers

Conclusions

- IIASA explores the quality of the input data to RAINS by a combination of consultation with country representatives, participation in scientific meetings, and encouraging comment from third Parties.

- IIASA seeks to verify the quality of the input data by a process of comparing data submission from various countries and then, in bilateral discussion with individual countries, seeking to explore and remove ambiguities.

- The input data quality is not guaranteed by either countries or by those who run the models that provide input to the RAINS model (i.e. PRIMES, CAPRI, and TREMOVE etc.). Consequently the quality of exogenous data is variable, so IIASA goes to considerable lengths to encourage the development and application of best practice. Through this iterative process of consultation, IIASA has encouraged the active involvement of those providing them information and, ultimately, improved the robustness of RAINS results.

- RAINS provides feedback to data providers in a variety of forms; these include bilateral meetings, reports, Internet-based information and reports to scientific meetings.

Stakeholder involvement

Conclusions

- Users and stakeholders are encouraged to exercise the RAINS model in the hope that an increased familiarity will provide the transparency to make it acceptable for policy use. IIASA reaches out to relevant stakeholders by participating in practically all relevant scientific and policy fora and through time-consuming consultations with country representatives. IIASA has made its documentation and analytical results available via the Web and has made it possible for individuals to execute the RAINS model via the Internet for free. To the extent their resources have allowed, IIASA has been diligent in responding to questions from individual users.

- Understanding and acceptance of the modelling approach has developed over time, through repeated exposure of stakeholders to presentations on the methodology and results, through iterative consultation processes about input data and methodologies, and through application in policy development. Confidence in the policy insights provided by the RAINS model has grown over time and with increasing familiarity with the model and the individuals who develop and apply it. As a result, confidence is higher in the elements of the model that are more mature and familiar than in the elements of the model that have been recently added, such as the treatment of urban scale exposures. More over, stakeholders who have been exposed to RAINS and its use in past policy applications are likely to be more confident in its policy advice than are new stakeholders who are part of the CAFE process but have not been involved in previous applications of RAINS.

- The division of responsibilities between IIASA and CAFE is not always clear, particularly with regard to target setting. Target setting is primarily a policy function but it has a technical component that limits the nature and range of possible targets and policy options. The further development of the model and the creativity of the team (e.g. the capability to introduce new ideas and concepts) are, consequently, important in the policy development process. Furthermore, the selection of some targets may have implications that require a great deal of familiarity with the model to understand or predict. The design implications of target setting concepts (such as gap closure or intra-country compensation) may not be obvious to someone who is not very familiar with the model despite their having important policy ramifications[15].

Communication of results
Conclusions

- Working with different stakeholder communities, IIASA has developed considerable skill in adapting the language or level of detail of their presentations to fit that of their audience. Their ability to display results using maps and other graphics has proven especially useful with policy audiences.

- To date, presentations about uncertainties in the results have not been very detailed and have focused on only statistical variance due to limitations in input data and parameterisations. Other sources of uncertainty, such as the lack of scientific understanding, the use of assumptions or simplifications, and the inability to predict future socio-economic developments, have not been well characterized or communicated. Uncertainties, in general, have not been the subject of stakeholder consultations, and this should be improved.

Model Transparency
Conclusion

- The general structure of the RAINS model is transparent, however, the details are quite complex and comprehensive documentation has not kept pace with model improvements. The extensive documentation developed by IIASA to support this review is an important contribution to providing more transparency and efforts should be made to continue to update this documentation as the model continues to evolve.

- The modelling process requires many decisions; these can be technical, practical, and political, in that they often have implications for the policies that are shown to be optimal. Our general impression is that IIASA has been careful in the choices they have made, balancing the practical considerations while ensuring the technical credibility and political acceptability of the RAINS results. However, it is very important that decision-makers understand the choices embedded in the model and engage the modellers in the interactive process of learning, dialogue, and adaptation of the model.

- The RAINS model is a collection of 'compartment (meta) models,' each mimicking a more comprehensive scientific model or database – each of which was subject to the peer review process. The IIASA practice of consultation, examining issues with providers of methodology and data, on a bilateral basis is an effective way of ensuring that the important features of the original model/databases are reflected in an adequate way. It would be desirable, to improve transparency, to have a list of specification of the models or databases that make up the disciplinary basis underlying the modules of RAINS (i.e. specify the nodes/interfaces under each module).

Rationale (for all sets of conclusions)
Communication between IIASA and the scientific community, the Member States, and other stakeholders is fundamental to the legitimacy of the RAINS model.

The IIASA 'openness' policy is commendable and should be encouraged. The success of RAINS is as much due the versatility of the IIASA team and their active engagement with the scientific community as it is to do with the model itself. The process of model development and verification by bilateral dialogue with interested parties and the scientific community is effective. IIASA seeks to verify the quality of the input data by a process of comparing data submissions from various countries and then, in bilateral discussion with individual countries, seeking to explore and remove ambiguities. This is not always successful, as noted above, the model is used in a top down manner, consequently it doesn't recognise (or always reflect) the interests of specific stakeholders.

IIASA has been successful in fostering the active involvement of those providing them information and, ultimately, improving the robustness of RAINS results. They go to considerable lengths to encourage the development and application of best practice by providing a variety of feedback. Users and stakeholders, furthermore, are encouraged to use and manipulate the model in the hope that an increased familiarity will provide the transparency to make it acceptable for policy use.

IIASA has, in general, been very open to those interested in the model and model applications and several of those who have visited IIASA have testified to their cooperativeness. The model has also been widely distributed free or for a limited cost. There have, however, been difficulties in getting a general and comprehensive description of the model and its different modules. The material prepared for the review addresses many of these concerns. If the IIASA staff are able to keep the information in the documentation report updated this material will be very useful for anyone who want to get a deeper insight into the model and its different modules.

The legitimacy of the RAINS model rests on the long term relation of the actors involved in the model and policy system, from those supporting the model with knowledge and data, IIASA staff themselves, experts and policymakers who communicate with IIASA on policy options and who use the output of the model as the basis for policy. The legitimacy is, therefore, not only based on the quality of the scientific material itself but also on the way the material is reflected in the model and on the overall perception of the model's ability.

The RAINS team contributed significantly to the credibility won by the model during its early use under CLRTAP and EU. The team has demonstrated, in general, that they have been able to accommodate the various different scientific views of relevance in the evolving RAINS model.

Transparency is not always as good as it might be. Notwithstanding the resource requirements of further exposition, there is the underlying danger that if you make things too transparent, then stakeholders ask to change assumptions without taking into account the correlation to other assumptions. There is always expert judgment that should be heeded that won't be able to be expressed.

Recommendations

- Both IIASA and the CAFÉ Secretariat should ensure that the roles of the key players and their responsibilities in the policy development process are clearly understood. This may require further definition. In the process of target setting, CAFE should clearly define its role and its *modus operandi*. Likewise, CAFE participants need to understand the capabilities and limitations of the model, articulate their policy judgments, and think through the implications of their choices.

- The CAFÉ Secretariat may wish to encourage greater industrial participation in the generation and discussion of cost of abatement data.

- Both the EC and IIASA should encourage the parties submitting data to RAINS to provide documentation related to the quality management of the information submitted. In the case of emission data, this should include a National Inventory Report.

- The RAINS team is requested to communicate to the suppliers of exogenous (activity) data sets the recommendation of the Review Team that all the data used in the RAINS model should be complete, consistent, comparable and accurate; supporting documentation should also be available. The RAINS team are urged to continue to work with these groups to further improve data quality.

- With regard to a broader 'turning the inside out,' IIASA may wish to consider adopting the quality management principles (as described in ISO 9001:2000 for instance) of documenting: its quality policy, management responsibilities, planning and model design processes, communications processes, and review activities. The Review material prepared for this review has many of these items already and should form, by continuous updating, a documentation of the model for those who want a deeper insight in the model and its modules.

7 Effect module assessments

In this section we have elaborated the issues of representing reality and uncertainties for each of the modules of the RAINS model. We have done that from a number of issues representing factors that form scientific understanding and validation of models versus reality.

Acidification

Scientific maturity	Acidification of soils and surface waters has been an international research topic for more than 30 years and the problem is widely understood throughout Europe and by policy-makers.
Process and mechanism understanding	The underlying mechanisms for acidification due to nitrogen and sulphur deposition are well understood. There remain uncertainties with respect to the role of ammonia and nitrogen immobilisation in soils, which are important for dynamic modelling.
Evidence from controlled experiments	A large number of laboratory and field experiments have shown the overall processes and ecological consequences of acid deposition.
Evidence from field observations	Field observations are overwhelming and recent evidence of recovery has been detected following the large decrease in emissions.
Atmospheric source-receptor relationships	The EMEP model review concluded that source-receptor matrices can be established for policy purposes. Dynamic modelling will require data on historic and future deposition of base cations. Atmospheric deposition in coastal areas do not reflect the effects of shipping sources.
Transfer to the RAINS model	There is a well-developed method for the transfer of data on static critical loads and how the partitioning between sulphur and nitrogen should be handled. There is not yet a final agreement on how results from dynamic modelling could be handled in RAINS. The application of the dynamic approach may also be limited due to lack of input data.
Biases	Although the EMEP model has been substantially improved after the introduction of an ecosystem specific deposition module, there is still an underestimation of the deposition in complex terrain (hills, forest edges), which may lead to an underestimation of the control needs. Soil processes for N may cause biases in critical loads for N. Scientific field studies indicate that the immobilisation of nitrogen in soils are larger than presently assumed in the estimation of critical loads for acidification. This means that critical loads for acidification may be higher.
Recommendations	- A historic base cation deposition map over Europe should be established (EMEP, short term)

- Countries should be encouraged to submit data for dynamic modelling. (Short term).
- The dynamic critical loads concept should be tested in relation to the static. This is necessary in order to understand the reasons for changes in exceedance maps and general control requirements. (Short term)

Eutrophication

Scientific maturity	The knowledge of eutrophication has largely developed over the last 15 years. Dose-response relationships are well established for a large number of ecosystems. The importance of nitrogen for biodiversity changes in Europe is not well understood by policy makers and the issues are not being addressed in the policy arena. The largest effects occur in agricultural areas and are due to reduced nitrogen from agricultural sources.
Process and mechanism understanding	The underlying mechanisms of eutrophication due to oxidized and reduced N deposition is well understood. There is however less knowledge about the dynamics of vegetation changes in (semi)natural ecosystems. There is also a cascade of effects of deposited N, on vegetation, soils and coastal waters, including loss of biodiversity, greenhouse gas emissions and algal blooms.
Evidence from controlled experiments	Laboratory and field experiments have demonstrated the overall processes and ecological consequences of N deposition.
Evidence from field observations	Field studies throughout Europe have shown large changes in (semi)natural terrestrial and aquatic ecosystems in relation to N deposition. The signal of eutrophication can easily be detected in country scale vegetation surveys.
Atmospheric source-receptor relationships	The EMEP model review showed that source-receptor matrices can be established for policy purposes. However, within grid variability in N emission and deposition is not possible to quantify in the current model.
Emissions	There are problems with the accuracy and time and spatial scales of ammonia emissions and impacts.
Transfer to the RAINS model	The RAINS model will depend on the same type of data as for the earlier strategies. The spatial scale of reduced N impact (like that of urban air quality) is small relative to the 50 km scale of the RAINS model.
Biases	Recent research on critical loads for vegetation change indicates that critical loads are probably smaller than in present assessments. This may lead to an underestimation of the control requirements to reach a certain environmental status. Some of the control measures may lead to other effects than those considered in the air pollution strategy (pollutant swapping e.g. reduce ammonia and increase N_2O emissions).

	The present use of a fixed critical loads approach will not be able to pick up the dynamic aspects that are involved in eutrophication of ecosystems. However, there is no model available yet that can describe the dynamics in a way that can be useful for control strategies.
Recommendation	- There is a need for further development of dynamic models to include nitrogen processes in vegetation and soils. (Long term) - The spatial resolution of the RAINS eutrophication modelling should be increased. (Long term) - Models should be developed to fully account for the different fates of deposited N in the effects assessment. (Long term)

Ozone effects to vegetation

Scientific maturity	The problem of regional ozone concentrations and effects to vegetation became evident and accepted on a European scale in connection with the preparation of the Gothenburg Protocol and the NEC Directive. The main knowledge within most countries has been established from ICP vegetation studies with indicator plants. A limited number of countries have established advanced dose-effect research.
Process and mechanism understanding	Effects to vegetation from regional increases in ozone concentrations are well understood with respect mechanisms and final effects, especially for agricultural crops and some forest trees. There is increasing evidence that ozone flux measures give a better estimate of the overall effect to vegetation than concentration data (expressed as AOTXX).
Evidence from controlled experiments	A large number of laboratory and field experiments have shown the overall processes and ecological consequences of elevated ozone concentrations.
Evidence from field observations	Most evidence of regional ozone effects comes from ICP studies with indicator species. There are no field inventories of ozone damage to vegetation, mainly due to lack of established methods.
Atmospheric source-receptor relationships	The EMEP model review concluded that source-receptor matrices can be established for policy purposes. The large inter-annual variations may cause a problem to establish robust source-receptor matrices.
Transfer to the RAINS model	The IIASA team is up to date with current science, which within Europe is now at the leading edge of international developments, and they have good links with the scientific community in the field. The contributions of IIASA to workshops on ozone issues have been notable. The AOT30 or AOT40 are well established as effect measures and recommended to be used. The flux approach is also a

	possibility for two crops, however it has not been fully tested. Non-linearities in source-receptor relationships may cause a problem in the application to RAINS, although these issues have been dealt with satisfactorily in the past. The flux approach will change the picture for Europe and thus control strategies.
Biases	AOT vs. flux concentrations. The use of the AOT concept is developed in relation to the common concentration pattern in Europe. The concentration pattern is changing, however, with increasing background concentrations and lower concentrations during episodes. This may lead to a bias in the relations between measures and effects. Decreasing European peak concentrations and increasing background concentrations may result in the risk of priority being given to internal European control measures at the expense of not considering the needs for control measures on a hemispheric scale.
Recommendations	- Source-receptor relationships should be established for several years in order to achieve a more stable source-receptor relationship. (Short term) - The choice of AOT30 or AOT40 should be made based on an evaluation of which concept that has the lowest uncertainty in the exceedance calculations and not exclusively based on physiological or atmospheric exposure judgements. (Short term) - There is a need to include background ozone concentrations and its control in the RAINS model. In a short term we recommend to include marine sources within the EMEP domain. (Short and long term)

Health effects from particles

Scientific maturity	There is rapidly increasing evidence on the relationship between particles and health effects and on the large influence that particles have on human health all over Europe.
Process and mechanism understanding	The underlying mechanisms are more and more understood, including the role of inflammatory responses. Still the importance of different PM characteristics for human health and exposure response functions (ERF) are not well described.
Evidence from controlled experiments	Human experiments have studied short-term effects only. Different PM components/sources have not yet been studied in detail, especially not at relevant exposure levels.
Evidence from field observations	The only exposure responses functions for use in health impact assessment come from epidemiological studies. Progress is hampered by a lack of epidemiological studies with ambient measurements of PM characteristics.

Atmospheric source-receptor relationships	There is considerable underestimation of PM2.5 concentrations from the EMEP model. Secondary organic and natural aerosols are entirely missing. Modelling of urban air quality is not resolved at a sufficiently fine spatial scale to quantify the full magnitude of health effects. Thus only ERF reflecting the effect of the urban background exposure may currently be applied. There is also a lack in consistency between measured and modelled urban air concentrations.
Transfer to the RAINS model	Only WHO exposure-response relationships for mortality in adults are included in RAINS and used for the emission control of anthropogenic primary particles and secondary inorganic aerosols. Source-receptor (SR) relationships are limited in the aerosols included and the spatial scale of the assessment introduces limitations. Non-linearity in SR relationships is a problem to be solved.
Bias	Current models underestimate effects in urban areas due to both the scales of the assessment and the fact that secondary organic aerosols are missing. Thus the bias is related to sector control measures at local scales.
Recommendations	The PM2.5 components need to be more fully predicted and the spatial resolution improved. As soon as experts find it possible the unspecific ERF for urban background PM2.5 and the long-term effect on adult mortality should be compared with alternative assumptions taking PM characteristics and effects on mortality of more local exposures (sources as large roads) into consideration.

Health effects from ozone

Scientific maturity	Short-term effects are well described, but susceptibility and effect modifiers are not so well understood.
Process and mechanism understanding	The underlying mechanisms for these health effects are quite well understood.
Evidence from controlled experiments	Human exposure studies have mainly used concentrations above 60 ppb and shown several types of effects in the respiratory tract.
Evidence from field observations	Epidemiological studies quite consistently find short-term effects on respiratory problems, hospitalisations and the daily number of deaths, also below 60 ppb. The evidence is weaker, however, for any long-term effects.
Atmospheric source-receptor relationships	The model describes the regional concentration of ozone and its relationship with emissions within Europe is reliable. However, urban scale ozone exposure assessment is not resolved spatially.
Transfer to the	Only short-term effects on mortality are estimated. No effects

RAINS model	below 35 ppb are quantified (WHO). Non-linearities in response to NOx and VOC controls remain to be resolved.
Bias	Health effects of ozone are underestimated by not including other health outcomes and the use of the 35 ppb cut off. Health effects resulting from the limited spatial scale of the assessment may result in a bias in either direction.
Recommendations	Potential bias due to the cut off at 35 ppb and potential effect modification in European regions should be further addressed in collaboration with health experts.

Annex A – Task 1 Coordination and reporting

The CAFE secretariate aims to review the RAINS integrated assessment model using a Review Team of 10 experts from Europe and North America.

The work plan and call for tender can be found on
http://europa.eu.int/comm/environment/air/cafe/activities/rain_model.htm

To ensure their independence the Team members signed a formal declaration of interest modelled on that used by the World Health Organisation.

Organisation of the review, the requests from the commission, the tender and the work plan.

The Review Team collected written evidence from reports, publications, Internet information and policy related documents, formal evidence submitted by IIASA (summarised on http://www.iiasa.ac.at/rains/review/), discussion with the CAFE secretariat, and oral evidence collected from presentations and interviews. This evidence was challenged via review by members of the Review Team, through discussions at Review Team meetings, through consultation with representatives of IIASA, with stakeholders (including the CAFE Steering Group), and with the scientific community. An enquiry-based approach was used to challenge and probe the collected evidence. An important starting point for our enquires was the IIASA's tender and contract with CAFE on the Development of Baseline and Policy Scenarios and Integrated Assessment modelling Framework[d].

7.1 Methodological approach

The methodology used is shown diagrammatically in Figure 1 below:

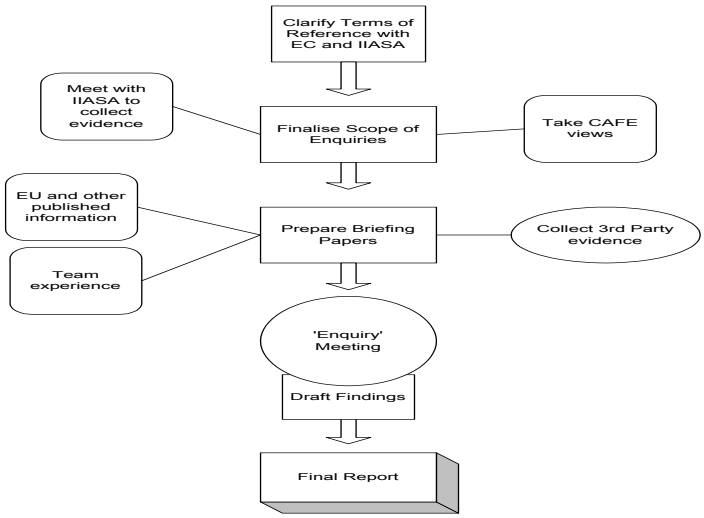

Figure 1 – Outline Methodology

[d] Tender from IIASA in ENV.C1/SER/2002/0031, available on IIASA's web page.

The methodology consisted of the following operations:

a) A kick-off meeting with the Commission at which a detailed work plan was discussed and agreed.
b) A formal contact, via email, with prominent third party stakeholders in order to get their views and advice for the evaluation.
c) A first meeting between the review group and the RAINS team to collect information and evidence for the 'Enquiry' i.e. to determine the questions to address, the key reports and scientific papers to examine etc.
d) Preparation of briefing material for each of the Task Areas 2-5 based on the results from the first meeting and views from third party stakeholders and the CAFE secretariat.
e) A second meeting of the whole Review Team and IIASA – the "Enquiry meeting"– at which our Team examined the evidence collected and sought clarification of IIASA.
f) A Draft Final Report that was distributed to IIASA, CAFÉ and the TFIAM for comment; IVL and AEAT authors then took account of feedback in drafting the final report.
g) The final Report answering the questions posed by the Commission, identifying unresolved issues for IIASA to pursue in the course of their work, and making recommendations to the Commission on developmental needs.

The first review meeting with IIASA followed the conventional process of presentations and discussions, putting forward questions to the IIASA team etc. The questions presented in the Call for Tender were used as the basis for the discussions.

The Enquiry meeting examined the evidence collected. Members of the Review Team Members acted as advocates for the various aspects of the RAINS modelling while the rest of the Review Team, acting together, challenged the robustness of the supporting evidence. This approach was designed to detect strengths and weaknesses in the RAINS methodology, to cut across conventional wisdom, detect blind spots and open new areas of questioning. Following the meeting the Review Team drafted its conclusions; these formed the main component of the Draft Report to the EC and the CAFE secretariat.

A number of stakeholders were contacted at start of the review in order to get comments from them on the work plan and also get advice on aspects to be included in the review.

7.2 Appendix A - Division of responsibilities

	GA	DF	Em	ECC	AcN	Com	PM	HOz	VOz	Opt	Unc
Mike Woodfield			X	X						X	
Peringe Grennfelt	X			X		X					
Terry Keating	X					X					
David Fowler									X		X
Oystein Hov					X					X	X
Jan Willem Erisman		X			X				X		

Mihalis Lazarides					X	X
Bertil Forsberg					X	X
Janina Fudala	X	X				
Tomas Tzylicz		X	X			

GA: General approach
DF: Driving forces
Em: Emissions
ECC: Emission control and costs
AcN: Acidification and nitrogen effects
Com: Communication
PM: Health effects from particulate matter
HOz: Health effects from ozone
VOz: vegetation effects from ozone
Opt: Optimisation
Unc: Uncertainties

[1] **Supplementary information**

[2] The RAINS model has been the focus for reviews prior to the review under this contract. Most of them have, however, been part of reviews of the research activities within IIASA. An examination of the RAINS Asia model , together with a review in the 1980s, was the most penetrating review before this current study. The model, developed for analysing cost-effective solutions for the reduction of SO2 emissions in South-East Asia, was found to "offer(s) a useful tool that now can be used for policy analysis, as well as for education". It may however be pointed out that the review was made on the model available 10 years ago.

In 1993, 1996 and 2000 the Trans-boundary Air Pollution project was evaluated as part of larger reviews of IIASA's activities related to environment, global change and natural resources. None of these reviews, however, analysed the RAINS model in detail; they made, instead, an analysis of the value of RAINS and a Trans-boundary Air Pollution project in the IIASA project portfolio and they mainly gave advice on directions for further research. They highlighted, among other things, the importance of incorporating uncertainty analysis in order to clarify the robustness of the model.

Parts of the model have also been reviewed in terms of reliability of the data and performance of particular modules of the model. In the process of developing the strategies for the Gothenburg Protocol, the costs and how uncertainties in costs influenced the output were analysed. (Philippe Méral and Martin O'Connor, C3ED, Cost-Effectiveness Analyses for Reduction of Atmospheric Emissions for Stationary Sources). Their conclusion was that RAINS did not properly address error propagation and points to the fact that the bottom-up process has some limitations. They recommend that the model output also should be considered in a macro-economic perspective,

In a recent publication S. Soleille, Ineris has reviewed the uncertainties and optimisation aspects of the RAINS model. The review is, in lack of data, reviewed on the RAINS version used for the Gothenburg Protocol and the NEC Directive. In the review, uncertainties in emission inventories and the underlying decisions for the optimisation calculations are discussed. He points to the large differences in the estimates of uncertainties estimated in different emission inventories. He discusses the different constraints introduced in connection with the earlier policy development. He also gives some recommendations in order to improve transparency and simplify use of the model. (*S. Soleille; The RAINS model, uncertainty and optimisation. Ministère de l'écologie et du dévelopment durable. June 2004, Ineris.*)

[3] The existence of the RAINS model is dependent on decisions at the IIASA Council, which consists of representatives from those countries supporting IIASA, some of them outside Europe and not part of the CLRTAP. Contacts with the Director at IIASA have indicated, however, that there are good possibilities for a change and that the Transboundary Air Pollution project and the RAINS model would be ensured five years of support from IIASA. As a consequence, the Director also indicated that key persons will be contracted for similar lengths.

[4] The interaction with countries and other stakeholders is reviewed and discussed in connection with Task 5.

5 The RAINS model has undergone large changes in almost all areas due to changes in environmental interests, improved scientific knowledge and improvements in model formulation. The main changes are compiled in the following table. The changes have solved some of the most obvious problems with the earlier version of RAINS such as the underestimation of deposition to forested ecosystems, and the omission of particle effects to humans.

Table Improvements/changes in RAINS and the compartment systems since the model was used for the Gothenburg Protocol and the NEC directive.

Compartment system	Earlier strategies	CAFE strategy
Integrated assessment model	Regional assessment, four types of emissions, four effects. 150 km resolution.	Regional and urban assessment, five types of emissions, five effects. 50 km resolution. New module for optimisation.
EMEP model	Lagrangian 2D model. 150 km. Separate models for N/S deposition and ozone	Eulerian 3 D model. 50 km. Unified model for N/S dep, ozone and particles
Acidification	Static critical loads	Dynamic critical loads (not yet fully defined)
Eutrophication	Static critical loads	Static critical loads
Ozone impact on vegetation	AOT 40	The possibility for an inclusion of flux-based critical loads
Ozone impact on health	Included	Included
PM impact on health	Not included	Included
Urban scale	Not included	Considered for ozone and particles
Climate change policies	Not included	Included in baseline scenarios

[6] The country emissions-to-grid cell concentration/deposition approach was used in generating the optimisation results for the Gothenburg Protocol and NEC Directive. This approach aggregates some of the source-receptor relationships which potentially leads to a less than optimal distribution of emissions controls. The alternative would be to use a region to grid cell approach or grid cell to grid cell approach. Because of the higher spatial resolution of the source-receptor relationships employed in these approaches, a more optimal spatial distribution of emissions may result, with more stringent controls in some areas and less control in others. However, optimisation using these alternate approaches would be more sensitive to extreme cases, increasing the control requirements in some areas, although intra-country compensation (as introduced in the Gothenburg Protocol analysis) may alleviate this sensitivity. In the end, however, it seems that it is the issues of national sovereignty and subsidiarity which make it necessary to take a country-to-grid approach, as opposed to a technical issue.

[7] Recent scientific publications indicate that climate change may severely influence the temperature and climate in Central and South Europe. The influence will not only influence the mean temperatures but also the inter-annual variations are expected to increase. These changes may lead to increased ozone lifetime and more severe ozone episodes during high temperature events in Europe.

[8] This has been done in the U.S. for individual control strategies, studying innovation and control costs were found to decrease over time; see also the Stockholm Environment Institute (SEI) report on Second S Protocol.

[9] In the version of the RAINS model used for the NEC Directive and the Gothenburg Protocol, emissions are abated according to the magnitude/nature of the emission and the availability/suitability of control techniques; abatement techniques are introduced stepwise according to their order on a cost curve. This is a tried and tested technique, but it suffers from being limited to technology-based strategies. It is not able, furthermore, to attribute the costs of abatement to more than one pollutant, so the costs of strategies where one measure simultaneously reduces emissions of a number of pollutants are not properly spread across the different pollutants.

[10] IIASA Interim report IR-04-015 The extension of the RAINS Model to Greenhouse Gases.

[11] These include the EC JRC (Institute for Prospective Technological Studies) programme and the UN ECE Expert Group on Techno-economic issues.

[12] While there are not any major errors or omissions of emission sources, there are problems, nonetheless, with some aspects of the emission inventories used in RAINS. The sources of most importance are, or are becoming, the best characterised. Some pollutant emissions are better characterized than others – inventories for NH3 and PM are less well developed as those of SO2 and NOx. Significant technical issues remain with ammonia emissions, suspended particles, elemental carbon, organic carbon, and precursors to secondary organic aerosols. These problems contribute to the problems of modelling health impacts of particles and nitrogen deposition noted above. There is much work ongoing to understand the influence of the uncertainty in emission estimates on model output – and policy implications.

[13] RAINS calculates a hypothetical uncontrolled emission rate and then modifies it for different control techniques. Countries actually calculate emissions = EF * Activity Level. Dialogue between IIASA and the country is important in making sure this is done appropriately.

[14] Nevertheless the emission factors, abatement efficiency factors, and implementation rates applied are capable of improvement.

[15] A point brought out by Soleille et al, INERIS, May 2004.